ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

BEHAVIOR OF PILED RAFTS ON MULTI-LAYERED SOIL
(A CASE STUDY ON ORDA PROJECT OF ADDIS ABABA)

A Thesis in Geotechnical Engineering

By Meron Assefa
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A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geotechnics.

The undersigned have examined the thesis entitled 'Behavior of piled raft on multi-layered soil (A case study on ORDA project of Addis Ababa)' presented by **MERON ASSEFA**, a candidate for the degree of **Master of Science in Geotechnics** and hereby certify that it is worthy of acceptance.

Dr.-Ing. Henok Fikre Gebregziabher		
Advisor	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date
Chair person	Signature	Date

UNDERTAKING

I certify that research work titled “Behavior of piled raft on multi-layered soil (A case study on ORDA project of Addis Ababa)” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Meron Assefa

ABSTRACT

It is becoming abundant in Addis Ababa, to conservatively place high-rise buildings on deeper hard stratum through very long piles. However, the use of piled raft foundation seems to be more advantageous than the conventional pile foundation since both the raft and piles contribute to the resisting capacity of the system. In an attempt to investigate the extent of this principle, a case study was undertaken in this paper. The case under consideration, ORDA project of Addis Ababa, incorporates three blocks of different height, accessed as one building. The highest block of the structure rested on long piles to transfer the load to a basalt layer found at a great depth. In the study, the as-built conventional pile foundation scheme was analyzed and compared with that of a proposed piled raft foundation system. In doing so, a finite element analysis software, ABAQUS, was utilized to investigate the behavior of the foundation systems under study. The Effect of one block on the other as well as differential settlement due to varying loads of the blocks is considered in the analysis.

The analysis result revealed that the proposed piled raft foundation was able to safely support the vertical load coming from the super structure by utilizing a shorter and much smaller number of piles than used in the as-built foundation system. It was possible to reduce the number of piles from 162 to 50 and the length of piles from 25.4m to 20.4m, with the adequate margin of safety. The enormous economic benefit of using piled rafts is also shown through direct comparison of expenses for the as-built and proposed foundations. A potential cost reduction of 75% was observed in the analysis.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	**Description**
B	*width of raft*
bpf	*blow per foot*
c'	*effective cohesion*
CPRF	*combined piled raft foundation*
D	*diameter of pile*
e	*original spacing between piles*
$2e$	*doubled spacing between piles*
E	*young's modulus*
Es	*stiffness modulus*
FEM	*finite Element Method*
$F_{tot,k}$	*total characteristic load*
G-	*shear elastic modulus*
GWT	*ground water table*
Gs	*specific gravity of soil*
H	*thickness of the compressible layer*
Ip	*Plasticity indices*
$[K]$	*global stiffness matrix derived from individual stiffness matrices*
L	*original length of pile*
L_p	*length of pile*

N_{30}	*standard penetration test for 30% machine efficiency*
$\{p\}$	*external force vector*
q_b	*resistance per unit area of the pile base*
q_s	*resistance per unit area of the pile shaft*
$R_{b,k,j}(s)$	*settlement dependent base resistance of individual piles in*
$R_{raft,k}(s)$	*settlement dependent resistance of raft in piled raft foundation*
$R_{s,k,j}(s)$	*settlement dependent shaft resistance of individual*
$R_{pile,k,j}(s)$	*settlement dependent resistance of individual piles in piled raft foundation*
$R_{tot,k}(s)$	*settlement dependent total resistance of piled raft foundation*
RQD	*rock quality designation*
s	*settlement*
ΔS	*differential settlement*
S_{max}	*maximum settlement*
S_{min} -	*minimum settlement*
SPT	*standard penetration test*
$\{u\}$	*Global displacement vector*
UCS	*uni-axial compressive strength*
W	*width of raft*
w	*Stiffness exponent*
x	*Cartesian coordinate axis 1*
XSYMM	*boundary condition in ABAQUS for symmetry along the yz plane*

y	*Cartesian coordinate axis 2*
z	*Cartesian coordinate axis 3*
α_{pr}	*ratio of resistance of the piles to the total resistance /piled raft ratio/*
Υ	*total unit weight*
Υsat	*unit weight of saturated soil*
Υw	*unit weight of water*
σ	*normal stress*
μ	*Stiffness coefficient*
τ	*shearing stress*
τ_{xy}	*the shear stress on the plane perpendicular to x and in the direction of y*
τ_{xz}	*the shear stress on the plane perpendicular to x and in the direction of z*
υ	*Poisson's ratio*
ξ_s	*maximum settlement reduction factor*
φ'	*effective angle of internal friction*

CHAPTER 1 INTRODUCTION

1.1 Background

The usual practice in foundation design is to transfer load to a deeper capable layer in case a shallow (raft) foundation does not satisfy design requirements. Though piled raft foundations are better alternatives in certain cases, due to lack of knowledge in the area, end bearing piles are often conservatively used. In the conventional pile design, the pile cap is not considered as load bearing even though it is in direct contact with the soil. But in piled raft foundation design, all three members' (pile, raft and soil) resistance contribution are considered, (Balakumar et al, 2013).

This study focuses particularly on an ongoing project site that is owned by Organization for Rehabilitation and Development in Amhara (ORDA). The project site is located around Leghar, Kirkos sub city, Addis Ababa. The proposed building has three blocks of varying height separated by expansion joints. The bearing soil formation at the site is a very thin clayey silt layer underlain by mixed-soil and basalt. The fracture and weathering rate becomes less as one goes through depth in the mixed layers, and finally the intact basalt rock layer is encountered.

Currently foundation work at the site is completed according to, the recommendation and design given by the structural consulting firm. The first block (4B+G+5) rested on a raft foundation, and the second block (4B+G+15) rested on a piled raft foundation. The raft under these two blocks is a single raft with no expansion joint. The third block (4B+G+25) is separately rested on end bearing piles. The main focus of this study is, the beneficial use of limited number of piles under a raft to reduce settlement and optimize the foundation supporting the 4B+G+25 block.

The trend of using unnecessarily long and large number of piles where optimum piled rafts or even raft-only can offer capable resistance is repeatedly observed in Addis Ababa. Previous studies done on the topic are briefly discussed in the following chapter. This unnecessary expense that highly affects the country's economy is a big problem that must be addressed.

Familiarization of the complex piled raft foundation behavior is important to use it knowledgably, for the obvious economic advantages. The current study being an optimization study for a particular case, will inspire applicability to similar large projects in the city. Analysis method used for this study is purely numerical. Finite element analysis software ABAQUS, because of its successful application in the field by (de Sanctis and Mandolini, 2006), (Maharaj and Gandhi, 2004) and many more scholars.

1.2 Objectives of the study

The economic benefit of using piled raft instead of conventional pile in certain cases, has been studied and proven to be factual by many researchers. This study aims at describing and clarifying, how the performance of piled raft on Addis Ababa multi-layered soil is affected under vertical load, taking the case of ORDA project. The building incorporates three blocks of varying heights. Therefore, effect of one block on the others is one factor to be considered besides the differential settlement due to variable loading. This study is done to evaluate efficiency of the "As-built condition" and come up with a more efficient solution, to show the direct economic benefit of using piled raft foundation. Through the process, variable factors that affect performance of the piled raft shall also be studied.

1.3 Scope of the study

- Behavior of piled raft foundation discussed in this study is focused on settlement and load sharing of piled raft.
- Only the vertical loading condition is considered.
- Additional field or laboratory tests were not performed for this study, all relevant data were collected from the design office.
- No internal element design is done for this study.

1.4 Organization of the thesis

An overview of the concept and design methods of piled raft foundation is discussed in chapter 2. Previous studies that made theoretical and methodological contributions to the latest knowledge on performance of piled raft foundation are comprehended and briefed in this chapter

In chapter 3, sub soil condition of the study area is described and major soil parameters needed for the finite element analysis are determined.

Chapter 4 presents how the basic solution method of FEM works, with brief discussion on its theoretical background. Constitutive model adopted for the analysis and modeling of contact zones are also discussed in this chapter. Explanation of modeling process in ABAQUS is explained in detailed manner for other’s reference.

Results of the finite element analysis on the as-built and proposed foundation designs for ORDA project of Addis Ababa are discussed in chapter 5. Cost comparison for the two cases is also shown. Effects of pile length, number and arrangement, on the settlement and load sharing of piled raft foundations are also presented in this chapter.

Chapter 6 covers brief summary of the research and gives recommendations on the matter.

CHAPTER 2 LITRATURE REVIEW

2.1 Introduction

Piled raft foundations are the composite structures which consist of three elements; piles, raft and the subsoil. Applied loads are transferred to the subsoil both through the raft and the piles. Load sharing between raft and piles is the main distinctive feature that diversifies this type of foundation from other type of piled foundations.

This chapter discusses the concept, design approach and methods of analysis of piled raft foundation. Scholarly papers with substantive findings that made theoretical and methodological contributions to the latest knowledge on performance of piled raft foundation are comprehended. Skim review of some of these studies are also incorporated in this chapter.

2.1.1 Concept and benefit of piled raft foundation

The CPRF Guideline defines Piled Raft Foundation as a geotechnical composite construction that combines the bearing effect of both foundation elements, raft and piles by taking into account interactions among themselves and the bearing layer as pictorially presented in Figure 2-1((Kaztenbach and Choudhury, 2013). Four types of interaction namely pile- soil interaction, pile- pile interaction, pile- raft interaction and raft- soil interaction should be accounted for.

Resistance of a piled raft is contributed by both the raft and piles' resistances, which are settlement dependent. The raft resistance $R_{raft,k}(s)$ is the integral of the pressure $\sigma\ (x,y)$ over the raft- soil contact area:

$$R_{raft,k}(s) = \iint \sigma(s,x,y)dx\,dy \qquad \text{Equation 2.1}$$

The resistance of the piles is the sum of resistance of individual piles $R_{pile,k,j}(s)$, which is contribution of the base and skin friction resistances:

$$R_{pile,k,j}(s) = R_{b,k,j}(s) + R_{s,k,j}(s) \qquad \text{Equation 2.2}$$

The settlement dependent total resistance of piled raft can then be equated as:

$$R_{tot,k}(s) = \sum_{j=1}^{n} R_{pile,k,j}(s) + R_{raft,k}(s) \qquad \text{Equation 2.3}$$

The total exerted force is shared between the piles and the contact pressure developed between the raft and the soil. Ratio of resistance of the piles to the total resistance denoted by the coefficient α_{pr} is used to express the proportion of load carried by the piles and raft.

$$\alpha_{pr} = \frac{\sum_{j=1}^{n} R_{pile,k,j}(s)}{R_{tot,k}(s)} \qquad \text{Equation 2.4}$$

The coefficient depends on the load level and settlement of the piled raft. Value of the coefficient α_{pr} ranges between 0 and 1 indicating a shallow foundation and pure pile foundation respectively.

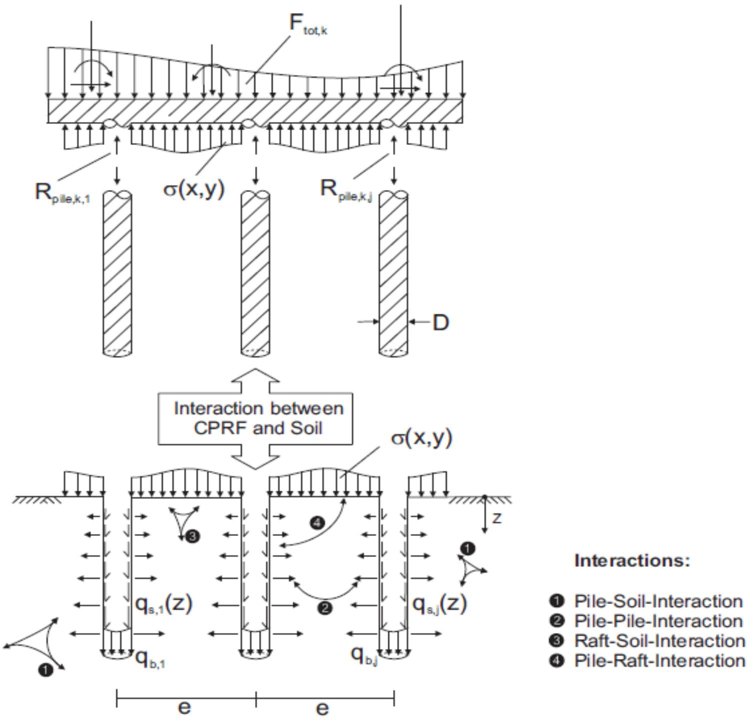


Figure 2-1: Interactions coining the bearing behavior of piled raft foundation (Kaztenbach and Choudhury, 2013)

The benefits of considering both raft and piles in the assessment of the foundation system are clearly illustrated in Figure 2-2. The use of un-piled raft (raft- only) could be incompetent due to load resistance incapability or excessive settlement. In the conventional design of pile groups (piles-only), the piles are assumed to be the only load bearing structures. This approach ignores the contribution of the raft which leads to conservative and uneconomical design and reduction of settlement beyond the required limit.

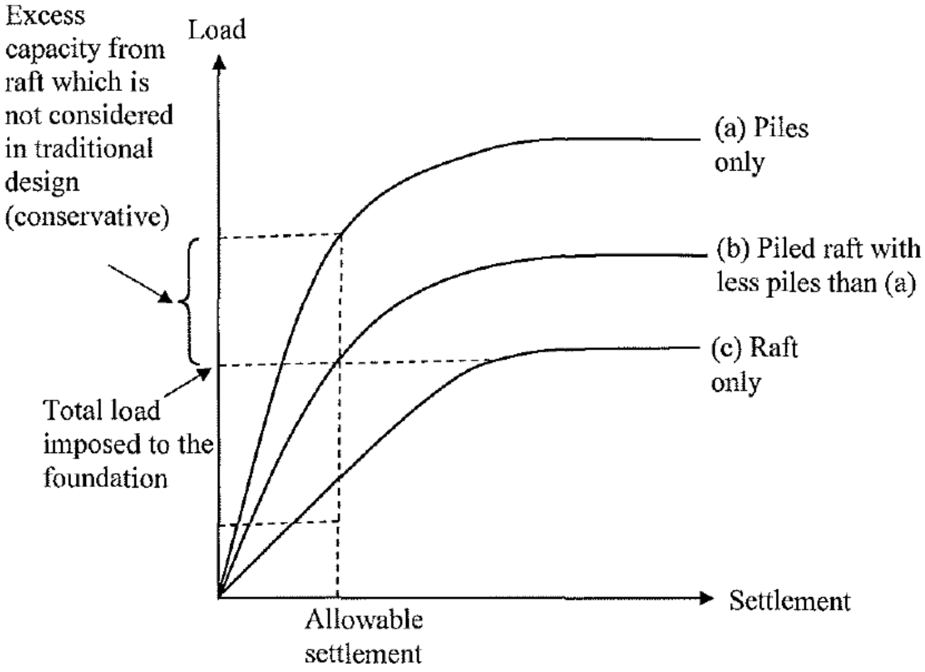


Figure 2-2: Concept of piled raft (Chow and Tan 2004)

However, use of piled raft with a smaller number of piles rather than piles-only, helps achieve the most optimum design.

2.2 Piled Raft Design philosophies

Three piled raft design philosophies are defined by (Randolph, 1994). The first one is the “conventional approach ”in which, group of piles are designed to carry major part of the load while the raft’s contribution is minimal. The second approach is the “creep piling” approach, in which the piles are designed to operate at a working load at which significant creep starts to occur, typically 70-80% of the ultimate load capacity. This approach is intended to maintain the net contact pressure between the raft and soil below pre-consolidation pressure of the soil by providing necessary adequate piles under the raft.

When full ultimate load capacity of most of the piles are utilized the more extreme version of creep pilling is achieved. which is similar to the concept of using piles mainly for total settlement reduction. Third design philosophy is the differential settlement control approach in which piles are located at areas of high settlement or high concentrated forces. Settlement control at local areas is focused on, rather than the overall settlement.

Depending on the intended use of addition of piles on raft, piles could be either stress reducing piles or settlement reducing piles. This is a similar concept with the two classes of piled raft foundations, “small’ and “large” piled rafts, distinguished by (Russo and Viggiani, 1998)

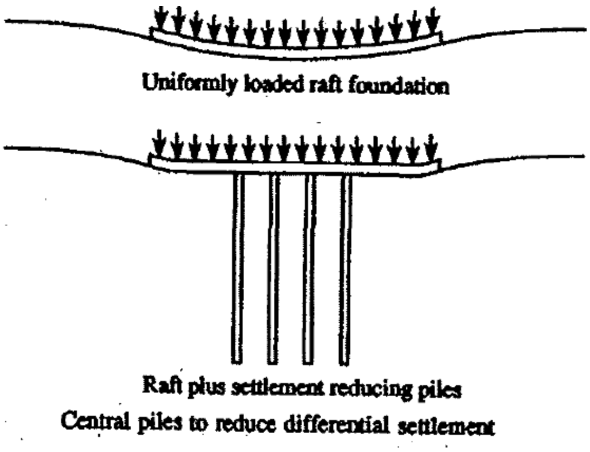


Figure 2-3: Concept of settlement reducing piles (Randolph, 1994)

Friction piles with little or no end bearing resistance are more efficient for settlement reduction. Nevertheless, it does not mean that settlement reducing piles do not reduce stress on the raft.

In case of small piled rafts, piles are added to account for the insufficient bearing capacity of the un-piled raft and attain a suitable margin of safety. Width of the raft for this type of piled rafts are smaller relative to the length of pile, $\frac{B}{L_p} < 1$. The small width of the raft, usually 5m-15m, contributes to the reduced bearing capacity of the raft, while its flexural stiffness is usually high which in turn contributes to differential settlement reduction. The idea of introducing piles to reduce the stress induced on the raft is denoted as stress reducing piles (Burnald,1986).

The large piled rafts on the other hand are used when the un-piled raft is capable of carrying the load safely but the addition of piles is necessary to reduce settlement. This type of piled rafts in general have larger width of raft in comparison to the length of piles, $\frac{B}{L_p} > 1$, (de Sanctis and Mandolini, 2006).

The settlement reducing piles can be of two types, total settlement reducing piles or differential (local) settlement reducing piles (Chow and Tan, 2004). The use of piles to reduce total settlement and local deformation are illustrated in Figure 2-3 and Figure 2-4 respectively.

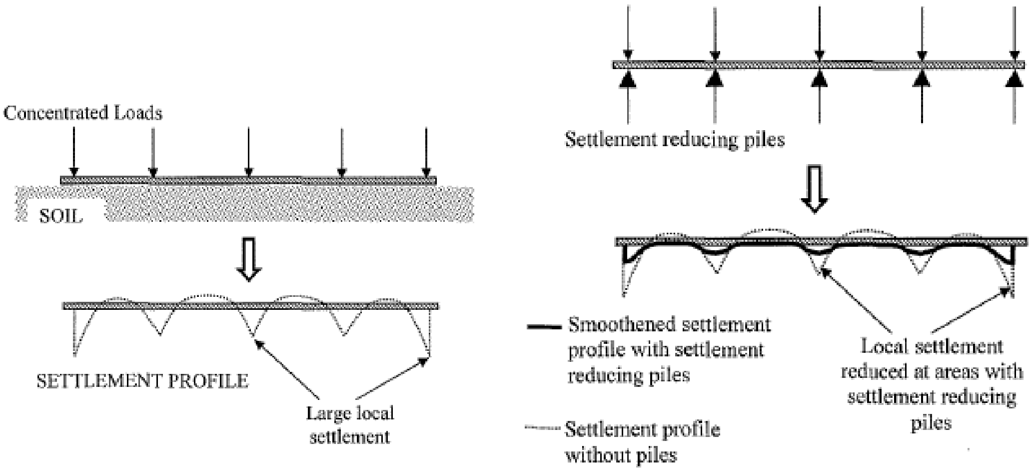


Figure 2-4: Settlement reducing piles to control local deformations (Chow and Tan, 2004)

2.3 Methods of analysis and design of piled raft foundation

As the different design approaches discussed earlier a variety of analysis methods also exist. Needless to say, that a certain method is not applicable only for one type of approach, all of the methods to be discussed allow every approach to be implemented. According to

(Poulos et al, 1997), these approaches can be classified into three major categories, discussed in the next sub topics. The first one is the simplified calculation methods which is mainly used during a feasibility studies of large-scale projects because it uses a number of simplifying assumptions concerning the geometry, loading and material conditions which are used in the analysis (Gebregziabher, 2011)

2.3.1 Simplified method

Simplified method consists of hand calculations that make use of the theoretical solution for both the raft and pile in elastic continuum. The simplification arises from analyzing both the pile and raft in elastic continuum and one example can be assuming the soil to be homogenous. Poulos and Davis, Randolph, Burland are major contributors to expansion of simplified methods although all these methods involve a number of simplifications when considering the soil domain and applying load on the raft. On simplified methods one can find diverse literatures from (Davis and Poulos, 1972) to the most recent ones by (Lutz, 2002).

As mentioned above the basis of simplified method is that it is based on elastic medium and uses approximate hand calculation (Davis and Poulos, 1972). However, this approach was later modified to analyze individual pile-rafts by (Poulos and Davis, 1980) to then analyzing raft responses through a single interaction factor which is known as individual pile-raft unit by (Randolph, 1994). The widely known Poulos-Davis-Randolph (PDR) method was an extension of this concept. In order to find the ultimate capacity, the PDR method propose one should take the lesser value between the sum of ultimate capacities of the separate raft and piles and the ultimate capacity of a block containing the piles and raft, with the portion of the raft outside the periphery of the piles.

Burland (1977) has developed some simplified process of design for piles designed to act as settlement reducer and to develop their full capacity at the design load. Design method for estimating pile load share and settlement, limited to serviceability limit state was proposed by (Lutz, 2002) based on the works of (Clancy and Randolph, 1993). The concept was further extended by ((El-Mossallamy et al, 2006)) to accommodate the ultimate limit state.

2.3.2 Approximate computer-based method

The approximate computer-based method was presented by Randolph in the paper published in 1983. This simplified method was needed because computer capabilities and storages were minimal at that time therefore took a long calculation period.

The approximate method, plate on spring approach based on elastic theory, developed by (Poulos et al, 1999), was used as a groundwork for a program named GARP (Geotechnical Analysis of Raft with Piles) by considering four major interactions. The interaction considered by the program are: interactions between piles, influence of the raft on the piles, influence of the piles on the raft and interaction between elements of the raft. all type of vertical, lateral and moment loading effects, as well as, layered soil non-homogeneity is included in the model by means of suitable analytical approximation. Though this method has significant advantages like considering the ultimate capacity of pile as well as being used to obtain the distribution of stress inside the raft, below are notions that can be given as major drawbacks (Nguyen et al, 2013)

While using GARP, the raft is represented by a strip, the supporting piles as springs whereas the soil as an elastic continuum and the piles as interacting springs. If the soil is not modelled reliably and since many parameters are required when using this program, it can cause the behavior of the piles to deviate from the real behavior and consequently the obtained settlement of the foundation will undoubtedly include some errors (Sinha, 2013).

The other method Strip on springs approach (GASP) is a way of representing the raft by a strip and the supporting piles by springs. The analysis is carried out by taking some allowance of interaction factors to obtain the settlements and moments due to the applied loading on that strip section. Though this method can be used for practical purposes the fact that it doesn’t consider the effect of torsional moments with in the raft and not giving consistent settlement when two strips are analyzed through a particular point can be mentioned as major limitations of this method (Gebregziabher, 2011). Another shortcoming is that the when using this method is used to analyze behavior of piles under a discrete beam it cannot be identical with the pile group action under a mat. Therefore, this type of analysis can produce unrealistic settlement behavior for piled raft foundation (Sinha, 2013).

2.3.3 More rigorous numerical methods

The numerical methods used to analyze the complex piled raft foundation are primarily the Finite Element Method (FEM), Boundary Element Method (BEM), Finite Layer Method (FLM), Finite Difference Method (FDM) or a combination of two or more of these methods.

These methods use discretization of the foundation elements hence require large computation memory with high speed processors. Of course, the development of these methods is directly related to the availability of high capacity personal computers. Though these methods are readily available the focus of this thesis will be 3D finite element analysis with the software ABAQUS. With the help of advancement in technology like never before, sophisticated computer hardware and software are being introduced, making the 3D finite element method the ideal approach to suitably represent piled raft's complicated interactions in a manner closest to its actual behavior.

Finite Difference Method (FDM) was used to analyze the raft behavior of a piled raft foundation. The rectangular rigid raft of constant stiffness was discretized into nodes and elements, for which, the equation of plate bending was expressed in incremental finite difference form. FDM uses the concentrated and applied moment load as uniformly distributed load. Load displacement curves were used to obtain the vertical displacement of the soil at the junctions of the piles. Initially the load displacement curves for the interaction of two rigid circular cap pile unit are calculated and then applied for all pile cap (Poulos, 1994).

In Boundary Element Methods, both the raft and the piles within the system are discretized, and most of the analysis with BEM consider linear elastic soil conditions. Raft is discretized as a two-dimensional thin plate and represented by integral equation. Soil, on the other hand, is treated as elastic homogenous layer, in which piles are embedded (Sinha, 2013). According to (Banerjee et al, 1986) the boundary Element Method is applicable only to the linear homogenous medium. Because the application of soil structure interaction is limited to the use of joint elements (Frank et al, 1994) and when analyzing a rigid raft (Hemsley, 2000) a more complete method of analysis was required which can be used for a largescale project.

A complete three-dimensional analysis of a piled raft foundation system can be carried out by finite element analysis and in theory, using such a program plays a major role by removing the need for the approximate assumptions which are integral in all of the above analyses. Some problems still remain, however, in relation to the modelling of the pile-soil interfaces, and whether interface element should be used. If they are, then approximations are usually involved in the assignment of joint stiffness properties. Apart from this difficulty, the main problem is the time involved in obtaining a solution, in that a non-linear analysis of a piled raft foundation can take several days, even on a modern computer (Sinha, 2013).

Lots of scholars have studied the performance of piled raft considering the effects of the soil type, pile dimensions and configuration, raft dimensions on its load sharing and settlement behaviors. (Sinha, 2013) has performed a three-dimension finite element analysis on sand to understand the load sharing behavior between the piles and raft by focusing on the soil geometry and raft geometry (diameter, length, spacing of piles) and he was able find out piles carry more loads if placed closely consequently making the raft to carry more load at a large spacing but if the piles are spaced more than seven times the diameter of the pile, it will be rendered ineffectual.

Omeman (2013), also carried out a finite element analysis of piled raft foundation in sand under vertical load and suggested investigating the settlement of piled-raft foundation is the primary step to determine the load sharing between the piles and the raft. The study also discovered that the load sharing mechanism between piles and raft foundation is highly dependent on the ratio of stiffness of the pile group to stiffness of the raft in question and settlement was also giving the much-needed attention on this study hence found that settlement of the foundation plays a major role in distributing the load between the foundation's element.

The method used by (Reul and Randolph, 2004) was also based on completely using finite element method. ABAQUS software was the program chosen by the authors to simulate piled rafts and predicted that modelling the soil and foundation by finite elements can allow the most rigorous treatment of the soil–structure interaction. This method is said to have noteworthy advantages based on different literature because of the reasons stated below.

Studies of behavior of piled raft foundation taking cases of projects in Addis Ababa are also done by previous researchers. The piled raft foundation used for the Commercial Bank of Ethiopia Headquarters located in Addis Ababa, was studied by (Fisseha, 2019) using a simplified design method and three-dimensional Finite Element based software. The piled raft consists of 46 bored piles and an irregular shaped raft. The study aimed at investigating the contribution of the raft to bearing behavior of piled raft foundation and to assess load sharing mechanisms between raft and piles while the pile is tipped on strong stratum. The results of the finite element computations reveal the unnecessary use of 46 bored piles beneath the raft, in which the raft only was adequate in terms of bearing capacity and settlement requirements. Nearly all, 93%, of the load is carried by the piles in the built design. Following the concepts of bearing capacity of layered soils, the effect on the soil underlying the hard stratum in which the pile tips rest might be significant, and hence, further computations are made assuming the hard stratum is underlined by weaker formations. The computations show the effect of the weak layer is negligible unless the relative stiffness between the weak and hard strata is reduced by less than half. Also, the behavior of the piled raft is not affected if the weak layer is located 9m below the hard strata for considered stiffness ratio between 0.05 to 0.80.

A similar case study was conducted using three-dimensional finite element-based software by (Mahidre, 2018) on three specific buildings founded on rocky formations namely; Nib, Zemen, and United Bank Headquarters. The piled raft of the Nib bank headquarters comprises 126 bored piles and a rectangular raft of dimensions 35.0m x 21.6m with a raft thickness of 2m. The length of piles is 24m with diameter of 0.8m. The results of the finite element computations show the settlement of the raft alone, estimated to be 3mm is insignificant. Therefore, providing piles is not necessary at all. The majority of the load, 97%, is carried by the piles for the spacing of three times the pile diameter and doubling the pile spacing decrease the load carried by the piles to 75%.

The piled raft of the Zemen bank headquarters comprises 99 bored piles and a rectangular raft of dimensions 27.0m x 21.5m with a raft thickness of 2.78m. The lengths of the piles are 20m and 28m with a pile diameter of 0.6m and 0.8m. The results of the finite element computations for this case also shows that, settlement of the raft alone, 8.97mm, is insignificant. Thus, providing the piles is unnecessary. The majority of the load, 90%, is carried by the piles for the spacing of three times the pile diameter, and doubling the pile spacing decrease the load carried by the piles to 61%.

The piled raft of the United Bank headquarters comprises 135 bored piles and a rectangular raft of dimensions 35.7m x 21.0m with a raft thickness of 4.03m. The length of the pile is 28m with a pile diameter of 0.8m. The results of the finite element computations show the settlement of the raft alone, 9.71mm, is similarly insignificant. Hence, use of piles is unnecessary. The majority of the load, 91%, is carried by the piles for the spacing of three times the pile diameter, and doubling the pile spacing decrease the load carried by the piles to 76%.

The above discussion shows four case studies that reveal the trend of using unnecessarily long and large number of piles where raft-only foundation can offer capable resistance. These case studies are done on project sites where hard stratums dominates, whereas the current study considers the case of multi-layered soil. The current case study incorporates three different blocks of varying height. The effect of each block on the other is additional factor considered. Furthermore, there is a significant loading magnitude variation among these blocks, given the varying number of stories they each have.

CHAPTER 3 SITE CHARACTERIZATION AND SOIL PARAMETERS

Soil investigation and detailed material report data are the basic input, for the FEM analysis of all geotechnical problems. In this chapter, geological characteristics of the site and layer stratifications with their corresponding soil parameters are presented. Parameters obtained from tests as observed in the geotechnical investigation report are taken directly. The geotechnical investigation reports, test results on undisturbed samples for the soil layers above the bearing layer, rather than focusing on the formations below the foundation. One of the challenges faced was determination of the appropriate soil parameters for the bearing layers. The soil parameters that are not available, are correlated empirically based on available data.

3.1 General Case Description

The Organization for Rehabilitation and Development of Amhara (ORDA) project site is located in Addis Ababa, Kirkos sub city, around Legehar. The building has three blocks of varying heights 4B+G+5, 4B+G+15 and 4B+G+25 (*referred hereafter as G5, G15 and G25),* separated using expansion joints. The three blocks all together cover an area of 2463m$^{2.}$ The 4B+G+5 and 4B+G+15 blocks cover the widest and smallest area with a built-up area of 1017m^2 and 455m^2 respectively. Foundation level is 15.56m below natural ground level. Areal plot of each block can be observed in Figure 3-1. Foundation works at the site are completed according to the recommendation and design given by the structural consulting firm.

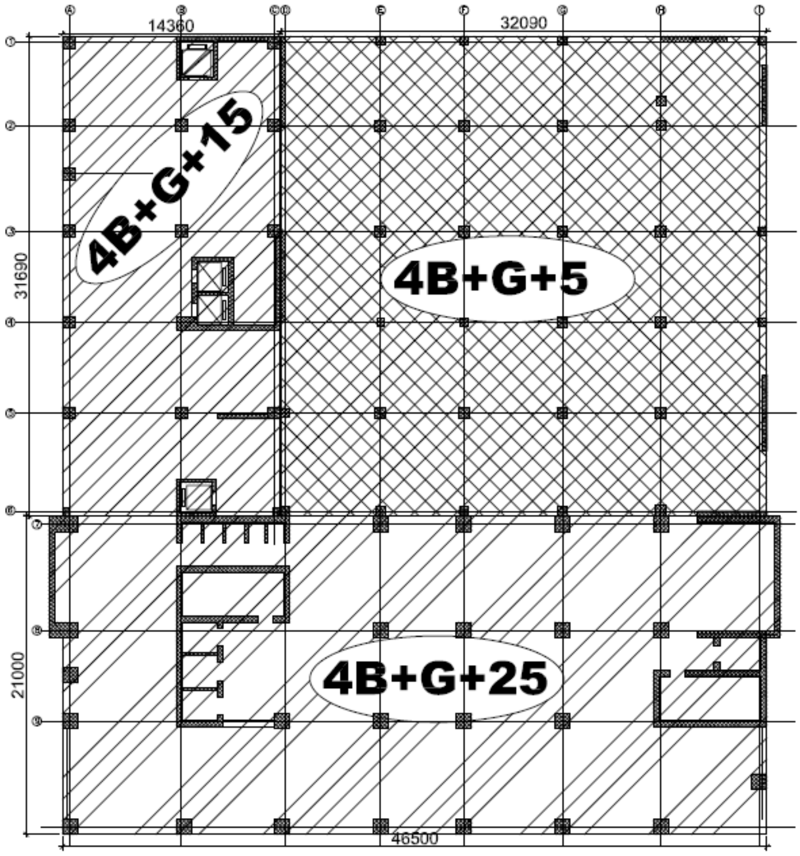


Figure 3-1: Areal plot of each block *(dimensions are in mm)*

3.2 Geotechnical Investigation Report

Geotechnical Investigation was done by Ethiopian Construction Design and Supervision Works Corporation; Transport Design and Supervision Works sector. Core drilling of six boreholes; one to 35 meters, three to 40 meters and two to 50 meters depth along with in-situ and laboratory tests was conducted.

Recommendation by the geotechnical investigation team was to use raft foundation for the 4B+G+5 and 4B+G+15 blocks and raft on pile foundation system for the 4B+G+25 block. Allowable bearing capacities for both raft foundations were given. Allowable design load capacity for the pile frictional resistance was estimated using empirical equation based on SPT values and end bearing resistance was given based on results of laboratory compressive strength of intact rock samples.

Most of the geotechnical reports that are usually available and/or used in current design and construction practices are commonly done with the intention of determining only the indicative index soil properties. However other important parameters should be determined to get sufficient input parameters for the FEM model.

Availability of such soil data is one of the main issues for this analysis. Laboratory tests performed on undisturbed samples to determine the basic soil parameters like cohesion and angle of internal friction are done for soil samples above 15m depth; even though the soil with in this range is excavated out, for the construction of the four basements and foundation. The only available data for the whole investigated depth is standard penetration, natural moisture content, gradation, Atterberg limit and specific gravity test results. Therefore, soil parameters which are not available are calculated from available data using direct and empirical relations.

3.3 Subsurface Condition

After careful observation of the borehole logs attached in appendix A, the geotechnical layers encountered in the six boreholes are summarized in to five major layers as follows:

1. Brown, soft to medium stiff, highly plastic silty clay
2. Brownish and reddish, very stiff to hard, medium to highly plastic consolidated clayey silt
3. Light grey and brown, medium dense, silty sand/ sandy gravel with medium plastic clayey silt
4. Brownish, very stiff to hard, medium to highly plastic clayey silt with medium to highly decomposed rock (tuff)
5. Greyish, medium strong to strong basalt with an average RQD value of 25%

Level of ground water was established to be at 15.25m below the natural ground level. Hence in the analysis, submerged unit weight of the soil is taken for layers located below the ground water level.

3.4 Determination of basic soil parameters

From geotechnical point of view, formations at the site are subdivided in to five major layers. Reasonable soil parameters collected directly from the geotechnical investigation and to be estimated with brief discussion in appendix B for the four layers that are directly modeled on the numerical analysis software are presented in Table 3-1. Most typical soil parameter values are chosen to be adopted from (Briaud, 2013), due to the detailed descriptions he provided.

3.4.1 Unit weight (ϒ)

Unit weight of each layer is determined and since the foundation bearing layer is below level of ground water table effective unit weight is adopted for the numerical analysis. Accustomed unit weight of each soil layer is shown in Table 3-1. A value of 25.0kN/m3 was adopted for reinforced concrete materials in accordance with the Euro code.

3.4.2 Effective shear strength parameters- Cohesion (c’) and angle of internal friction (φ’)

Effective cohesion and angle of internal friction values for can be estimated from direct shear tests in the laboratory. Direct shear tests results reported on soil investigation of the site are all performed above the depth foundation bearing layer. For the layers under the bearing layer typical values are adopted as seen in Table 3-1.

3.4.3 Elastic deformation parameters- Young’s modulus (E) and Poisson’s ratio (υ)

There are different empirical correlations that can be used to estimate the Young’s modulus depending on the soil type and consistency (density). None of these equations account for the change of stress the formation will experience. The Young’s modulus depends primarily on the strain level at which it is estimated and on the confining pressure. Therefore, the equation given by (DIN 4094-2:2003) is used to estimate the stress dependent Young’s modulus. Poisson’s ratio is adopted from typical values suggested by (Briaud, 2013).

For C-30 Reinforced concrete with minimum cylindrical strength f_{ck} of 25MPa, Young's modulus and Poisson's ratio of 31,476MPa and 0.2 are adopted respectively according to (EN1992-1-1).

3.4.4 Initial stress coefficient (K_o)

To estimate the initial stress coefficients different empirical equations are adopted from (Bowels, 1997). These equations make use of the angle of internal friction or plasticity index to calculate the coefficient.

Table 3-1: Accustomed soil parameters for each layer

Depth [m]	Layer description	ϒ /ϒ' [kN/m^3]	c' [kPa]	φ' [°]	υ [-]	K_o [-]	E_s [MN/m^2]
15.5-18	Very stiff, clayey SILT	19.3/9.3	25	26	0.3	0.49	24
18-30	Medium dense, sandy GRAVEL with silt	20/10	20	36	0.3	0.44	85
30-40	Very stiff, clayey SILT with decomposed rock	19.5/9.5	20	40	0.3	0.43	100
40-50	Medium strong to strong BASALT	25.5/15.5	10,000	45	0.25	0.29	1500

CHAPTER 4 FINITE ELEMENT FORMULATION AND MODELING

4.1 Introduction

Among the methods used for analysis of piled raft foundation, advantages of using the rigorous method of three-dimensional finite element method is briefly discussed in the literature review. Sequentially, similar method has to be used to represent the soil supporting the foundation. Soil being an anisotropic, three phased material, its behavior is best characterized by behavior and interaction of its discrete particles, which would be highly complex to express. Therefore, individual effects of the particles are averaged to a larger practical scale, so that it can be analyzed as a continuum (Katzenbach et al, 1997).

The continuum has an infinite number of degrees of freedom, while the discretized bounded model has a finite number of degrees of freedom. Hence the origin of the name - Finite Element Method, (Henok, 2009). This chapter discusses failure criterion used, modeling of contact zones, the basic solution method of FEM and modeling in ABAQUS.

4.2 Mohr Coulomb yield criterion

Mohr in the 1700’s used to work as a military engineer involving in the construction of several large earth-retaining structures. He began by observing that all the materials derived strength from two sources: cohesion and friction. His observations of real soils suggested that failure will usually be associated with a surface of rupture within the soil mass, (Davis and Selvadurai, 2002). Restricting attention to this surface he wrote his failure criterion as:

$$\tau = c + \sigma \tan \phi \qquad \text{Equation 4.1}$$

where τ and σ represent the shearing stress and normal stress on the physical plane through which material failure occurs. The constant c is called the cohesion. It has dimensions of stress. The quantity $\tan \phi$ is similar to a coefficient of friction. The angle ϕ is referred to as the angle of internal friction. Coulomb did not write the criterion exactly as we have done here, but his words clearly expressed the meaning we associate with the equation today. The graph of Equation 4.2 is a straight line on the Mohr diagram. If failure is to occur for a combination of principal stresses $\sigma_1 \geq \sigma_2 \geq \sigma_3$ the critical Mohr stress circle, derived from σ and σ_3 must be a tangent to this line. Therefore, the values of τ and σ can be related to the major and minor principal stresses σ_1 and σ_3. by considering the geometry of the dashed triangle

$$\tau = \frac{1}{2}(\sigma 1 - \sigma 3)\cos\phi \qquad \text{Equation 4.3}$$

$$\sigma = \frac{1}{2}(\sigma 1 + \sigma 3) - \frac{1}{2}(\sigma 1 - \sigma 3)\sin\phi \qquad \text{Equation 4.4}$$

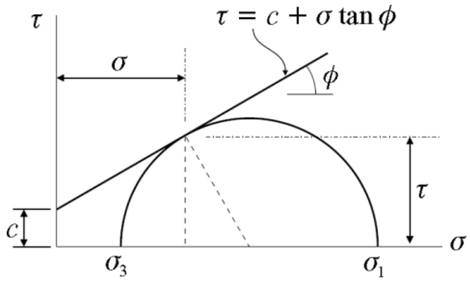


Figure 4-1: The Mohr Coulomb failure criterion, (Davis and Selvadurai, 2002)

The linear envelope in the Mohr diagram is plotted as pyramidal surface in principal stress space as follows:

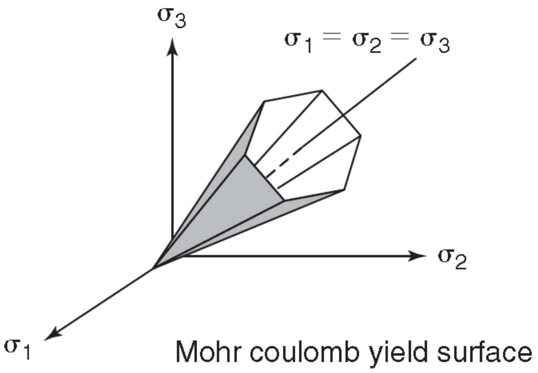


Figure 4-2: The Mohr Coulomb yield surface, (Briaud, 2013)

Even though the Mohr Coulomb does not incorporate plastic potential function and hardening rule, it is advantageous in that it proficiently defines plastic yield of soil with the basic soil parameters. Since one of the challenges in this study is shortage of available geotechnical investigation data of the bearing layers, the methods straightforwardness in defining the failure criterion is beneficial. Mohr Coulomb being one of the plastic behaviors integrated in ABAQUS is chosen, to predict the plastic failure of the geotechnical medium for this study.

4.3 Formulation of finite element solutions

Stress equilibrium and strain compatibility equations must be satisfied for a solution in an elastic medium. Basic steps followed in formulating a finite element solution are discussed below, (Henok, 2009).

The first step in FEM is to divide the structure or solution region into smaller elements of simple geometry connected by nodes. Element type and size directly affect convergence of a solution. Size of the elements is influenced by a number of factors, including how fast the stress changes from one point to another in the region. Types of elements available in ABAQUS for three-dimensional analysis are the hexahedral, tetrahedral and wedge elements.

The following step is identifying a function called an interpolation or shape function that describes variation of the unknown across each element and between its nodes. Primary variable for the geotechnical problems is usually taken to be the displacement. The function defining the displacement variation is assumed to have a simple polynomial form.

Subsequently stiffness matrix and load vector of the element are derived. Most methods used, to derive the element stiffness matrices are based on equilibrium conditions and defined material behavior. The load vector is then derived from the displacement equation and stiffness matrix.

The next step is to assemble global equations from the separate element equilibrium equations. The assembly is done by summing the individual element contributions taking into account the common degrees of freedom between the elements. It is then that the global equations and large system of simultaneous equations are formed where boundary condition are to be applied. The global equation can be written as:

$$[K] * \{u\} = \{p\} \qquad \text{Equation 4.5}$$

Where: $[K]$= Global stiffness matrix derived from individual stiffness matrices

$\{u\}$= Global displacement vector

$\{p\}$= External force vector

For a problem with linear material behavior, nodal displacements can easily be solved using different mathematical techniques, like the Gaussian method. But if a non-linear material behavior is dealt with, the stiffness matrix and external force vector become dependent on the nodal displacement. In such case the global equation will have the form:

$$[K]\{u\} * \{u\} = \{p\}\{u\} \qquad \text{Equation 4.6}$$

The Newton- Raphson and Quasi- Newton are among the different solution methods for solving non-linear equations. Once the nodal displacements are estimated, the strains and stresses will be evaluated using the compatibility and constitutive model equations.

4.4 Model validation

In order to use the ABAQUS software to analyze the situation at hand, first it is numerically validated against other simplified and generally accepted methods. This is done by using a piled raft and loading condition previously analyzed by (Poulos, 2001). The simplified method of Poulos-Davis-Randolph and other four approximate and more regourous analysis methods are used by Poulos to analyze the foundation system shown in Figure 4-3. This model simulated by Omeman (2013) using PLAXIS 2D is also included in the comparison.

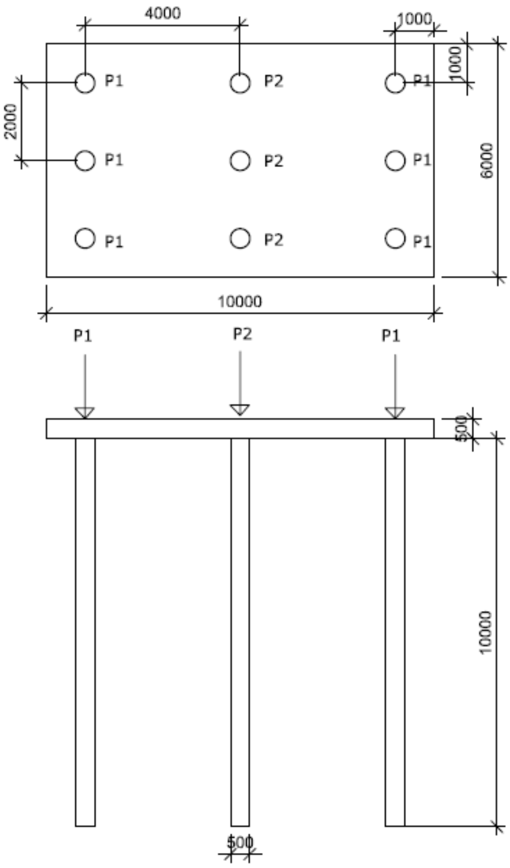


Figure 4-3: Foundation layout analyzed for validation */dimensions are in mm/*

This is similarly modeled in ABAQUS and material properies are adopted accordingly,Table 4-1. Volume of soil directly modeled in the soil is 20m*20m*20m. Even though it is possible to model only a quarter of the model due to its symmetry in plan, the full model is drawn with relatively coarser meshes in order to compare it with a similar quarter model of finer meshes previously done by (Fisseha, 2019) on ABAQUS.

Table 4-1: Material properties for the validation model

	γ [kN/m^3]	E[MN/m^3]	υ[-]
Soil	17	20	0.3
Raft	25	30,000	0.2
Pile	25	30,000	0.2

The six piles around the edge assigned P1 and the middle three piles assigned P2 are subjected to concentrated load of 1MN and in middle three piles in transverse direction were subjected to the concentrated load of 2MN and 1MN respectively, Figure 4-3. Contour of settlement simulated in ABAQUS is shown in Figure 5.13.

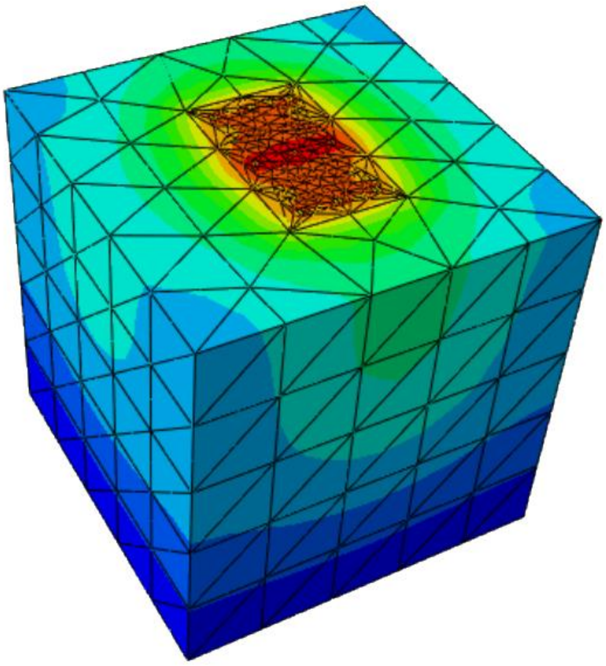


Figure 4-4: Settlement contour of validation model analysis

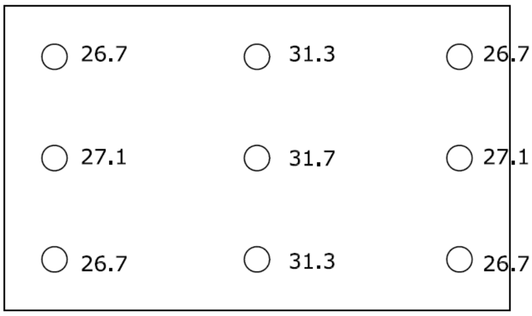


Figure 4-5: Settlements of each pile [mm] from analysis result

Table 4-2: Comparison of settlement among different methods

Method of analysis	P1 piles settlement [mm]	P2 piles settlement [mm]
Poulos-Davis-Randolph	-	36.8
GARP5	26	34.2
GASP	22	33.8
Burland	29.7	33.8
FLAC 2-D	60.5	65.9
FLAC 3-D	35.8	39.9
PLAXIS 2-D	26	32
ABAQUS 3-D (quarter model)	26.4	31
ABAQUS 3-D (full model)	26.8	31.4

Settlements for center and edge piles are compared to settlements obtained by other researchers with different methods, and is found in a close proximity with the approximate computer-based method. Comparison with Fisseha (2019) quarter model of finer mesh modeled with ABAQUS shows very similar results.

4.5 Modeling of contact zone

The contact between concrete and soil plays very important role in load transfer, specially load transferred through skin friction of the piles, indicating that emphasis should be given to the subject. Different methods of representing realistic idealization of the interaction between the structural and geological media, generally handled through the use of contact or interface element is briefly summarized by (Sinha, 2013). Four different approaches of numerically treating the contact elements are stated. One dimensional Winkler’s spring, zero thickness interface element, thin layer interface element and use of master slave surfaces.

In this study the use of very thin continuum elements also known as the ideal contact (Frank et al, 1982) is adopted to model contacts. This method avoids use of any interface element or numerical formulation used for contact representation.

Use of interface element in FEM model will reduce capacity of the pile and increase computational cost (Wang and Sitar, 2004). According to Gebregziabher (2011), practice at the Institute of Geotechnics of TU Darmstadt has showed that the use of ideal contacts for modeling soil- structure interaction, is more suitable for deep foundations with bored piles, due to the roughness of the surfaces of the soil and concrete. The ideal contact was used for numerical analysis studies involving piled rafts, by (Reul, 2004), (Sanctis and Mandolini, 2003, 2006; Gebregziabher, 2011). The very thin continuum element, also called the ideal contact is chosen for this study. The ideal contact will have similar material properties with the soil, both in the pile- soil and raft-soil interaction zone. Deciding on the thickness of the thin element is another factor to be considered. (Sanctis and Mandolini, 2003, 2006) made several attempts to come up with an effective thickness for the thin layer and decided on thickness of 0.1D to be used. This thickness is similarly adopted for soil-structure interactions in this study.

4.6 Modeling in ABAQUS

ABAQUS is a general-purpose FE analysis software first released in 1978. It is named after abacus (ancient mechanical tool used for calculation). It is owned by Simulia Incorporated. Its adaptability for vast fields makes it an incredible tool, contradictorily making it user-unfriendly. In order to model the foundation system and bearing continuum on ABAQUS certain steps are followed. The modeling and analysis process, with challenges faced related to the case are discussed in this subtopic.

4.6.1 Geometric modeling and meshing

The geometry is drawn using the drawing tool in the part module. While modeling, a boundary extent large enough should be adopted to avoid over stiffening the geotechnical medium. However, its size is directly related to computational time, hence a suitable boundary extent, where stress influence becomes insignificant, must be recognized. Sinha (2013) recommends depth extent of $2L_p$ for his study. In this study, the vertical extent is adopted accordingly. A horizontal boundary extent of three times width of the raft is accustomed. Using Sinha’s recommendation, given the large size difference between the studies might be misleading nevertheless, expanding the boundary extent further makes the size of the problem unfeasible.

Since the structure under study incorporates three blocks of different heights that are accessed as one building, the ideal way would be to model the whole foundation system as one unit. One of the main issues faced during modeling on ABAQUS is, the large number of piles found under the G25 block (Figure 4-6) requiring finer meshes, which in turn necessitates a 3D model with very large number of elements and days of running period. In order to limit the running time to a feasible amount and keep it with in achievable capacity for the computer processing system, the G25 block is modeled separately. Taking advantage of ABAQUS analysis of half symmetry and the foundation's geometric symmetry half of the problem's size is modelled. Axis of symmetry for the G25 block is designated with the cross-section A-A in Figure 4-6. As- built of the G25 block and its optimization is analyzed on this model, referred hereafter as model-II.

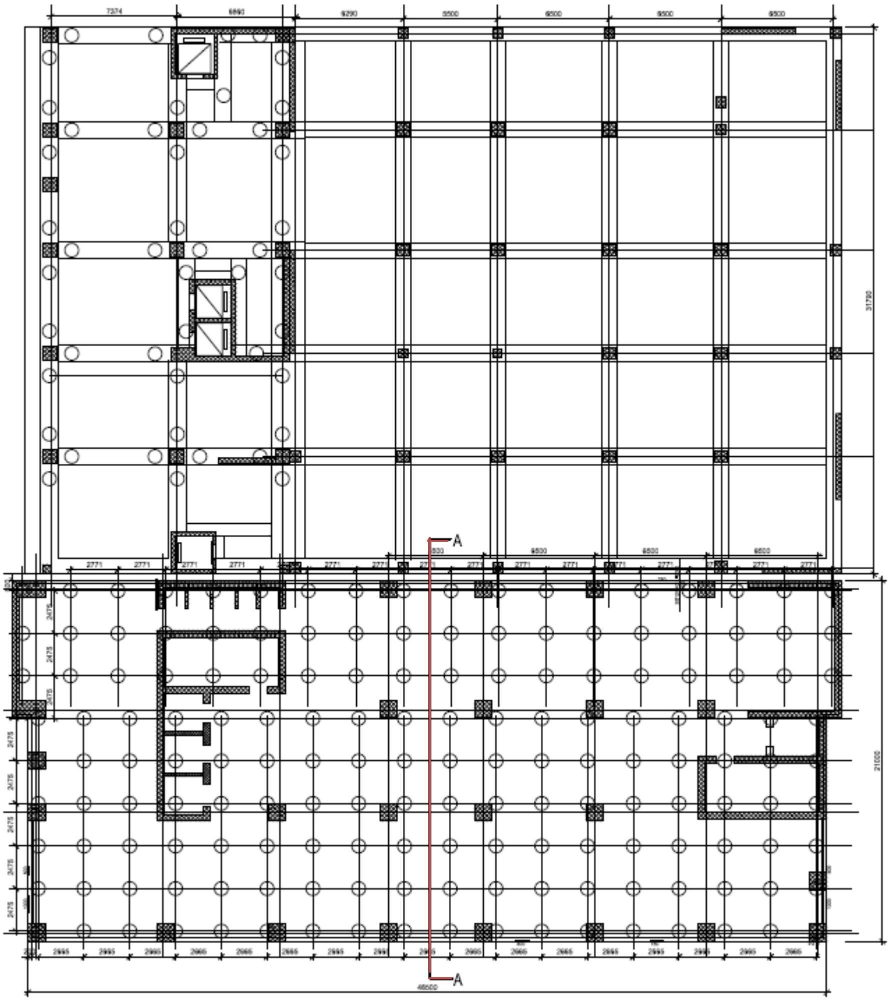


Figure 4-6: Foundation layout of the blocks

Meanwhile behavior of the whole foundation system (G5, G15 & G25) is analyzed on another model, where piles under the G25 block are not incorporated, referred hereafter as model-I. Behavior and thickness of soil under the two models are completely similar.

Actual geometry and size of the rafts and piles, with exact arrangements of piles are directly drawn for study of the as-built condition. Except in model-II, where the G5-15 raft is indirectly assumed to be installed through its weight, since it does not comply to the geometric symmetry needed. The thin layer for contact zones is created by partitioning soil elements around the pile and under the raft, with a thickness of one tenth of the pile diameter and the raft thickness respectively. Thin layer of one tenth the raft thickness is also used to represent contact zone between the pile and raft.

Structural and geotechnical components drawn as separate parts are assigned material parameters with the corresponding behavioral models in the property module. Then the parts are assembled together using the assembly module.

The linear eight nodded hexahedral element type (C3D8R) is used for meshing. This element shape was chosen because it is the first recommendation for structured meshing on ABAQUS. In addition, for a same volume of continuum, hexahedral with its eight nodes rather than four nodal tetrahedral or six nodal wedges would be more accurate and involve least computing costs, (Sinha,2013).

ABAQUS incorporates mesh verifying option in the mesh module, which identifies elements that will cause convergence issues. This option is made use of to decide on the mesh element size. Total number of C3D8R elements in model I is 267,624 with 275,416 nodes. Meanwhile model II has 347,226 elements with 332,742 nodes, which is a collective contribution of 298,334 C3D8R elements and 48892 linear wedge elements of type C3D6. The non-linear finite element analysis took an averaged running time of 8hours and 26hours for model-I and model-II respectively.

4.6.2 Analysis steps

The actual construction process is simulated through step-by-step loading, defined in an analysis using the step module. All defined steps follow the built-in default initial stress step. Boundaries, loadings and model changes assigned using the loading and interaction module are discussed in their respective steps.

4.6.2.1 Initial stress condition

Boundary conditions of the soil mass are assigned in this step or the default initial stress step. All bounding planes are restrained from displacing in their respective orthogonal directions, except the symmetric plane that is restrained from displacing in its orthogonal direction and rotating in its tangential directions. Figure 4-7 shows the XSYMM boundary assigned on one side of the y-z plane.

Predefined field stresses and self-weight of soil mass are also assigned to satisfy internal and external stress equilibrium. The in-situ stress state of the modeled soil, before start of construction process is simulated. Pressure due to the soil above the bearing layer is applied to simulate the overburden pressure at initial stress condition. Raft and pile elements are also removed for this step.

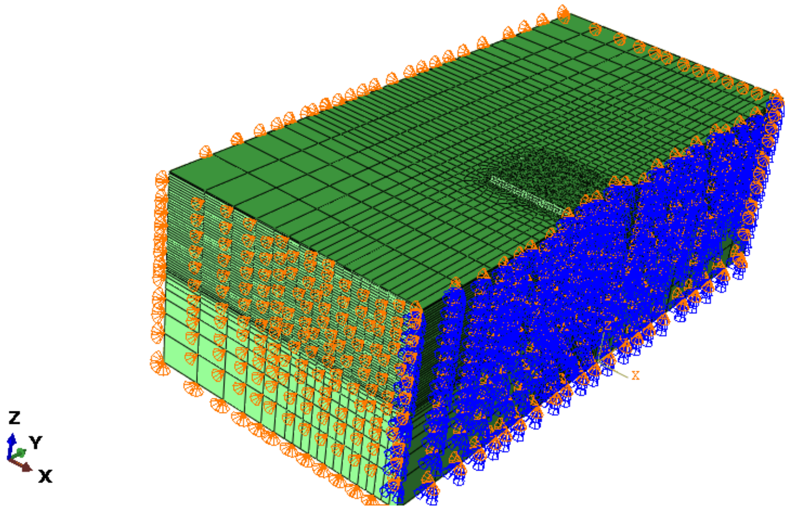


Figure 4-7: Boundary condition assignment in the load module

4.6.2.2 *Excavation*

Excavation is done by removing the overburden pressure assigned earlier, only at the raft area. In this step holes, where the piles are to be placed, are also bored by removing the soil elements.

4.6.2.3 *Pile Installation*

The pile elements removed in the first step are reactivated and are assigned gravity force to simulate the pile installation processes in construction.

4.6.2.4 *Raft installation*

Similar to the pile elements, the raft elements removed earlier are reactivated and are assigned gravity force to simulate the raft installation processes in construction.

4.6.2.5 Loading

This is where vertical external loading is assigned. The unfactored vertical loads collected from the structural engineer are 143,373kN, 152,920kN and 551,712kN for the G5, G15 and G25 blocks respectively.

For model I, the G15 base reactions are applied as point loads for each column and shear wall, on nodes at approximate location, Figure 4-8. Whereas for the G5 and G25, uniformly distributed loads are applied, due to the wide area they cover and the uniform arrangement of piles under the G25 raft. The total loads divided by their respective raft area gives 141kPa and 557kPa for the G5 and G25 raft areas respectively.

While, the as-built G5-15 foundation is analyzed with the proposed G25 foundation, 116kPa is applied on the G25 raft, which is 21% of 557kPa. This percentage accounts for load resisted by the raft in the proposed system, since piles under the G25 block are not directly drawn in model I. The rest of the load ,79% is carried by the piles.

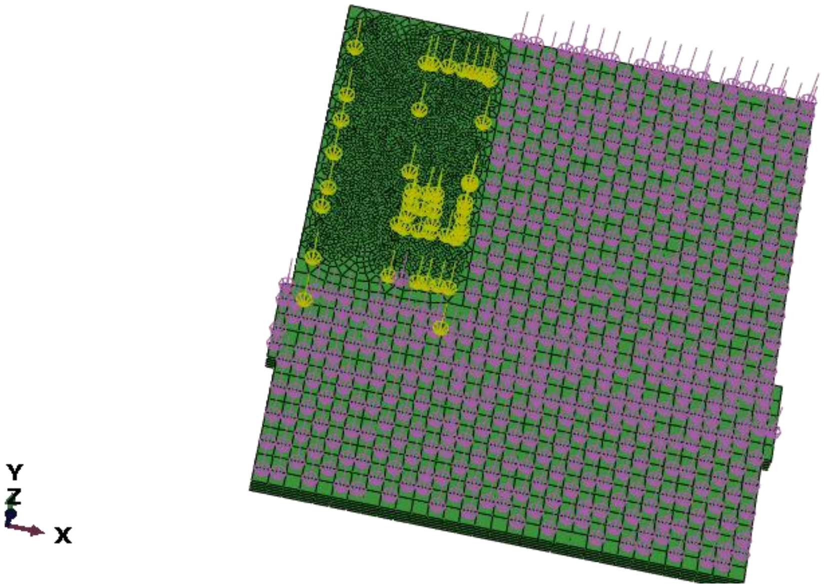


Figure 4-8: External load assigned on raft for model I

For model II, uniformly distributed load of 557kPa is applied on the G25 raft. However, since the G5-15 raft is not directly drawn in this model due geometry asymmetry, pressure of 141kPa is applied on the soil. This pressure is approximately equal to resistance contribution the G15 raft and the exact structural pressure exerted by the G5 block. The need for this approximation was essential, since there was no other way around the problem.

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Introduction

Among the factors that affect behavior of piled raft foundation, the ones considered for optimization are somehow limited since this is a case study and most factors are non-variable. Load magnitude and soil stiffness variation could not be considered, hence are constant through-out the analysis. Effect of geometric parameters of the foundation, which are pile length, pile number and arrangement are variables under study.

Influence of pile diameter is insignificant on the average and differential settlement (Prakoso et al, 2001). Due to this reason, in addition to complications that arise during modeling, effect of pile diameter is also not considered. Raft thickness variation is also deemed unnecessary. Increasing the raft thickness, given the wide raft area would be uneconomical. (Maharaj and Gandhi, 2004) observed that, for a uniformly loaded raft, decreasing raft thickness contributes to higher differential settlement. Due to this reason, and structural design thickness requirement to transfer the column loads to the pile, decreasing the raft thickness is not recommended.

Besides the as-built condition for the G5-15 foundation system and raft-only foundation for the whole system, eight other variants have been considered as described in Table 5-1. L stands for original length of pile, used as reference length. Detailed description about the variants is given in their respective subtopics.

Table 5-1: Description of variants considered for analysis

Spacing / Number of piles	Length of piles			
Original spacing/ 162	L	0.8L	0.6L	0.4L
Doubled spacing/ 50	L	0.8L	0.6L	0.4L

FEM analysis done on model-I covers as-built behavior of the foundation under the G5 & G15 block. Behavior of raft-only condition is also considered for the whole foundation unit, in this analysis. Meanwhile, analysis on model-II involves only the G25 block.

First the foundation system is analyzed as-built and then analysis is run to come up with a more efficient design of piled raft foundation. Results of model-I and model-II are discussed in the next subtopics respectively.

According to (ES-EN, 1997:2015), it is usually the differential settlement that causes damage to structures, rather than total settlement. For most of the ordinary structures, such as office buildings differential settlement may be permissible such that the angular distortion of the frame of the building does not exceed 1:500. This angle of distortion (tilt) is defined as the ratio of the differential settlement to the distance between locations of maximum and minimum settlement. Serviceability requirement of the foundation is checked against this limit.

5.2 Results of model-I

5.2.1 Raft-only condition

Before going through optimization of the piled raft design, it is checked if un-piled raft can safely support the whole structure. This raft-only condition is analyzed using a raft thickness of 2m for both rafts. Figure 5-1 shows settlement contours of both rafts for the raft-only case.

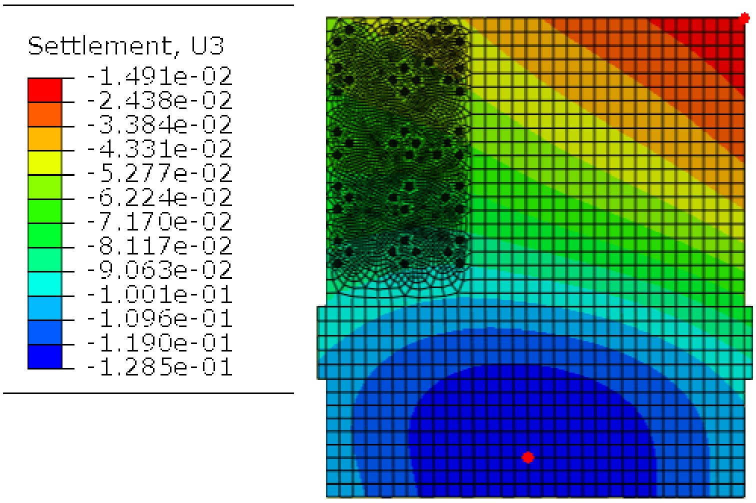


Figure 5-1: Contour of settlement with location of maximum and minimum settlement for raft-only condition

Maximum and minimum settlement of the raft are located around the middle of the G25 raft and corner of the G5-15 raft respectively, Figure 5-1, due to the highest and lowest loaded area of raft.

Table 5-2: Summary of results for the raft-only foundation analysis

S_{max} [mm]	S_{min} [mm]	ΔS [mm]	Tilt [-]
128.5	14.9	113.6	1:476

Maximum and minimum settlement of raft are 128.5mm and 14.9mm respectively. Differential settlement is 88% of the total settlement and the tilt is above the limited angular distortion for a regular building, [Table 5-2]. It is therefore concluded that it is not safe to use raft-only foundation for the building.

5.2.2 As-built condition

As-built condition of G5-15 foundation system, with the proposed G25 foundation is analyzed in this model. Main focus of study on this model is behavior of the built piled raft foundation under the G-15 block, which covers relatively smaller area than the other two blocks.

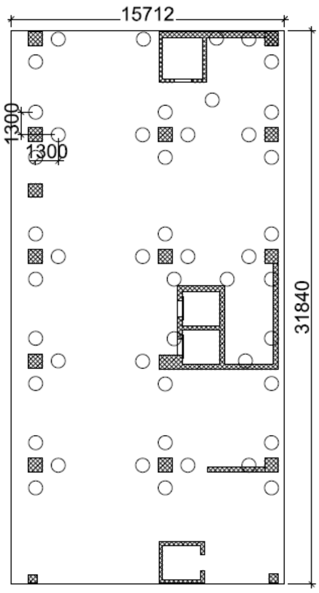


Figure 5-2: Pile arrangement of the G15 block

Piles are placed around areas of load concentration, i.e. around columns and shear walls, [Figure 5-2]. 47 piles of length 17m and diameter 0.8m are installed under the 2m thick raft. Pile tips rest on the third layer.

Table 5-3: Summary of results for the G15 piled raft foundation analysis

S_{max} [mm]	S_{min} [mm]	ΔS [mm]	Tilt [-]	α_{pr} [-]
38.5	16.5	22.0	1:1470	0.54

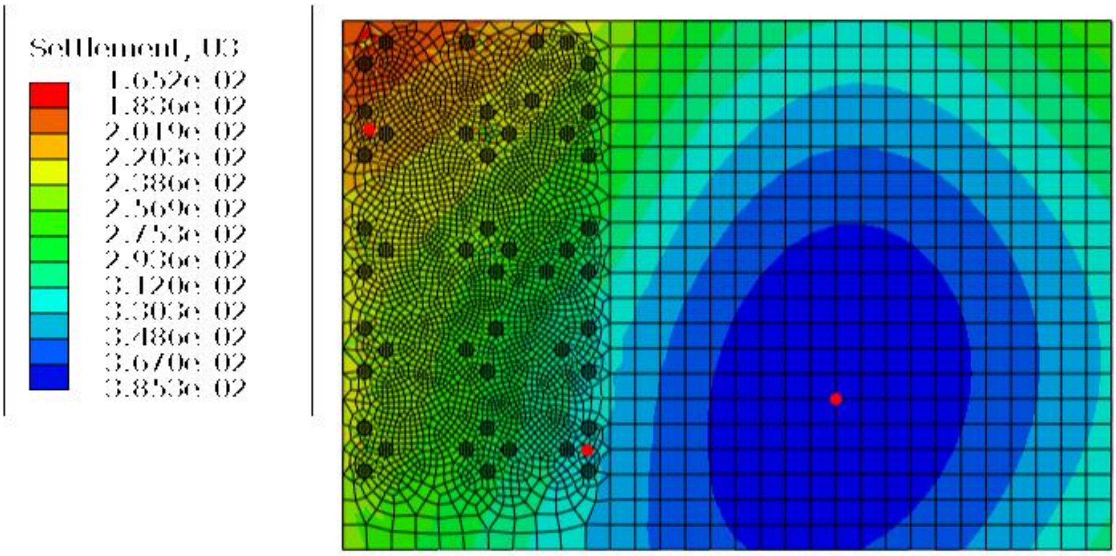


Figure 5-3: Contour of settlement with location of maximum and minimum settlement for G5-15 raft

Locations of maximum and minimum settlement are shown using red dots, in the settlement contour, [**Error! Reference source not found.**]. Maximum and minimum settlement of raft are 38.5mm and 16.5mm respectively. Maximum settlement on the G15 loaded area is 37.4mm. An overall maximum raft settlement of 38.5mm is observed around the middle of the G5 loaded area. Location of minimum settlement is around the corner of the raft on the G15 loaded area. Differential settlement for the raft is 22.0mm. Tilt of the raft is below the specified value, which is 1:500. The piles carry 54% of the total load subjected by the G15 structure load. The raft shares a significant amount of the total load. Design of the G5-15 foundation is very safe, it is judged to have room for optimization.

5.3 Results of model-II

5.3.1 As-built condition

As-built condition of the G25 block has 162 piles of length 25.4m with tips of piles embedded a meter in to the hard basalt layer. Diameter of the piles (D) and thickness of the raft are 0.8m and 2m respectively. Piles are arranged uniformly in the Y-direction with center to center pile spacing of 2.475m, 3.1D). Meanwhile in the X-direction center to center spacing of 2.665m and 2.711m, which are 3.3D and 3.5D are used.

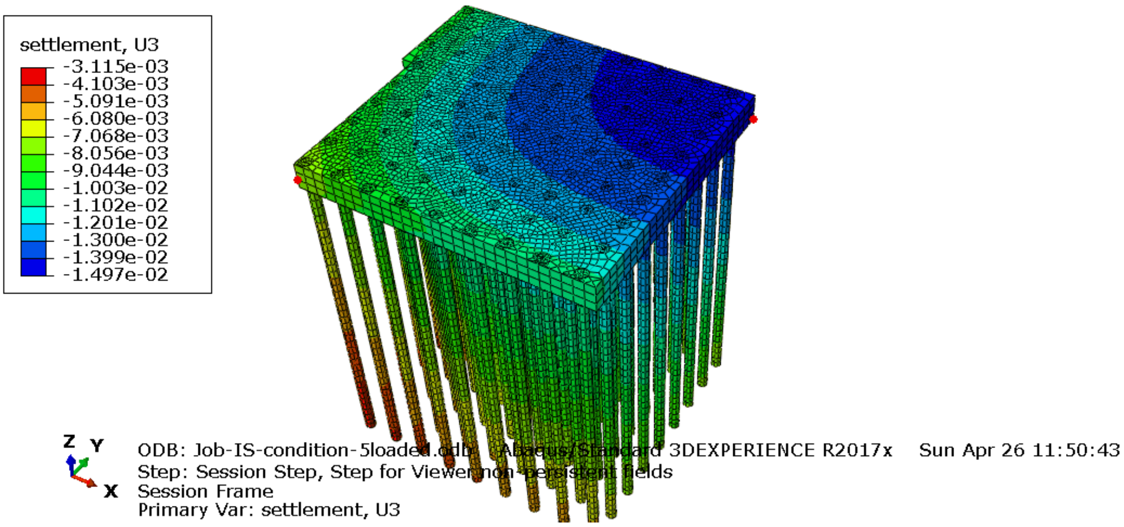


Figure 5-4: Settlement of G25 raft and pile for As-built condition

As mentioned in the previous chapter, half of the foundation unit is modeled, as seen in [Figure 5-4], taking advantage of its geometric symmetry along the x-axis. As discussed in the first chapter, the settlement of piled foundations is found to be insignificant. Results of analysis for the as-built condition of the G25 piled foundation verify this notion.

Maximum and minimum settlement of the raft are 14.98mm and 7.00mm respectively. Given that pile tips rest on basalt layer, source of settlement could be axial compression of the piles. The piles carry 94% of the total load (α_{pr}=0.94). Raft resistance that could have been exhausted, is almost completely neglected. Foundation tilt is 1:4000. Locations of the minimum and maximum settlements are at the corner of the raft and at midway of border line to the other blocks respectively, as the red dots in Figure 5-4 show.

5.3.2 Optimization

5.3.2.1 Length of piles

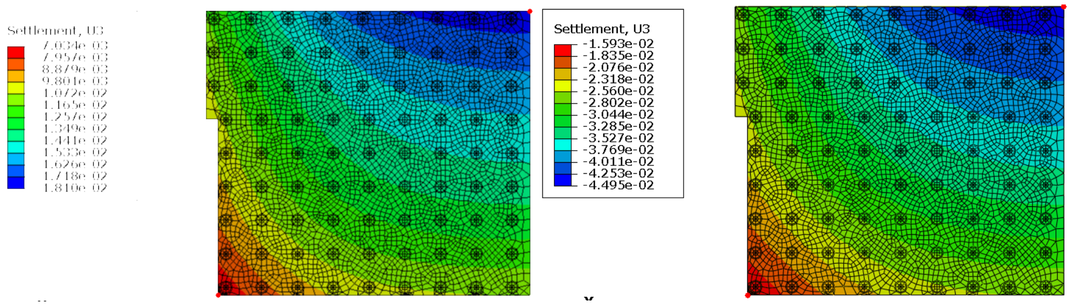
Results of the analysis for varying pile length are discussed here, keeping every other parameter constant. Three different pile lengths; 0.4L, 0.6L and 0.8L are considered, L being the original pile length used as a reference length. Tips of piles rest in the 2nd and 3rd layer for the shortest pile length and other two lengths respectively. Raft minimum and maximum settlements and pile raft coefficient of each analysis is presented in Table 5-4.

Table 5-4: Summary of effects pile length on Settlement and α_{pr}

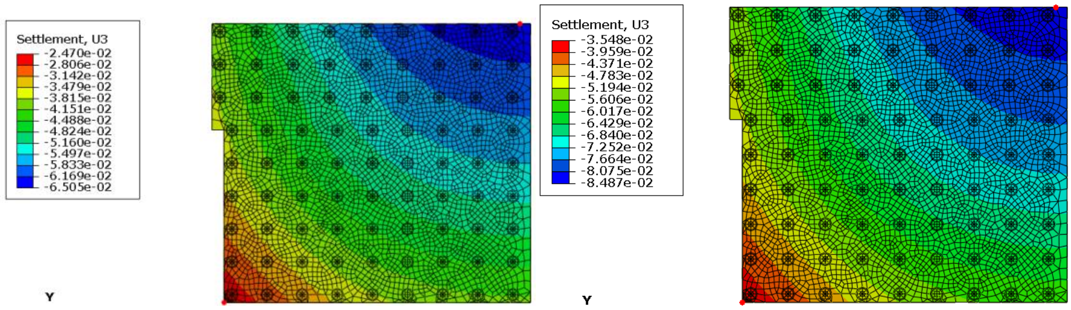
L_p [mm]	L_p/L	S_{max} [mm]	S_{min} [mm]	ΔS [mm]	Tilt [-]	α_{pr} [-]
25.4	1.0	15.0	7.0	8.0	1:4000	0.94
20.4	0.8	44.9	15.9	29.0	1:1075	0.94
15.1	0.6	65.1	24.7	40.4	1:775	0.92
10.4	0.4	84.9	35.5	49.4	1:633	0.90

Large increment in settlement of raft is observed with reducing length of pile. Sommer et al, (1985) observed that settlements become smaller with increasing pile length. The largest increase in settlement is observed in the reduction of pile length from L to 0.8L. An increase of 200% in S_{max} is observed in this pile reduction range. This is due to around 93% difference in soil stiffness, between layer 3 and layer 4, where piles tips of the 0.8L and L lengths rest, respectively. The increase in settlement for decreasing pile length is not only because of the decreasing shaft length resistance. As piles get shorter, pile tips rest on a relatively less stiff soil layer. And this change in soil stiffness is not only due to increasing overburden pressure through depth but also because the soil formation is multilayered, the soil type variation also contributes to the change in soil stiffness.

On the contrary, the effect of pile length on the pile raft coefficient (α_{pr}) is observed to be very small. For 60% of pile length reduction, only 4% reduction in α_{pr} is achieved. Owing to this observation, it can be concluded that effect of pile length on the pile- raft load sharing, with pile spacing of 3D, is nominal.



a) L_p=L b) L_p=0.8L



c) L_p=0.6L d) L_p=0.4L

Figure 5-5: Contours of settlements for varying pile length with 3D spacing

Contour of settlements, in addition to locations of maximum and minimum settlement are identical for the varying length of piles, except for the varying magnitudes in settlements. This can be clearly observed in Figure 5-5. Locations of maximum settlement are pulled to the edge shared with the other rafts, because they are simultaneously loaded.

5.3.2.2 *Number and arrangement of piles*

For an optimum design of piled rafts, pile spacing less than 7D, with the ideal range being 3D-6D is recommended (Sinha,2013). Arrangement of piles is varied by doubling the original spacing between piles. The original pile spacings of, 2.475m in the Y-direction and 2.665m and 2.711m in the X-direction, are all doubled to give center to center pile spacing of 6.2D, 6.6D and 7D respectively, with the exception of the piles along the symmetry axis.

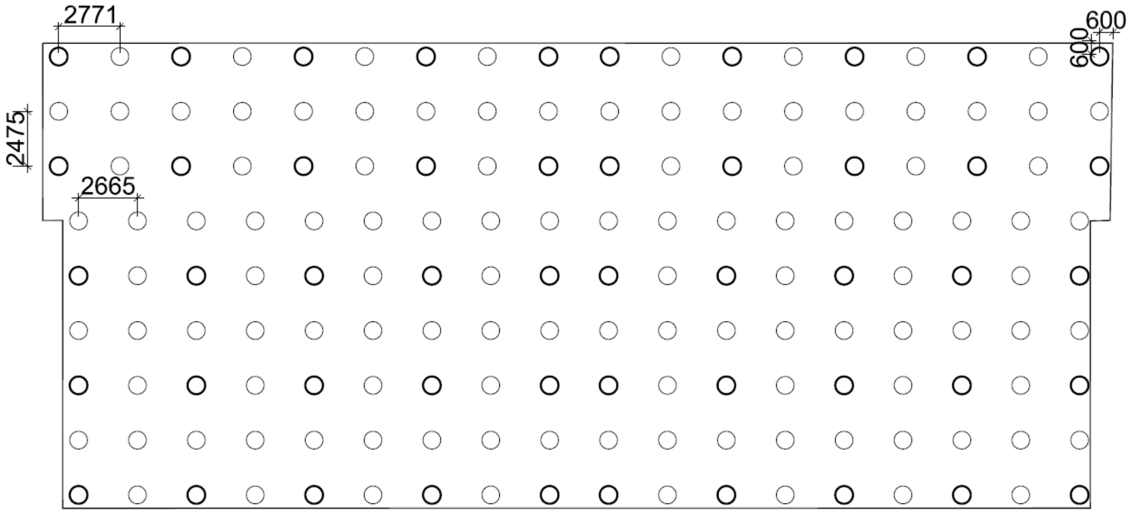


Figure 5-6: Original and altered arrangement of piles *(dimensions are in mm)*

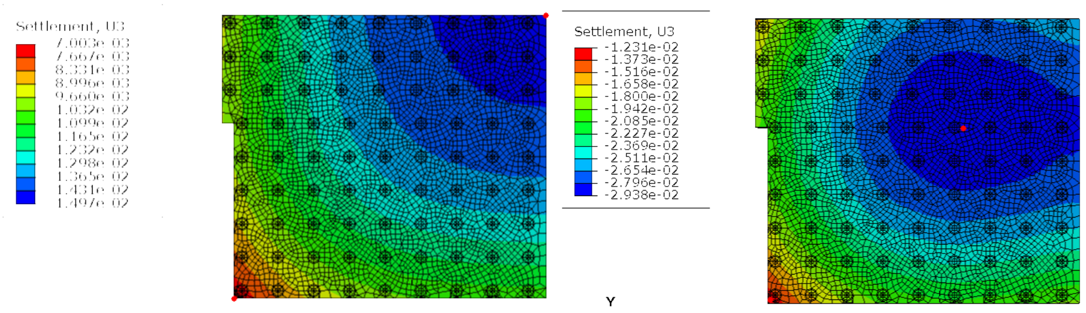
This arrangement in Figure 5-6, is chosen to keep the distance of raft edge from the edge piles minimized. In order to lessen the magnitude of settlements of a raft under uniformly distributed load, it is suggested to arrange piles in such a way that the edge distance is minimized, preferably less than half the pile spacing (Gebregziabher, 2011)

The original pile spacings and altered pile spacings are referred hereafter as e and 2e respectively. Original arrangement of piles includes all of the circles, while the altered arrangement includes only the bold circles, as presented in Figure 5-6. Pile spacing and number of piles, over a constant area are supplementary factors. For the doubled pile spacing, the original number of piles which is 162 is reduced to 50.

Table 5-5 Effect of doubling pile spacing on Settlement and α_{pr}

Spacing	L_p [mm]	S_{max} [mm]	S_{min} [mm]	ΔS [mm]	Tilt [-]	α_{pr} [-]
e	25.4	15.0	7.0	8.0	1:4000	0.94
2e	25.4	29.4	12.3	17.1	1:1150	0.88

Summarized results for the original and 69% decrease in number of piles are presented in Table 5-5. Maximum settlement is almost doubled and the raft shares 6% more of the total load. Even with the doubled maximum settlement an excessive safety margin is kept and the raft's resistance is still under-utilized, because tips of the piles are resting on a hard basalt. In order to achieve a more efficient design, length of piles is varied keeping the new arrangement and number of piles.



a)Spacing- e, L_p=25.4, n=162 b)Spacing- 2e, L_p=25.4, n=50

Figure 5-7: Comparison of contours of settlements and location of maximum and minimum settlement for different pile spacings

Location of minimum settlement for the two different arrangements is similar while location of the maximum settlement differs, [Figure 5-7]. Spacing of piles in the x-direction along the symmetry line is not doubled and piles are resting on hard stratum. For that reason, middle area of the raft seems to have gained more flexural stiffness, shifting maximum settlement location away from the symmetry edge.

5.3.2.3 Variation of length of piles with the new arrangement of piles

Keeping the altered number and arrangement of piles, length of piles is reduced in a manner similar to the one discussed in sub section 5.3.2.1. results are summarized in Table 5-6.

Table 5-6: Summary of effects pile length on Settlement and α_{pr}

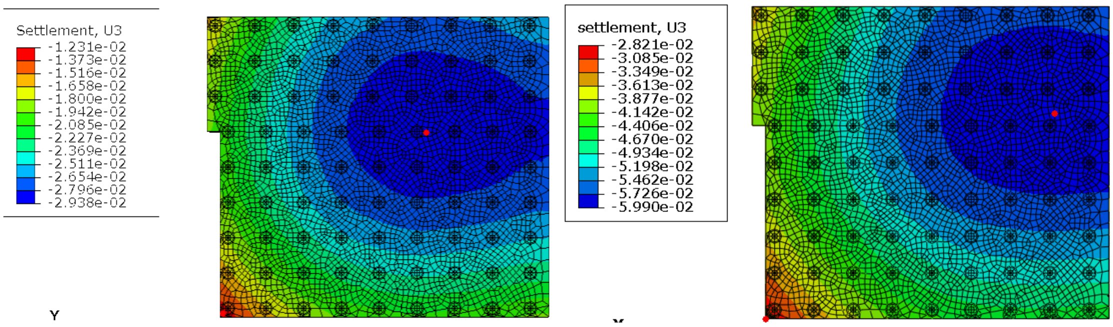
L_p [mm]	L_p/L	S_{max} [mm]	S_{min} [mm]	ΔS [mm]	Tilt [-]	α_{pr} [-]
25.4	1.0	29.4	12.3	17.1	1:1150	0.88
20.4	0.8	59.9	28.2	31.7	1:750	0.79
15.1	0.6	86.8	37.1	49.7	1:585	0.73
10.4	0.4	98.6	52.2	46.5	1:600	0.59

For the new pile arrangement, significant increment both in settlement and load sharing of raft is observed as the length of the pile is reduced. The largest increase in settlement is observed from the reduction of pile length from L to 0.8L, this is because of the large variation of soil stiffness, briefly discussed in the earlier set of pile length variation. Effect of pile length on the pile raft coefficient (α_{pr}) is observed to substantial, unlike the case of original spacing (e). For 60% of pile length reduction, 30% reduction in α_{pr} is achieved.

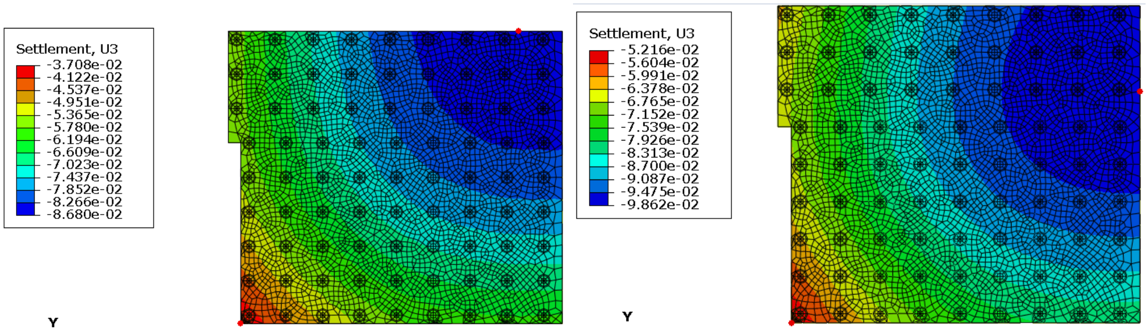
Even with a decrease of, 60% in length of piles and 69% in number of piles the raft tilt is in good margin with the suggested value for serviceability. Nevertheless, 10.4m cannot be taken as the length for the optimized design because differential settlement between the two rafts must be considered. Minimum settlement for the G5-15 raft is 17mm. Therefore, in order to reduce the differential settlement and tilt between the two rafts to the permissible limit, pile length of 20.4m is chosen. The 50 piles for the doubled pile spacing with a length of 20.4m is a more efficient pile number, arrangement and length for the given raft size and loading. Settlement and tilt for the whole foundation system with the proposed parameter for the G25 block piled raft is presented in Table 5-7.

Table 5-7: Settlement and tilt for the whole foundation system with the proposed parameters

S_{max} [mm]	S_{min} [mm]	ΔS [mm]	Tilt [-]
59.9	16.5	43.4	1:1000



a) L_p=L b) L_p=0.8L



c) L_p=0.6L d) L_p=0.4L

Figure 5-8: Comparison of contours of raft settlements with positions of maximum and minimum settlement for varying pile length with doubled spacing

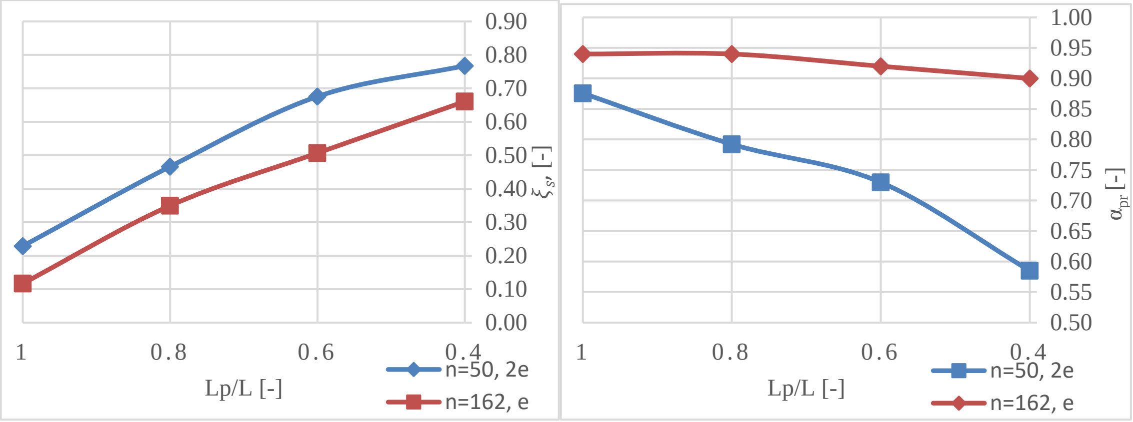
Contour of settlements, in addition to locations of maximum and minimum settlement are presented in Figure 5-8. Locations of minimum settlement vary for all variants. Owing to the reason that, spacing of piles in the x-direction along the symmetry line is not doubled and piles are resting on relatively stiffer stratum, middle area of the raft seems to have gained more flexural stiffness shifting maximum settlement location away from the symmetry edge, [Figure 5-8 a and b]. For the other two variants locations are changed to middle of shared edge and center of the raft, [Figure 5-8 c and d]. From the settlement contours it can be observed that pile length alone, with constant spacing of piles affects the position of maximum settlement. This change of position was not observed in the case of the 3D spacing.

5.3.3 Observations among all eight variants

It is common to normalize other settlements to the raft-only settlement, in order to make comparisons easier. The maximum settlement reduction factor, ξs, is introduced as:

$$\xi s = \frac{Smax}{Smax(raft)} \qquad \text{Equation 5.1}$$

Hereafter, maximum settlements are expressed in terms of the settlement reduction factor.



a) ξs b) α_{pr}

Figure 5-9: (a) Increase in ξs and (b) Decrease in α_{pr} with decreasing pile length for different number of piles and arrangement

Increase of similar manner in maximum settlement of raft with decreasing pile length is observed for the two different number of piles, [Figure 5-9, a], indicating that maximum settlement of the raft, increases with decreasing length of piles, independent of number of piles and spacing.

Unlike the settlement, effect of pile length on the pile raft coefficient (α_{pr}) is different for the two arrangements, [Figure 5-9, b]. In order to increase load sharing of the raft, increasing pile spacing plays a higher role than decreasing pile length. For 60% of pile length reduction, 30% reduction in α_{pr} is achieved in the case of the doubled spacing. Meanwhile, only 4% reduction in α_{pr} is achieved in the case of the original spacing.

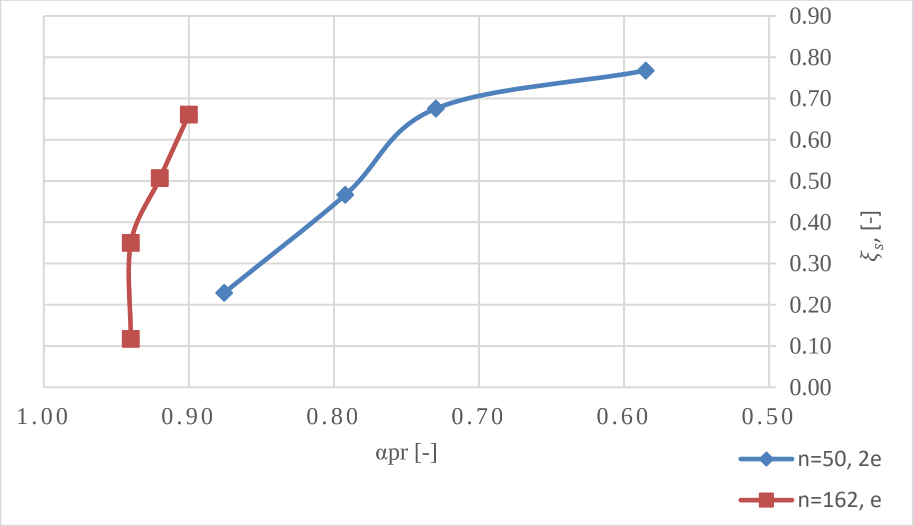


Figure 5-10: Relation between ξs and α_{pr} for different number of piles and arrangement

It is observed that settlement reduction factor and pile raft ratio have different relations for the e and 2e cases. Omeman, (2013)'s observation that the load carried by the raft increases significantly when the settlement of the raft increases is proved otherwise for piled rafts with closely spaced piles. This is because the original pile spacing, e, has number of piles too large making the raft very rigid and whole foundation system settles as a whole block rather than allowing differential settlement of the raft and raft load sharing.

5.4 Cost comparison for the original and proposed parameters

A 69% decrease in number of piles from 162 to 50 and 20% decrease in length of piles from 25.4m to 20.4m is achieved by taking resistance of the raft in to account. This is equivalent to 3094.8m decrease in total length of piles. A cost comparison was performed for the original and newly proposed foundation scheme. Detailed cost estimation can be referred in appendix C.

The cost computation was done excluding the reinforcement of the pile and the raft with the assumption that the reinforcement design for the two systems remains unchanged. To this effect, the material and labor cost of the original system calculated to be 32,130,000Br was reduced to 7,823,000Br utilizing the new pile arrangement, indicating a 75.6% reduction. Even though this figure is subject to reduce with the consideration of the reinforcement design, the economic advantage of considering the high resistance contribution of the raft in piled raft is undeniable.

CHAPTER 6 SUMMARY AND RECCOMENDATION

6.1 Summary

Study of the complex piled raft foundation behavior, is an important contribution to the engineering field because of its noticeable economic advantages. This paper is a case study on ORDA project of Addis Ababa. Implemented foundation design for all three blocks of varying height is assessed, using the three-dimensional finite element software ABAQUS. The effect of each block on the other is also considered for the analysis. The highest block (4B+G+25), rests on 162 Piles extended to the hard basalt layer. These piles are reduced in length and number to achieve a safe but cheaper solution. Cost for the original and more efficient design parameters is compared. Raft- only foundation was also considered to support the whole structure, but differential settlement is beyond the recommended limit. Results of the study are listed out as follows:

- Assessment of the long piles extended to the basalt layer that supports the highest block, showed the expected result that, conventional piles have very small settlements and contribution of the raft resistance is nominal.
- It is first checked if use of deep foundation for the structure was even essential, by trying the raft-only condition for the whole foundation system. Results showed that this option is not recommended because, settlements exceed limit set for safety of a building.
- The piled raft behavior study is for the foundation supporting the G25 block. The G5-15 foundation as- built system is unaltered and its performance, with the proposed G25 piled raft foundation is found to be adequately safe. The piled raft under the G15 block also has some room for improvement.

- Settlement and load sharing between the pile and raft is studied for different pile length, number and arrangement. Large increment in settlement of raft, is observed with reducing length of pile. Stiffness of soil where tip of the pile rest, also has influence on the raft settlement. On the other hand, effect of pile length on the pile-raft load sharing becomes less significant when the pile spacing is reduced.

- Doubling the pile spacing, equivalent to decreasing number of piles by 69%, doubled the maximum settlement of the raft. Nevertheless, only 6% more of the total load is shared by the raft. This is because tips of the piles are resting on a hard basalt. In order to achieve a more efficient design, length of piles is varied keeping the new arrangement and number of piles.
- For the doubled spacing, significant increment both in settlement and load sharing of raft is observed as length of pile is reduced. Maximum settlement of raft, increases with decreasing length of piles, independent of number of piles and spacing. Length of pile also affects the position of maximum settlement on the raft, which was not the case for the 3D spacing.

- In order to increase load sharing of the raft, increasing pile spacing plays a higher role than decreasing pile length. (Omeman, 2013)'s observation that the load carried by the raft increases significantly, when the settlement of the raft increases is proved otherwise for piled rafts with closely spaced piles.

- Safety of the whole foundation system is checked and doubled pile spacing with 20% decrease in length, is taken as a more efficient pile arrangement and length for the given raft size and uniform loading condition. Cost estimate for the original and proposed number and arrangement of piles with the assumption that the reinforcement design for the two systems remains unchanged, indicates a 75.6% cost reduction. This particular project can be one case of the conservative foundation design practice in Addis Ababa.

6.2 Recommendation

- Results in FEM analysis are as good as reliability of the input parameters. One of the challenges faced during this study was, absence of important soil parameters in the soil investigation report. Geotechnical investigations for large projects, if not all, should be done with extreme care. Pile load tests, loaded to near-ultimate load capacity of pile is also very important to determine soil parameters of the site.
- Given the obvious economic benefit of using piled raft foundation, study of their behavior is recently being focused on for application in our country. The prior recommendation being development of guidelines for design of piled rafts for Ethiopia, using the rigorous methods of analysis for large projects is found to be a more economical solution than using the conventional piles.
- This case study incorporating three blocks of different heights, raised a realization that neighboring buildings nowadays being built with in very close distance, are highly affected by each other. Study of influence of closely placed neighboring structures is recommended for future researches.

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APPENDIX A- BOREHOLE LOGS OF THE PROJECT SITE AS REPORTED IN THE GEOTECHNICAL INVESTIGATION REPORT

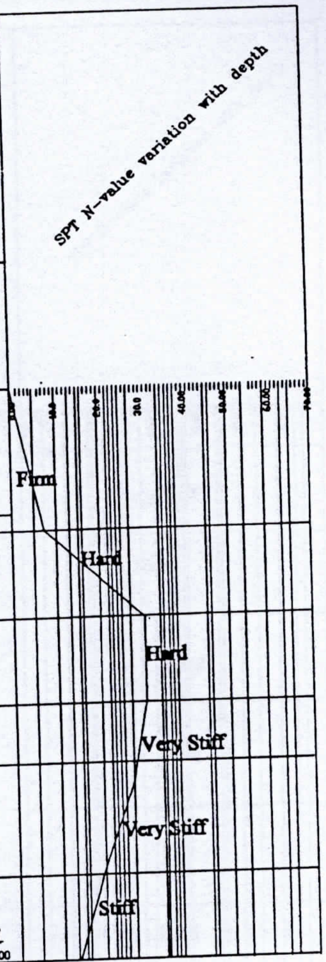
GEOTECHNCAL ENGINEERING SERVICE	BH ID No: 1

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 4014.0610
Northing (Y): 8029.1270
(Z): 198.2810

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 19/10/2016
Date completed: 23/10/2016
Total depth drilled(m): 50

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
0.00–1.50	75									Fill material with greyish hard slightly weatherd rock (tuff)	3.00	
1.50–3.00	86											
3.00–3.45							3.00 2/2/5	3.00 Ö 3.45				
3.45–5.05	100									Brown very stiff to hard, low to medium plasticity clay/silt	5.50	
5.05–5.30							5.05 18/23/12 refu. no recov.	5.05 Ö 5.50				
5.30–7.00	100									Reddish very stiff to hard, medium plasticity clay/silt	7.45	
7.00–7.45							7.00 9/13/26	7.00 Ö 7.45				
7.45–8.85	100									Ditto	8.85	
8.85–9.30							8.85 6/10/17	8.85 Ö 9.30		Light grey brown highly decomposed rock (tuff) with very stiff, medium plasticity clay/silt	11.50	
9.30–11.05	91											
11.05–11.50							11.05 4/7/12	11.05 Ö 11.50				
11.50–13.00	86									Ditto		▽ 13.00
13.00–13.45							13.00 3/5/8	13.00 Ö 13.45				
13.45–14.75	100											

CONT._BOREHOLE LOG



Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ö Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

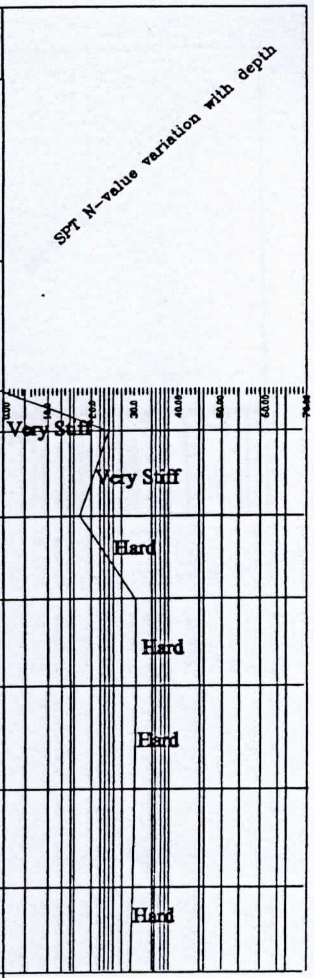
GEOTECHCNCAL ENGINEERING SERVICE

Con't...BH ID No: 1

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 4014.0610
Northing (Y): 8029.1270
(Z): 196.2810

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 19/10/2016
Date completed: 23/10/2016
Total depth drilled(m): 50

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
15.55 16.00							15.55 5/9/15	14.95 15.55 Ŏ		16.00		
17.50 17.95	100						17.50 4/7/18	16.00 17.50 Ŏ		Brown very stiff low to medium plasticity clay/silt 17.95		
19.45 19.90	100						19.45 11/16/25	17.95 19.45 Ŏ		Light grey brown very weak, moderatly decomposed rock (tuff)		
21.40 21.85	66						21.40 12/24/4 [illegible]	19.90 21.40 Ŏ				
23.05	83							21.85		23.05		
24.55	66											
26.05	46						26.05	26.05		Ditto 26.05		
26.50							6/10/27	Ŏ 26.50		Reddish hard, low to medium plasticty clay/silt 26.50		
28.00 28.45	100						28.00 [illegible]	28.00 Ŏ 28.45		Brown moderatly decomposed rock (tuff) with clay/ silt 28.45		
29.95	90									Ditto		



CONT___BOREHOLE LOG

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ŏ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

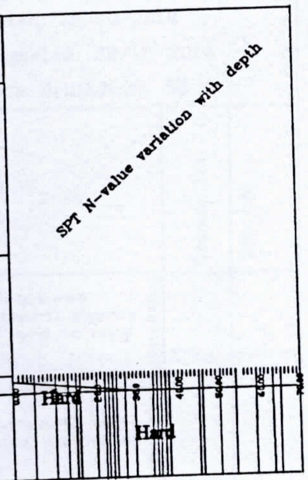
Ethiopian Construction Design & Supervision Works Corporation

GEOTECHNCAL ENGINEERING SERVICE	Con't...BH ID No: 1

Project: Geotechnical Inv. of B4+G+6,B4+G+15,B4+G+26 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 4014.0610
Northing (Y): 8029.1270
(Z): 198.2810

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 19/10/2016
Date completed: 23/10/2016
Total depth drilled(m): 50

Depth	Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
30.00	30.40							29.95 6/15/19	29.95 Ö 30.40				
31.00	32.05	93									Brown hard medium plasticity clay highly decomposed rock (tuff) 30.40–32.50		
32.00	32.50							32.05 7/12/18	32.05 Ö 32.50				
33.00	34.00	93									Brown silty/ clay with highly decomposed rock(tuff) 32.50–35.00		
34.00	35.15	100											
35.00–36.00	36.65	100									Light grey, moderatly fractured 9-23cm apparent spacing, slightly open,clean,slightly rough, slightly weatherd, partly healed, moderately hard to hard basalt 35.00–38.15		
37.00	38.15	100	24						▮				
38.00–39.00	39.65	100	36						▮		Light grey, moderatly fractured (9-38cm apparent spacing, slightly open,clean,slightly rough, vertical fracturat (39.32-39.65m slightly open clean,40.85-41.00m, slightly open, fill with calcite slightly weatherd, partly healed, moderately hard to hard basalt 38.15–41.15		
40.00	41.15	100	20						▮				
41.00–42.00	42.65	100	26						▮		Light grey, moderatly fractured (15cm apparent spacing, slightly open,clean,slightly rough, vertical fractur at (41.42-41.72m slightly open clean,fill with calcite slightly weatherd, partly healed, moderately hard to hard basalt 41.15–44.15		
43.00–44.00	44.15	100	43						▮				
45.00													



CONT.__BOREHOLE LOG

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ö Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

GEOTECHNCAL ENGINEERING SERVICE	Con't...BH ID No: 1

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 4014.0610
Northing (Y): 8029.1270
(Z): 198.2810

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 19/10/2016
Date completed: 23/10/2016
Total depth drilled(m): 50

Depth	Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
45.00	45.40												
46.00		100									Light grey, intensely to moderatly fractured (fracture spacing, cavities fill with chert) slightly weatherd, partly healed, moderately hard to hard basalt 47.05		
47.00	47.05	100									Light grey, moderatly fractured, cavities fill with calcite slightly weatherd, partly healed, moderately hard to hard basalt		
48.00	48.65												
49.00		100							■		50.00		
50.00											END OF BOREHOLE LOG AT 50.00M		

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ծ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

Construction Design ... Supervision Works Corporation

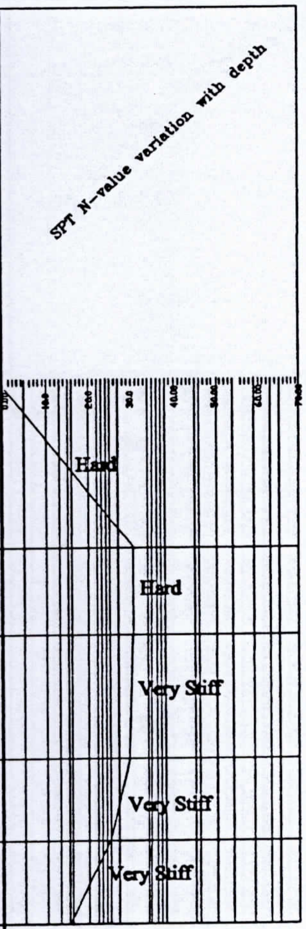
GEOTECHNCAL ENGINEERING SERVICE

BH ID No: 2

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3993.1940
Northing (Y): 8027.5200
(Z): 198.4250

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 25/10/2016
Date completed: 28/10/2016
Total depth drilled(m): 50

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
1.50	40									Fill material with brown very stiff clay/silt		
3.00	86							3.00		3.00		
3.60							3.60 7/15/18	3.60				
4.05								4.05		Brown hard, low to medium placticity clay/silt		∇ 4.60
5.65	100						5.65 7/14/18	5.65				
6.10								6.10		6.10		
8.00	68							8.00		Reddish hard low to medium placticity clay/silt		
8.60							8.60 7/12/17	8.60				
9.05								9.05		9.40		
10.55	100						10.55 5/10/13	10.55		Reddish to brown hard low to medium placticity clay/silt		
11.00								11.00		11.00		
12.50	76						12.50 5/8/18	12.50		Ditto		
12.95								12.95		12.95		
	60									Light grey brown very weak, moderatly deconposed rock (tuff) with silt/clay		


SPT N-value variation with depth

CONT.__BOREHOLE LOG

Consultant: ____________
Suboontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ö Disturbed sample
▯ Undisturbed sample
▮ Rock sample
∇ Static groundwater level

REMARK: ____________

Ethiopian Construction Design & Supervision Works Corporation

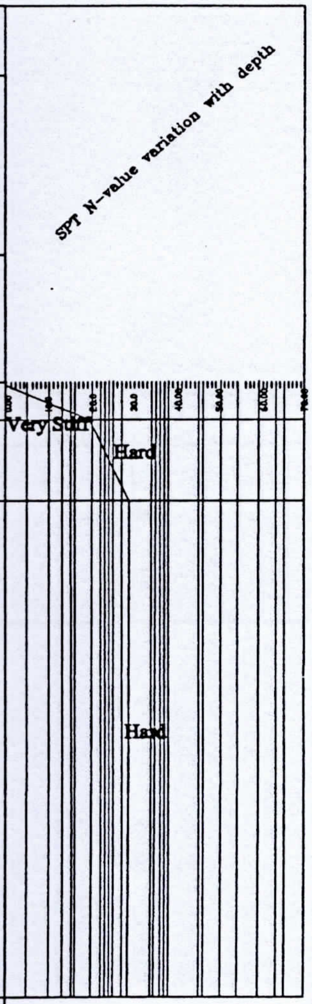
GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 2

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3993.1940
Northing (Y): 8027.5200
(Z): 198.4250

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 25/10/2016
Date completed: 28/10/2016
Total depth drilled(m): 50

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
15.45–15.90							15.45 4/9/11	15.45 Ŏ 15.90		15.90		
15.90–17.40	100									Light grey brown very weak, highly decomposed rock (tuff) with very stiff, low to medium plasticity silty/ clay		
17.40–17.85							17.40 5/17/29	17.40 Ŏ 17.85		17.85		
17.85–19.35	73									Light grey very weak, moderatly decomposed rock (tuff)		
19.35–20.85	80									20.85		
20.85–22.35	66									Ditto		
22.35–23.40	100									23.00		
23.40–24.50	86									Light grey very weak, moderatly decomposed rock (tuff)		
24.50–26.00	80									26.00		
26.00–27.50	90									Reddish brown hard low to medium placticity clay/silt		
27.50–29.00	80	54								27.80 Brown silty/ clay with highly decomposed rock(tuff)		
29.00–29.45							29.00 6/11/18	29.00 Ŏ 29.45		29.45		



CONT.__BOREHOLE LOG

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ŏ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

Ethiopian Construction Design & Supervision Works Corporation
Transport Design & Supervision Works Sector

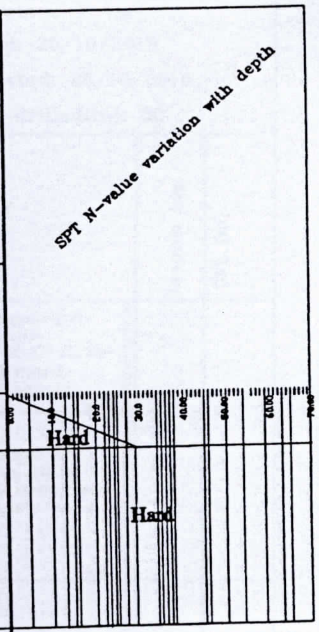
GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 2

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3993.1940
Northing (Y): 8027.5200
(Z): 198.4250

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 25/10/2016
Date completed: 28/10/2016
Total depth drilled(m): 50

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	APS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
30.95							30.95 7/13/4 [illegible]	30.95 Ö 31.40		Ditto 32.00		
31.40	60											
32.00	100									Highly decomposed rock (tuff) with brown silty/ clay 33.50		
33.50	60		33							Light grey,very weak, moderatly decomposed rock(tuff) with brown silty/ clay 36.95		
35.00							35.00 7/13/19	35.00 Ö 35.45				
35.45	100		20									
36.95	93		20							Ditto 39.95		
38.45	100		20									
39.95	52									Light grey brown very weak, moderatly decomposed rock (tuff) 42.10		
41.00	100		36									
42.10	86									Light grey, moderatly fractured (vertical fractur at (42.92-43.10, 43.84-44.00m slightly open,fill with calcite slightly weatherd, partly healed, moderately hard to hard basalt 44.00		
43.60	100											
44.00	100	14										



CONT.__BOREHOLE LOG

Consultant:
Subcontractor:
Supervisor:
Logged By:
Approved By:

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
APS=Averge fracture spacing

Ö Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK:

GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 2

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3993.1940
Northing (Y): 8027.5200
(Z): 198.4250

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 25/10/2016
Date completed: 28/10/2016
Total depth drilled(m): 50

Core run(m)	TCR(%)	SCR(%)	RQD(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
45.00	100		15					▮		Light grey, moderatly fractured (17cm apparent spacing, slightly rough slightly open,fill with chert(vertical fractur at (44.00-44.25, 45.07-45.30m slightly open,fill with calcite slightly weatherd, partly healed, moderately hard to hard basalt 47.00		
47.00	100							▮		Light grey, moderatly fractured (17cm apparent spacing, slightly rough slightly open,clean, 12cm apparent spacing, slightly rough slightly open,clean slightly weatherd, partly healed, moderately hard to hard basalt 50.00		
48.50	86											
50.00										END OF BOREHOLE LOG AT 50.00M		

Consultant: ______________________
Subcontractor: ______________________
Supervisor: ______________________
Logged By: ______________________
Approved By: ______________________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ŏ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ______________________

Ethiopian Construction Design & Supervision Works Corporation

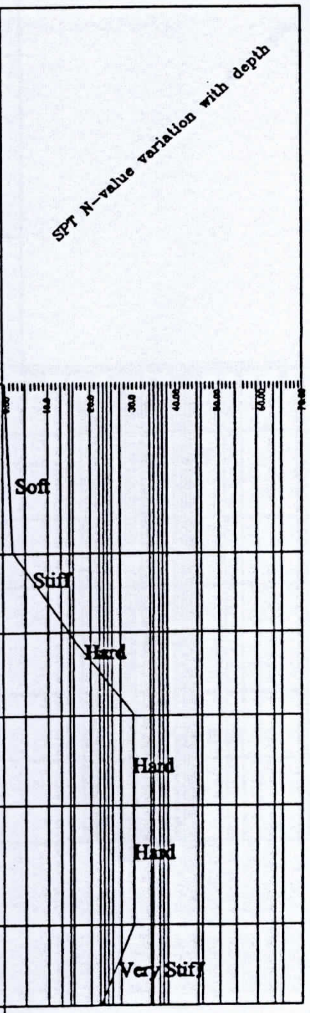
GEOTECHNCAL ENGINEERING SERVICE

BH ID No: 3

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 4005.8740
Northing (Y): 8002.0020
(Z): 200.0590

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 29/10/2016
Date completed: 01/11/2016
Total depth drilled(m): 40

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
1.50										Fill material with brown soft clay		
3.00	27							3.00			3.00	
3.60							3.60 1/1/1	3.60 Ô				
4.05								4.05				▽ 4.10
5.55	56						5.55 2/3/10	5.55 Ô		Brown very stiff, low to medium plasticity clay/silt		
6.00								6.00			6.00	
7.50	73						7.50 13/9/ refusal remain	7.50 Ô		Brown very stiff, low to medium plasticity clay/silt		
7.95								7.90			7.95	
9.45	93						9.45 8/15/23	9.45 Ô		Brown hard, low to medium plasticity clay/silt		
9.90								9.90			9.90	
11.20	92									Reddish hard, low to medium plasticity clay/silt		
11.65	100							11.65 ▯				
12.25							12.25 7/17/22	12.25 Ô				
12.70								12.70			12.70	
14.20	46						14.20 5/9/13	14.20 Ô		Ditto		
14.65	86							14.65			14.65	



CON'T___BOREHOLE LOG

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ô Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

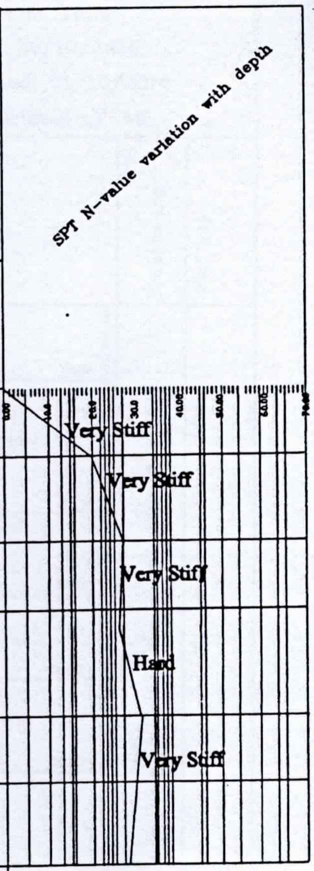
GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 3

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 4005.8740
Northing (Y): 8002.0020
(Z): 200.0590

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 29/10/2016
Date completed: 01/11/2016
Total depth drilled(m): 40

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
15.00–16.15							16.15	16.15		Brown very stiff, low to medium plasticity clay/silt		
16.15–16.60							4/8/12	Ö 16.60			16.60	
16.60–18.10	80						18.10	18.10		Ditto		
18.10–18.55							5/10/15	Ö 18.55			18.55	
18.55–20.20	100						20.20	20.20		Brown very stiff, low to medium plasticity clay/silt	20.20	
20.20–20.65							6/10/14	Ö 20.65		Light grey brown highly decomposed rock (tuff)with silty/clay		
20.65–22.15	80						22.15	22.15				
22.15–22.60							6/11/22	Ö 22.60			22.60	
22.60–24.10	90									Ditto	24.10	
24.10–25.60	86		23				25.60	25.60		Light grey brown moderatly decomposed rock (tuff)with silt/ clay		
25.60–26.05							8/11/18	Ö 26.05			26.05	
26.05–27.55	30									Light grey brown very weak moderatly decomposed rock (tuff)with silt/ clay		
27.55–29.20	63		12								29.20	
29.20–30.00	66		13									



CON'T__BOREHOLE LOG

Consultant: __________
Subcontractor: __________
Supervisor: __________
Logged By: __________
Approved By: __________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ö Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: __________

Ethiopian Construction Design & Supervision Works Corporation

GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 3

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 4005.8740
Northing (Y): 8002.0020
(Z): 200.0590

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 29/10/2016
Date completed: 01/10/2016
Total depth drilled(m): 40

Core run(m)	TCR(%)	SCR(%)	RQD(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
30.70	60									Ditto 31.30		
32.20	100									Reddish to brown very stiff, low plasticity silty clay with highly decomposed rock 33.70		
33.70	100									Ditto 35.20		
35.20	93									Highly decomposed rock with brown silty clay 36.70		
36.70	81		15							Light grey moderatly decomposed rock (tuff) with silt/ clay 38.35		
38.35	68		23							Ditto		

END OF BOREHOLE LOG AT 40.00M

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

♁	Disturbed sample
▯	Undisturbed sample
▮	Rock sample
∇	Static groundwater level

REMARK: ____________

Ethiopian Construction Design & Supervision Works Corporation

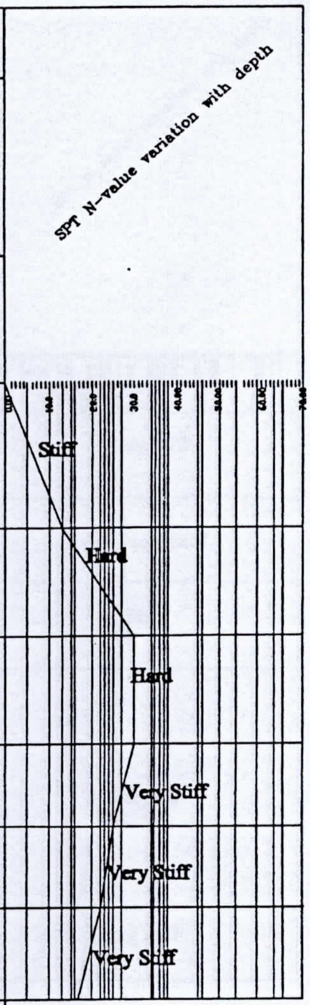
GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 4

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3989.7460
Northing (Y): 8021.0230
(Z): 199.0660

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 03/11/2016
Date completed: 06/11/2016
Total depth drilled(m): 40

	Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	APS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
0.00											Fill material with brown soft clay/silt		
1.00	1.50	16											
2.00	3.00	100									3.00		
3.00	3.45							3.00 3/6/7	3.00 Ö 3.45		Brown hard, low to medium plasticity clay/silt		
4.00	5.00	45							5.00 ▯				
5.00	5.60												
6.00	6.05							5.60 12/21/12 refusion remain	5.60 Ö 6.05		6.05		
7.00	8.05	100									Ditto		
8.00	8.50							8.05 7/13/19	8.05 Ö 8.50		8.50		
9.00	10.00	100									Reddish hard to very stiff, low to medium plasticity clay/silt		
10.00	10.45							10.00 6/10/15	10.00 Ö 10.45				▽ 10.20
11.00	11.95	98											
12.00	12.40							11.95 5/8/14	11.95 Ö 12.40		12.40		
13.00	14.05	100									Ditto 13.70		
14.00	14.50							14.05 4/7/10	14.05 Ö 14.50				
15.00													



CON'T...BOREHOLE LOG

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
APS=Averge fracture spacing

Ö Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

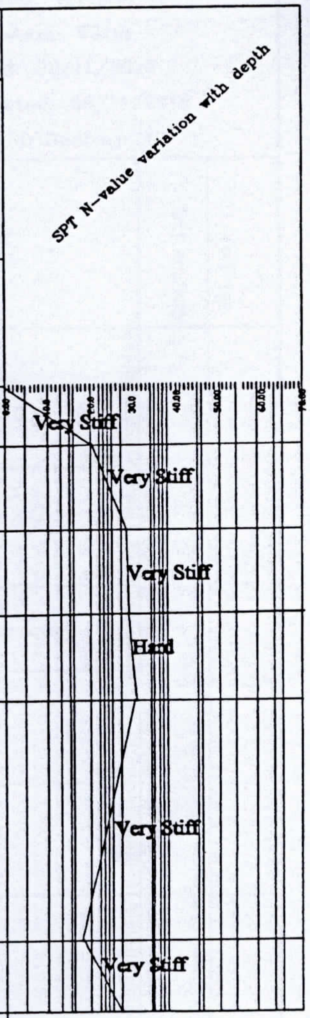
GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 4

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3989.7460
Northing (Y): 8021.0230
(Z): 199.0660

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 03/11/2016
Date completed: 06/11/2016
Total depth drilled(m): 40

	Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
15.00 16.00	16.00 16.45							16.00 6/10/10	16.00 Ô 16.45		Brown very stiff, low to medium plasticity clay/silt	16.45	
17.00 18.00	17.95 18.40	96						17.95 6/12/14	17.95 Ô 18.40		Brown very stiff, low to medium plasticity silty/clay	18.40	
19.00 20.00	20.05 20.50	61						20.05 4/10/19	20.05 Ô 20.50		Brown silty clay with light grey brown highly decomposed rock (tuff)	20.05	
21.00 22.00	22.00 22.45	43						22.00 15/28/ refusal remain	22.00 Ô 22.45		Light grey brown highly decomposed rock (tuff)with silty clay	22.00	
23.00 24.00 25.00	23.95 25.43	73 76									Ditto	25.45	
26.00 27.00	26.05	58 66		20							Light grey brown very weak, moderatly decomposed rock (tuff)with silty clay	27.17	
28.00	27.55 28.00							27.55 5/7/11	27.55 Ô 28.00				
29.00 30.00	29.65	100						29.65 4/11/14	29.65 Ô 30.10		Reddish to brown very stiff, low plasticity silty/clay	29.65	



CONT.__BOREHOLE LOG

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ô Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 4

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3989.7460
Northing (Y): 8021.0230
(Z): 199.0660

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 03/11/2016
Date completed: 06/11/2016
Total depth drilled(m): 40

	Core run(m)	TCR(%)	SCR(%)	RQD(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
30.00	30.10	76									Brown very stiff, low to medium plasticity silty clay	32.50	
31.00 32.00	31.60	96											
33.00	33.10	96									Brown very stiff, low to medium plasticity silt/ clay with highly decomposed rock(tuff)	34.60	
34.00 35.00	34.60	76									Light grey,very weak ,moderatly decomposed rock(tuff) with silty clay	36.10	
36.00 37.00	36.10	66	23								Ditto	38.05	
38.00 39.00	38.05	79									Light grey,highly decomposed rock(tuff) with silty clay		
40.00													

END OF BOREHOLE LOG AT 40.00M

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

ŏ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

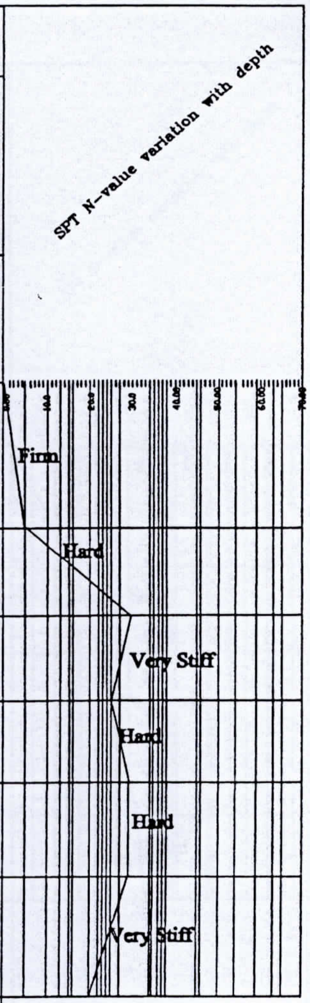
GEOTECHNCAL ENGINEERING SERVICE

BH ID No: 5

Project: Geotechnical Inv. of B4+G+6,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3996.0190
Northing (Y): 7989.4540
(Z): 199.8660

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 12/11/2016
Date completed: 14/11/2016
Total depth drilled(m): 40

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
0.00	33									Fill material with brown soft clay/silt		
1.50	100											
3.00							3.00 1/2/3	3.00 Ô 3.45			3.00	
3.45	78									Brown, very stiff, clay/silt with highly decomposed rock		
5.10							5.10 10/19/16	5.10 Ô 5.55			5.55	
5.55	66									Brown very stiff, low to medium plasticity clay/silt		
7.05							7.05 6/11/14	7.05 Ô 7.50				
7.50	64									Ditto		
9.00							9.00 7/13/21	9.00 Ô 9.45			9.45	
9.45	100									Reddish hard, low to medium plasticity clay/silt		
11.15							11.15 7/12/18	11.15 Ô 11.60			11.60	
11.60	100									Ditto		
13.40	100							13.40 ▯				
14.00							14.00 4/8/12	14.00 Ô 14.45				
14.45	100		36								15.00	



CONT'___BOREHOLE LOG

Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ô Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

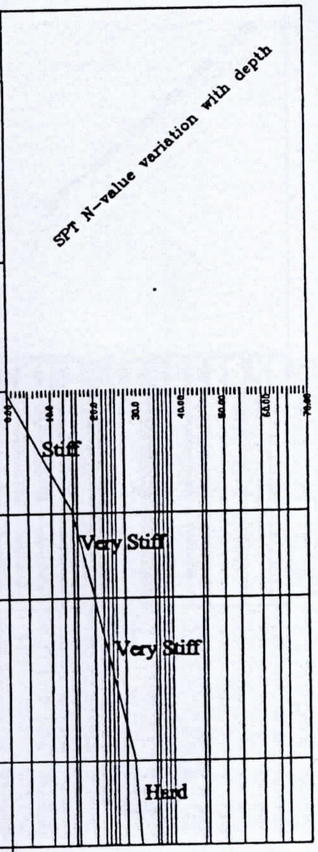
GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 5

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3996.0190
Northing (Y): 7989.4540
(Z): 199.8660

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 12/11/2016
Date completed: 14/11/2016
Total depth drilled(m): 40

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
15.00–15.95										Light grey brown very weak, moderatly decomposed rock (tuff) with silt/clay		15.25
15.95–17.45	96											
17.45–17.90							17.45 3/6/9	17.45 Ö 17.90		17.90		
17.90–19.40	100									Ditto		
19.40–19.85							19.40 4/8/12	19.40 Ö 19.85		19.85		
19.85–21.35	73									Light grey brown, highly decomposed rock (tuff) 21.35		
21.35–23.15	61									Ditto with silty/clay		
23.15–23.60							23.15 8/14/15	23.15 Ö 23.60		23.60		
23.60–25.10	66	30								Light grey brown, highly decomposed rock (tuff) with silty/clay		
25.10–25.55							25.10 9 refu [illegible]	25.10 Ö 25.55		25.55		
25.55–26.65	81									Light grey brown, very weak moderatly decomposed rock (tuff)		
26.65–28.15	100	46								27.35 Brown hard silty/clay 28.15		
28.15–29.65	73									Light grey brown, very weak moderatly decomposed rock (tuff)		



CON'T...BOREHOLE LOG

Consultant: ______________________
Subcontractor: ______________________
Supervisor: ______________________
Logged By: ______________________
Approved By: ______________________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ö Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ______________________

Ethiopian Construction Design & Supervision Works Corporation

GEOTECHNCAL ENGINEERING SERVICE

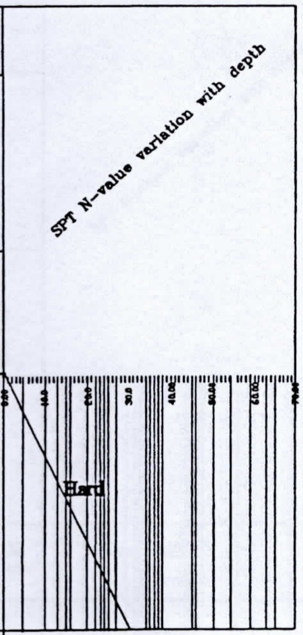
Con't...BH ID No: 5

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3996.0190
Northing (Y): 7989.4540
(Z): 199.8660

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 12/11/2016
Date completed: 14/11/2016
Total depth drilled(m): 40

Depth	Core run(m)	TCR(%)	SCR(%)	RQD(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
30.00		100											
31.00	31.15	100									Light grey brown, very weak moderatly decomposed rock (tuff) 31.15		
32.00	32.65	100									Ditto 32.65		
34.00	34.15	100									Reddish hard, clay/silt 34.15		
35.00	35.65							35.65 8/12/20	35.65 Ô 36.10				
36.00	36.10	100									Light grey brown, very weak moderatly decomposed rock (tuff) with silt/clay 36.55		
37.00	37.70	100											
39.00	39.35	100									Ditto 39.35		
40.00											40.00		

END OF BOREHOLE LOG AT 40.00M



Consultant: ____________
Subcontractor: ____________
Supervisor: ____________
Logged By: ____________
Approved By: ____________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ô Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________

Ethiopian Construction Design & Supervision Works Corporation
Transport Design & Supervision Works Sector

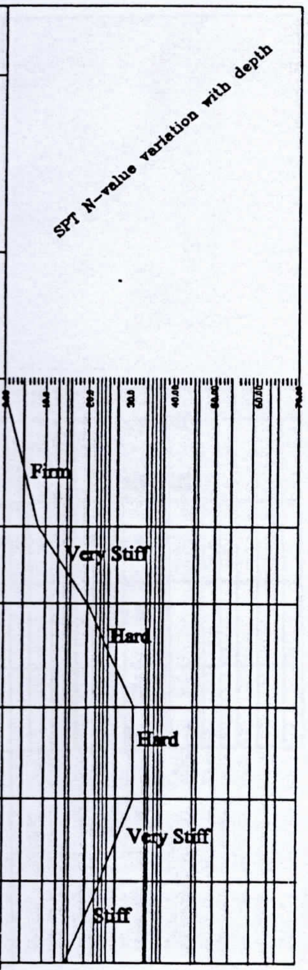
GEOTECHNCAL ENGINEERING SERVICE

BH ID No: 6

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3968.8230
Northing (Y): 8019.0920
(Z): 196.8720

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 10/11/2016
Date completed: 12/11/2016
Total depth drilled(m): 35

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
0.00–1.50	30									Fill material with brown soft clay/silt		
1.50–3.00	100										3.00	
3.00–3.45							3.00 2/3/5	3.00 Ŏ 3.45		Brown very stiff, low to medium plasticity clay/silt		
3.45–4.90	86											⊽ 4.30
4.90–5.35							4.90 4/9/11	4.90 Ŏ 5.35				
5.35–6.85	86										6.85	
6.85–7.45								6.85		Ditto		
7.45–7.90							7.45 10/18/18 [illegible]	7.45 Ŏ 7.90				
7.90–9.40	100											
9.40–9.95							9.40 7/13/15	9.40 Ŏ 9.95			9.95	
9.95–10.90	89									Reddish very stiff, low to medium plasticity clay/silt		
10.90–11.45	100											
11.45–11.90							11.45 6/9/14	11.45 Ŏ 11.90			11.90	
11.90–13.40	100									Ditto		
13.40–13.85							13.40 3/6/9	13.40 Ŏ 13.85			13.85	
13.85–15.00	96									Light grey brown very weak, moderatly decomposed rock (tuff)		



CONT.__BOREHOLE LOG

Consultant:
Subcontractor:
Supervisor:
Logged By:
Approved By:

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ŏ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
⊽ Static groundwater level

REMARK:

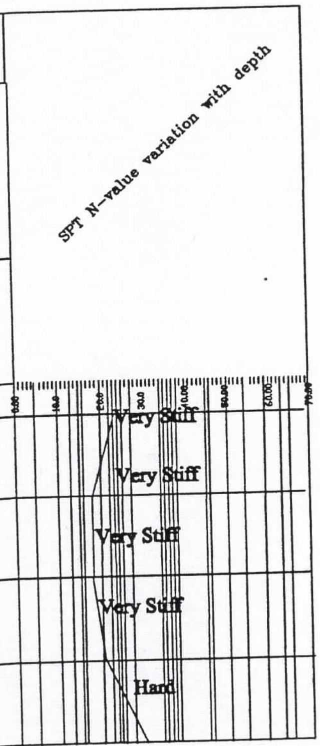
GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 6

Project: Geotechnical Inv. of B4+G+6,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM- Adindam Datum)
Easting (X): 3968.8230
Northing (Y): 8019.0920
(Z): 198.8720

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 10/11/2016
Date completed: 12/11/2016
Total depth drilled(m): 35

Core run(m)	TCR(%)	RQD(%)	SCR(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
15.00 15.35 15.80							15.35 4/10/18	15.35 Ŏ		15.80		
16.00 17.00 17.30 17.75	98						17.30 3/8/10	15.80 17.30 Ŏ		Brown silty clay with light grey brown very weak, moderatly decomposed rock (tuff) 17.75		
18.00 19.00 19.25 19.70	90						19.25 4/8/10	17.75 19.25 Ŏ		Light grey brown very weak, moderatly decomposed rock (tuff) 19.70		
20.00 21.00 21.20 21.65	66						21.20 4/7/14	19.70 21.20 Ŏ		Dark grey very stiff silty/clay 21.65		
22.00 23.00 23.15 23.60	100						23.15 12/18/ [illegible] remain	21.65 23.15 Ŏ		Light brown highly decomposed rock (tuff) with silty/clay 23.60		
24.00 25.00 25.30 26.00 26.60	88 83	26						23.60		Ditto 26.60		
27.00 28.00 28.40	100	22								Moderatly decopmosed rock(tuff) with reddis very stiff clay/silt 28.40		
29.00 30.00	100											



CON'T__BOREHOLE LOG

Consultant: __________
Subcontractor: __________
Supervisor: __________
Logged By: __________
Approved By: __________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

Ŏ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: __________

Ethiopian Construction Design & Supervision Works Corporation
Transport Design & Supervision Works Sector

GEOTECHNCAL ENGINEERING SERVICE

Con't...BH ID No: 6

Project: Geotechnical Inv. of B4+G+5,B4+G+15,B4+G+25 ORDA Building
Client: ORDA
Location: Addis Ababa
BH Coordinates (UTM– Adindam Datum)
Easting (X): 3968.8230
Northing (Y): 8019.0920
(Z): 198.8720

Ground Elevation (m):
BH Inclination: Vertical
Flushing System: Water
Date started: 10/11/2016
Date completed: 12/11/2016
Total depth drilled(m): 35

Core run(m)	TCR(%)	SCR(%)	RQD(%)	Casing Diameter (mm)	Hole Diameter (mm)	AFS(%)	SPT N-value	Sampling	USCS	Field Description of Soil/rock	Graphic Log	GWL (m)
30.00 31.00 31.65	66									Light brown silty clay with moderatly decopmosed rock(tuff) 32.05		
32.00 33.00 33.35	82									Brown to dark grey very stiff clay/silt with highly decopmosed rock(tuff) 35.00		
34.00 35.00	81											
36.00 37.00 38.00 39.00 40.00										END OF BOREHOLE LOG AT 35.00M		

Consultant: ____________________
Subcontractor: ____________________
Supervisor: ____________________
Logged By: ____________________
Approved By: ____________________

BH=Borehole
N=Blows/300mm
SPT=Standard Penetration Test
USCS=Unified Soil Classification System
RQD=Rock quality designation
TCR=Total core recovery
AFS=Averge fracture spacing

○ Disturbed sample
▯ Undisturbed sample
▮ Rock sample
▽ Static groundwater level

REMARK: ____________________

Ethiopian Construction Design & Supervision Works Corporation

APPENDIX B- DETERMINATION OF INPUT SOIL PARAMETERS

SOIL PROFILE AND DETERMINATION OF PARAMETERS

1.1 Sub surface condition

From the borehole log sheet attached in the previous appendix, it can be observed that the subsurface conditions of the project site comprise of the following major geotechnical layers.

Layer A- Top soil

This layer is brown, soft to very stiff CLAY which extends to an average depth of 3 meters. This layer will be fully excavated out during construction.

Layer B- Stiff silty CLAY/ clayey SILT

This stiff, reddish brown clayey SILT layer is encountered from a depth of 3 meters up to a maximum depth of 20 meters below the natural ground level.

Layer C- Upper Tuff (silty SAND/ sandy GRAVEL with silt)

This layer is brownish to yellowish grey, medium dense to dense, moist sandy GRAVEL with silt.

Layer D- Consolidated silty CLAY

This consolidated silty CLAY soil is brown in color and is found sandwiched between the upper and lower tuff layers. It has an average thickness of 1 meter, a very small thickness relative to the other layers and is not even encountered in two of the boreholes.

Layer E- Lower Tuff (silty sand/ sandy SILT with gravel)

This layer which is a similar formation with the upper tuff is brownish to yellowish grey, medium dense to dense moist sandy SILT with traces of gravel.

Layer F- Medium strong to strong BASALT

This rock stratum is encountered in the boreholes that extend to 50 meters depth from a depth of 35m and 40m to the end of the boreholes. The upper part of the basalt is intensively fractured with slightly open and weathered surfaces. The degree of weathering and fracturing progressively decreases and a stronger rock is encountered beneath 37m and 44m in the two boreholes. The scatter of the uni-axial compressive strength of the intact rock samples ranges from 37MPa to 140MPa with an average value of 98MPa. In general, the rock layer is medium strong to strong BASALT with an average RQD value of 25%.

1.1.1 Ground water level

Ground water measurement in all six bore holes had wide variations. From the shallowest level of 4.10m measured in the third borehole to the deepest level of 15.25m measured in the fifth borehole were given. To get the correct ground water level piezometer was installed. Level of ground water was established to be at 15.25m below the natural ground level. Hence in the analysis, submerged unit weight of the soil is taken for layers located below the ground water level.

1.2 Determination of parameters

The symbol * indicates values taken directly from the geotechnical investigation report. As mentioned earlier, the only available data for the whole investigated depth is standard penetration, natural moisture content and specific gravity test results. Therefore, soil parameters which are not available have been calculated from available data using direct and empirical relations.

Standard penetration test blows written on the borehole logs appear to have very small font, therefore this table is prepared to clearly present the SPT-N values in each borehole at approximate depths. Values are averaged for each depth and layer for all necessary calculations.

Table 1-1: SPT-N values in each borehole at approximate depths as presented in the borehole log

Depth	**BH-1**	**BH-2**	**BH-3**	**BH-4**	**BH-5**	**BH-6**	**Averaged SPT-N values**
3	7	33	2	13	5	8	7
5	46	32	15	34	35	20	30
7	41		38		25	30	34
9	27	29		32	34	32	31
11	19	33	39	25	30	23	28
13	13	18	22	22	20	15	18
15	24	20	20	17		22	21
17	17	37	25	20	15	18	22
19	39	50	32	28	20	24	32
21	28	50	33	29	50	21	35
23	50	50	29	50	29	50	43
26	37	50	50	50	50	50	48
28	31	50	50	18	50	50	42
30	34	30	50	25	50	50	40
32	50	27	50	50	50	50	46
35	50	50	50	50	32	50	47

Table 1-2: Accustomed unit weight and shear strength parameters for each layer

Layer No in numerical analysis	Layer description	Depth encountered (m)	Bulk unit weight (kN/m^3)	Effective cohesion (kPa)	Effective internal angle of friction (^{o})	SPT-N values (blows/300 mm)
	Soft to medium stiff, highly plastic silty clay	0-3	17*			
1	Very stiff to hard, medium to highly plastic clayey silt	3-15.5 ▼ GWT	18.3*			24*
		15.5-18	19.3*	25	23	22*
2	Moderately to highly weathered tuff. (medium dense, silty sand/ sandy gravel with medium plastic clayey silt)	18-30	20	25	36	40*
3	Very stiff to hard, medium to highly plastic clayey silt with highly decomposed rock (tuff)	30-40	19.5	25	40	47*
4	Slightly weathered, medium strong to strong basalt	40-50	25.5	10,000	45	>50*

1.2.1 Unit weight (ϒ)

Bulk unit weight of each soil layer is shown in Table 1-2. Values for Layers 1 and 2 are accustomed directly from the investigation report. For layers 2 and 3 values are adopted based on the soil type from ranges of typical values from (Budhu, 2015).

For the last basalt layer, the results of saturated surface dry specific gravity of basalts in the investigation report have an average value of 2.805. Nonetheless there is no data given about the weight or voids of the specimens therefore, a typical unit weight value of 25.5kN/m^3 is accustomed for the basalt layer. The most common unit weight values of rock substances are between 25 and 26 kN/m^3 (Briaud, 2013). Reinforced concrete has a unit weight of 25.0kN/m^3 (EN 1992-1-1).

1.2.2 Effective shear strength parameters- Cohesion (c') and angle of internal friction (φ')

Effective cohesion and angle of internal friction values for the layers under water are adopted from ranges of possible values given based on the soil type (Briaud, 2013). For dense sand and gravel with blow per foot (bpf) of 30-50 a range of 36°-41° is recommended. For silt and clay of high plasticity a range of 18°-30° and 16°-26° are given respectively.

Effective angle of internal friction value of 26° is used for layer 1 because it is very stiff. For layer 2 effective angle of internal friction value of 36° is adopted since the formation is medium dense and for layer 3, 40° is used because it is very stiff with decomposed rock. For the basalt formation (layer 4) a typical value of cohesion intercepts in the range of 5 to 40MPa and friction angles in the range of 30^o to 50^o is suggested (Briaud, 2013). Values of 10MPa and 45^o are taken from the low bound averaged and high bound ranges, as the cohesion and internal angle of friction for the slightly weathered, medium strong to strong basalt layer.

Effective cohesion is rarely higher than 25kPa. For the medium to highly plastic clayey silt, layer 1, effective cohesion of 25kPa is used. For layers 2 and 3 that are mixed coarse- and fine-grained formations a lesser value of 20kPa is adopted.

1.2.3 Elastic deformation parameters- Young's modulus (E) and Poisson's ratio (υ)

Equation 1.1 is adopted from (DIN 4094-2:2003) to estimate the stress dependent stiffness modulus (Es) values, which then can be changed to Young's modulus using Equation 1.2 from (EVB, 1996). Detailed calculation is presented in Table 1-4.

$$\boldsymbol{E_s} = \mu * \boldsymbol{p_a}\left(\frac{\boldsymbol{\sigma_z}+\boldsymbol{0.5}*\boldsymbol{\Delta\sigma_z}}{\boldsymbol{p_a}}\right)^{\boldsymbol{w}} \qquad \text{Equation 1.1}$$

$$\boldsymbol{E} = \boldsymbol{E_s}\left(\frac{\boldsymbol{1-\upsilon-2\upsilon^2}}{\boldsymbol{1-\upsilon}}\right) \qquad \text{Equation 1.2}$$

P_a - Atmospheric pressure (101.3KN/m^2)

σ_z– overburden pressure at depth z below the foundation

$\Delta\sigma_z$ - Increase in vertical stress by external load at depth z below the foundation

υ- Poisson's ratio

µ-Stiffness coefficient

$\mu=4*N_{30}+15$ for clay with $3 \le N_{30} \le 23$

Whereas $\mu=217*\log N_{30}+146$ for sand with $3 \le N_{30} \le 25$

N_{30}- number of blows for 30cm penetration

N_{30} value for the first layer is 22 which is in the given range but for the rest of the layers values are out of the given range. Therefore, the safest approach is to use the maximum value in the range and calculate µ accordingly.

w-Stiffness exponent=0.6 and 0.5 for clay and sand respectively

Table 1-3: Typical values of Poisson's ratio, (Briaud, 2013)

Type of soil	Poisson's ratio
Very stiff sandy clay	0.2-0.3
Silt	0.3-0.35
Dense gravel (SPT-N 30-50)	0.3-0.4

Dense sand (SPT-N 30-50)	0.25-0.45
Rock	0.15-0.3

Poisson’s ratio of each layer is adopted from Table 1-2. The lower bound of the silt layer Poisson’s ratio range is used for the first layer because it is classified as stiff to hard. For the mixed layers an averaged value of 0.3 is used, while for the basalt layer Poisson’s ratio of 0.25 is accustomed.

Table 1-4: Elastic deformation parameters

Layer	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**
Depth to mid of the layer (m)	9	15	20	25
N_{30}	22	40	47	
stiffness coef. (µ)	138	450	450	
Stiffness exponent (w)	0.6	0.5	0.5	
Poisson’s ratio	**0.3**	**0.3**	**0.3**	**0.25**
Overburden pressure (kN/m^2)	189.47	447.94	665.44	
Maximum change in vertical stress (kN/m^2)	426.2	363.1	320.7	
Stiffness modulus (Es) in (kN/m^2)	31,972	113,580	130,087	
Young's modulus (E) in kN/m^2	**23,751**	**84,374**	**96,636**	**1,500,000**

An experimental correlation is used to estimate the Young's modulus for the basalt layer (Ocak, 2008).

$$E = 0.5342UCS^{0.7672} \text{ ,UCS in MPa E in GPa} \qquad \text{Equation 1.3}$$

To be on the safe side the minimum UCS result of 37 MPa is taken for the calculation to give 8,500MPa. This value is checked with typical values of Young's modulus for slightly weathered basalt and is found to be over-estimated, therefore 1,500MPa is taken as Young's modulus for the basalt layer, because adoption of this value is observed in many literatures.

1.2.4 Initial stress coefficient (K$_o$)

Jacky's famous equation; Eq 1.5, is used to estimate the initial stress coefficient of the basalt layer. For the rest of the layers, average of three equations, as suggested by Brooker and Ireland (1965); Eq 1.6, Alpan (1967); Eq 1.7 and Holtz and Kovacs (1981); Eq 1.8 are used (Bowels, 1997), as they are suggested for soils of cohesive nature.

Plasticity Indices (Ip) are averaged for each layer from the Atterberg test results obtained from investigation report. Plasticity index values of 28, 21 and 28 are calculated for layer 2, 3 and 4 respectively. Estimated results are shown in Table 1-5.

$$k_o = 1 - \sin \varphi' \qquad \text{Equation 1.4}$$

$$k_o = 0.95 - \sin \varphi' \qquad \text{Equation 1.5}$$

$$k_o = 0.19 + 0.233 \log Ip \qquad \text{Equation 1.6}$$

$$k_o = 0.44 - 0.0042\, Ip \qquad \text{Equation 1.7}$$

Table 1-5: Initial stress coefficient for each layer

	Layer 1	Layer 2	Layer 3	Layer 4
K$_o$	0.494	0.435	0.427	0.293

APPENDIX C-COST ESTIMATION FOR THE ORIGINAL AND PROPOPSED PILE PARAMETERS

With Original Pile Parameters

TAKE-OFF SHEET FOR REINFORCEMENT BAR

Location	Bar diam.	C/C	Bar length	members	bars in each	Total No. of Bars	Length						
							Φ6 mm	Φ8 mm	Φ10 mm	Φ12 mm	Φ14 mm	Φ16 mm	Φ20 mm
original pile													
pile bar							-	-	-	-	-	-	-
longitudinal bar							-	-	-	-	-	-	-
asumming 1200mm lap length	20		12	162	18	2916	-	-	-	-	-	-	34,992.00
	20		12	162	18	2916	-	-	-	-	-	-	34,992.00
	20		3.8	162	18	2916	-	-	-	-	-	-	11,080.80
Stirrup	12	100	2.2	162	171	27702	-	-	-	60,944.40	-	-	-
spiral stirrups (approximate length calculated for comparison purpose)	12	150	2.2	162	58	9396	-	-	-	20,671.20	-	-	-
							-	-	-	-	-	-	-
			Total length				-	-	-	81,615.60	-	-	81,064.80
			Unit weight				0.222	0.395	0.617	0.888	1.210	1.580	2.470
			total weight (kg)				**-**	**-**	**-**	**72,474.65**	**-**	**-**	**200,230.06**

Earth and Concrete Work

no			**Unit**	**Description of Work**
				earth work
	1.00			diameter
162	0.79			area
	25.40			length
		3230.12	m^3	**pile excavation volume**
				concrete work
	0.80			diameter
162	0.50			area
	25.40			length
		2067.28	m^3	**pile concrete volume**

BOQ Concrete and Earth Work

Item no	Description	Unit	Qty	Rate	Amount
	A-SUB STRUCTURE				
	1. PILE Work				
1.10	Mobilization of staffs and all the required equipment for pile foundation work	LS	1.00	450,000.00	450,000.00
					-
1.20	Drilling of piles Diam. 800 mm piles in soil formations as described in geotechnical investigation report and/or as per structural drawing.	ML	4,114.80	2,640.00	10,863,072.00
1.30	Cart away Surplus excavated material to the appropraite tip as instructed by the Engineer	M^3	3,329.81	130.00	432,875.30
	TOTAL				**11,745,947.30**
	2. CONCRETE WORK				
2.10	Installation of concrete in Dia. 800 mm piles concrete quality C-30, with minimum cube strength of 30MPa pumpable concrete (which is provided by the client) pouring of concrete with tremie method or other method suitable for the site condition & crane and complete supervision. Price shall include all neccessary pumps, equipments and tools for concreting				-
					-
	a) In piles	M^3	2,131.08	250.00	532,770.08
					-
2.20	Install mild steel reinforcement according to structural drawings. Price only for placing in position, tying concrete spacers.				-
	a) 6mm diameter plain bar	Kg	0.00	3.50	-
	b) 8mm diameter deformed bar	Kg	0.00	3.50	-
	c) 10mm diameter deformed bar	Kg	0.00	3.50	-
	d) 12mm diameter deformed bar	Kg	72,474.65	3.50	253,661.28
	e) 14mm diameter deformed bar	Kg	0.00	3.50	-
	f) 16mm diameter deformed bar	Kg	0.00	3.50	-
	g) 20mm diameter deformed bar	Kg	200,230.06	3.50	700,805.20
	h) 24mm diameter deformed bar	Kg	0.00	3.50	-
	i) 32mm diameter deformed bar	Kg	0.00	3.50	-
					-
	TOTAL				**1,487,236.56**
	TOTAL CARRIED TO SUMMARY				**13,233,183.86**

Summary BOQ- Material and Labour

Item no	Description	Unit	Qty	Rate	Amount
	A-SUB STRUCTURE				
	1. PILE Work				
1.10	Mobilization of staffs and all the required equipment for pile foundation work	LS	1.00	450,000.00	450,000.00
1.20	Drilling of piles Diam. 800 mm piles in soil formations as described in geotechnical investigation report and/or as per structural drawing.	ML	4,114.80	2,640.00	10,863,072.00
1.30	Cart away Surplus excavated material to the appropraite tip as instructed by the Engineer	M^3	3,329.81	130.00	432,875.30
	TOTAL				**11,295,947.30**
	2. CONCRETE WORK				
2.10	Installation of concrete in Dia. 800 mm piles concrete quality C-30, with minimum cube strength of 30MPa pumpable concrete (which is provided by the client) pouring of concrete with tremie method or other method suitable for the site condition & crane and complete supervision. Price shall include all neccessary pumps, equipments and tools for concreting				-
					-
	a) In piles	M^3	2,131.08	3,250.00	6,926,011.04
					-
2.20	Install mild steel reinforcement according to structural drawings. Price only for placing in position, tying concrete spacers. (The client will provide already fabricated reinforcemnt bar as per the design)				
					-
	a) 6mm diameter plain bar	Kg	0.00	51.00	-
	b) 8mm diameter deformed bar	Kg	0.00	51.00	-
	c) 10mm diameter deformed bar	Kg	0.00	51.00	-
	d) 12mm diameter deformed bar	Kg	72,474.65	51.00	3,696,207.29
	e) 14mm diameter deformed bar	Kg	0.00	51.00	-
	f) 16mm diameter deformed bar	Kg	0.00	51.00	-
	g) 20mm diameter deformed bar	Kg	200,230.06	51.00	10,211,732.86
	h) 24mm diameter deformed bar	Kg	0.00	51.00	-
	i) 32mm diameter deformed bar	Kg	0.00	51.00	-
	TOTAL				**20,833,951.19**
	TOTAL CARRIED TO SUMMARY				**32,129,898.49**

With Proposed Pile Parameters

TAKE-OFF SHEET FOR REINFORCEMENT BAR

Location	Bar diam.	C/C	Bar length	members	bars in each	Total No. of Bars	Length						
							Φ6 mm	Φ8 mm	Φ10 mm	Φ12 mm	Φ14 mm	Φ16 mm	Φ20 mm
pile after Optimization													
pile bar							-	-	-	-	-	-	-
longitudinal bar							-	-	-	-	-	-	-
asumming 1200mm lap length	20		12	50	18	900	-	-	-	-	-	-	10,800.00
	20		9.6	50	18	900	-	-	-	-	-	-	8,640.00
						0	-	-	-	-	-	-	-
Stirrup	12	100	2.2	50	137	6850	-	-	-	15,070.00	-	-	-
spiral stirrups (approximate length calculated for comparison purpose)	12	150	2.2	50	46	2300	-	-	-	5,060.00	-	-	-
							-	-	-	-	-	-	-
			Total length				-	-	-	20,130.00	-	-	19,440.00
			Unit weight				0.222	0.395	0.617	0.888	1.210	1.580	2.470
			total weight (kg)				**-**	**-**	**-**	**17,875.44**	**-**	**-**	**48,016.80**

Earth and Concrete Work

no			Unit	Description of Work
				Earth work
	1.00			diameter
50	0.79			area
	20.40			length
		800.70	m^3	**pile excavation volume**
				Concrete work
	0.80			diameter
50	0.50			area
	20.40			length
		512.45	m^3	**pile concrete volume**

BOQ Concrete and Earth Work

Item no	Description	Unit	Qty	Rate	Amount
	A-SUB STRUCTURE				
	1. PILE Work				
1.10	Mobilization of staffs and all the required equipment for pile foundation work	LS	1.00	450,000.00	450,000.00
					-
1.20	Drilling of piles Diam. 800 mm piles in soil formations as described in geotechnical investigation report and/or as per structural drawing.	ML	1,020.00	2,640.00	2,692,800.00
1.30	Cart away Surplus excavated material to the appropraite tip as instructed by the Engineer	M^3	800.70	130.00	104,091.00
	TOTAL				**3,246,891.00**
	2. CONCRETE WORK				
2.10	Installation of concrete in Dia. 1000 mm piles concrete quality C-30, with minimum cube strength of 30MPa pumpable concrete (which is provided by the client) pouring of concrete with tremie method or other method suitable for the site condition & crane and complete supervision. Price shall include all neccessary pumps, equipments and tools for concreting				-
					-
	a) In piles	M^3	512.45	250.00	128,112.00
					-
2.20	Install mild steel reinforcement according to structural drawings. Price only for placing in position, tying concrete spacers. (The client will provide already fabricated reinforcemnt bar as per the design)				-
	a) 6mm diameter plain bar	Kg	0.00	3.50	-
	b) 8mm diameter deformed bar	Kg	0.00	3.50	-
	c) 10mm diameter deformed bar	Kg	0.00	3.50	-
	d) 12mm diameter deformed bar	Kg	17,875.44	3.50	62,564.04
	e) 14mm diameter deformed bar	Kg	0.00	3.50	-
	f) 16mm diameter deformed bar	Kg	0.00	3.50	-
	g) 20mm diameter deformed bar	Kg	48,016.80	3.50	168,058.80
	h) 24mm diameter deformed bar	Kg	0.00	3.50	-
	i) 32mm diameter deformed bar	Kg	0.00	3.50	-
					-
	TOTAL				**358,734.84**
	TOTAL CARRIED TO SUMMARY				**3,605,625.84**

Summary BOQ- Material and Labour

Item no	Description	Unit	Qty	Rate	Amount
	A-SUB STRUCTURE				
	1. PILE Work				
1.10	Mobilization of staffs and all the required equipment for pile foundation work	LS	1.00	450,000.00	450,000.00
1.20	Drilling of piles Diam. 800 mm piles in soil formations as described in geotechnical investigation report and/or as per structural drawing.	ML	1,020.00	2,640.00	2,692,800.00
1.30	Cart away Surplus excavated material to the appropraite tip as instructed by the Engineer	M^3	800.70	130.00	104,091.00
	TOTAL				**2,796,891.00**
	2. CONCRETE WORK				
2.10	Installation of concrete in Dia. 800 mm piles concrete quality C-30, with minimum cube strength of 30MPa pumpable concrete (which is provided by the client) pouring of concrete with tremie method or other method suitable for the site condition & crane and complete supervision. Price shall include all neccessary pumps, equipments and tools for concreting				-
					-
	a) In piles	M^3	512.45	3,250.00	1,665,456.00
					-
2.20	Install mild steel reinforcement according to structural drawings. Price only for placing in position, tying concrete spacers. (The client will provide already fabricated reinforcemnt bar as per the design)				
					-
	a) 6mm diameter plain bar	Kg	0.00	51.00	-
	b) 8mm diameter deformed bar	Kg	0.00	51.00	-
	c) 10mm diameter deformed bar	Kg	0.00	51.00	-
	d) 12mm diameter deformed bar	Kg	17,875.44	51.00	911,647.44
	e) 14mm diameter deformed bar	Kg	0.00	51.00	-
	f) 16mm diameter deformed bar	Kg	0.00	51.00	-
	g) 20mm diameter deformed bar	Kg	48,016.80	51.00	2,448,856.80
	h) 24mm diameter deformed bar	Kg	0.00	51.00	-
	i) 32mm diameter deformed bar	Kg	0.00	51.00	-
	TOTAL				**5,025,960.24**
	TOTAL CARRIED TO SUMMARY				**7,822,851.24**