

**BEARING CAPACITY AND COMPRESSIBILITY
CHARACTERISTICS OF GELAN SOILS FOR SHALLOW
FOUNDATION DESIGN**

(Illustration and Comparison using different Building Codes)

By

ALEX ATANAW

Thesis

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The Thesis Committee of
Adama Science and Technology University (ASTU), in School of Civil Engineering and
Architecture, Department of Civil Engineering
Certifies that this is the approved version of the following Thesis:

BY:

Alex Atanaw (GSR/8676/05)

Date

APPROVED BY

BOARD OF EXAMINERS:

Addiszemen Teklay Gebreselassia, (Dr.),
Advisor

Date

External Examiner

Date

Internal Examiner

Date

Chairman

Date

Head of Department

Date

School Dean

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Alex Atanaw

Adama, Ethiopia

August 1, 2016

Abstract

Capacity and Compressibility Characteristics of Southern Addis Ababa Soils for Shallow Foundations Design (Illustration and Comparison using different Building Codes)

Alex Atanaw

Master of Science degree in Civil Engineering
(Geotechnical Engineering Major, M.Sc.)
Adama Science and Technology University, 2008

Supervisors: Addiszemen Teklay

Any engineered structures constructed on the soil need to respond safely for static and dynamic loading to insure the bearing capacity and compressibility characteristics of the soil. Unbalanced load of soil leads excessive structural distortion and mass collapse against shear failure and excessive settlement which result, structural damage to building frames, cracks, sticking of doors and windows. The unbalanced super structural load is factored to account several factors among these are soil types on which foundation laid on, foundation shape, depth and design approach using different codes. This study tried to determine the bearing capacity and compressibility characteristics of southern Addis Ababa sub city (Gelan) soils with illustration of different codes and SOFA software and the evaluation of Ethiopian building code compared to other codes including sofa software.

To achieve the objective of the study different literatures were first reviewed and for laboratory works, disturbed and undisturbed samples from four test pits at 2m depth were taken. From disturbed samples dry sieve analysis, moisture content, specific gravity, bulk density, Atterberg limits, unconfined compressive strength; direct shear test and consolidation tests were done using undisturbed samples. From the test results, drained cohesive strength was 10.5-21kN/m², angle of internal friction ranges from 15-23°, undrained cohesive strength was 35.7-68Mpa, swelling index/recompression index and

coefficient of compressibility range was 0.037-0.071 and 0.214-0.286 respectively. It is known that the expansive potential of the soil depends on the swelling index fully and it is observed in all the study area that the soils are non expansive and under medium expansiveness and are grouped under Kaolinite clay type with the values swelling index of 40-97% with initial moisture content of 29-39.1%. Using these test results, the analysis and discussion for bearing capacity and settlement were made for square, rectangular and strip footings at a depth of 2m and 3m. In this regard the following are important.

Comparison of EBCS-7 with different codes of standards was done using analytical method and sofa software, both in the case of long term and short term analysis. From the analysis, long term bearing capacity in all points with EBCS-7 codes ranges from 313 to 957kPa and 384 to 1009kPa for square footing in 2m and 3m depth respectively, 293 to 880kPa and 361 to 1037kPa for rectangular footing at a depth of 2m and 3m respectively and 258 to 749kPa and 316 to 875kPa of the strip footing at a depth of 2m and 3m depth respectively.

Generally the short term bearing capacities found in each borehole and loading cases are conservative compared to the long term bearing capacities for the corresponding phenomena. For practitioners, engineers involved in construction in Gelan area long term bearing capacity in all points with EBCS-7 codes are determined in the case of square and rectangular footing at a depth of 2m and 3m. The study area in four loading cases has resulted bearing capacity value ranges from 309-944kPa and 380-999kPa of square footing and 256-706kPa and 311-874kPa of rectangular footing at a depth of 2m and 3m respectively in the EBCS-7 method of analysis of the four loading causes. This study clearly pointed out that in almost all cases the EBCS-7 method result a large footing dimension and a small bearing capacity and settlement. Design engineers in Ethiopia have an immediate trend of selecting the minimum bearing capacity value for their design

foundation, however, this trend needs to be changed and we should take into account design economy at least by using average values. Therefore, we can conclude that the EBCS-7 method determined footing size, bearing capacity and settlement values are conservative and demands some revision to make it more economical. The study suggests that the average bearing capacity and settlement values of all the results obtained from the methods seen must be used for design as a result EBCS-7 method must encompass these revisions in a way to lead average values.

Keywords: *Bearing Capacity, Compressibility, Shallow Foundation, Illustration, EBCS-7, Codes and Sofa Software.*

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Nomenclature

i_i	the inclination factor of the load, with subscripts c for cohesion , surcharge and γ for weight density;
I_f	Influence factor;
L	the foundation length;
L'	the effective foundation length;
m	exponent in formulas for the inclination factor I ;
M_x	moment about xx axis;
M_y	moment about y-y axis;
N	the bearing capacity factors, with subscripts cohesion c, surcharge q and weight density γ ;
p_o	overburden or surcharge pressure at the level of the foundation base;
q_u	Ultimate bearing capacity of the shallow foundation;
S	the shape factors of the foundation base, with subscripts c for cohesion , q for surcharge and γ for weight density;
V	the vertical load;
Z	vertical distance (depth);
α	the inclination of the foundation base to the horizontal;
β	soil inclination according to DIN 4017;
γ'	the design effective weight of the soil below the foundation level;
I	importance factor;
γ_s	dry soil unit weight;
γ_{sat}	saturated soil unit weight;
ν	Poisson's ratio;
ϕ'	angle of internal friction;
ϕ_k	effective angle of internal friction;
ϕ_{uk}	friction angle for undrained cohesive soils;

A_{eff}	effective area of the footing;
b_i	the design values of the factors for the inclination of the base, with subscripts c for cohesion , q for surcharge and γ for weight density;
B	the foundation width;
B'	the effective foundation width;
C	soil cohesion;
c'	cohesion of soil in terms of effective stress;
c_u	undrained shear strength of soil;
c'_k	cohesion (for drained loading);
C_c	compression index;
d_i	the design values of the factors for the depth of foundation, with subscripts c for cohesion , q for surcharge and γ for weight density;
d_f	depth of foundation;
d_w	depth of water level;
e_o	Initial void ratio;
E_s	Young's modulus of elasticity;
g_i	the design values of the factors for the soil inclination, with subscripts c for cohesion , q for surcharge and γ for weight density
H	stratum thickness;
H_x	horizontal force in x direction;
H_y	horizontal force in y direction;
δ	Angular distortion;
s_{max}	Maximum permissible settlement;
C_r	Static cone resistance;
C_s	Swelling index;
C_c	Compression index;
S_c	Consolidation settlement;
p_c	Pre-consolidation stress;

m_v	Volumetric coefficient of consolidation;
s_i	Elastic settlement;
I_s	Shape factor for settlement;
I_f	Depth factor;
μ_0	Correction factor for depth of embedment of foundation;
μ_1	Correction factor for finite thickness of elastic layer;
B_e	Equivalent width;
I_G	Influence factor for variation of E with depth;
I_F	Foundation rigidity correction factor;
I_E	Foundation embedment correction factor;
K	sub grade modulus;
OCR	over-consolidation ratio;
ASTM	American society testing material;
SOFA	analysis of shallow foundation;

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND OF THE STUDY

1.1.1. General Description of the study area and the problem

Gelan is a sub city found in Addis Ababa with a population of 26753 as shown Figure 1.1. It is located with latitude of $8^{\circ}52'04''\text{E}$ and a longitude of $37^{\circ}47'\text{S}$ in Ethiopia, 2200m above mean sea (1). It is a highly flooded area and steeply slopes with a daily temperature of $10\text{-}15^{\circ}\text{C}$ (1). Since it is a village where extensive construction activities are underway, the execution of safe and economical Geotechnical and structural design for structures is essential. In this regard, a proper investigation of the soil and a reliable bearing capacity and settlement (compressibility) analysis, both in static and dynamic loading cases have a fundamental importance as this thesis tries to demonstrate.

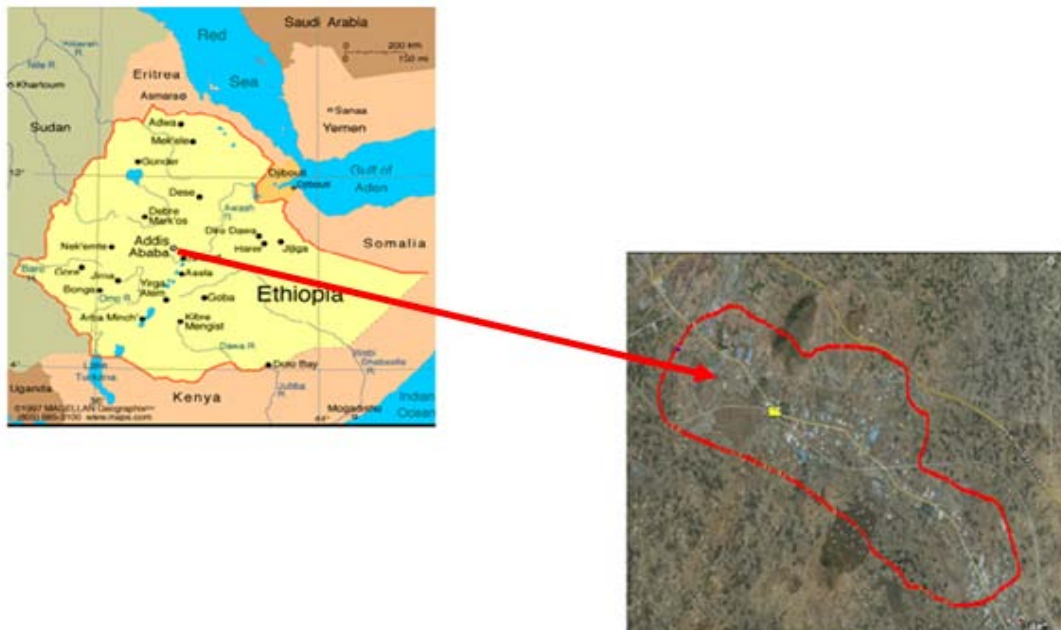


Figure 1.1. Geographical location of the study area

1.1.2. The Physical Problem and Its Significance

Soil mechanics involve a combination of applying the principles of mechanics and hydraulics to engineering problems dealing with soil as an engineering material. In many regions; including arid and semi-arid regions, shallow

foundations are usually used above the ground water table where the soil is typically in a state of unsaturated condition. Bearing capacity and compressibility characteristics of the foundation soil are the key parameters required in the design of shallow foundations. The response and safety of any engineered structures constructed on the soil due to static and dynamic loading depend on the bearing capacity and compressibility characteristics of the soil. For stable and safe structures founded in the ground, the soil must be capable of carrying the loads from any engineered structure placed upon it without shear failure and excessive settlement beyond the recommended limit (1). A soil shear failure can result in excessive building structural distortion and even collapse and excessive settlement can result in structural damage to frame elements, nuisances such as sticking doors and windows cracks on finishing layers and excessive wear or equipment failure from misalignment resulting from foundation settlement shear failure and with the resulting settlements being tolerable for that structure.

Shallow foundation design practices particular to the analytical approach/computations of bearing capacity and settlement of soils in Ethiopia reveal the use of previous Geotechnical data and follow mixed approaches from the empirical formulations developed from American and European experience found in different codes of standards without a specific understanding of soils shear resisting capacity and compressibility nature of the specific site. Unless we care, estimation of the bearing capacity and settlement of shallow foundations using the conventional approaches practiced in Ethiopia might lead to uneconomical and unsafe designs which may eventually lead failure. The misconception practiced in using the same approach for different magnitude of design leads to different types and erratic nature of the soils currently showing various failure symptoms. This is typically on shallow foundations used in substructure of buildings in Addis Ababa and the surrounding areas. Figure 1.2inFigure 1.5 shows some of the damaged structures caused by the any combination of factors such as design and construction, but are related to the soil around the study area.

Bearing capacity and settlement analysis of shallow foundations are computed using several methods/approaches, even though the different methods are having different reliability. The practice common in Ethiopia is to use both presumptive values and empirical formulations proposed by different researchers included in a variety of ways in respective codes of each country such as, EBCS-7, EURO-7, DIN-1054, EAK-2000, DIN-4017 and IS.

This thesis focus to study the bearing capacity and settlement, determination approaches of shallow foundations using the different empirical formulations included in the above codes as this helps to compare the results obtained from EBCS-7 with others. Therefore, it is recommended to undertake research to facilitate the integration into the EBCS codes of the latest developments in scientific and technological knowledge.



Figure 1.2. Shear of tie beam in Gelan city car parking basement building around the asphalt area



Figure 1.3. Detachment of tie beam and column in Gelan senior secondary school classrooms.



Figure 1.4. Settlement of masonry wall below grade beam in *Gelan* area around the municipality



Figure 1.5. Tilting and sever crack of masonry store fence in the study site

The literally developed bearing capacity determination empirical formulae's included in different codes of various countries include Terzaghi, Meyerhof, Vesic, and Hansen's formulations. The first theoretical solution of the bearing capacity problem is attributed to Prandtl and Reissner in the early 1920's. Terzaghi (1943) defined three types of failure mechanism as a general shear failure and derived the first empirical equation for the bearing capacity of continuous footings.

Several local and international researches mainly focus on a single parametric study or interaction effect such as the geometry of the footing ($B \times L$) and soil type in bearing capacity and settlement computations. Though these researchers did their study on bearing capacity and settlement computations of soils, the majority uses only single empirical method to determine the two important design parameters: bearing capacity and compressibility characteristics of soils. However, these methods with the same Geotechnical design parameters of the soil, the geometry of the footing and loading condition, it is impossible to incur equivalent bearing capacity and settlement values. It is known commonly that a structural design can be manipulated on the basis of a single value of bearing capacity and settlement. So that different values for one design requirement cause an extensive ambiguity and

problem of selection of design value as to which empirical approach and Code values are the best. Therefore, in this study a typical soil profile developed through laboratory testing of soils along with a typical geometry of the foundation and different loading categories is used to determine bearing capacity and compressibility for shallow foundation design using different empirical formulations included in different country codes. This helps to compare and contrast different formulations and code recommendations and reviewing the status of Ethiopian Building code of standard (EBCS-7) approaches.

To address the goals of this study, several soil testing and design approach analysis is performed in stages as follows. In the first part several literatures related to bearing capacity and compressibility are reviewed to obtain sufficient theoretical information about the methods. The second part of the study involves the collection and organization of field data, soil sampling and conducting laboratory experimental soil tests. In these stages disturbed and un-disturbed soil samples are collected, carrying out Atterberg limits, dry sieving, moisture content, specific gravity, bulk density, direct shear test, consolidation test and unconfined compression strength laboratory tests are conducted. This helps to establish a one dimensional Geotechnical design profile for the site. In the third phase, using the Geotechnical design profile, bearing capacity and compressibility of the soils for different geometry and loading category are determined for shallow foundations at different depth using different empirical formulations included in different codes. The fourth phase of the study includes analysis and discussion of the results obtained in different sections from different codes and empirical formulations. Moreover, this study investigates the effect of depth and geometry when using the different procedures. Finally the conclusion and recommendation of the results encompassed.

1.2. STATEMENT OF THE PROBLEM

Bearing capacity and compressibility characteristics of Gelan city soil is not yet studied. In the past, bearing capacity and compressibility of soils was analyzed using various empirical formulations included in the codes on the basis of simple

conceptual facts. The formulations included in these codes resulted in different values. These different results are found in different codes and software lead to a non-compromising design judgment which causes over loading (shear failure and settlement) or under loading (conservative) design of the foundation [11]. It is vital to determine the bearing capacity and settlement of the soil using different empirical formulations/methods, code recommendations and using Geotechnical software for safe foundation design. Thus, assessment of the status of EBCS-7 for shallow foundation design in comparison with other codes using analytical method and software application is the most important task studied in this thesis.

1.3. OBJECTIVE AND SCOPE OF THE STUDY

1.3.1. General Objective

The objective of the study is to investigate the soils in the study area as this helps to define the engineering properties of the soils for the design of foundations determine the bearing capacity and compressibility characteristics of *Gelan* sub city soils using analytical formulations proposed by different codes and software application and compare the results with the empirical approach obtained in EBCS-7.

1.3.2. Specific Objective

The specific focus of the present research program was directed towards the determination of the bearing capacity and settlement and is hierarchically presented below:

- a) To experiment and examine some engineering and index properties of soils of the study area mainly the bearing capacity and compressibility characteristics of *Gelan* sub city soils for developing one dimensional design profile.
- b) To review the different building codes and formulations proposed for evaluating the bearing capacity and compressibility characteristics of soils
- c) To analyze the ultimate bearing capacity and settlement characteristics of the major soils found in the study area for both short term and long term loading conditions utilizing the actual Geotechnical data obtained and using empirical formulations of different building codes and software proposed in literature.
- d) To investigate and compare the status of the bearing capacity and compressibility characteristics formulations and principles included in EBCS-7 with other codes and propose any required improvements if any.

- e) To compare the results obtained from this study with similar data from literatures.

1.3.3. Scope of the Study

Estimation of bearing capacity and compressibility using the most reliable methods like using field test data, such as SPT, CPT, plate load test, are difficult and are very expensive to use in countries like Ethiopia. In this study analytical/empirical formulation and software approaches were used for modification of the formulations included in codes and software is another research which needs further modeling. Therefore, the scope of this study includes undertaking an intensive review of important literatures which are helpful to determine the ultimate bearing capacity and settlement of soils for shallow foundation design together with an accurate collection of data and laboratory testing on soils up to limited depth is the major focus for this study. Besides, correlations proposed in several studies were taken for those parameters which were expensive and time taking to be tested reasonably with the time and budget given for this research. Numerical analysis for both bearing capacity and compressibility has been made using different analytical methods proposed in different ways in different countries of various codes of standards but only for static load analysis only.

1.4. EXPECTED SIGNIFICANCE OF THE STUDY

The study output will serve as a reference guide for practicing engineers and for researchers that are involved in the design and in the construction industry in the city and related study areas. It leads us to make a probable relation and a recommendation on the basis of EBCS-7 to the other codes discussed in this study. It also reduces the analysis time required for bearing capacity and settlement analysis using software. This helps to further extend the formulations included in the Ethiopian building code of standard if it is compatible by observing its limitation.

CHAPTER 2

LITERATURE REVIEWS

2.1. INTRODUCTION

Foundations, like the structures or equipment they support, are usually designed to meet certain serviceability and strength criteria. Serviceability conditions dictate that the foundation should perform such that under normal operating loads the structure or equipment it supports may fulfill its design purpose.

These serviceability limitations are typically described by settlement or other motion limitations. The strength criteria have the purpose of insuring that the foundation has sufficient reserve strength to resist the occasional large load that may be experienced due to extreme environmental forces or other sources. In most, but not all cases, the serviceability or settlement criteria and the strength criteria may be treated as unrelated design tasks. Serviceability is typically a long-term consideration for the foundation that may depend on time dependent consolidation characteristics. Foundation strength, or bearing capacity, may be a short-term problem such as an embankment construction on an undrained clay foundation or a long-term problem in which the maximum foundation load may appear at some unknown time.

This chapter will consider the review of literatures on the strength or bearing capacity and compressibility characteristics of shallow foundations. A shallow foundation may be defined as one in which the embedment depth of the foundation is less than its least characteristic dimension. Usually, the bearing capacity of a foundation is determined by limit equilibrium, limit analysis, or slip-line solutions. The variety of solutions available for a particular problem may lead to some uncertainty about which is the more appropriate procedure. In the following, the basis of these solution procedures will be summarized and methods for their use presented.

Bearing capacity is defined as the ultimate load resistance capacity of the soil under loaded foundations (2). The ultimate bearing capacity depends on several parameters: size and shape of the loaded area, the depth of the loaded area below the

ground surface, ground base condition, ground water condition, configuration of the foundation, the type, stratification and strength of foundation material and the manner in which the load is applied [14]. Consolidation is one of the most important processes in soil engineering. It accounts for the settlement of structures founded on compressible soils, and its understanding together with pertinent laboratory tests permits the calculation of total settlement as well as of its time rate. Consolidation (as well as its inverse: expansion) is affected by and itself affects such physical parameters as permeability, compressibility, and shear strength.

Several literatures indicated that the ultimate bearing capacity and compressibility value for the same engineering property of the soil is not similar. This is basically due to the difference in their conceptual understanding of the parameters and methods they considered.

2.2. BEARING CAPACITY ESTIMATION METHODS

At the present time, the analysis bearing capacity of foundations can be made by employing one of the following four widely used methods:

2.2.1. Bearing Capacity Analysis using Presumptive values

This method of analysis didn't consider the stress history of the soil such as, water table location, depth of the foundation, sub soil type's depth wise and tolerable settlement. For minor construction; it often provides fairly acceptable guidelines. However, these bearing capacity values are based primarily on the visual classification near-surface soils and past experience of existing structures Table 2.1- Table 2.8 shows some of the presumptive bearing capacity values suggested for different soils.

According to EBCS-7 presumed bearing capacity is considered with some relation of stress history without any analytical activities. These values with certain modifications are given accordingly, but still a satisfactory judgment is not found in this method because more relevant influential factors are not considered for instance bearing capacity in this method can be determined with more emphasis of compactness or consistency values. However a foundation material with the same

consistency and compactness will not have exactly equivalent design bearing capacity as shown in Table 2.1 and Table 2.2.

Table 2.1. Some presumptive bearing capacity values based on the type of soils (IS1904/1978) [14].

Type of Soil/Rock	Allowable Bearing Capacity (kN/m ²)
Rock	3240
Soft rock	440
Coarse sand	440
Medium sand	245
Fine sand	100
Soft shale/stiff clay	440
Soft clay	100
Very soft clay	50

Table 2.2. Presumed design bearing resistance under vertical static load according to EBCS-7[15]

Supporting Ground	Description	Compactness or consistency	Presumed bearing capacity(KN/m ²)
Rock	Massively crystalline igneous and metamorphic(granite, basalt,gneiss)	Hard and sound	5600
	Foliated metamorphic rock(slate, schist)	Medium Hard and sound	2800
	Sedimentary rock (hard shale, silt stone, sand stone, limestone)	Medium Hard and sound	2800
	Soft Shale	Medium hard and sound	2800
		Soft	1400
Non-cohesive soils	Gravel, sand and gravel	Dense	560
		Medium dense	420
		Loose	280
	sand	Dense	420
		Medium dense	280
		Loose	140
Cohesive soils	Silt	Hard	280
		Stiff	200
		Medium stiff	140
		Soft	70
	clay	Hard	420
		Stiff	280
		Medium stiff	140
		Soft	70
		Soft	70
		Very soft	Not available

Pursumetive Soil Bearing capacity according to DIN-1054 is determined with regard to the foundation geometry, cohesiveness and their consistency for clays and silts as shown below from Table 2.3-Table 2.9 [15].

Table 2.3. Allowable soil pressure non- cohesive soils

1.	Allowable soil bearing capacity for construction that is sensitive to settlement					
Foundation depth (m)	Allowable average soil pressure in kPa for spread footing with given width (m)					
	0.5	1	1.5	2	2.5	3
0.5	200	300	330	280	250	220
1	270	370	360	310	270	240
1.5	340	440	390	340	290	260
2	400	500	420	360	310	280

Table 2.4. Bearing capacity of cohesive soils

2.	Allowable soil bearing capacity for construction that is not very sensitive to settlement			
Foundation Depth (m)	Allowable average soil pressure in kPa for spread footing with given width (m)			
	0.5	1	1.5	2
0.5	200	300	400	500
1	270	370	470	570
1.5	340	440	540	640
2	400	500	600	700

Table 2.5. Bearing Capacity of pure silt

3	Allowable soil bearing capacity for cohesive soils
Foundation Depth (m)	Allowable average soil pressure in kPa for spread footing with given width (m)
0.5	130
1	180
1.5	220
2	250

Table 2.6. Mixed soil (grain size from clay to sand and gravel)

Foundation Depth (m)	Allowable Average Soil Pressure in kPa for spread footing with given width (m)		
	Consistency		
	<i>stiff</i>	<i>semi-hard</i>	<i>hard</i>
0.5	150	220	330
1	180	280	380
1.5	220	330	440
2	250	370	500

Table 2.7. Bearing capacity clayey silt

Foundation Depth (m)	Allowable Average Soil Pressure in kPa for spread footing with given width (m)		
	Consistency		
	Stiff	semi-hard	Hard
0.5	120	170	280
1	140	210	320
1.5	160	250	360
2	180	280	400

Table 2.8. Soil pressure of Clay

Foundation Depth (m)	Allowable Average Soil Pressure in kPa for spread footing with given width (m)		
	Consistency		
	Stiff	semi-hard	Hard
0.5	90	140	200
1	110	180	240
1.5	130	210	270
2	150	230	300

2.2.2. Bearing Capacity Estimation using Analytical Methods

2.2.2.1. Bearing capacity by Prandtl and Reisser

Analytical method of bearing capacity estimation is viewed by Prandtl and Reisser; they initially considered shear zones as active and passive on either side of the footing. According to their principle the soil is assumed to be weightless and bearing capacity is determined only by cohesion component in Prandtl's theory and both cohesion and surcharge factor in Reisser [1]. Even they messed up plenty of influential factors that affect bearing capacity value.

2.2.2.2. Bearing capacity by Karl Terzaghi

Terzaghi (1943) was the first to present a theory for the evaluation of the ultimate bearing capacity of rough shallow foundations. Terzaghi suggested that a foundation is shallow, if the depth of the foundation is less than or equal to the width of the foundation. Later investigators like Meyerhof and Hansen, however, have suggested that foundations with having 3 to 4 times the width of the foundation may be considered as shallow foundations [1].

Table 2.8 shows that Terzaghi ignored items such as the shear strength of the soil between the bottom of the foundation and the ground surface as well as footings placed on any inclined ground surfaces. Terzaghi's (1943) equation for the calculation of bearing capacity of shallow foundations is conservative[16]. That is part of the reason for limiting the method to relatively shallow foundations ($D \leq B$), where the other methods do not have a depth restriction.

In this section several bearing capacity formulas from code provisions are presented with the following footing section and tables.

Table 2.9. Comparison of three Bearing Capacity Theories [6]

Theme	Terzaghi (1943)	Meyerhof (1953)	Hansen (1961)
Consolidation	No consolidation of the soil occurs. (I.e., settlement of the foundation is due only to the shearing and lateral movement of the soil).	Same	Same
Foundation Rigidity	The foundation is very rigid in comparison to the soil.	Same	Same
Footing/Soil Interaction	Bottom of the foundation is sufficiently rough, so that no sliding occurs between the foundation and the soil.	Same	Same
Assumption of Sand Layering	The soil beneath the foundation is homogeneous semi-infinite mass.	Same	Same
Shear Strength	The shear strength of the soil is described by the formula $s = c + S \tan f$	The shear strength of the soil is described by the formula $s = c + S \tan f$	The shear strength of the soil is described by the formula $s = c + S \tan f$
Failure Mode	General Shear Mode of Failure governs (but reduced by 2/3 to account for local shear).	General shear mode of failure governs. Proposed adjusting the friction angle obtained in a triaxial test for a plane-strain value based on footing shape.	General shear mode of failure governs. Proposed adjusting the friction angle obtained in a triaxial test for a plane-strain value as a direct 10 % increase.

Cont.

Definition of Depth of Shallow Foundation	Depth of foundation is less than or equal to its width ($D_f \leq B$).	No limitation on the depth of the footing. Addition of depth factors, d_c , d_q and d_γ .	No limitation on the depth of the footing. Addition of depth factors, d_c , d_q and d_γ .
Assumption of Shear Strength	Neglects the shear strength of the soil between the ground surface and a depth D. The soil serves only as a surcharge load.	Takes the shear strength of the soil between the ground surface and depth, D, into account with a depth factor.	Takes the shear strength of the soil between the ground surface and depth, D, into account with a depth factor.
Shape Factors	Developed theory for continuous foundations (i.e., with very large L/B ratio). This is a 2-D problem. He extended the theory to square and round foundations by adding empirical coefficients obtained from model tests.	Considered a broader range of footing shapes and defined additional shape factors.	Considered a broader range of footing shapes and defined additional shape factors.
Load Inclination	The applied load is compressive and applied vertically to the centroid of the foundation and no applied moment loads are present.	Addition of load inclination factors, i_c , i_q , and i_γ for loads that do not act perpendicular to the base of the footing but still act through its centroid.	Addition of load inclination factors, i_c , i_q , and i_γ for loads that do not act perpendicular to the base of the footing but still act through its centroid.
Foundation Placement	Foundations placed on horizontal ground.	Foundations placed on horizontal ground.	Addition of ground inclination factors, g_c , g_q and g_γ to account for footings located at the top of a slope.
Geometry of Footings	Geometry of active zone underneath a foundation is defined by $\beta = \phi$	Geometry of active zone underneath a foundation is $\beta = 45 + 1/2 \phi$	Geometry of active zone underneath a foundation is defined by $\beta = 45 + 1/2 \phi$

2.2.3. In situ Methods

2.2.3.1. Bearing Capacity using Plate Load Test

The plate bearing test is an important field test for determining the bearing capacity and settlement of the foundation in a rapid way. In this method a compressive stress is applied to the soil pavement layer through rigid plates of relatively large size and the deflections are measured for various stress values. The coefficient of sub-grade reaction is also determined using this plate load test. This is also a very useful parameter in the design of rigid highway and airfield pavements. The plate load test though very useful in obtaining necessary information about soil design of foundation has following limitations[17].

The test results reflect only the character of soil located within a depth less than twice the width of bearing plate. Normally the foundations are larger than the test plates, the settlement and shear resistance of soil against shear failure will depend on the properties of much thick stratum. Thus the results of the test could be misleading if the character of the soil changes in shallow depths.

Plate load test being of short duration, does not give the ultimate settlement in case of cohesive soils. For clay soils the bearing capacity (from shear consideration) for a large foundation is almost same as that for the smaller test plate. But in dense sandy soils the bearing capacity increases with the size of the foundation and hence the test with smaller size test plate tends to give conservative values in dense sand soils.

In view of the above limitations, the plate load test method of determining safe bearing capacity of soil may be considered adequate for light weight or less important structures under normal condition. However, in case of an unusual type of soil stratum and for all heavy and important structures, relevant laboratory tests or field tests are essential to establish the safe bearing capacity of the soil.

2.2.3.2. Bearing Capacity by Standard Penetration Test method

The ultimate bearing capacity of cohesion less soil is determined from the standard penetration number N . The standard penetration test is conducted at a number of selected points in the vertical direction below the foundation level at intervals of 75 cm or at point where there is a change of strata [18]. An average value of N is obtained between the level of the base of footing and the depth equal to 1.5 to 2 times the width of the foundation [18]. The value is obtained from the N value and the bearing capacity factors are found. The SPT is subject to many errors which affect the reliability of the SPT index, N . Correlation between the SPT index and the internal friction angle of sand is very poor. Consequently, the calculation of allowable bearing pressure from N values should be considered with caution. The SPT index is not appropriate for determining the bearing pressure in fine-grained cohesive soils.

2.2.4. Building Codes

2.2.4.1. Bearing Capacity from Indian Standard (IS)

Analytical method of bearing capacity determination included in Indian standard is the same as that of Meyerhof's approach, but the influence of the ground water table is different. To account the effect of the water table which is more empirical and apparent compared to the others method the factor W' taken into account. If the water table is at or below a depth of B , measured from the ground surface, $W' = 1$. If the water table rises to the base of the footing or above, $W' = 0.5$. If the water table lies in between then the value is obtained by linear interpolation is used [18].

2.2.4.2. Bearing Capacity according to the Ethiopian Building Code of Standard (EBCS-7)

The basis of the Ethiopian building code of standard is DIN- 4017, which is the German code [11]. The Analytical methods of bearing capacity determination included in EBCS-7 are described as follows:

UNDRAINED CONDITIONS: the design resistance is calculated from the following:

$$q_{ult} = (2 + \rho) s_c c_u i_c + q \quad 2.1$$

The dimensionless factors found are computed as follows:

Shape Factors

- **For Rectangular Shape** $s_c = (1 + 0.2B/L)$
- **For Square and Circular Shapes:** $s_c = 1.2$
- Inclination factors of the load, due to a horizontal load H:

$$i_c = 0.5 \left(1 + \sqrt{1 - (H / (A c_u))} \right)$$

DRAINED CONDITIONS: the design resistance is calculated from:

$$q_{ult} = c' N_c s_c i_c + q' N_q s_q i_q + 0.5 B g' N_g i_g s_g \quad (2.1)$$

Dimensionless factors for the bearing resistance:

$$N_q = \tan^2 \left(45^\circ + \frac{\phi'}{2} \right) \left(e^{\pi \tan \phi'} \right), \quad N_c = (N_q - 1) \cot \phi', \quad N_\gamma = 2(N_q - 1) \tan \phi'$$

The shape of foundation:

For a Rectangular Shape	For Square or Circular Shape	For Rectangular, Square or Circular Shape
$s_q = 1 + \frac{B'}{L'} \sin \phi'$ $s_\gamma = 1 - 0.3 \frac{B'}{L'}$	$s_q = 1 + \sin \phi'$ $s_\gamma = 0.7$	$s_c = \frac{s_q N_q - 1}{N_q - 1}$

The inclination of the load, due to a horizontal load H parallel to L' (the longer side):

$$i_q = i_\gamma = 1 - \left(\frac{H}{v + A' c \cot \phi'} \right); \quad i_c = \frac{i_q N_q - 1}{N_q - 1}$$

The inclination of the load, due to a horizontal load H parallel to B' (the shorter side):

$$i_q = \left(1 - \frac{0.7H}{v + A' c \cot \phi'} \right)^3 \quad i_\gamma = \left(1 - \frac{H}{v + A' c \cot \phi'} \right)^3 \quad i_c = \frac{i_q N_q - 1}{N_q - 1}$$

The additional factors which influence bearing capacity is embedment depth, inclination of the base of the foundation and of the ground surface should also be considered. Even if these factors are theoretically considered, there is no critical formula to interpret the factors numerically.

2.2.4.3. Bearing Capacity using Eurocode-7(2004)

European standard is used to analyze both dynamic and static bearing capacities. The static bearing capacity is calculated with the formula below.

UNDRAINED CONDITION

$$q_u = 5.14 C_u s_c i_c b_c + p_o \quad (2.2)$$

Where

$$i_c = \frac{1}{2} + \frac{1}{2} \left(\sqrt{1 - \frac{H}{BLC_u}} \right), \quad s_c = 1 + 0.2 \left(\frac{B}{L} \right), \quad b_c = 1 - \left(\frac{2a}{p+2} \right)$$

DRAINED CONDITION

$$q_u = c' N_c s_c i_c b_c + p_o' N_q s_q i_q b_q + 0.5 B' N_\gamma s_\gamma i_\gamma b_\gamma \quad (2.3)$$

Where:

$$N_c = \frac{N_q - 1}{\tan \phi'}; \quad N_\gamma = 2(N_q - 1) \tan \phi; \quad N_q = \tan^2 \left(\frac{p}{4} + \frac{\phi}{2} \right) e^{\pi \tan \phi'}$$

$$s_c = \left(\frac{s_q N_q - 1}{N_q - 1} \right) \quad s_q = 1 + \left(\frac{B}{L} \right) \sin \phi; \quad s_\gamma = 1 - 0.3 \left(\frac{B}{L} \right) \sin \phi$$

$$i_c = \left(\frac{i_q N_q - 1}{N_q - 1} \right) \quad i_q = \left[1 - \frac{H}{VBL \left(\frac{c'}{\tan \phi'} \right)} \right]^m \quad i_\gamma = \left[1 - \frac{H}{VBL \left(\frac{c'}{\tan \phi'} \right)} \right]^{(m+1)}$$

$$m = m_L + \cos^2 \theta + m_B \sin^2 \theta$$

$$b_c = \frac{b_q N_q - 1}{N_q - 1}; \quad b_q = (1 - \alpha \tan \phi')^2; \quad b_\gamma = (1 - \alpha \tan \phi')^2$$

$$m_L = \frac{2 + \frac{L}{B}}{1 + \frac{L}{B}}; \quad m_B = \frac{2 + \frac{B}{L}}{1 + \frac{B}{L}}$$

2.2.4.4. Bearing capacity by DIN-4017

It is a standard by *Deutsches Institute Fur Normung E. V.* (German National Standard) soil - calculation of design bearing capacity of soil beneath shallow foundations.

UNDRAINED CONDITION

$$q_u = 5.14 C_u s_c i_c b_c g_c + p_o \quad (2.3)$$

Where:

$$i_c = \frac{1}{2} + \frac{1}{2} \left(\sqrt{1 - \frac{H}{BLC_u}} \right); \quad s_c = 1 + 0.2 \frac{B}{L}; \quad b_c = 1 - \left(\frac{2\alpha}{\pi + 2} \right); \quad g_c = 1 - 0.4 \tan \beta$$

DRAINED CONDITION

$$q_u = c' N_c s_c i_c b_c g_c + p_o' N_q s_q i_q b_q g_q + 0.5 B' \gamma' N_\gamma s_\gamma i_\gamma b_\gamma g_\gamma \quad (2.4)$$

Where

Shape Factors

$$s_c = \left(\frac{s_q N_q - 1}{N_q - 1} \right), \quad s_q = 1 + \left(\frac{B}{L} \right) \sin \phi, \quad s_\gamma = 1 - 0.3 \left(\frac{B}{L} \right) \sin \phi$$

Bearing Capacity factors

$$N_c = \left(\frac{N_q - 1}{\tan \phi} \right), \quad N_q = \tan^2 \left(\frac{\pi}{4} + \frac{\phi}{2} \right), \quad N_\gamma = 2 (N_q - 1) \tan \phi$$

Inclination Factors

$$i_c = \left(\frac{i_q N_q - 1}{N_q - 1} \right), \quad i_q = (1 - \tan \theta)^m, \quad i_\gamma = (1 - \tan \theta)^{m+1}$$

Ground Factors

$$g_c = \left(\frac{N_q e^{-2\beta \tan \phi} - 1}{N_q - 1} \right), \quad g_q = (1 - \tan \beta)^{1.94}, \quad g_\gamma = (1 - 0.5 \tan \beta)^6$$

Base Factors

$$b_c = e^{-2.58 \alpha \tan \phi'}, \quad b_q = e^{-2.58 \alpha \tan \phi'}, \quad b_\gamma = e^{-2.58 \alpha \tan \phi'}$$

$$m = m_L + \cos^2 \theta + m_B \sin^2 \theta$$

$$m_L = \frac{\left(\frac{2 + \frac{L}{B}}{\left(1 + \frac{L}{B} \right)} \right)}{\left(\frac{2 + \frac{L}{B}}{\left(1 + \frac{L}{B} \right)} \right)}; \quad m_B = \frac{\left(\frac{2 + \frac{B}{L}}{\left(1 + \frac{B}{L} \right)} \right)}{\left(\frac{2 + \frac{B}{L}}{\left(1 + \frac{B}{L} \right)} \right)}$$

2.2.4.5. Bearing Capacity by EAK (2000)

Greek Code (EAK - 2000) uses several parameters/factors for static and seismic bearing capacity analysis accordingly.

UNDRAINED CONDITION

$$q_u = 5.14 C_u s_c i_c + p_o \quad (2.5)$$

Where

$$i_c = \frac{1}{2} + \frac{1}{2} \left(1 - \frac{H}{BL C_u} \right), \quad s_c = 1 + 0.2 \frac{B}{L} \quad s_c = 1 + 0.2 \frac{B}{L}$$

DRAINED CONDITION

$$q_u = c' N_c s_c i_c + p_o N_q s_q i_q + 0.5 B' \gamma' N_\gamma s_\gamma i_\gamma \quad (2.6)$$

Where:

$$N_\gamma = 2(N_q - 1) \tan \phi', \quad N_c = \left(\frac{N_q - 1}{\tan \phi'} \right), \quad N_q = \tan^2 \left(\frac{\pi}{4} + \frac{\phi'}{2} \right) e^{\pi \tan \phi'}$$

$$s_q = 1 + \left(\frac{B}{L} \right) \sin \phi, \quad s_c = 1 + \left(\frac{B}{L} \right) \left(\frac{N_q}{N_c} \right), \quad s_\gamma = 1 - 0.3 \left(\frac{B}{L} \right)$$

$$i_{qL} = \left(1 - \frac{0.7 H_B}{v + \frac{BL C'}{\tan \phi'}} \right)^3, \quad i_{\gamma L} = \left(1 - \frac{H_B}{v + \left(\frac{BL C'}{\tan \phi'} \right)} \right)^3$$

$$i_c = \frac{i_q N_q - 1}{N_q - 1}; \quad i = i_B \left(1 - \frac{\theta}{90}\right) + i_L \left(\frac{\theta}{90}\right), \text{ where: } \tan \theta = \frac{H_B}{H_L}$$

2.2.4.6. Bearing Capacity by Meyerhof (1953, 1963)

UNDRAINED CONDITION

$$q_u = 5.14 C_u s_c i_c d_c + p_o s_q i_q d_q \quad (2.7)$$

$$\text{Where } i_c = \left(1 - \frac{\theta}{\pi}\right)^2, \quad i_q = \left(1 - \frac{2\theta}{\pi}\right)^2, \quad s_q = 1, \quad d_q = 1, \quad d_c = 1 + 0.2 \left(\frac{D}{B}\right)$$

DRAINED CONDITION

$$q_u = c' N_c s_c i_c d_c + p_o N_q s_q i_q d_q + 0.5 B' N_\gamma s_\gamma i_\gamma d_\gamma \quad (2.8)$$

Where:

$$\text{if } \phi \leq 10^\circ \rightarrow s_q = 1, \quad N_\gamma = (N_q - 1) \tan(1.4\phi'), \quad S_\gamma = 1 + 0.1 \frac{B}{L} \tan^2 \left(\frac{\pi}{4} + \frac{\phi'}{2} \right)$$

$$\text{if } \phi \leq 10^\circ \rightarrow s_\gamma = 1$$

$$i_c = \left(1 - \frac{2\theta}{\pi}\right)^2, \quad d_c = 1 + 0.2 \frac{B}{L} \tan^2 \left(\frac{\pi}{4} + \frac{\phi'}{2} \right)$$

$$i_q = \left(1 - \frac{2\theta}{\pi}\right)^2, \quad d_q = 1 + 0.1 \frac{B}{L} \tan^2 \left(\frac{\pi}{4} + \frac{\phi'}{2} \right)$$

$$\text{if } \phi \leq 10^\circ \rightarrow d_q = 1, \quad i_\gamma = \left(1 - \frac{\theta}{\phi'} * \frac{180}{\pi}\right)^2$$

$$\text{if } \phi = 0^\circ \rightarrow i_\gamma = 0, \quad d_\gamma = 1 + 0.1 \frac{B}{L} \tan^2 \left(\frac{\pi}{4} + \frac{\phi'}{2} \right)$$

$$\text{if } \phi \leq 10^\circ \rightarrow d_\gamma = 1$$

$$m = m_L * \cos^2 \theta + m_B * \sin^2 \theta$$

$$m_B = \frac{2 + \frac{B}{L}}{1 + \frac{B}{L}}, \quad m_L = \frac{2 + \frac{L}{B}}{1 + \frac{L}{B}}$$

2.2.4.7. Bearing capacity by Hansen (1970)

UNDRAINED CONDITION

$$q_u = 5.14 C_u \min \left[(1 + s_c B + d_c B - i_c B - b_c - g_c), (1 + s_c L + d_c L - i_c L - b_c - g_c) \right] \quad (2.9)$$

Where

$$s_{cB} = \frac{B}{L} * i_{cB} \quad i_{cB} = \frac{1}{2} - \frac{1}{2} \sqrt{1 - \frac{H_B}{BLc_u}} \quad d_{cB} = \frac{0.4d_f}{B}$$

$$s_{cL} = \frac{L}{B} * i_{cL} \quad i_{cL} = \frac{1}{2} - \frac{1}{2} \sqrt{1 - \frac{H_L}{BLc_u}} \quad d_{cL} = \frac{0.4d_f}{L} \quad b_c = \frac{2\alpha}{\pi + 2}$$

DRAINED CONDITION

$$q_u = \min(q_{uB}, q_{uL}) \quad (2.10)$$

$$q_{uB} = c' N_c s_{cB} b_{cB} i_{cB} d_{cB} g_c + p_o N_q s_{qB} i_{qB} d_{qB} g_q b_q + 0.5 B' \gamma' s_{\gamma B} i_{\gamma B} d_{\gamma B} g_{\gamma} b_{\gamma}$$

$$q_{uL} = c' N_c s_{cL} b_{cL} i_{cL} d_{cL} g_c + p_o N_q s_{qL} i_{qL} d_{qL} g_q b_q + 0.5 B' \gamma' s_{\gamma L} i_{\gamma L} d_{\gamma L} g_{\gamma} b_{\gamma}$$

Where:

$$N_c = \frac{N_q - 1}{\tan \phi'}$$

$$N_q = \tan^2 \left(\frac{\pi}{4} + \frac{\phi'}{2} \right) e^{\pi \tan \phi'}$$

$$N_{\gamma} = 1.5 (N_q - 1) \tan \phi'$$

$$s_c = s_{cB} b_{cB} i_{cB} d_{cB} g_c = \left(\frac{N_q s_{qB} i_{qB} d_{qB} g_q b_q - 1}{N_q - 1} \right)$$

$$s_{cL} = b_{cL} i_{cL} d_{cL} g_c = \left(\frac{N_q s_{qL} i_{qL} d_{qL} g_q b_q - 1}{N_q - 1} \right)$$

$$s_{qB} = 1 + \left(\frac{B}{L} \right) i_{qB} \sin \phi'; \quad s_{\gamma B} = 1 - 0.4 \frac{B}{L} \left(\frac{i_{\gamma B}}{i_{\gamma L}} \right); \quad s_{\gamma L} = 1 - 0.4 \frac{L}{B} \left(\frac{i_{\gamma L}}{i_{\gamma B}} \right)$$

$$i_{qB} = \left(1 - \left(\frac{0.5 H_B}{\frac{BLc'}{v + \frac{BLc'}{\tan \phi'}}} \right) \right)^5, \quad i_{qL} = \left(1 - \left(\frac{0.5 H_L}{\frac{BLc'}{v + \frac{BLc'}{\tan \phi'}}} \right) \right)^5, \quad i_{\gamma L} = \left(1 - \left(\frac{0.5 H_L}{\frac{BLc'}{v + \frac{BLc'}{\tan \phi'}}} \right) \right)^5$$

$$d_{qB} = 1 + \frac{2d_f}{B} \tan \phi' (1 - \sin \phi')^2$$

$$d_{qL} = 1 + \frac{2d_f}{L \tan \phi'} (1 - \sin \phi')^2 \quad b_q = e^{-2\alpha \tan \phi'}$$

$$d_{\gamma L} = 1 \quad g_q = (1 - 0.5 \tan \phi')^5$$

$$d_{\gamma B} = 1 \quad g_{\gamma} = (1 - 0.5 \tan \beta)^5$$

2.2.5. Bearing Capacity using Geotechnical Software's

Reliable determination of ultimate bearing capacity and foundation settlement is the most crucial step in the design of shallow foundations. Analytical solutions are preferred to numerical methods (i.e. complex finite element models) in engineering practice, mainly because of their inherent simplicity [19]. Zerihun Negussie (2008) has developed the software called 'BEARING' to determine the ultimate bearing capacity of soils using analytical methods according to Ethiopian building code of standard EBCS-7 recommendations and factors, Vesic, Meyerhof, Hansen and using any combination[19]. However best it is, the prepared software has some draw backs. Firstly, as he has recommended, the software didn't assess the settlement characteristics of the soil and it didn't help to calculate the bearing capacity in dynamic loading condition and also it didn't consider the soil type, base inclination factor, ground inclination factor and different loading conditions.

Sofa software is stand-alone simple Geotechnical software and is developed based on MatLab Programming for the calculation of bearing capacity and settlements of shallow foundations. In Sofa software, safety factors are calculated for the ultimate bearing capacity using several well-known formulas from literature[19]. Short-term components of settlements are calculated using the adjusted elasticity method, while confined one-dimensional deformation of the soil is assumed for the consolidation. Sofa provides solutions for all three design approaches implemented in Eurocode-7, as well as in Euro code-8 for earthquake loading. Cohesive and cohesion less soils, static and dynamic loads, drained and undrained conditions are examined. The software is used to determine the bearing capacity and settlement using different methods found literatures (DIN-4017, Euro code-7, EAK (2000), Meyerhof and Hansen). Among these methods DIN-4017 is the basis of Ethiopian building code of standard EBCS-7.

2.3. COMPRESSIBILITY CHARACTERISTICS OF SOILS

2.3.1. General

Any structure built on the ground causes an increase of pressures on the underlying soil layers and contributes for settlement in structures. So, settlement determination plays a considerable role in assessing the safety and architectural aesthetics of any structure [15]. If a structure settles uniformly, no damage will be done as such, but the function of the structure may be affected. A more serious case is non-uniform or differential settlement of the structures, in which part of a foundation or two adjoining footings settle differently. If the effect of the differential settlement is not taken into the design of the structure, the structure may crack very badly and the safety of the structure becomes questionable [15]. The magnitude of the differential settlement that can be accommodated by a structure depends upon the soil type, the type of construction, the type foundation and column spacing.

The soil layers are unable to spread laterally as the surrounding soil strata confines them. Hence the soil reacts by the adjustment to the new pressure by deforming vertically. The compression of the soil mass leads to the decrease in the volume of the mass, which result in the settlement of the structure, built on the mass. The vertical compression of the soil mass under increased pressures is thus made up of the following components [20]: deformation/particle rearrangement of the soil grains, the compression of air within the voids and an escape of water and air from the Veds

Deformation of the soil grains is the primary feature of elastic settlement also named as distortion settlement or contact settlement and usually taken to occur immediately on the application of the foundation load .Such immediate settlement in the case of partially saturated soils is primarily due to the expulsion of gases and to the elastic compression and rearrangement of particles. In the case of saturated soils immediate settlement is considered to be the result of vertical soil compression, before any change in volume occurs. The other two components of settlement result of the gradual expulsion of water from the voids and the concurrent compression of

the soil skeleton are characterized by consolidation settlement. Primary consolidation settlement of soil is the gradual reduction in volume of voids upon loading. In saturated soils (Clays), the reduction of void volume occurs due to dissipation of excess pore-water pressure. The theory for the time rate of one-dimensional consolidation was first proposed by Terzaghi and Peck for Granular soils [9]. The underlying assumptions in the derivation of the mathematical equation are the following:

- a) The soil is homogeneous and isotropic
- b) The soil is fully saturated the soil particles and the water in the voids are incompressible. The consolidation occurs due to expulsion of water from the voids
- c) Darcy's law is valid throughout the consolidation process
- d) Soil is laterally confined and the consolidation takes place only in the axial direction.
- e) Drainage of water also occurs only in the vertical direction

The assumptions made by Terzaghi are not fully satisfied in actual field conditions. The results obtained from the use of the theory to practical problem are approximate. However, considering complexity of the problem, the theory gives reasonably accurate estimate of the time rate of settlement, the total consolidation settlement and elastic settlement of a structure built on the soil[21].

2.3.2. Settlement Analysis by Skempton and Macdonald Approach

From statically analysis Skempton and MacDonald concluded that as long as the angular distortion (δ/l) of a building is less than 1/300, there should be no settlement damage [15]. This finding was also substantiated by having established the permissible limits of differential settlement.

Table 2.10. Maximum permissible settlement based on Skempton and MacDonald [15]

	Type of Soil and Footing	Empirical Formula	Total Settlement mm	Angular Distortion
For Sand soil	Isolated Footing	$\frac{d}{l} = \frac{s_{\max}}{600}$	50	to keep ≤ 1300
	Raft Foundation	$\frac{d}{l} = \frac{s_{\max}}{750}$	60	
For Clay soil	Isolated Footing	$\frac{d}{l} = \frac{s_{\max}}{1000}$	80	
	Raft Foundation	$\frac{\delta}{l} = \frac{s_{\max}}{1250}$	90	

2.3.3. Presumptive values of Total Settlement

Taking into consideration the recommendation of Skempton and MacDonald, bowels recommended the total permissible settlement as follows

Table 2.11. Bowels Maximum Permissible Settlement [15]

	Type of Soil and Footing	Total Settlement mm	Angular Distortion
Sand	Isolated Footing	50	to keep 111300
	Raft Foundation	50-75	
Clay	Isolated Footing	75	
	Raft Foundation	75-125	

The Ethiopian Building code of standard for foundation recommends a permissible total settlement of 50mm and 75mm on sandy and clayey soils, respectively and this is for an angular distortion not exceeding 1/300.

Table 2.12. Maximum Permissible Settlement according to Indian Standard Based on Structural Materials[22].

Type of Footing and Structural Material	Total Settlement (mm)	Angular Distortion
Steel Structure		to keep ≤ 1300
Isolated Footing	50	
Raft Foundation	75	
R.C.C structure		
Isolated Footing	50	

Raft Foundation	75	
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2.3.4. Immediate Settlement determination

This part occurs immediately after the construction. Based on the soil type considered, this is computed using different formulae.

2.3.4.1. Immediate Settlement of Cohesion less Soils

Because of the high permeability, the elastic as well as the primary compression effects occur more or less together in the case of cohesion less soils [23]. The method available for predicting this settlement is far from perfect; either the standard penetration test or the use of charts is resorted. The result which is the number of blows required for causing a standard depth of penetration under specified standard conditions can be used to evaluate immediate settlement in cohesion less soil (De Beer and Martens, 1957). Relationship between pressure and settlement of a 305mm square plate, for different values of N, in cohesion less soils is shown Figure 2.1 (After Thorn burn, 1963). Another method has been developed for use with the Dutch cone penetrometer but can also be adapted for the standard penetration test.

$$s_i = \frac{1.5p_o H}{c_r} \log_e \left(\frac{p_o + \Delta p}{p_o} \right) \quad (2.12)$$

Where:

H = thickness,

Po = over burden pressure

Cr = recompressibility index

Si = immediate settlement

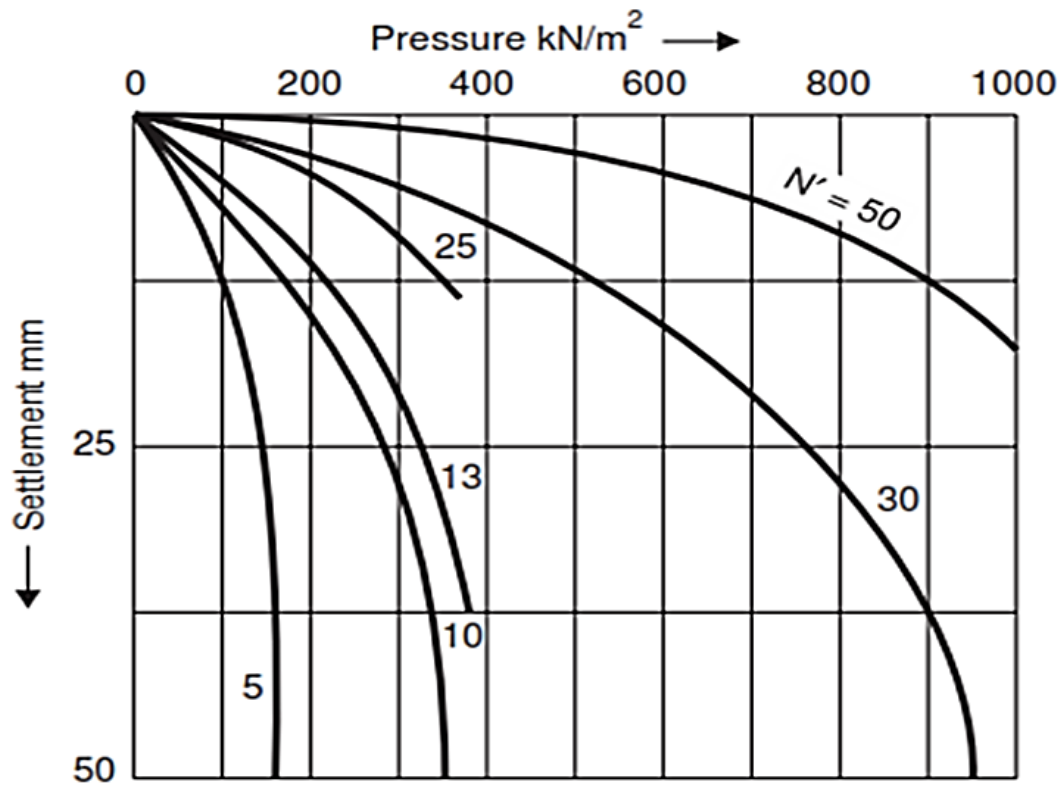


Figure 2.1. Relationship between pressure and settlement of a 305mm square plate, for different values of N , in cohesion less soils (After Thornburn, 1963).

2.3.4.2. Immediate Settlement in Cohesive Soils (Terzaghi)

Using theory of elasticity of the soil in saturated or partially saturated clay, the immediate settlement occurred is the vertical deformation due to the change in shape but virtually no volume change of the soil [23]. The immediate settlement of flexible foundation according to Terzaghi (1943) at the center of the footing is given by

$$s_i = \frac{2qBI_sI_f}{E_s}(1 - v^2) \quad (2.11)$$

Where:

S_i = immediate settlement

q = surcharge load

I_s = shape factor for settlement

I_f = Depth factor

v = poissonous ratio

The poison's ratio is defined as an elastic settlement variable which is determined by the ratio of the axial compressive strain to lateral compressive strain using Triaxial test, but for simplicity, it has been taken with the correlated value with

a plasticity index of the soil. For undrained clay soils the piousness ratio is 0.5 and for partially saturated cohesive soils Poison's ratio is represented by the following equation.

$$n = 0.25 + 0.00225(\text{PI}) \quad (2.12)$$

In computing I_f factor:

$$I_s = F_1 + \frac{1-2\nu}{1-\nu} F_2 \quad F_2 = \frac{n}{2\pi} \tan^{-1} A_2 \quad F_1 = \frac{1}{\pi} (A_0 + A_1)$$

$$A_0 = m \ln \left(\frac{1 + \sqrt{m^2 + 1} \sqrt{m^2 + n^2}}{m(1 + \sqrt{m^2 + n^2 + 1})} \right) \quad A_1 = \ln \left(\frac{m \sqrt{m^2 + 1} \sqrt{1 + n^2}}{m + \sqrt{m^2 + n^2 + 1}} \right)$$

$$A_2 = \frac{m}{m + \sqrt{m^2 + n^2 + 1}} \quad m = \frac{L}{B} \quad n = \frac{2H}{B} \quad I_f = f \left(\frac{D_f}{B}, \nu, \frac{L}{B} \right)$$

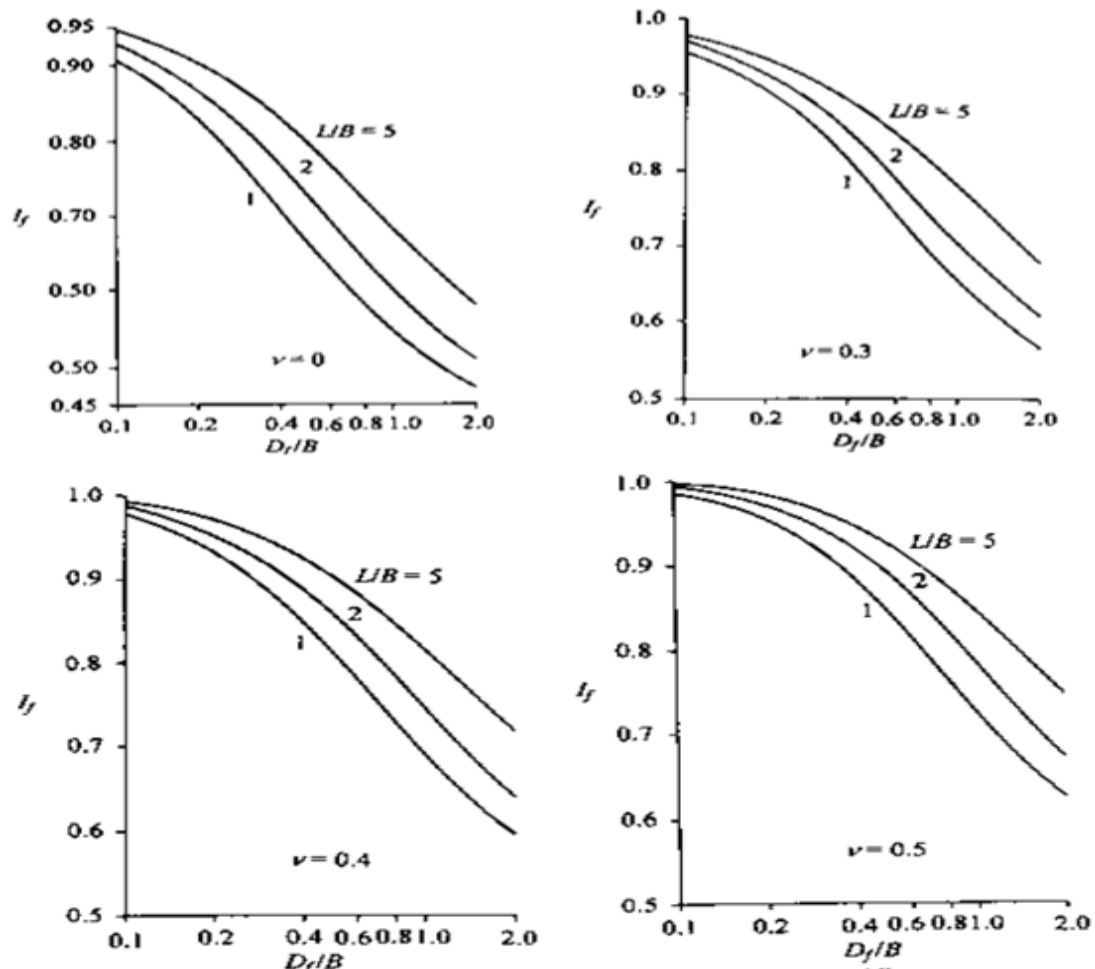


Figure 2.2. Influence Factor for depth of foundation[23]

2.3.4.3.Generalized Average Elastic Settlement Method

Janbu (1956) proposed a generalized equation for average elastic settlement for uniformity loaded flexible foundation, but this is done for soil with piousness ratio of 0.5 or in the state of saturation of the soil.

$$s_{i(\text{flexible})} = m_0 m_f \frac{qB}{E_s} \quad (2.13)$$

Where:

m_0 = constant

m_f = constant

q = surcharge load

E_s = modulus of elasticity

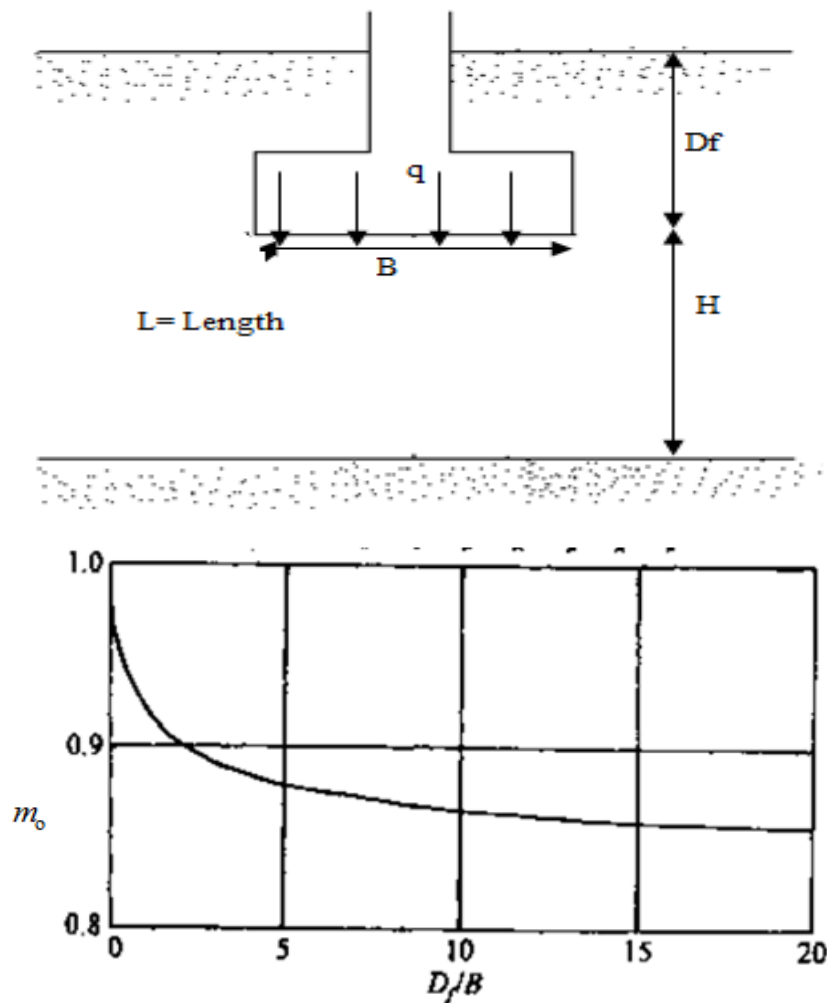


Figure 2.3. Correction Factor for depth of embedment of foundation [23]

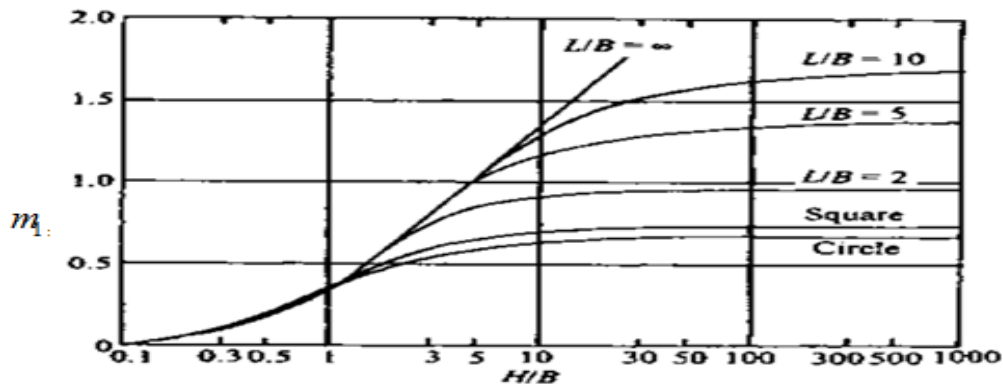


Figure 2.4. Correction Factor of finite thickness of elastic layer [23]

2.3.4.4. An Improved Equation for Elastic Settlement

Mayne and Poulos (1999) presented an improved formula for calculating the elastic settlement of foundations. The formula takes into account the rigidity of the foundation, the depth of the embodiment of the foundation, the increase in modulus of elasticity of the soil with depth, and the location of the rigid layer at a limited depth. Even though it is improved method for settlement calculation, there are limitations to involve in this study, the first one is the scope of study to determine sub grade modulus using plate load test, the second is the equation use soil sub grade modulus as a variable for calculation but the target of this study is to get a reasonable value of settlement to reach the appropriate sub grade modulus value.

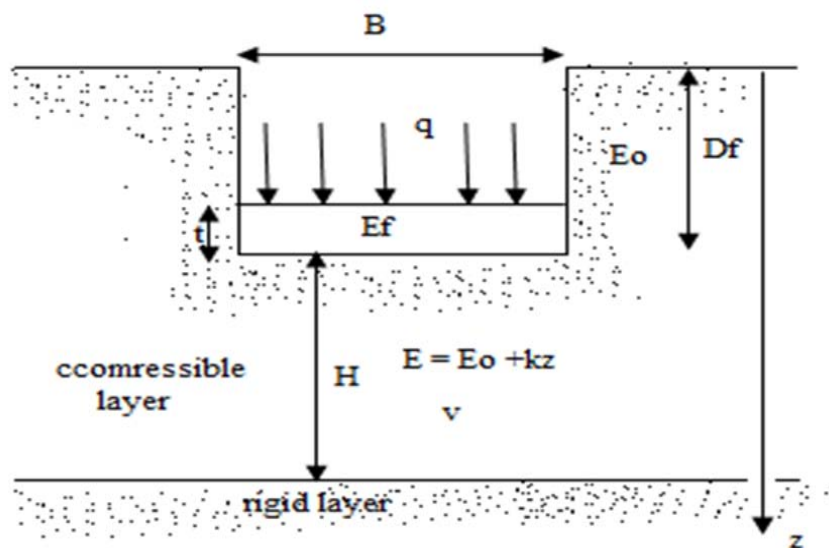


Figure 2.5. Modulus of elasticity of compressible and rigid layer

$$s_i = \frac{qB_e I_G I_F I_E}{E_o} (1 - \nu^2) \quad (2.14)$$

Where B_e is an equivalent width or diameter of the foundation

$$B_e = \sqrt{\frac{4BL}{\pi}} \quad (2.15)$$

2.3.5. Calculation of Consolidation Settlement

Consolidation settlement is calculated using various analytical methods and using Geotechnical software.

2.3.5.1. Using $e - \log p$ Plot

Settlement due to consolidation in this case is computed with two methods of the theory of elasticity. The formulae below is given according to the type of consolidation: Saturated clay soil layer of thickness H , cross-sectional area A , existing overburden pressure P_o , increase in pressure Δp , and resulting ultimate primary consolidation settlement s_c .

METHOD I

For Normally Consolidated Soils ($p_c = p_o + \Delta p$)

$$s_c = \frac{C_c H}{1 + e_o} \log \left(\frac{p_o + \Delta p}{p_o} \right) \quad (2.16)$$

For Over Consolidated Soils ($p_c > p_o + \Delta p$)

$$s_c = \frac{C_s H}{1 + e_o} \log \left(\frac{p_o + \Delta p}{p_o} \right) \quad (2.17)$$

For Over Consolidated and ($p_c < p_o + \Delta p$)

$$S_c = \frac{C_s H}{1 + e_o} \log \left(\frac{p_c}{p_o} \right) + \frac{C_c H}{1 + e_o} \log \left(\frac{p_o + \Delta p}{p_c} \right) \quad (2.18)$$

For evaluation of the increased stress use a general chart of stress distribution beneath rectangular and strip footing shown below[9].

The average value of applied stress variation in depth at the center of the footing –

The diagram illustrates a vertical well in a confined aquifer. The total height of the aquifer is labeled H . The well is represented by a vertical line. The pressure profile is shown as a curve that starts at the bottom boundary (indicated by a dashed line) and rises to the top boundary. The pressure difference between the wellbore and the formation at the top boundary is labeled Δp_i . The pressure difference between the wellbore and the formation at the bottom boundary is labeled Δp_b . The pressure difference between the wellbore and the formation at an intermediate depth is labeled Δp_m . The vertical axis is labeled Z .

METHOD II

For Over Consolidated Soils and $(p_c < p_o + \Delta p)$

For Over Consolidated Soils and $(p_c > p_o + \Delta p)$

$$s_c = \frac{0.1C_c H}{1 + e_o} \log \left(\frac{p_o + \Delta p}{p_o} \right) \quad (2.21)$$

2.3.5.2.Using m_v Method

This method of consolidation settlement was analyzed by Skempton and Bjerrum [24]. In this method the value of m_v even for a particular soil is not constant it mainly depend on the stress range over which it is calculated.

$$s_c = \frac{\Delta p H_o}{1 + e_o} \left(\frac{e_o - e_1}{p_1 - p_o} \right) \quad (2.22)$$

2.4. CONCLUDING REMARKS

Bearing capacity and compressibility are the basic design criteria for safe design of statically loaded structures. In this study, various literatures were reviewed and the factors considered for the derivations are observed. Presumptive bearing capacity is determined simply based on the soil physical characteristics, it is not based on stress history of the foundation soil, and also a geometrical influence of the foundation is not taken into account. Other analytical methods of bearing capacity formulae are illustrated in this study like Prandtl, Reissner and Terzaghi which are ancient methods of bearing capacity formulation codes with the apparent assumption of the bearing capacity parameters. Indian Standard to determine bearing capacity with a different assumption of ground water table condition are also reviewed along with using Meyerhof's, Vesic's and Hansen's bearing capacity parameters. Bearing capacity using standard penetration test is the most reliable method of bearing capacity and settlement analysis with limitation of SPT indices, N . Using plate load test, the insitu undisturbed field data could also be found and it makes the study realistic and fast enough but for stratified layers which depth greater than 30cm is difficult to be tested. Settlement is also the other design component which is required to check the safety of the foundation. Three components of settlement are assessed these are caused due to deformation of the soil grains, the compression of air within the voids, an escape of water and air from the voids and an arrangement of soil particles. Secondary settlement caused by the arrangement of soil particles is almost negligible in inorganic soils. Settlement using standard penetration test method is

mostly used for cohesion less soils, but incurs an error unless the chart or the value of N is resorted. Consolidation settlement using m_v method is not commonly used because of the variability of m_v for a particular soil. Presumptive settlement values are suggested based on general soil type, construction material, and type of foundation.

CHAPTER 3

EXPERIMENTAL METHODS/TECHNIQUES, MATERIALS AND TEST RESULTS

3.1. INTRODUCTION

Proper laboratory testing of soils to determine their physical properties is an integral part in the design and construction of structural foundation, the placement and improvement of soil properties, and the specification and quality control of soil compaction works. It needs to be kept in mind that natural soil deposits often exhibit a high degree of non-homogeneity. The fundamental theoretical and empirical equations that are developed in soil mechanics can be properly used in practice if and only if, the physical parameters used in those equations are properly evaluated in the laboratory. So, learning to perform laboratory tests of soils plays an important role in the Geotechnical engineering profession to conduct the necessary researches.

In this study some base laboratory tests were carried out to get the necessary data of helpful to this study. These are Dry sieve analysis, liquid limit, plastic limit, moisture content, specific gravity, bulk density, direct shear test, unconfined compressive strength and one dimensional consolidation test.

3.2. SAMPLING TECHNIQUE

For the purpose of getting a better result, the test sampling of the soil is taken in the dry season in January and April in Gelan sub city located around Addis Ababa city towards Adama route in four places shown below.



Figure 3.1. Borehole *Ferro Area* (left) and Railway surface soil (right)

Before sampling, it was the primary task to get permission from the administrative municipality of the city, after field survey was made simply by visually inspection of the area and the structures built on four places, Ferro area, municipality area, asphalt area and Railway areas were selected for detailed study. The samples for moisture content, dry sieve analysis, Atterberg limits, the specific gravity and bulk density were taken as disturbed and for direct shear test, UCS test and consolidation tests soils are taken as undisturbed at four different points where critical soil characteristic variation is expected.

Both disturbed and undisturbed samples are taken at 2m depth in four pits. Undisturbed and disturbed samples were collected independently at those four pits with a unique designation to identify easily one sample to the other. For undisturbed samples the data were collected using molds on site and for disturbed samples three test data were collected at 2m depth from each pit for each place.

3.3. MATERIALS AND TEST PROCEDURES

To achieve the study objectives of this research, different materials were used in field and laboratory.

3.3.1. Dry Sieve Analysis

The weight of each sieve as well as the bottom pan to be used in the analysis was weighted and recorded as shown from Table 3.1. A 1647gm dry soil sample was

first measured. The sieves were assembled in ascending order of sieve numbers 37.5mm opening sieve on top and 0.075mm opening sieve at bottom, .Then the pan was placed bellow No. 200 sieve / Sieve opening 0.075mm/. Table 3.1shows the calculation detail of the sieve test.

Table 3.1. Dry Sieve Analysis data-typical

Designation	Sieve opening, mm	Mass of Sieve, gm.	Mass of Sieve +dry soil, gm.	Mass Retained,g m	Percentage Retained	Cumulative % Retained	Percentage Finer
3/2"	37.5	329.6	329.6	0	0	0	100
1"	25	333.9	333.9	0	0	0	100
3/4"	19	330.3	330.3	0	0	0	100
3/8"	9.5	304.8	312.05	7.25	0.44	0.44	99.56
No. 4	4.75	307.1	315.4	8.3	0.50	0.95	99.05
No. 10	2	315.6	334.6	19	1.16	2.10	97.90
600 μ	0.6	270.9	290.2	19.3	1.17	3.27	96.73
No. 40	0.425	377.2	449	71.8	4.37	7.64	92.36
No. 60	0.25	263	349.4	86.4	5.25	12.89	87.11
No. 100	0.15	261.2	379.43	118.23	7.19	20.08	79.92
No. 200	0.075	248.2	549.5	301.3	18.3	38.4	61.6
Pan	Pan	277.3	1290.2	1012.9	61.6	100.0	0.0
Total				1644.44	100		

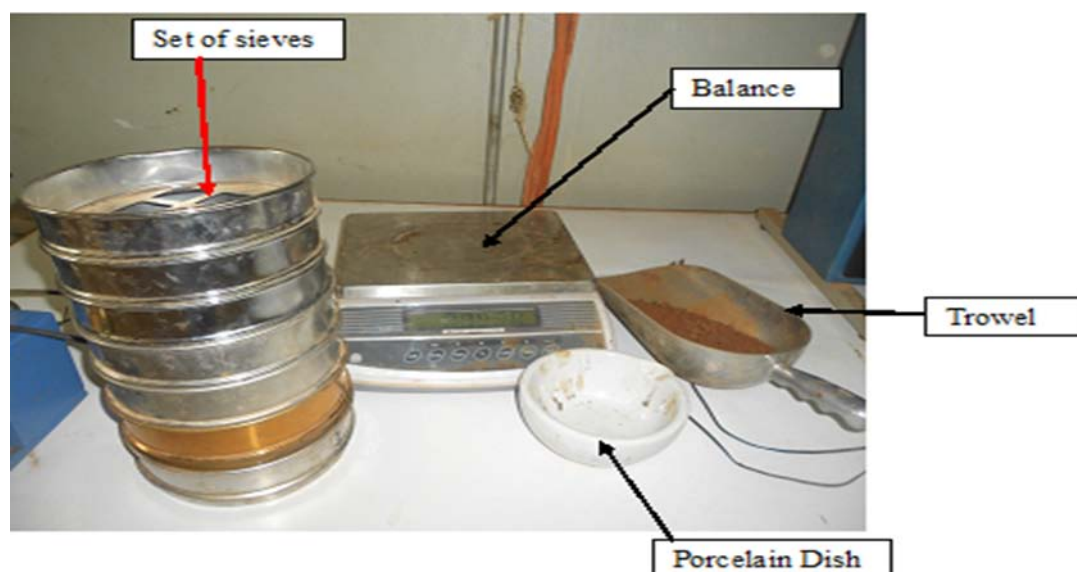


Figure 3.2. Dry sieve analysis apparatus

3.3.2. Natural Moisture Content (ω)

Using the necessary apparatus shown in Table 3.2, first the mass of clean and dry specimen container /can/ be determined and recorded. The representative test specimen was selected. The mass of the container and the moist soil was measured and recorded. The container with moist soil was placed in drying oven, which is maintained at a temperature of 105°C. After the material has dried to a constant mass, the container was removed from the oven. The removed container and dried soil sample was cooled outside the oven and finally the mass of the dried soil and the container was determined as indicated from Table 3.2.

Table 3.2. Moisture Content data sheet - typical

FERRO AREA			
MOISTURE CONTENT TEST (%)			
Can ID.	A18	A11	A12
Mass of can, gm.	37.7	37.5	37.5
Mass of can + wet soil sample, gm.	163.2	153	157.3
Mass of can + dry soil sample, gm.	134.6	126.4	130.2
Mass of Water, gm.	28.6	26.6	27.1
Mass of dry soil, gm.	96.9	88.9	92.7
Moisture content (%)	29.52	29.92	29.23
Average moisture content (%)	29.56		



Figure 3.3. Moisture Content Test Apparatus

3.3.3. Specific Gravity Determination (G)

Using the apparatus shown in Figure 3.4, the specific gravity test is started by measuring first by using 25gm mass of oven dried soil sample (passes in Sieve No.10) for the Ferro area. A sample of soil was added in the density bottle was filled to one third of its volume with distilled water. The entrapped air was removed by applying vacuum or by shaking using an end-over-end- shaker for 10 minutes to soak the soil. After the air has been expelled and no more air bubble is seen escaping, then the density bottle was filled with distilled water up to its calibration. Then the mass of density bottle, the soil sample and distilled water up to its calibration was measured and recorded. The temperature was taken during the test by making empty the density bottle from its contents and cleaned from outside and filled with distilled water. The mass of density bottles with distilled water was measured and recorded. Finally, the specific gravity was measured using simple empirical equation as shown from Table 3.3.

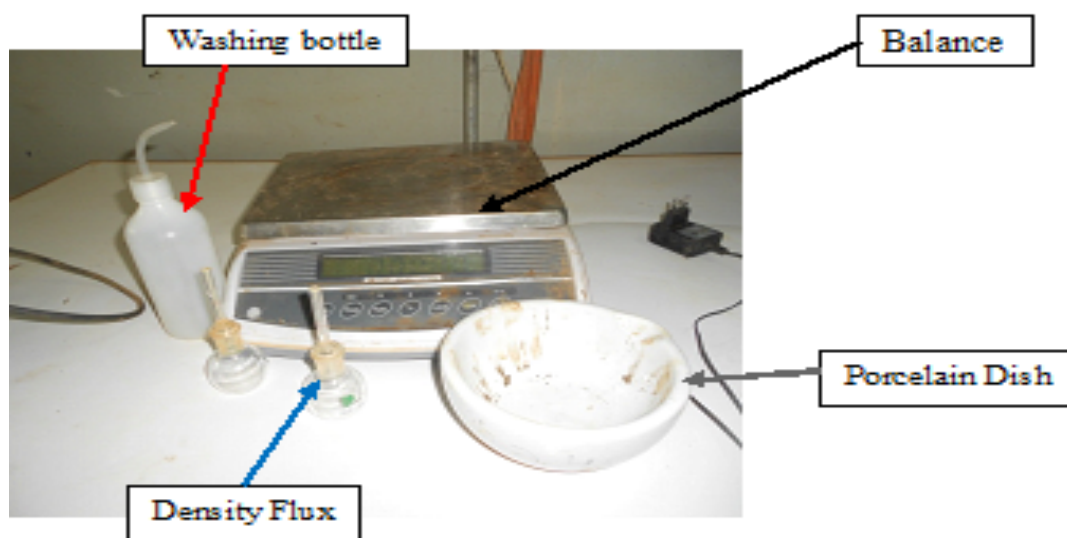


Figure 3.4. Specific Gravity test apparatus

Table 3.3. Specific Gravity Test data sheet – typical

FERRO AREA**SPECIFIC GRAVITY TEST**

	Test No.		
Item	1	2	3
Volumetric bottle No.	1	4	3
Mass of bottle + water filled to mark, W1 (g)	97.2	98.5	89.5
Mass of flask + soil + water filled to mark,W2 (g)	113.4	118.7	106.4
Mass of dry soil, Ws(g)	25.5	32.3	27.1
Mass of equal volume of water as the soil	9.3	12.1	10.2
Solids, Ww(g) = (W1 + Ws) - W2			
Temperature where test is taken(Tc°)	29		
Gs of water at 20°c	1		
Gs of water at T°c	0.996	0.996	0.996
correction factor(K)= Gs@Tc/Gs@20°c	0.996	0.996	0.996
Gs= K*Ws/Ww(at Tc°)	2.730968	2.66	2.65
Average	2.68		

3.3.4. Atterberg Limit Tests

First 200g of soil sample passing No.40 sieve was weighted. Distilled water was added to the soil and it is mixed thoroughly to form a uniform paste. The amount of water added should be such that the number of blows required to close the groove is about 28-35. A portion of the paste was placed in a Casagrande Apparatus by smoothing the surface, using spatula groove the sample along the symmetrical axis of the Casagrande. By turning the handle of the standard of at a rate of two revolutions per second and the blows necessary to close gaps for a distance of about 12mm was recorded. Sample near the closed portion was taken for moisture content determination. The remaining soil was transferred into evaporation dish. The Casagrande Apparatus and grooving tool were washed and dried, reattach the Casagrande Apparatus to prepare for subsequent trials. The entire soil specimen was remixed in the storage dish by adding distilled water to increase the water content. 2 additional trials were made to reduce No. of blows. Ideally the amount of water added in the second and third trial should yield a constant blow count of 15-20, 20-30 blows respectively as shown from Table 3.4.

Table 3.4. Liquid limit test procedure of Railway area, typical

Trial	Can ID.	Mass of Can, (gm.)= a	Mass of Can+wet soil (gm.)= b	Mass of Can+dry soil (gm.)= c	Mass of water (gm.)= d = b-c	Mass of dry soil (gm.)= e= c-a	Moisture content (%)= d/e	No blow N
1	4	37.2	53.2	46.8	6.4	9.6	66.67	15
2	C-8	37.3	57.8	49.7	8.1	12.4	65.32	30
3	A-2	37.2	58.9	50.5	8.4	13.3	63.16	35
Average LL %							65.5	

For plasticity limit determination 50gm of soil sample passing sieve size 0.425mm /No. 40/was weighted. Distilled water was added to the soil and it is mixed thoroughly to form a uniform paste. The amount of water added should be such that the water content is less than liquid limit. The soil paste was rolled on a large glass plate with hand until a 3mm diameter of soil threads is obtained as indicated from Figure 3.5. When a 3mm diameter soil thread obtained, break the thread into pieces. The portion of the crumble soil sample gathered and the water content as plasticity limit as shown from Figure is determined.

Table 3.5. Plasticity limit test procedures

Trial	Can ID.	Mass of Can (gm.)= a	Mass of Can+Wet soil (gm.)= b	Mass of Can+Dried soil (gm.)= c	The mass of water (gm.)=d=b-c	The mass of Dried soil(gm.)= e=c-a	Moisture content (%)= (d/e)
1	39.29	39.29	39.29	39.29	39.29	39.29	39.29
2	42.86	42.86	42.86	42.86	42.86	42.86	42.86
3	30.56	30.56	30.56	30.56	30.56	30.56	30.56
PL (%)							37.57



Figure 3.5. Materials used for the Atterberg Limit test

3.3.5. Unconfined Compression (UC) Test

The sample extracted from the field as undisturbed using sampling mold. The leveled sample was then trimmed with trimming equipment. The soil test sample is then extruded with a sampler tube of diameter 38mm and height 76mm and trimmed the soil to prepare it for uniform load application.

After putting the sample to the center point of the compression device, turn the machine on and repeated reading is taken until failing to decrease as indicated from Annex A.



Figure 3.6. Materials used for UCS test

3.3.6. Direct Shear Test

To conduct the direct shear test, undisturbed soil samples were compacted at the required density using molds. Then the sample was extruded with shear box as shown in Figure 3.7. The width and height of the shear box were determined. After leveling the sample at the top of the shear box was assembled and placed in the direct shear device and then porous stone was placed. Alignment of screws from the shear box was removed. Load and deformation dial gauges were checked. The rate of shearing was adjusted. Reading was taken until the vertical load and the sample were changed after the completion of each test. The test procedure is shown from Annex A



Figure 3.7. Direct Shear Test apparatus

3.3.7. Consolidation Test

Using the apparatus shown in Figure 3.8, the empty consolidation ring was cleaned, dried and weighted. The height (H_0) of the ring and its diameter (D) was measured to 20mm and 50mm respectively. The initial moisture content and specific gravity of the soil was determined. Undisturbed sample was taken. The sample was leveled off carefully by trimming. The porous stones that have been soaked on the

top and bottom surfaces of the test soil specimen were centered after having been adjusted. The filter paper was placed at the top and bottom of the porous stone. To make sure that the stones adhered to the sample, the stone was pressed very slightly. The assembly was lowered carefully into the base of the water reservoir. The water reservoir was filled with water until the specimen was covered and fully saturated. The consolidation dial readings at elapsed times were recorded after the adjustment of the dial gauge reading to zero. For each vertical load the reading was taken for loading and unloading cases as shown in Annex A.

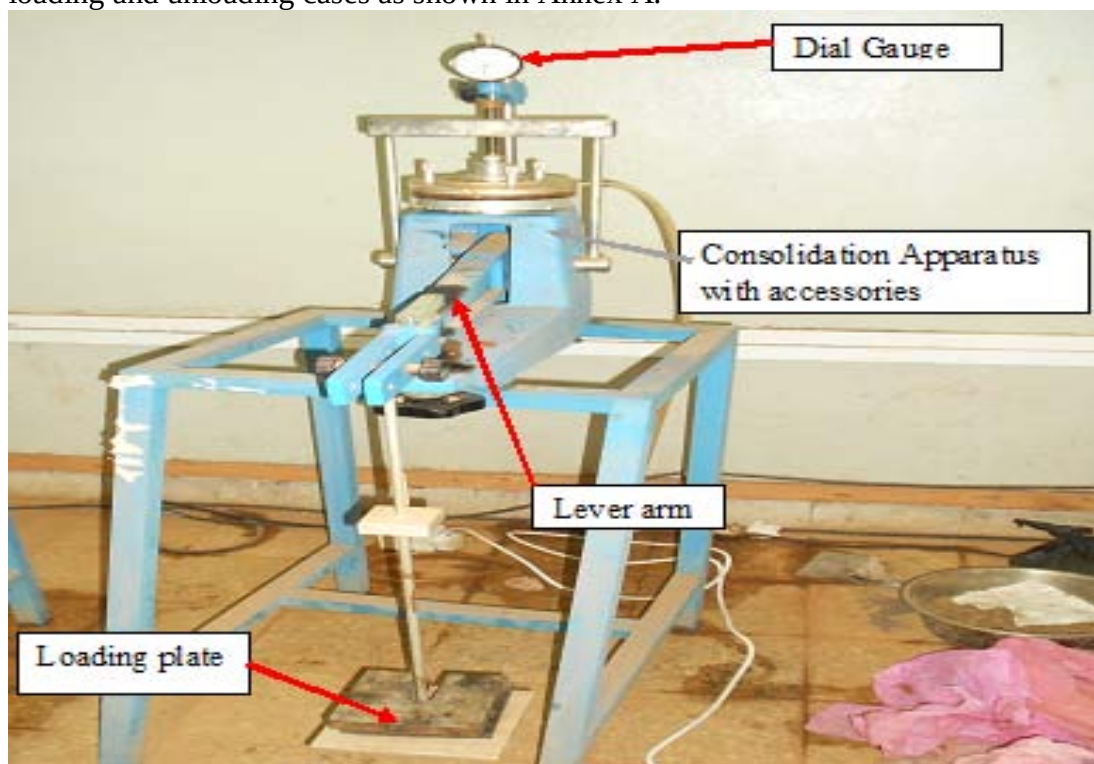


Figure 3.8. Consolidation Test Apparatus

3.3.8 Free swell test

This test gives the fair approximation expansiveness of the degree of soil sample. The amount of volume change exhibited by various soils under water condition greatly varies.

The test has been conducted from 20-30gm sample which passes in sieve no. 40 was prepared. The soil sample was added in to the graduated tube shown below up to 10ml reading (V_0). Water was added in a graduate tube which contain in the soil sample up to a level of 100ml. The graduated tube which contains soil sample and water was kept in the laboratory for 24hr to complete the expansiveness of soil. After 24 hr, the volume of soil was taken (V_f).

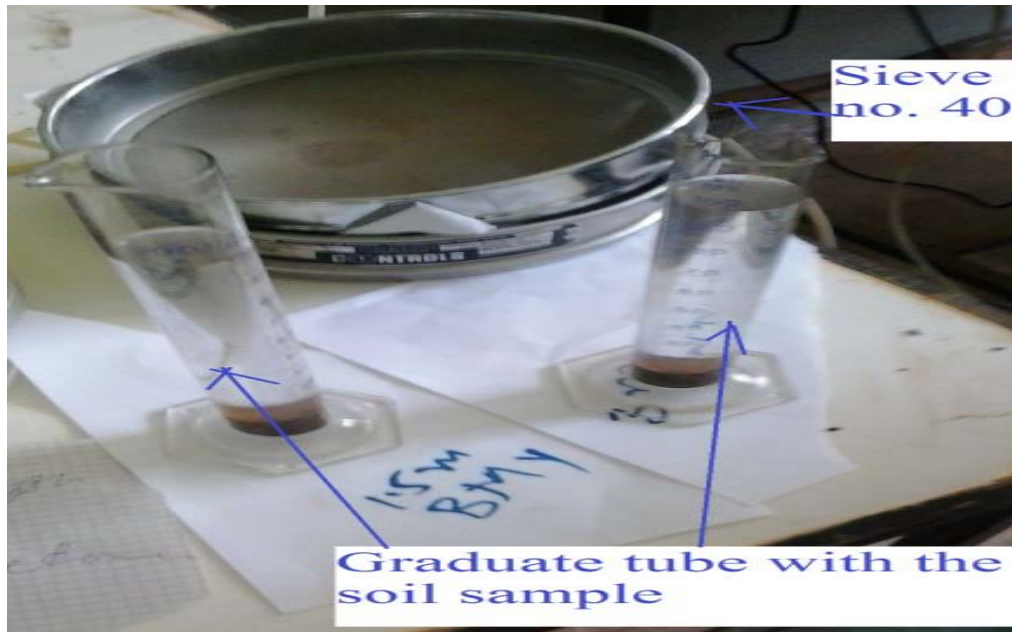


Figure 3.9 Free swell test apparatus

3.4. TEST RESULTS

All the required tests and the corresponding data's recorded are collected from the laboratory tests shown above. For each disturbed sample, 3 tests per pit were conducted according to ASTM standard and for undisturbed samples from sites were taken and extruded with samples of each test type. The test results were recorded for all tests. The average results of each Geotechnical parameters for each area are used for design as shown in Table 3.6. A direct shear test is carried out at four undisturbed samples collected from Gelan sub city where a better variation is expected. Average bulk density was determined. The ground water table is far below the base of the footing i.e. more than its width and has no effect for the design. The horizontal displacement reading is recorded with an appropriate division interval with application of four normal loads and among the force recorded with the corresponding horizontal dial gauge reading, the maximum value was taken as the shear stress for each normal loading.

Table 3.6. Test results of samples

Location	Depth	Moisture content	Liquid limit	Plastic limit	Plasticity index PI	Specific gravity	Bulk density	Percent finer than 0.075mm	Free swelling index
	(m)	(%)	(%)	(%)	(%)	-	Kg/m ³	(%)	(%)
BH.F	2	29	54	36.2	17.8	2.68	1.785	61.6	30
BH.R	2	36.6	65.5	24.0	27.9	2.64	1.444	56.8	79.5
BH.M	2	39.1	80	54.3	25.7	2.66	1.504	63.2	42.3
BH.A	2	34.0	67.3	38.0	29.3	2.65	1.411	58.4	97.4

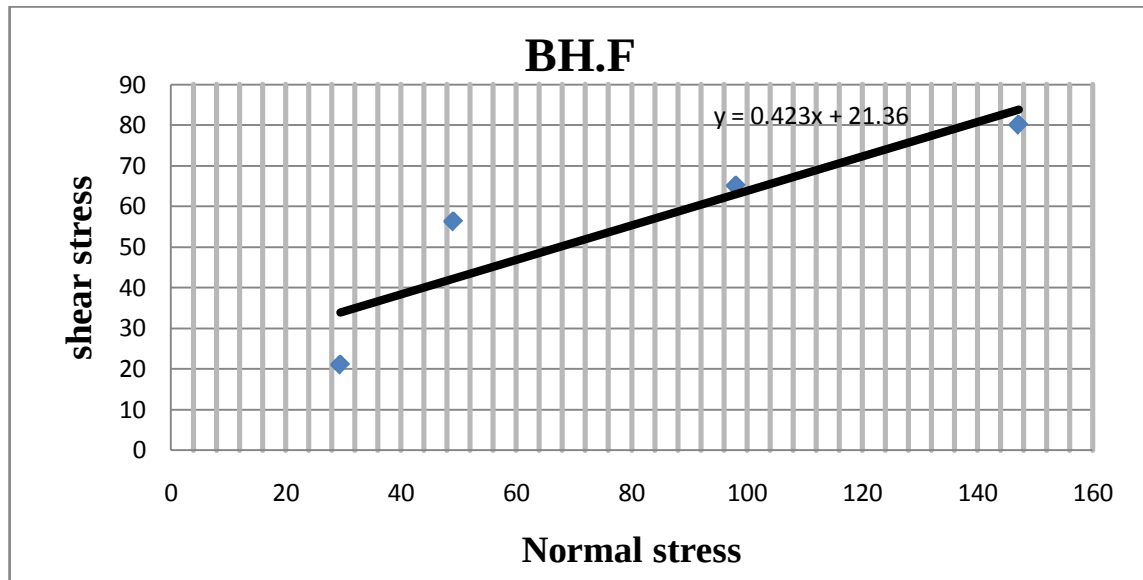


Figure 3.9. Typical value of Normal Stress versus Shear Stress of Gelan Area soils

Finally the direct shear strength parameters j' and $c\phi$ were estimated from the graph indicated in Figure 3.9. The normal stress versus shear stress of the appropriate straight line slope relating the points is used. Drained bearing capacity of these collected samples are later used to determine bearing capacity and settlement using methods found in EBCS-7 and other codes discussed in literature review as well as in SOFA software.

The second test result is an unconfined compressive strength test, on which undrained shear strength was determined. This parameter was determined from the graph of the horizontal dial gauge reading versus the vertical dial gauge reading with the placement of the specimen in a compression device of which the maximum inflection point of the vertical dial gauge with a conversion factor 44.7 was taken as the unconfined compressive strength then the undrained shear strength of the samples of the city was determined by taking the half of unconfined compressive strength. Figure 3.10 represents UCS test results.

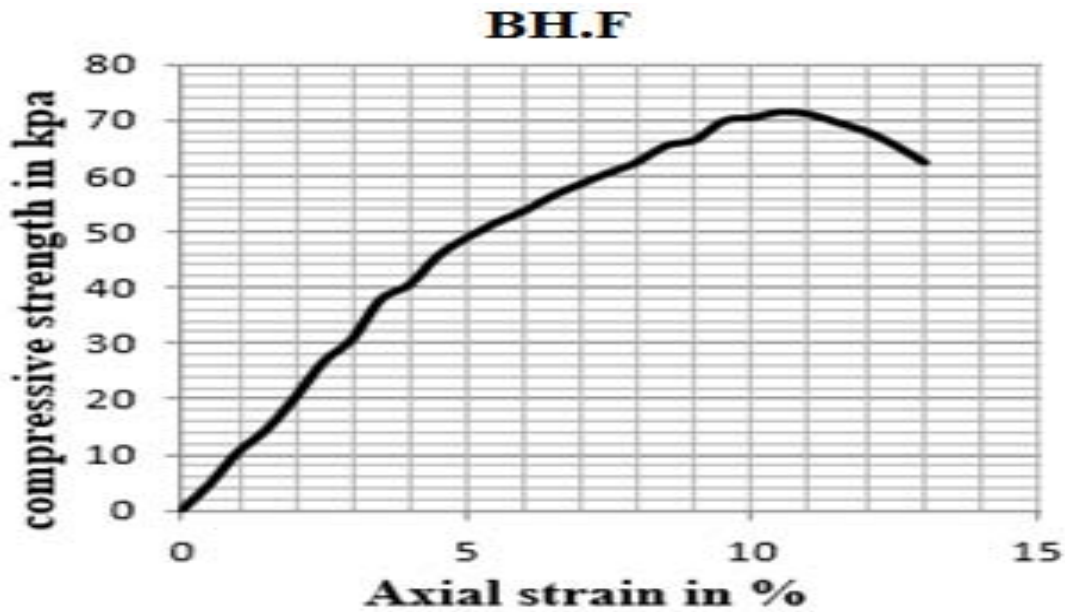


Figure 3.10. Typical value of Axial Strain in percent versus compressive strength of sub city soil

Table 3.7. Summary of direct shear and UCS test results

Location	$c'(kpa)$	$\phi'(^{\circ})$	$C_u (Mpa)$	$\gamma (kN / m^3)$
BH.F	13.64	19	50.04	17.85
BH.R	10.5	15	51.68	14.44
BH.M	18.35	21	46.016	15.04
BH.A	21.4	23	35.72	14.11

A consolidation test is carried out on four undisturbed samples of Gelan sub city. The test results obtained from consolidation test on undisturbed sample of soil of different density and initial moisture content are represented by dial reading vs. square root of time plots graph, this method is selected according to the type of data relation from Arora[22]. From the graph plotted for each load cases the value of t_{90} s and the corresponding Dial gauge readings were determined, then the coefficient of consolidations was found but it is not the concern of the study. The graph of voidratio-logpressure were also represented by the final void ratio at 1440min and log of pressure imposed repeatedly loading-unloading-reloading process were carried out. These results were used to determine the range of value of consolidation parameters C_c , C_s and P_c . The typical representative Figure below illustrates the theory above. For the purpose of estimating the elastic settlement, the

modulus of elasticity and piousness ratio were found with simple mathematical relation. Modulus elasticity of the soil was found with a relation of undrained shear strength estimated above. $E_s = (500-1500)$ times of undrained shear strength whereas piousness ratio is taken simply from reliable empirical formulae[28]. Influence factor of the soil is determined from the geometrical relation of selected footing and stratum thickness. Piousness ratio was determined from general soil characteristics using an empirical formula which correlates with a Plasticity Index as recommended for partially saturated soils.

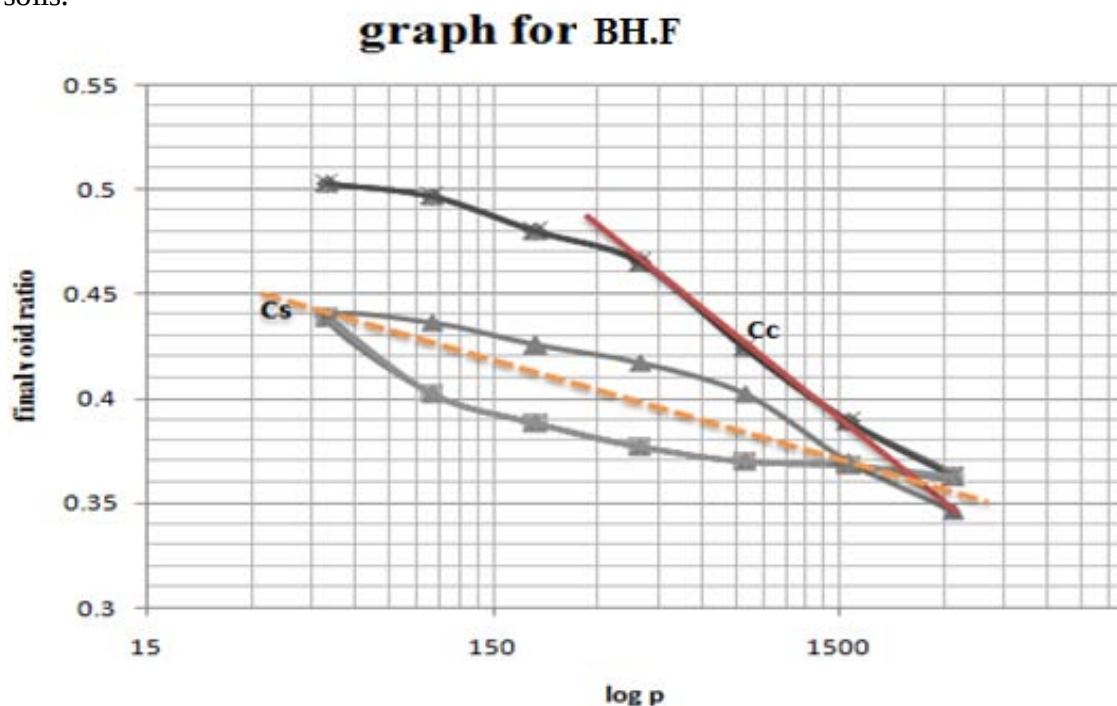


Figure 3.11. Plot of Void Ratio Versus Log-Pressure for soil sample of ($\omega=29.56$, $\rho_b = 1.785 \text{ gm / cm}^3$)

Table 3.8. Summary of consolidation test results and correlated Modulus of Elasticity

Location	Depth of Sample-(M)	Swelling Index-(Cs)	Compression Index-(Cc)	Preconsolidation Pressure-(Pc),kPa	Overburden Pressure-(Po) kPa	Modulus of Elasticity (MPa)
BH.F	2	0.047	0.115	178	35.7	50.04
BH.R	2	0.063	0.19	234	28.88	51.68
BH.M	2	0.089	0.15	154	30.08	46.015
BH.A	2	0.059	0.218	167.5	28.22	35.72

3.4.1. Settlement and Bearing Capacity Determination Procedures

After the test results are determined, the detail of the subsequent study is to compute the settlement and bearing capacity using a representative soil profile. The geometrical section of the footing considered are square, rectangular and strip footing for bearing capacity computation at 2m and 3m depth of the footing and square and rectangular for settlement at 2m depth below the footing with a single layer with the variation of the following plan view of the footing. The information obtained from railway professionals suggests that the soils up to 4m depth of the soil are homogeneous.

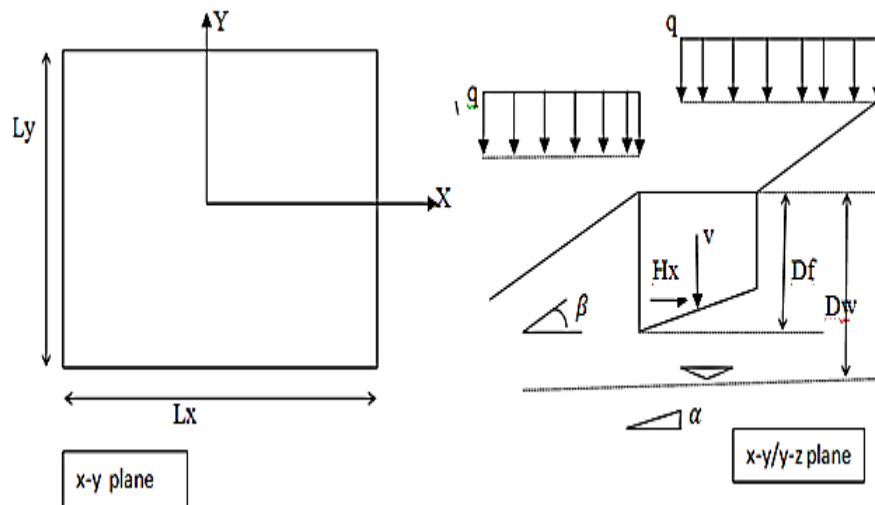


Figure 3.12. The geometrical section of the footing considered are square, rectangular footing for bearing capacity computation

3.4.2. Concluding Remarks

The ground water table of the study area is found far to the surface according to the information found from previous studies. Up to a depth 2m considered in this study the soil property is isotropic in all parameters. The test results obtained signifies the physical properties of soils of the study area, according to the analysis; all pits had more than 50% of percentage finer than 0.075mm sieve size. As a result the soil of the study area is fine grained soil. A moisture content of the three places is range between 30-50% i.e. in soft clay category and Ferro area soil is in between 20-30%. Plasticity index of soil is partially an indication of expansiveness and a factor for clay type content as shown Table 3.10. Thus all pits have behaved medium expansive property. Even though there are some deviations from the range given in following tables, the Specific gravity of the soils determined in four pits for the corresponding soil types are within the range.

Table 3.9. Braja Das standard of moisture content of soils[29].

Soil	Natural water content in a saturated state (%)
Loose uniform sand	25-30
Dense uniform sand	12-16
Dense angular-grained Silty sand	25
Dense angular-grained Silty sand	15
Stiff clay	20
Soft clay	30-50
Soft organic clay	80-130
Glacial till	10

Table 3.10. Braja Das swelling potential effect on plastic index and clay minerals[29, 30]

Swelling potential	Plastic index
Low	0-15
Medium	10-35
High	20-55
Very high	>55
Clay mineral	Plasticity index
Kaolinite	20-40
Illite	35-50
Montmorillonite	50-100

Table 3.11. Das specific gravity value standards [29]

Soil type	Range of Gs
Sand	2.63-2.67
Silts	2.65-2.7
Clay And Silty Clay	2.67-2.9

According to the result found in the odometer one dimensional consolidation test soil at four pits was over consolidated ($p_c > p_o$) as indicated above in Table 3.7.

3.5. GEOTECHNICAL DESIGN PROFILE

For the geotechnical design profile of the studied area 2m and 3m depth are taken for foundation analysis. The ground water table as given by the nearby artesian it is far from the ground surface. As shown from figure below, the soils almost up to the 3m depth of the foundation is fined grained and below 4m the foundation goes to coarser gradation.

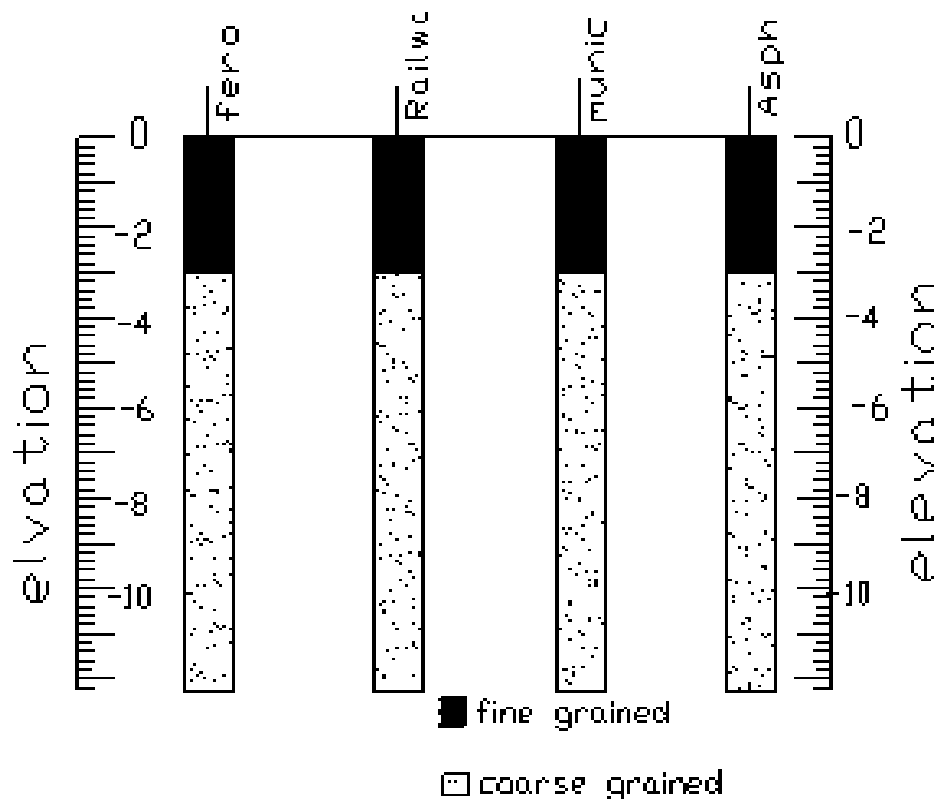


Figure 3. 13. Profile of Geotechnical design of the study area for four boreholes

CHAPTER 4

BEARING CAPACITY AND SETTLEMENT ANALYSIS DISCUSSION OF RESULTS

4.1. INTRODUCTION

Bearing capacity and settlement is computed based on different analytical formulations as described in different codes of standards differently. The soil test results obtained are presented in the Geotechnical soil profile and different scenarios of loading and foundation geometry are discussed. Three main parts i.e. Long term bearing capacity, short term bearing capacity and settlement scenario for square, rectangular and strip footings at 2m and 3m of foundation depth are presented and discussed along with the respective analytical approaches used. The load ranges from this study for both bearing capacity and settlement are divided into four, of which one typical value for each case was taken as 700kN, 950kN, 1450kN and 1950kN

4.2. BEARING CAPACITY AND SETTLEMENT: SQUARE FOOTING AT 2M DEPTH

From the Geotechnical design profile shown above bearing capacity and settlement of shallow foundation at 2m depth is calculated. In addition to the loading ranges division, both bearing capacity and settlement are computed in different formulations as described in different codes as follows.

4.2.1. Bearing Capacity Analysis for Square Footing/ Depth 2m for Loading Case 1= [0-700kN]

In all loading ranges, values computed using formulations included in different codes for both drained and undrained cases are tabulated below. Since the bearing capacity of the soil in each loading case is not equivalent, it is explanatory to determine the geometry of square size footing for each loading and the bearing capacity values found first.

4.2.1.1. Square footing size using different formulations in codes

The typical loading for this range is taken as 700kN. By using this value and bearing capacity equation of each method, the size of square footing was calculated as shown below Table 4.1. The calculated value of this range included both drained and undrained values.

In the first load range, the footing sizes determined as shown in Table 4.1 in around the asphalt area is very economical in its drained condition and to the opposite in undrained condition as compared to other boreholes in the same condition. In all cases EBCS 7 lead a very large footing dimension for both drained and undrained cases. At the same borehole in a drained condition the difference of the footing size of other codes to EBCS-7 code ranges from 0 with DIN-4017 and 0.18m in Hansen's method, but in the case of undrained case the resulted values found in DIN, EAK, EURO and EBCS-7 is almost equivalent. The size determined using undrained value of Meyerhof and Hansen are economical as compared to the others. Emphasizing that the diminishing is for the same loading and Geotechnical soil data, the computations indicated that in almost all cases the value computed using EBCS 7 is the largest.

4.2.1.2. Bearing Capacity values using different Codes: using Analytical Methods

Bearing capacity values obtained using different codes are computed below in Table 4.2. Beside of this the bearing capacity of the four pits was calculated by using analytical and SOFA software methods by using the corresponding dimensions.

Bearing capacity is computed for all cases considered above using formulations and methods seen above. For each method both drained and undrained cases are considered. Bearing capacity in this load range was calculated with the corresponding dimensions estimated. As shown in Tables 4.2, 4.3 and 4.4, bearing capacity values are different even in a small number with the same input and the same condition. In the analytical method of bearing capacity computations, the values for each pit of different building codes for drained condition are range 560-923kPa for *Ferro*, 309-455kPa for Railway, 721-1265kPa for municipalities and 921-1785kPa for asphalt area. In addition to

this the average bearing capacity values in soils in *Ferro*, Railway, municipality and asphalt area are 672kPa, 352kPa, 903kPa and 1199kPa respectively.

In the undrained condition the bearing capacity value in building codes of EBCS-7, DIN, EAK and EURO are equivalent, but Meyerhof's and Hansen's method estimated the largest value. For ease of visualizing the values, Figure 4.1 shows bearing capacity values obtained from different analytical methods. In the two design approach of sofa software, the bearing capacity values are relatively the same as an analytical method. In sofa software the codes are the same as analytical method, but the values are determined in two different design approaches.

In the first design approach the bearing capacity value is estimated to be larger and smaller in the second design approach due to the change of partial safety factors.

Table 4.1. Size of square footing in the first loading case depth 2

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.1	1.09	1.09	0.98	0.97	1.1	1.10	0.97	1.06
	Undrained case	1.43	1.43	1.43	1.31	1.39	1.43	1.43	1.31	1.40
BH.R	Drained case	1.49	1.49	1.48	1.35	1.31	1.49	1.49	1.31	1.44
	Undrained case	1.42	1.42	1.42	1.3	1.37	1.42	1.42	1.30	1.39
BH.M	Drained case	0.97	0.96	0.96	0.85	0.85	0.97	0.97	0.85	0.93
	Undrained case	1.49	1.49	1.49	1.37	1.45	1.49	1.49	1.37	1.46
BH.A	Drained case	0.86	0.84	0.85	0.74	0.75	0.86	0.86	0.74	0.82
	Undrained case	1.68	1.68	1.68	1.55	1.65	1.68	1.68	1.55	1.65
	Max	1.68	1.68	1.68	1.55	1.65	1.68			
	Min	0.86	0.84	0.85	0.74	0.75	0.86			
	Avg	1.305	1.3	1.3	1.18125	1.2175	1.305			

Table 4. 2 Bearing capacity of square footing in the first loading case using analytical methods at depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	560.03	566.27	568.03	854.46	923.07	560.03	923.07	560.03	671.9817
	Undrained case	344.35	344.35	344.35	430.94	404.79	344.35	430.94	344.35	368.855
BH.R	Drained case	309.49	313.14	311.89	413.16	455.53	309.49	455.53	309.49	352.1167
	Undrained case	347.64	347.64	347.64	437.5	420.53	347.64	437.5	347.64	374.765
BH.M	Drained case	721.5	727.73	735.25	1244.96	1264.64	721.5	1264.64	721.5	902.5967
	Undrained case	313.9	313.9	313.9	389.92	366.65	313.9	389.92	313.9	335.3617
BH.A	Drained case	920.89	927.74	943.45	1784.84	1698.47	920.89	1784.84	920.89	1199.38
	Undrained case	248.54	248.54	248.54	301.05	272.61	248.54	301.05	248.54	261.3033
Max		920.89	927.74	943.45	1784.84	1698.47	920.89			
Min		248.54	248.54	248.54	301.05	272.61	248.54			
Avg		470.7925	473.6638	476.6313	732.10375	725.7863	470.7925			

4.2.1.3. Bearing Capacity based on Sofa software in first design approach

Table 4.3. Bearing capacity of square footing in the first design approach of SOFA software method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	Max	Min	Avg
BH.F	Drained case	561.9	569.88	561.69	767.12	925.86	925.86	561.69	677.29
	Undrained case	344.35	344.35	344.35	371.44	409.62	409.62	344.35	362.82
BH.R	Drained case	310.37	312.82	310.29	388.24	456.99	456.99	310.29	355.74
	Undrained case	347.64	347.64	347.64	372.07	415.28	415.28	347.64	366.05
BH.M	Drained case	724	738.05	724	1077.68	1270.31	1270.31	724.00	906.81
	Undrained case	313.9	313.9	313.9	334.84	363.51	363.51	313.90	328.01
BH.A	Drained case	924	946.74	924.08	1488.37	1708.25	1708.25	924.00	1198.29
	Undrained case	248.54	248.54	248.54	256.33	271.03	271.03	248.54	254.60
	Max	924.00	946.74	924.08	1488.37	1708.25			
	Min	248.54	248.54	248.54	256.33	271.03			
	Avg	471.84	477.74	471.81	632.01	727.61			

4.2.1.4. Bearing Capacity using Sofa software method in the second design approach

Table 4.4. Bearing capacity of square footing in the second design approach of SOFA software method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	Max	Min	Avg
BH.F	Drained case	508.93	516.05	508.72	683.87	833.6	833.60	508.72	610.23
	Undrained case	256.16	256.16	256.16	275.52	292.56	292.56	256.16	267.31
BH.R	Drained case	279.33	281	279.25	345.44	408.47	408.47	279.25	318.70
	Undrained case	256.57	256.57	256.57	274.02	296.64	296.64	256.57	268.07
BH.M	Drained case	641.98	654.06	641.74	938.5	1119.75	1119.75	641.74	799.21
	Undrained case	232.81	232.81	232.81	245.63	259.65	259.65	232.81	240.74
BH.A	Drained case	813.03	832.42	812.71	1283.97	1494.81	1494.81	812.71	1047.39
	Undrained case	185.59	185.59	185.59	191.16	159.59	191.16	159.59	181.50
	Max	813.03	832.42	812.71	1283.97	1494.81			
	Min	185.59	185.59	185.59	191.16	159.59			
	Avg	396.80	401.83	396.69	529.76	608.13			

4.2.2. Bearing Capacity Analysis for Square Footing/ Depth 2m for Loading Rage Case 2 = [700--1200kN]

For this case the typical load incorporated for calculation is 950kN, which is the average of the two extremes. It is a common principle that the size of the footing increases as the applied load gets larger. From the methods observed in Table4.5, uneconomical size of the footing is found with DIN or EBCS-7 methods.

4.2.2.1. Square Footing Size using Different Codes

It is a practical fact that as the super structural load increases; the size of the footing tends to be large. The footing size for undrained load case is uniform except Meyerhof's and Hansen's method. In the four pits of drained load case the most economical dimension is computed as 0.86-1.52m in either of Meyerhof and Hansen's method.

In all most all cases, large or Conservative Square footing dimensions are determined in **EBCS-7** in all pits as shown in Table4.5.

Table 4.5. Size of square footing in the second loading case depth 2m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.28	1.27	1.27	1.15	1.13	1.28	1.28	1.13	1.23
	Undrained case	1.66	1.66	1.66	1.53	1.62	1.66	1.66	1.53	1.63
BH.R	Drained case	1.74	1.73	1.73	1.57	1.53	1.74	1.74	1.53	1.67
	Undrained case	1.65	1.65	1.65	1.52	1.6	1.65	1.65	1.52	1.62
BH.M	Drained case	1.13	1.12	1.12	0.99	0.99	1.13	1.13	0.99	1.08
	Undrained case	1.74	1.74	1.74	1.6	1.69	1.74	1.74	1.60	1.71
BH.A	Drained case	1	0.98	0.99	0.86	0.88	1	1.00	0.86	0.95
	Undrained case	1.96	1.96	1.96	1.8	1.92	1.96	1.96	1.80	1.93
	Max	1.96	1.96	1.96	1.8	1.92	1.96			
	Min	1	0.98	0.99	0.86	0.88	1			
	Avg	1.52	1.51375	1.515	1.3775	1.42	1.52			

4.2.2.2. Bearing capacity values of different codes: bearing capacity using analytical methods

Table 4.6. Bearing capacity of square footing in the second loading case of analytical method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	563.76	566.27	571.69	814.87	872.39	563.76	872.39	563.76	658.79
	Undrained case	344.35	344.35	344.35	425.06	383.89	344.35	425.06	344.35	364.3917
BH.R	Drained case	311.45	313.14	313.81	399.63	435.22	311.45	435.22	311.45	347.45
	Undrained case	347.64	347.64	347.64	431.55	398.6	347.64	431.55	347.64	370.1183
BH.M	Drained case	725.4	727.73	739.07	1173.21	1188.48	725.4	1188.48	725.4	879.8817
	Undrained case	313.9	313.9	313.9	384.81	348.23	313.9	384.81	313.9	331.44
BH.A	Drained case	925.4	927.74	947.84	1665.87	1589.24	925.4	1665.87	925.4	1163.582
	Undrained case	248.54	248.54	248.54	297.45	260	248.54	297.45	248.54	258.6017
	Max	925.4	927.74	947.84	1665.87	1589.24	925.4			
	Min	248.54	248.54	248.54	297.45	260	248.54			
	Avg	472.555	473.6638	478.355	699.05625	684.5063	472.555			

Bearing capacity in this study depends on the size of the footing and the footing size is dependent on the load imposed on the soil mass. Transitively the super structural load has an effect on bearing capacity values. The results found from this analysis as indicated in Table 4.6 displays elaborative information. Bearing capacity in sofa software in two design approaches has got larger in the first and smaller and conservative in the second design approach, but the value in the first design approach has got closer to the analytical method of the corresponding building codes. To observe the status of EBCS-7 to the other codes, regarding the bearing capacity obtained in analytical methods is focused. Preliminarily maximum, minimum and average bearing capacity values are driven out from Table 4.6. it is mentioned that BH.F, BH.R, BH.M and BH.A areas resulted the range of 564-872kPa, 311-435kPa, 725-1188kPa and 925-1589kPa respectively and the average values consecutively are also 659kPa, 347kPa, 880kPa and 1164kPa. from this and forth the undrained bearing capacity values in building codes of EBCS-7, EURO, EAK and DIN are equal and independent of load variation but Meyerhof's and Hansen's method are influenced by load difference. Figure 4.2 below shows a good visual analysis of the values obtained.

4.2.3. Bearing Capacity Analysis for Square Footing/ Depth 2m for Loading Rage Case 3 = [1200--1700kN]

In this load range the typical load was taken to be the average of the two extremes i.e. 1450kN. The economical and conservative footing dimensions for each studied areas are shown in Table 4.9. Specifically the economical footing dimension for each of the studied areas in the drained loading cases are found to be 1.4m, 1.89m, 1.22m and 1.06m respectively for, BH.F, BH.R, BH.M and BH.A asphalt areas the conservative ones in the same consequence of drained loading are 1.58m, 2.15m, 1.39m and 1.23m. in all loading cases undrained footing dimension leads to a conservative design except in railway areas.

4.2.3.1. Square footing size using different formulating codes

Table 4.7. Size of square footing in the third loading case depth 2m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.58	1.57	1.57	1.42	1.4	1.58	1.58	1.40	1.52
	Undrained case	2.05	2.05	2.05	1.89	2.01	2.05	2.05	1.89	2.02
BH.R	Drained case	2.15	2.14	2.13	1.94	1.89	2.15	2.15	1.89	2.07
	Undrained case	2.04	2.04	2.04	1.88	1.97	2.04	2.04	1.88	2.00
BH.M	Drained case	1.39	1.38	1.38	1.22	1.23	1.39	1.39	1.22	1.33
	Undrained case	2.15	2.15	2.15	1.98	2.09	2.15	2.15	1.98	2.11
BH.A	Drained case	1.23	1.21	1.22	1.06	1.08	1.23	1.23	1.06	1.17
	Undrained case	2.42	2.42	2.42	2.23	2.38	2.42	2.42	2.23	2.38
Max		2.42	2.42	2.42	2.23	2.38	2.42			
Min		1.23	1.21	1.22	1.06	1.08	1.23			
Avg		1.87625	1.87	1.87	1.7025	1.75625	1.87625			

4.2.3.2. Bearing capacity values of different codes of analytical methods

Table 4. 8. Bearing capacity of square footing in the third loading case of analytical method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	569.96	579.01	577.84	771.25	814.91	569.96	814.91	569.96	647.155
	Undrained case	344.35	344.35	344.35	409.68	359.74	344.35	409.68	344.35	357.8033
BH.R	Drained case	314.7	319.94	317.05	385.07	412.32	314.7	412.32	314.7	343.9633
	Undrained case	347.64	347.64	347.64	415.56	373.26	347.64	415.56	347.64	363.23
BH.M	Drained case	731.88	740.77	745.49	1092.53	1101.62	731.88	1101.62	731.88	857.3617
	Undrained case	313.9	313.9	313.9	371.3	326.94	313.9	371.3	313.9	325.64
BH.A	Drained case	932.9	942.75	955.24	1530.99	1464.35	932.9	1530.99	932.9	1126.522
	Undrained case	248.54	248.54	248.54	288.13	245.44	248.54	288.13	245.44	254.6217
	Max	932.9	942.75	955.24	1530.99	1464.35	932.9			
	Min	248.54	248.54	248.54	288.13	245.44	248.54			
	Avg	475.4838	479.6125	481.2563	658.06375	637.3225	475.4838			

The bearing capacity values computed followed the same trend of the previous loading case. The average values of bearing capacity obtained using analytical method as shown in Table 4.10 in a consecutive configuration of boreholes are 647kPa, 344kPa, 857kPa and 1126kPa. The maximum and minimum range of the same arrangement is 570-815kPa, 315-412kPa, 732-1102kPa and 933-1531kPa. Figure 4.3 characterizes these values for ease of comparison.

4.2.4. Bearing Capacity Analysis for Square Footing/ Depth 2m for

4.2.5. Loading Range Case 3 = [1200--1700kN]

4.2.5.1. Square Footing size using different formulating codes

The typical load taken for this range is 2450kN which is the average of the two ends top and bottom. The footing size range as shown Table 4.13 of BH.F, BH.R, BH.M and BH.A for the drained condition ranges 1.81-2.06m, 2.4-2.8m, 1.59-1.81m and 1.38-1.6m respectively.

Table 4. 9 Size of square footing in the fourth loading case depth 2m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	2.06	2.04	2.04	1.84	1.81	2.06	2.06	1.81	1.98
	Undrained case	2.67	2.67	2.67	2.46	2.61	2.67	2.67	2.46	2.63
BH.R	Drained case	2.8	2.78	2.77	2.53	2.45	2.8	2.80	2.45	2.69
	Undrained case	2.65	2.65	2.65	2.44	2.57	2.65	2.65	2.44	2.60
BH.M	Drained case	1.81	1.79	1.8	1.59	1.59	1.81	1.81	1.59	1.73
	Undrained case	2.79	2.79	2.79	2.57	2.72	2.79	2.79	2.57	2.74
BH.A	Drained case	1.6	1.58	1.59	1.38	1.41	1.6	1.60	1.38	1.53
	Undrained case	3.14	3.14	3.14	2.89	3.09	3.14	3.14	2.89	3.09
Max		3.14	3.14	3.14	2.89	3.09	3.14			
Min		1.6	1.58	1.59	1.38	1.41	1.6			
Avg		2.44	2.43	2.43125	2.2125	2.28125	2.44			

4.2.5.2. Bearing capacity values of different codes analytical methods

Table 4. 10 Bearing capacity of square footing in the fourth loading case of analytical method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	579.72	591.48	587.51	732.59	760.68	579.72	760.68	579.72	638.6167
	Undrained case	344.35	344.35	344.35	394.61	336.09	344.35	394.61	336.09	351.35
BH.R	Drained case	319.82	326.63	322.14	372.89	390.97	319.82	390.97	319.82	342.045
	Undrained case	347.64	347.64	347.64	399.89	348.43	347.64	399.89	347.64	356.48
BH.M	Drained case	742.09	753.76	755.58	1017.76	1018.68	742.09	1018.68	742.09	838.3267
	Undrained case	313.9	313.9	313.9	358.06	306.08	313.9	358.06	306.08	319.9567
BH.A	Drained case	944.7	957.5	966.88	1403.84	1344.5	944.7	1403.84	944.7	1093.687
	Undrained case	248.54	248.54	248.54	279	231.18	248.54	279	231.18	250.7233
	Max	944.7	957.5	966.88	1403.84	1344.5	944.7			
	Min	248.54	248.54	248.54	279	231.18	248.54			
	Avg	480.095	485.475	485.8175	619.83	592.0763	480.095			

For the typical load presumed the bearing capacity values for drained and undrained cases were determined as shown above in Tables 4.14, 4.15 and 4.16. The bearing capacity values obtained using different codes in undrained case follows a similar trend in the above load cases, but in drained load cases the variation of the value is significant. The usual minimum and maximum ranges and average value of the bearing capacity of the soils in the studied areas computed using analytical method bearing capacity analysis are 580-761kPa, 321-360kPa, 742-1019kPa and 945-1404kPa for Ferro, railway, municipality and asphalt areas respectively. The average values for the above pits respectively are, 6389kPa, 342kPa, 838kPa and 1094kPa.

4.3. CONCLUDING REMARKS

To summarize the results obtained in square footing depth 2m, it is better to observe minimum, maximum, average and EBCS-7 values with a figurative expression of different codes. It is more important to see the difference or the closeness of the values with the result obtained from the EBCS_7 method of analysis.

As shown from Figure 4.1 for square footing in all loading cases it was found out that with the exception of Meyerhof and Hansen's method, the undrained loading cases are equal in value and independent of load variation. The other result found for square footing at the 2m depth is the value of bearing capacity in the EBCS-7 method of analysis overlapped with the minimum results found in all cases. Generally in square footing the EBCS-7 method of analysis underestimated the values.

The maximum difference in value of bearing capacity between the maximum obtained from the EBCS-7 method of analysis from loading variation of 700kN to 2450kN is found to be 863.95kPa, 740.5kPa, 598.09kPa and 459.14kPa respectively with the methods mentioned above. The values obtained in four loading cases showed that the difference between EBCS-7 and the maximum value in another one typical method of

analysis is decreased as the loading cases are increased. This indicates that the bearing capacity increases as the loading goes up and the reverse is with the one that the maximum value is obtained. To compare bearing capacity values found by an EBCS-7 method with the values determined in the literature review of square footing to the maximum width 2m expressed for cohesive soil is 700kPa whereas bearing capacity in square footing with the corresponding 2m width is reached up to 590kPa. So the value found in literature review can resist more super structural load than the computed value.

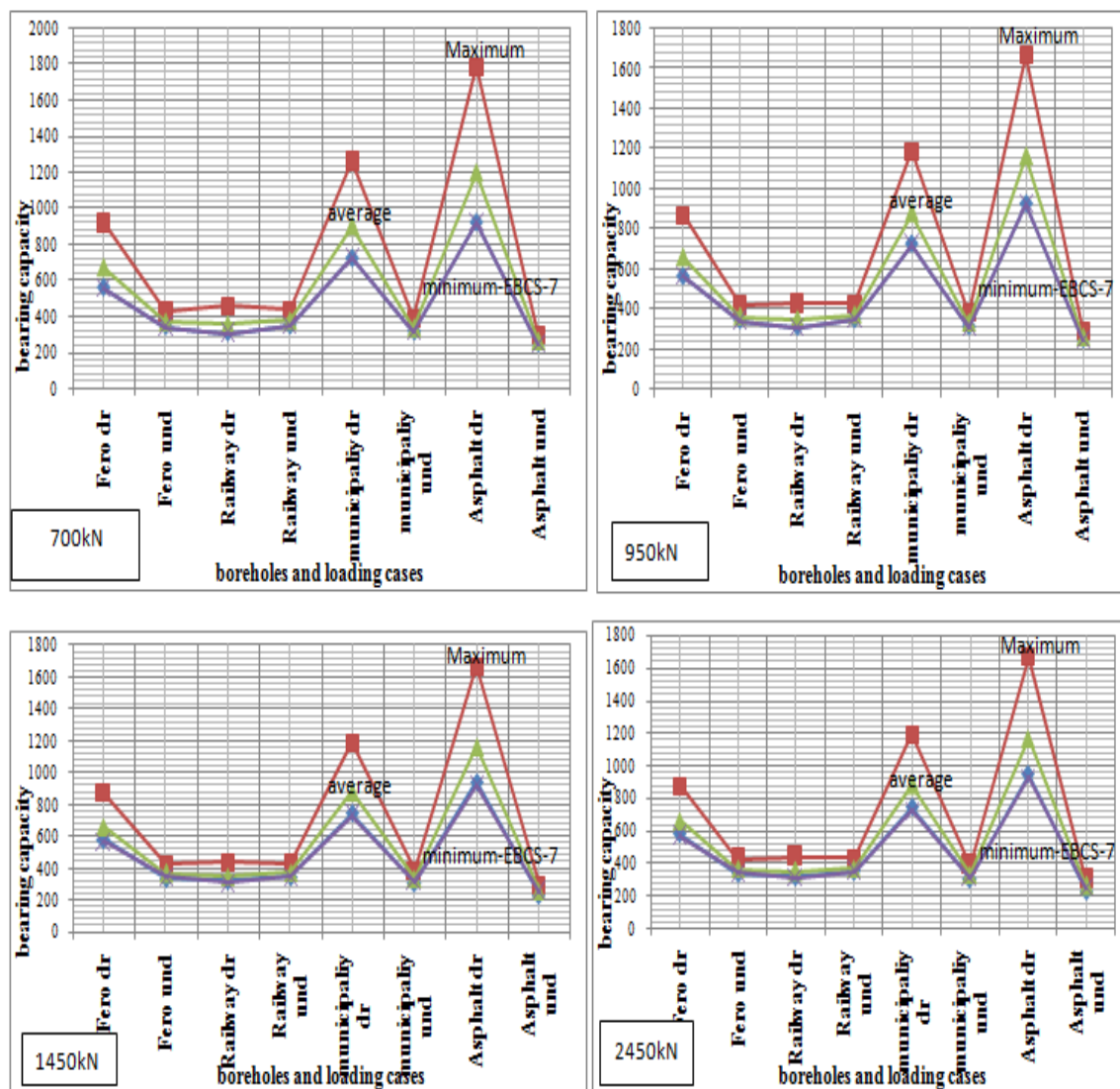


Figure4.1. Typical bearing capacity values of square footing depth 2m

4.4. SETTLEMENT ANALYSIS FOR SQUARE FOOTING DEPTH 2M

The settlement of the different load cases specified both for drained and undrained cases can be estimated. Settlement of undrained load cases are uniquely determined for each site and each code.

4.4.1. Settlement for Loading Case 1[0-700kN]

Using the typical load range dealt above for drained case, the settlements are observed in the minimum, maximum, and average values with EBCS-7. Comparing results obtained as shown in Tables 4.17 and 4.18, the settlement computed in analytical method and sofa software method is different from the same load case and use of the same method obtained in the codes. Comparisons of the values obtained from the two methods indicate the software method overestimate the settlement value than the value obtained from analytical method.

Table 4. 11 Settlement of square footing in the first loading case depth 2m

Loading Cases	Location	Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
700kN	BH.F	11.83	11.88	11.9	12.68	12.8	11.83
	BH.R	13.91	13.93	13.96	14.61	14.83	13.91
	BH.M	20.2	20.31	20.3	21.89	21.84	20.2
	BH.A	18.9	19.05	19.01	20.91	20.6	18.9

Table 4. 12 Settlement of square footing in the first loading case of sofa software method depth 2m

Loading Cases	Location	Settlement of Square Footing				
		DIN	EAK	EURO	Meyerhof	Hansen
		(mm)	(mm)	(mm)	(mm)	(mm)
700kN	BH.F	20.86	21.1	21.1	25.05	25.51
	BH.R	18.38	18.38	18.44	19.55	19.28
	BH.M	32.55	33.01	33.01	37.69	37.69
	BH.A	57.94	59.31	58.63	65.31	64.88

The analytical method of analysis leads a range of the settlement value of 11.83-12.80mm, 13.91-14.83mm, 20.20-21.89mm and 18.90-20.91mm respectively for pits indicated respectively in the Ferro area to Asphalt where as sofa software overestimated the settlement values.

4.4.2. Loading Case 2 [700-1200kN]

In the typical load of 950kN the settlement values of the undrained case were computed from Table4.19. This suggests that as the load range increase the settlement of the soil increase. The value of sofa software method shows the same trend in the first load case.

Table 4. 13 Settlement of square footing in the second loading case depth 2m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	mm)	(mm)	(mm)	(mm)	(mm)
950kN	BH.F	13.75	13.82	13.83	14.66	14.78	13.75
	BH.R	16.26	16.3	16.32	17.04	17.28	16.26
	BH.M	23.19	23.32	23.3	24.9	24.85	23.19
	BH.A	21.53	21.71	21.64	23.58	23.27	21.53

The settlement range computed in this load case for BH.F, BH.R, BH.M and BH.A respectively, are 13.75-14.78mm, 16.26-17.28mm, 23.19-24.9mm and 21.53-23.58mm.

4.4.3. Loading Case 3 [1200-1700kN]

As mentioned below table4.20 the typical load incorporated in this loading case is 1450kN. The settlement value with the load variation shows an increment as the load increased.

Table 4. 14 Settlement of square footing in the third loading case depth 2m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1450kN	BH.F	16.9	16.98	16.99	17.91	18.05	16.9
	BH.R	21.19	21.25	21.28	22.27	22.6	21.19
	BH.M	27.53	27.67	27.64	29.24	29.2	27.53
	BH.A	24.27	24.44	24.38	26.18	25.89	24.27

The minimum settlement values of the indicated loading case is 16.9mm, 21.19mm, 27.53mm and 24.27mm for BH.F, BH.R, BH.M and BH.A asphalt areas respectively. Whereas the maximum settlement value among the presumed codes with the respective order of the above areas is 18.05mm, 22.6mm, 29.24mm and 26.18mm.

4.4.4. Loading Case 4 [2200-2700kN]

The specific load taken from this range is 2450kN which is the average of the peak and the minimum value. The values as usual in the respective order as minimum and maximum range are 21.49-22.9mm, 24.86-26.51mm, 35.22-37.27mm and 32.34-34.8mm

Table 4. 15 Settlement of square footing in the fourth loading case depth 2m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
2450kN	BH.F	21.49	21.59	21.6	22.74	22.9	21.49
	BH.R	24.86	24.93	24.96	26.13	26.51	24.86
	BH.M	35.22	35.39	35.36	37.27	37.21	35.22
	BH.A	32.34	32.56	32.48	34.8	34.43	32.34

4.4.5. Concluding remarks for settlement of square footing depth 2m

To summarize the above discussion for settlement computation approaches, it is compulsory to show the results graphically. As shown from the Figure 4.2, the settlement variation in each code with the value obtained with EBCS-7 and the minimum value is not

as such significant. The maximum settlement difference between EBCS-7 and the maximum value for each loading case are respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7 is 21.89mm, 24.9mm, 29.24mm and 37.27mm. This indicates that the variation of settlement increases up as the loading increases and the difference of the maximum and EBCS-7 computed values have resulted from loading 700kN-2450kN varied from 1.69-2.05mm.

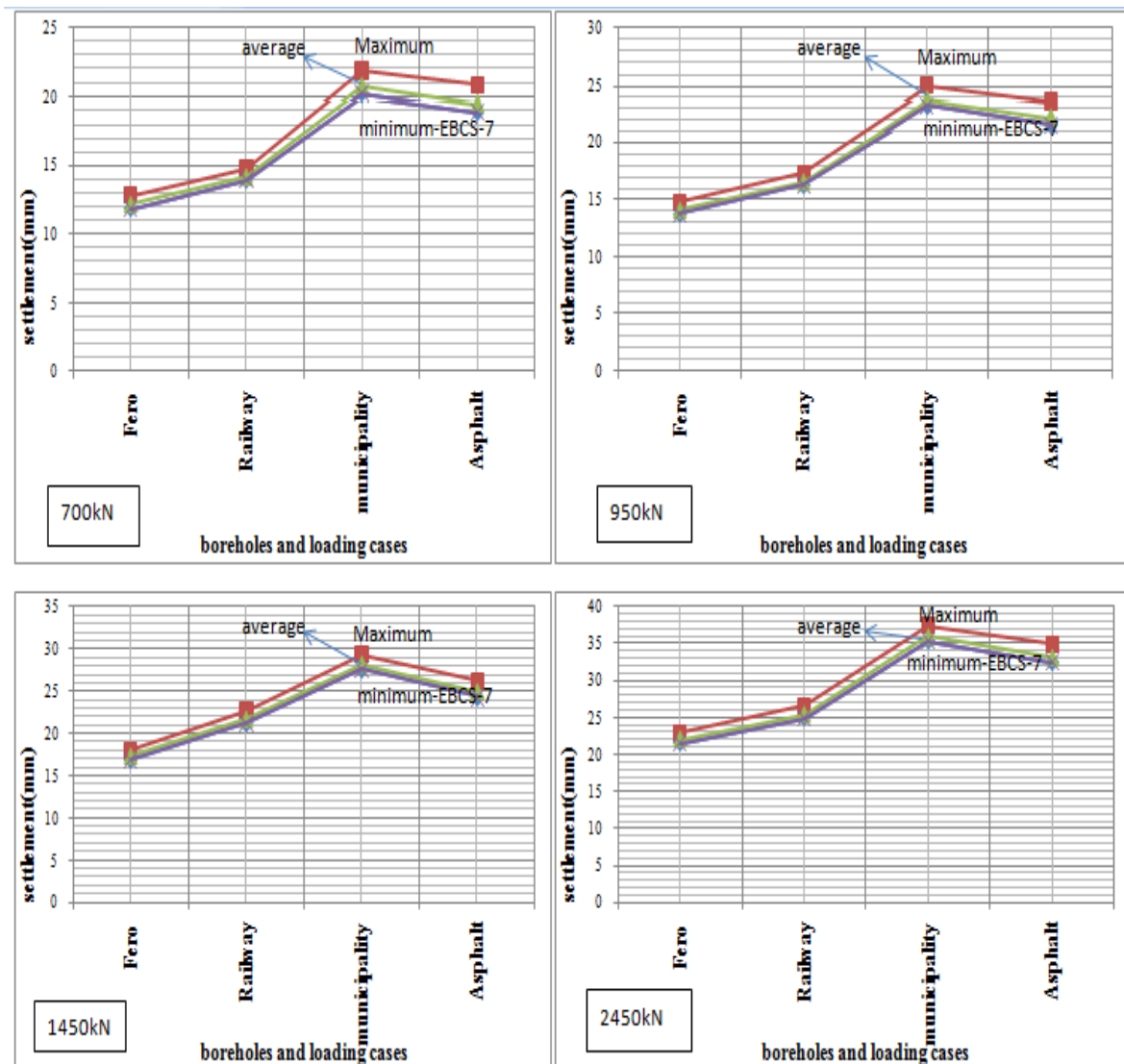


Figure4.2. Typical settlement values of square footing depth 2m

4.5. BEARING CAPACITY ANALYSIS FOR SQUARE FOOTING DEPTH 3M

4.5.1. Loading Case 1 [0-700kN]

Generally bearing capacity and increment of depth have a direct relationship. This fact is observed when it is theoretically proved. Beside of this, the dimensions are also economical compared to 2m depth.

4.5.1.1. Square Footing size using different formulating codes

The size of the square footing as is shown from Table 4.22 is computed in drained and undrained loading cases. In undrained case the dimensions are equal in all building codes except Meyerhof and Hansen's case where as in the drained case except in DIN and EBCS-7 the values in the other codes are almost unequal. With this typical load the minimum dimensions are computed in Hansen's method for all pits. The maximum footing size has been found alternatively in building codes which is numerically 0.98m, 1.35m, 0.88m and 0.87m respectively of BH.F, BH.R, BH.M and BH.A.

Table 4. 16 Size of square footing in the first loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	0.9	0.98	0.98	0.85	0.82	0.9	0.98	0.82	0.91
	Undrained case	1.39	1.39	1.39	1.24	1.3	1.39	1.39	1.24	1.35
BH.R	Drained case	1.35	1.34	1.34	1.18	1.12	1.35	1.35	1.12	1.28
	Undrained case	1.39	1.39	1.39	1.24	1.28	1.39	1.39	1.24	1.35
BH.M	Drained case	0.83	0.88	0.88	0.75	0.74	0.83	0.88	0.74	0.82
	Undrained case	1.46	1.46	1.46	1.3	1.36	1.46	1.46	1.30	1.42
BH.A	Drained case	0.87	0.78	0.78	0.65	0.66	0.87	0.87	0.65	0.77
	Undrained case	3.14	3.14	3.14	2.89	3.09	3.14	3.14	2.89	3.09
	Max	3.14	3.14	3.14	2.89	3.09	3.14			
	Min	0.83	0.78	0.78	0.65	0.66	0.83			
	Avg	1.41625	1.42	1.42	1.2625	1.29625	1.41625			

4.5.1.2. Bearing Capacity values of different codes analytical methods

Bearing capacity in this study was computed in different building codes and separate loading cases as well as varying the depth of the footing. As it is observed from the corresponding tables of depth variation bearing capacity values are increased as depth changed from 2m to 3m. bearing capacity of undrained loading case independent of the building codes variation except Meyerhof and Hansen's method. Bearing capacity as shown from Table 4.23, 24, and 25 are computed in two methods using analytical method and sofa software method.

Analytical method of computing bearing capacity is the main focus of the study, whereas sofa software method had two design approaches in which resulted values in the first and second design approach the values are underestimated. From the analytical method of analysis of the studied areas, the range of the bearing capacities of Ferro, railway, municipality and asphalt areas respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7., are 842-1501kPa, 380-697kPa, 981-2001kPa and 889-2713kPa. The respective average value of bearing capacity is 980kPa, 468kPa, 1143kPa and 1564kPa.

Table 4. 17 Bearing capacity of square footing in the first loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	842.22	700.18	704.43	1290.62	1500.96	842.22	1500.96	700.18	980.105
	Undrained case	362.2	362.2	362.2	511.47	493.86	362.2	511.47	362.2	409.0217
BH.R	Drained case	379.78	383.13	382.7	588.04	697.13	379.78	697.13	379.78	468.4267
	Undrained case	362.08	362.08	362.08	516.74	514.02	362.08	516.74	362.08	413.18
BH.M	Drained case	980.94	869.15	879.92	1866.89	2000.65	262.65	2000.65	262.65	1143.367
	Undrained case	328.94	328.94	328.94	459.92	445.2	328.94	459.92	328.94	370.1467
BH.A	Drained case	889.47	1094.29	1114.76	2713.31	2682.74	889.47	2713.31	889.47	1564.007
	Undrained case	262.65	262.65	262.65	353.24	326.33	262.65	353.24	262.65	288.3617
	Max	980.94	1094.29	1114.76	2713.31	2682.74	889.47			
	Min	262.65	262.65	262.65	353.24	326.33	262.65			
	Avg	551.035	545.3275	549.71	1037.52875	1082.611	461.2488			

4.5.2. Loading Case 2 [700-1200kN]

4.5.2.1. Square footing size using different formulating codes

From Table 4.26 as the super structural load increased it is a common idea that uneconomical footing dimension will be resulted. The range of the footing dimensions of the places where samples were taken respectively, according to the order of presentation in table are 0.96-1.14m, 1.3-1.57m, 0.86-1.03m and 0.76-1.01m. The dimensions of the square footing in undrained case obviously are uneconomical.

Table 4. 18 Size of square footing in the second loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.05	1.14	1.14	0.99	0.96	1.05	1.14	0.96	1.06
	Undrained case	1.62	1.62	1.62	1.45	1.52	1.62	1.62	1.45	1.58
BH.R	Drained case	1.57	1.56	1.56	1.37	1.3	1.57	1.57	1.30	1.49
	Undrained case	1.62	1.62	1.62	1.44	1.5	1.62	1.62	1.44	1.57
BH.M	Drained case	0.97	1.02	1.03	0.87	0.86	0.97	1.03	0.86	0.95
	Undrained case	1.7	1.7	1.7	1.51	1.58	1.7	1.70	1.51	1.65
BH.A	Drained case	1.01	0.91	0.91	0.76	0.76	1.01	1.01	0.76	0.89
	Undrained case	1.9	1.9	1.9	1.7	1.8	1.9	1.90	1.70	1.85
	Max	1.9	1.9	1.9	1.7	1.8	1.9			
	Min	0.97	0.91	0.91	0.76	0.76	0.97			
	Avg	1.43	1.43375	1.435	1.26125	1.285	1.43			

4.5.2.2. Bearing capacity values of different codes analytical methods

Bearing capacity is the main focus of the study, which characterizes the status of the values in different codes and correlates these with EBCS-7. In addition to this analytical method of analysis is viewed with the comparison of the sofa software method of analysis.

At a depth of 3m of square footing one unique characteristic, i.e. the values obtained in DIN or EBCS-7 methods is going to the intermediate value, unlike the values of square footing assessed in depth of 2m. The average value of the bearing capacity as shown in Table 4.27 for drained case respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7 are 980kPa, 468kPa, 1143kPa and 1564kPa. The range of bearing capacity is 704-1387kPa, 382-652kPa, 874-1840kPa and 894-2484kPa. On this footing type also the values found in sofa software method in the two design approach it underestimated in both approaches shown Table 4.28 and Table 4.29. Like the previous footing type the bearing capacity of undrained case are independent of the loading cases except Meyerhof's and Hansen's method but as depth of the footing increased from 2m to 3m the value of bearing capacity is increased.

Table 4. 19 Bearing capacity of square footing in the second loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	845.27	704.48	707.76	1206.43	1387.21	845.27	1387.21	704.48	949.4033
	Undrained case	362.2	362.2	362.2	490.33	460.35	362.2	490.33	362.2	399.9133
BH.R	Drained case	381.55	385.45	384.46	558.87	652.43	381.55	652.43	381.55	457.385
	Undrained case	362.08	362.08	362.08	494.84	478.85	362.08	494.84	362.08	403.6683
BH.M	Drained case	984.3	873.66	883.46	1725.19	1840.09	984.3	1840.09	873.66	1215.167
	Undrained case	328.94	328.94	328.94	441.37	415.65	328.94	441.37	328.94	362.13
BH.A	Drained case	894.06	1099.47	1118.87	2484.25	2457.49	894.06	2484.25	894.06	1491.367
	Undrained case	262.65	262.65	262.65	340.41	306.12	262.65	340.41	262.65	282.855
	Max	984.3	1099.47	1118.87	2484.25	2457.49	984.3			
	Min	262.65	262.65	262.65	340.41	306.12	262.65			
	Avg	552.6313	547.3663	551.3025	967.71125	999.7738	552.6313			

4.5.3. Loading Case 3 [1200-1700kN]

4.5.3.1. Square footing size using different formulating codes

The footing size obtained for typical load of 1450kN is shown in Table 4.30. It goes uneconomical since the load and footing size have a direct relationship. As indicated from Table 4.30, the economical footing size is found in Meyerhof's and Hansen's method. On the contrary, conservative footing size is determined in DIN, EAK, and EURO codes to a small extent. The footing size of undrained load case in all codes is more conservative or uneconomical even compared with the maximum footing size of drained cases.

4.5.3.2. Bearing capacity values of different codes of analytical methods

Bearing capacity with load increment has followed the general fact, most of which in Meyerhof's and Hansen's method. EBCS-7 method of bearing capacity analysis, unlike 2m depth, is not the least value which is greater than EAK and EURO codes. The average values of bearing capacity in drained loading case respectively for DIN, EAK, EURO, Meyerhof, Hansen, and EBCS 7 are 915kPa, 446kPa, 1162kPa, and 1410kPa, and the range of minimum to maximum values shown in Table 4.31 is 712-1257kPa, 385-601kPa, 881-1657kPa, and 902-2222kPa. The software method underestimated the values to the largest extent in both design approaches as shown in Table 4.32 and Table 4.33.

Table 4. 20. Size of square footing in the third loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.29	1.41	1.41	1.23	1.18	1.29	1.41	1.18	1.30
	Undrained case	2	2	2	1.79	1.88	2	2.00	1.79	1.95
BH.R	Drained case	1.94	1.93	1.93	1.69	1.61	1.94	1.94	1.61	1.84
	Undrained case	2	2	2	1.78	1.85	2	2.00	1.78	1.94
BH.M	Drained case	1.2	1.26	1.27	1.07	1.06	1.2	1.27	1.06	1.18
	Undrained case	2.1	2.1	2.1	1.87	1.96	2.1	2.10	1.87	2.04
BH.A	Drained case	1.25	1.12	1.13	0.94	0.94	1.25	1.25	0.94	1.11
	Undrained case	2.35	2.35	2.35	2.1	2.22	2.35	2.35	2.10	2.29
	Max	2.35	2.35	2.35	2.1	2.22	2.35			
	Min	1.2	1.12	1.13	0.94	0.94	1.2			
	Avg	1.76625	1.77125	1.77375	1.55875	1.5875	1.76625			

Table 4. 21. Bearing capacity of square footing in the third loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	850.34	711.62	713.3	1110.99	1256.71	850.34	1256.71	711.62	915.55
	Undrained case	362.2	362.2	362.2	465.91	421.63	362.2	465.91	362.2	389.39
BH.R	Drained case	384.48	389.3	387.38	526.1	601.26	384.48	601.26	384.48	445.5
	Undrained case	362.08	362.08	362.08	469.54	438.21	362.08	469.54	362.08	392.6783
BH.M	Drained case	989.88	881.24	889.35	1563.43	1655.57	989.88	1655.57	881.24	1161.558
	Undrained case	328.94	328.94	328.94	419.94	381.51	328.94	419.94	328.94	352.8683
BH.A	Drained case	901.68	1108.29	1125.7	2221.89	2198.4	901.68	2221.89	901.68	1409.607
	Undrained case	262.65	262.65	262.65	340.41	306.12	262.65	340.41	262.65	282.855
	Max	989.88	1108.29	1125.7	2221.89	2198.4	989.88			
	Min	262.65	262.65	262.65	340.41	306.12	262.65			
	Avg	555.2813	550.79	553.95	889.77625	907.4263	555.2813			

4.5.4. Loading case 2 [2200-2700kN]

4.5.4.1. Square footing size using different formulating codes

For the typical load of 2450kN the corresponding footing size in different building codes are computed from Table 4.34. The size of the footing respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7 ranges 1.54-1.84m, 2.09-2.52m, 1.38-1.65m and 1.22-1.63m. The footing size in undrained case is almost equal except in Meyerhof's and Hansen's method and the size is very large even it makes an ambiguity to be out of an engineering truth for isolated footing.

4.5.4.2. Bearing capacity values of different codes of analytical methods

The average bearing capacity of the typical load 2450kN in drained cases, respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7 is 886kPa, 436kPa, 1112kPa and 1336kPa and the range of bearing capacity is 723-1131kPa, 389-552kPa, 893-1477kPa and 914-1969kPa respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7. The undrained case of bearing capacity followed the same tendency as the previous loading case.

Table 4. 22. Size of square footing in the fourth loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.68	1.84	1.84	1.59	1.54	1.68	1.84	1.54	1.70
	Undrained case	2.6	2.6	2.6	2.32	2.44	2.6	2.60	2.32	2.53
BH.R	Drained case	2.52	2.51	2.51	2.2	2.09	2.52	2.52	2.09	2.39
	Undrained case	2.6	2.6	2.6	2.31	2.4	2.6	2.60	2.31	2.52
BH.M	Drained case	1.56	1.64	1.65	1.39	1.38	1.56	1.65	1.38	1.53
	Undrained case	2.73	2.73	2.73	2.43	2.54	2.73	2.73	2.43	2.65
BH.A	Drained case	1.63	1.46	1.46	1.22	1.23	1.63	1.63	1.22	1.44
	Undrained case	3.05	3.05	3.05	2.73	2.89	3.05	3.05	2.73	2.97
	Max	3.05	3.05	3.05	2.73	2.89	3.05			
	Min	1.56	1.46	1.46	1.22	1.23	1.56			
	Avg	2.29625	2.30375	2.305	2.02375	2.06375	2.29625			

Table 4. 23. Bearing capacity of square footing in the fourth loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	858.32	722.85	722.02	1021.01	1130.61	858.32	1130.61	722.02	885.5217
	Undrained case	362.2	362.2	362.2	441.98	383.7	362.2	441.98	362.2	379.08
BH.R	Drained case	389.1	395.36	391.98	495.81	552.06	389.1	552.06	389.1	435.5683
	Undrained case	362.08	362.08	362.08	444.75	398.4	362.08	444.75	362.08	381.9117
BH.M	Drained case	998.65	892.97	898.6	1408.7	1476.66	998.65	1476.66	892.97	1112.372
	Undrained case	328.94	328.94	328.94	398.95	348.06	328.94	398.95	328.94	343.795
BH.A	Drained case	913.68	1128.49	1141.87	1969.23	1946.73	913.68	1969.23	913.68	1335.613
	Undrained case	262.65	262.65	262.65	311.07	259.89	262.65	311.07	259.89	270.26
	Max	998.65	1128.49	1141.87	1969.23	1946.73	998.65			
	Min	262.65	262.65	262.65	311.07	259.89	262.65			
	Avg	559.4525	556.9425	558.7925	811.4375	812.0138	559.4525			

4.6. CONCLUDING REMARKS OF SQUARE FOOTING DEPTH 3M

All necessary calculations are conducted with the required parameters. As shown from Figure 4.3 the difference of the maximum value to EBCS-7 varied from 1824 kPa, 1590 kPa, 1320 kPa and 1056 kPa respectively, for loading cases of 700 kN to 2450 kN. Like square footing here also bearing capacity for undrained loading are independent of super structural loading variation. The minimum values computed in this case have some difference in the EBCS-7 method of analysis. From the value of difference of maximum and minimum observed above it decreases as the load increases. For depth variation the difference of maximum and EBCS-7 magnified numerically.

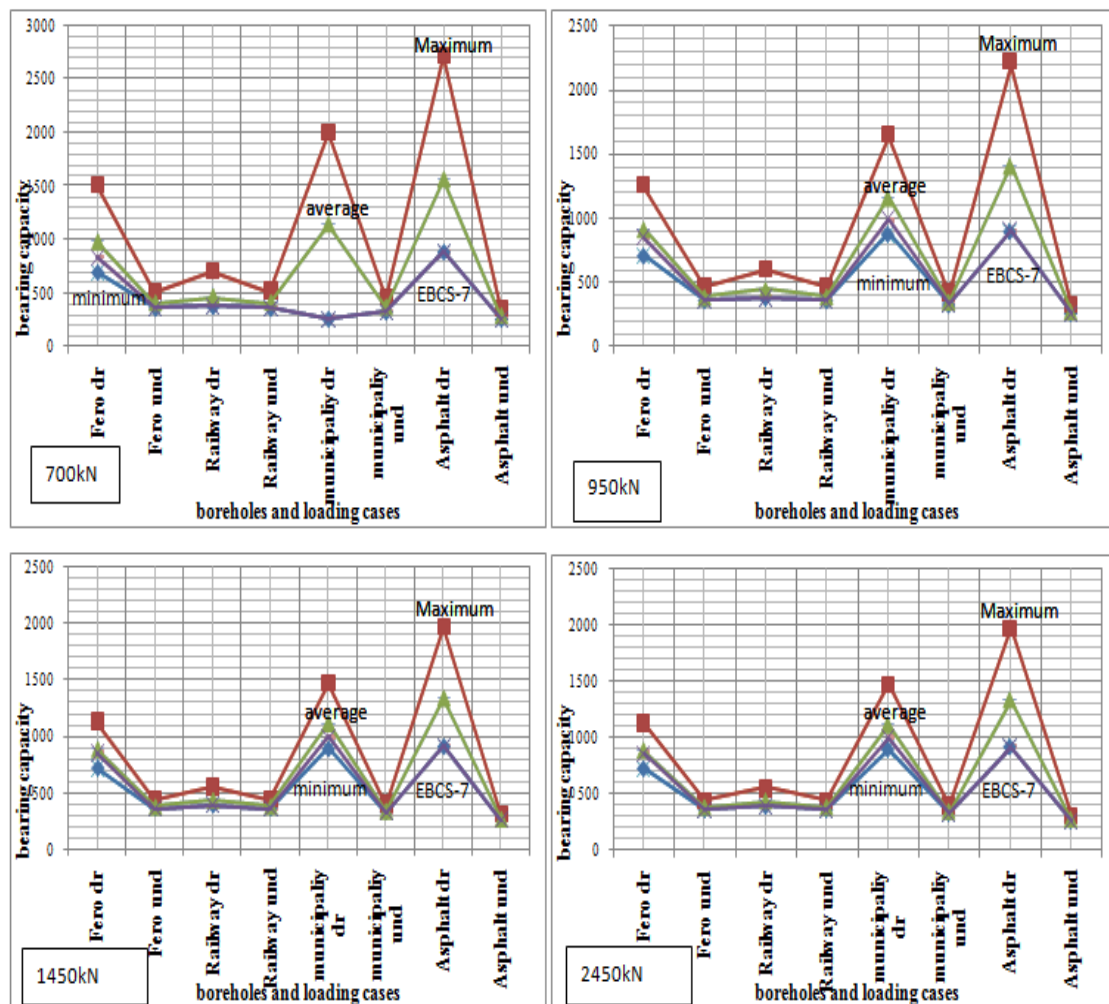


Figure 4. 3. Typical bearing capacity values of square footing depth 3m

4.7. SETTLEMENT ANALYSIS OF SQUARE FOOTING DEPTH 3M

Generally the settlement of the footing has an inversely relationship with depth. Compared to the value discussed from square footing at 2m depth the settlement decreased with corresponding loading.

4.7.1. Loading Case 1 [0-700kN]

As shown from Table4.38 the settlement in the codes studied are different in value even in a small number. For this typical load of 700kN, the settlement ranges from Ferro to Asphalt area in the adjusted in the Table is 7.71-8.93mm, 10.24-11.69mm, 16.18-18.89mm and 16.37-21.31mm respectively

Table 4. 24. Settlement of square footing in the first loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
700kN	BH.F	8.28	7.71	7.72	8.66	8.93	8.28
	BH.R	10.24	10.27	10.29	11.27	11.69	10.24
	BH.M	16.95	16.21	16.18	18.67	18.89	16.95
	BH.A	16.37	18.04	17.97	21.31	21.15	16.37

4.7.2. Loading Case 2 [700-1200kN]

Settlement increased with the load changed to 950kN all parameters kept constant.

The variability of the computed value followed the preceding loading case. The minimum settlements of the footing in respective order as presented in Table4.39 is 9.06mm, 9.76mm, 14.57mm and 13.6mm, whereas the maximum value from the table in the same order is 10.35mm, 10.86mm, 16.62mm and 17.13mm. Here and above the settlement in the case of EBCS-7 is almost smallest in railway and asphalt areas but the maximum value is obtained from Hansen's method of analysis.

As shown from Table4.40 the settlement in sofa software result the maximum value this is because sofa software method of analysis by default divides the layer into four layers.

Table 4. 25 Settlement of square footing in the second loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
950kN	BH.F	9.66	9.06	9.07	10.07	10.35	9.66
	BH.R	9.76	9.78	9.80	10.54	10.86	9.76
	BH.M	15.15	14.59	14.57	16.45	16.62	15.15
	BH.A	13.60	14.79	14.74	17.13	17.02	13.60

Table 4. 26. Settlement of square footing in the second loading case of sofa software method depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
700kN	BH.F	21.41	19.34	19.34	23.93	25.28	21.41
	BH.R	18.51	18.57	18.57	19.74	20.18	18.51
	BH.M	31.85	29.51	29.02	36.10	36.50	31.85
	BH.A	45.16	53.06	53.06	62.88	62.88	45.16

4.7.3. Loading Case 3 [1200-1700kN]

The computation conducted in this load range has valued in Table4.41from 11.4-12.83mm for Ferro, 13.86-15.38mm for railway, 17.54-19.59mm for municipality and 15.35-18.67mm for asphalt areas.

Table 4. 27. Settlement of square footing in the third loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1450kN	BH.F	12.07	11.40	11.41	12.52	12.83	12.07
	BH.R	13.86	13.89	13.91	14.94	15.38	13.86
	BH.M	18.12	17.56	17.54	19.42	19.59	18.12
	BH.A	15.35	16.47	16.42	18.67	18.56	15.35

4.7.4. Loading Case 4 [2200-2700kN]

Still up to the fourth range of the load the settlement is limited within the maximum limit state. In all places of borehole areas the maximum settlement observed from Table 4.42 is 26.4mm. the range of the settlement for boreholes adjusted are respectively 15.17-16.87mm, 16.78-18.36mm, 23.83-26.23mm and 22.05-26.27mm.

Table 4. 28. Settlement of square footing in the fourth loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
2450kN	BH.F	15.97	15.17	15.18	16.50	16.87	15.97
	BH.R	16.78	16.82	16.84	17.92	18.36	16.78
	BH.M	24.52	23.86	23.83	26.04	26.23	24.52
	BH.A	22.05	23.55	23.49	26.41	26.27	22.05

4.8. CONCLUDING REMARKS OF SETTLEMENT OF SQUARE FOOTING DEPTH 3M

It is a common principle that depth and settlement have an indirect relationship. As shown in Figure 4.4, the settlement in the EBCS-7 method of analytical approaches to the minimum value. The maximum difference of settlement occurred between the maximum values and EBCS-7 method of analysis for each loading case reached up to 4.94mm, 3.53mm, 3.32mm and 4.36mm respectively. Unlike bearing capacity the settlement difference is not regularly decreased as the loading increased. The settlement didn't exceed the maximum limit for all loading cases encountered. The maximum settlement has been usual in the Hansen's method of analysis.

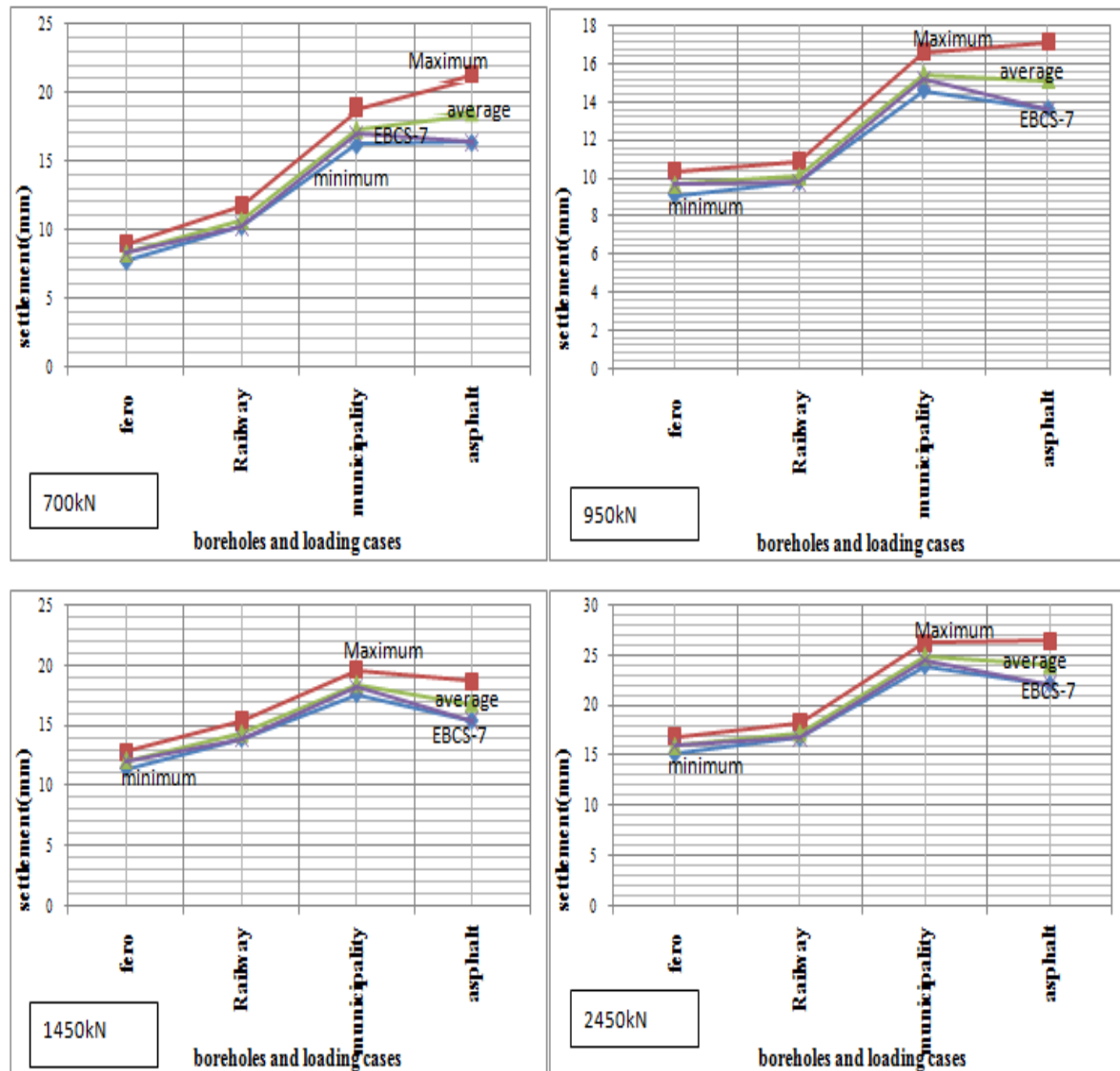


Figure4. 4 Typical settlement values of square footing depth 3m

4.9. BEARING CAPACITY AND SETTLEMENT: RECTANGULAR FOOTING AT 2M DEPTH

The analysis of the rectangular footing is different in some methodologies from the square footing. In the rectangular footing to compute the footing size with the presumed load cases is impossible because of the difference of the footing width and length. Hence a reasonable assumption of the footing length was taken. The reason why 3m footing length was assumed is that to restrict the width of the footing less than longer side. Even if this fact is deviated from some cases the assumption is logical on most analysis.

4.9.1. Bearing Capacity Analysis for Rectangular Footing Depth 2m for Loading Case 1 [0-700kN]

4.9.1.1. Square footing size using different formulating codes

At the commencement the length of the footing is already determined with an assumption the dimension of the width looked small. The width of the rectangular footing shown from Table 4.43 has no difference in the proposed codes except in Meyerhof's and Hansen's method in both drained and undrained cases. Here also one unique property observed in undrained loading case the width of the footing in Meyerhof's and Hansen's method of analysis is equal. In drained case of loading the values found in Hansen's method evaluation are economical compared to the codes.

4.9.1.2. Bearing Capacity values of different codes of analytical methods

In rectangular footing as per the dimensions determined, bearing capacity was computed and, the value in codes DIN, EAK, EURO and EBCS-7 are almost equal. Bearing capacity in Meyerhof's and Hansen's method are different even in undrained case of which the dimensions are equal. The range of bearing capacity in the adjusted order of the table for drained loading case 431-1271kPa, 257-525kPa, 537-1910kPa and 666-2805kPa respectively for DIN, EAK, EURO, Meyerhof, Hansen, and EBCS 7, where as in undrained case 305-605kPa, 308-637kPa, 279-531kPa and 224-361kPa. In software method of analysis shown Table 4.45 in the first design approach the bearing capacity in all codes except Meyerhof's and Hansen's method overestimated compared to analytical method but in Meyerhof's and Hansen's method underestimated. With the second design approach of Table 4.46 the estimated values are not regular.

Table 4. 29. Size of rectangular footing in the first loading case depth 2m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	0.46	0.46	0.46	0.4	0.33	0.46	0.46	0.33	0.43
	Undrained case	0.73	0.73	0.73	0.59	0.59	0.73	0.73	0.59	0.68
BH.R	Drained case	0.84	0.84	0.84	0.74	0.6	0.84	0.84	0.60	0.78
	Undrained case	0.73	0.73	0.73	0.57	0.57	0.73	0.73	0.57	0.68
BH.M	Drained case	0.36	0.36	0.36	0.31	0.26	0.36	0.36	0.26	0.34
	Undrained case	0.8	0.8	0.8	0.64	0.64	0.8	0.80	0.64	0.75
BH.A	Drained case	0.28	0.28	0.28	0.23	0.2	0.28	0.28	0.20	0.26
	Undrained case	1.01	1.01	1.01	0.83	0.83	1.01	1.01	0.83	0.95
	Max	1.01	1.01	1.01	0.83	0.83	1.01			
	Min	0.28	0.28	0.28	0.23	0.2	0.28			
	Avg	0.65125	0.65125	0.65125	0.53875	0.5025	0.65125			

Table 4. 30. Bearing capacity of rectangular footing in the first loading case of analytical method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	430.58	430.58	431.83	500.86	1271.34	430.58	1271.34	430.58	582.6283
	Undrained case	305.46	305.46	305.46	483.8	604.99	305.46	604.99	305.46	385.105
BH.R	Drained case	256.54	256.54	257.23	291.14	524.95	256.54	524.95	256.54	307.1567
	Undrained case	307.38	307.38	307.38	497.22	636.59	307.38	636.59	307.38	393.8883
BH.M	Drained case	537.13	537.13	538.81	642.74	1910.24	537.13	1910.24	537.13	783.8633
	Undrained case	279.27	279.27	279.27	430.09	530.6	279.27	530.6	279.27	346.295
BH.A	Drained case	666.24	666.24	668.41	814.51	2805.18	666.24	2805.18	666.24	1047.803
	Undrained case	262.65	262.65	262.65	311.07	259.89	262.65	311.07	259.89	270.26
Max		666.24	666.24	668.41	814.51	2805.18	666.24			
Min		256.54	256.54	257.23	291.14	259.89	256.54			
Avg		380.6563	380.6563	381.38	496.42875	1067.973	380.6563			

4.9.2. Bearing Capacity Analysis for Rectangular Footing Depth 2m for

4.9.3. Loading Case 2 [700-1200kN]

4.9.3.1. Rectangular Footing Size using Different Codes

The width of the rectangular footing o the typical super structural load of 950kN had been computed from Table 4.47. Still the width of the footing obtained with the exception of Meyerhof's and Hansen's methods is equal and Hansen's method also underestimated the values. The range of the width of the footing has ranged from 0.45-0.62m, 0.81-1.14m, 0.35-0.49m and 0.28-0.39m respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7. and the width of the footing in undrained cases is uneconomical compared to the drained value.

4.9.3.2. Bearing Capacity values of different codes of analytical methods

Bearing capacity in the second loading case also followed the same tendency of the previous cases. As it is indicated in Table 4.48, bearing capacity ranges in the drained case 443-1063kPa, 266-462kPa, 550-1565kPa and 680-2262kPa respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7. The undrained bearing capacity obtained in this loading case is conservative except railway areas compared to the drained cases. The calculated value of the bearing capacity in sofa software method of analysis in the two design approaches is not regular to make a comparison to analytical methods it is simply a method to determine the bearing capacity in a short manner.

Table 4. 31. Size of rectangular footing in the second loading case depth 2m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	0.62	0.62	0.62	0.54	0.45	0.62	0.62	0.45	0.58
	Undrained case	0.99	0.99	0.99	0.8	0.8	0.99	0.99	0.80	0.93
BH.R	Drained case	1.14	1.14	1.14	1	0.81	1.14	1.14	0.81	1.06
	Undrained case	0.99	0.99	0.99	0.78	0.78	0.99	0.99	0.78	0.92
BH.M	Drained case	0.49	0.49	0.49	0.41	0.35	0.49	0.49	0.35	0.45
	Undrained case	1.09	1.09	1.09	0.87	0.87	1.09	1.09	0.87	1.02
BH.A	Drained case	0.38	0.38	0.38	0.32	0.28	0.38	0.38	0.28	0.35
	Undrained case	1.38	1.38	1.38	1.12	1.12	1.38	1.38	1.12	1.29
	Max	1.38	1.38	1.38	1.12	1.12	1.38			
	Min	0.38	0.38	0.38	0.32	0.28	0.38			
	Avg	0.885	0.885	0.885	0.73	0.6825	0.885			

Table 4. 32. Bearing capacity of rectangular footing in the second loading case of analytical method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	Max	Min	Avg
BH.F	Drained case	442.71	443.07	444	511.19	1062.58	1062.58	442.71	580.71
	Undrained case	309.95	309.95	309.95	441.66	513.47	513.47	309.95	377.00
BH.R	Drained case	266.2	267.04	266.88	299.83	461.71	461.71	266.20	312.33
	Undrained case	311.98	311.98	311.98	452.03	538.97	538.97	311.98	385.39
BH.M	Drained case	549.74	549.9	551.64	653.63	1564.78	1564.78	549.74	773.94
	Undrained case	283.8	283.8	283.8	395.02	453.21	453.21	283.80	339.93
BH.A	Drained case	679.56	679.59	682.1	826.1	2262.33	2262.33	679.56	1025.94
	Undrained case	228.66	228.66	228.66	295.77	314.18	314.18	228.66	259.19
	Max	679.56	679.59	682.10	826.10	2262.33			
	Min	228.66	228.66	228.66	295.77	314.18			
	Avg	384.08	384.25	384.88	484.40	896.40			

4.9.4. Bearing Capacity analysis for rectangular footing depth 2m for Loading Case 3 [1200-1700kN]

4.9.4.1. Rectangular Footing size using different formulating Codes

For the typical load of 1450kN adopted for this load case the footing width is obviously observed as it is increased. In undrained loading cases the footing widths are almost equal in codes of DIN, EAK, EURO and EBCS-7 and Meyerhof and Hansen have also equivalent value.

4.9.4.2. Bearing Capacity values of different codes of analytical methods

With the above corresponding footing width and the assumed length discussed bearing capacity both drained and undrained loading are determined below Table 4.52 in analytical method and from Table 4.53 and Table 4.54 in sofa software method of analysis. Comparing the drained and undrained loading cases the later underestimated the value except in railway areas. So the range of bearing capacity in drained cases is 467-869kPa, 285-407kPa, 575-1240kPa and 706-1747kPa respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7.

Table 4. 33. Size of rectangular footing in the third loading case depth 2m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	0.96	0.95	0.95	0.83	0.69	0.96	0.96	0.69	0.89
	Undrained case	1.52	1.52	1.52	1.23	1.23	1.52	1.52	1.23	1.42
BH.R	Drained case	1.74	1.73	1.73	1.53	1.23	1.74	1.74	1.23	1.62
	Undrained case	1.51	1.51	1.51	1.19	1.19	1.51	1.51	1.19	1.40
BH.M	Drained case	0.75	0.74	0.74	0.63	0.53	0.75	0.75	0.53	0.69
	Undrained case	1.67	1.67	1.67	1.33	1.33	1.67	1.67	1.33	1.56
BH.A	Drained case	0.59	0.58	0.59	0.49	0.42	0.59	0.59	0.42	0.54
	Undrained case	2.1	2.1	2.1	1.72	1.72	2.1	2.10	1.72	1.97
Max		2.1	2.1	2.1	1.72	1.72	2.1			
Min		0.59	0.58	0.59	0.49	0.42	0.59			
Avg		1.355	1.35	1.35125	1.11875	1.0425	1.355			

4.9.4.3. Bearing Capacity of Analytical Methods

Table 4. 34. Bearing capacity of rectangular footing in the third loading case of analytical method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	466.49	467.74	468.53	532.05	868.96	466.49	868.96	466.49	545.0433
	Undrained case	318.92	318.92	318.92	404.73	425.1	318.92	425.1	318.92	350.9183
BH.R	Drained case	284.91	287.2	286.09	317.4	406.94	284.91	406.94	284.91	311.2417
	Undrained case	321.17	321.17	321.17	412.15	444.72	321.17	444.72	321.17	356.925
BH.M	Drained case	574.61	575.08	577.3	675.55	1239.59	574.61	1239.59	574.61	702.79
	Undrained case	292.85	292.85	292.85	364.91	378.49	292.85	378.49	292.85	319.1333
BH.A	Drained case	705.93	705.82	709.81	849.39	1747.13	705.93	1747.13	705.82	904.0017
	Undrained case	237.52	237.52	237.52	280.51	269.15	237.52	280.51	237.52	249.9567
	Max	705.93	705.82	709.81	849.39	1747.13	705.93			
	Min	237.52	237.52	237.52	280.51	269.15	237.52			
	Avg	400.3	400.7875	401.5238	479.58625	722.51	400.3			

4.9.5. Bearing Capacity Analysis for Rectangular Footing Depth 2m for Loading case 4 [2200-2700kN]

4.9.5.1.Rectangular footing size using different formulating codes

The specific load involved in this range is 2450kN which is the fourth and largest loading case. The extent of the footing width with the considered footing length is mentioned on Table4.55. As usual the footing dimension in undrained loading case is equal in Meyerhof's and Hansen's method as well as the other codes to each other. The values obtained in this case are uneconomical or conservative. the ranges of the footing size obtained for the defined load are 1.16-1.62m,2.08-2.94m,0.9-1.27m and 0.71-1.00m respectively of Ferro , railway, municipality and asphalt areas.

4.9.5.2.Bearing Capacity values of different codes of analytical methods

The typical load of 2450kN that is the fourth loading case the bearing capacity in the analytical and sofa software method of analysis are shown Table4.56,Table 4.57 and Table4.58.The range of the bearing capacity in this loading case in the adjusted order presented in the Tables is 512-737kPa, 320-378kPa, 623-1007kPa and 758-1368kPa

Table 4. 35. Size of rectangular footing in the fourth loading case depth 2m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.62	1.61	1.61	1.4	1.16	1.62	1.62	1.16	1.50
	Undrained case	2.56	2.56	2.56	2.07	2.07	2.56	2.56	2.07	2.40
BH.R	Drained case	2.94	2.93	2.92	2.58	2.08	2.94	2.94	2.08	2.73
	Undrained case	2.54	2.54	2.54	2.01	2.01	2.54	2.54	2.01	2.36
BH.M	Drained case	1.27	1.25	1.26	1.07	0.9	1.27	1.27	0.90	1.17
	Undrained case	2.81	2.81	2.81	2.25	2.25	2.81	2.81	2.25	2.62
BH.A	Drained case	1	0.98	0.99	0.82	0.71	1	1.00	0.71	0.92
	Undrained case	3.55	3.55	3.55	2.9	2.9	3.55	3.55	2.90	3.33
	Max	3.55	3.55	3.55	2.9	2.9	3.55			
	Min	1	0.98	0.99	0.82	0.71	1			
	Avg	2.28625	2.27875	2.28	1.8875	1.76	2.28625			

Table 4. 36. Bearing capacity of rectangular footing in the fourth loading case of analytical method depth 2m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	512.13	516.38	515.63	574.54	736.92	512.13	736.92	512.13	561.2883
	Undrained case	336.85	336.85	336.85	384.96	425.1	336.85	425.1	336.85	359.5767
BH.R	Drained case	319.87	326.72	321.69	353.41	378.47	319.87	378.47	319.87	336.6717
	Undrained case	339.56	339.56	339.56	390.1	444.72	339.56	444.72	339.56	365.51
BH.M	Drained case	622.95	625.23	627.91	719.98	1006.71	622.95	1006.71	622.95	704.2883
	Undrained case	310.96	310.96	310.96	350.42	378.49	310.96	378.49	310.96	328.7917
BH.A	Drained case	757.52	758.5	764.12	896.48	1368.33	757.52	1368.33	757.52	883.745
	Undrained case	255.25	255.25	255.25	277.54	269.15	255.25	277.54	255.25	261.2817
	Max	757.52	758.5	764.12	896.48	1368.33	757.52			
	Min	255.25	255.25	255.25	277.54	269.15	255.25			
	Avg	431.8863	433.6813	433.9963	493.42875	625.9863	431.8863			

4.10. CONCLUDING REMARKS OF BEARING CAPACITY OF RECTANGULAR FOOTING DEPTH 2M

For the rectangular footing of length 3m for all cases bearing capacity has been calculated and valued at the minimum, maximum, average and EBCS-7 from figure 4.5. The maximum values were computed in the Hansen's method of analysis to four loading cases and the minimum values were taken in the case of the EBCS-7 method of analysis. The difference of the maximum and minimum values found in the four loading cases is respectively 2139kPa, 1583kPa, 1041kPa and 611kPa. The average values calculated for all cases considered reduces the difference of maximum and minimum values.

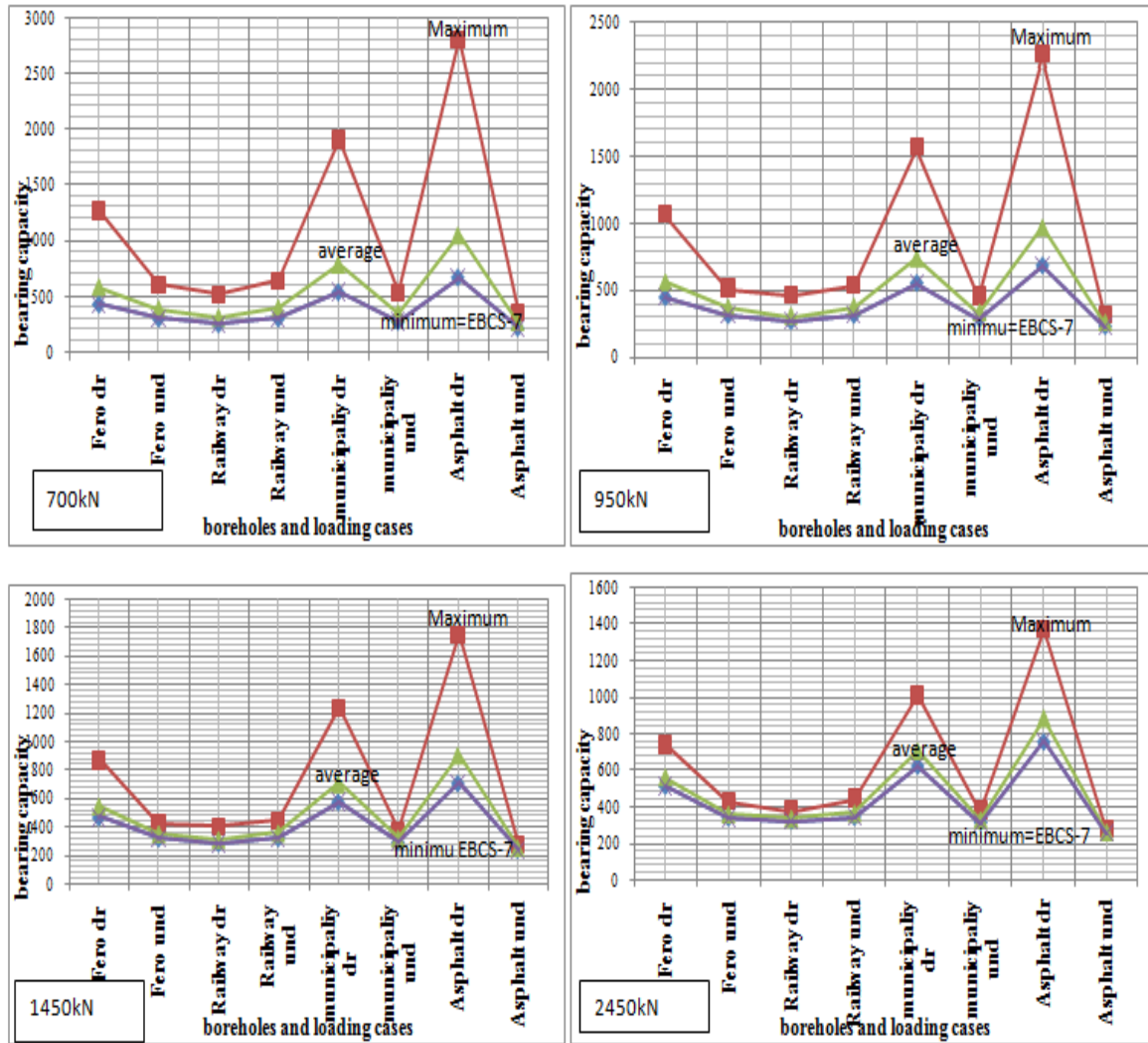


Figure 4.5. Typical bearing capacity values of square footing depth 2m

4.11. SETTLEMENT ANALYSIS FOR RECTANGULAR FOOTING DEPTH 2M

4.11.1. Loading Case 1 [0-700kN]

Since the length of the footing assumed is large the settlement shown from Table 4.59 are diminished. In this typical load of 700kN the settlement of the footing is less than 10mm, because as it is the settlement in each code is almost the same with some difference of Hansen's and Meyerhof's method. The minimum maximum range of settlement for this loading case as the order of the table 2.37-3.26mm, 5.41-7.35mm, 2.82-3.9mm and 2.1-2.9mm

Table 4. 37. Settlement of rectangular footing in the first loading case depth 2m

Loading Cases	Location	Settlement of Square Footing					
		DIN (mm)	EAK (mm)	EURO (mm)	Meyerhof (mm)	Hansen (mm)	EBCS-7 (mm)
700kN	BH.F	3.26	3.26	3.26	2.85	2.37	3.26
	BH.R	7.35	7.35	7.35	6.55	5.41	7.35
	BH.M	3.9	3.9	3.9	3.31	2.82	3.9
	BH.A	2.9	2.9	2.9	2.41	2.1	2.9

4.11.2. Loading Case 2 [700-1200kN]

In the load deformation principle and relation settlement has a direct relationship with the load. The range of the settlement for drained case for this typically loads From Table4.60 is 4.25-5.8mm, 9.36-12.46mm, 5.05-6.9mm and 3.8-5.2mm respectively of the bore hole.

Table 4. 38. Settlement of rectangular footing in the second loading case depth 2m

Loading Cases	Location	Settlement of Square Footing					
		DIN (mm)	EAK (mm)	EURO (mm)	Meyerhof (mm)	Hansen (mm)	EBCS-7 (mm)
950kN	BH.F	5.8	5.76	5.75	5.08	4.25	5.8
	BH.R	12.46	12.42	12.39	11.2	9.36	12.46
	BH.M	6.9	6.84	6.86	5.9	5.05	6.9
	BH.A	5.19	5.13	5.16	4.33	3.79	5.19

4.11.3. Loading Case 3 [1200-1700kN]

The defined load involved in this loading range is 1450kN and the corresponding settlement of rectangular footing is indicated from Table4.61. The range of the values computed can be numerical as 9.29-12.43mm, 22.21-29mm, 10.55-14.08mm and 7.58-10.18mm respectively. The settlement in sofa software indicated in Table4.62 is very large compared to analytical method.

Table 4. 39 Settlement of rectangular footing in the third loading case depth 2m

Loading Cases	Location	Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1450kN	BH.F	12.43	12.34	12.34	10.99	9.29	12.43
	BH.R	28.99	28.9	28.85	26.24	22.21	28.99
	BH.M	14.08	13.95	13.99	12.18	10.55	14.08
	BH.A	10.18	10.06	10.11	8.59	7.58	10.18

Table 4. 40. Settlement of rectangular footing in the third loading case of sofa software depth 2m

Loading Cases	Location	Settlement of Square Footing				
		DIN	EAK	EURO	Meyerhof	Hansen
		(mm)	(mm)	(mm)	(mm)	(mm)
1450kN	BH.F	27.54	27.72	27.72	29.53	30.7
	BH.R	23.84	23.86	23.86	24.32	31.42
	BH.M	37.04	37.26	37.26	41.51	43.53
	BH.A	65.07	65.54	65.07	68.67	69.24

4.11.4. Loading Case 4 [2200-2700kN]

For the typical load of 2450kN the settlements observed in Table4.63 reaches the maximum settlement limit of EBCS-7 standard. The ranges of the settlement of each borehole areas are 23-30mm, 42-52.61mm, 26.39-34.06mm and 21.09-27.72mm respectively of the table.

Table 4. 41. Settlement of rectangular footing in the fourth loading case depth 2m

Loading Cases	Location	Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
2450kN	BH.F	29.97	29.79	29.77	30.19	22.99	29.97
	BH.R	52.61	52.46	52.38	41.06	42	52.61
	BH.M	34.06	33.8	33.87	27.26	26.39	34.06
	BH.A	27.72	27.41	27.55	22.62	21.09	27.72

4.12. CONCLUDING REMARKS OF SETTLEMENT OF RECTANGULAR FOOTING DEPTH 2M

Here in this case the unique characteristic is observed for rectangular footing compared to square footing that in the rectangular footing the maximum value fitted with the EBCS-7 method of analysis. The other unique characteristics investigated for rectangular footing are for the maximum loading case typically for 2450kN the settlement exceeds its maximum limit state for on typical borehole shown from Table4.63 whereas for the first loading cases the settlements are diminished in a large extent. The maximum, minimum difference calculated for the four leading cases are 1.94mm, 3.1mm, 6.78mm and 11.55mm respectively. It is numerically observed that the difference is increased for loading increment.

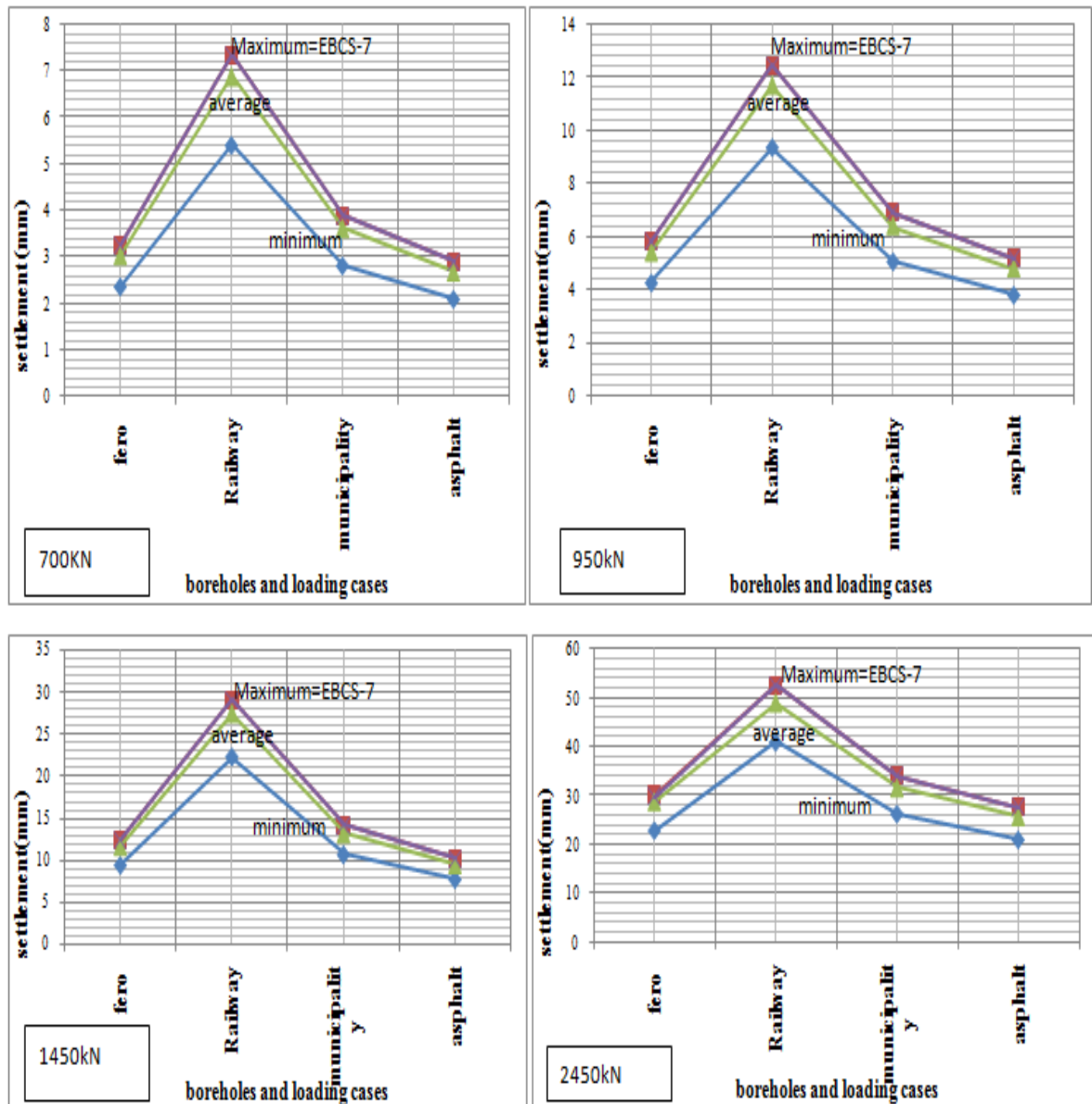


Figure4. 6. Typical settlement values of rectangular footing depth 2m

4.13. BEARING CAPACITY ANALYSIS FOR RECTANGULAR FOOTING DEPTH 3M

4.13.1. Loading Case 1 [0-700kN]

For the described rectangular footing at a depth of 3m the dimension (width) of the footing is more economical and almost near to each other for codes used in this case. In both drained and undrained loading cases Hansen's method of analysis underestimated the values leads to a more economical design of shallow foundation. Meyerhof's and Hansen's

method of analysis has result the smallest and unique values. As shown in the Table4.64, the range of the dimensions for drained loading cases are 0.23-0.37m, 0.42-0.68m, 0.19-0.3m and 0.15-0.24m respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7.

4.13.1.1. Rectangular footing size using different formulating codes

Table 4. 42. Size of rectangular footing in the fourth loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	0.37	0.37	0.37	0.31	0.23	0.37	0.37	0.23	0.34
	Undrained case	0.69	0.69	0.69	0.52	0.5	0.69	0.69	0.50	0.63
BH.R	Drained case	0.68	0.68	0.68	0.57	0.42	0.68	0.68	0.42	0.62
	Undrained case	0.7	0.7	0.7	0.52	0.49	0.7	0.70	0.49	0.64
BH.M	Drained case	0.3	0.3	0.3	0.24	0.19	0.3	0.30	0.19	0.27
	Undrained case	0.76	0.76	0.76	0.57	0.55	0.76	0.76	0.55	0.69
BH.A	Drained case	0.24	0.24	0.24	0.19	0.15	0.24	0.24	0.15	0.22
	Undrained case	0.96	0.96	0.96	0.72	0.71	0.96	0.96	0.71	0.88
	Max	0.96	0.96	0.96	0.72	0.71	0.96			
	Min	0.24	0.24	0.24	0.19	0.15	0.24			
	Avg	0.5875	0.5875	0.5875	0.455	0.405	0.5875			

4.13.1.2. Bearing Capacity values of different codes of analytical methods

Bearing capacity of the corresponding dimensions (width) and an assumed length of 3m as shown the Table4.65 increased compared to the corresponding loading case of footing depth 2m.bearing capacity of the undrained case with the exception of railway areas those are underestimated the bearing capacity values which made the engineer conservative. Since the design constraints are dependent on the long term bearing capacity and more variation of the values among the codes are adopted comparisons are better to be made on this case. So the range of the values from Table4.65 respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7 is 531-2752kPa, 311-1004kPa, 641-4012 and 786-5901kPa.the values are also determined by sofa software method of analysis from Table4.66 and 4.67 with the two design approaches in such a way that the values obtained in the first design approach is closer to the analytical method but a conservative value was determined in the second design approach due to the variability of the partial safety factors.

Table 4. 43. Bearing capacity of rectangular footing in the first loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	531.32	531.34	532.31	659.8	2752.38	531.32	2752.38	531.32	923.0783
	Undrained case	322.65	322.65	322.65	627.33	869.61	322.65	869.61	322.65	464.59
BH.R	Drained case	311.49	311.88	312.17	374.79	1003.89	311.49	1003.89	311.49	437.6183
	Undrained case	321.27	321.27	321.27	637.73	918.84	321.27	918.84	321.27	473.6083
BH.M	Drained case	641.17	641.38	642.86	824.44	4012.21	641.17	4012.21	641.17	1233.872
	Undrained case	293.69	293.69	293.69	549.05	754.36	293.69	754.36	293.69	413.0283
BH.A	Drained case	786.19	786.35	788.36	1038.68	5900.67	786.19	5900.67	786.19	1681.073
	Undrained case	237.62	237.62	237.62	395.53	495.65	237.62	495.65	237.62	306.9433
	Max	786.19	786.35	788.36	1038.68	5900.67	786.19			
	Min	237.62	237.62	237.62	374.79	495.65	237.62			
	Avg	430.675	430.7725	431.3663	638.41875	2088.451	430.675			

4.13.2. Loading Case 2 [700-1200kN]

4.13.2.1. Rectangular footing size using different formulating codes

The dimensions found with the typical load of 950kN shown from the Table 4.68 are somewhat larger than the first loading this indicated the loading and dimension of the footing have a direct relationship. The dimensions obtained for this loading case are also close in codes except in the case of Meyerhof and Hansen. The range of the dimensions from Table 4.68 are 0.32-0.51m, 0.57-0.93m, 0.25-0.41m and 0.2-0.33m respectively for DIN, EAK, EURO, Meyerhof, Hansen, and EBCS 7.

4.13.2.2. Bearing capacity values of different codes of analytical methods

Bearing capacity in the building codes are increased as the load increased and decreased in Meyerhof's and Hansen's method. Unlike the square footing in undrained loading case bearing capacity values are influenced by load variation. The minimum and maximum value range of bearing capacity of bore holes arranged in the table in order is 543-2185kPa, 321-831kPa, 653-3148 and 799-4584kPa respectively for DIN, EAK, EURO, Meyerhof, Hansen, and EBCS 7.

Table 4. 44. Size of rectangular footing in the second loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	0.51	0.5	0.5	0.41	0.32	0.51	0.51	0.32	0.46
	Undrained case	0.94	0.94	0.94	0.7	0.68	0.94	0.94	0.68	0.86
BH.R	Drained case	0.93	0.92	0.92	0.77	0.57	0.93	0.93	0.57	0.84
	Undrained case	0.94	0.94	0.94	0.7	0.66	0.94	0.94	0.66	0.85
BH.M	Drained case	0.41	0.41	0.41	0.32	0.25	0.41	0.41	0.25	0.37
	Undrained case	1.04	1.04	1.04	0.77	0.74	1.04	1.04	0.74	0.95
BH.A	Drained case	0.33	0.32	0.33	0.25	0.2	0.33	0.33	0.20	0.29
	Undrained case	0.96	0.96	0.96	0.72	0.71	0.96	0.96	0.71	0.88
Max		1.04	1.04	1.04	0.77	0.74	1.04			
Min		0.33	0.32	0.33	0.25	0.2	0.33			
Avg		0.7575	0.75375	0.755	0.58	0.51625	0.7575			

Table 4. 45. Bearing capacity of rectangular footing in the second loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS- 7 (kPa)	Max	Min	Avg
BH.F	Drained case	542.7	542.9	544.09	669.12	2185.21	542.7	2185.21	542.7	837.7867
	Undrained case	326.89	326.89	326.89	552.25	708.45	326.89	708.45	326.89	428.0433
BH.R	Drained case	320.64	321.16	321.36	382.66	830.58	320.64	830.58	320.64	416.1733
	Undrained case	325.67	325.67	325.67	559.67	746.94	325.67	746.94	325.67	434.8817
BH.M	Drained case	653.16	653.24	655.14	834.46	3147.67	653.16	3147.67	653.16	1099.472
	Undrained case	297.99	297.99	297.99	486.74	618.09	297.99	618.09	297.99	382.7983
BH.A	Drained case	798.91	798.89	801.15	1049.42	4584.03	798.91	4584.03	798.89	1471.885
	Undrained case	241.8	241.8	241.8	358.28	413.53	241.8	413.53	241.8	289.835
	Max	798.91	798.89	801.15	1049.42	4584.03	798.91			
	Min	241.8	241.8	241.8	358.28	413.53	241.8			
	Avg	438.47	438.5675	439.2613	611.575	1654.313	438.47			

4.13.3. Loading Case 3 [1200-1700kN]

4.13.3.1. Rectangular footing size using different formulating codes

In this load case three the typical load considered was 1450kPa as per this value the dimensions are determined from Table 4.70. The dimensions in the undrained load case are conservative compared to those of drained cases. The range of the footing size of drained loading is 0.48-0.77m, 0.87-1.41m, 0.39-0.63m and 0.31-0.5m in the respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7.

4.13.3.2. Bearing capacity values of different codes of analytical methods

Bearing capacity in the load defined and the corresponding dimensions are manipulated from Table 4.71. The minimum and maximum range of the values in order for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7 of drained loading cases is 565-1644kPa, 339-669kPa, 677-2320kPa and 824-3320kPa respectively.

Table 4. 46. Size of rectangular footing in the third loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	0.77	0.77	0.77	0.63	0.48	0.77	0.77	0.48	0.70
	Undrained case	1.44	1.44	1.44	1.07	1.04	1.44	1.44	1.04	1.31
BH.R	Drained case	1.41	1.41	1.41	1.17	0.87	1.41	1.41	0.87	1.28
	Undrained case	1.44	1.44	1.44	1.07	1.01	1.44	1.44	1.01	1.31
BH.M	Drained case	0.63	0.62	0.62	0.5	0.39	0.63	0.63	0.39	0.57
	Undrained case	1.58	1.58	1.58	1.18	1.14	1.58	1.58	1.14	1.44
BH.A	Drained case	0.5	0.49	0.5	0.38	0.31	0.5	0.50	0.31	0.45
	Undrained case	1.98	1.98	1.98	1.49	1.46	1.98	1.98	1.46	1.81
Max		1.98	1.98	1.98	1.49	1.46	1.98			
Min		0.5	0.49	0.5	0.38	0.31	0.5			
Avg		1.21875	1.21625	1.2175	0.93625	0.8375	1.21875			

Table 4. 47 Bearing capacity of rectangular footing in the third loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	565.14	565.85	567.27	687.88	1644.24	565.14	1644.24	565.14	765.92
	Undrained case	335.39	335.39	335.39	483.04	552.85	335.39	552.85	335.39	396.2417
BH.R	Drained case	338.52	340.2	339.91	398.53	668.59	338.52	668.59	338.52	404.045
	Undrained case	334.47	334.47	334.47	487.68	580.97	334.47	580.97	334.47	401.0883
BH.M	Drained case	676.89	677.31	679.91	854.6	2319.97	676.89	2319.97	676.89	980.9283
	Undrained case	306.6	306.6	306.6	429.91	486.51	306.6	486.51	306.6	357.1367
BH.A	Drained case	824.15	824.85	827.59	1071	3320.31	824.15	3320.31	824.15	1282.008
	Undrained case	250.15	250.15	250.15	325.56	334.25	250.15	334.25	250.15	276.735
	Max	824.15	824.85	827.59	1071	3320.31	824.15			
	Min	250.15	250.15	250.15	325.56	334.25	250.15			
	Avg	453.9138	454.3525	455.1613	592.275	1238.461	453.9138			

4.13.4. Loading Case 4 [2200-2700kN]

4.13.4.1. Rectangular footing size using different formulating codes

With the typical load of 2450kN the dimension of the footing in different codes shown from the Table 4.72 is the largest of all the loading cases. The tendency of the values has followed the same procedure as the above cases. The range of the footing size for drained loading case are 0.81-1.31m, 1.48-2.39m, 0.66-1.06m and 0.53-0.85m respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7.

4.13.4.2. Bearing Capacity values of different codes analytical methods

Bearing capacity for this loading case of typically selected as 2450kN are calculated from Table 4.73. The range of bearing capacity for drained loading case in different codes is 609-1241kPa, 373-555kPa, 723-1694kPa, and 874-2358kPa respectively for DIN, EAK, EURO, Meyerhof, Hanson, and EBCS 7.

Table 4. 48. Size of rectangular footing in the fourth loading case depth 3m

Location	Conditions	Size B by B	EAK	EURO-8	Meyerhof	Hansen	EBCS-7	Remark		
		(m)	(m)	(m)	(m)	(m)	(m)	Max	Min	Avg
BH.F	Drained case	1.31	1.3	1.3	1.07	0.81	1.31	1.31	0.81	1.18
	Undrained case	2.43	2.43	2.43	1.82	1.76	2.43	2.43	1.76	2.22
BH.R	Drained case	2.39	2.38	2.38	1.99	1.48	2.39	2.39	1.48	2.17
	Undrained case	2.43	2.43	2.43	1.81	1.71	2.43	2.43	1.71	2.21
BH.M	Drained case	1.06	1.05	1.06	0.84	0.66	1.06	1.06	0.66	0.96
	Undrained case	2.68	2.68	2.68	2	1.92	2.68	2.68	1.92	2.44
BH.A	Drained case	0.85	0.83	0.84	0.65	0.53	0.85	0.85	0.53	0.76
	Undrained case	3.34	3.34	3.34	2.51	2.47	3.34	3.34	2.47	3.06
Max		3.34	3.34	3.34	2.51	2.47	3.34			
Min		0.85	0.83	0.84	0.65	0.53	0.85			
Avg		2.06125	2.055	2.0575	1.58625	1.4175	2.06125			

Table 4. 49. Bearing capacity of rectangular footing in the fourth loading case of analytical method depth 3m

Location	Conditions	DIN (kPa)	EAK (kPa)	EURO (kPa)	Meyerhof (kPa)	Hansen (kPa)	EBCS-7 (kPa)	Max	Min	Avg
BH.F	Drained case	608.76	611.36	612.29	725.86	1240.09	608.76	1240.09	608.76	734.52
	Undrained case	352.37	352.37	352.37	437.16	432.18	352.37	437.16	352.37	379.8033
BH.R	Drained case	372.67	376.97	374.66	430.8	555.21	372.67	555.21	372.67	413.83
	Undrained case	352.06	352.06	352.06	439.84	452.26	352.06	452.26	352.06	383.39
BH.M	Drained case	723.35	725.12	727.99	895.25	1694.46	723.35	1694.46	723.35	914.92
	Undrained case	323.82	323.82	323.82	393.69	384.47	323.82	393.69	323.82	345.5733
BH.A	Drained case	873.82	875.01	879.66	1114.49	2357.89	873.82	2357.89	873.82	1162.448
	Undrained case	266.85	266.85	266.85	307.87	272.76	266.85	307.87	266.85	274.6717
	Max	873.82	875.01	879.66	1114.49	2357.89	873.82			
	Min	266.85	266.85	266.85	307.87	272.76	266.85			
	Avg	484.2125	485.445	486.2125	593.12	923.665	484.2125			

4.13.5. Concluding remarks of bearing capacity of rectangular footing depth 3m

Bearing capacity of rectangular footing at a depth of 3m with an assumed length of 3m has been summarized in Figure 4.4. It is shown that the bearing capacity in each bore hole and loading case has almost the same value except Meyerhof and Hansen's method of analysis. The minimum value and EBCS-7 value of bearing capacity has been fitted in each loading case. The maximum difference between the maximum and minimum (EBCS-7) values for each load case was calculated as 5114kPa, 3785kPa, 2496kPa and 1484kPa respectively of each load. The different values are decreasing with loading increased.

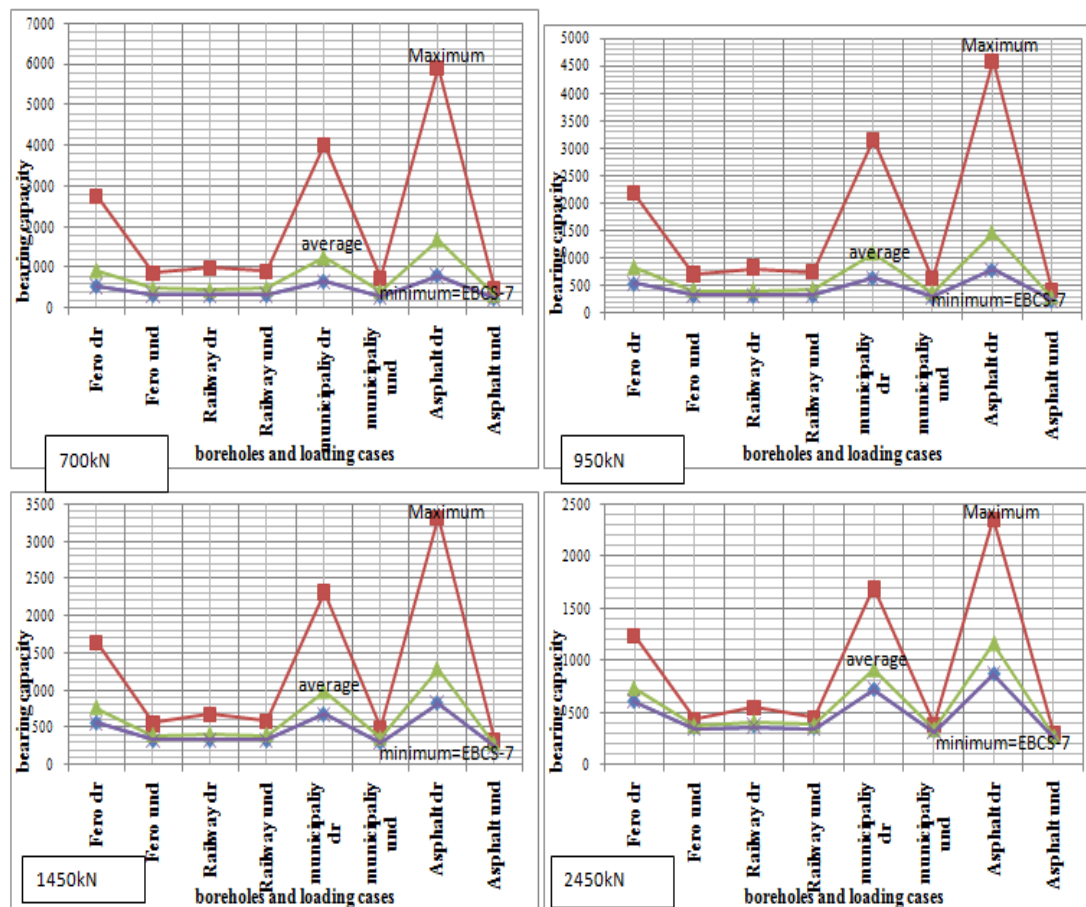


Figure 4.7. Typical bearing capacity values of rectangular footing depth 3m

4.14. SETTLEMENT ANALYSIS FOR RECTANGULAR FOOTING DEPTH 3M

4.14.1. Loading Case 1 [0-700kN]

Generally, as the depth of the footing increased the settlement diminished as shown Table 4.74. the settlement for the load expressed in the Table of this range are very small values. The values are closest for different codes of a borehole. The minimum, maximum values of the settlement of the footing are 4.32-4.54mm, 4.78-5.41mm, 4.75-5.09mm and 5.69-5.91mm.

Table 4. 50. Settlement of rectangular footing in the first loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
700kN	BH.F	4.54	4.54	4.54	4.43	4.32	4.54
	BH.R	5.41	5.41	5.41	5.14	4.78	5.41
	BH.M	5.09	5.09	5.09	4.9	4.75	5.09
	BH.A	5.91	5.91	5.91	5.77	5.69	5.91

4.14.2. Loading Case 2 [700-1200kN]

The difference of the values from case one to case two is visible of the load increment. The extent of the settlement as shown from the Table 4.75 from minimum to maximum in the adjusted order of the Table is 6.03-6.43mm, 6.96-8.02mm, 6.7-7.31mm and 7.89-8.28mm respectively.

Table 4. 51. Settlement of rectangular footing in the second loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
950kN	BH.F	6.43	6.42	6.42	6.24	6.03	6.43
	BH.R	8.02	8.01	8.01	7.57	6.96	8.02
	BH.M	7.31	7.29	7.29	6.98	6.7	7.31
	BH.A	8.28	8.26	8.28	8.04	7.89	8.28

4.14.3. Loading Case 3 [1200-1700kN]

For this load range the estimated settlements are shown from Table4.76. The settlement values found in minimum and maximum extent of each borehole is 9.7-10.53mm, 15.27-17.27mm, 10.03-11.32 and 10.06-10.89mm.

Table 4.52. Settlement of rectangular footing in the third loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1450kN	BH.F	10.53	10.52	10.53	10.14	9.7	10.53
	BH.R	17.27	17.25	17.27	16.43	15.27	17.27
	BH.M	11.32	11.28	11.32	10.62	10.03	11.32
	BH.A	10.89	10.86	10.89	10.39	10.06	10.89

4.14.4. Loading Case 3 [2200-2700kN]

With the final load of 2450kN the settlement still not more than the maximum limit state. 17.74-19.55mm, 22.68-25.98mm, 20.63-23.49mm and 22.57-24.49mm are the settlement range of the footing in different codes respectively as shown from Table4.77.in this the settlement is also determined by sofa software method of analysis which have enabled to obtain a very exaggerated value as indicated from Table4.78.

Table 4. 53. Settlement of rectangular footing in the third loading case depth 3m

		Settlement of Square Footing					
		DIN	EAK	EURO	Meyerhof	Hansen	EBCS-7
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
2450kN	BH.F	19.55	19.52	19.52	18.73	17.74	19.55
	BH.R	25.98	25.95	25.94	24.7	22.68	25.98
	BH.M	23.49	23.41	23.44	21.97	20.63	23.49
	BH.A	24.49	24.42	24.46	23.34	22.57	24.49

Table 4. 54. Settlement of rectangular footing in the third loading case of sofa software method depth 3m

		Settlement of Square Footing				
		DIN	EAK	EURO	Meyerhof	Hansen
Loading Cases	Location	(mm)	(mm)	(mm)	(mm)	(mm)
700kN	BH.F	27.49	27.75	27.75	32.64	35.37
	BH.R	26.85	26.88	26.88	27.9	34.57
	BH.M	41.16	41.29	41.16	44	49.7
	BH.A	67.25	67.4	67.33	76.56	79.5

4.14.5. Concluding remarks of Settlement of Rectangular Footing depth 3m

A settlement with the increment of depth has a common attitude of decrement in each corresponding loading case. The settlement values of rectangular footing in the EBCS-7 method of analysis have corresponded with the maximum value in the four loading cases. The maximum difference of settlement found between maximum (EBCS-7) and minimum values are reached up to 0.63mm, 1.06mm, 2mm and 3.3mm respectively of each loading case. Here the difference goes increased with the increment of loading.

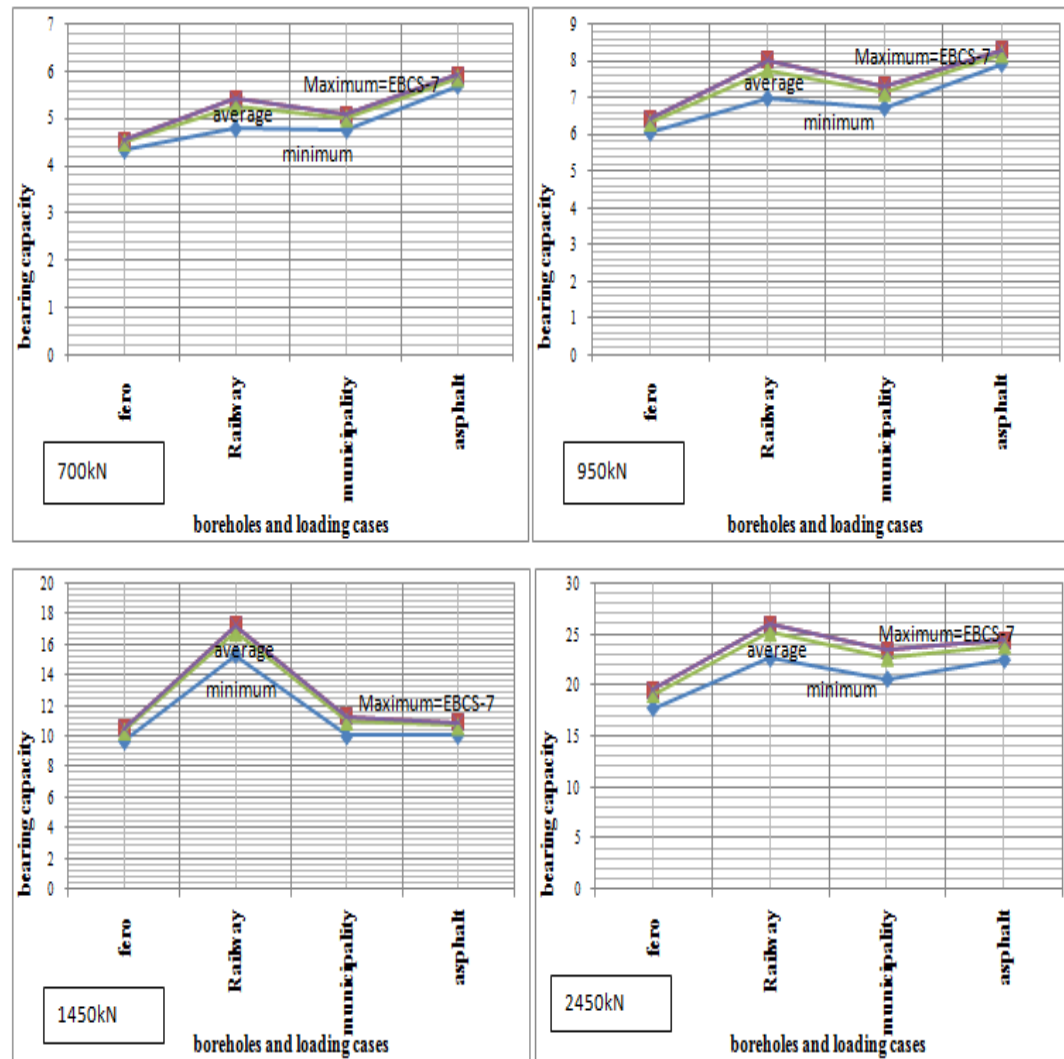


Figure4.8. Typical settlement values of rectangular footing depth 3m

CHAPTER 5:

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The bearing capacities of saturated clay soils were determined under different scenarios of loading cases. Several conclusions drawn from the present study are summarized in this chapter. Some recommendations are also provided for future search and better understand the bearing capacity behavior of soils. The following are some of the conclusions

1. It is known that the expansive potential of the soil depends on the swelling index fully and it is observed in BH.F and BH.M that the soils are Non expansive and the soils found on BH.R and BH.A are medium expansive.
2. Generally the short term bearing capacities found in each borehole and loading cases are conservative compared to the long term bearing capacities for the corresponding phenomena.
3. For practitioners, engineers involved in construction on Gelan area long term bearing capacity in all points with EBCS-7 codes are determined in the case of square and rectangular footing at a depth of 2m and 3m. The study area in four loading cases has resulted bearing capacity value ranges from 309-944kPa and 380-999kPa of square footing and 256-706kPa and 311-874kPa of rectangular footing at a depth of 2m and 3m respectively in the EBCS-7 method of analysis of the four leading cases.
4. The maximum difference occurred between the maximum and EBCS-7 method of analysis reached up to 864kPa and 999kPa for square footing at depth 2m and 3m respectively, and 2139kPa and 5114kPa for rectangular footing depth of 2m and 3m respectively.

5. In square footing size in both depths considered the bearing capacity values in different codes resulted a unique value for long term bearing capacity where as in rectangular footing with the exception of Meyerhof's and Hansen's method bearing capacity values are almost equal in both long term and short term bearing capacity cases.
6. This study clearly pointed out that in almost all cases the EBCS-7 method result a large footing dimension.
7. The settlement of the foundation considered for this study for square footing depth 2m and 3m in the EBCS-7 method of analysis for loading cases from 700-2450kN ranged 11.83mm-35.2mm and 8.28-24.52mm respectively. Whereas for rectangular footing the settlement is 3-52mm and 4.5-26mm respectively, of depth 2m and 3m. In square footing the settlement in the EBCS-7 method of analysis result the minimum value where as in the rectangular footing the values are the maximum result.
8. This study clearly pointed out that in almost all cases the EBCS-7 method result a small bearing capacity and settlement.
9. Design engineers in Ethiopia have an immediate trend of selecting the minimum bearing capacity value for their design foundation, however this trends needs to be changed and we should take into account design economy at least by using average values. Therefore we can conclude that EBCS-7 method determined footing size, bearing capacity and settlement values are conservative and demands some revision to make it more economical.
10. The study suggests that the average of all the results must be used for design as a result EBCS-7 method must encompass these revisions in a way to lead average values.

5.2. RECOMMENDATION

To increase the level of accuracy of the analysis, extensive laboratory tests, especially using undisturbed samples should be conducted for future research programs. To further justify the computations it is better to practice model insitu tests.

Due to budget restriction the effect of sofa software in dynamic response for bearing capacity and settlement with actual parameter value was not reviewed. Elastic settlement parameters were also not taken with the actual tested data because of the complexity of the process with the allotted budget.

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Appendix (or Appendices)

ANNEX A

SOFA SOFTWARE INTERFACE

Shallow Foundation Bearing Capacity & Settlement Calculation

Geometry of the problem

Rectangular Foundation

$L_x = 2.60$ [m]
 $L_y = 2.60$ [m]
 $d_f = 2.0$ [m]
 $d_w = \text{inf}$ [m]
 $\alpha = 0$ [rad.]
 $\beta = 0$ [rad.]

Show me Larger Image...

Soil Properties

Soil Type : Cohesive
Loading : Drained

$\phi_{uk} = 35$ [deg.]
 C_u (UNdr)= 200 [kPa]
 $\phi_k = 35$ [deg.]
 $C' k$ (dr) = 5.5 [kPa]
 $\gamma_s = 18.0$ [kN/m³]
 $\gamma_{sat} = 20.0$ [kN/m³]

Partial Factors

$F_{\phi} = 1.00$
 $F_{C_u} = 1.00$
 $F_{\phi_k} = 1.00$
 $F_{C'} = 1.00$

Buttons

Bearing Capacity View Report
Settlements View Report
HELP! About
Clear All
Quit...

Loads

Design 2
 $\alpha = 0.0$ [kN/m²]
Earthquake design NO

STATIC Load Case

Partial Safety

$V = 1300$ [kN]
 $H_x = 60$ [kN]
 $H_y = 75$ [kN]
 $M_x = 130$ [kNm]
 $M_y = 120$ [kNm]

Settlement Calculation Data

Cohesive Soils

$E = 15$ [MPa]
 $\nu = 0.45$ [-]
 $H = \text{inf}$ [m]
OCR = 15 [-]
 $e_o = 0.45$ [-]
 $C_c = 0.45$ [-]

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