

**ADDIS ABABA UNIVERSITY**  
**SCHOOL OF GRADUATE STUDIES**



**A STUDY ON**  
**CRITICAL ASSESSMENT OF GEOTECHNICAL**  
**INVESTIGATION PRACTICE IN ETHIOPIA IN LIGHT OF**  
**PERTINENT BUILDING CODE PROVISIONS**

**By: MAHALET SOLOMON SEYOUM**

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**A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements of the Degree of Masters of Science in Civil Engineering.**

By: Mahalet Solomon Seyoum

## **DECLARATION**

This thesis is my original work. It has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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## Abstract

Geotechnical investigation is the process by which geological, geotechnical, and other relevant information, which might affect the construction or performance of a civil engineering or building project, is acquired. The geotechnical investigation phase of any structure design plays a vital role, where inadequate characterization of the subsurface conditions may contribute to either a significantly over-designed solution which is not cost-effective, or an under designed one, which may lead to potential failures. One of the site investigation objectives is to help to overcome any possible difficulties and delays that may arise during construction period due to ground and other local conditions.

In this research the geotechnical investigation practice in Ethiopia is critically assessed and compared with the pertinent codes available. Most ground investigations are carried out by soil investigation firms or the ground investigation program is designed by structural engineers from design offices.

Primary data is collected from professionals, who are geotechnical engineers and structural engineers. Responses are collected using a self-administered questionnaires and interview. Criteria from different codes are used to compare and evaluate the findings. The primary data collected is analyzed and a comparative research type is used.

Different criteria are selected and different provisions/requirements from the pertinent codes are reviewed to come up with a complete soil investigation system. Provisions/requirements for every criterion are evaluated to give the necessary information to draw a conclusion. The quality of soil exploration practice in Ethiopia is compared with these pertinent codes and result shows that for the geotechnical engineers, the percentage of compliance is 43% .For the structural engineers, the percentage of compliance is 29% .In general, the local soil investigation practice is poor as can be seen from the percentage of compliance calculated.

### Key Words:

Geotechnical investigation

Pertinent codes

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## List of Abbreviations

FDRE	Federal Democratic Republic of Ethiopia
MoWUD	FDRE Ministry of Works & Urban Development
ICC	International Code Council
ECS	European Committee for Standardization
EBCS	Ethiopian Building Code Standards
EBCS-8	Ethiopian Building Code Standards (Earthquake)
ISI	Indian Standards Institution
NMC	Natural Moisture Content
CLSM	Controlled Low-Strength Material
NC Clay	Normally Consolidated Clay
OC Clay	Over-Consolidated Clay
CPT	Cone Penetration Test
RQD	Rock Quality Designation
SPT	Standard Penetration Test
MMS	Minimum Mass for Sieving
BH	Borehole
TP	Test Pit
DCP	Dynamic Cone Penetration Test
GWL	Groundwater Level
UN-ECA	United Nations Economic Commission for Africa
E	Young's modulus of plate material
Q	Load per sq. meter
$\nu$	Poisson's ratio
$I_{s50}$	Strength index
$c'$	Effective Cohesion Value
$\phi'$	Effective Angle of Internal Friction
$\tau$	Shear Stress
$\rho$	Bulk mass density

$C_u$	Strength index
K	Coefficient of permeability
$I_{CBR}$	California bearing ratio index
CBR	California bearing ratio
$e_{max}$	Maximum Void ratio
$e_{min}$	Minimum Void Ratio
( $w_p$ )	Plastic Limit Values
( $w_L$ )	Liquid Limit Values
$W$	Water content
$\sigma_T$	Tensile strength
% age	Percentage

# 1. Introduction

## 1.1 General

Site investigation is the process by which geological, geotechnical, and other relevant information, which might affect the construction or performance of a civil engineering or building project, is acquired.

Soil and rock are created by many processes out of a wide variety of materials. Because deposition is irregular, soils and rocks are notoriously variable, and often have properties which are undesirable from the point of view of a proposed structure. Unfortunately, the decision to develop a particular site cannot often be made on the basis of its complete suitability from the engineering viewpoint; geotechnical problems therefore occur and require geotechnical parameters for their solution.

A good geotechnical investigation involves a proper program of test points, material sampling and laboratory and in-situ testing. The number, depth and locations of these test points, samples, laboratory and field tests are dependent on the structure size, the loads imposed by the structure and the anticipated subsurface profile.

The growth Ethiopia's economy registered over the last decade is indisputable. This growth has been evident across many sectors but perhaps none more so than in construction sector especially in and around Addis Ababa. From the large office complexes on Bole road and large apartments around UN-ECA to the residential housing communities budding in the suburbs, it is amongst the first signs of progress to catch a visitor's eyes.

Considering the intensity of the rapidly growing construction industry especially buildings, the government has been involved in monitoring the quality of construction. Since one of the most important parts of building construction is the foundation. Therefore the Ethiopian government considered regulating the geotechnical investigation practice (ground investigation or soil investigation can be used alternatively) in the country before issuing building permit for all kinds of buildings. This is a very foundational step for both the growth of geotechnical investigation field and also for the improvement of construction.

As a professional on this sector and as a concerned Ethiopian citizen the unsafe practices, in the field of geotechnical investigation, are difficult to overlook and require major improvement. The main cause of the problem is lack of knowledge in the field of geotechnical

engineering. Additionally, the Ethiopian Building Code Standard [8], which is serving as a guideline in the country has been raising ambiguities. There are areas that should be improved while considering the geotechnical investigation practice in our country for better results.

Some of the areas which require improvements include:

- Detailed procedures in geotechnical investigation for evaluation purpose.
- Lack of mechanism to evaluate the uncertainties encountered during the geotechnical investigation work.

(This can improve the whole procedure if the practice is evaluated in comparison with other dependable codes /codes that have been found effective in other countries.)

- Lack of understanding of the benefits of detailed soil investigation.
- No guideline for the evaluation of the already done soil investigations reports from government offices.

So, it is certain that if unreliable geotechnical investigation methods are employed, the structural design will not be safe and economical.

## **1.2 Importance of the Study**

The geotechnical investigation phase of any structural design plays a vital role, where inadequate characterization of the subsurface conditions may contribute either a significantly over-designed solution which is not cost effective or an under designed one, which may lead to a potential failure.

One of the main objectives of geotechnical investigation is to help to overcome any possible failure that may arise both during and after construction period. This might be due to ground and other local conditions.

Insufficient geotechnical investigation is the primary source of project delay, disputes, claims, and project cost overruns. Due to lack of proper regulation or code of practice regarding the quality of site investigation work, geotechnical failures often occur. These failures sometime lead to catastrophic disaster that impose serious threat to public safety.

Therefore, this thesis work helps to assess the current geotechnical investigation practices and show some of the limitations. It also introduces strategies on how to monitor and improve the geotechnical investigation practice in Ethiopia for a better result.

### 1.3 Problem Statement

Most of the time, the procedures to be followed in geotechnical investigations are not considered as critical by geotechnical engineers. The absence of mechanisms to evaluate the uncertainties acquired during the geotechnical investigation work is also one of the problems. These uncertainties in comparison with other dependable codes (codes that have been found effective in other countries) will show where the problems lie. The other difficulty is lack of understanding on the benefits of detailed geotechnical investigation by local professionals. Therefore, identifying the problems and introducing strategies on how to improve the practice is very important for any engineering structural design.

### 1.4 Objective

In general, the objective of this research is to show the limitation on the ground investigation practice in Ethiopia. This includes the practices in geotechnical investigation firms, government offices/sub cities and design consulting offices.

Comparison between the actual geotechnical investigation practices and pertinent code provisions and requirements are made. This will show the severity of the local malpractice.

Proposing strategies on how to monitor and improve the practice is another objective. This will be made mainly by creating awareness among professionals on the advantage of doing a detailed geotechnical investigation. Supervising and controlling methods for the institution who will evaluate the geotechnical investigation reports in the country.

### 1.5 Methodology

Different methods and approaches are used to achieve the objective of this thesis. Selection of the pertinent codes that will be used to evaluate the local practice is the primary task. Questionnaire and interview are the major data collecting mechanisms used in this study. The primary data is collected from different target groups. These target groups are:

1. Professionals from geotechnical investigation firms,
2. Professionals form engineering consultants /structural design offices.
3. Professionals in the municipality/ Sub City / (who evaluate the soil investigation reports)

**Note:** The inquiries in the questionnaire are a combination of choices and of a subjective type to allow the professionals to express the response as desired.

Numerical scale method (Donald R. Cooper & Pamela S. Schindler, 2014) is used to weight the significance of different pertinent code provisions and requirements. Comparison will be made between the practice and the pertinent code provisions and requirements.

### **1.6 Organization of the Thesis**

Organization of this research is demonstrated in different chapters and short review of each chapter is given below.

The first Chapter consists of the introductory part. The research problem and objectives are also discussed here. The second Chapter discusses different stages/steps that will be relevant to do a complete ground investigation. Selecting criteria from the pertinent codes that will help to compare the actual practice in Ethiopia with these codes is also covered in this chapter. In the third chapter, review of the pertinent provisions and requirements of selected codes of practice is given. According to the provisions and requirements, the selected pertinent building codes are studied thoroughly for each element of the investigation procedure. A short summery is given under each provision and requirement. This is to evaluate the different practices from the pertinent codes selected. In the fourth chapter, comparison and analysis of collected data is done. This includes processing the data collected from the questionnaire and interview. And finally, conclusion and recommendations are given in the last chapter.

## 2. REVIEW OF PERTINENT PROVISIONS AND REQUIREMENTS OF SELECTED CODES OF PRACTICE

### 2.1 General

Geotechnical investigation for a specific project site is essential before a design can be finalized. This will provide important information for the engineers about the existing subsurface condition.

In order to gather the necessary information for the needed extent and quality of geotechnical investigations, detailed planning and constant site supervision during ground investigation and construction stage must be carried out.

While considering geotechnical investigation, there are two bodies which are responsible to carry out complete ground investigation. They are Geotechnical Contractors and Geotechnical Consultants and these bodies have a big role to play in controlling the quality of the geotechnical investigation.

**The Geotechnical Consultant:** is a consultant who is responsible for planning the soil investigation program. The consultant is also responsible for the supervision of the work and all the necessary steps that will be carried out by the contractor. To ensure quality of the works, supervision for at different stages of pre-design ground investigation field works should comply with the requirements set out in the relevant local code of practice [1].

The entire necessary detailed and complete work plan should be provided by the consultant geotechnical engineer. The following are the main issues that need to be planned:

- Selection of exploration method
- Investigation depth
- Type and frequency of field tests
- Type and frequency of sampling /disturbed and undisturbed/
- Groundwater measurement
- Type of laboratory tests and classification
- Data interpretation, analysis and presentation

These services should be supervised continuously until all the information needed is collected both in the field and in the laboratory. Lack of monitoring the investigation by professionals' may result in uneconomical and unsafe structure.

**The Geotechnical Contractor:** is a contractor who implements the soil investigation program that is given by the geotechnical consultant. The planning will be successful if the implementation is supervised to make sure that the investigation is carried out as per the plan.

Early stage discussion with a specialist contractor helps to prepare an efficient and economical plan. In many cases, a preliminary investigation may be desirable depending on the project size, so that one can conduct a cost effective detailed ground investigation [9].

In order to evaluate the ground investigation practice in Ethiopia, four pertinent codes are selected. These codes are reviewed in detail according to the selected code provisions of available codes. The criteria considered for the selection of the pertinent codes are the following:

- **Ethiopian Building Code Standard, 1995** – This code is published in Ethiopia and the practice under evaluation is also located in the same country. The code is a dominating, legally accepted and available code in Ethiopia.
- **European Standard, 2007** - This code represents many European countries.
- **International Building Code, 2009** – This code is published in the United States of America. The fact that the country has a worldwide acceptance and its influence in the global economy made this code one of the pertinent codes to be selected. Additionally, the code is available in English.
- **Indian Standard, 1985** – This code is issued in India. The fact that it represents the rather large region of Asia makes it selected as an important document.

The pertinent codes are reviewed for provisions and requirements of critical geotechnical investigation stages. Under each investigation stage all four pertinent codes are reviewed. Tables are provided to show code provisions and requirements from each pertinent code and are considered as the main body of this chapter. These Tables range from A.1 to A.30 and are presented in Appendix A.

## 2.2 Ground Investigation Methods and Planning

Ground investigation shall be carried out for any engineering structure before its foundation is designed and method of construction is determined. Based on the projects requirement, different investigation methods will be applied. These selected investigation methods will be planned to increase effectiveness, to have a safe and economical design.

### 2.2.1 Ground Investigation Method

Generally, the extent on which the ground investigation is carried out can go up to three stages. These are reconnaissance, preliminary and detailed investigations. Review of requirements from each pertinent code for selection of investigation methods is given in Appendix A- Table A.1. Tables with similar structures can be treated like wise.

#### **Observation**

While considering the method of ground investigation, the Ethiopian Building Code Standard and the European Standard give similar considerations. International Building code gives high regard for the decisions made by the registered design professional. It also gives more detailed requirement and also considers potential geologic and seismic hazards. Cost and topography considerations are not mentioned in the other codes but are the main factors in Indian Standard for exploration method selection.

#### **a) Site Reconnaissance and Preliminary Investigation**

Site reconnaissance, preliminary and detailed investigation is carried out for big projects. And the first two phases are very important to decide on the extent of the detailed investigation. Review of pertinent code provisions for site reconnaissance and preliminary investigation is shown in Appendix A-Table A.2.

#### **Observation**

Both European Standard and Indian Standard give more or less similar provisions concerning site reconnaissance and preliminary investigation, but a more elaborated method is given by the Indian Standard. Ethiopian Building Code Standard and International Building Code do not mention this stage of investigation.

#### **b) Detailed Investigations**

The detailed investigation is carried out after the preliminary investigation. It should be planned based on the data provided during site reconnaissance and preliminary investigations. This plan may be reviewed and revised as the investigations progresses. The primary objective

of detailed exploration is to determine the engineering properties of strata which the preliminary exploration deemed to be critical [5]. Reviews of pertinent code provisions for detailed investigations are shown in Appendix A-Table A.3.

### **Observation**

The Indian Standard is the only standard from the four codes that give a provision concerning detailed ground investigation. This stage gives more detailed information, as the name clearly shows, to design the foundation economically.

## **2.2.2 Ground Investigation Planning**

Ground investigation should be planned to carry out the investigation properly. Since the plan includes different steps, supervision is mandatory for proper implementation of the plan and also for a better quality of investigation. Review of pertinent code provisions for ground investigation planning is shown in Appendix A-Table A.4.

### **Observation**

The Ethiopian Building Code Standard considers majorly the project type, the loads that act on the structure and the nature of the ground. The European Standard unlike the other codes gives a detailed planning procedure for the ground investigation. The code considers different stages of field investigation up to sampling and laboratory tests. Therefore, using this planning procedure will lead to a more organized, safe and economical investigation. International Building Code states only four points to consider and is not wise to use this as the only requirements for designing the investigation. Indian Building Code did not indicate any information about planning the investigation.

## **2.3 Location, Number and Spacing of Testing Points**

Location, number and spacing of investigation points shall be selected based on the information gathered from preliminary investigations. Additionally, site geology, importance of the structure and area on which the structure covers plays an important role. Review of pertinent code requirements for location, number and spacing of testing point is shown in Appendix A- Table A.5.

### **Observation**

Different views have been reflected concerning number, spacing and location of investigation points by the codes. Type of the project is common factor for Ethiopian Building Code Standard, European Standard and Indian Standard while considering number, spacing and

location of test points. Soil stratification is also another factor to determine this information but only Ethiopian Building Code Standard and European Standard use it. European Standard and Indian Standard states that additional field tests might be carried out and proper consideration is given for the spacing of these different tests. The only code that considered the area of the project as a determining factor for the case under study is Indian Standard. International Building Code gives total responsibility for the professional to decide on the number, spacing and location of investigation points.

#### **2.4 Depth of Exploration**

Exploration is normally carried out to a depth which includes all strata likely to be affected by the structural load [8].. Review of pertinent code requirements to determine depth of exploration is shown in Appendix A- Table A.6.

##### **Observation**

Type of the project, stress/load on the foundation, geology of the site, width of the foundation is the common factors considered to determine the depth of exploration in EBCS 7, Euro Code 7 and Indian Standard. EBCS 7 suggests different values to consider investigating deep foundations (pile foundations). In Euro Code 7, the effect of ground water level is also considered to determine the depth of exploration. International Building Code gives no detailed requirements except for a structure located on a rock layer which have doubtful characteristics in the structure of the rock.

#### **2.5 Drilling Rigs for Boring**

During investigation if the exploration depth is shallow and if the soil profile is soft formation /alluvial deposit, Auger can be used but they are difficult to operate below the water table. And so different types of drilling rigs are introduced for different type of soil layer to do the exploration task [5].Review of pertinent code requirements for selection of drilling rigs for boring is shown in Appendix A- Table A.7.

##### **Observation**

According to the Ethiopian Building Code Standard, the type of machines used for exploration method depends on the depth of exploration. Some of the machines mentioned in this code are found also in the Indian Standard. The Indian Standard also considers type of field tests and samples required while investigating the ground. European Standard and International Building Code give no specific requirement, for selection of drilling machineries.

## 2.6 In-Situ Tests /Field Tests

Field tests are carried out on the soil without removing the material from its existing position. This test plays a major role where extraction of soil sample for laboratory test is impossible to provide information about the soil profile. Review of Pertinent Code Requirements for In-Situ Tests /Field Tests is shown in Appendix A- Table A.8.

### **Observation**

The local code /EBCS 7/, Euro Code 7 and Indian Standard considered design parameters required by the professionals, as a requirement to select the type of field test. But Euro Codes 7 gives more detailed consideration while selecting the field tests. Most of the tests given by the codes are similar. The International Building Code gives the full mandate to a registered design professional.

## 2.7 Sampling

While sampling soil/rock for soil investigation purposes, there are many factors that should be considered. Sampling methods and planning, sampling tools, type of samples collected, frequency of sampling, and depth of sampling are some of these factors.

### 2.7.1 Sampling Methods and Planning

Sampling of soils and rocks by drilling and excavations shall be conducted so comprehensively that the necessary geotechnical design data are obtained (ECS, 2007).

Review of pertinent code requirements for sampling methods and planning is shown in Appendix A- Table A.9.

### **Observation**

Ethiopian Building Code Standard, European Standard and Indian Standard give different considerations for sampling methods and planning. Indian Standard gives a more detailed and elaborated procedures compared to the others on the other hand International Building Code gives no specific concern regarding sampling methods and planning.

## 2.7.2 Sampling Tools

Generally, properly designed sampling tools are required to take undisturbed samples from bore holes. These differ for cohesive, non-cohesive soils and for rocks. Review of pertinent code requirements for sampling tools are shown in Appendix A- Table A.10.

### **Observation**

Ethiopian Building Code Standard, European Standard and Indian Standard give sampling tools. Indian Standard gives more detailed considerations for different soil classes. International Building Code gives no specific direction regarding sampling tools but sampling tools shall be determined by a registered design professional.

## 2.7.3 Soil Sampling

Soil sampling in ground investigation plays a very important role in determining the foundation recommendation. Soil sampling includes frequency of samples, categories of soil sampling methods, laboratory quality classes, soil identification and size of samples.

### **a. Frequency of Soil Sampling**

Different type of sampling methods is reviewed above and in the following sub sections soil sampling frequency, categories of sampling methods, and laboratory quality classes of samples and size of soil sampling will be discussed. Review of pertinent code requirements for soil sampling frequency is shown in Appendix A-Table A.11.

### **Observation**

The Local Code and Indian Standard give some considerations regarding sampling frequency for soil. European Standard stated that change of the stratum is the main factor that should be considered while considering the frequency of sampling.

### **b. Categories of Soil Sampling Methods, Laboratory Quality Classes and Size of Samples**

Different soil sampling methods are in use and both disturbed and undisturbed soil samples are collected according to the professional's discussion. These samples extracted will have difference in quality classes which are showed in section 2.7.3.

Review of pertinent code requirements concerning the categories of soil sampling methods, laboratory quality classes and size of samples is shown in Appendix A-Table A.12.

**Observation**

European Standard specific soil sampling methods, laboratory quality classes and size of samples for soil and both the local code and the Indian Standard give identical requirements concerning size of samples. International Building Code recommended nothing regarding soil sampling frequency

**c. Soil Identification**

Major constituents of the soil shall be identified before other field and laboratory tests are carried out for ground investigation purpose. Review of pertinent codes requirement for soil identification is shown in Appendix A-Table A.13.

**Observation**

The Ethiopian Building Code Standard and European Standard give different considerations while identifying the soil sample recovered. On the other hand, both International Building Code and Indian Standard did not specifically state anything regarding soil identification.

**2.7.4 Rock Sampling**

Rock sampling is usually done with core drilling machines for recovering rock samples. Since different characterizations of a rock can be identified, frequency and laboratory test types should carefully be programmed.

**a. Frequency of Rock Sampling**

Rock sampling frequency should be determined before performing the investigation. It is the most critical method for both bearing capacity and settlement calculations.

Review of pertinent code requirement for frequency of rock sampling is shown in Appendix A-Table A.14.

**Observation**

Only Indian Standard gave a guide on how frequently a professional should collect rock samples.

**b. Categories of Rock, Sampling Methods, Laboratory Quality Classes and Size of Rock Sample**

Review of pertinent codes requirement to categorizer, select sampling methods, identify laboratory quality classes and size of rock sample is shown in Appendix A-Table A.15.

**Observation**

The Ethiopian Building Code Standard and European Standard give detailed criteria to characterize, classify rock mass and select sampling methods. Indian Standard gives factors used

to evaluate the quality of rock profile. International Building Code gave no criteria concerning the rock sampling in general.

### **c. Rock Identification**

To identify rock, a professional should use different methods as can be seen from different standards.

Review of pertinent codes requirement to identify rock samples is shown in Appendix A-Table A.16.

#### **Observation**

Ethiopian Building Code Standard and European Standard give different systems to characterize and identify rock samples. Indian Standard and International Building Code gave no remark regarding rock identification.

### **2.7.5 Protection, Handling, Labeling, Transporting and Storing of Samples**

To conduct a reliable ground investigation one must give due considerations and take a great deal of care while extruding, protecting, handling, labeling, transporting and storing of samples.

Review of pertinent code requirements for protection, handling, labeling, transporting and storing of samples is shown in Appendix A-Table A.17.

#### **Observation**

The Ethiopian Building Code Standard briefly mentions that protection and handling of sample is important and labeling of samples must be done immediately. The local code and its Indian counterpart gave sample labeling formats. European Standard states the need for protection and clear labeling of samples, careful handling and transportation, especially for undisturbed soil samples, is require. Indian Stands deals with the matter rather in detail compared to the other codes. This code addressed the issues by dividing samples in three categories, disturbed soil samples, undisturbed soil samples and rock samples. International Building Code gave no directives regarding protecting, handling, labeling, transporting and storing of samples.

### **2.7.6 Extrusion of Samples**

Samples are taken from the site as per the investigation plans and these samples should be carefully extracted from sampling tools.

Review of pertinent code requirements for extrusion of samples is shown in Appendix A-Table A.18.

### **Observation**

The Ethiopian Standard emphasizes that sample shall not be disturbed while extrusion. To maintain this undisturbed state of the sample, the code states type of tools, method, orientations and direction of extrusion. The Indian Standard having given the same emphasis on maintaining the undisturbedness of sample as that of the local code, it also adds some extra points, like the precaution that needs to be taken while employing tools such as screw type extruders and while handling soft clay samples. Both the European Standard and the international Building Codes gave no directives regarding extrusion of samples.

## **2.8 Laboratory Tests on Soil, Rock and Water**

Laboratory tests for soil samples are done to provide reliable data for designing the geotechnical investigation. Different tests are carried out as per the investigation plan.

### **2.8.1 Laboratory Tests on Soil**

The laboratory test is established in conjunction with the other parts of the ground investigation program. The information gathered from field tests is used to select the test for samples.

Soil samples must be tested in the laboratory to find data used for the bearing capacity and settlement calculation.

Review of pertinent codes requirements for laboratory tests on soil is shown in Appendix A-Table A.19.

### **Observation**

The Ethiopian Standard state that a laboratory test on soil provides mainly the soil engineering properties and this is considered also by the rest of the standards. The local code gives laboratory test types that are used to indicate the physical characteristics of the soil. The European code provided numerous laboratory test types compared to the other standards and it also gives the respective test results which should be presented in the ground investigation report. The Indian standard divides and tabulates the laboratory test in to two categories, physical tests and chemical test; it is not as elaborate as the European counterpart. The international Building Codes gave no directives regarding laboratory tests on soil.

### 2.8.2 Laboratory Tests on Rock

Proper type of laboratory test is carried out for rock samples. The result is very important to design foundation report.

Review of pertinent codes requirements for laboratory tests on rock is shown in Appendix A-Table A.20.

#### **Observation**

Concerning the laboratory test on rocks, the Ethiopian standard and its Indian counterpart somewhat provide similar laboratory tests. The European Standard states the tests with their result /engineering parameters/ of rock samples. The international Building Codes gave no directives regarding laboratory tests on Rocks.

### 2.8.3 Laboratory Tests on Water

The objective laboratory test is to determine the water chloride, Sulphate content & PH value. The results provide an index for the possible effect of the groundwater towards concrete, steel, other materials and soil.

Review of pertinent codes requirements for laboratory tests on water is shown in Appendix A-Table A.21.

#### **Observation**

The presence of certain chemical constituents in ground water can be very significant while considering the durability of the structure. The European Standard stipulates the conduction of routine chemical tests. In the Indian Standards, the mode of water sample extraction is stipulated as well tabulated test list is provided. The local code and the international Building Codes gave no directives regarding laboratory tests on Water.

### 2.9 Classification of Soils and Rocks

As a major part of ground investigation, the classification of soil and rock is of a paramount importance. Therefore, classification of soils and rock must be done according to their grain size, material composition and plasticity, as materials of construction and consistency.

Review of pertinent codes provisions for classification of soils and rock is shown in Appendix A-Table A.22.

### **Observation**

The Ethiopian Standard has set three classification parameters for the classification of Soils and rock classification as a function of consistency. And this standard is the only standard among the pertinent code assessed, which provided classification parameters.

#### **2.9.1 Symbols for Presentation of Soils and Rocks**

Different soil and rock types are presented in symbols agreed.

Review of pertinent codes provision of symbols for presentation of soils and rocks is shown in Appendix A-Table A.23.

### **Observation**

The Ethiopian Standard and the Indian standards have stipulated different types of Symbols for representation of soils & rock. On the contrary the European and the International standards did not include such a provision.

#### **2.10 Groundwater Level Measurement**

The presence of ground water is critical in foundation design and construction. Particularly where dewatering is likely to be required, adequate information on groundwater and geological conditions should be gathered. These include permeability, compressibility and consolidation characteristics of the various soil data, particle size analysis and other test results which are relevant to the consideration of dewatering activities (MoWUD, 1995).

##### **2.10.1 Planning and Execution of Groundwater Level Measurement**

Ground water measurement should be planned and the plan should be implemented. Different building codes use various planning methods.

Review of pertinent codes provisions for planning and execution of groundwater level measurement is shown in Appendix A-Table A.24.

### **Observation**

The European Standard gave a guide line on how to plan and execute groundwater level measurement.

## **2.11 Ground Investigation Report**

Reporting geotechnical investigation includes the factual data, analysis of the data gathered from both field and laboratory tests and documentation of the methods used to carry out different tests and design calculation.

### **2.11.1 Presentation of Geotechnical Information /Descriptive Report or Factual Report**

Factual report is mandatory while presenting the results of the ground investigation. Visual inspection, laboratory tests and engineering judgments are the most commonly used methods to present the findings.

Review of pertinent codes provisions for presentation of geotechnical information is shown in Appendix A-Table A.25.

#### **Observation**

Presentation of geotechnical information should incorporate sufficient data about the project site, project and also different methods during the ground investigation. And all the codes suggest very similar and detailed provisions.

### **2.11.2 Evaluation of Geotechnical Information/Engineering Interpretation**

Geotechnical information /report are evaluated by cross checking the information gathered from the field tests, laboratory tests and other related data with the report.

Review of pertinent codes provisions for evaluation of geotechnical information is shown in Appendix A-Table A.26.

#### **Observation**

The local code and European Standard states more or less similar consideration to evaluate the geotechnical information. Both Indian Standard and International Building Code mentioned nothing regarding evaluation of the geotechnical information.

### **2.11.3 Geotechnical Design Calculations**

The engineering structure might experience different type and intensity of loading. Each of these loads should be analyzed and design calculations should be performed to give the bearing capacity.

**a) Loads Applied on Foundations**

One of the major criteria that should be considered is super-structure loading.

Review of pertinent codes considerations for the loads applied on foundations for geotechnical design calculations is shown in Appendix A-Table A.27.

**Observation**

Ethiopian Building Code Standard considered various types of actions for foundation design calculation. On the other hand, International Building Code considers load types that are not mentioned in the local code. Some of these are vibratory loads and shifting or moving soils. European Standard and Indian Standard gave no specific suggestion regarding design loads.

**b) Bearing Capacity Calculation Methods**

Bearing capacity is one of the critical values to be estimated when designing a foundation. It is the highest pressure the soil can resist .

Review of pertinent code provisions regarding bearing capacity calculation methods is shown in Appendix A-Table A.28.

**Observation**

All except the International Building Codes give different approaches to estimate the bearing capacity. The International Building Code provides presumptive bearing capacity values for different foundation layers.

**c) Settlement Calculation Methods**

Once the ultimate bearing capacity has been calculated and the dimensions of the footing have been established, the settlement under the foundation pressure is calculated. The settlement of a structure is often decomposed into an elastic component /elastic settlement, then a time delayed component associated with water stress dissipation/consolidation, then a time-delayed component associated with the slow movement of particles as a function of time /creep settlement .

Review of pertinent code provisions regarding settlement calculation methods is shown in Appendix A-Table A.29.

**Observation**

All except the International Building Codes give different approaches to calculate the settlement beneath the foundation.

## **2.12 Supervisions at the Investigation Stage and During Construction**

The ground investigation gives a site-specific data for the foundation design but this not the final stage. The recommended foundation design with all the detail has to be implemented on the project site and the ground investigation report should be rechecked to attain the final goal which is safety and being economical.

Review of pertinent code considerations while supervising at the investigation stage and during construction is shown in Appendix A-Table A.30.

### **Observation**

All except the Indian Standard give different control measures that should be considered while doing the supervision.

### 3. ANALYSIS AND RESULT

The local practice in the field of soil investigation is assessed by collecting primary data (questionnaire and interviewing) from different professionals in the country.

The primary data gathered is organized and analyzed for each category of respondents. Categories of respondents with all the necessary information are shown in Table 1.

Table 1: Categories of Respondents and General Assessment

<b>Response from Questionnaires</b>				
<b>No.</b>	<b>Category of Respondents</b>	<b>No. of Respondents/ Sample</b>	<b>General Evaluation</b>	<b>Remark</b>
1	Professionals from geotechnical investigation firms (both government and privately owned) and from government regulatory body	23	Majority of them have responded almost to every inquest	These are the main target groups to assess the geotechnical investigation practice
2	Professionals from engineering consulting offices	15	Very few of the respondents completed filling the questionnaires	-
Total Respondents =		38		
<b>Response from Interview</b>				
1	Professionals from government regulatory body (sub cities)	3	All of them have responded almost to every inquest	-
Total Respondents =		3		

Generally, 3/4<sup>th</sup> of the respondents responded well. But more than 43% Structural Engineers and 15% Geotechnical Engineers reject to fill the questionnaires. More than half of the Structural Engineers who refused to fill the questionnaires declare that it is not their field of specialty. They recommend that the questioner should be given for the geotechnical Engineers only. On the other hand, the geotechnical engineers decline to fill the questionnaires because they believed that there will be no use in doing so.

Interview is also conducted with the professionals from government regulatory body (sub cities). These professionals have the mandate to reject or approve any geotechnical investigation reports. Interview made with these professionals is analyzed in section 3.5 and the query made in the interview is given in Appendix B.

To critically assess the geotechnical investigation practice in Ethiopia in light of the pertinent building code provisions the following steps are followed.

The primary step is to categorize the responses gathered from questionnaire. Secondly, for each criterion chosen, which are also mentioned and clearly presented in detail in section one, list of pertinent code provisions and requirements /factors to consider are given in each table. This is so, because the actual ground investigation practice will be compared with the pertinent codes as follows.

While selecting pertinent code provisions and requirements, the following general points are given stress:

- Emphasis is given to Ethiopia Building Code Standard for it governs the local practice,
- Common code provisions and requirements from each pertinent code are considered and is used,
- The responses gathered from the respondents are organized, filtered and categorized according to the codes provision and requirements listed previously.

The third step is evaluating the responses with respect to the considered pertinent code provisions and requirements. After doing so, percentage of respondents is calculated and comparison with the analysis is done. The sample questionnaire is given in Appendix A.

Note that Geotechnical Engineers are the main target groups to evaluate the geotechnical investigation practice in Ethiopia.

And finally, for a complete presentation and evaluation of the data, the selected code provisions and requirements are given different weights. And to accomplish this ‘Numerical Scaling Method’, (Donald R. Cooper & Pamela S. Schindler, 2014) is used.

Numerical Scaling method is a type of approach that uses verbal anchors such as ‘Very important,’ ‘More important,’ ‘Important,’ ‘Less important,’ and ‘Unimportant’ (Donald R. Cooper & Pamela S. Schindler, 2014). It is used to label the significance of the provisions/requirements. An equal interval is used between any two consecutive verbal anchors. The scales are designed with five point scales.

Accordingly, the numerical scale method gives weight for the detailed provisions and requirements of the four pertinent codes. This is presented as follows:

- For provisions/requirements mentioned in four of (all of) the pertinent codes, the weighting factor given is 4. This implies that the provisions/requirements are labeled as a Very Important factor.
- For provisions/requirements mentioned in three of the pertinent codes, the weighting factor given is 3. This implies that the provisions/requirements are labeled as a More Important factor.
- For provisions/requirements mentioned in two of the pertinent codes, the weighting factor given is 2. This implies that the provisions/requirements are labeled as an Important factor.
- For provisions/requirements mentioned in one of the pertinent codes, the weighting factor given is 1. This implies that the provisions/requirements are labeled as a Less Important factor.
- For provisions/requirements mentioned in none of the pertinent codes, the weighting factor given is 0. This implies that the provisions/requirements are labeled as an Unimportant factor.

The scales linearity, simplicity and production of interval data make it suitable for this research, to present the desired results as necessary.

After weighting and calculating the weighted percentage, percentage of compliance is calculated for the local ground investigation practice in comparison with the selected pertinent code standards. This is done by considering the weighted total percentage. The presentation for both categories of respondents is shown in section 3.2 and 3.3. Comparison is also made between the two target groups (Geotechnical Engineers and Structural Engineers).

In section 3.1, the local ground investigation practice is evaluated based on the responses gathered/questionnaire/ from professionals from geotechnical investigation firms. For each criterion, the result is presented using both tables and figures.

The same procedure is followed for the structural engineers from engineering consulting offices and summery of the result is presented in Figure 34.

### 3.1 Analysis of Questionnaires /From Geotechnical Investigation Firms/

#### 3.1.1 Exploration Method Selection & Ground Investigation Planning

Selection of exploration method and planning the ground investigation is a primary job in the field of ground investigation. Different considerations and factors that affect this step are shown below.

##### a) Qualified Professionals for Exploration Method Selection and Ground Investigation Planning

A qualified professional should be assigned to select exploration methods and plan the ground investigation. Table 2 shows the response from professionals (from Geotechnical Investigation Firms) concerning the selection of qualified professionals for these investigation stages.

The composition of the table can be described as follows. The first column of Table 2 describes different pertinent provision and considerations/factors that affect the selection of the professionals. The second column describes number of respondents corresponding to the codes provision and requirements. The third column gives percentage of response for each provision/requirement given. And tables with similar structures (as we will see later) can be treated like wise.

Table 2: Qualified professionals for exploration method selection and ground investigation planning

Qualified Professionals for Exploration Method Selection and Ground Investigation Planning	No. of Responses (Total Respondent 23)	% age of Responses
Geotechnical Engineers	19	83%
Geologists & Engineering Geologists	4	17%

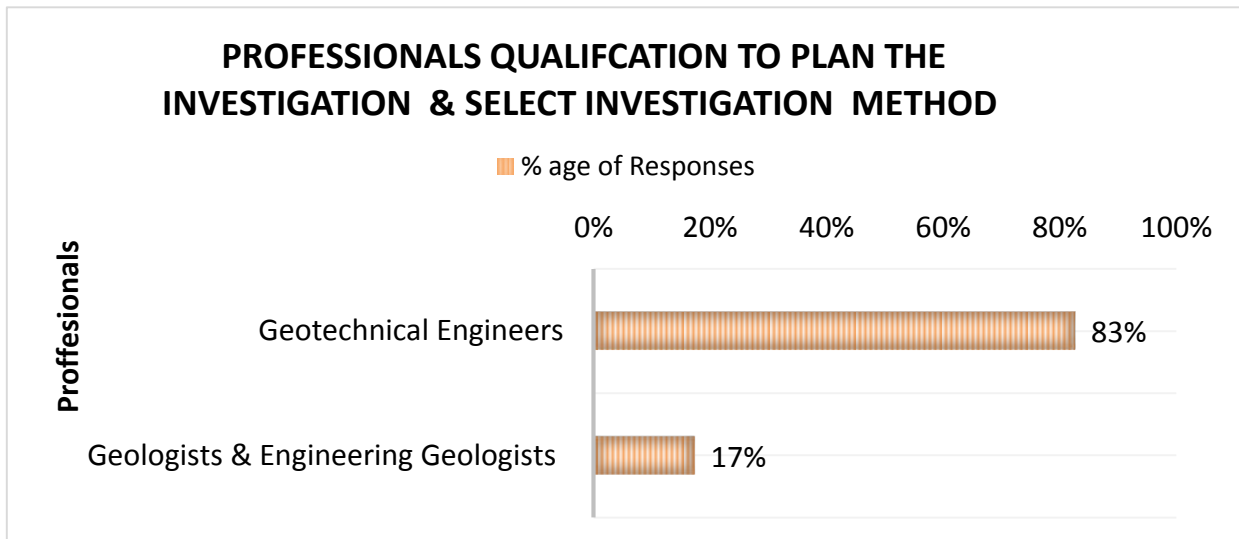


Figure 1 Plot showing percentage of response against professionals' qualification for planning investigation and selection of investigation method.

Table 2 and Figure 1 show that 83% of the respondents agreed on delegating geotechnical engineers to decide the exploration methods and to carry out the exploration planning. And yet 17% of them believe Geologists / Engineering Geologists should be responsible in carrying out these task.

#### **b) Selection of Ground Exploration Method**

The first crucial step in ground investigation is selection of ground exploration method. Careful selection of the method will guarantee the quality of the exploration. Accordingly, Table 3 presents the result from the respondent's corresponding to the factors that affects the selection of ground exploration method from the codes.

The composition of the table can be described as follows. The first column of Table 3 describes different pertinent provision and considerations/factors that affect the selection of the ground investigation. Second column gives number of respondents for each pertinent provisions and requirements. The third column gives percentage of respondents. The fourth column gives weight for each factor affecting the selection of the exploration method with respect to their significance as discussed earlier. This ranges from 4 (Very important) to 0 (Unimportant).

Weighted percentage is presented in the fifth column. It is calculated by considering percentage of respondents and weighing factor from column three and column four respectively. The last column displays the weighted total percentage. This figure is computed by dividing sum of the weighted value with the sum of weight factors. This value represents percentage of compliance of the response with the specific pertinent code provision and requirement / for ground exploration method selection (Refer Figure 22, 23&24).

And for presentation purpose Figure 1 is plotted taking percentage of respondents against pertinent requirements and provisions from Table 3. Tables and figures with similar structures can be treated like wise.

Table 3: Factors Considered for Selection of Ground Exploration Method

Factors Affecting Selection of Ground Exploration Method	No. of Responses (Total Respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Preccence of groundwater	None	0%	3	0%	
The amount of existing information	2	9%	3	26%	
Nature of ground/geology of the site	6	26%	4	104%	
Type and design of the construction	20	87%	3	261%	
Topography	None	0%	1	0%	
Cost	None	0%	1	0%	
Exploration near to existing foundation	None	0%	2	0%	
Seismicity	None	0%	1	0%	
		Row Sum	18	391%	

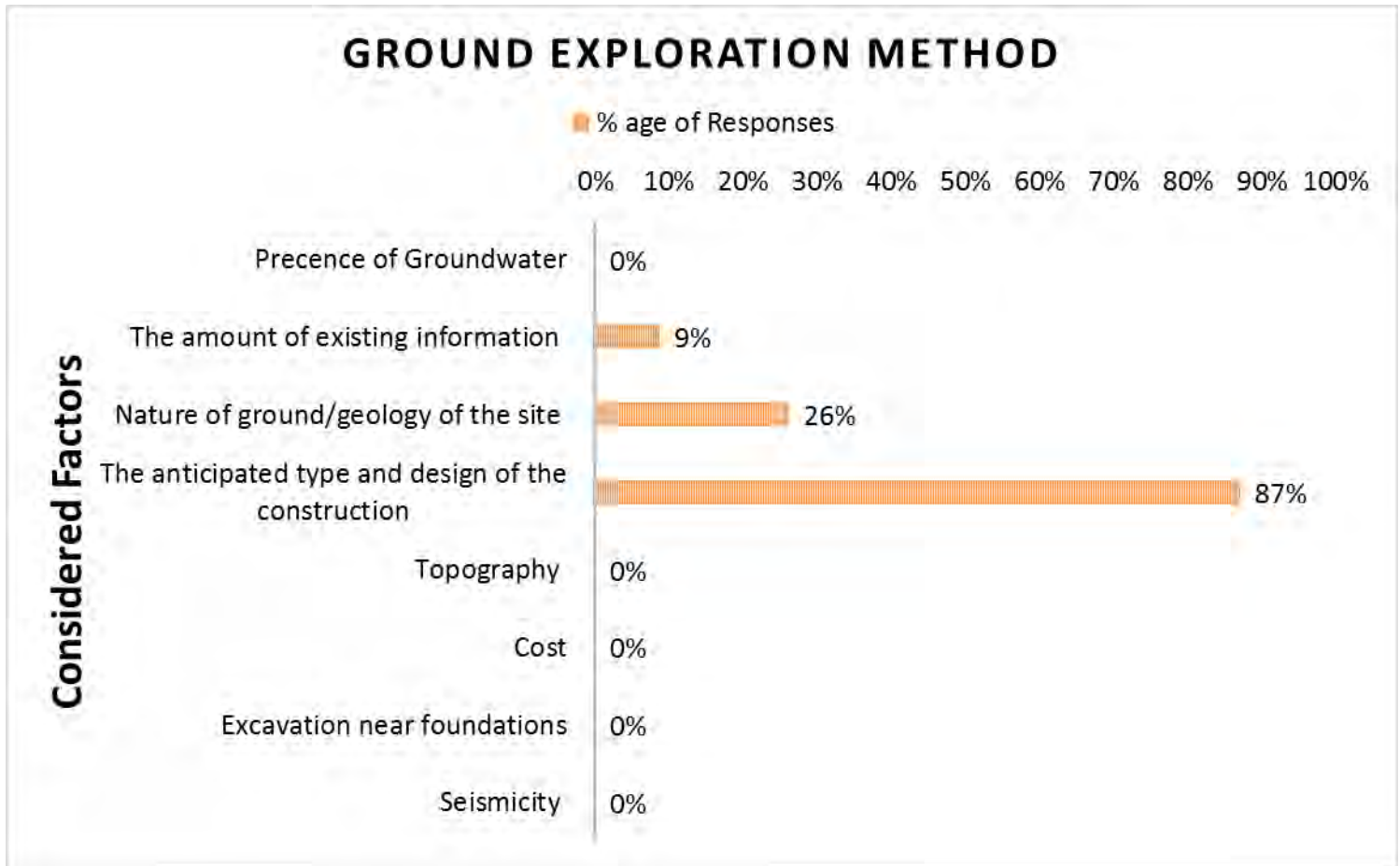


Figure 2: Plot showing percentage of respondents against factors affecting selection of ground exploration method

Figure 2 shows that 87% of the respondents consider that the anticipated type and design of the construction is a main factor in selecting the investigation method. 26% and 9% of them consider nature of the ground and the amount of existing information respectively will be useful in the selection process. The rest of the factors are not considered at all by the respondents.

**c) Site Reconnaissance & Preliminary Investigations**

Site reconnaissance and preliminary investigations are the primary stages of the ground investigations. Table 4 shows 87% of the respondents consider these investigation phases significant.

Table 4: Degree of Significance in Conducting Site Reconnaissance & Preliminary Investigation

Significance of Reconnaissance & Preliminary Investigations	No. of Responses (Total respondent 23)	% age of Responses
Significant	20	87.0%

Tables 5 and Figure 3 show different methods on how to conduct site reconnaissance & preliminary investigation against percentage of respondents. 22% of the respondents carry out desk study and review previous studies, whereas only 4% of the respondents consider drilling small number of boreholes and carry out field tests as needed to conduct the preliminary investigation.

Table 5: Methods for Conducting Site Reconnaissance and Preliminary Investigations

Methods for Conducting Preliminary and Reconnaissance Investigations	No. of Responses (Total respondent 23)	% age of Responses
Drill few no. of boreholes / tests pits and conduct field tests	1	4%
Desk study	5	22%
Electrical resistivity method	None	0%
Seismic method	None	0%

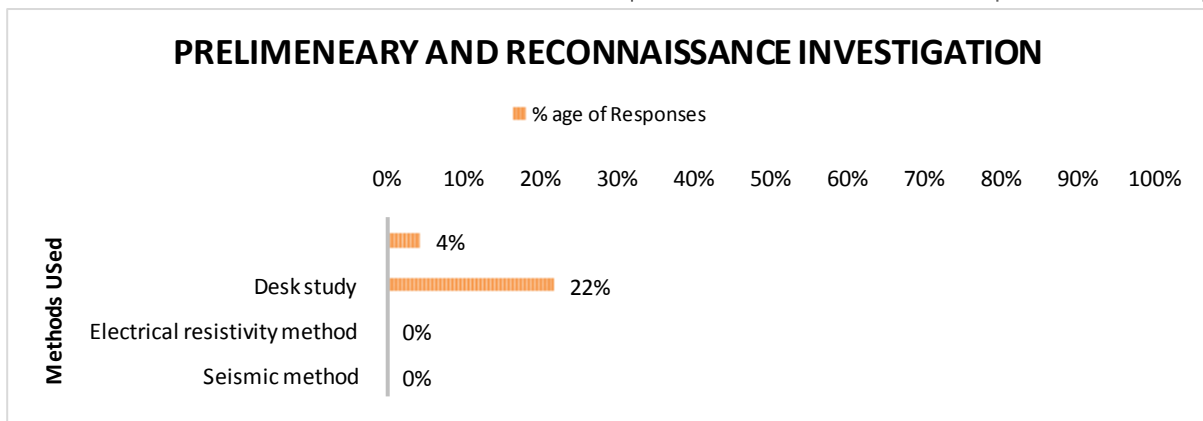


Figure 3 Plot showing percentage of response against methods used for preliminary and reconnaissance investigation.

#### d) Significance of Ground Investigation Planning

Proper planning of the ground investigation is necessary for safe and economical foundation design. Table 6 and Figure 4 plot showing percentage of response against methods used for preliminary and reconnaissance investigation. Presents the response from the professionals concerning the significance of ground investigation planning. And 13% of the respondents' objective in doing the investigation planning is safety and 17% to be economical. The rest 70% of the respondents gave no comment and this shows that the professionals are not aware of the significance of the discipline.

Table 6: Significance of ground investigation planning

Significance of Ground Investigation Planning	No. of Responses (Total respondent 23)	% age of Responses
Safty	3	13%
Economy	4	17%
Both(Safe & Economy)	2	9%

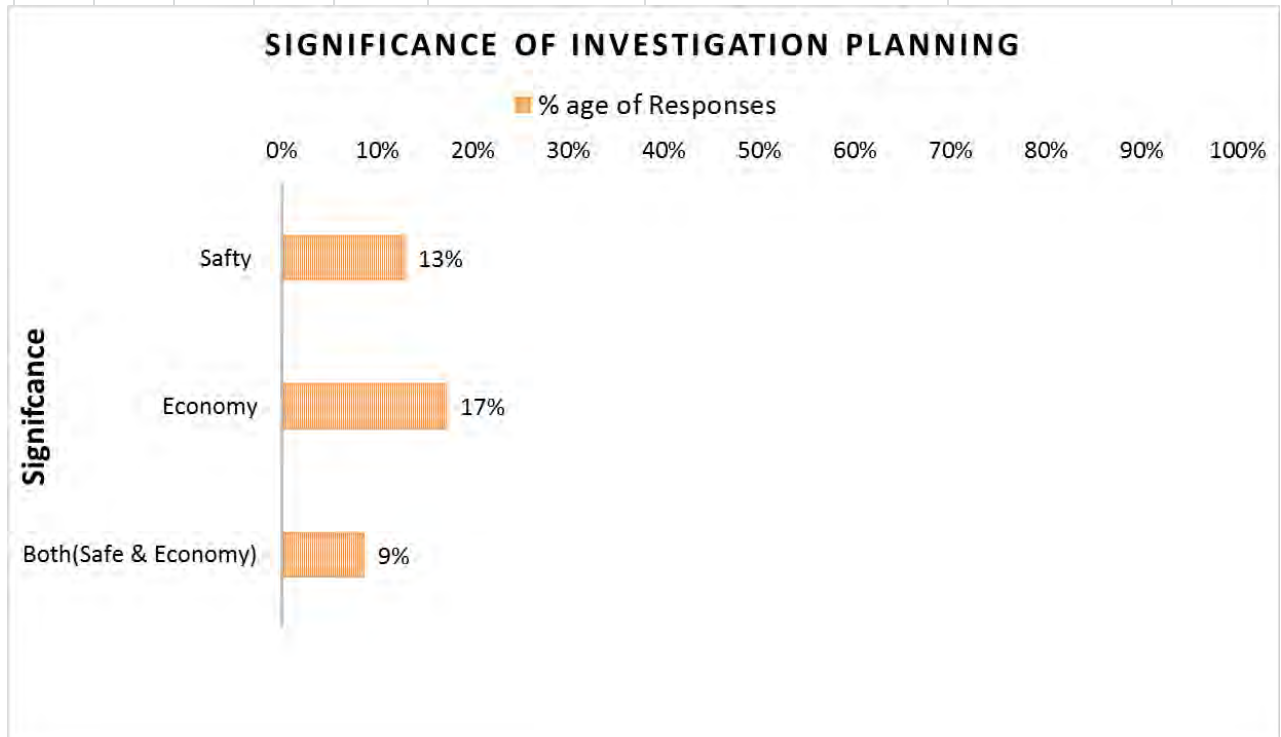


Figure 4: Plot showing percentage of response against significance of investigation planning.

**e) Planning Ground Investigation**

After the Investigation method is selected the planning will progress. Whether it needs a detailed or a preliminary investigation, the planning is very crucial for estimating work volume, methods to follow, time schedule and cost.

The planning should mainly specify exploration method (drilling/or test pit), depth and frequency of sampling, Type and frequency of both laboratory and field tests and the standards to be guided by.

Table 7 and Figure 5 shows the professionals' response concerning planning of ground investigation. Accordingly, 13% of the respondents consider planning laboratory tests and

exploration method are the only factors that should be considered when planning the ground investigation.9% of the professionals consider field test and sampling with the frequency and 4% of the geotechnical engineers plan the investigation using available standards and codes.

Table 7: Considerations made for planning ground investigation.

Factores Considered for Planning Ground Investigation	No. of Responces (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age	
Suitability of the ground for the structure	None	0%	2	0%		
Drilling equipments used	None	0%	1	0%		
Mine working, caves or other underground structures	None	0%	2	0%		
Structural Loads, their combinations and load cases ,effect of earthquake	None	0%	1	0%		
Exploration program(drilling or pit excavation)	3	13%	2	26%		
Groundwater measurements	None	0%	2	0%		
Field tests and frequency of the test	2	9%	3	26%		
Soil and rock sampling and frequency of the test	2	9%	2	17%		
Laboratory tests	3	13%	2	26%		
Codes and standards applied	1	4%	1	4%		
			<b>Row Sum</b>	<b>18</b>	<b>100%</b>	<b>5.6%</b>

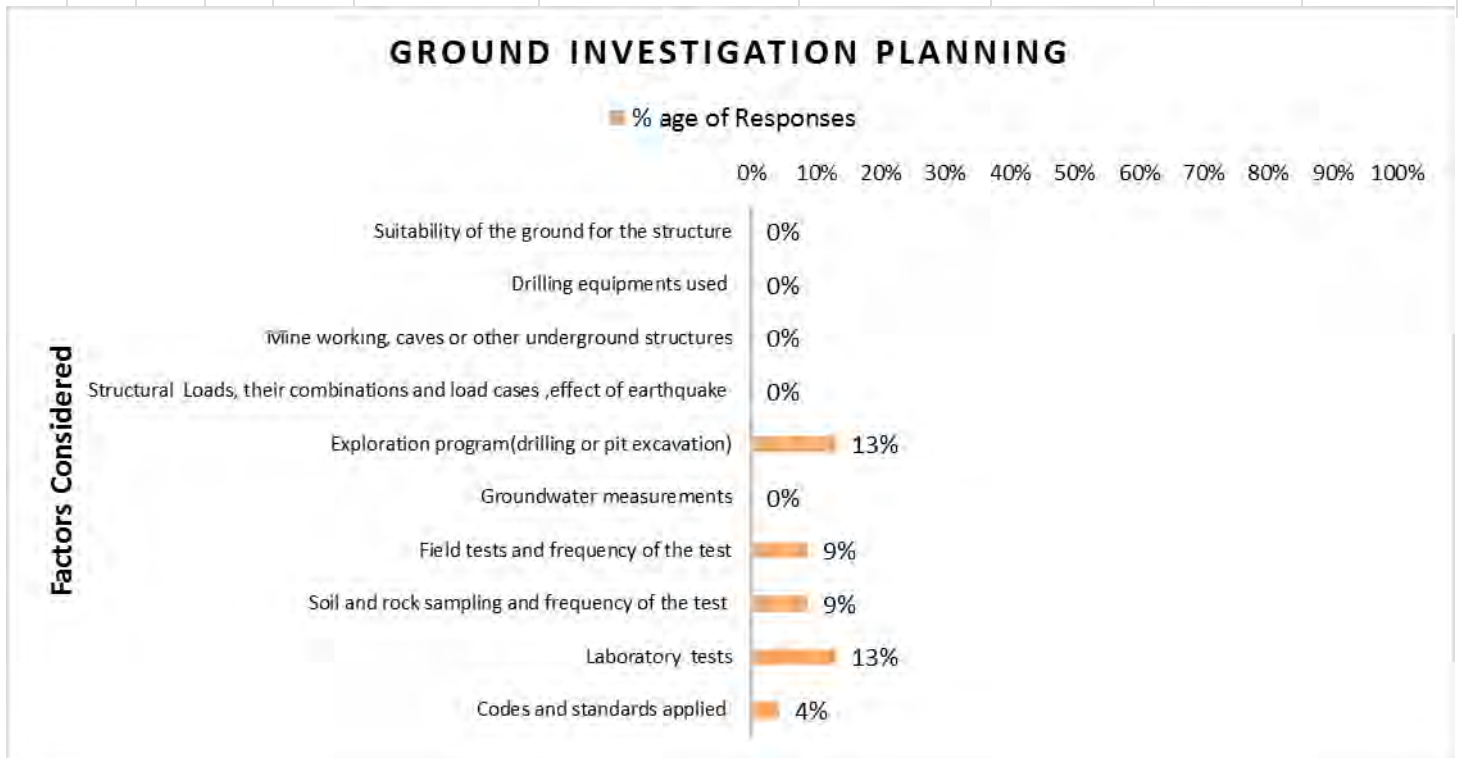


Figure 5 : Plot showing percentage of respondents against considerations for ground investigation planning

### 3.1.2 Location, Number and Spacing of Testing Points

The investigation points should be arranged in such a pattern that the stratification can be assessed across the site and should be placed at critical points relative to the shape of the structure and expected load distribution.

#### a) Number of Testing Points

Number of test points varies depending on different factors as shown in Table 8 and Figure 6. It shows the response of the geotechnical engineers in relation to different considerations that are provided by the codes. Accordingly, 91% of the respondents consider the project area and type of the building and 57% say existing site information is important to decide the number of exploration points. 43% of the professionals agreed that accessibility of the project site is an important criterion. The rest 26% and 9% of them consider shape of the project and importance of the project respectively.

Thus, most professionals are aware that the size/area of the projects and the type of the project are very important factors. On the other hand, not few professionals gave unnecessary emphasis on the accessibility of the project site while considering number of testing points.

Table 8: Factors Affecting Number of Testing Points

Factors Affecting Number of Test Points	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Type of the building,	21	91%	2	183%	
Importance of the building	2	9%	1	9%	
Project Size	21	91%	1	91%	
Shape of the project Area	6	26%	1	26%	
Accessibility of the project site	10	43%	0	0%	
Existing information about the site	13	57%	0	0%	
Ground condition	0	0%	1	0%	
		Row Sum	6	309%	51%

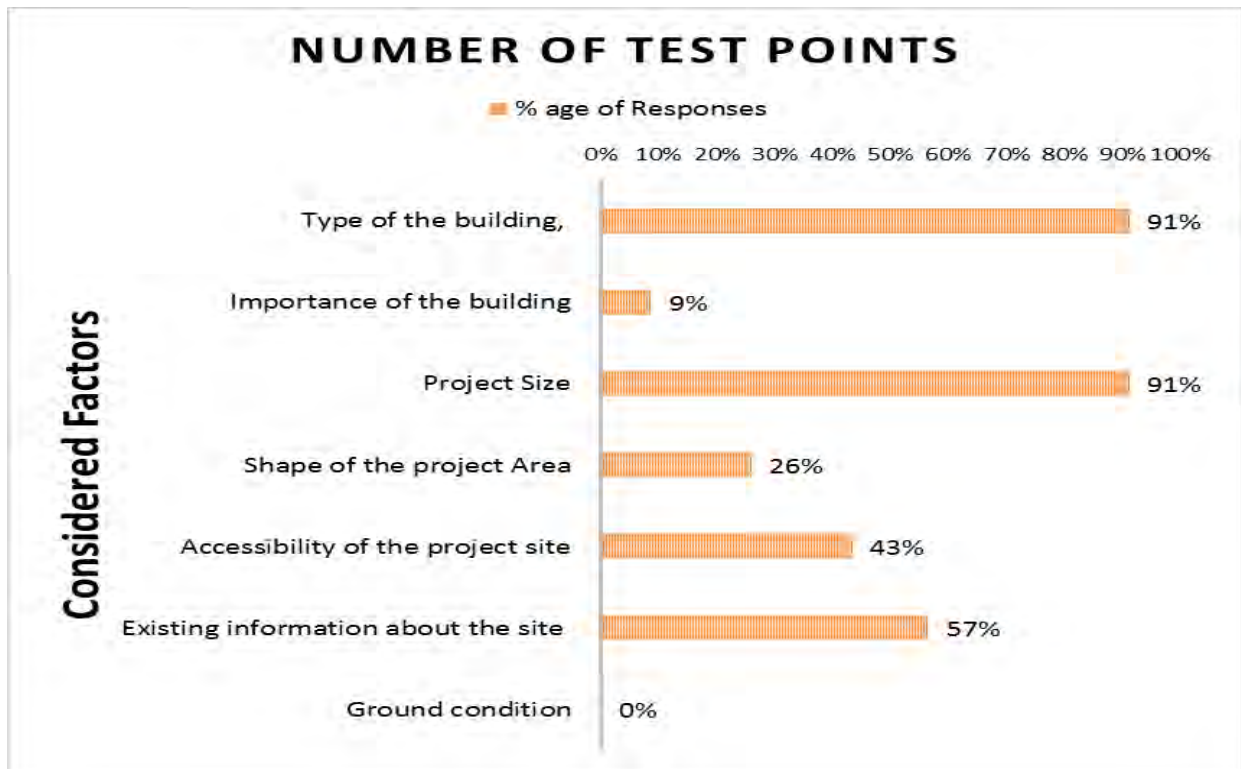


Figure 6: Plot showing percentage of respondents against pertinent code considerations to decide on the number of testing points.

#### b) Location and Spacing of Testing Points deciding

Decision on the location and spacing of testing point is compulsory. Table 9 and Figure 7 show the response from the professionals in relation with different factors/considerations that affects this decision. Accordingly, 65% of the respondents consider project size as a main factor in deciding the location and spacing of the test points. 48% and 35% of the respondents considered existing information and type of the building. More than a quarter (26%) of the respondents considers accessibility of the site. Number of professionals that considered shape of the project area is 17% and 10% of the respondents gives groundwater level and importance of the building as a major factor.

Table 9: Factors affecting decisions on location & spacing of test points

Factors Affecting the Location & Spacing of Test Pionts	No. of Responses (Total Respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Type of the building,	8	35%	3	104%	
Importance of the building	2	9%	3	26%	
Project size	15	65%	1	65%	
Shape of the project Area	4	17%	1	17%	
Accessibility of the project Site	6	26%	0	0%	
Existing information about the site/studies made	11	48%	0	0%	
Location of Groundwater measuring points/for continued monitoring /	1	4%	1	4%	
Subsurface condition	0	0%	1	0%	
<b>Row Sum</b>			<b>10</b>	<b>113%</b>	

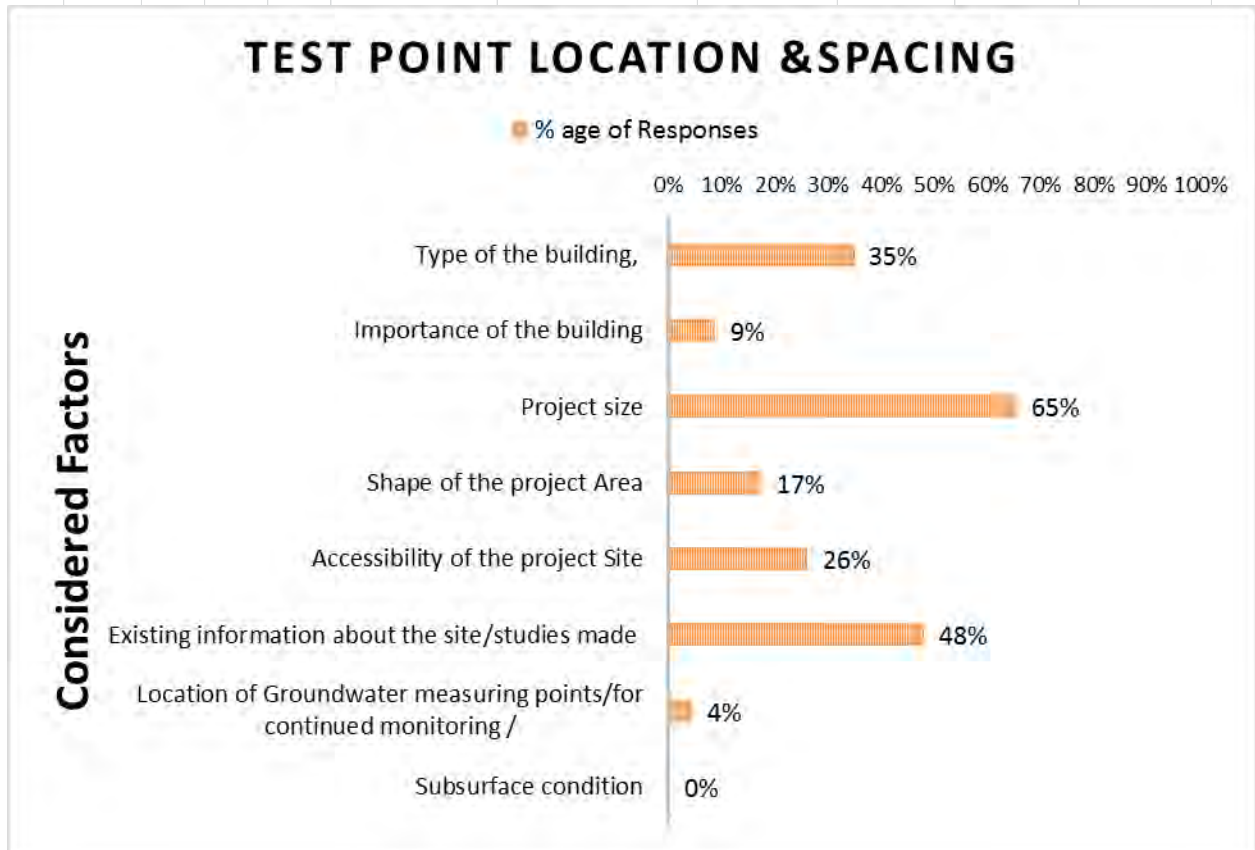


Figure 7: Plot showing percentage of respondents against different considerations for deciding location and spacing of testing points.

### 3.1.3 Depth of Exploration

Exploration is normally carried out to a depth which includes all geological strata likely to be significantly affected by the structural load. Table 10 and Figure 8 shows the respondents’

consideration in relation to different factors affecting the depth of exploration according to the codes.

Accordingly, 83% of the professionals consider type of the proposed structure while 39% of them say only soil profile is a determining factor for the exploration depth. Additionally, 13% and 4% of them consider the depth of sub-structure and width of the foundation respectively, matters when determining depth of exploration. None of them gave considered the length of piles and groundwater level as a factor influencing depth of exploration.

Table 10: Factors Affecting Exploration Depth

Factors Affecting Exploration Depth	No. of Responses (Total respondent 23)	% age of Responses	Weighing factor	Weighed %age	Weighted Total %age
Soil profile	9	39%	3	117%	
Width of the foundation	1	4%	2	9%	
Length of the piles	None	0%	1	0%	
Type of the proposed structure	19	83%	1	83%	
Depth of groundwater level	None	0%	0	0%	
Depth of sub-structure below the NGL	3	13%	0	0%	
		Row Sum	7	209%	29.8%

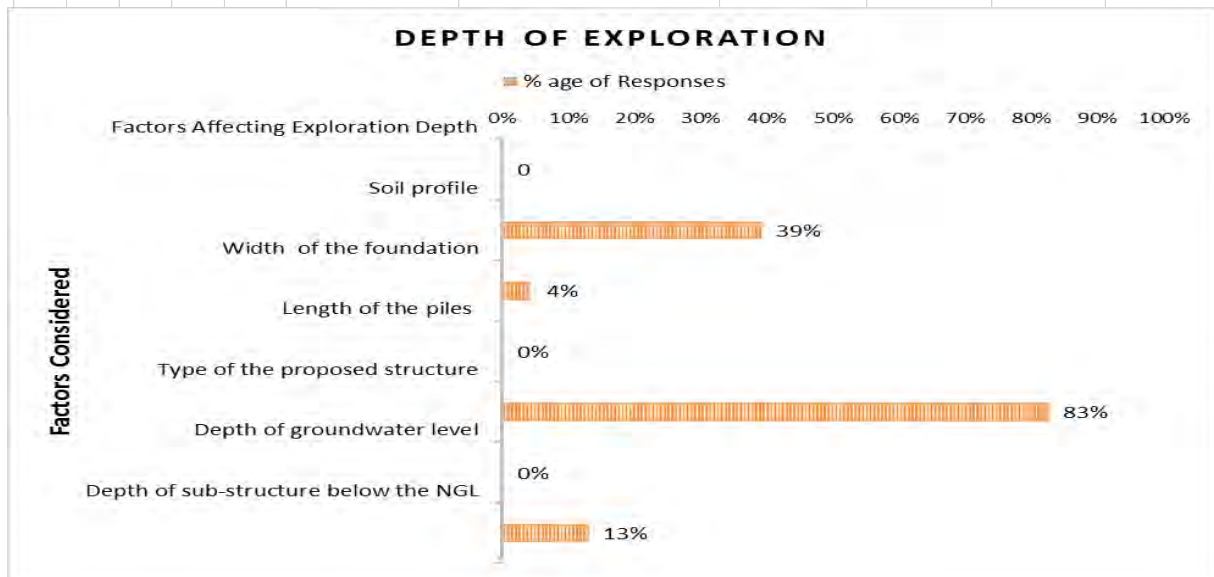


Figure 8: Plot showing percentage of respondents against different factors affecting exploration depth.

### 3.1.4 Drilling Rig for Boring

In most codes the sample class collected, type of field tests, importance of the structure, drilling depth and speed of the machine and ground condition (soil/rock) are the main factors

considered while selecting the drilling machine. Accessibility of the site and availability of the machine are the additional factors to be considered. Table 11 and Figure 9 show these considerations and present the professionals response as follows.

Accordingly,57% of the respondents considered majorly the importance of the project and accessibility of the site to select the type of drilling rig.43% and 17% of the professionals consider machine drilling speed and depth of drilling respectively affects the rig selection. Only 4% of the professionals consider sample class and ground condition as a main factor while selecting the rig. Surprisingly none of the professionals considered the type of field tests as an essential factor.

Table 11: Factors considered for selection of drilling rig

Factors Considered for Selection of Drilling Rig	No. of Responses (Total respondent 23)	% age of Responses	Weighing factor	Weighed %age	Weighted Total %age
Type of sample classes collected	1	4%	1	4%	
Type of Field tests required	none	4%	1	4%	
Importance of the project	13	57%	0	0%	
Availability of the machine	4	17%	0	0%	
Required drilling depth	10	43%	2	87%	
Accessibility of the site	13	57%	0	0%	
Ground condition	1	4%	0	0%	
		<b>Row Sum</b>	<b>4</b>	<b>95%</b>	<b>23.8%</b>

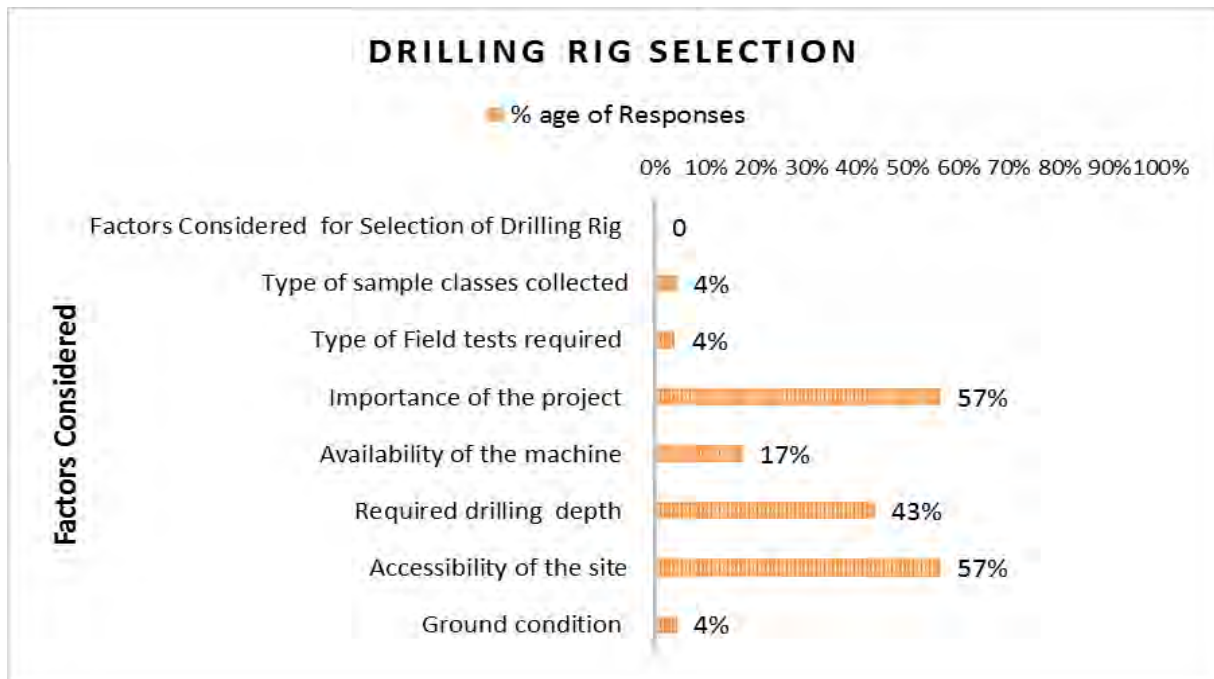


Figure 9: Plot showing percentage of respondents against factors considered for selection of drilling rig.

### 3.1.5 In-Situ Tests/Field Tests in Soil and Rock/

Field tests are tests that are conducted without the necessity of removal of the material under investigation from its original position.

#### c) Field Test Types

There are different types of field tests that are carried out for different soil types and for different design results. Different exploration machines carry out different field tests, and thus they should be selected by the professionals. Table 12 and Figure 10 present different field tests and professionals' utilization percentage. Accordingly, the most commonly used field test is standard penetration tests (SPT) and 96% of the professionals use this test and the next commonly executed field test is dynamic cone penetration test (DCP) which take a share of 83%. Less than 10% of them carry out plate load test, vane shear test, and dynamic probing test.

Utilization levels of the tests indicate that most of the professionals mainly use the standard penetration test and dynamic cone penetration test. This implies that machinery that accommodates these tests is widely in use.

Table 12 : Types of field test and rate of utilization by the geotechnical engineers

Field Test Types	No. of Responses (Total respondent 23)	% age of Utilization
Plate loading test	2	9%
Static cone penetration and piezocone penetration tests	none	0%
Standard penetration test (SPT)	22	96%
Dynamic cone penetration test(DCP)	19	83%
Vane shear tests:	1	4%
Pressure meter tests	None	0%
Flexible dilatometer tests	None	0%
Weight sounding tests	None	0%
Measurement of density of soil	None	0%
Dynamic probing tests (DP)	1	4%
Flat dilatometer test (DMT)	None	0%

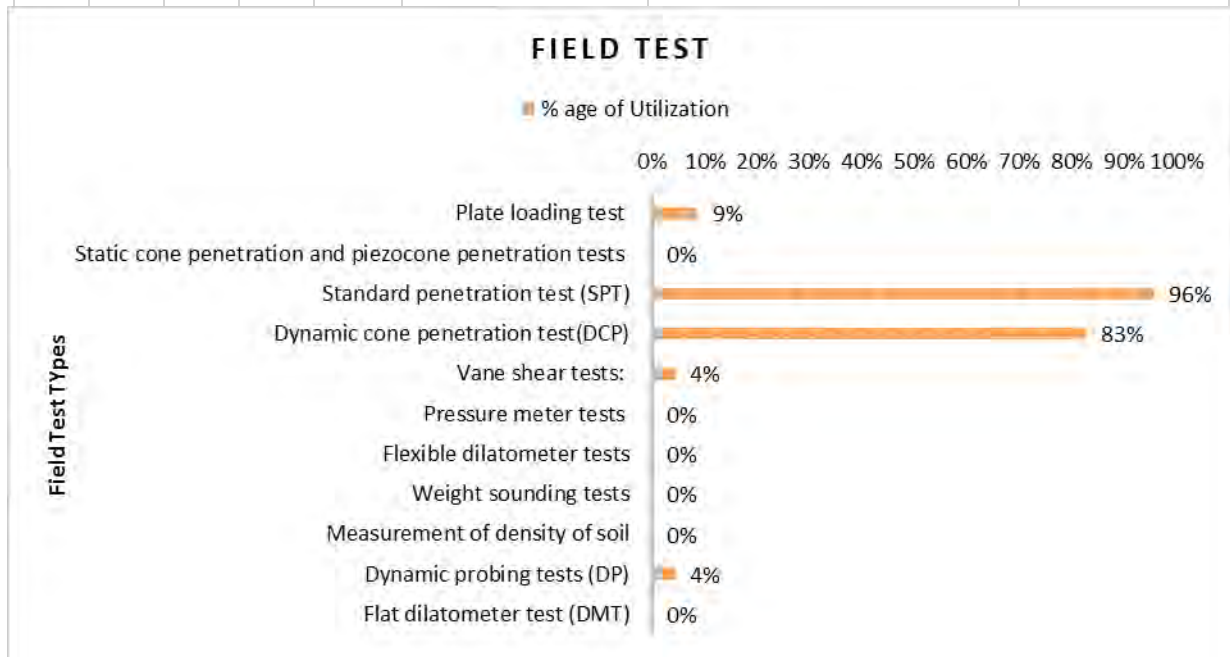


Figure 10: Plot showing percentage of respondents against different filed test types.

#### d) Field Test Frequency

The main reason the soil investigation is carried out is to get soil/rock parameters for settlement and bearing capacity calculations. Failing to provide these parameters at the needed frequency and depth causes a serious problem in the design. Table 13 and Figure 11 shows different factors affecting field test frequency and depth and responses from the professionals

are evaluated as follows. Accordingly, 70% and 52% of the Geotechnical Engineers indicate that the soil profile and depth of drilling respectively determine the field test frequency with depth. 43% of the geotechnical engineers take type of the structure and sub-structure depth below the natural ground level (NGL) as an additional factor to decide the frequency and depth of the tests. None of the professionals mentioned the type of the design parameters required as a factor useful to decide the depth and frequency of the field test.

Table 13 : Factors affecting field test frequency

Factors Affecting Field Test Frequency	No. of Responses (Total Respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Soil profile	16	70%	1	70%	
Depth of drilling	12	52%	0	0%	
Type of structure	10	43%	2	87%	
Geotechnical parameter required	None	0%	1	0%	
			<b>Row Sum</b>	<b>4</b>	<b>157%</b>
					<b>39.1%</b>

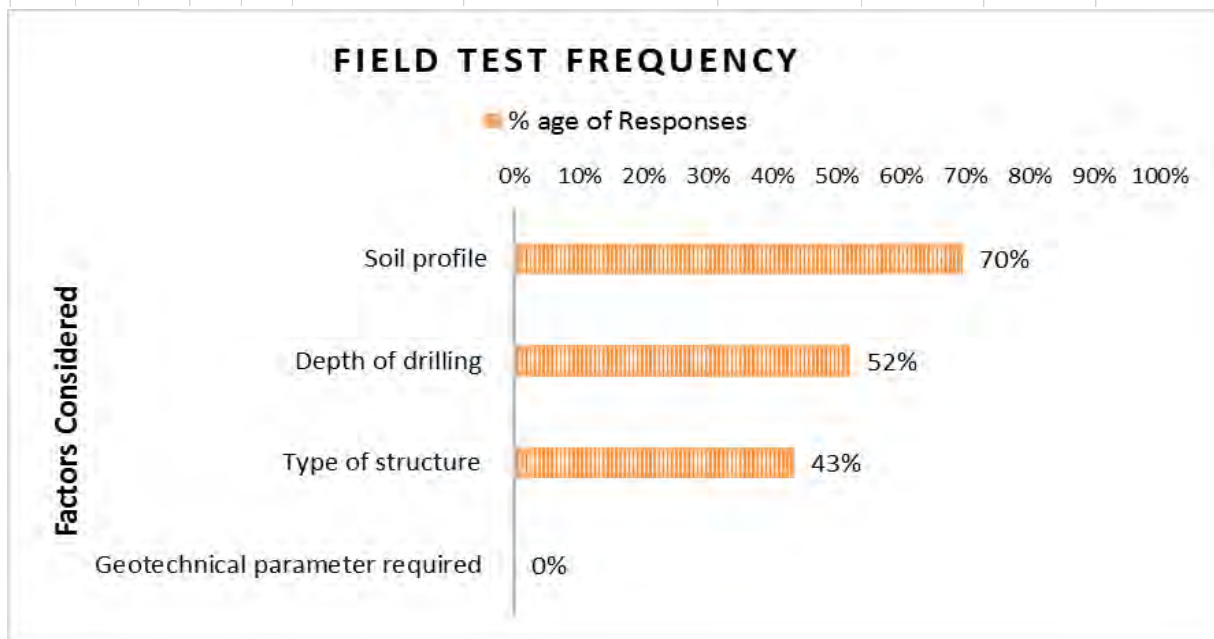


Figure 11: Plot showing percentage of respondents against factors affecting field test frequency.

### 3.1.6 Sampling

Sampling of soils and rocks by drilling or excavations shall be conducted so thoroughly that the necessary geotechnical design data are obtained. Basically, there are two types of samples:

undisturbed and disturbed samples. The following subsections discuss sampling frequency with depth for both sample types.

**a) Frequency of Soil Sampling**

Different considerations are taken while collecting soil samples (both disturbed and undisturbed soil sampling) at a certain frequency. The percentages of response relative to these factors are given in Table 14 and Figure 12. And accordingly, 83% of the respondents use the geology of the soil profile as a factor for selecting the frequency of soil sampling. 48% and 39% of the professionals consider the depth of substructure and depth of drilling respectively affects this process. Very few professionals consider type of sampling tools and stress influence depth as a factor affecting this investigation stage.

Design parameters needed (for bearing capacity and settlement calculation) is not considered at all by any of the professionals.

Table 14 : Factors affecting frequency and depth of soil sampling

Factors Affecting Frequency and Depth of Soil Sampling	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Soil profile	19	83%	3	248%	
Depth of drilling	9	39%	0	0%	
Depth of the sub- structures below NGL	11	48%	0	0%	
Soil parameters needed for investigation design	none	0%	1	0%	
Type of the structure /Influence depth of the superstructure load /Stress	1	4%	0	0%	
Type of the sampling tools used	2	9%	0	0%	
		<b>Row Sum</b>	<b>4</b>	<b>248%</b>	<b>62.0%</b>

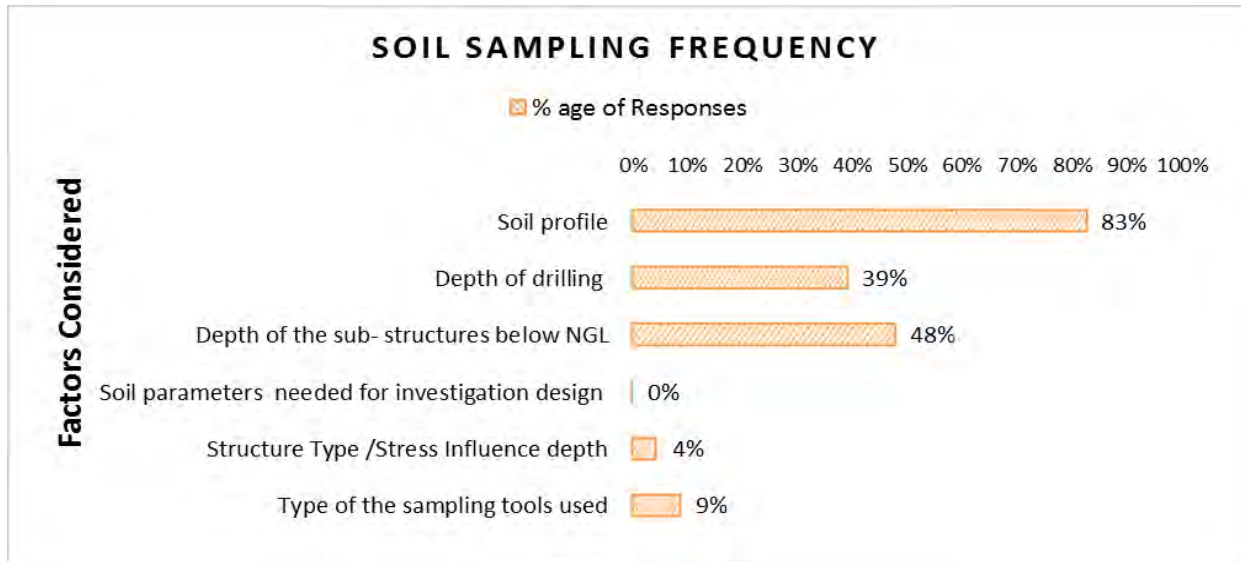


Figure 12: Plot showing percentage of respondents against factors affecting frequency and depth of undisturbed soil sampling.

**b) Rock Samples for Laboratory Test**

Rock sampling is usually done with core drilling machines for recovering rock samples for it is very difficult otherwise. Table 15 and Figure 13 show percentage of respondents’ considerations for rock sampling for laboratory tests relative to the rock sampling requirements (as per the codes). Accordingly, Rock quality designation and intensity of weathering is considered by 78% of the respondents to select the rock samples for laboratory test.65% and 35% of the professionals considered stress influence depth of the superstructure and depth of the sub-structure below the natural ground level respectively for selection of rock samples. None of the professionals considered the sampling methods/tools used as a factor in sampling the rock for laboratory tests. In summary, more than half of the code requirements are considered by the professionals.

Table 15: Rock sampling criteria for laboratory tests

Factors Affecting Rock Sampling	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	55.8
State of the rock (Intency of weathering)	18	78%	2	157%	Weighted Total %age
Rock quality designation (RQD)	18	78%	1	78%	
Type of the structure /Influence depth of the superstructure load /Stress	15	65%	4	261%	
Depth of the structures below the natural ground level of the building/foundation level	8	35%	0	0%	
Type of the sampling tools/methods used	none	0%	1	0%	
		Row Sum	8	496%	62.0%

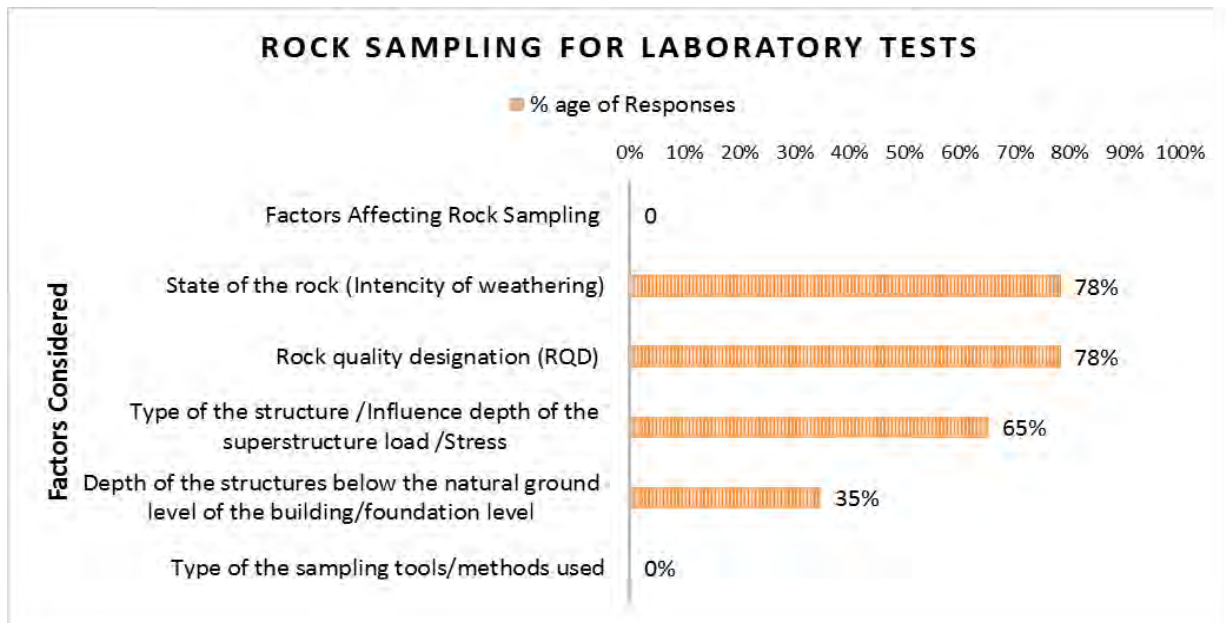


Figure 13: Plot showing percentage of respondents against factors affecting rock sampling for laboratory tests

### c) Sample Retention Period

Samples are retained for different purposes, and preferably it should be kept as long as possible. These samples might help to carry out further investigations if additional information is needed.

Table 16 and Figure 14 shows 34.8% of the geotechnical engineers suggested that the samples should be retained for three months and more. 17.4% of them suggested that two weeks is enough but 17% of them say samples should be kept depending on the project size. Less than 10% of the professionals considered different sample retention period such as: less than a week, one month, two months and more than a year. Few suggested that the sample should be kept until the final report is submitted.

Table 16: Sample Retention Period

Sample Retention Period	No. of Responses (Total Respondent 23)	% age of Responses
Less than a week	2	8.7%
Two weeks	4	17.4%
One month	1	4.3%
Two month	2	8.7%
Three month and more	8	34.8%
More than a year	1	4.3%
Until the final report is submitted	1	4.3%
Depends on the size of the project	4	17.4%

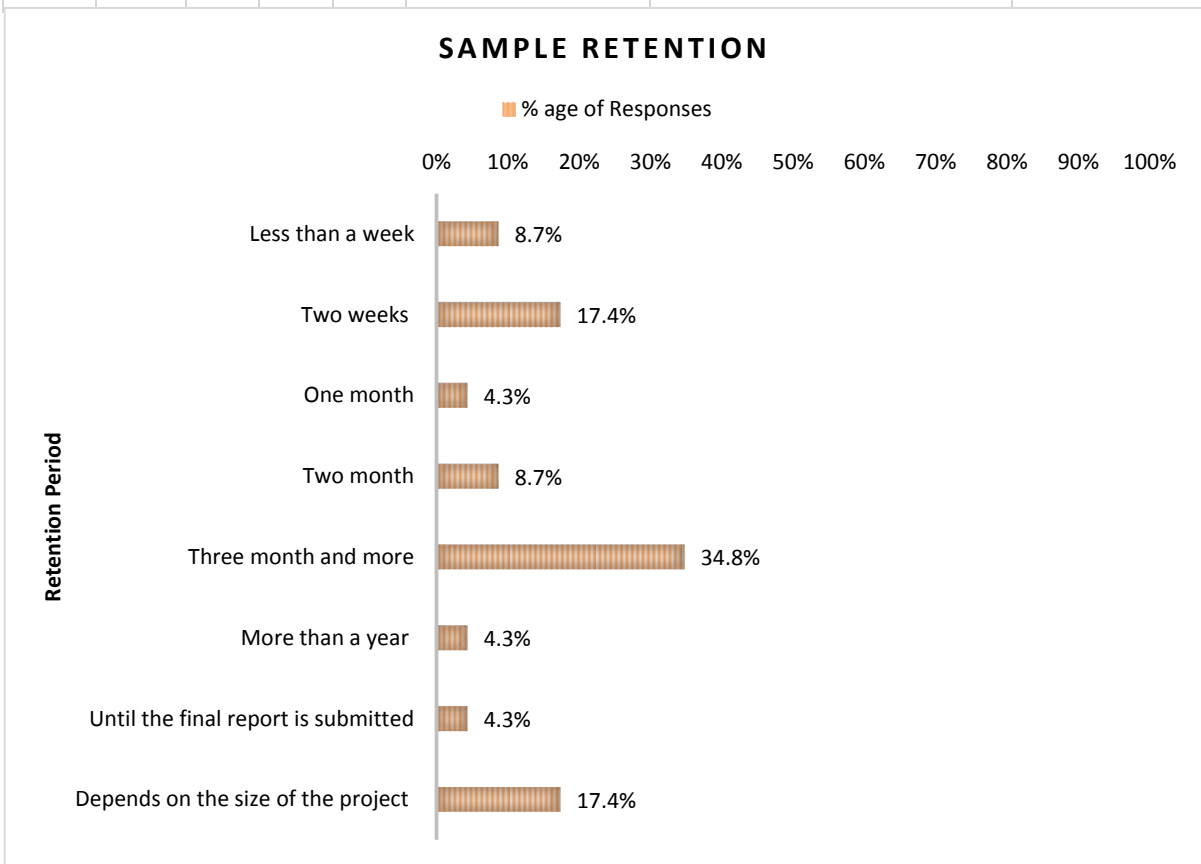


Figure 14: Plot showing percentage of respondents against factors affecting rock sampling for laboratory tests

### 3.1.7 Laboratory Tests on Soil, Rock and Water

Soil and rock samples are tested in the laboratory for determining their engineering properties and chemical tests are done for groundwater samples.

**a) Factors Affecting the Selection of Laboratory Tests**

There are different code considerations for the selection of laboratory tests (for soil and rock samples). This consideration is given in relation with the factors considered by the geotechnical engineers in Table 17 and Figure 11. Accordingly, 95.7% of the professionals consider the formation of the soil strata as one factor affecting the selection of laboratory test types (for soil/rock). 34.8% and 13% of them consider the type of the structure, and design parameters required for calculation purpose respectively for selecting laboratory tests types.

The ultimate goal of the investigation is to come up with a safe and economical foundation design and to do so the soil/rock designs parameters has to be provided. But only few of the professionals consider the design parameters (for calculation purpose) as a factor to select the laboratory test types.

Table 17: Factors affecting the selection of laboratory tests

Factors Affecting Laboratory Test Selection	No. of Responses (Total Respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age	
Type of structure	8	34.8%	0	0%		
Soil profile	22	95.7%	1	96%		
Design parameters for Calculation	3	13.0%	3	39%		
			<b>Row Sum</b>	<b>4</b>	<b>135%</b>	<b>33.7%</b>

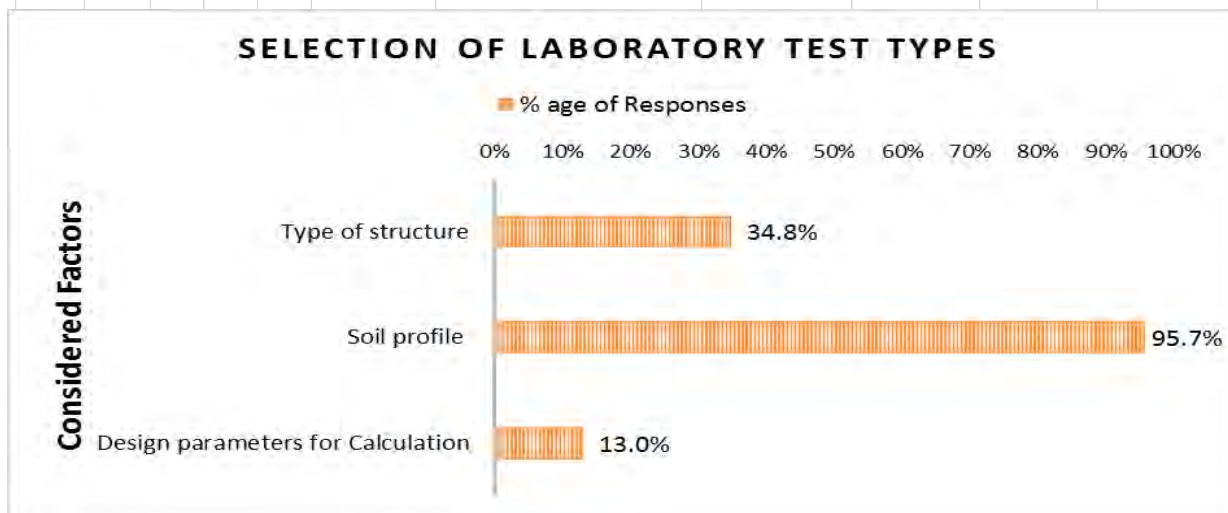


Figure 15: Plot showing percentage of respondents against factors affecting the selection of laboratory tests types

### b) Common Laboratory Tests for Soil

Different types of laboratory soil tests are known but some of them are common and they are shown in Table 18 and Figure 16. It shows 91% of the professionals frequently carry out classification tests, 74% of them will test the soil for index property.52% and 35% of the professionals commonly perform shear strength and compressibility test respectively. None of the professionals suggested chemical and permeability tests.

Great emphasis should have been given to share strength and compressibility tests, for these are the most commonly and widely used tests. These tests mainly give design parameters for bearing and settlement calculations.

Table 18: Common laboratory test types for soil

Common Laboratory Tests for Soil	No. of Responses (Total respondent 23)	% age of Responses
Grainsize & hydrometer tests	21	91%
Atturburg limit tests	17	74%
Shear strength tests (Direct shear, Triaxial shear test)	12	52%
Compressibility tests (Compressibility oedometer, Consolidated Triaxial Compression )	8	35%
Chemical test (for soil)	None	0%
Permeability test	None	0%

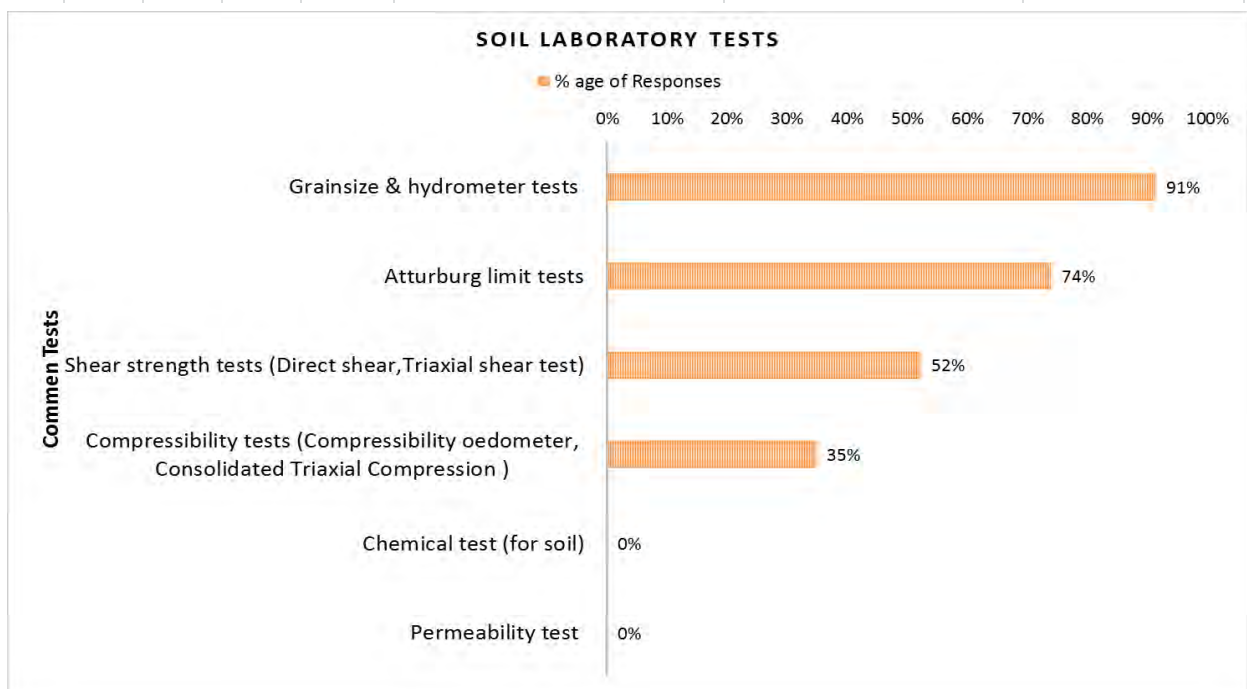


Figure 16: Plot showing percentage of respondents against common soil laboratory tests.

### c) Shear Tests Conducted

Shear strength calculation is the main part of the analysis which plays a significant role in determining the bearing capacity of the soil. Table 19 and Figure 17 describe frequency of shear tests conducted by the professionals. Accordingly, 39.1% of the geotechnical engineers carry out the shear test frequently for the ground investigation purpose and 34.8% of them conduct the test sometimes. 26.1% of them use this test very frequently. In general, the professionals perform the shear test.

Table 19: Frequency of the shear strength tests conducted

Frequency of the Shear Test	No. of Responses (Total Respondent 23)	% age of Responses
Rare	none	0.0%
Sometimes	8	34.8%
Frequently	9	39.1%
Very frequently	6	26.1%

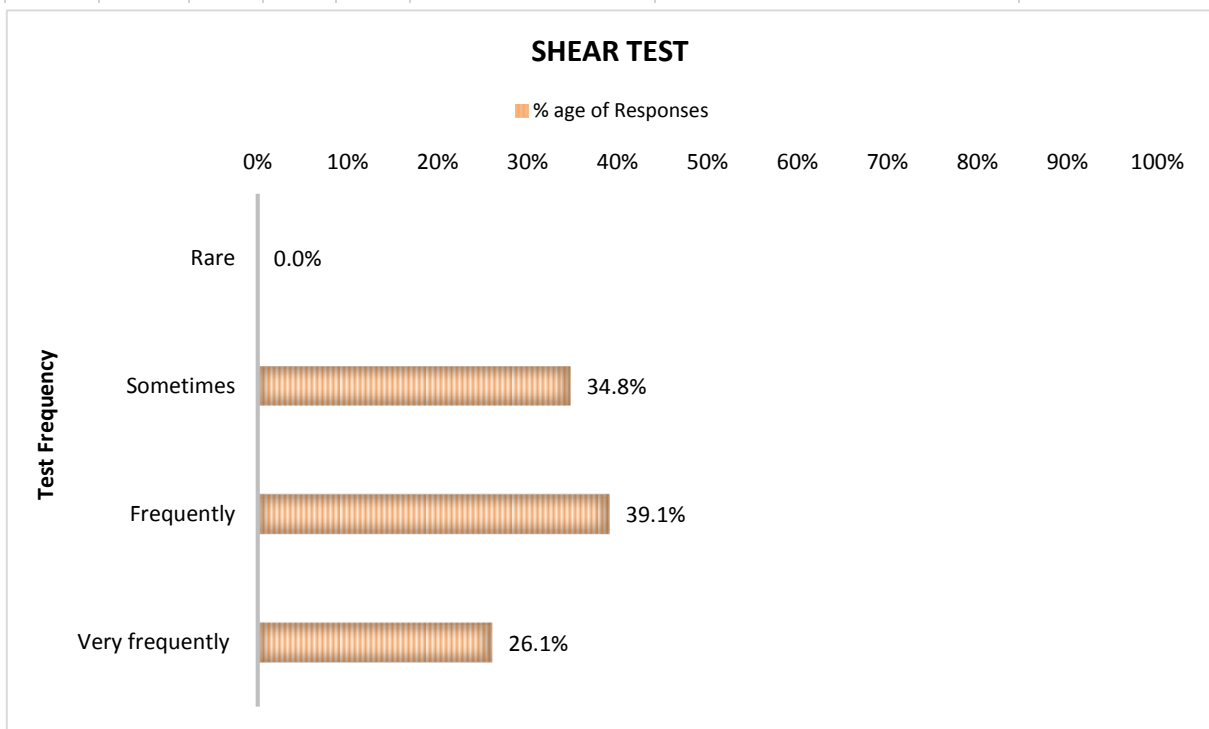


Figure 17: Plot showing percentage of respondents against frequency of shear strength tests.

### d) Commonly Used Shear Strength Tests

Different types of shear strength tests exist and according to the preferred parameters the test types are selected. Table 20 and Figure 17 show percentage of responses with different type of shear strength tests according to the pertinent codes. Accordingly, it shows 65.2% of the professionals conduct unconfined compressive strength tests to calculate the bearing capacity calculation. 47.8% of the professionals carry out direct shear test and 26% of them carry out triaxial test.

These three shear strength tests give parameters valuable for bearing capacity calculation. The only difference is the quality of the results collected from the tests. Triaxial test is the most reliable test but few of the respondents chose this test. Direct shear test is the second reliable and unconfined compressive strength test comes at last.

More than half of the respondents use the unconfined compressive strength test and not few of them use the direct shear test. This shows that the shear strength parameters extracted from shear strength test are mostly done using direct shear or unconfined compressive strength. Only few of the geotechnical engineers use the triaxial tests where an economical and safe design is definite.

Table 20: Commonly used shear strength tests with percentage of utilization by the professionals.

Commonly Used Shear Strength Tests	No. of Responses (Total Respondent 23)	% age of Responses
Direct shear	11	47.8%
UCS (Unconfiend Compressive Strength)	15	65.2%
Triaxial (UU,CD,CU)	6	26.1%

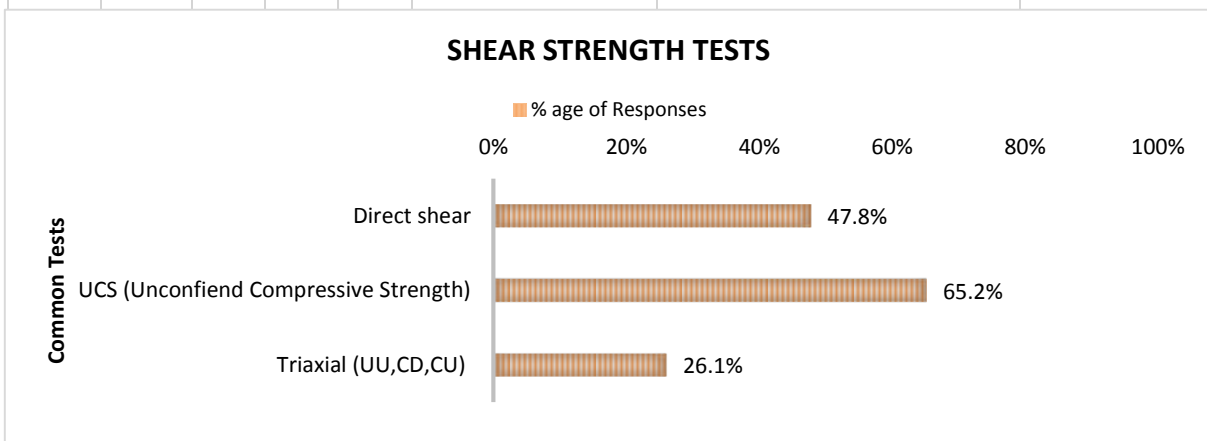


Figure 18: Plot showing percentage of respondents against common shear strength tests types.

**a) Frequency of Compressibility Test**

Settlement calculations, which use parameters from compressibility test, are mandatory for a complete geotechnical investigation design. Table 21 and Figure 19 show the percentage of professionals’ responses regarding how frequent the compressibility test will be conducted.

Accordingly, 56.5% of the professionals conduct compressibility test sometimes and 21.7% of the professionals carry out the test rarely where as 17.4% of them carry out the test frequently. Some suggested that the test will be carried out depending on the type of the project.

Table 21: Frequency of compressibility test conducted

Frequency of Compressibility Test	No. of Responses (Total respondent 23)	% age of Responses
Rare	5	21.7%
Sometimes	13	56.5%
Frequently	4	17.4%
Very frequently	none	0.0%

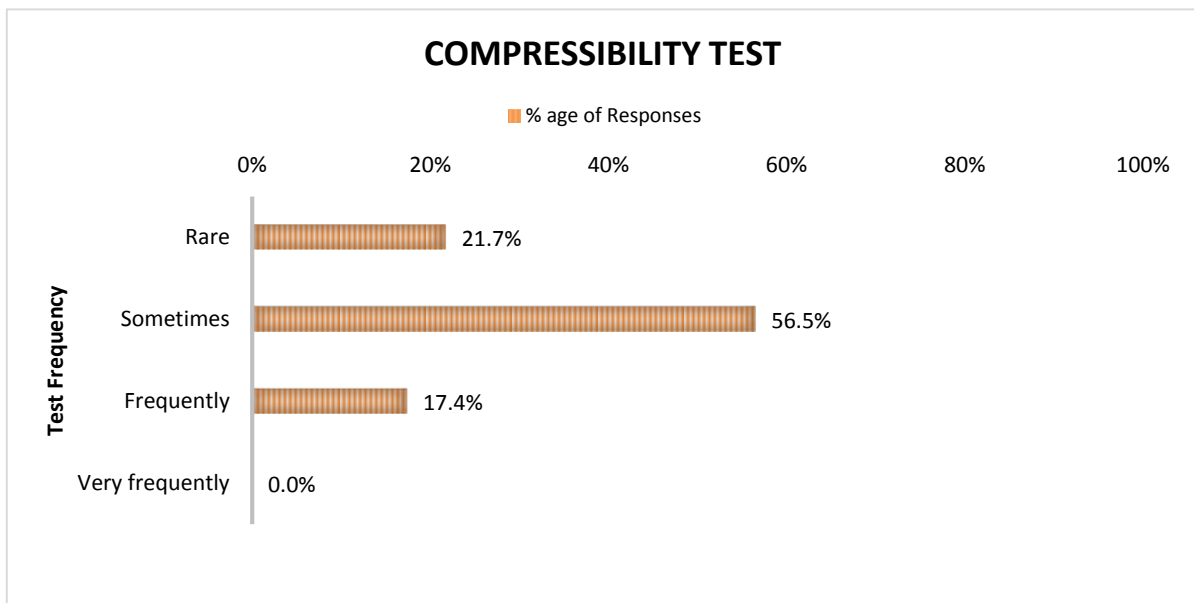


Figure 19: Plot showing percentage of respondents against frequency of compressibility test.

**b) Project Types Which Needs Permeability Test**

Permeability test can be carried out both in the laboratory and on the field. This test is conducted for different types of projects as can be seen from Table 22 and Figure 20.

Accordingly, 73% of the professionals conduct permeability tests for structures like earth dams, embankments, waste water treatment facilities and reservoirs. And 4.3% of them conduct this test for excavation and slop stability projects. Others suggested irrigation, factories, land scrapers and stadium are the once that require the permeability test.

Table 22: Project types which needs permeability test

Type of Projects which Needs Permeability Tests	No. of Responses (Total respondent 23)	% age of Responses
Excavations and slope stability	1	4.3%
Earth dams,embankments,waste water tretment facilities,reserviors	17	73.9%

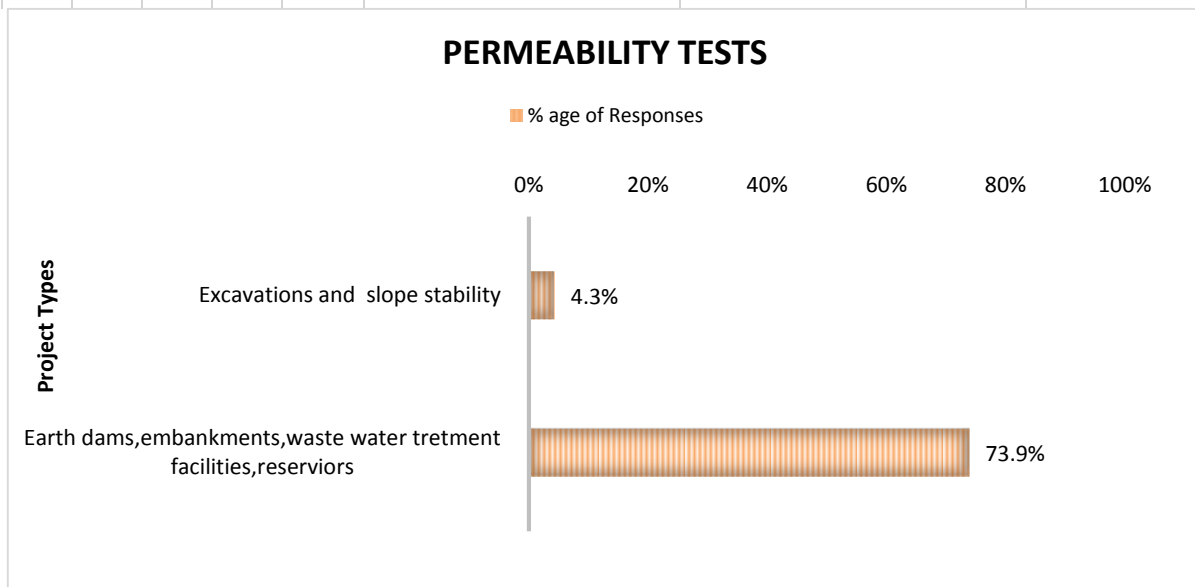


Figure 20 : Plot showing percentage of respondents against projects that need permeability tests.

### 3.1.8 Soil and Rock Classification

Soil and rock classification can be done using different methods and some of them are described as follows for soil and rock strata.

#### a) Soil Classification

Soil classification can be done by visually inspecting, evaluating laboratory test results and using the total core recovery values (TCR). Table 23 and Figure 21 show different methods used to classify soil (according to the codes) and the professionals' response (% age) is given with respect to the requirements. Accordingly, 95.7% of the respondents carrying out visual

inspection for soil classification purpose and 65.3% of them consider laboratory test results. 43% of the responses consider total core recovery values for soil classification purpose.

Visual inspection is the most common practice that is used to analyze soil class. Some of the professionals, considered laboratory test results as a means to classify soil. This method is accurate and can be used with full confidence to draw any conclusion regarding soil class. Despite the benefits, most professionals avoided using this method.

When Total core recovery values are used to classify soil. But the type of exploration method used greatly affects the type of core samples extracted and might give miss-leading information for the professional. Chemicals (additives) and water used to extrude the core samples during exploration will also affect both the chemical and physical composition of the soil sample. This as a result will affect the soil classification in a great deal and is not recommended to relay engineering judgments on this factor. But 43% of the professionals consider this approach for soil classification.

Table 23: Methods used for soil classification

Methods Used for Soil Classificaion	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Visual inspection	22	95.7%	1	96%	
Laboratory test results	15	65.2%	2	130%	
Total core recovery (TCR)	10	43.5%	0	0%	
Row Sum			3	226%	75.4%

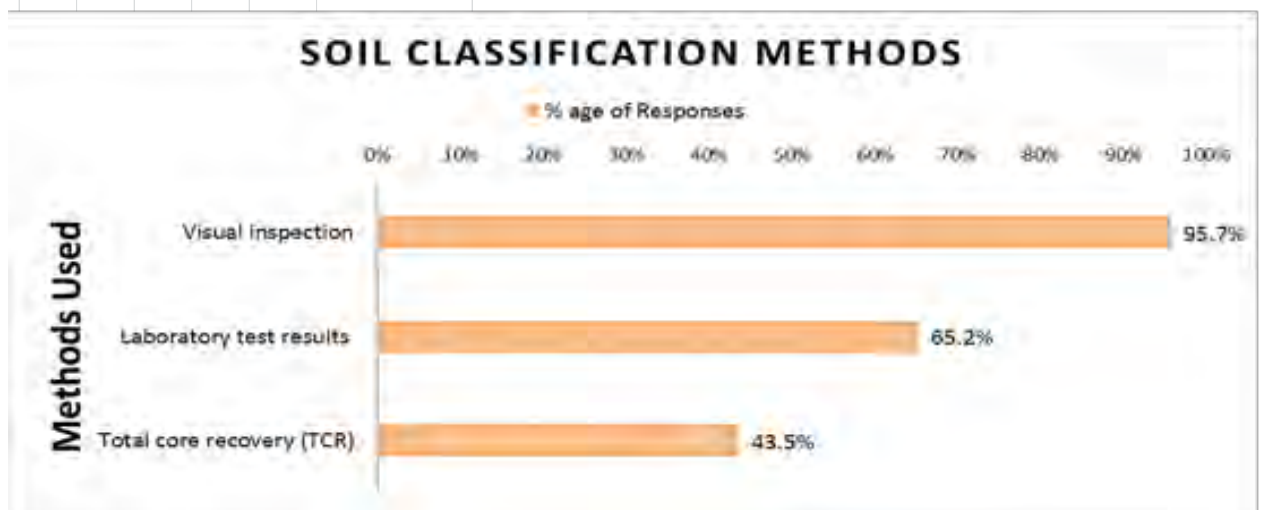


Figure 21 : Plot shows percentage of response against different methods used for soil classification.

**b) Rock Classification**

Rock can be classified using rock quality designation (RQD) and TCR. Visual inspection and degree of weathering are also other factors used to classify rock. Table 24 and Figure 22 show percentage of responses by the professionals in comparison with different factors (used by the pertinent codes) that are used to classify rock. Accordingly, 95% of the professionals consider RQD & TCR to classify rock samples. The rest 82.6% and 73.9% of the professionals recommend that degree of weathering and visual inspection have to be used respectively for rock classification. Almost every factor mentioned above has been given similar stress by the professionals.

Table 24 : Methods used for rock classification

Methods Used for Rock Classification	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Rock RQD and TCR	22	95.7%	2	191%	
Degree of weathering	19	82.6%	1	83%	
Rock classification (Using rock visual identification)	17	73.9%	2	148%	
<b>Row Sum</b>			<b>5</b>	<b>422%</b>	<b>84.3%</b>

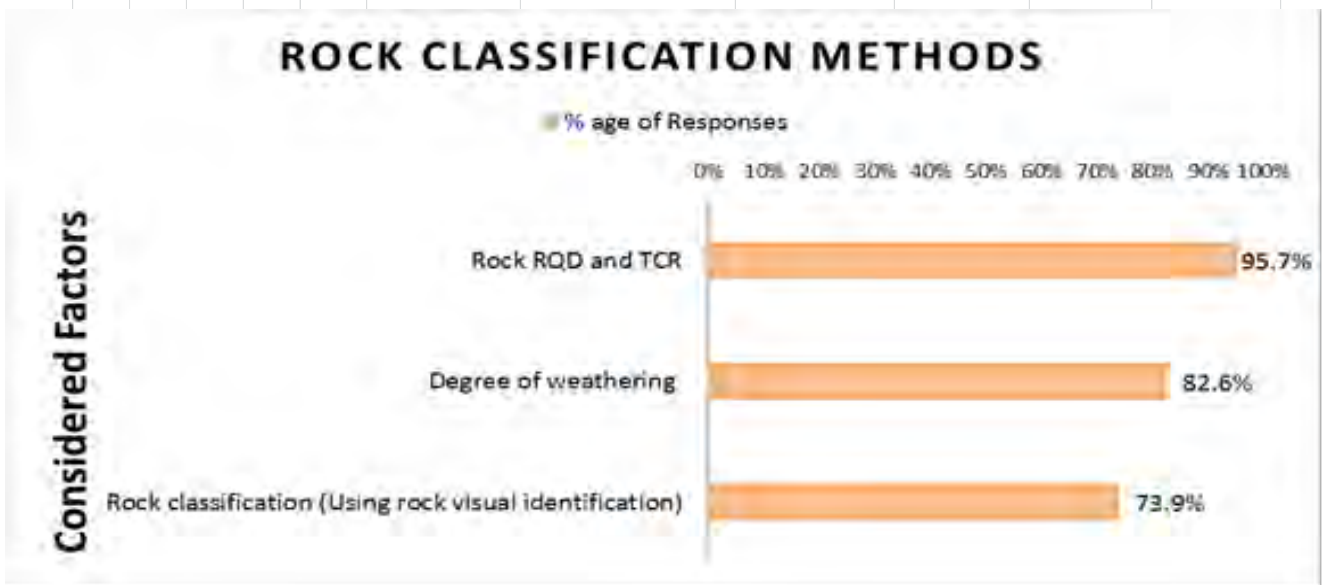


Figure 22 : Plot percentage of respondents against methods used for rock classification.

### 3.1.9 Groundwater Level Measurement and Laboratory Test on Water

Groundwater level is measured while ground investigation is carried out. Identification of pore-water pressures and ground water level fluctuation with time is also assessed for this factor affects the ground investigation result greatly. Additionally, the presence of certain chemical constituents in groundwater should be investigated, while considering the durability of the structure. Both Table 25 and Figure 23 show response from the professionals concerning methods used to measure groundwater level and type of laboratory tests as per the considerations of the pertinent codes. Accordingly, 87% of the professionals use groundwater level measurement tools to measure the groundwater level and 39.1% of them will carry out chemical tests on the water sample collected. 34.8% of the respondents will perform permeability test.

Most of the professionals use tools to measure the groundwater level. And few of the professionals practice chemical and permeability test while doing the ground investigation.

Table 25 : Methods used for groundwater level measurement and laboratory test types

Groundwater Level Measurement and Laboratory Tests	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Ground water measurement tool	20	87.0%	1	87%	
Chemical test (Sulphate, Chloride content, PH)	9	39.1%	2	78%	
Field tests / Permeability	8	34.8%	1	35%	
Row Sum			4	200%	50.0%

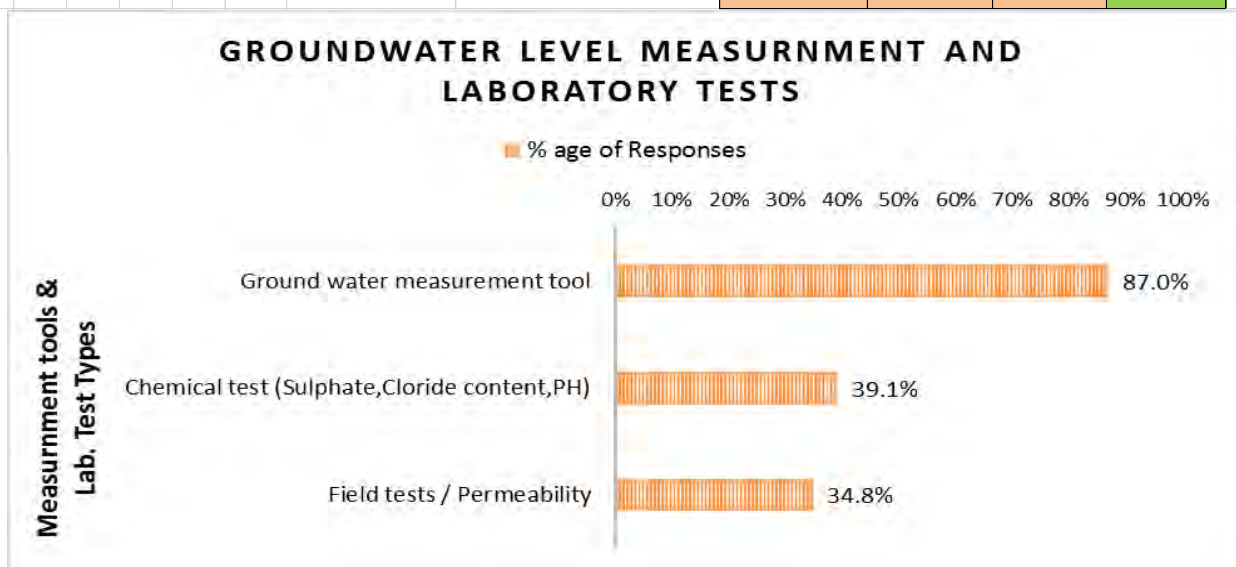


Figure 23: Plot showing percentage of respondents against methods used for groundwater level measurement and laboratory test types.

### 3.1.10 Ground Investigation Report

The presentation of geotechnical information shall include a factual account of all field and laboratory work. Accordingly, documentation of the methods used to carry out field investigation, laboratory tests and different design calculations with the respective recommendation should be presented clearly in the report.

#### a) Qualified Professionals for Reporting the Ground Investigation

Ground investigation reporting should be done by professionals who have specialized in this field. And Geotechnical Engineers are the qualified professionals to report the geotechnical investigation report. Table 26 and Figure 24 show response regarding the professionals' qualification for reporting the complete ground investigation. Accordingly, 82 % of the professionals consider geotechnical engineers should do the soil investigation report. The rest of the respondents suggested that civil engineers, geologists, engineering geologist should carry out this task.

Table 26 : Respondents' Response Concerning Professionals Assigned for Reporting the Ground Investigation

<b>Qualified Professionals for Reporting the Ground Investigation</b>	<b>No. of Responses (Total Respondent 23)</b>	<b>% age of Responses</b>
<b>Civil engineer(BSc.)</b>	<b>5</b>	<b>21.7%</b>
<b>Geologist (BSc.)</b>	<b>8</b>	<b>34.8%</b>
<b>Geotechnical Engineer (MSc. in Geoethnics )</b>	<b>19</b>	<b>82.6%</b>
<b>Geologist (MSc. in Geoethnics )</b>	<b>5</b>	<b>21.7%</b>
<b>Msc. in Engineering Geology</b>	<b>8</b>	<b>34.8%</b>

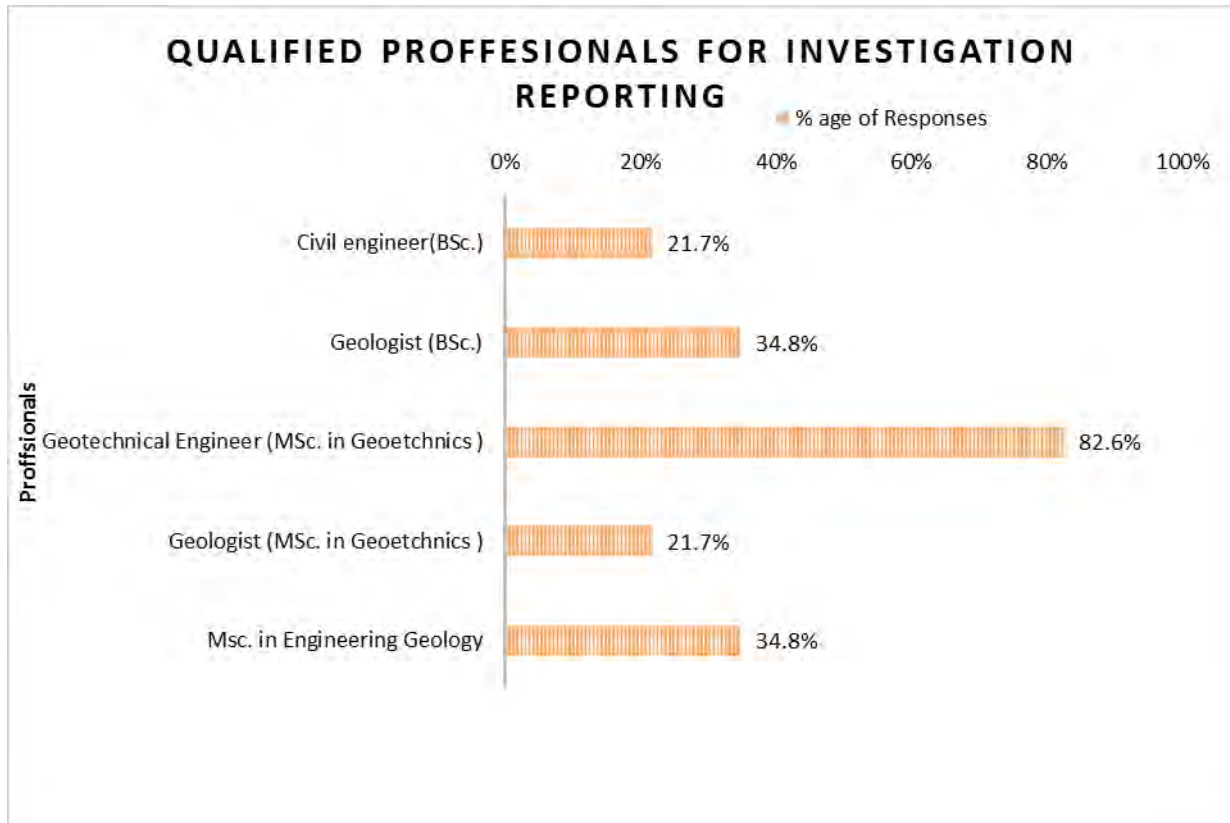


Figure 24 : Plot showing percentage of respondents against qualified professionals for investigation reporting.

**b) Identifying Soil Strata**

Different methods are used to log the soil profile on the field. Table 27 and Figure 25 show response from the professionals for alternative approaches used to log soil profile (according to the pertinent codes). Accordingly, 95.7% and 65.3% of the respondents‘ use visual inspection and laboratory test result, respectively, to describe the soil layer and 43% of the professionals use TCR to report the soil profile.

More emphasis is given for the visual inspection. Laboratory test results for the soil and TCR results are given less concern regarding logging soil stratum.

Table 27 : Professionals response concerning approaches used to identify soil strata

Approaches Used to Identify Soil Strata	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Visual inspection	22	95.7%	1	96%	
Laboratory test results for the soil	15	65.2%	1	65%	
Total core recovery (TCR)	10	43.5%	1	43%	
<b>Row Sum</b>			<b>3</b>	<b>204%</b>	

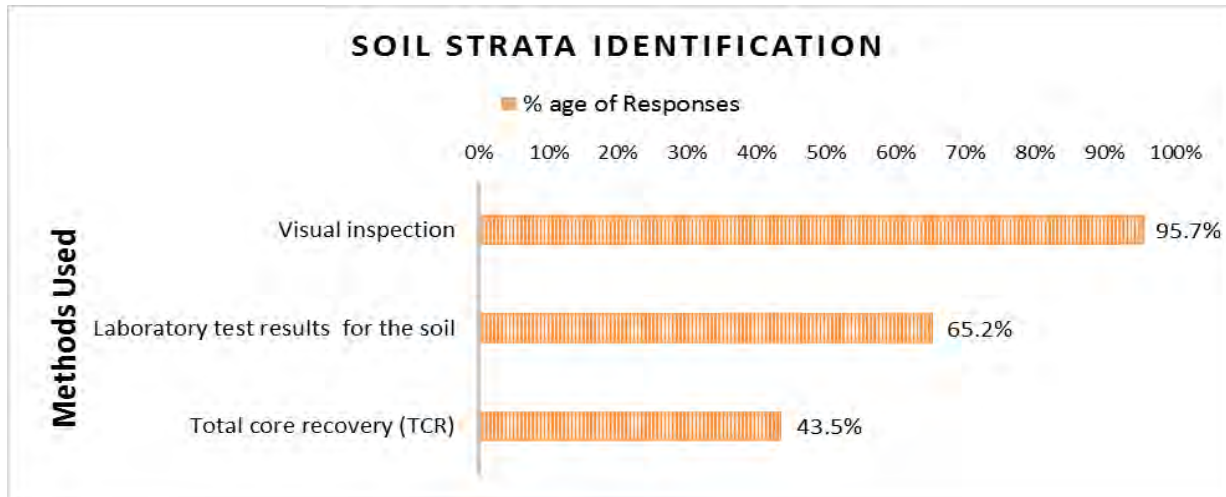


Figure 25 : Plot showing percentage of response against methods used to log soil stratum.

**c) Logging Rock Stratum**

Different methods are used to log the rock profile on the field. Table 28 and figure 26 show response from the professionals for alternative approaches used to log rock profile (according to the pertinent codes). Accordingly, 95.7% and 82.6% of the professionals consider TCR & RQD and degree of weathering respectively to describe the rock profile. And 73.9% of the respondents use visual inspection to log the rock strata.

Table 28 : Professionals response concerning approaches used to identify rock strata

Approaches Used to Identify Rock Strata	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
RQD and TCR	22	95.7%	1	96%	
Degree of weathering	19	82.6%	1	83%	
Visual Inspection	17	73.9%	1	74%	
		Row Sum	3	252%	84.1%

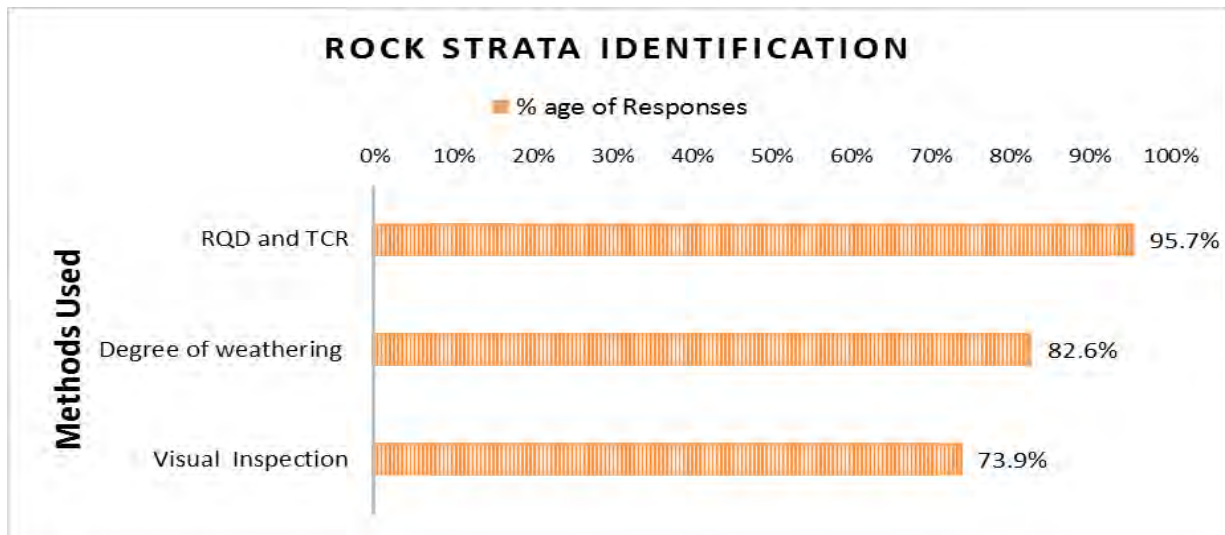


Figure 26 : Plot showing percentage of responses against methods used to log rock stratum.

#### d) Approaches Used for Bearing Capacity and Settlement Calculation

The presentation of geotechnical information shall include a factual account of all field and laboratory work. The major part of the report is the design. This includes bearing capacity and settlement calculations. All the field and laboratory tests will provide parameters for these calculations. Table 29 and Figure 27 show response from the professionals in relation to the alternative approaches used for bearing capacity and settlement calculation (cording to the pertinent codes).

Accordingly, 91.3% of the professionals use analytical method and 56.5% of them use empirical calculation methods. While 65.7% of the professional use presumptive values. More than half of the professionals use presumptive values for designing both bearing capacity and settlement. A lot of reliance should not be put on presumptive values and design should be done for the specific site under investigation. Designing parameters should be manipulated primarily using analytical, empirical methods, semi- Analytical/empirical method to give both safe and economical foundation design.

Table 29 : Professionals view in comparison with the approaches used for bearing capacity and settlement calculation according to the codes

Approachs Used for Bearing Capacity and Settlement Calculation	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Analytical	21	91.3%	2	183%	
Empirical	13	56.5%	2	113%	
Semi- Empirical	0	0.0%	2	0%	
Presumptive	15	65.2%	2	130%	
Row Sum			8	426%	53.3%

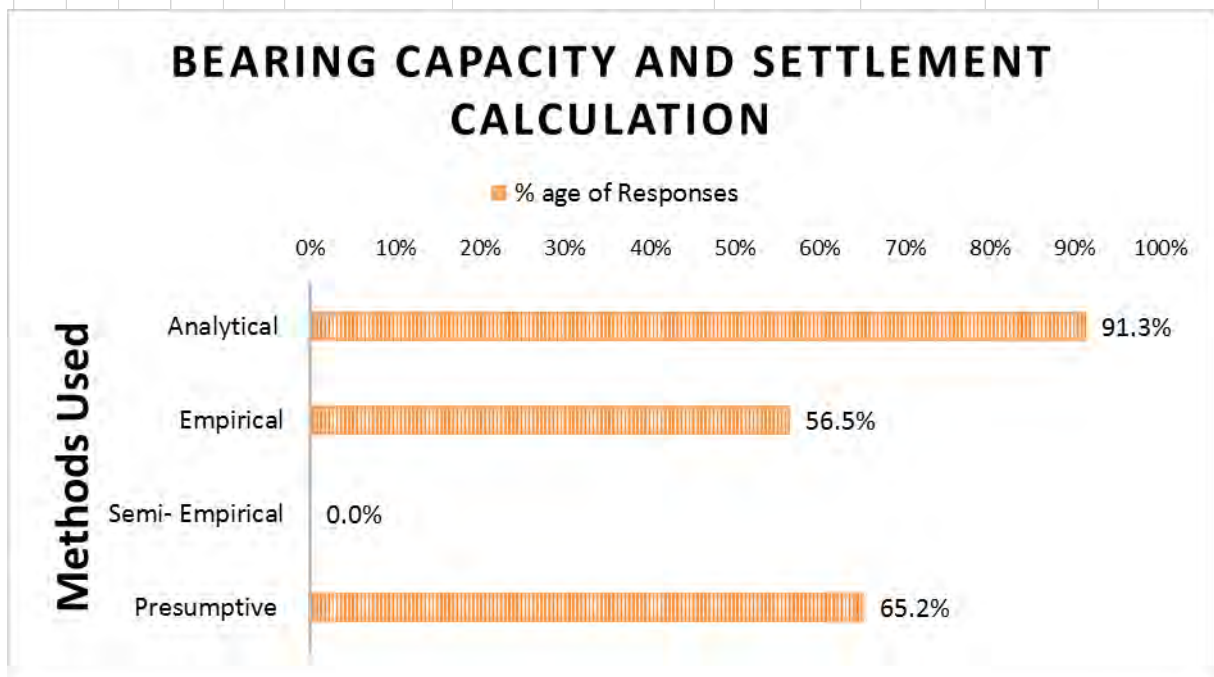


Figure 27 : Plot showing percentage of responses against approaches for bearing capacity and settlement calculation according to code provisions.

### 3.1.11 Supplementary Investigation

If the results obtained during the ongoing investigation do not correspond to the initial information recorded about the test site and the purpose of the investigation, then additional measures shall be considered. Different scenarios that need supplementary investigation are presented below.

#### a) Importance of Supplementary Ground Investigation during Construction

Since the geology of the earth is not uniform, it is difficult to give guaranty that the data gathered during the ground investigation will not deviate. So, supplementary investigation

should be carried out during substructure construction, if unforeseen situations are encountered. The percentages of responses that acknowledge the significance of the supplementary investigation during construction are shown in Table 30. Accordingly, 95% of the professionals recognized the significance of supplementary investigation during construction.

Table 30 : Importance of supplementary ground investigation during construction

Importance of Supplementary Ground Investigation During Construction	No. of Responses (Total Respondent 23)	% age of Responses
Significant	22	95.7%

**b) Project Located on an Old Damping Site**

The project might be located on an old damping site and primary investigation plan might not consider this irregularity, and to gather more detailed information, different measures are considered. Other supplementary recommendations should also be given both on design and construction stages. Table 31 and figure 28 shows measures considered if the project is located in an old damping site. And accordingly, 87% of the respondents will increase the depth of exploration and few of them (34.8%) will increase the number of drilling points.

Most geotechnical engineers suggested that increasing the depth of investigation will use to gather enough information about the project site. This measure is very useful to give safe investigation design for the engineering structure/project/.

Table 31 : Measures taken by the professionals if the project is located in an old damping site

Measures Taken if the Project is Located on an Old Damping Site	No. of Responses (Total respondent 23)	% age of Responses
Increase the investigation depth	20	87.0%
Drill additional borehole	8	34.8%
Detailed desk study	1	4.3%
Geophysical investigation	1	4.3%

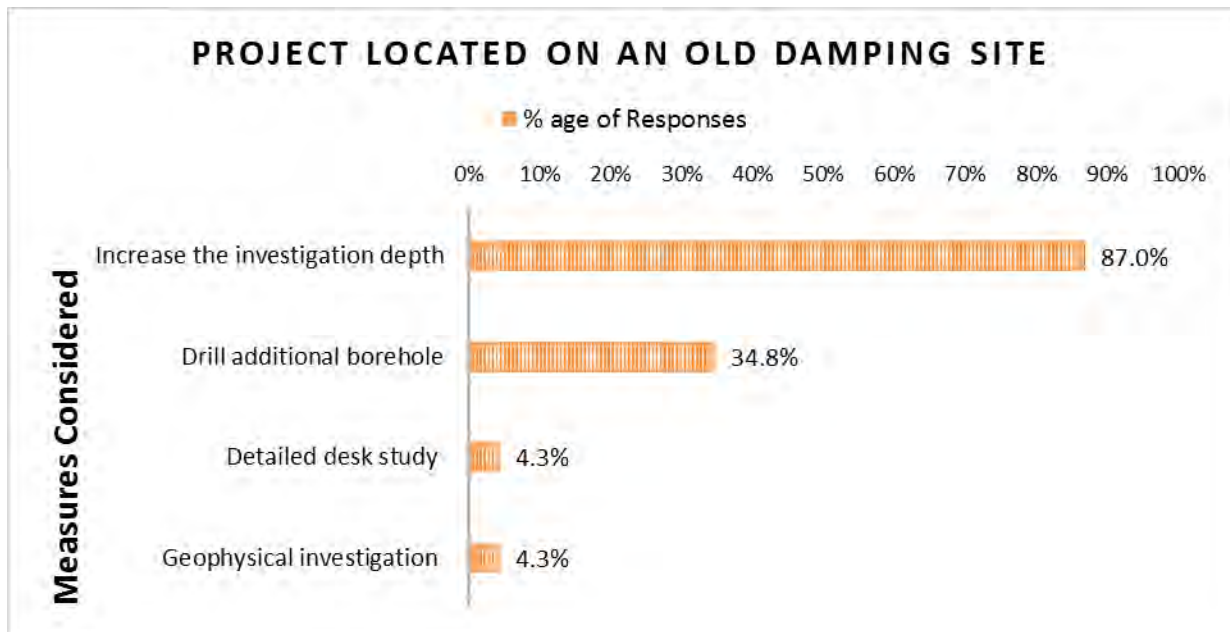


Figure 28 : Plot showing percentage of responses against measures considered if the project is located on an old damping site.

### c) Site Located on Vertically Erratic Soil Profile

The site might be vertically erratic and primary investigation plan might not consider this irregularity and so to gather more detailed information, different measures are considered. Table 32 and Figure 29 show the percentage of responses with respect to different measures taken to investigate this site with a given irregularity. Accordingly, 69% of the professionals suggested that increasing the depth of exploration should be done to find the full information about the site. And this is the common approach that is practiced to gather the necessary information for the foundation design. 39.1% of the professionals suggest that drilling additional boreholes/increasing investigation points will provide the necessary information for the project site under investigation. Very few of them (4.3%) use geophysical investigation method to assess the site.

As can be seen from the percentage of the professionals that have responded, most of the professionals are on the right track to deal with such site condition. 43.4% of the professionals will increase number of investigation points and carry out geophysical investigation methods.

Table 32 : Measures taken by the professionals if vertically erratic soil profile is found.

Measures Taken for a Project Located on Vertically Erratic Soil Profile	No. of Responses (Total respondent 23)	% age of Responses
Will increase the investigation depth	16	69.6%
Will drill additional borehole	9	39.1%
Geophysical investigation	1	4.3%

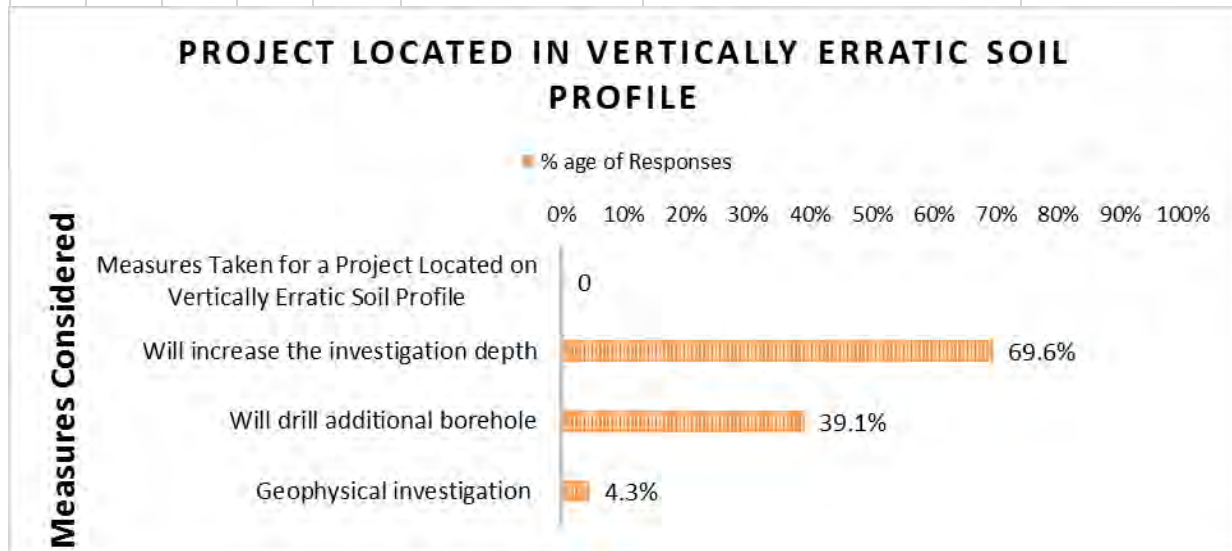


Figure 29 : Plot showing percentage of responses against measures considered for vertically erratic soil profile.

**d) Site Located on Horizontally Erratic Soil Profile**

The site might be horizontally erratic and primary investigation plan might not consider this irregularity and so to gather more detailed information, different measures are considered. Table 33 and Figure 30 show the percentage of responses with respect to different measures taken to investigate this site with a given irregularity. Accordingly, 91.5% of the respondents will drill additional boreholes to understand the project site with horizontally erratic soil profile. 13% of the professionals will increase the investigation depth and only 8.7% of these professionals use geophysical investigation method to investigate the problematic site.

Increasing depth of boreholes will not help to gather the necessary information for the design purpose and 13% of the professionals apply this measure. Few professionals will carry out geophysical investigation method and this is used as a primary investigation method not as a detailed investigation and so should be supported with other methods such as increasing the number of boreholes on the project site.

Table 33 : Measures considered by the professionals for horizontally erratic soil profile

Measures Taken for a Project Located on Horizontally Erratic Soil Profile	No. of Responses (Total Respondent 23)	% age of Responses
Increase the investigation depth	3	13.0%
Drill additional boreholes	21	91.3%
Geophysical investigation	2	8.7%

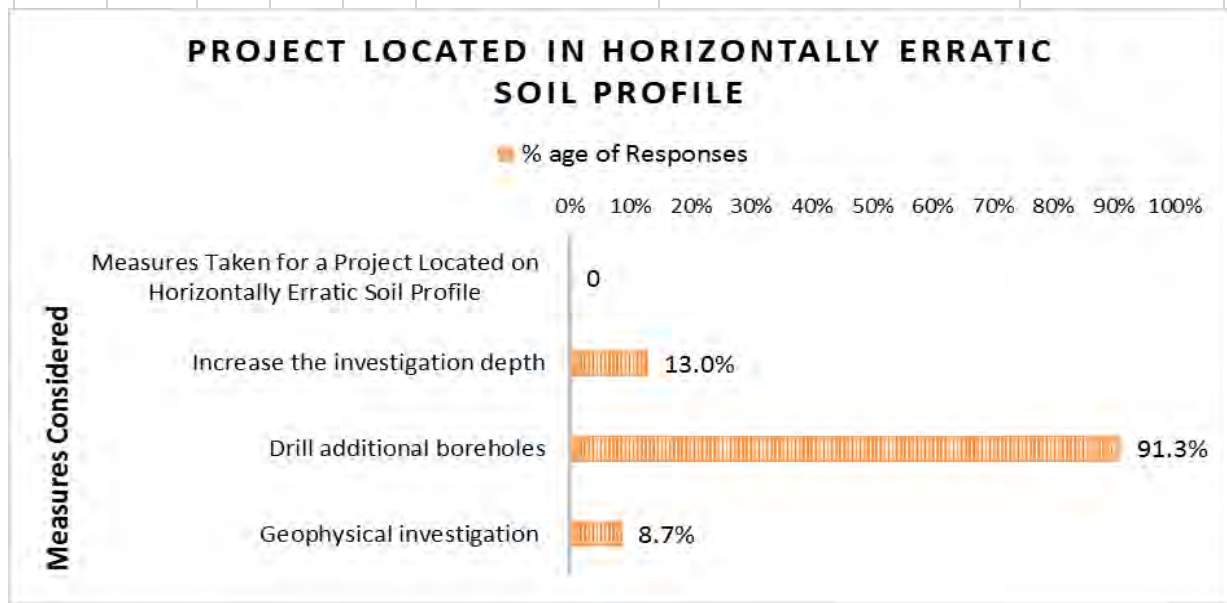


Figure 30 : Plot showing percentage of responses against measures considered for horizontally erratic soil profile.

**e) Frequency on Supplementary Investigation**

It is not usual to find problematic site and so the supplementary investigation will be carried out when unexpected soil profile is found during construction. Table 34 and Figure 31 will show the rate on which the supplementary investigation is carried out by the professionals. Accordingly, 43% the professionals carry out the supplementary investigation sometimes and 39.1% of them use additional investigation method rarely and 13% of the professionals carry out supplementary investigation frequently. Since supplementary investigation is required for certain projects with unusual soil profile, these steps can be eliminated if the soil profile and each data is found to be the same during construction as it is forecasted in the ground investigation.

Table 34 : Frequency on carrying out supplementary investigation by professionals

Frequency of Carrying out Supplementary Investigation	No. of Responses (Total Respondent 23)	% age of Responses
Rare	9	39.1%
Sometimes	10	43.5%
Frequently	3	13.0%
Very frequently	none	0.0%

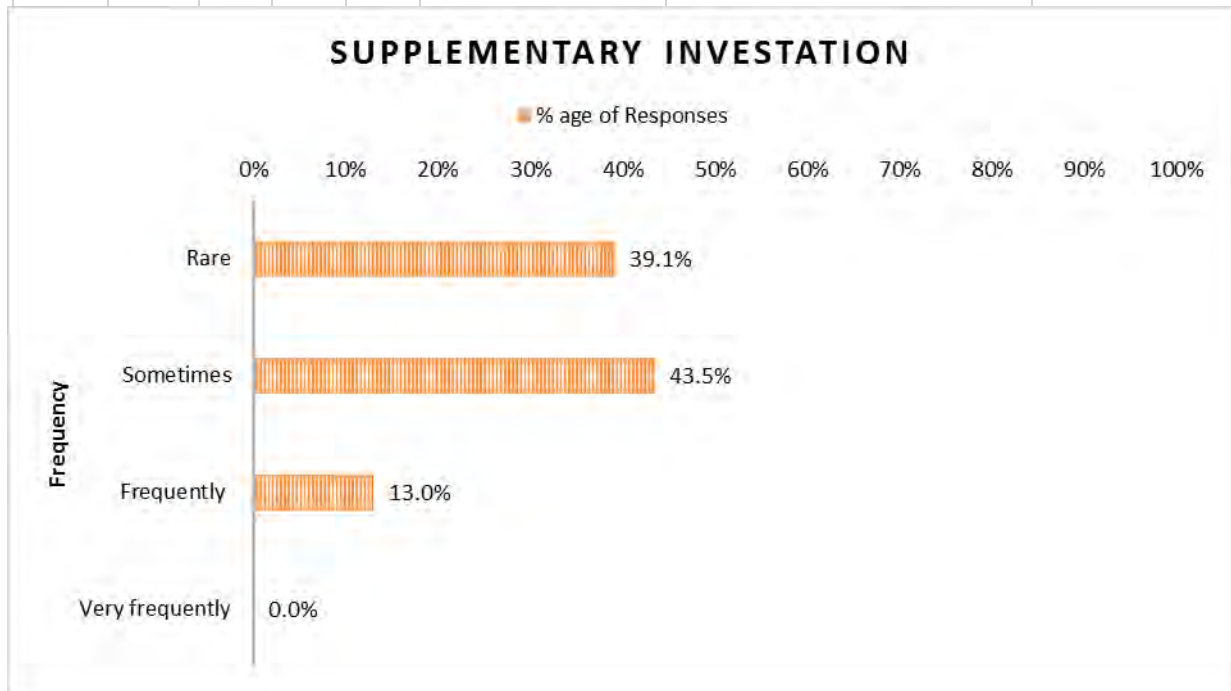


Figure 31: Plot showing percentage of respondents against frequency of supplementary investigation.

### 3.1.12 Supervision at the Investigation and During Construction Stages

Supervision is required during investigation and construction stages and different methods are used by professionals.

#### a) Methods for Supervising Geotechnical Investigation

Different methods are used to supervise the investigation once the ground investigation plan is made. Table 35 and Figure 32 show the percentage of responses concerning different supervision methods for geotechnical investigation. Accordingly, 34.8% of the professionals use a check list /to check the applicability of investigation program/ and only 13% of the

professionals will send a qualified professional on the project site, which is the most reliable method.

Table 35 : Supervision methods used for geotechnical investigation

Supervision Methods for Geotechnical Investigation	No. of Responses (Total respondent 23)	% age of Responses	Weighing Factor	Weighed %age	Weighted Total %age
Using a check list	8	34.8%	2	70%	
Supervision by qualified staff on the site	3	13.0%	3	39%	
		Row Sum	5	109%	21.7%

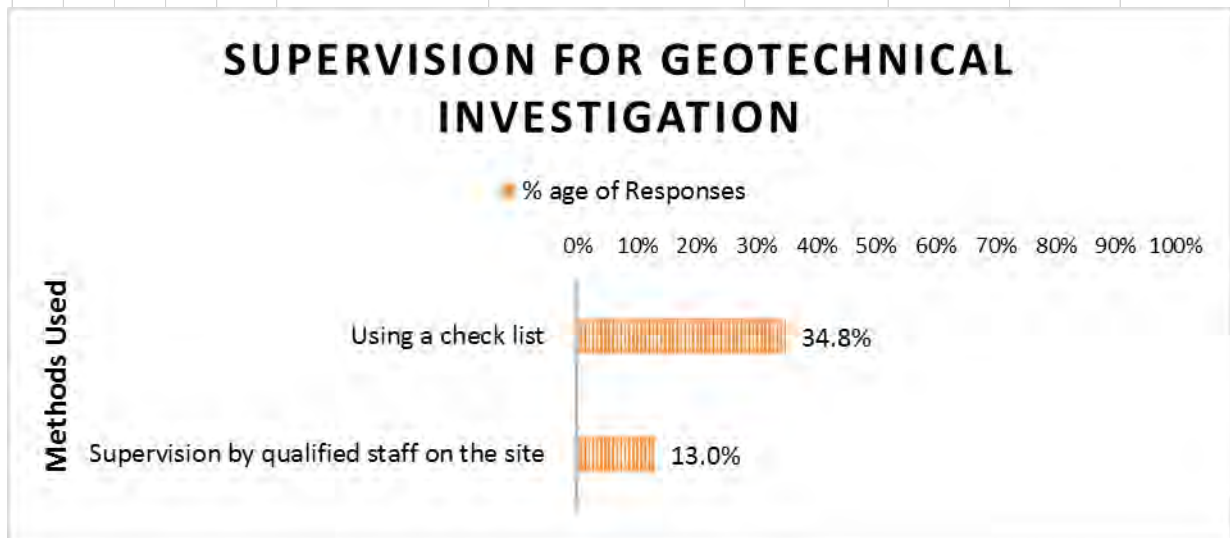


Figure 32: Plot showing percentage of responses against methods used for supervising geotechnical investigation.

**b) Importance of Supervision for Geotechnical Investigation**

Supervision for the ground investigation by a qualified professional will assure the quality of the investigation. This also can be done on the construction stages. Table 36 shows the percentage of professionals that consider the site supervision important. Accordingly, almost a quarter (26.1%) of professionals does not believe in the importance of site supervision during ground investigation. This clearly shows the root cause for poor ground investigation practice in our country. As a conclusion failing to supervise the ground investigation on site will result in unreliable investigation results.

Table 36 : Professionals View concerning the importance of supervision for the ground investigation

Importance of Supervision for Ground Investigation	No. of Responses (Total respondent 23)	% age of Responses
Important /Significant	17	73.9%

### 3.2 Analysis Summary of Questionnaires Gathered from Geotechnical Engineers (Geotechnical Investigation Firms)

Analysis is made on the data collected from the geotechnical engineers to evaluate the local ground investigation practice. The local practice is compared with the pertinent building codes to evaluate the conformity with the codes' standard. Figure 33 shows pertinent code provisions and requirements for the selected criteria, which will affect the ground investigation significantly, against the percentage of compliance for the local investigation practice (by Geotechnical Engineers). Accordingly, the local practice shows that more than half of the ground investigation criteria, have percentage of compliance below 50% and most of these values are below 25%. Some of these criteria are:

- Selecting ground investigation method
- Planning ground investigation
- Sampling methods
- Deciding field test types and frequency
- Deciding depth of exploration
- Location and spacing of test points
- Selection of laboratory test types
- Selection of drilling rig and
- Approaches used for both bearing and settlement calculation

The fact that percentage of compliance deviates greatly from the pertinent code standards shows that the local practice concerning the specific criteria mentioned is poor. As can be seen, many of the practices need serious improvements.

## GEOTECHNICAL INVESTIGATION (RESPONCE FROM GEOTECHNICAL ENGINEERS)

Critical Stages Considered for Ground Investigation

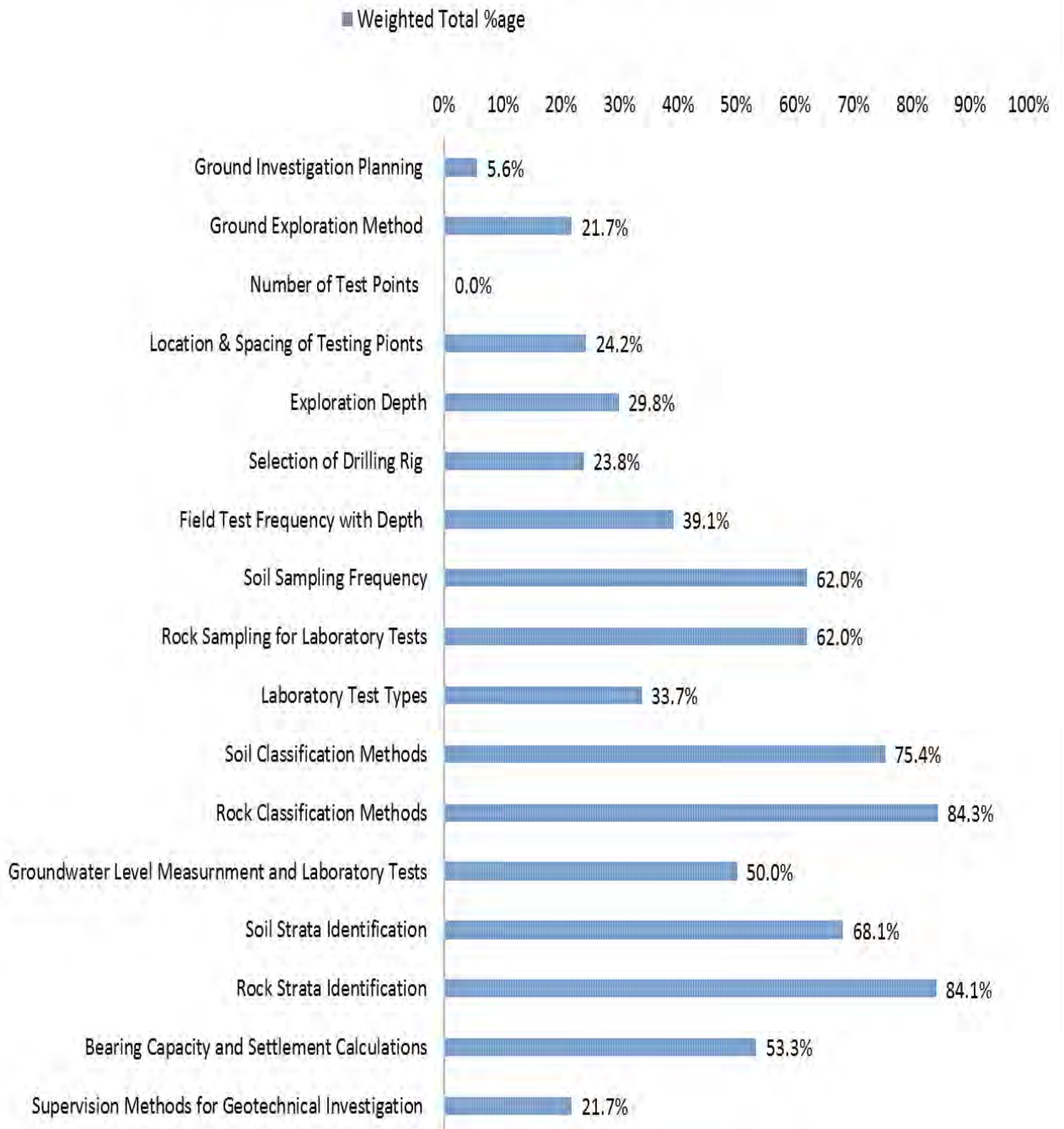


Figure 33 : Plot pertinent code provisions and requirements against weighted total percentage (percentage of compliance) for the geotechnical investigation practice (for Geotechnical Engineers)

### **3.3 Analysis Summary of Questionnaires Gathered from Structural Engineers (Engineering Consulting Offices)**

The detailed analysis of the data collected from the structural engineers regarding the ground investigation practice is carried out in a similar manner made for the geotechnical engineers. Figure 34 shows pertinent code provisions and requirements for the selected criteria against the percentage of compliance for the local investigation practice (by Structural Engineers).

As can be seen in Figure 23, local practice shows that more than 2/3 of the ground investigation criteria give percentage of compliance less than 40%. This result shows that almost compliance on every criterion needs major improvement.

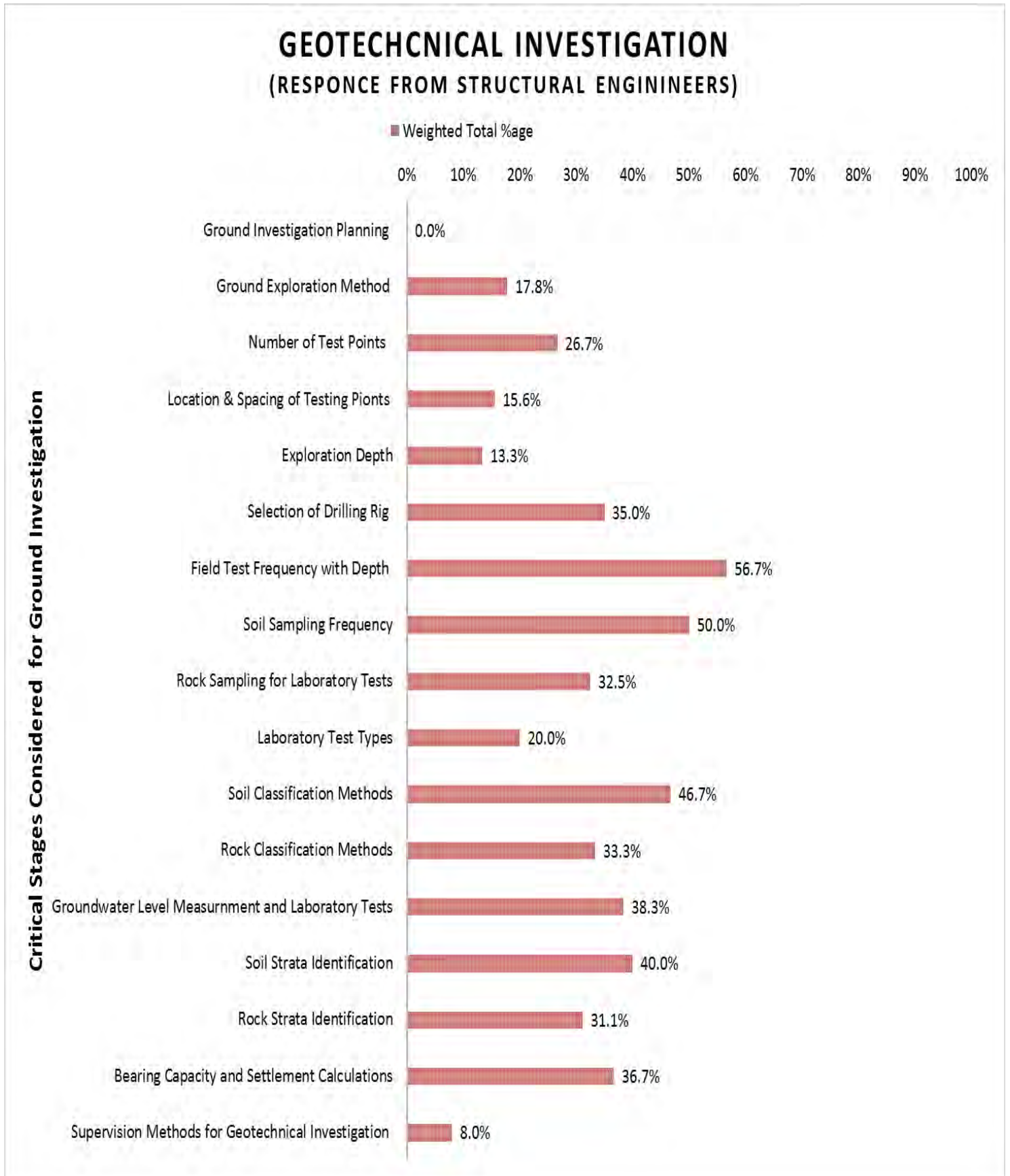


Figure 34 : Plot pertinent code provisions and requirements against weighted total percentage (percentage of compliance) for the geotechnical investigation practice (for Structural Engineers)

### **3.4 Comparison between geotechnical investigation made by Geotechnical Engineers and Structural Engineers**

As can be seen in Figure 35 comparison between geotechnical engineers and structural engineers is made. Percentage of compliance or conformity with the pertinent code provisions and requirements are given for each target groups.

The practice of the geotechnical engineers shows compliance/conformity percentage with the pertinent codes provisions/ requirements, which is almost twice than that of the structural engineers.

These analysis shows that the geotechnical investigation carried out by geotechnical engineers conform to the pertinent code provisions and requirements than ground investigation made by structural engineers.

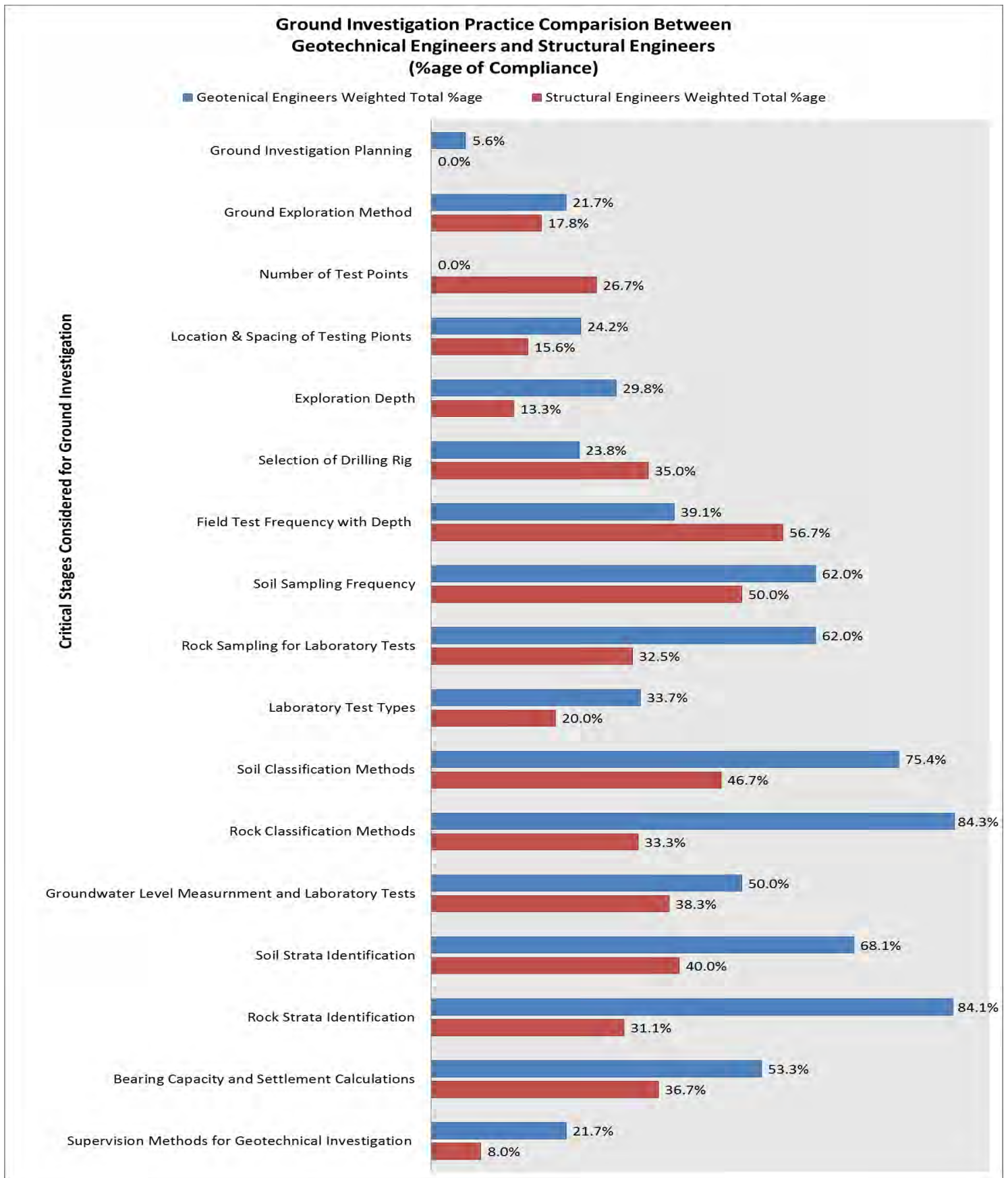


Figure 35: Plot pertinent code provisions and requirements against weighted total percentage (percentage of compliance) for geotechnical and structural engineers

### 3.5 Analysis and Result of Interview with Professionals from Regulatory Municipal Body (Sub- Cities)

Interview with the professionals at the municipality, who regulate the quality of the geotechnical investigation report, is presented and analyzed as follows.

Three professionals from different sub cities have been interviewed. And their summarized response is presented under each query.

#### 1. Evaluation method for the geotechnical investigation report (made by different geotechnical investigation firms)

Two of these professionals evaluate the report by first checking the legality of both trade and professionals license. They agreed on the fact that the geotechnical investigation firm is the one that take full responsibility for the investigation work. And the next step will be to look through the report for type of foundation, depth of foundation and allowable bearing capacity from the recommendation. The report will be acceptable if these data are presented in the report.

Professional from the other sub-city claims that the investigation firm should have legal licenses and additionally factors such as depth of exploration and laboratory tests are also evaluated. Selection of foundation type and depth, and bearing capacity calculation is given emphasis for tests are the final output of the investigation.

In summary, there are different evaluation methods for each sub-city as can be seen from the responses and there is no written standard to evaluate the geotechnical investigation reports. This shows these professionals are subjective and don't have a common standard to evaluate the report. Though, it is fact that the investigation firms are responsible for ground investigation, the professionals from the regulatory bodies should also share their portion in keeping the quality of the report as it is done for other deign works. The regulatory professionals should evaluate every step starting from selection of ground investigation method to giving foundation recommendation. The foundation recommendation includes selection of foundation type, determination of foundation depth, settlement and bearing capacity calculations. Thus, the way these professionals evaluate is poor beyond explanation and the poor practice in this sector should be addressed.

#### 2. Evaluation of exploration methods for different type of engineering structures.

All of these professionals agreed that for the building structures starting from G+0 to G+4 buildings, test pit have to be dug for the ground investigation and for buildings above G+4, drilling rig or auger should be used to do the exploration.

In summary, while comparing these evaluation methods with the pertinent provisions and requirements, the practice in our country is incomplete and incompetent. For the requirements set by the professionals do not give attention for the detail criteria. Some of these criteria are number, location and spacing of test points, depth of exploration (considering depth of substructure/basement if any), type, number, frequency and depth of samples and field tests. Bearing capacity and settlement calculation methods should also be evaluated.

### 3. Evaluation of bearing capacity and settlement calculation

Two of the professionals replied that bearing capacity calculation is evaluated by checking the results given in the report with the presumptive bearing capacity values from Ethiopian Building Code Standard for foundation (EBCS 7) to see if it does not exceed the limit stated in the presumptive value.

The third professional responded saying, if the bearing capacity calculation considered laboratory or field tests results then the result is acceptable for him.

None of the respondents evaluate settlement calculation for they think it is necessary to carry out settlement calculation for high rise buildings only.

In summary, methods used to evaluate the bearing capacity calculation are poor and evaluation of settlement calculation it is only being considered for high rise structure. This is a wrong assumption for settlement problem might occur on any structure located on a compressible soil layer. The practice is generally poor to evaluate the bearing capacity and settlement calculation

### 4. Site supervision during ground investigation

None of them will carry out site supervision for the ground investigation.

For an activity, such as ground investigation, the majority of the work is completed on the site. Failing to supervise this activity will result in serious problem for the procedures claimed in ground investigations reports might not actually be done on the site. In general site supervision for the ground investigation is absent and the investigation procedure is merely evaluated by the writings in the geotechnical investigation report.

## 4. CONCLUSION AND RECOMMENDATION

### 4.1 Conclusion

The evaluation of questionnaires as well as the interview is used to compare the detailed geotechnical investigation practice with the pertinent code provisions and requirements which are critical to carry out a complete ground investigation. Comparison is made between these, to evaluate the degree of compliance of the practice on the ground.

The local practice in light of the data gathered from the geotechnical engineers (from geotechnical investigation firms) and structural engineers (from engineering consulting offices) is compared with the pertinent code provision and requirements, and also these two target groups are compared with each other. This is used to evaluate the degree of compliance/conformity of the two target groups separately, with the pertinent codes and also compare the degree of compliance/conformity to one another.

In this regard, the findings clearly show that the geotechnical investigation practice is very poor in our country and the practice on the ground is substandard. This is clearly shown in the data analysis part that the geotechnical professionals showed 43.5% compliance and the structural engineers exhibited 29.5% compliance compared to the provisions and requirements found in the selected pertinent codes.

The practices carried out by geotechnical engineers' shows relatively better result in comparison to the structural engineers. This shows that the geotechnical investigation planning, execution, supervision on the site during the investigation and also preparation of the report should be carried out by geotechnical engineers for a better result.

Generally, the current local practice is poor mainly because of following reasons:

- i. Lack of appropriate and deep knowledge on the field
- ii. Lack of strict supervision on Investigation & construction sites by regulatory bodies
- iii. Lack of awareness on the significance of detailed geotechnical investigation

As can be seen, the results from the questionnaires and interviews, negligence and poor practice result in uneconomical and unsafe foundation design.

## 4.2 Recommendations

As can be seen from the analysis the field of geotechnical investigation is dying every day as the new professionals have no firm ground to stand on for a better practice.

Therefore, the following are recommended to alleviate the problem Caused or faced by the geotechnical investigation practices in our country.

- The Governing/Existing Ethiopian Building Code should be amended to incorporate more detailed and updated guidelines.
- Ground investigation should not be planned and supervised by any professions but by geotechnical engineers.
- Regulatory bodies that evaluate the ground investigations should prepare and enforce procedures and process for the regulations of the geotechnical investigations conducted. Continuous trainings should also be given to regulatory professionals to insure quality of the ground investigation practice in Ethiopia.
- Regular supervision should be conducted on the project site during the investigation. Using a check list and other methods available is also recommended.
- Creating a legal association composed of the geotechnical engineers to contribute a lot for the field of geotechnical investigation. This will create a critical mass that can influence changes on the generally accepted geotechnical principles and practices. In addition, it will create a platform to:
  - Discuss and debate on different issues regarding geotechnical engineering practices and bodies of knowledge.
  - Local researches and publishing will be encouraged so that indigenous data and intellect are incubated to incorporate in our codes and practices.
  - It will create problem solving, proactive and skilled professionals
- Workshops should be prepared on the field for it will improve the professionals' point of view about the importance and applicability of the ground investigation.
- Senior professionals in this field should be available purposely to give critics, comments and recommendation for concerning bodies/advise seeking professionals to bring the best results on improving the quality of the investigation.

All the above activities and more will assure high quality geotechnical investigation practice in our country.

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## APPENDIX A

### *(List of Tables for Pertinent Code Requirements and Provisions for Critical Ground Investigation Stages)*

The following tables represent the main idea of the thesis. Detailed code provisions and requirements for each code are described in a table format.

The table's composition is portrayed as follows. The first row describes geotechnical investigation stages. The second row shows code requirements or code provisions for the detailed description given in the 4<sup>th</sup> row. The 3<sup>rd</sup> row shows the pertinent code considered for the review. The last (4<sup>th</sup>) row shows requirements considered or provisions given by the codes for different investigation stages.

Organizing the table in this format uses to compare and contrast each provisions and requirements of the codes. It also uses to evaluate the data collected from questionnaire and interview.

Table A. 1 Review of Pertinent Code Requirements for Ground Investigation Method

Ground Investigation Method			
Code Requirements/Factors to be Considered			
In Light of Ethiopian Building Code Standard: EBCS 7(MoWUD, 1995)	In Light of European Standard, Euro Code 7 (ECS, 2007)	In Light of International Building Code (ICC, 2009)	In Light of Indian Standard (ISI, 1985)
<p>The method /extent of ground investigation is determined by:</p> <ul style="list-style-type: none"> <li>▪ The character and variability of the ground,</li> <li>▪ The presence of ground water,</li> <li>▪ The type of the project and</li> <li>▪ The amount of existing information about the project site.</li> </ul>	<p>The extent of the ground investigations should be based on:</p> <ul style="list-style-type: none"> <li>▪ The anticipated type and design of the construction, (Type of foundation, retaining structure, location and depth of the construction),</li> <li>▪ The results of the desk studies and site inspection,</li> <li>▪ The variation in ground conditions for soil, rock and</li> <li>▪ The presence of groundwater.</li> </ul>	<p>This code considers the following points to conduct the ground investigation.</p> <ul style="list-style-type: none"> <li>▪ If doubtful data is available regarding expansiveness of the soil, soil classification, strength or compressibility of the soil.</li> <li>▪ Where investigation indicates variations or doubtful characteristics in the structure of the rock upon which foundations are to be constructed,</li> <li>▪ If excavation will be done near foundations,</li> <li>▪ Where shallow foundations will bear on Controlled Low-Strength Material (CLSM) and compacted fill material,</li> <li>▪ The presence of potential geologic and seismic hazards(theses are slope instability, liquefaction, differential settlement and surface displacement due to faulting or lateral spreading) and</li> <li>▪ The presence of ground-water.</li> </ul> <p><b>Note:</b> The building official is permitted to waive the requirement for a ground investigation where satisfactory data from adjacent areas is available.</p>	<p>The extent of ground investigation depends on:</p> <ul style="list-style-type: none"> <li>▪ The nature of ground: <ul style="list-style-type: none"> <li>○ <b>Soils:</b> In clayey soils borings are suitable for deep exploration and pits for shallow exploration.</li> <li>○ <b>Rocks:</b> Borings are suitable in hard rocks and pits in soft rocks. Core borings are suitable for the identification of types of rocks.</li> </ul> </li> <li>▪ The topography: In hilly country the choice between vertical openings and horizontal openings depend on the topography and the geological structure.</li> <li>▪ The cost: For deep exploration, borings are used and are costly but trial pits are more economical.</li> </ul>

Table A. 2: Review of Pertinent Code Provisions for Site Reconnaissance and Preliminary Investigation

<b>Site Reconnaissance and Preliminary Investigation</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>These phases of investigation will provide estimates of soil data concerning:</p> <ul style="list-style-type: none"> <li>▪ The type of soil or rock and their stratification</li> <li>▪ The groundwater table</li> <li>▪ The preliminary strength and deformation properties for soil and rock &amp;</li> <li>▪ The potential occurrence of contaminated ground</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>The scope of preliminary exploration is limited to:</p> <ul style="list-style-type: none"> <li>▪ The determination of depths, thickness, extent and composition of each soil stratum,</li> <li>▪ Providing the location of rock and ground water and</li> <li>▪ Obtaining approximate information regarding strength in compressibility of the various strata. The following two methods are useful guides for preliminary investigation.                             <ol style="list-style-type: none"> <li>1. Geophysical Methods: Seismic refraction &amp; electrical resistivity surveys are widely used.</li> <li>2. Tests with cone penetrometers and sounding rods.</li> </ol> </li> </ul>

Table A. 3: Review of Pertinent Code Provisions for Detailed Investigations

<b>Detailed Investigations</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>Detailed investigation provides engineering properties of strata which are obtained by preliminary exploration to be critical. And it includes:</p> <ul style="list-style-type: none"> <li>▪ Boring program and</li> <li>▪ Detailed sampling</li> <li>▪ Field tests &amp; Laboratory tests</li> </ul>

Table A. 4: Review of Pertinent Code Provisions for Ground Investigation Planning

Ground Investigation Planning			
Code Provisions			
In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)	In Light of European Standard, Euro Code 7 (ECS, 2007)	In Light of International Building Code (ICC, 2009)	In Light of Indian Standard (ISI, 1985)
<p>The Ground investigation planning include :</p> <ul style="list-style-type: none"> <li>▪ General suitability of the ground</li> <li>▪ Nature and classification of the various zones of soil, rock and construction elements</li> <li>▪ Mine working, caves/other underground structures&amp; dipping bedding planes</li> <li>▪ Inter-bedded hard and soft strata ,faults, joints and fissures&amp; solution cavities, such as swallow holes or fissures filled with soft material, and continuing solution processes if the structure is resting on or near rock :</li> <li>▪ All load action</li> <li>▪ Effect of the new structure on existing structures</li> <li>▪ The nature of the environment. This includes:                             <ul style="list-style-type: none"> <li>○ Effects of scour, erosion, excavation holes created by animal activities, subsidence due to mining</li> <li>○ Effects of chemical corrosion;</li> <li>○ Effects of weathering;</li> </ul> </li> <li>▪ Ground water level fluctuation</li> <li>▪ The presence of gases emerging from the ground.</li> </ul>	<p>Ground investigation planning include:</p> <ul style="list-style-type: none"> <li>▪ Types of investigations</li> <li>▪ Locations of test points</li> <li>▪ The types of equipment to be used</li> <li>▪ The depth of the investigations of field test</li> <li>▪ The types of sample to be taken, number and depth of sampling</li> <li>▪ Specifications on the groundwater measurement</li> <li>▪ Measurements and down hole logging</li> <li>▪ Large scale tests to determine the bearing capacity</li> <li>▪ Asses the applicability of field investigation planning</li> <li>▪ Assess ground contamination of soil gas</li> <li>▪ The standards to be applied / referred.</li> </ul> <p><b>Laboratory Investigation Planning:</b> This shall contain:</p> <ul style="list-style-type: none"> <li>▪ Visual inspection and preliminary ground profile,                             <ul style="list-style-type: none"> <li>○ Number of Tests: This considers homogeneity of the ground, quality and amount of comparable experience with the ground</li> <li>○ Geotechnical category of the problem.</li> </ul> </li> <li>▪ Classification Tests: Samples for this test should be equally distributed.</li> </ul>	<p>Ground investigation planning include:</p> <ul style="list-style-type: none"> <li>▪ The number and types of borings or soundings</li> <li>▪ The equipment used to drill or sample,</li> <li>▪ The in-situ testing equipment and</li> <li>▪ The laboratory testing program.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>

Table A. 5: Review of Pertinent Code Requirements for Location, Number and Spacing of Testing Point

<b>Location, Number and Spacing of Testing Points</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>The number and spacing of test points depend on:</p> <ul style="list-style-type: none"> <li>▪ The extent of the site and</li> <li>▪ The nature of structures</li> </ul> <p>The spacing and the minimum number of trial pits and boring are shown in Appendix C- Table C.1</p>	<p>Spacing of investigation points is give for different projects as follows:</p> <ul style="list-style-type: none"> <li>▪ For high-rise and industrial structures, a grid pattern with points at 15 m to 40 m distance;</li> <li>▪ For large-area structures, a grid pattern with points at not more than 60 m distance;</li> <li>▪ For linear structures a spacing of 20 m to 200 m;</li> <li>▪ For special structures like bridges, stacks and machinery foundations, two to six investigation points per foundation;</li> <li>▪ For dams and weirs, 25 m to 75 m distance, along relevant sections.</li> </ul>	<p>In a nutshell the test points should be positioned at appropriate locations.</p> <ul style="list-style-type: none"> <li>▪ The scope of the ground/geotechnical investigation including the number of borings shall be determined by a registered design professional.</li> </ul>	<p>The number and spacing of test points will depend upon:</p> <ul style="list-style-type: none"> <li>▪ The extent of the site/area and</li> <li>▪ The type of structures coming on it/importance of the structure (Refer Appendix C- Table C.2).</li> </ul>

Table A. 6 : Review of Pertinent Code Requirements to Determine Depth of Exploration

<b>Depth of Exploration</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC,2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>he depth of exploration required depends on:</p> <ul style="list-style-type: none"> <li>▪ The depth of hard or dense material,</li> <li>▪ Location of the structure on the sites, with rock stratum near the surface, depth of exploration shall extend to:                             <ul style="list-style-type: none"> <li>○ 2.0m into un-weathered rock stratum and</li> <li>○ 3.0m inside weathered rock stratum but one or two boreholes shall extend 6.0m into the weathered rock stratum.</li> </ul> </li> <li>▪ The estimated width (W) for structures:                             <ul style="list-style-type: none"> <li>○ On footing foundation, the depth of exploration shall be 3*W from the base level of the footing, but not less than 1.5m.</li> <li>○ On mat foundation, the depth of exploration shall be 1½*W from the base level of the mat, but not less than 6.0m.</li> <li>○ On piled foundation the depth of exploration shall exceed by at least 3.0m that at which the piles may be found.</li> </ul> </li> </ul>	<p>The following approach is used to determine the exploration depth <math>Z_a</math>. <math>Z_a</math> depends on :</p> <ul style="list-style-type: none"> <li>▪ The soil strata where the foundation is placed on .Using the approach given below, the largest value of <math>Z_a</math> will be selected:                             <ul style="list-style-type: none"> <li>○ If structures are built on competent strata, the depth of investigation will be <math>Z_a = 2</math> m,</li> <li>○ If the geology is indistinct, at least one borehole should extend to a minimum of <math>Z_a=5</math>m.</li> <li>○ If a bedrock formation is encountered at the proposed base of the structure, this should be taken as the reference level for <math>Z_a</math>. Otherwise, <math>Z_a</math> refers to the surface of the bedrock formation.</li> </ul> </li> <li>▪ The width of the foundation. Different approach is given to calculate <math>Z_a</math> for different structures and the largest value will be selected:                             <ul style="list-style-type: none"> <li>○ For high-rise structures and civil engineering projects (Refer Appendix C-Figure C.1 (a) and Equation C.3).</li> <li>○ For raft foundations (Refer Appendix C- Figure C.1 (b)).</li> <li>○ Linear structures( Refer Appendix C- Figure C.2 and Equation C.4):</li> <li>○ For piles (Appendix C- Figure 27 and Equation C.5),</li> </ul> </li> </ul>	<p>The depth of exploration depends on:</p> <ul style="list-style-type: none"> <li>▪ The strata on which the structure is to be placed on:                             <ul style="list-style-type: none"> <li>○ If doubtful characteristics appear in the structure of the rock on which the foundation is to be placed, then sufficient number of borings shall be made to a depth of not less than 3.048m depth below the level of the foundations.</li> </ul> </li> </ul>	<p>The depth of exploration required depends mainly on:</p> <ul style="list-style-type: none"> <li>▪ The type of proposed structure,</li> <li>▪ Its total weight, the size, shape and disposition of the loaded areas,</li> <li>▪ Soil profile</li> <li>▪ Width (W) of the footing - Refer Appendix C Table C.3.                             <ul style="list-style-type: none"> <li>○ It should be 1½*W below foundation level.</li> <li>○ In certain cases, take at least one bore hole or cone test or both to 2*W.</li> <li>○ If a number of loaded areas are in close proximity. In such cases, exploration should be carried out up to 1½*W.</li> </ul> </li> <li>▪ Structural loads :                             <ul style="list-style-type: none"> <li>○ In weak soils, exploration depth should extend to firm strata that can withstand excess settlement and shear failure.</li> <li>○ Due allowance being made for the overlapping effects of load from closely spaced footings (2V:1H from all sides of the foundations).</li> </ul> </li> <li>▪ The depth to which seasonal variations affect the soil</li> </ul>

Table A. 7 : Review of Pertinent Code Requirements for Selection of Drilling Rigs for Boring

<b>Drilling Rigs for Boring</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
Drilling machines are selected considering the depth of exploration. As it can be seen below: <ul style="list-style-type: none"> <li>▪ For shallow depth explorations:                             <ul style="list-style-type: none"> <li>○ Hand operated augers</li> </ul> </li> <li>▪ For deeper borings:                             <ul style="list-style-type: none"> <li>○ Machinery operated augers,</li> <li>○ Rotary core drilling and</li> <li>○ Percussion drilling /Drill casings are normally used to support unstable ground/.</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>• Specifically, not stated</li> </ul>	For selection of the drilling machines the following points are considered: <ul style="list-style-type: none"> <li>▪ Type of field test required,</li> <li>▪ Type of samples,</li> <li>▪ Depth of exploration</li> </ul> Some of the drilling machine used are: <ul style="list-style-type: none"> <li>○ Auger Boring</li> <li>○ Shell and Auger Boring</li> <li>○ Percussion Boring</li> <li>○ Wash Boring</li> <li>○ Rotary Boring: There are three types of rotary boring machine theses are Mud-rotary Drilling, Simplified Mud-Boring Method, Core Drilling and Shot Drilling machine.</li> <li>○ Pressure Meter</li> </ul>

Table A. 8: Review of Pertinent Code Requirements for In-Situ Tests /Field Tests

<b>In-Situ Tests /Field Tests</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
These tests are selected by considering: <ul style="list-style-type: none"> <li>▪ The design parameters required by the professionals. Some of the field tests are:                             <ul style="list-style-type: none"> <li>○ Plate Loading Test</li> <li>○ Penetration Tests</li> <li>○ Vane Shear Tests</li> <li>○ Pressure Meter Tests</li> </ul> </li> </ul>	Before carrying out the test the following points are considered: <ul style="list-style-type: none"> <li>▪ Geology/stratification of the ground;</li> <li>▪ Type of structure, the possible foundation and the anticipated work during the construction;</li> <li>▪ Type of geotechnical parameter required;</li> <li>▪ Design method to be adopted.</li> </ul> Some of the test types are: <ul style="list-style-type: none"> <li>○ Cone penetration test;</li> </ul>	This code gives full responsibility for the selection of in-situ testing to a registered design professional.	These tests are selected by considering: <ul style="list-style-type: none"> <li>▪ To determine the design parameters for calculation purposes. Some of the field tests are:                             <ul style="list-style-type: none"> <li>○ Vertical Loading Tests</li> <li>○ Deep Penetration Tests</li> <li>○ Dynamic Penetration Tests</li> <li>○ Sounding Tests-Deep</li> <li>○ Vane Shear Tests</li> <li>○ The standard penetration Test</li> </ul> </li> </ul>

	<ul style="list-style-type: none"> <li>○ Pressure meter and dilatometer tests;</li> <li>○ Standard penetration test;</li> <li>○ Dynamic probing;</li> <li>○ Weight sounding test;</li> <li>○ Field vane test;</li> <li>○ Flat dilatometer test;</li> <li>○ Plate loading test</li> <li>○ Geophysical methods</li> </ul>		
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Table A. 9 : Review of Pertinent Code Requirements for Sampling Methods and Planning

<b>Sampling Method and Plan</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
Different sampling method and plan are used to collect both disturbed and undisturbed samples. Sampling methods and plans should be based on: <ul style="list-style-type: none"> <li>▪ Drilling methods used,</li> <li>▪ Type of the sample required(core sample, undisturbed sample, disturbed sample, block sample ,etc ...) and</li> <li>▪ Sampling tools used.</li> </ul>	Sampling method and plan should be based on: <ul style="list-style-type: none"> <li>▪ The aim of the soil investigations,</li> <li>▪ The geology of the site/type of soil,</li> <li>▪ The complexity of the structure and the type of tests to be performed.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	The method and plan of taking the sample should consider: <ul style="list-style-type: none"> <li>▪ The type of tests to be performed,</li> <li>▪ The quality of the samples required</li> <li>▪ The exploration type (boring, Auger ,test pits, etc....) (refer Appendix C- Table C.5) and</li> <li>▪ The level of ground water (disturbed sample is collected when taken below the ground water level (GWL).</li> </ul>

Table A. 10 : Review of Pertinent Code Requirements for Sampling Tools:

<b>Sampling Tools</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
Some of the sampling tools required are: <ul style="list-style-type: none"> <li>▪ Split tube sampler (e.g. open tube samplers and thin – walled samplers)</li> <li>▪ Drill tools /Tube with a cutter at its lower end collect core sample</li> </ul> Sampling tube of 100mm internal diameter provided with a cutting edge – to collect block sample.	Two different sampling tools should be used when using a drilling machine: <ul style="list-style-type: none"> <li>▪ Drilling tools</li> <li>▪ For a given project, specific sampling equipment may be required within the sampling categories.</li> </ul>	<ul style="list-style-type: none"> <li>▪ The equipment used to sample shall be determined by a registered design professional.</li> </ul>	Different sampling tools are used for different soil layers and few of them are: <ul style="list-style-type: none"> <li>▪ For Cohesive soil: Split spoon, sampler, open tube sampler and piston sampler.</li> <li>▪ For cohesion less soil: Control at the top and bottom of the sampler and solidification by the introduction of chemicals or emulsions.</li> </ul>

Table A. 11: Review of Pertinent Code Requirements for Soil Sampling Frequency

<b>Frequency of Soil Sampling</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
The following points should be considered while deciding frequency of sampling: <ul style="list-style-type: none"> <li>▪ Change of a stratum,</li> <li>▪ Homogeneity /uniformity/:</li> <li>▪ If a detailed definition of the ground conditions is required, continuous sampling / samples recovered at very short intervals is mandatory.</li> </ul>	The following point should be considered while deciding frequency of sampling: <ul style="list-style-type: none"> <li>▪ Change of a stratum.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	The following considerations should be made while deciding the frequency of sampling: <ul style="list-style-type: none"> <li>▪ Importance of the investigation</li> <li>▪ Type of the soil / continuous core sampling in any soft clay layers/.</li> </ul>

Table A. 12: Review of Pertinent Code Requirements Concerning Categories of Soil Sampling Methods, Laboratory Quality Classes and Size of Samples

<b>Categories of Soil Sampling Methods, Laboratory Quality Classes and Size of Samples</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS7(MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
The size of the sample is determined by: <ul style="list-style-type: none"> <li>▪ Soil type and</li> <li>▪ Type of test to be carried out</li> </ul> Mass of soil sample required for various laboratory tests (Refer Appendix C - Table C.6).	Different sampling categories are considered and these depend on: <ul style="list-style-type: none"> <li>▪ The desired sample quality and</li> <li>▪ Laboratory test types required (Refer Appendix C- Table C.4).</li> </ul> Size of soil samples depend on: <ul style="list-style-type: none"> <li>▪ The quality of the soil sample extracted /disturbed, undisturbed or remolded, etc.</li> <li>▪ The type of the soil /size of particles/ and</li> <li>▪ The laboratory tests required (Refer Appendix C-Table C.7, Table C.8 &amp; Table C.9)</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	The size of the sample required depends on: <ul style="list-style-type: none"> <li>▪ Soil type and</li> <li>▪ Type of test to be conducted (Refer Appendix C Table C.10).</li> </ul> The quality classes of soil samples for laboratory testing and sampling categories depend on(Refer Appendix C Table C.5): <ul style="list-style-type: none"> <li>▪ Nature of the ground,</li> <li>▪ Type of samples and</li> <li>▪ Method of sampling (tools used to extract soil samples)</li> </ul>

Table A. 13: Review of Pertinent Codes Requirement for Soil Identification.

<b>Soil Identification</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
Important points that should be considered when identifying soil layers are: <ul style="list-style-type: none"> <li>▪ The soil sample should be visually inspected,</li> <li>▪ Described in accordance with a recognized nomenclature and</li> <li>▪ Geological evaluation shall be made.</li> </ul> Some of the soil properties/from the laboratory test /that can be used for identification purposes are: <ul style="list-style-type: none"> <li>○ Grain size distribution, Grain shape &amp; Grain surface roughness,</li> <li>○ Relative density,</li> <li>○ Unite weight,</li> <li>○ Natural water content,</li> <li>○ Atterberg limits&amp; Swelling and</li> <li>○ Carbonate content &amp;Organic matter content</li> </ul>	While considering soil identification the following point is important. <ul style="list-style-type: none"> <li>▪ Laboratory based examination of the samples recovered.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not Stated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not Stated</li> </ul>

Table A. 14: Review of Pertinent Code Requirement for Frequency of Rock Sampling

<b>Frequency of Rock Sampling</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, EuroCode7(ECS,2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<ul style="list-style-type: none"> <li>▪Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>▪Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>▪Specifically, not stated</li> </ul>	The following points should be considered while deciding frequency of rock sampling: <ul style="list-style-type: none"> <li>▪Change in stratum (intervals not exceeding 1.5 m within a continuous stratum).</li> </ul>

Table A. 15. Review of Pertinent Codes Requirement to Categorize Rock, Select Sampling Methods, Identify Laboratory Quality Classes and Size of Rock Sample

<b>Categories of Rock, Sampling Methods, Laboratory Quality Classes and Size of Rock Sample</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS7 (MoWUD,1995)</b>	<b>In Light of European Standard, Euro Code7(ECS,2007)</b>	<b>In Light of International Building Code(ICC,2009)</b>	<b>In Light of Indian Standard(ISI,1985)</b>
<p>The following factors are considered to characterize and classify rock mass.</p> <ul style="list-style-type: none"> <li>▪ Spacing, Orientation, Aperture, Continuity, Tightness, Roughness, inducing the effects of previous movements on the joints and filling.</li> <li>▪ Rock Quality Designation (RQD),</li> <li>▪ Sensitivity of rocks to climate, stress changes and consequence of chemical degradation, Solution rates /to ground water/,</li> <li>▪ Porosity and swelling due to absorption of water by clay minerals.</li> </ul>	<p>Selection of sampling methods depend on :</p> <ul style="list-style-type: none"> <li>▪ The quality of sample needed for laboratory tests,</li> <li>▪ Disturbance of the rock structure,</li> <li>▪ Change in constituents or in chemical composition of the rock mass and</li> <li>▪ The structure of the rock mass and its discontinuities.</li> </ul> <p>The required sample volume depends on the test program. For many purposes, samples of 300 mm - 1000 mm long with a diameter &gt; 50 mm are collected for laboratory tests.</p>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>Factors considered to evaluate the quality of rock profile are:</p> <ul style="list-style-type: none"> <li>▪ Total Core Recovery (TCR)</li> <li>▪ Type of exploration methods</li> <li>▪ Rock sampling tools</li> </ul>

Table A. 16: Review of Pertinent Codes Requirement for Rock Identification.

<b>Rock Identification</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Eurocode7(ECS, 2007)</b>	<b>In Light of International Building Code (ICC,2009)</b>	<b>In Light of Indian Standard(ISI,1985)</b>
<p>The following methods are considered to identify rock profile.</p> <ul style="list-style-type: none"> <li>▪ Visual inspection,</li> <li>▪ Using rock properties (both laboratory and field test results) such as: Mineralogy, Petrography, Water Content, Uniaxial Compressive Strength, Porosity, So both laboratory and field test results und velocity, Quick water absorption, Stake - durability index and</li> <li>▪ Using strength obtained from uniaxial compressive test results.</li> </ul>	<p>Factors considered for rock identification are:</p> <ul style="list-style-type: none"> <li>▪ Visual rock identification (Examination of the rock masses for decomposition and discontinuities),</li> <li>▪ Weathering classification (this grades between fresh rock and decomposed into soil),</li> <li>▪ Discontinuities (quantified with respect to pattern, spacing and inclination) and</li> <li>▪ Rock quality designation (RQD), total core recovery (TCR), and solid core recovery (SCR), shall be determined.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>

Table A. 17: Review of Pertinent Code Requirements for Protection, Handling, Labeling, Transporting and Storing of Samples

<b>Protection, Handling, Labeling, Transporting and Storing of Samples</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard:EBCS7(MoWUD,1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS,2007)</b>	<b>In Light of International Building Code(ICC,2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>The following should be done While labeling samples:</p> <ul style="list-style-type: none"> <li>▪ Title, emphasized by a brief statement that care should be taken in protection and handling of samples and</li> <li>▪ Full labeling record (borehole/test pit number, date of sampling, reference level of ground surface, depth of sample, type of sample (disturbed/undisturbed), location of the site, serial number and remarks if any and signature (Refer Appendix C- Table C.11).</li> </ul>	<p>The following procedure has to be done for storing disturbed soil samples:</p> <ul style="list-style-type: none"> <li>▪ Immediately place the sample in a proper storage to preserve the natural moisture.</li> </ul> <p>While labeling samples the following points should be done:</p> <ul style="list-style-type: none"> <li>▪ Numbered/labeled,</li> <li>▪ Placed immediately under a cover in a container and</li> <li>▪ Be tested for natural water content immediately on arrival at the laboratory.</li> </ul> <p>While transporting, samples should be:</p> <ul style="list-style-type: none"> <li>▪ Stored in a cool room Samples would be in a good condition if tested within:</li> <li>▪ For 1-2 weeks for disturbed soil samples.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>The following should be done While labeling samples:</p> <ul style="list-style-type: none"> <li>▪ Full labeling (Refer Appendix C Table C.12). The following procedure has to be done for storing</li> <li>▪ Undisturbed soil samples: <ul style="list-style-type: none"> <li>○ Ends of sample should be cut and removed, immediately after extracting sample,</li> <li>○ Several layers of molten wax should be applied to each end (sample),</li> <li>○ If the sample is porous, then a layer of waxed paper should first be placed over the ends of the sample,</li> <li>○ The samples should be stored in a stout wooden box container.</li> </ul> </li> <li>▪ Disturbed soil samples: <ul style="list-style-type: none"> <li>○ Immediately place the sample in a proper storage to preserve the natural moisture.</li> </ul> </li> <li>▪ Rock samples: <ul style="list-style-type: none"> <li>○ Samples should then be wrapped in several thicknesses of paper and packed in a wooden box/core box.</li> </ul> </li> </ul> <p>Samples would be in a good condition if tested within the following time frame:</p> <ul style="list-style-type: none"> <li>▪ Two weeks for undisturbed &amp;disturbed soil samples.</li> </ul>

Table A. 18: Review of Pertinent Code Requirements for Extrusion of Samples

<b>Extrusion of Samples</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>Extruding methods used by the local code are as follows:</p> <ul style="list-style-type: none"> <li>▪ Undisturbed samples of soil retained in seamless tube sampler, sealed with wax at both ends, need to be taken out of the tubes for actual testing and the disturbance while extruding the sample should be by all means avoided.</li> <li>▪ If tubes are oiled before use for samples of certain moisture range to be pushed out by means of suitably designed piston extrudes.</li> <li>▪ If the sample extruder is horizontal, to provide a support for the sample as it comes out from the tube, so that it may not break.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>Sample extrusion mechanisms required are listed below:</p> <ul style="list-style-type: none"> <li>▪ The wax on the sample may be chipped off by a penknife</li> <li>▪ Oiling inside the sampling tubes will help the sample to push out easy by means of suitably designed piston extruders.</li> <li>▪ If the extruder is horizontal, there should be a support for the sample as it comes out from the tube so that it may not break.</li> <li>▪ For screw type extruders, the pushing head must be free from the screw shaft so that no torque is applied to the soil sample in contact with the pushing head.</li> <li>▪ For soft clay samples a high-speed hacksaw in proper test lengths and fill the testing molds, by placing the cut portions directly over the molds and pushing the sample in, with a suitable piston.</li> </ul>

Table A. 19: Review of Pertinent Codes Requirements for Laboratory Tests on Soil

Laboratory Tests on Soil			
Code Requirements/Factors to be Considered			
In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)	In Light of European Standard, Euro Code 7 (ECS, 2007)	In Light of International Building Code (ICC, 2009)	In Light of Indian Standard (ISI, 1985)
<p>The laboratory tests results provide soil engineering properties. Some of the tests that are carried out are listed below:</p> <ul style="list-style-type: none"> <li>▪ Unit Weight</li> <li>▪ Relative Density</li> <li>▪ Degree of Compaction</li> <li>▪ Undrained Shear Strength of Cohesive tests</li> <li>▪ Effective Shear Strength Parameters</li> <li>▪ Permeability and Consolidation tests</li> </ul>	<p>Laboratory test that are used to determine the parameters for geotechnical calculations and these are given in Appendix C-Table C.13.</p>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>Soil laboratory test provide the soil engineering properties and the various tests, which are usually necessary for different phases of exploration, are listed in Appendix C-Table C.14.</p>

Table A. 20: Review of Pertinent Codes Requirements for Laboratory Tests on Rock

Laboratory Tests on Rock			
Code Requirements/Factors to be Considered			
In Light of Ethiopian Building Code Standard: EBCS 7(MoWUD, 1995)	In Light of European Standard, Euro Code 7 (ECS, 2007)	In Light of International Building Code (ICC, 2009)	In Light of Indian Standard (ISI, 1985)
<p>The following laboratory tests should be done for identification purposes:</p> <ul style="list-style-type: none"> <li>▪ Mineralogy</li> <li>▪ Petrography</li> <li>▪ Water Content</li> <li>▪ Unite Wight</li> <li>▪ Porosity</li> <li>▪ Sound velocity</li> <li>▪ Quick water absorption</li> <li>▪ Stake - durability index;</li> <li>▪ Uniaxial Compression strength</li> <li>▪ Permeability and Consolidation tests</li> </ul>	<p>Different laboratory tests should be carried out to determining their engineering properties. Some of the tests are:</p> <ul style="list-style-type: none"> <li>▪ <b>The uniaxial compression and deformability test:</b> It measures the Young’s modulus of elasticity and Poisson’s ratio of rock</li> <li>▪ <b>The point load test:</b> It is intended as a strength index test</li> <li>▪ <b>The direct shear test:</b> It is used to determine the basic shear strength parameters and the surface characteristics of a discontinuity that controls the shear strength.</li> <li>▪ <b>The Brazil test:</b> It measures indirectly the uniaxial tensile strength of a cylindrical rock specimen.</li> <li>▪ <b>The tri-axial compression test:</b> A numbers of tests provide the values necessary to determine the strength envelope in a Mohr-Coulomb diagram. From this envelope, the angle of shearing resistance and the cohesion intercept may be determined.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>Different laboratory tests should be carried out to determining their engineering properties.</p> <p>The various tests that is necessary for detailed exploration is tabulated in Appendix C-Table C.15.</p>

Table A. 21: Review of Pertinent Codes Requirements for Laboratory Tests on Water

<b>Laboratory Tests on Water</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD,1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS,2007)</b>	<b>In Light of International Building Code (ICC,2009)</b>	<b>In Light of Indian Standard(ISI, 1985)</b>
▪Specifically, not stated	The following laboratory tests should be done for water: ▪ Sulfate content, ▪ PH value (acidity or alkalinity) and ▪ Chloride content.	▪Specifically, not stated	The Necessary tests on ground water sample are presented in Appendix C-Table C.16.

Table A. 22: Review of Pertinent Codes provisions for Classification of Soils and Rocks

<b>Classification of Soils and Rocks</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD,1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS,2007)</b>	<b>In Light of International Building Code (ICC,2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
Soils and rocks classification is shown below. <b>For Soil:</b> ▪ Classification based on grain-size (Refer Appendix C-Table C.17) ▪ Classification based on material composition and plasticity (Refer Appendix C-Table C.18) ▪ The unified soil classification system, classification of soils as materials of construction (Refer Appendix C-Table C.19) <b>For Rock:</b> ▪ Classification of rocks according to their consistency (Refer Appendix C-Table C.20). Grouping of weak and broken rocks (Refer Appendix C-Table C.21).	▪Specifically, not stated	▪Specifically, not stated	▪Specifically, not stated

Table A. 23: Review of Pertinent Codes Provision of Symbols for Presentation of Soils and Rocks

<b>Symbols for Presentation of Soils and Rocks</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
Symbols for soils and rocks are provided in Appendix C-Figure C.6.	▪Specifically, not stated	▪Specifically, not stated	Symbols for soils and rocks are provided in Appendix C-Figure C.7.

Table A. 24: Review of Pertinent Codes provisions for planning and Execution of Ground Water Level Measurement.

<b>Planning and Execution of Groundwater Level Measurement</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code(ICC,2009)</b>	<b>In Light of Indian Standard(ISI,1985)</b>
▪Specifically, not stated	Selection of equipment for groundwater measurements depends on: <ul style="list-style-type: none"> <li>▪The type and permeability of ground,</li> <li>▪The purpose of the measurements,</li> <li>▪The required observation time,</li> <li>▪The expected groundwater fluctuations and</li> <li>▪The response time of the equipment and ground.</li> </ul> The number, location and depth of the measuring stations are chosen considering: <ul style="list-style-type: none"> <li>▪The purpose of the measurements,</li> <li>▪The topography and</li> <li>▪The soil conditions, especially the permeability of the ground</li> </ul>	▪Specifically, not stated	▪Specifically, not stated

Table A. 25: Review of Pertinent Codes provisions for Presentation of Geotechnical Information

<b>Presentation of Geotechnical Information /Descriptive Report or Factual Report/</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>The geotechnical investigations report contains:</p> <ul style="list-style-type: none"> <li>▪ Purpose and scope of the geotechnical investigation,</li> <li>▪ Brief description of the project,</li> <li>▪ Dates between which field and laboratory work were performed,</li> <li>▪ Procedures used for sampling, transportation and storage,</li> <li>▪ Types of field equipment used &amp; survey data,</li> <li>▪ Names of all consultants and sub-contractors,</li> <li>▪ Seismicity, history and geology of the site,</li> <li>▪ Information from available aerial photographs and local experience in the area,</li> <li>▪ Quantities of field and laboratory work, presentation of field observations /by the supervising field personnel/,</li> <li>▪ Data of ground water fluctuation level/piezometer,</li> <li>▪ Compilation of boring logs including: <ul style="list-style-type: none"> <li>○ Photographs of the cores and</li> <li>○ Descriptions core samples (based on field &amp; laboratory test results) and</li> </ul> </li> <li>▪ Grouping and presentation of field and laboratory test results in appendices.</li> </ul>	<p>The geotechnical investigations report contains:</p> <ul style="list-style-type: none"> <li>▪ Purpose and scope of the classification of the structure into a geotechnical category,</li> <li>▪ Names of all consultants and subcontractors,</li> <li>▪ The dates between which field and laboratory investigations were performed,</li> <li>▪ Evidence of groundwater,</li> <li>▪ Behavior of neighboring structures &amp; areas of instability,</li> <li>▪ Any exposures of mining activity at the site and exposures in quarries and borrow areas,</li> <li>▪ Seismicity, history and geology of the site, including faulting,</li> <li>▪ Survey data with plans showing the structure and the location of all investigation points,</li> <li>▪ Information from aerial photographs, local experience in the area and field reconnaissance of the site and</li> <li>▪ Documentation of the methods, procedures and results for: desk studies, field investigations, laboratory tests.</li> </ul>	<p>The geotechnical investigations report contains:</p> <ul style="list-style-type: none"> <li>▪ A plot showing the location of the soil investigations,</li> <li>▪ A complete record of the soil boring and penetration test logs and soil samples,</li> <li>▪ A record of the soil profile,</li> <li>▪ Elevation of the water table, if encountered,</li> <li>▪ Recommendations for foundation type and design criteria,</li> <li>▪ Deep foundation information, Special design and construction provisions for foundations of structures founded on expansive soils, and</li> <li>▪ Compacted fill material properties and testing in accordance with.</li> </ul>	<p>The geotechnical investigations report contains:</p> <ul style="list-style-type: none"> <li>▪ Agency,</li> <li>▪ Location with map and plan reference,</li> <li>▪ Pit number, reduced level of ground surface,</li> <li>▪ Dates/started and completed/,</li> <li>▪ Supervision,</li> <li>▪ Dimensions, types of sheeting and other materials of stabilization,</li> <li>▪ General description of strata, position and attitude of contacts, faults, strong joints,</li> <li>▪ Groundwater level, inflow of water and</li> <li>▪ Dip and strike of bedding and of cleavage; and any other information and remarks.</li> </ul>

Table A. 26: Review of Pertinent Codes Provisions for Evaluation of Geotechnical Information

<b>Evaluation of Geotechnical Information/Engineering Interpretation</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code(ICC,2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>Evaluation of the geotechnical information should consider the following points:</p> <ul style="list-style-type: none"> <li>▪ The sampling, transportation and storage procedures,</li> <li>▪ Submission of proposals for further field and laboratory work,</li> <li>▪ Tabulation and graphical presentation of the results of the field and laboratory</li> <li>▪ Determination of the groundwater level and its seasonal fluctuations,</li> <li>▪ Subsurface profile(s) showing detailed description of all formations including their physical properties, compressibility and strength characteristics,</li> <li>▪ Comments on irregularities such as pockets and cavities,</li> <li>▪ In case where there are inaccurate data, then it shall be stated and</li> <li>▪ Grouping and presentation of the range of values of the geotechnical data for each stratum. This presentation should be clear to provide the most appropriate ground parameter used for the design.</li> </ul>	<p>While evaluating the geotechnical information, the following considerations should be stated:</p> <ul style="list-style-type: none"> <li>▪ Description of the geometry of the strata,</li> <li>▪ Comments on irregularities,</li> <li>▪ Results interpreted,</li> <li>▪ The strata subdivision assumed from desk studies and site inspections were reconsidered in light of the results obtained,</li> <li>▪ The tabulation and graphical presentation of the results of field investigation and laboratory testing in cross-sections of the ground showing the relevant strata and their boundaries including the groundwater table,</li> <li>▪ The geotechnical parameters for each stratum and comparisons of the specific results with experience for each geotechnical parameter,</li> <li>▪ Fine layers with greatly differing composition may be considered as one stratum and can be represented by the stratum parameter and</li> <li>▪ For investigation points, which have homogeneous geology and found in close proximity, both groundwater level and different ground layers can be linearly interpolated and justification should be reported.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>

Table A. 27: Review of Pertinent Codes Considerations for the Loads Applied on Foundations for Geotechnical Design Calculations

<b>Loads Applied on Foundations</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS,2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>The following shall be considered as actions on the foundation:</p> <ul style="list-style-type: none"> <li>▪ Surcharge weights &amp; hydrostatic forces,</li> <li>▪ Free water pressure, seepage forces and ground water pressure,</li> <li>▪ Permanent, imposed and environmental actions (loads) from structures,</li> <li>▪ Traffic loads,</li> <li>▪ Swelling and shrinkage caused by vegetation, climate or moisture changes,</li> <li>▪ Movements due to degradation, decomposition, self-compaction, solution, mining, creeping or sliding of soil masses,</li> <li>▪ Movements caused by earthquakes, explorations, vibrations and dynamic loads,</li> <li>▪ Temperature effects and</li> <li>▪ Pressure in ground anchors or struts.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>The following group of loads are considered as a design loads:</p> <ul style="list-style-type: none"> <li>▪ Dead loads and live loads,</li> <li>▪ Seismic overturning,</li> <li>▪ Vibratory loads and</li> <li>▪ Shifting or moving soils.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>

Table A. 28: Review of Pertinent Code Provisions Regarding Bearing Capacity Calculation Methods

<b>Bearing Capacity Calculation Methods</b>			
<b>Code Provisions</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS7(MoWUD,1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS,2007)</b>	<b>In Light of International Building Code (ICC,2009)</b>	<b>In Light of Indian Standard(ISI, 1985)</b>
<p>Various bearing capacity calculation methods are given below for different foundation strata. For a spread foundation on rock layer, the following Methods are used:</p> <ul style="list-style-type: none"> <li>▪ Use the presumptive bearing pressure. (Refer Appendix C– Table C.22 &amp; Figure C.8). By consider the following rock features: <ul style="list-style-type: none"> <li>○ Deformability&amp; strength of the rock mass and the permissible settlement of the superstructure,</li> </ul> </li> </ul>	<p>Bearing capacity calculation methods are given below for different foundation strata. Bearing resistance of a spread foundation on soil is derived from:</p> <ul style="list-style-type: none"> <li>▪ CPT results using: <ul style="list-style-type: none"> <li>○ Semi-empirical or</li> <li>○ Analytical design method</li> </ul> </li> <li>▪ The effective angle of shearing</li> </ul>	<p>The following methods are used to calculate the bearing capacity of a foundation layer:</p> <ul style="list-style-type: none"> <li>▪ Presumptive bearing capacity (Refer Appendix C -Table C.23). While using this method one should note that the following point are not considered: <ul style="list-style-type: none"> <li>○ The amount of settlement</li> </ul> </li> </ul>	<p>Different methods are used to estimate bearing resistance. Some of them are:</p> <ul style="list-style-type: none"> <li>▪ Empirical methods (their value lies in the amount of experience behind them) using penetration test results:</li> <li>▪ Estimating Bearing Resistance Using Sounding Tests:</li> </ul>

<ul style="list-style-type: none"> <li>○ Presence of any weak layer, solution features, fault zones</li> <li>○ Presence of bedding and other discontinuities,</li> <li>○ State of weathering, decomposition and fracture of the rock and</li> <li>○ Disturbance during construction near the foundation.</li> </ul> <p>For a spread foundation on soil layer, the following Methods are used :</p> <ul style="list-style-type: none"> <li>▪ Semi-Empirical Method,</li> <li>▪ Analytical Method and</li> <li>▪ Presumed Design Bearing pressure: - Is intended for:             <ul style="list-style-type: none"> <li>○ Preliminary estimation/when detailed investigation of soil properties is not justified and</li> <li>○ These values should be used with cautions.</li> </ul> </li> </ul>	<p>resistance (<math>\phi'</math>) determined from the cone resistance (<math>q_c</math>).</p> <p>Bearing resistance of a spread foundation on sand is derived from:</p> <ul style="list-style-type: none"> <li>▪ Analytical Method using <math>\phi'</math> derived from             <ul style="list-style-type: none"> <li>○ SPT results.</li> </ul> </li> <li>▪ The value of <math>\phi'</math> that is derived empirically from:             <ul style="list-style-type: none"> <li>○ Direct correlations with SPT results.</li> </ul> </li> </ul>	<p>occurs due to the foundation loads,</p> <ul style="list-style-type: none"> <li>○ The weathering condition of the rock or the density of the soil,</li> <li>○ The size or depth of the footing,</li> <li>○ Reduction in shear strength of the material during an earthquake/for some types of soils and rocks/.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Non-empirical method /Estimating Bearing Resistance Using Vane Tests/: This can be calculated for soft clay soil, at all depths from the surface to at least 30 m. It is particularly useful in the measurement of strength in deep beds of soft sensitive clays (Refer Appendix C -Table C.24).</li> </ul>
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Table A. 29: Review of Pertinent Code Provisions Regarding Settlement Calculation Methods

Settlement Calculation Methods			
Code Provisions			
In Light of Ethiopian Building Code Standard EBCS 7 (MoWUD, 1995)	In Light of European Standard, Euro Code 7 (ECS, 2007)	In Light of International Building Code(ICC,2009)	In Light of Indian Standard (ISI, 1985)
<p>Various settlement calculation methods are given below for different foundation strata.</p> <p><b>For foundation on non-cohesive soils:</b></p> <ul style="list-style-type: none"> <li>▪ Use semi-empirical method based on the results of static cone, dynamic penetration or plate load tests.</li> <li>▪ Using plate Load Test</li> </ul> <p><b>For foundation on cohesive soils:</b></p> <ul style="list-style-type: none"> <li>▪ Use the Equations stated in Appendix C- Equations C.1, Equation C.2 &amp; Equation C.33 to calculate the total settlement.</li> </ul> <p><b>For foundation on cohesive and non-cohesive soils:</b></p> <ul style="list-style-type: none"> <li>▪ Use standard penetration test results to estimate the total settlement. If the water table is at a shallow depth, the settlement read shall be multiplied by the correction factor <math>w'</math> (Refer Appendix C -Figure C.9).</li> </ul>	<p>Settlement calculation methods are given below for different foundation strata.</p> <p>Settlement calculation(s) for spread foundation on soil is derived from:</p> <ul style="list-style-type: none"> <li>▪ Semi-empirical method (Refer Appendix C- Equation C.4).</li> <li>▪ The standard Young's modulus of elasticity (<math>E'</math>) derived from the N-values through empirical correlations,</li> <li>▪ The direct design methods based on comparisons of the N-values and results of plate loading tests or records of measured settlements of foundations. The resistance of sand to deformation is often increased if consolidated/ over-consolidated. This is reflected the blow counts. To calculate the settlement:</li> <li>▪ Use an indirect/analytical design method, the geotechnical parameters of shear modulus shall be derived from the dilatometer curve Correlations.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>	<p>Methods that can be used to estimate settlement calculation are given below:</p> <ul style="list-style-type: none"> <li>▪ Vertical Loading Test</li> <li>▪ Guidance for estimating settlement of structures for various types of geological layers is given in Appendix C-Table C.27.</li> </ul>

Table A. 30: Review of Pertinent Code Considerations While Supervising at the Investigation Stage and/or During Construction.

<b>Supervisions at the Investigation Stage and/or During Construction</b>			
<b>Code Requirements/Factors to be Considered</b>			
<b>In Light of Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)</b>	<b>In Light of European Standard, Euro Code 7 (ECS, 2007)</b>	<b>In Light of International Building Code (ICC, 2009)</b>	<b>In Light of Indian Standard (ISI, 1985)</b>
<p>During supervision, the following points should be noted.</p> <ul style="list-style-type: none"> <li>▪ When the required checks have been carried out during construction, they shall be recorded in an appendix to the report.</li> <li>▪ The object of each set of observations or measurements.</li> <li>▪ The part of the structure which are to be monitored and the stations at which observations are to be made</li> <li>▪ The frequency with which readings are to be taken</li> <li>▪ The way in which the results are to be evaluated</li> <li>▪ The range of values within which the results are to be considered</li> <li>▪ The period of time for which monitoring is to continue after construction is completed</li> <li>▪ The parties responsible for making measurements and observations, for interpreting the results obtained and monitoring and maintaining the instruments.</li> <li>▪ An extract of the geotechnical design report containing the supervision, monitoring and maintenance requirements for the completed structure shall be provided to the owner/client.</li> <li>▪ A note of items to be checked during construction or requiring maintenance or monitoring</li> <li>▪ Statements on the codes and standards applied</li> </ul>	<p>Several general control measures can be carried out. Some of them are:</p> <ul style="list-style-type: none"> <li>▪ Checking ground profile when excavating and inspection of the bottom of the excavation, are mandatory</li> <li>▪ Measurement of groundwater level or pore pressures and their fluctuations,</li> <li>▪ Measurements of the behavior of neighboring constructions, services or civil engineering works;</li> <li>▪ Measurements of the behavior of the actual construction.</li> <li>▪ The standard stipulates that the results of the control measures shall be compiled, reported and checked against the design requirements and that decisions shall be taken based on these findings.</li> </ul>	<p>The investigation procedure and apparatus ought to be in accordance with generally accepted engineering practice. And that the registered design professional:</p> <ul style="list-style-type: none"> <li>▪ Shall have a fully qualified representative on site during all boring or sampling operations.</li> <li>▪ And if the desired investigation depth is not reached, the code also stipulates that the client should be informed immediately.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Specifically, not stated</li> </ul>

## APPENDIX B

### Questionnaire & Interview Questions

#### Questionnaire

Direction: -Please choose the best that describes your answer

1. What is the profession of the person who prepares the geotechnical investigation program in your organization?
  - A. Geotechnical Engineer
  - B. Structural Engineer
  - C. Architect
  - D. Geologist
  - E. Other \_\_\_\_\_
2. What are factors affecting the selection of exploration method and the design of the investigation program? And the significance (if any)?
3. Do you conduct site reconnaissance and preliminary investigation while doing the investigation? How?
  - A. Yes      B. No
  - C. Other \_\_\_\_\_
4. How do you select the machines for soil investigation purpose?
  - A. Availability in the market
  - B. Drilling Speed and drilling depth capacity
  - C. Depending on the project size(building type)
  - D. Accessibility of the site
  - E. Other \_\_\_\_\_
5. How do you decide on the number of investigation points (like Test pits or boreholes)?
  - A. Project Area
  - B. Shape of the project Area
  - C. Accessibility of the project area
  - D. Existing information about the site
  - E. Other \_\_\_\_\_
6. What are factors affecting the decision on number of investigation points and spacing between them (such as Test pits or Boreholes)?
7. How do you decide borehole and test pit depth?
8. What are the most common soil laboratory test types you conduct (for soil)?
  - A. Grain Size Analysis
  - B. Index property (Atturberge Limit)
  - C. Shear strength tests
  - D. Compressibility tests

9. How frequent the shear test is requested?
  - A. Rare
  - B. Sometimes
  - C. Frequently
  - D. Very frequently
10. How frequent the compressibility is requested?
  - E. Rare
  - A. Sometimes
  - B. Frequently
  - C. Very frequently
11. Which of the following test are most frequently conducted?
  - A. Direct Shear
  - B. Unconfined Compressive Strength
  - C. Triaxial Tests (Undrained Unconfined , Confined Drained , Confined Untrained)
12. For type of projects do you recommend permeability tests?
13. Do you supervise the geotechnical investigation on the site? If yes, How?
14. What are factors for selecting the above laboratory tests for different projects?
15. What type of field testing methods do you commonly use? (You may use more than one item)
  - A. Static Cone penetration and piezocone penetration tests
  - B. Standard Penetration test (SPT)
  - C. Dynamic Cone Penetration Test(DCP)
  - D. Pressure Meter Test (PMT)
  - E. Plate Load Test
  - F. Flexible dilatometer test (FDT)
  - G. Dynamic probing tests (DP)
  - H. Weight sounding test (WST)
  - I. Vane test (FVT)
  - J. Flat dilatometer test (DMT)
  - K. Other \_\_\_\_\_
16. How do you decide the frequency with depth for the field test?
  - A. Depending on the anticipated profile of the formation
  - B. Depending on the depth of drilling
  - C. Depending on the depth of the structures below the natural ground level of the building /Sub structure / (basement, water tankers, septic tank, etc.....)
  - D. Other \_\_\_\_\_
17. How frequent are undisturbed soil samples taken?
  - A. Depending on the type of the soil profile
  - B. Depending on the depth of the drilling
  - C. Depending on the depth of the structures below the natural ground level of the building /Sub structure / (basement, water tankers, septic tank, etc.....)
  - D. Other \_\_\_\_\_

18. What are the criteria used for selecting rock samples to consider for laboratory test?
- State of the rock (weathering, RQD)
  - Influence depth of the superstructure load /Stress
  - Depth of the structures below the natural ground level of the building /Sub structure / (basement, water tankers, septic tank, etc.....)
  - Other \_\_\_\_\_
19. How frequent are disturbed samples taken?
- Type of the soil profile
  - Influence depth of the superstructure load /Stress
  - Depth of the structures below the natural ground level of the building /Sub structure / (basement, water tankers, septic tank, etc.....)
  - Other \_\_\_\_\_
20. Which of the following approaches do you use to log the trial pits or Boreholes (you may give multiple answers)
- For Soil**
    - Visual inspection
    - Laboratory test results (Atterberg, grain size and Free swell)
    - Total Core Recovery (TCR)
    - Other \_\_\_\_\_
  - For Rock**
    - If Rock RQD and TCR
    - Degree of weathering for
    - Rock classification (Using rock visual identification)
    - Other \_\_\_\_\_
21. What type of measures will be taken if your project is located on an old damping site?
- Will increase the investigation depth
  - Will drill additional borehole
  - Other \_\_\_\_\_
22. What type of measures will be taken if the soil profile is found to be horizontally erratic in the project area?
- Will increase the investigation depth
  - Will drill additional borehole
  - Other \_\_\_\_\_
23. What type of measures will be taken if the soil profile is found to be vertically erratic in the project area?
- Will increase the investigation depth
  - Will drill additional borehole
  - Other \_\_\_\_\_
24. How ground water level is measures taken and what types of tests are made?
- GWT measurement tool
  - Chemical test
  - Field Permeability/in rocks and soil/
  - Other \_\_\_\_\_

25. Which expert does the ground investigation report/profession/and with what qualification?
- A. Civil engineer(BSc.)
  - B. Geologist (BSc.)
  - C. Geotechnical Engineer (MSc. in Geotechnics)
  - D. Geologist (MSc. in Geotechnics)
  - E. MSc. in Engineering Geology
  - F. Other \_\_\_\_\_
26. What type of approach is used to calculate bearing capacity and settlement calculation and any additional information we need to complete the report?
- A. Analytical
  - B. Empirical
  - C. Presumptive
  - D. Other \_\_\_\_\_
27. For how long does the core soil sample will be kept for further investigation?
- A. Less than a week
  - B. Two weeks
  - C. One month
  - D. Two Month
  - E. Three Month and more
  - F. Other \_\_\_\_\_
28. Have you ever done a supplementary investigation during construction? (Yes, No)  
If Yes, How Often?
- A. Rare
  - B. Sometimes
  - C. Frequently
  - D. Very Frequently

### **Interview Questions**

1. How do you evaluate the geotechnical investigation report?
2. How do you evaluate the exploration methods for different type of engineering structures?
3. How do you evaluate bearing capacity and settlement calculations?
4. Do you carry out site supervision during ground investigation?
5. How many reports do you evaluated each day?

## APPENDIX C (TABLES, FIGURES AND EQUATIONS)

Table C. 1 Requirement for trial pits and boring layout, Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)

Area of Investigation	Spacing of Boring in m for Horizontal Stratification of Soil			Minimum Number of Borings
	Uniform	Moderate	Erratic	
Multi – Story Building	50	25	10	2 *
Single or Two Story Building	60	30	15	2
Towers, Piers, etc.	-	30	7.5	1 to 2 for each foundation

\*If supplemented with sounding tests; otherwise 4.

Table C. 2: Location, number and spacing of borings / test pits, Indian Standard (ISI, 1985)

Importance of the Building	Building Site Covering an Area (hectare)	No. of BH/TP	Location of BH/TP	Other Field Tests
Compact	0.4	5	One BH/TP in each corner and one at the center	-
Less Important	Small areas (<0.4)	1	One BH/TP at the center	-
Industrial and Residential Colonies	very large areas (0.4)	Number of BH/TP depends on the variation in the penetration curves. Geophysical method will be done, If CPT is not applicable		CPT every 50 m by dividing the area in a grid pattern

Table C. 3: Depth of exploration, Indian Standard (ISI, 1985)

Sr. No.	Type of Foundation	Depth of Exploration(D)
i)	Isolated spread footing or raft	One and a half the width (B)
ii)	Adjacent footings with clear spacing less than twice the width	One and a half times the length (L) of the footing
iii)	Adjacent rows of footings	See Figure. 4
iv)	Pile and good foundations	To a depth of one and a half times the width of structure from the bearing level (toe of pile or bottom of well)
v)	1. Road cuts 2. Fill	Equal to the bottom width of the cut Two meters below ground level or equal to the height of the fill whichever is greater

Table C. 4: Quality classes of soil samples for laboratory testing and sampling categories to be used, European Standard, Euro Code 7 (ECS, 2007)

Soil Properties / Quality Class	1	2	3	4	5
<b>Unchanged soil properties</b>					
Particle size	*	*	*	*	
Water content	*	*	*		
Density, density index, permeability	*	*			
Compressibility, shear strength	*				

Properties that can be determined					
Sequence of layers	*	*	*	*	*
Boundaries of strata – broad	*	*	*	*	
Boundaries of strata – fine	*	*			
Atterberg limits, particle density, organic content	*	*	*	*	
Water content	*	*	*		
Density, density index, porosity, permeability	*	*			
Compressibility, shear strength	*				
Sampling category according to EN ISO 22475-	A				
			B		
					C

Table C. 5: Quality classes of soil samples for laboratory testing and sampling categories to be used Indian Standard (ISI, 1985)

Nature of the Ground	Type of Sample	Method of Sampling
Soil	Disturbed	Hand samples
		Auger samples (for example, in clays)
		Shell samples (for example, in sand)
	Undisturbed	Chunk samples
Tube samples		
Rock	Disturbed	Wash samples from percussion or rotary drilling
	Undisturbed	Cores

Table C. 6: Mass of soil sample required for various laboratory tests, Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995)

Purpose of Sample	Soil Type	Mass of Sample Required
Soil Classification, natural moisture content tests, mechanical analysis and Index properties and Chemical Tests	Cohesive Soils	1kg
	Sand & Gravels	3kg
Compaction Tests	Cohesive Soils and Sands Gravelly Soils	12.5kg 25kg
Comprehensive examination of Construction materials including soil stabilization	Cohesive Soils and Sands Gravelly Soils	25 to 50 kg 50 to 100kg

Table C. 7: Mass of Soil required for tests on disturbed samples, European Standard, Euro Code 7 (ECS, 2007)

Test	Initial mass required	Minimum mass of prepared test specimen			
		Clay and silt 30 g	Sand 100 g	Gravelly soil	
Water content	At least twice specimen mass			D = 2 mm – 10 mm MMS	D > 10 mm 0,3 × MMS, min 500 g
Particle density	100 g	10g (particle size < 4 mm)			
Grain size		MMS			
Sieving	2 × MMS				
Sedimentation					
Hydrometer	250 g	50 g	100 g		
Pipette	100 g	12 g	30 g		
Consistency limits	500 g	300 g (particle size < 0.4 mm)			
Density index	8 kg				
Dispersibility	400 g				
Compaction	S	NS			
“Proctor” mould	25 kg	10 kg			
“CBR” mould	80 kg	50 kg			
CBR	6 kg				
Permeability <sup>†</sup>					
Diameter					
100 mm	4 kg				
75 mm	3 kg				
50 mm	500 g				
38 mm	250 g				

Notation:  
D – Largest particle diameter in significant proportion (10 % or more by dry mass)  
MMS – Minimum mass to be taken for sieving (see Table 1-2)  
NS – Soil particles not susceptible to crushing  
S – Soil particles susceptible to crushing during compaction  
† – Mass of specimen depends on soil behaviour during test  
‡ – Permeability specimens with height equal to twice the diameter

Table C. 8: Minimum mass for sieving, European Standard, Euro Code 7 (ECS, 2007)

Largest particle diameter ( <i>D</i> ) mm	Minimum mass for sieving (MMS) kg
75	120
63	70
45	25
37,5	15
31,5	10
22,4	4
20	2
16	1,5
Largest particle diameter ( <i>D</i> ) mm	Minimum mass for sieving (MMS) g
11,2	600
10	500
8	400
5,6	250
4	200
2,8	150
≤2	100

Table C. 9: Mass of soil required for tests on undisturbed samples, European Standard, Euro Code 7 (ECS, 2007)

Type of test	Specimen dimensions		Minimum mass required g
	Diameter mm	Height mm	
Oedometer	50	20	90
	75	20	200
	100	20	350
Compression <sup>b</sup> -Unconfined -Unconsolidated-undrained -Triaxial compression test	35	70	150
	38	76	200
	50	100	450
	70	140	1 200
	100	200	3 500
Shear box	Planar size		30 000
	60 × 60	20	
	100 × 100	20	
	300 × 300	150	
Density Largest particle size <sup>a</sup>	Largest particle size		1,4 (MMS) <sup>c</sup>
	<i>D</i> = 5,6 mm		
	<i>D</i> = 8 mm		
	<i>D</i> = 10 mm		
			500
			1,4 (MMS) <sup>c</sup>

a *D* is the largest particle diameter in significant proportion (10 % or more by mass).  
b Specimen dimensions and minimum required volume apply to all three tests  
c MMS is the minimum mass to be taken for sieving, as specified in Table L.2.

Table C. 10: Quantity of soil samples required, Indian Standard (ISI, 1985)

No.	Purpose of Sample	Soil Type	Weight of Sample Required (kg)
i)	Soil identification, natural moisture content tests, mechanical analysis and index properties Chemical tests	Cohesive soils	1
		Sand and gravels	3
ii)	Compaction tests	Cohesive soils and Sands	12.5
		Gravelly soils	25
iii)	Comprehensive examination materials including soil stabilization	Cohesive soils and sands	25 to 50
		Gravelly soils	50 to 100

Table C. 11: Sample Labeling Format, Ethiopian Building Code Standard: EBCS 7(MoWUD, 1995)

<p><b>No: 1234*</b></p> <p style="text-align: center;"><b>SAMPLE RECORD</b></p> <p><b>Location..... Date.....</b>  <b>Boring . . . . . O.D of ground surface</b>  <b>Position of sample, from . . . . .</b>  <b>To ..... below ground surface.</b>  <b>Container No .....Type of Sample .....</b></p> <p style="text-align: center;"><b>Remarks:</b></p> <p><b>Signature:</b></p>	<p style="text-align: center;"><b>No: 1234*</b></p> <p style="text-align: center;"><b>No: 1234*</b></p> <p style="text-align: center;"><b>No: 1234*</b></p>
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Table C. 12: Labeling of sample, Indian Standard institution, 1981

<p><b>No: 1 100</b></p> <p style="text-align: center;"><b>SAMPLE RECORD</b></p> <p><b>Location.....Date.....</b>  <b>BoringNo . . . . . R.L.ofgroundsurface . . . . .</b>  <b>Position of sample, from . . . . .</b>  <b>to..... below ground surface</b>  <b>Container No .....Type of Sample</b>  <b>Disturbed/Undisturbed</b></p> <p style="text-align: center;"><b>Remarks:</b> <b>Signed:</b></p>	<p style="text-align: center;"><b>No: 1 100</b></p> <p style="text-align: center;"><b>No: 1 100</b></p> <p style="text-align: center;"><b>No: 1 100</b></p>
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Table C. 13: List of test results of geotechnical standards, European Standard, Euro Code 7 (ECS, 2007)

Laboratory test	Test results
Water content (soil)	Value of ( $w$ )
Bulk mass density (soil)	▪ Value of ( $\rho$ )
Particle mass density (soil)	▪ Value of ( $\rho_s$ )
Particle size distribution(soil)	▪ Grain size distribution curve
Consistency limits (soil)	▪ Plastic and liquid limit values ( $w_p$ ), ( $w_L$ )
Density index (soil)	▪ Values of $e_{max}$ , $e_{min}$
Organic content (soil)	▪ Value of organic content ( $C_{OM}$ )
Carbonate content (soil)	▪ Value of carbonate content ( $C_{CaCO_3}$ )
Sulfate content (soil)	▪ Value of sulfate content ( $C_{SO_4^{2-}}$ ) or ( $C_{SO_3^{2-}}$ )
Chlorite content (soil)	▪ Value of chlorite content ( $C_{Cl}$ )
PH (soil)	▪ Value of pH
Compressibility Oedometer (soil)	▪ Compressibility curve (different options) ▪ Consolidation curves (different options) ▪ Secondary compression curve (creep curve)
Laboratory vane (soil)	▪ Value of strength index ( $c_u$ )
Fall cone (soil)	▪ Value of strength index ( $c_u$ )
Unconfined compression(soil)	▪ Value of strength index $q_u = 2c_u$
Unconsolidated undrained compression (soil)	▪ Value of undrained shear strength ( $c_u$ )

Consolidated Triaxial compression (soil)	<ul style="list-style-type: none"> <li>▪ Stress-strain curve(s) and pore pressure curve</li> <li>▪ Stress paths</li> <li>▪ Mohr circles</li> <li>▪ <math>c', \phi'</math> or <math>c_u</math></li> <li>▪ Deformation parameter(s)</li> </ul>
Consolidated direct shear box (soil)	<ul style="list-style-type: none"> <li>▪ Stress-displacement curve</li> <li>▪ <math>\tau-\sigma</math> diagram</li> <li>▪ <math>c', \phi'</math></li> <li>▪ Residual parameters</li> </ul>
California bearing ratio(soil)	<ul style="list-style-type: none"> <li>▪ Value of the CBR index (<math>I_{CBR}</math>)</li> </ul>
Permeability (soil)	<ul style="list-style-type: none"> <li>▪ Value of the coefficient of permeability (k):                             <ul style="list-style-type: none"> <li>○ from direct laboratory permeability test</li> <li>○ from field permeability tests</li> <li>○ from oedometer test</li> </ul> </li> </ul>
Water content (rock)	<ul style="list-style-type: none"> <li>▪ Value of w</li> </ul>
Density and porosity (rock)	<ul style="list-style-type: none"> <li>▪ Value of r and n</li> </ul>
Swelling (rock)	<ul style="list-style-type: none"> <li>▪ Swelling Strain Index</li> <li>▪ Swelling Strain Index</li> <li>▪ Swelling pressure</li> <li>▪ Free swell</li> <li>▪ Swell under constant load</li> </ul>
Uniaxial compression and deformability (rock)	<ul style="list-style-type: none"> <li>▪ Value of <math>\sigma_c</math></li> <li>▪ Value of deformation modulus (E)</li> <li>▪ Value of Poisson's ratio (<math>\nu</math>)</li> </ul>
Point-load test (rock)	<ul style="list-style-type: none"> <li>▪ Strength index <math>I_{s50}</math></li> </ul>
Direct shear test (rock)	<ul style="list-style-type: none"> <li>▪ Stress-displacement curve</li> <li>▪ Mohr diagram</li> <li>▪ <math>c', \phi'</math></li> <li>▪ Residual parameters</li> </ul>
Brazil test (rock)	<ul style="list-style-type: none"> <li>▪ Tensile strength (<math>\sigma_T</math>)</li> </ul>
Triaxial compression test (rock)	<ul style="list-style-type: none"> <li>▪ Stress-strain curve(s)</li> <li>▪ Stress paths</li> <li>▪ Mohr circles</li> <li>▪ <math>c', \phi'</math></li> <li>▪ Values of deformation modulus (E) and Poisson's ratio (<math>\nu</math>)</li> </ul>

Table C. 14: List of soil tests necessary for detailed exploration, Indian Standard (ISI, 1985)

Phase of Exploration	Type of Test	Tests Necessary on a Sample
Detailed Exploration	Physical Tests	Visual classification
		Liquid and plastic limits
		Grain size analysis
		Specific gravity
		Natural moisture content
		Unit weight
		Consolidation test (including pre-consolidation pressure)
		Shear strength: Unconfined compression Triaxial compression Direct shear permeability test
	Chemical Tests	Soluble salt content:
		<ul style="list-style-type: none"> <li>▪ Chlorides and sulfates</li> <li>▪ Calcium carbonate content (if warranted)</li> <li>▪ Organic matter content (if warranted)</li> </ul>

Table C. 15: List of rock tests necessary for detailed exploration, Indian Standard (ISI, 1985)

Phase of exploration	Type of test	Tests necessary on a sample
Detailed exploration	Rock drilling	<ul style="list-style-type: none"> <li>▪ Visual examination</li> <li>▪ Unit weight</li> <li>▪ Petrographic analysis</li> <li>▪ Compressive strength</li> <li>▪ Water absorption</li> <li>▪ Shear strength</li> <li>▪ Porosity</li> </ul>

Table C. 16: List of groundwater tests necessary for detailed exploration, Indian Standard (ISI, 1985)

Phase of exploration	Tests Necessary on Ground Water Sample	
	Type of Test	Detailed tests
Detailed exploration	Ground water	<ul style="list-style-type: none"> <li>- Chemical analysis including PH determination</li> <li>- Bacteriological analysis ( if necessary )</li> </ul>

Table C. 17: Classifications based on grain- size, mm, Ethiopian Building Code Standard: EBCS 7(MoWUD, 1995)

Stone		Gravel			Sand			Silt			Clay
Boulder	Cobble	Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
201	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

Table C. 18: Classification based on material composition and plasticity, Ethiopian Building Code Standard: EBCS 7(MoWUD, 1995)

Group	Soil Type	Symbol	Particle Size Fraction in percent by weight	Plasticity Index, In Percent and position with Reference to A- Line	Liquid Limit Wl, in Percent	
coarse Grained	Soil	Gravel	G	> 60	WD	-
		Sand	S	> 60	-	-
	Silt	Low Plasticity	ML	>40	< 4 below th A- Line	≤35
		Medium Plasticity	MI	>40	11 to 22 and below th A- Line	35 to 50
		High Plasticity	MH	>40	> 22 and below the A- Line	> 50
coarse Grained	Clay	Low Plasticity	CL	>30	> 7 and above the A- Line	≤35
		Medium Plasticity	CI	>30	11 and above th A- Line	35 to 50
		High Plasticity	CH	>30	> 22 and above the A- Line	> 50
Organic Silt & Organic Silty Clay		Low Plasticity	OL	>40	< 4 below th A- Line	≤35
		Medium Plasticity	OI	>40	11 and 23 and below th A- Line	35 to 50
Organic Clay		High Plasticity	OH	>30	> 22 and below the A- Line	> 50
Slightly Organic Soil	Peat		Pt			
Made- up Ground or Fill	Natural Soils or Extraneous Materials					

Table C. 19: The unified soil classification system, Ethiopian Building Code Standard: EBCS7(MoWUD, 1995).

Major divisions		Group symbol	Typical names	Classification criteria for coarse-grained soils		
Coarse-grained soils (more than half of material is larger than No. 200)	Gravels (more than half of coarse fraction is larger than No. 4 sieve size)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	$C_u = D_{60}/D_{10} > 4$ $C_r = 1 < D_{20}^2/D_{10} \times D_{60} < 3$		
		GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	Not meeting all gradation requirements for GW		
		GM	Silty gravels, gravel-sand-silt mixtures	Atterberg limits below A line or $I_p < 4$	Above A line with $4 < I_p < 7$ are borderline cases requiring use of dual symbols	
		GC				Clayey gravels, gravel-sand-clay mixtures
	Sands (more than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	$C_u = D_{60}/D_{10} > 6$ $C_r = 1 < D_{20}^2/D_{10} \times D_{60} < 3$	
			SP	Poorly graded sands, gravelly sands, little or no fines	Not meeting all gradation requirements for SW	
		Sands with fines (appreciable amount of fines)	SM	Silty sands, sand-silt mixtures	Atterberg limits below A line or $I_p < 4$	Limits plotting in hatched zone with $4 \leq I_p \leq 7$ are borderline cases requiring use of dual symbols
			SC			
Fine-grained soils (more than half of material is smaller than No. 200)	Sils and clays (liquid limit < 50)	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	1. Determine percentages of sand and gravel from grain-size curve. 2. Depending on percentages of fines (fraction smaller than 200 sieve size), coarse-grained soils are classified as follows: Less than 5%—GW, GP, SW, SP, More than 12%—GM, GC, SM, SC 5 to 12%—Borderline cases requiring dual symbols		
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
		OL	Organic silts and organic silty clays of low plasticity			
	Sils and clays (liquid limit > 50)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
		CH	Inorganic clays of high plasticity, fat clays			
		OH	Organic clays of medium to high plasticity, organic silts			
Highly organic soils	Pt	Peat and other highly organic soils				

Table C. 20: Classification of rocks according to their consistency, Ethiopian Building Code Standard: EBCS 7(MoWUD, 1995)

Class	Type of Rock	Consistency in Place
1	Massively crystalline igneous and metamorphic rock: Granite,diorite,basalt, gneiss,thoroughly cemented conglomerate	Hard ,sound rock*
2	Foliated metamorphic rock: Slate ,schist	Medium hard ,sound rock*
3	Bedded limestone in sound condition	Medium hard ,sound rock*
4	Sedimentary rock: Hard cemented shales,siltstone sandstone	Medium hard ,sound rock*
5	Weathered or broken bedrock(excluding shale),soft limestone	Soft rock*
6	Soft shale	Soft rock*

\* Sound condition allows minor cracks.

Table C. 21 Grouping of Weak and Broken Rocks, Ethiopian Building Code Standard: EBCS (MoWUD, 1995).

Group	Type of Rock
1	Pure limestone and dolomites Carbonate sandstones of low porosity
2	Igneous Oolitic and marly limestone Well cemented sandstones Indurate carbonate mudstones Metamorphic rocks, including slates and schists (flat cleavage/foliation)
3	Very marly limestones Poorly cemented sandstones Slates and schists (steep cleavage/foliation)
4	Incremented mudstones and shales

Table C. 22: Presumed design bearing resistance under vertical static loading, Ethiopian Building Code Standard: EBCS7 (MoWUD, 1995).

Supporting Ground Type	Description	Compactness** Consistency ***	Presumed Design Bearing Pressures (kPa)	Remark
Rocks	Massively Crystalline Igneous and Metamorphic Rock (Granite, Basalt, Gness)	Hard and Sound	5600	These values are made on the assumption that the foundations are carried down to un-weathered Rock
	Foliated Metamorphic Rock (slate)	Medium Hard and Sound	2800	
	Sedimentary Rock (silt stone, sand stone, lime stone)	Medium Hard and Sound	2800	
	Weathered or bedrock (soft limestone)	Soft	1400	
	Soft Shale	Soft	850	
	Decomposed rock to be assessed soil	-	-	
Non- Cohesive Soils	Gravel, Sand and Gravel	Dense	560	Width of the foundation should be not less than 1m
		Medium Dense	420	
		Loose	280	
	Sand	Dense	420	Ground Water Level assumed to be depth of less than B below the base of the foundation
Medium Dense		280		
Loose		140		
Cohesive Soil	Silt	Hard	280	
		Stiff	200	
		Medium Stiff	140	
		Soft	70	
	Clay	Hard	420	
		Stiff	280	
		Medium Stiff	140	
		Soft	70	
	Very Soft	Not Applicable		

\*The given design bearing values do not include the effect of the depth of embedment of the foundation  
 \*\*Compactness: Dense  $N > 30$ ,  
 Medium Dense:  $N$  is 10 to 30  
 Loose:  $N$ , 10, where  $N$  is standard penetration Value  
 \*\*\* Consistency: Hard:  $q_a > 400$  kPa  
 Stiff: 100 to 200 kPa  
 Medium Stiff:  $q_a = 50$  to 100 kPa  
 Soft:  $q_a = 25$  to 50 kPa, where  $q_a$  is unconfined compressive strength

Table C. 23 : Presumptive load-bearing values, International Building Code (ICC, 2009).

Class of Materials	Vertical Foundation Pressure (psf)	Lateral Bearing Pressure (psf/f) Below Natural Grade)	Lateral Sliding Resistance	
			Coefficient of Friction	Cohesion (psf) <sup>b</sup>
Crystalline bedrock	12,000	1,200	0.70	—
Sedimentary and foliated rock	4,000	400	0.35	—
Sandy gravel and/or gravel (GW and GP)	3,000	200	0.35	—
Sand, silty sand, Clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	2,000	150	0.25	—
Clay, sand clay, silty clay clayey silt, silt and sandy silt (CL, ML, MH and CH)	1,500	100	—	130

For SI: 1 pound per square foot (psf) = 0.0479 kPa.  
 1 pound per square foot per foot of depth (psf/f) = 0.157 kPa/m.  
<sup>a</sup> Coefficient to be multiplied by the dead load.  
<sup>b</sup> Cohesion value to be multiplied by the contact area.

Table C. 24: Methods of estimation of bearing capacity, Indian Standard (ISI, 1985).

Methods of Estimation of Bearing Capacity		Methods of Estimation
Sr. No.	Type of Strata	Ultimate Bearing Capacity
1	a) Hard Rock	L
	b) Soft rocks, such as shales, weak limestone and sand stones	FL
	c) Non-cohesive soils	FL
	d) Soft compressible soils	LF
	e) Stiff, fissured clays	LF
2	Soft, compressible stratum overlying hard stratum	LF
3	Hard stratum overlying compressible stratum	LF*
4	Very variable strata varying in type, thickness and arrangement	Each case to be dealt with on its merits

NOTE - Methods are given in order of preference:  
 F = Field load test  
 L = Laboratory tests: Compression and shear tests on undisturbed samples. Consolidation test on undisturbed samples. Elastic modulus tests on undisturbed samples.  
 \*Tests should be made on each stratum.

Table C. 25 The shape coefficients,  $\lambda_c$ ,  $\lambda_d$  for settlement of spread foundation, European Standard, Euro Code 7 (ECS, 2007)

L/B	Circle	Square	2	3	5	20
$\lambda_d$	1	1,12	1,53	1,78	2,14	2,65
$\lambda_c$	1	1,1	1,2	1,3	1,4	1,5

Table C. 26: Correlations for deriving the coefficient  $\alpha'$  for spread foundations, European Standard, Euro Code 7 (ECS, 2007)

Type of ground	Description	$E_M/p_{LM}$	$\alpha$
Peat			1
Clay	Over-consolidated	<16	1
	Normally consolidated	9–16	0,67
	Remoulded	7–9	0,5
Silt	Over-consolidated	>14	0,67
	Normally consolidated	5–14	0,5
Sand		>12	0,5
		5–12	0,33
Sand and gravel		>10	0,33
		6–10	0,25
Rock	Extensively fractured		0,33
	Unaltered		0,5
	Weathered		0,67

Table C. 27: Methods of Estimation of Settlement, Indian Standard (ISI, 1985).

Sr. No.	Type of Strata	Settlement of Structures
1	a) Hard Rock	L
	b) Soft rocks, such as shales, weak limestone and sand stones	L
	c) Non-cohesive soils	F
	d) Soft compressible soils	LF
	e) Stiff, fissured clays	LF
2	Soft, compressible stratum overlying hard stratum	L
3	Hard stratum overlying compressible stratum	L
4	Very variable strata varying in type, thickness and arrangement	Each case to be dealt with on its merits
NOTE - Methods are given in order of preference: F = Field load test L = Laboratory tests: Compression and shear tests on undisturbed samples. Consolidation test on undisturbed samples. Elastic modulus tests on undisturbed samples. *Tests should be made on each stratum.		

FIGURES

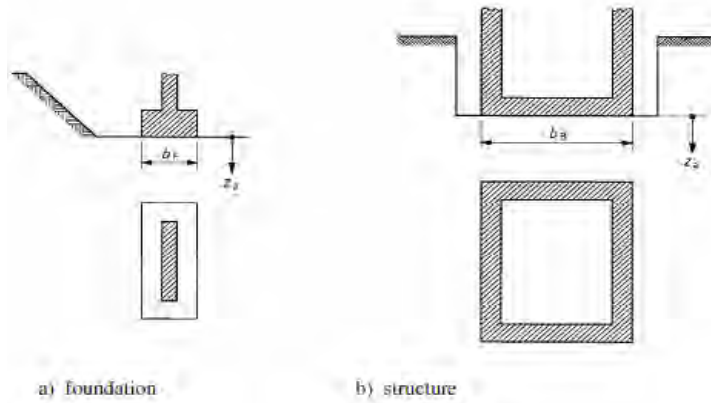


Figure C.1: High-rise structural, civil engineering projects, European Standard, Euro Code 7 (ECS, 2007)

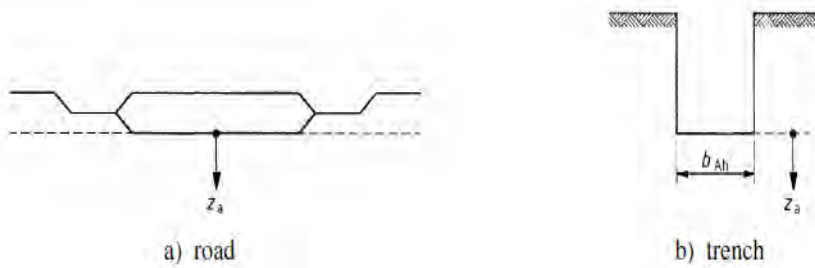


Figure C. 2: Linear structure, European Standard, Euro Code 7 (ECS, 2007)

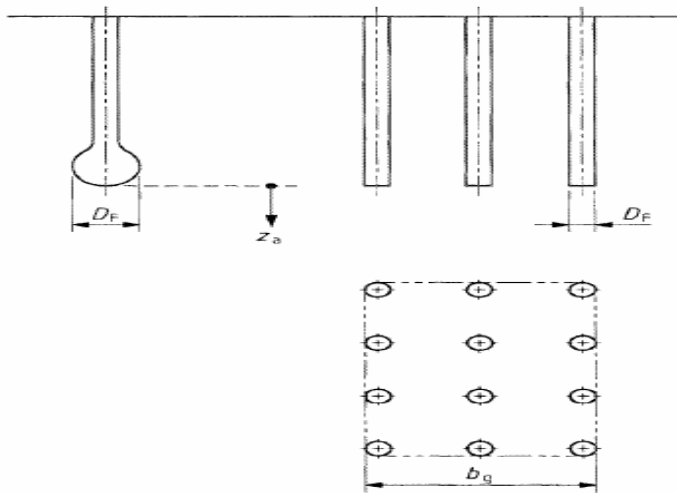


Figure C. 3: Pile Groups, European Standard, Euro Code 7 (ECS, 2007)

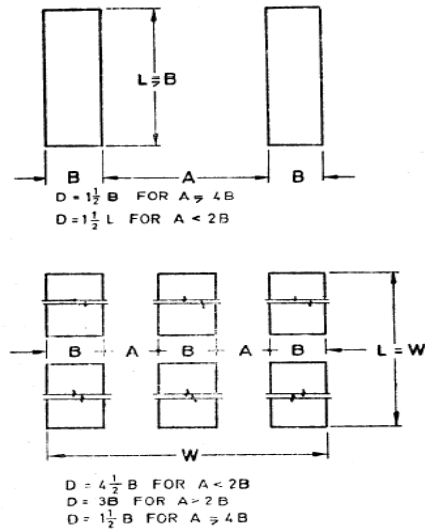


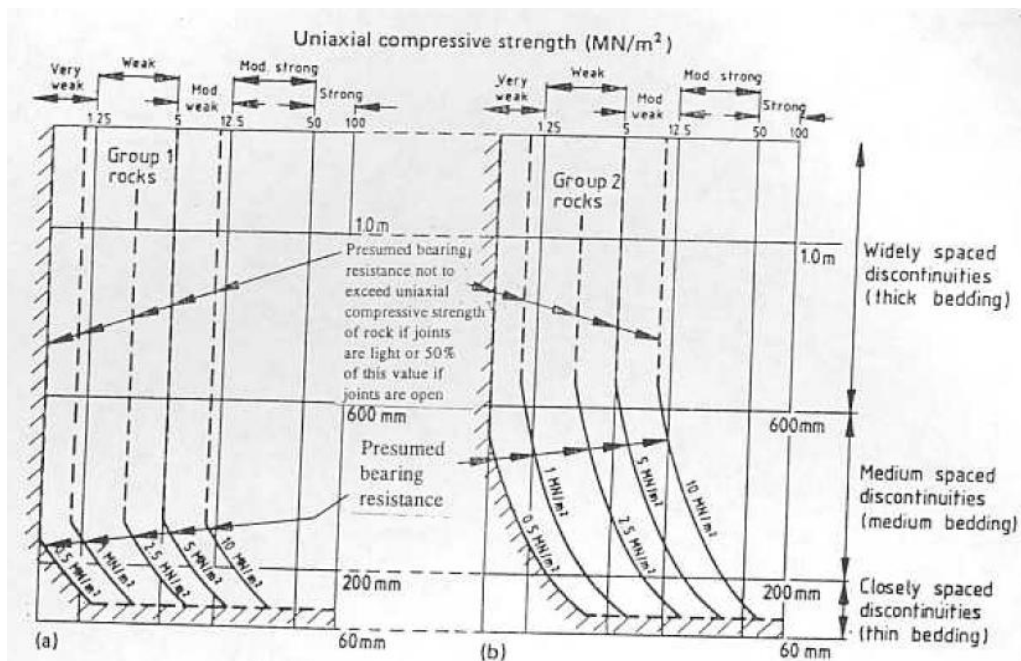
Figure C. 4: Depth of exploration, Indian Standard (ISI, 1985).

SOIL	ROCK		
	Sedimentary	Metamorphic	Igneous
Made-Up Ground	Made-Up Ground	Gneiss	Granite
Boulders & Cobbles	Boulders & Cobbles	Schist	Rhyolite
Gravel	Gravel	Quartzite	Gabbro
Sand	Breccia	Marble	Basalt (Trap)
Silt	Sandstone	Slate	Trachyte
Clay	Siltstone		Agglomerate or flow breccia
Peat	Mudstone		Ignimbrite
NOTE :- Composite Silt Type will be signified by combined symbols, e.g.	Shale		Tuff or Tuff Breccia
	Dolomite		Volcanic Rocks (Unspecified)
	Gypsum Rocksalt etc		Volcanic ash
Silty Sand			

Figure C. 5: Recommended symbol for soils and rocks, Ethiopian Building Code Standard: EBCS 7(MoWUD, 1995)

Recommended Symbol	Type of soil Classification
<b>(1) Course grained soils</b> (more than half of soil (by wt) retained on 75 micron sieve)	
	Well Graded Gravel (GW)
	Poorly Graded Gravels (GP)
	Silty gravel (GM)
	Clayey gravel (GC)
	Well Graded Sands (SW)
	Poorly Graded Sands (SP)
	Silty Sands (SM)
	Clayey Sands (SC)
<b>(2) Fine grained soils</b> (more than half of soil (by wt) passes through 75 micron sieve)	
	Inorganic Silt and Fine Sand (ML)
	Inorganic clays Silty Clays(C) with low compressibility (L) having liquid limit less than 35 (CL)
	Inorganic clays Silty Clays(C) with medium compressibility (I) having liquid limit greater than 35 (CI)
	Inorganic clays Silty Clays(C) with high compressibility (H) having liquid limit greater than 50 (CH)

Figure C. 6: Recommended symbols for soils and rocks, Indian Standard (ISI, 1985)



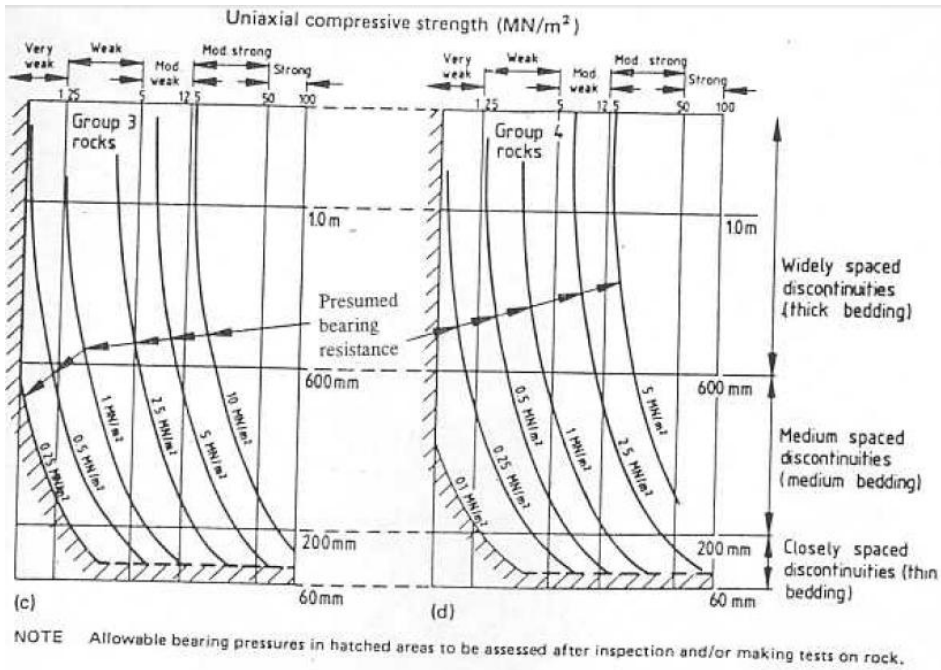


Figure C. 7: Presumed bearing resistance of square pad foundations bearing on rock (for settlements not exceeding 0.5% of foundation width). For types of rock in each of four groups, See Table 60. Presumed bearing resistance in hatched areas to be assessed after inspection and /or making tests on rock, Ethiopian Building Code Standard: EBCS7 (MoWUD, 1995).

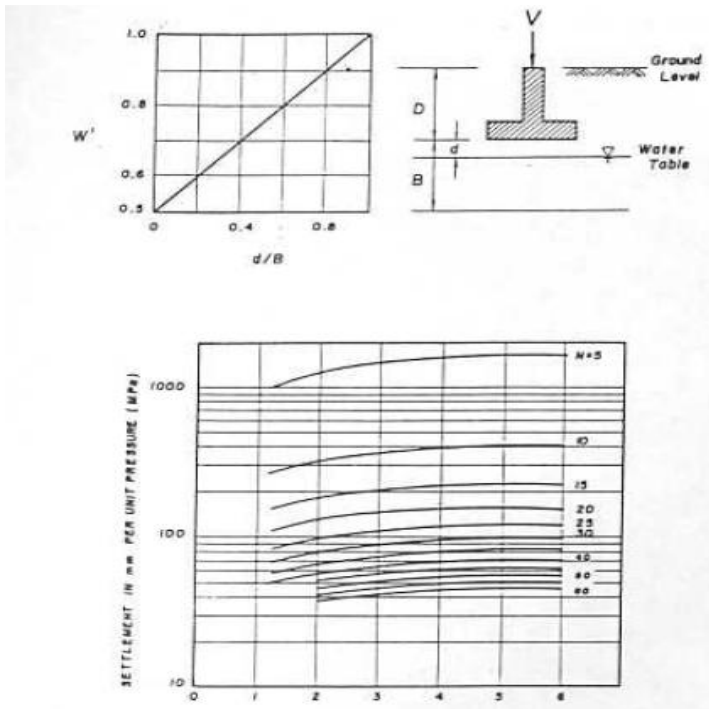


Figure C. 8: Settlement from Unit Pressure from Standard Penetration Resistance, European Standard, Euro Code 7 (ECS, 2007)

## EQUATIONS

Equation C.1: (Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995))

$$S_f = S_i + S_c \dots\dots\dots \text{Eq. 1}$$

Where:  $S_i$  the immediate settlement  
 $S_c$  the consolidation settlement

Equation C.2: (Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995))

$$S_c = \frac{H}{1 + e_o} C_c \log_{10} \frac{P_o + \Delta P}{P_o} \dots\dots\dots \text{Eq. 2}$$

Where:  $H$  the thickness of clay layer  
 $e_o$  the initial void ratio at the mid-height of layer  
 $C_c$  the compression index  
 $P_o$  the initial effective overburden pressure at the mid-height of layer  
 $\Delta P$  the pressure increment

Equation C.3: (Ethiopian Building Code Standard: EBCS 7 (MoWUD, 1995))

$$S_c = \Delta P m_v H$$

Where:  $m_v$  the coefficient of volume compressibility

Equation C.4: (European Standard, Euro Code 7 (ECS, 2007))

$$s = (q - \sigma_{v0}) \times \left[ \frac{2B_0}{9E_d} \times \left( \frac{\lambda_d B}{B_0} \right)^a + \frac{\alpha \lambda_c B}{9E_c} \right]$$

Where:  $B_0$  is a reference width of 0.6 m;  
 $B$  is the width of the foundation;  
 $\lambda_d, \lambda_c$  are shape factors given in Table C.25;  
 $\alpha$  is archeological factor given in Table C.26;  
 $E_c$  is the weighted value of  $E_M$  immediately below the foundation;  
 $E_d$  is the harmonic mean of  $E_M$  in all layers up to  $8B$  below the foundation;  
 $\sigma_{v0}$  is the total (initial) vertical stress at the level of the foundation base;  
 $q$  is the design normal pressure applied on the foundation.

Equation C.5: (European Standard, Euro Code 7 (ECS, 2007))

For high-rise structures and civil engineering projects, the larger value of the following conditions should be applied (Appendix C-Figure C.1 (a)):

$$Z_a \geq 6 \text{ m};$$

$$Z_a \geq 3.0 b_F.$$

Where:  $b_F$  is the width of the foundation.

- For raft foundations and structures with several foundation elements whose effects in deeper strata are superimposed on each other

$$Z_a \geq 1.5 b_B$$

Where:  $b_H$  is the smaller side of the structure, (Appendix C-Figure C.1 (b)).

Equation C.6: (European Standard, Euro Code 7 (ECS, 2007))

- Linear structures, the larger value of the following conditions should be met (Appendix C- Figure C.2):

a) For roads and airfields:

$$Z_a \geq 2 \text{ m below the proposed formation level.}$$

b) For trenches and pipelines, the larger value of:

$$Z_a \geq 2 \text{ m below the invert level;}$$

$$Z_a \geq 1.5 b_{Ah}$$

Where:  $b_{Ah}$  is the width of excavation.

- c) Where relevant, the recommendations for embankments and cuttings should be followed.

Equation C.7: (European Standard, Euro Code 7 (ECS, 2007))

- For piles (Appendix C- Figure C.3), the following three conditions should be met:

$$Z_a \geq 1.0 B_g$$

$$Z_a \geq 5.0 \text{ m}$$

$$Z_a \geq 3 D_F$$

Where:  $D_F$  is the pile base diameter; and  
 $B_g$  is the smaller side of the rectangle circumscribing the group of piles forming the foundation at the level of the pile base