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By

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"Supplementing Site Investigation Techniques of Earthworks and Sub grade Soils with Geophysical Investigation in Road Designs."

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ABSTRACT

In the construction of road projects in Ethiopia, one of the main factors for the delay and increase in cost of road construction projects is huge variation of earthwork item and quantities. This caused the concerned authorities problems of budgetary, questioning of design documents, untrustworthiness on consulting offices, etc.

The purpose of this research is to necessitate the use of geophysical investigation in an attempt to reduce the discrepancy of earthwork quantity and project cost between the design and construction phases.

In order to have sufficient data for the study, records of already designed roads that are not yet constructed or under construction are collected from reliable sources (Ethiopian Roads Authority and International and Local consulting offices). Those data are verified or compared at selected sections (particularly deep cut sections) of the project road using geophysical investigation in the field.

Comparison is also made between the experimental results obtained with the help of geophysical investigation and data collected from the already designed roads.

Based on the results found from the data presentation and discussion, it is observed that lack of detailed site investigation using appropriate method caused major cost overrun and delays in several road projects.

Thus, by studying the area of interest with respect to the required subsurface investigation, planning an exploration technique on a sound geotechnical basis using the test pits supplemented by geophysical technique would bring cost effective result with better accuracy.

1. INTRODUCTION

1.1 General

Because of the economic status, Ethiopia has been categorized among the highly indebted poor countries (HIPC). With this grave situation and understanding, Ethiopia's economic policy is now focused on poverty reduction strategy (PRS) based on long-term growth of Agricultural Development-Led Industrialization (ADLI).The ADLI incorporates different intervention programs including agriculture, education, health and infrastructures (roads, electricity, water supply and telecommunication) especially in the rural areas where the majority of poor are encountered.

In order to effectively tackle poverty, the improvement of infrastructure, mainly road, has become one of the major objectives of the Ethiopian Government since the mid-1990.

The Ethiopian Highlands form the largest continuous area of its altitude in the whole continent, with little of its surface falling below 1500 m, while the summits reach heights of up to 4550 m. [1]

The Ethiopian Plateau, which occupies 66% of the land, consists of a high or central plateau that is bisected diagonally by the Great Rift Valley to the west and the Somali Plateau to the east. The central or high plateau also has a number of mountain ranges. In the northern and eastern parts of the country, the regions are relatively low lying. The Danakil Depression in the northeast dips to 116 metres below sea level and is said to be the hottest place on the earth. [2]

Constructing roads on such rugged mountains and isolated valleys is accompanied by high volume of earthworks, which strives for a need of careful, professional and economic design and construction technique. Applying appropriate field geotechnical investigation technique is an important and necessary tool for economical and proper design.

Knowledge of the soil profile is essential to the engineering design of projects like roadways. A major risk for such projects is that the subsurface geology will differ from the assumptions made in the initial design and cost estimation stages of the project. Such miscalculations due to differing site conditions can be costly.

One of such tools to get the desired effect is Geophysical Investigation, which is the application of principles of physics to study the subsurface environment (strata, material type, thickness, etc) of the earth.

Geophysical methods for road investigation have the task to identify the structure of soil or rock mass and to characterise its individual parts by geotechnical properties in order to apply physical and mathematical techniques enabling to ensure the proper and safe use of the construction during building as well as subsequent operation. In essence, it means searching for an answer to the behaviour of the ground during the construction of a work and after its completion. Since the structure of a rock mass and its behaviour are so much complicated phenomena that unending questions can be asked which will never be fully answered. But the point is that all basic problems can be solved within given economic limits and at a given time so that a safe and functional construction can be designed and built in compliance with applicable standards and common national and international practice. [3]

To design appropriate survey methods and their applications requires a visualisation of a studied environment and of possibilities of implementation of particular methods.

The interpretation of measured values in relation to other characteristics and parameters obtained by an engineering-geological survey enables to develop a structural model of the studied belt along a line construction. The model should be approximated to the reality as much as possible. Due to the complexity and heterogeneity of the natural environment, any geophysical method, even if chosen as appropriately as possible, leads only to approaching a reality. The quality of results of survey work depends on the appropriate choice of methods used, on the difference between the real geological environment and the theoretical model, and on the experience of the interpreter. [3]

Geophysical methods always provide the basic information on the geologic structure of a studied area. Sometimes this information is precise and concrete, and at other times this result cannot be fully achieved. Due to the complexity of conditions in the basement and vicinity of a construction, or for financial reasons, it is only about general information. At any rate, it is possible to acquire data which will enable the configuration and direction of direct survey work (boreholes, pits, etc.) in further stages of a survey. Obtained information is always useful because it means the reduction of financial demands for costly field work, and enables the implementation of survey work in the most suitable places at the shortest possible time. Such application of geophysical work leads to the improvement in the quality of results of the entire engineering-geological survey. The basic demand laid on an engineering-geological survey of constructions is its effectiveness, while keeping the required quality of survey. When observing this condition, it is, however, necessary to obtain all basic data for the safe design and operation of a construction. Mistakes in initial phases of a survey recur in later stages of work and their elimination is extremely demanding in technical, time and financial terms. Geophysics, as a science discipline, is capable of yielding a great number of information within reasonable economic limits in all phases of a survey. In certain cases it also delivers basic data, which are otherwise virtually unavailable or which can be acquired for considerably higher sums. [3]

1.2 Objective of the Study

In the construction of road projects in Ethiopia, one of the main factors for the delay in time and increase in cost of road construction projects is huge variation of earthwork item and quantities. This caused the concerned authorities problems of budgetary, questioning of design documents, untrustworthiness on consulting offices, etc.

This is mainly due to insufficient/limited geotechnical field investigation due to difficult topographical features in the country.

Some studies have showed that the earthwork quantity and cost of project at the end of construction has increased from the estimated quantity and project cost at the design stage. Such variation is mainly due to quantity discrepancy between soil and rock excavation. However such increase in quantity of the earthwork is not only from quantity discrepancy. Some are due to design modifications introduced that are necessary to improve operational adequacy of the road.

In the practiced detail design of roads in Ethiopia, the scope of site investigation made for earthworks and sub-grade soils is limited to test pits dug not more than 1.5 m below natural ground level. For a deep cut section the result of such limited investigation would leave designers with no option but to apply their engineering judgment. Thus the estimation of quantity for soil and rock excavation is based on judgment from the geology of the area and experience. The possibility of introducing errors in this regard is very clear.

The general objective of this study is to necessitate the use of geophysical investigation on areas of deep cut in an attempt to have a better knowledge on the characteristics of the overburden material to be cut, and specifically to reduce the variation in earthwork items (soil and rock) and project cost between the design and construction phases.

1.3 Scope of the Thesis

The research addresses the general objectives and tries to investigate the cause of the difference in the design and construction of earthwork volumes. The study includes assessment of records of the earthwork quantities and the item costs at the beginning and end of some completed road projects from Ethiopian Roads Authority. For the discrepancy between the beginning and end of the project, assessment of the reason for the difference for the selected projects is discussed specific to earthwork activities. Records of already designed roads that are under construction are collected from reliable sources. Those data are verified or compared at selected sections (particularly deep cut sections) of the project road using geophysical investigation in the field.

1.4 Organization of the Thesis

The thesis consists of four Chapters. The first Chapter is the introduction part and it discusses briefly the common problems related to construction of roads, the objective and the scope of the thesis. Following the introduction, the second Chapter is literature review of geotechnical investigation, geotechnical geophysics, and its use, the different types of geophysical methods to be employed and limitations of the geophysical methods. It presents a logical sequence through the process of using geophysical investigation methods in site characterisation. It also presents the standards of different countries design manuals/ publications. The third Chapter comprises data collection, presentation and discussion of results. The forth Chapter presents of the conclusion and recommendation of the thesis.

2. LITERATURE REVIEW

2.1 Significance and Use of Conducting Geotechnical Subsurface Investigation

An adequate soil, rock, and groundwater subsurface investigation provides pertinent information for decision making on one or more of the following subjects: [4]

i. Location of the proposed construction both vertically and horizontally;
ii. Location and preliminary evaluation of suitable borrow and other local sources of construction material;
iii. Need for special excavating and dewatering techniques;
iv. Investigations of stability in natural slopes and cuts, and embankment foundation stability;
v. Conceptual selection of embankment types and hydraulic barrier requirements;
vi. Conceptual selection of alternate foundation types and elevations of the corresponding suitable bearing strata;
vii. Development of additional detailed subsurface investigations for specific structures or facilities;
viii. Need for and type of subgrade or embankment foundation treatment or drainage;
ix. Selection of roadway or area pavement type;
x. Need to identify areas requiring special environmental protection; and/or
xi. Identify potential hazardous locations and types of hazardous materials.

The investigation may require the collection of sufficiently large soil and rock samples of such quality as to allow adequate testing to determine the soil or rock classification or mineralogic type, or both, as well as other engineering properties pertinent to the proposed design.

2.2 Geotechnical Investigation

Investigations performed to determine the geologic setting of the project include: the geologic, seismologic, and soil conditions that influence selection of the project site; the characteristics of the foundation soils and rocks; geotechnical conditions which influence project safety, design, and construction; critical geomorphic processes; and sources of construction materials. A close relationship exists between the geologic sciences and other physical sciences used in the determination of project environmental impact and mitigation of that impact. Those individuals performing geotechnical investigations are among the first to assess the physical setting of a project. Hence, senior-level, experienced personnel are required to plan and supervise the execution of a geotechnical investigation. Geotechnical investigations are to be carried out by engineering geologists, geological engineers, geotechnical engineers, and geologists and civil engineers with education and experience in geotechnical investigations. Geologic conditions at a site are a major influence on the environmental impact and impact mitigation design, and therefore a primary portion of geotechnical investigations is to observe and report potential conditions relating to environmental impact. Factors influencing the selection of methods of investigation include: [5]

a. Nature of subsurface materials and groundwater conditions.
b. Size of structure to be built or investigated.
c. Scope of the investigation, e.g., feasibility study, formulation of plans and specifications.
d. Purpose of the investigation, e.g., evaluate stability of existing structure, design a new structure.
e. Complexity of site and structure.
f. Topographic constraints.
g. Difficulty of application.
h. Degree to which method disturbs the samples or surrounding grounds.
i. Budget constraints.
j. Time constraints.
k. Environment requirements/consequences.
l. Political constraints.

Geotechnical investigations are performed to evaluate those geologic, seismologic, and soils conditions that affect the safety, cost effectiveness, design, and execution of a proposed engineering project. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs, delays in construction schedules, costly construction modifications, use of substandard borrow material, environmental damage to the site, post construction remedial work, and even failure of a structure and subsequent litigation. [5]

2.3 Geophysics

Geophysics is the application of physics principles to the study of the Earth. The Earth is comprised of materials that have different physical properties. Clay and granite, for example, have different densities, acoustic velocities, elastic moduli, electrical conductivities, magnetic susceptibilities, and dielectric constants. [6]

Geophysical instruments are designed to map spatial variations in the physical properties of the Earth. One limitation of most surface-based geophysical instruments is the inability to resolve relatively small-scale (but potentially significant) variations in the physical properties of the subsurface. [6]

Geophysicists interpret these measured variations and use them to generate geologic models (geotechnical applications) of varying sophistication. If the subsurface target of interest can be differentiated from the encompassing strata on the basis of contrasting physical properties, the output geologic model can be of great utility to a geotechnical/ highway engineer. [6]

2.4 Geotechnical Geophysics

Geotechnical geophysics is the application of geophysics to geotechnical engineering problems; such investigations normally extend to a total depth of less than several hundred feet but can be extended to thousands of feet in some instances. Geotechnical geophysical surveys are performed on the ground surface, within boreholes, and from the water and air. [6]

Geotechnical geophysics is not a substitute for boring or testing, but it is often a very cost-effective and reliable means of imaging the subsurface between and below boreholes and for determining the in situ bulk properties of soil and rock. Reconnaissance geophysical investigations can also be used as the basis for making better selection of borehole locations.

Geotechnical geophysical investigations, in many instances, enhance the reliability and speed of geotechnical investigations, and reduce the cost of the investigation. However, geophysical tools are not always capable of meeting the objectives–requirements of Geotechnical/ Highway Engineers. The subsurface targets of interest may be too small or deep to resolve, or impossible to effectively image because its physical properties are too similar to those of the encompassing data. Moreover, if constraints (generally borehole control) are not available, geophysical interpretations may be inaccurate because of their inherent non-uniqueness.

Geotechnical geophysics is routinely used for many types of highway engineering investigations, including: [6]

1. Subsurface characterization: bedrock depth, rock type, layer boundaries, water table, groundwater flow, locating fractures, weak zones, expansive clays, etc.;
2. Engineering properties of Earth materials: stiffness, density, electrical resistivity, porosity, etc.;
3. Highway subsidence: detecting cavities beneath roadways caused by sinkholes, abandoned mines, etc.; and
4. Locating buried manmade objects—buried utilities, underground storage tanks, etc.

2.5 Why use Geotechnical Geophysics

A geotechnical geophysical survey is often the most cost-effective and rapid means of obtaining subsurface information, especially over large study areas. [6]

Other advantages of geotechnical geophysics are related to site accessibility, portability, non-invasiveness, and operator safety. Geophysical equipment can often be deployed beneath bridges, in heavily forested areas, at contaminated sites, in urban areas, on steeply dipping slopes, in marshy terrain, on pavement or rock, and in other areas that might not be easily accessible to drill rigs or cone penetration test (CPT) rigs. Also, most surface-based geophysical tools are non-invasive and, unlike boring or trenching, leave little, if any, imprint on the environment. These considerations can be crucial when working in environmentally sensitive areas, on contaminated ground, or on private property. In addition, geophysical surveys are generally considered less dangerous than drilling since there are fewer risks associated with utility encounters and operations. [6]

Geotechnical geophysics is not a substitute for boring and direct physical testing. Rather it complements a well-planned, cost-effective drilling and testing program, and provides a volumetric image of the subsurface rather than a point measurement. [6]

Geophysical explorations are of greatest value when performed early in the field exploration program in combination with limited subsurface exploration. They are appropriate for a rapid location and correlation of geologic features such as stratigraphy, lithology, discontinuities, ground water, and the in situ measurement of elastic moduli and densities. The cost of geophysical explorations is generally low compared with the cost of core borings or test pits, and considerable savings may be realized by judicious use of these methods.

2.6 Employed Geotechnical Geophysical Method

Geotechnical geophysical tools are routinely used to image the subsurface of the Earth in support of transportation-related geotechnical investigations. Commonly employed geophysical methods include seismic refraction, seismic reflection, SASW (Spectral Analysis of Surface Waves), ReMi (Refraction Microtremor), cross-hole seismic tomography, GPR (Ground Penetrating Radar), EM (Electromagnetic), electrical resistivity, IP (Induced Polarization), magnetics, SP (Self Potential), and gravity. [6]

Seismic refraction and electrical resistivity are the techniques most familiar to the geotechnical community.

2.6.1 Seismic Methods

Seismic methods (refraction and reflection) involve the measurement of the transmission velocity of mechanical waves in soil and rock units. Seismic wave velocities are controlled by the density of the materials and the presence of discontinuities such as joints and faults. The density of an earth material is affected by the mineralogy, porosity (void ratio), moisture content, degree of saturation, and degree of fracturing of the material. Seismic wave velocities are indicative of the gross or bulk nature of these combined material characteristics. [7]

To perform a seismic survey, energy is imparted to the ground by striking a plate on the ground with a sledge hammer or by setting off an explosive chare at the ground surface or in a borehole. Mechanical or seismic waves propagate from the energy source and are detected by geophones placed at known distances from the energy source. The travel times of the seismic waves from the energy source to the geophones are measured by a seismograph. The distances of the geophones from the energy source divided by the travel times indicate the seismic wave velocities of the materials through which the mechanical waves travelled. [7]

The velocities of seismic waves in earth materials are directly proportional to the bulk densities of the materials. Seismic wave velocities of rock are generally higher than in soils and unconsolidated sediments. Intact rocks will demonstrate higher wave velocities than fractured rocks, and soils with low porosities (void ratios) will demonstrate higher wave velocities than soils with high porosities. The seismic wave velocities of saturated earth materials are usually greater than those of partly saturated earth materials. Table 1 below demonstrates the difference in seismic wave velocities in different materials. [7]

The two types of seismic methods are seismic refraction methods and seismic reflection methods. Refraction methods utilize the refraction of mechanical waves at the interfaces of different materials. Reflection methods utilize the reflection of mechanical waves at the interfaces. For the purposes of engineering geophysics, refraction methods are best suited for use on land while reflection methods are best suited for use in aqueous environments. [7]

Table 2-1: Typical Seismic Wave Velocities of Various Earth Materials* [7]

Earth Material	Wave Velocity m/s
Dry Top Soil	180-275
Moist to Wet Top Soil	305-760
Clay, Dense and Wet	915-1800
Gravel	600-790
Cemented Sand	855-975
Weathered and Fractured Rock	455-3050
Shale	790-3660
Chalk	1920-2440
Sandstone	2195-2745
Phyllite	3050-3350
Granite, Fresh	4875-6095
Granite, Highly weathered	470
Granite, Fractured and weathered	670-2440
Granite, Open Joints Present	3050-3960
Basalt	2745-4265
Metamorphic Rocks	5000-6155
Water	1525
Air	335

** Data from U.S. Army Corps of Engineers (1979)*

The essential parameters of the seismic refraction method are indicated in Figure 2.1 below. The figure represents a two-layer case with horizontal boundaries where the seismic wave velocity in layer 2 is higher than in layer 1. The interface between layers 1 and 2 may represent the top of bedrock, the groundwater level, or the contact of two geologic units. Between the shot point and distance X_c, the first seismic waves to arrive at the geophones are those that travel through layer 1. Beyond the distance X_c, the seismic waves to arrive first at the geophones are those that are refracted at the boundary and travel through layer 2, where the seismic wave velocity is higher than in layer 1. [7]

The travel time is the time between the energy shot and the first arrival of the seismic waves at each of the geophones which is recorded by the seismograph. Plotting the travel time to each geophone against the distance of the geophone from the shot point puts the field data into a form from which the seismic velocities of layers 1 and 2 may be calculated, as well as the depth of the interface between the two layers. Figure below shows the time-distance plot of data which may be obtained from the situation depicted in the Figure above it. The inverse of the slopes of the curves are equal to the seismic wave velocities in the two layers. The critical distance, Xc, is the distance from the shot point at which the first arrival is a seismic wave which has travelled through both layers 1 and2. The curve to the left of Xc represents the seismic wave velocity in layer 1 while the curve to the right of Xc represents the seismic wave velocity in layer 2. The curve to the right of Xc is flatter than the curve to the left of Xc, indicating that the seismic wave velocity in layer 2 is greater than in layer 1. [7]

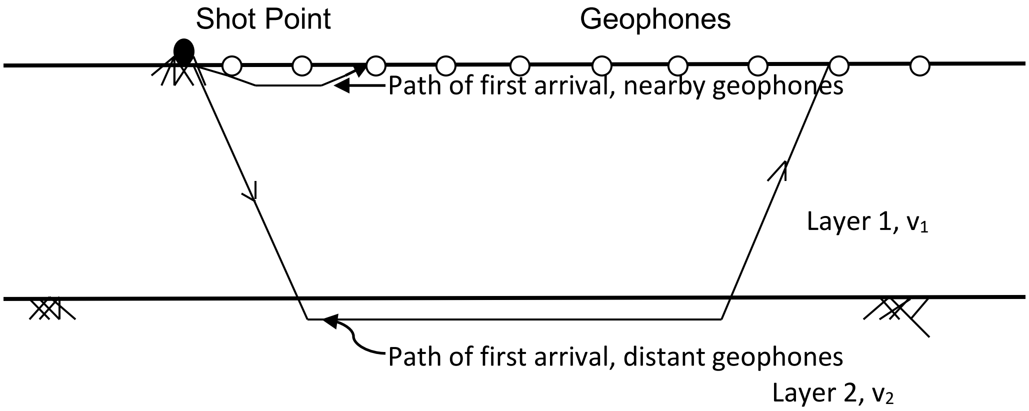


Figure 2-1: Essential Parameters of Seismic Refraction Method for 2-Layer Case with Horizontal Boundaries

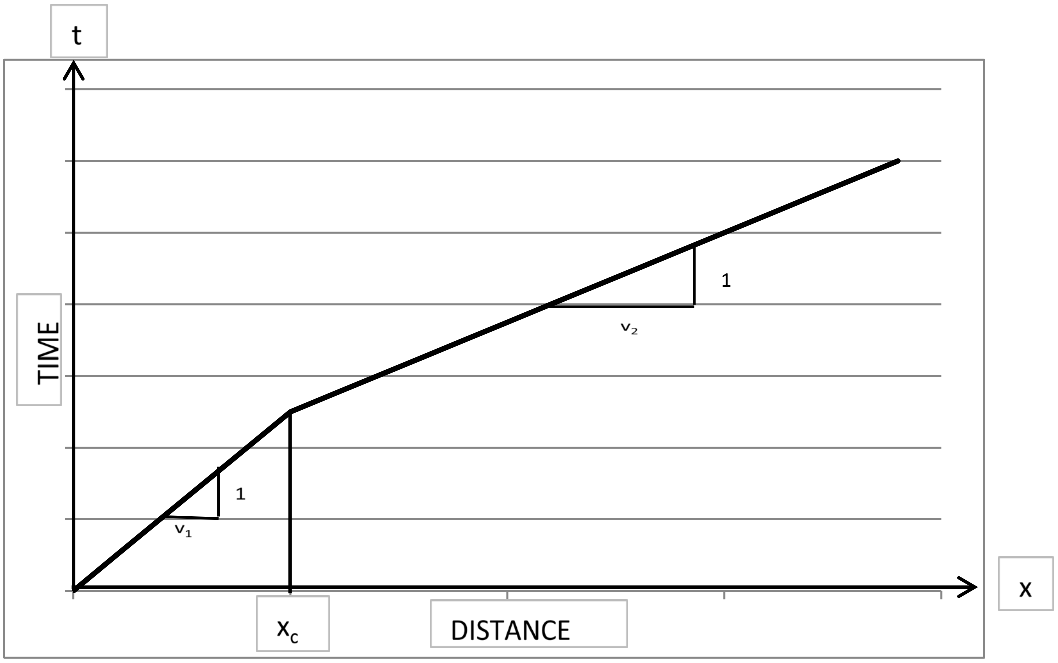


Figure 2-2: Time-Distance Plot from Refraction Survey

When planning seismic refraction surveys, the source of mechanical energy, spacing of geophones, and direction of survey lines must be tailored to the geology of the site and to the information requirements of the survey. Energy may be imparted to the ground by striking the ground with a sledge hammer, dropping a weight, or by setting off an explosion at or near the ground surface. Large-energy sources will result in deeper penetration of seismic waves and will allow for the analysis of geologic conditions at greater depths than if small energy sources are utilized. [7]

The spacing of the geophones will be controlled by the depths and thicknesses of the geologic units along the survey lines. If individual subsurface layers are thin, small geophone spacings must be used in order to define the layers. If the subsurface layers are thick, wider geophone spacings can be used. The total length of the geophone lines should be at least as long as the depth of the deepest geologic unit of interest. Better results can be obtained if the geophone lines are at least three times the desired depth of penetration. [7]

The method of performing a refraction survey will depend on the type of seismograph which is used. Multiple channel units consist of several (usually 6 to 24) geophones which are connected with a single seismograph. A single energy source is used and the travel times of the seismic waves from the shot point to the geophones are recorded by the seismograph. The field setup of a multiple channel unit will be similar to the arrangement of geophones shown in Figure 2-1 above. [7]

A single channel unit consists of a single geophone which is connected to a seismograph. When using a single channel unit, the position of the geophone is kept constant while the distance between the geophone and the shot point is increased. The travel times of the seismic waves between the shot points and the geophone are recorded for each shot point location. The furthest distance between the geophone and the shot point should be at least as large as the depth of the deepest geologic unit of interest, and preferably three times as large as the desired depth of penetration. [7]

Seismic surveys should always be run in opposite directions along a line so that dipping subsurface layers or breaks in bedrock topography can be detected. When using multiple-channel seismographs, the line can be reversed by moving the shot point from one end of the geophone line to the other. When using single-channel seismographs, the direction of the line can be reversed by moving the geophone to the position of the last shot point on the previous line and increasing the distance between the geophone and shot point in a direction opposite to that used in the previous line. [7]

The geology of a site or transportation route should be considered when establishing seismic refraction survey lines. Survey lines should be oriented nearly perpendicular to the strike of major geologic structures (fault and fracture zones, folds, scarps on the bedrock surface) so that linear anamolies can be traced across parallel survey lines. [7]

The Geophones should have good contact with the ground. Thin layers of loose surficial material or organic material should be removed so that the geophones can be placed on firm ground. Likewise, the energy source should have good contact with the ground. A poor contact will result in loss of penetration depth of the seismic waves. [7]

Seismic wave velocities of materials beneath a survey line can be calculated from the time-distance plots of the field data and the materials can be tentatively identified on the basis of these velocities. Seismic wave velocities of materials encountered at a site can be determined by running refraction surveys with short geophone lines across outcrops of the various materials. The first travel-time curve on the time-distance plots will indicate the seismic wave velocity in the outcropping material. Care must be taken to perform the calibration surveys at locations where the materials exposed at the surface have similar mechanical properties to the materials in the subsurface. The materials tested at the ground surface should be weathered to the same degree as the materials in the subsurface. [7]

Certain conditions may result in ambiguous and/or incorrect interpretation of seismic refraction data. These conditions include: [7]

- Insufficient density contrast at boundaries between layers.
- Presence of low-density layer in the stratigraphic section.
- Upper layer with a seismic wave velocity less than that of air.

- Surface topography which is not level
- Shot point not at ground surface

Refraction of seismic waves will occur at the boundary of two materials only if there is a sufficient contrast in the density of the two materials at the boundary. Sufficient density contrasts will occur at the boundaries between lithologic units, at the groundwater level in granular materials, and at the top of fresh bedrock. Insufficient density contrasts may occur at the boundaries between units of similar lithology, and at the groundwater level in fine-grained materials. [7]

In order for a subsurface layer to be detected by a seismic refraction survey, the seismic waves must be refracted upwards toward the interfaces of the layers. This will occur if the densities of successively deeper layers increase. If a low-density layer occurs in the section (a layer with a seismic wave velocity less than that of the overlying layer), the seismic waves will be refracted downward and away from the boundaries and a travel time curve for the low-density layer will not occur on the time-distance plot of the field data. Depths to individual layers, calculated from such as time-distance plot, would be incorrect since the thickness of the low-density layer would not be included in the depth calculations. The presence of low-density layers, as well as the depth and thickness of such layers, may be determined from boring logs and cross-hole seismic surveys. The thickness data may be used to correct the depths calculated from time-distance plots. [7]

2.6.2 Electrical Resistivity Methods

Electrical resistivity methods utilize the differences in the electrical resistivities of different earth materials. Since the resistivity of earth materials are affected by mineralogy, porosity, degree of saturation, moisture content, and chemistry of the pore fluids, electrical resistivity surveys can be used to define subsurface layering, locate cavities and gravel pockets, and locate the groundwater table. For example, clays tend to have low resistivities because of the presence of exchangeable cations in the pore fluids while sands containing fresh water have high resistivities. The resistivity of an earth material usually decreases as the moisture content of the material increases. The resistivities of certain earth materials are given in Table 2.2 below. [7]

Table 2-2: Electrical Resistivity of Various Earth Materials Usually Encountered in Electrical Resistivity Surveys [7]

Material	Resistivity, ohm-meters
Clay	1-20
Sand, wet to moist	20-200
Shale	1-500
Porous limestone	100-1,000
Dense limestone	1,000-1,000,000
Metamorphic rocks	50-1,000,000
Igneous rocks	100-1,000,000

US Army Corps of Engineers (1979)

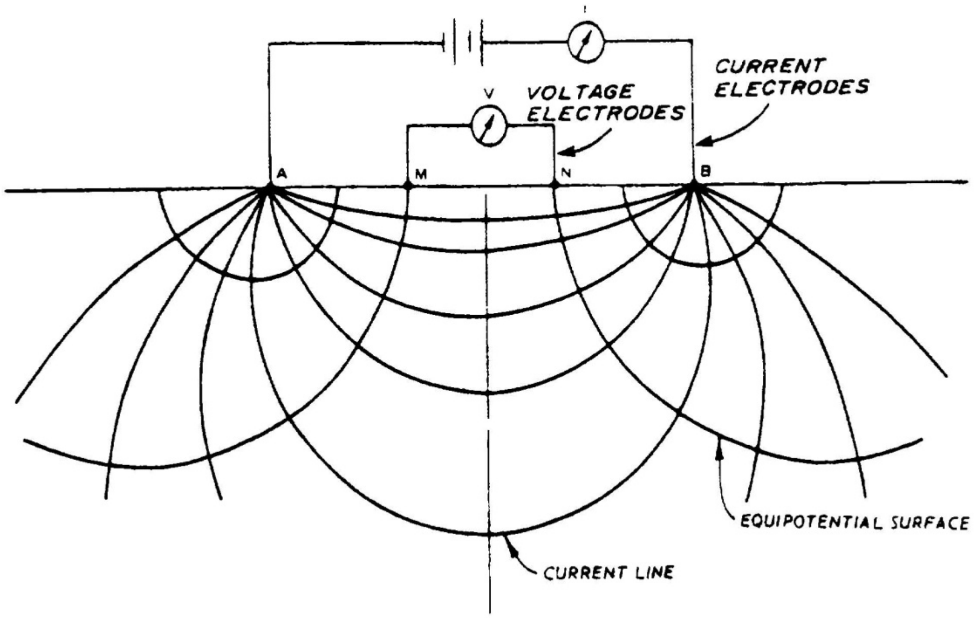


Figure 2-3: Diagram of an Electrical Resistivity Array

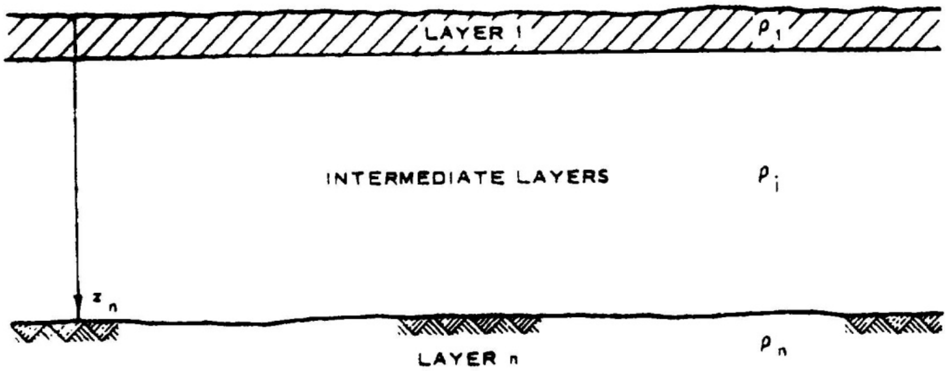
An electrical resistivity array consists of four electrodes which are pushed into the ground. Two of the electrodes transmit an electrical current to the ground and the other two electrodes measure the voltage drop in the earth materials between the current electrodes (Figure 7-3). The resistivity of the earth materials can be calculated using a form of Ohm’s Law. The resistivities which are calculated are apparent resistivities and not true resistivities. The apparent resistivities are average resistivities of all of the earth materials through which the electrical current flows. As the electrode spacing is increased, the electrical current flows through more material, and the apparent resistivities calculated from the field arrays are averages of the resistivities of more materials. Subsurface materials with unusually high or low electrical resistivities will result in anomalously high or low apparent resistivities. High resistivities will become detectable as the electrode spacing is increased and electrical current flows through the material. [7]

Two types of resistivity surveys can be performed. Depth Sounding involves increasing the spacing between electrodes so that the apparent resistivities of earth materials at increasing depths are measured. The center part of the array is kept at the same location while the electrodes are moved further away from the center point for each sounding. Maximum electrode spacing should be 1 to 3 times the depth of the geologic unit which is being investigated. Profiling involves running a resistivity survey line while maintaining constant electrode spacings. A profile survey will measure the apparent resistivities of earth materials along the survey line to a relatively constant depth. The most efficient way to identify a subsurface feature using electrical resistivity methods is to perform a depth sounding to locate the anomaly and then to perform a profile survey to delineate the anomaly, using the same electrode spacing at which the anomaly was discovered in the depth sounding. [7]

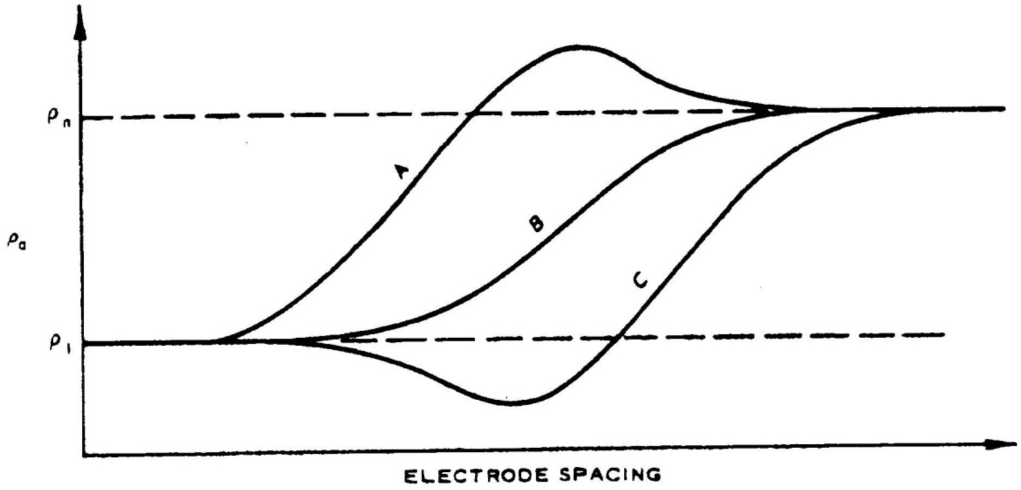
Qualitative interpretations of resistivity data are made on the basis of discovering and delineating an anomaly in the apparent resistivity of the subsurface materials. Figure 2-4 illustrates different types of apparent resistivity anomalies. The earth model consists of three layers with resistivities of ρ_1, ρ_i, and ρ_n. For very small electrode spacings, all of the electrical current passes through layer 1 and the calculated apparent resistivities will be approximately equal to ρ_1. For very large electrode spacings, most of the electrical current will be passing through layer n and the apparent resistivities will be approximately equal to ρ_n. [7]

Curves A, B and C represent the effects of different resistivity conditions in the intermediate layers. Curve A represents the case where the intermediate layer has a higher resistivity than layer n. This may occur when an air-filled solution cavity, pocket of organic material, lense of clean sand or gravel, or igneous intrusion occurs in the intermediate layer. Curve C represents the case where the intermediate layer has a lower resistivity than layer n. This may occur if the groundwater level exists in the intermediate layer, or if a lense of saturated clay or zone of saturated fault gouge exists in the intermediate layer. Any anomaly in the apparent resistivity of subsurface material should be defined by borings made at the location of the anomaly. [7]

Quantitative interpretation of electrical resistivity data involves curve matching or generation of theoretical resistivity curves by a computer. [7]



a. LAYERED EARTH



b. APPARENT RESISTIVITY

Figure 2-4: Resistivity Anomalies Due to Varying Electrical Resistivity of the Intermediate Layer of a 3-Layer System

2.7 Limitations of Geophysics

The most significant limitation of geotechnical geophysics is its non-uniqueness. In the absence of any external constraints (ground truth or basic conceptual model), a single geophysical data set can be transformed into an infinite number of "theoretically correct" output models. For example, in the absence of ground truth, a negative gravity anomaly could be attributed to a structural low at bedrock, to a small air-filled void within bedrock, or to a large water-filled cavity within bedrock. Therefore, in order for an output geologic model to be accurate, the interpretation of geophysical data must be constrained and verified by ground truth acquired using intrusive methods. [6]

Other significant limitations are related to the intrinsic nature of the parameters geophysical tools are designed to measure, the spatial resolution such tools provide, and background noise levels. [6]

The information obtained in geophysical surveys is often subject to more than one reasonable interpretation. Also, depending on specific site-conditions such as geology, target dimensions, cultural interface, and the engineering problem to be investigated, a combination of methods or techniques may be utilized in a given investigation. In other words there is no one, unique interpretation to a set of geophysical data. [8]

It is important to keep in mind that some targets are too deep or too small to be reliably imaged using any geotechnical geophysical tool. Other targets cannot be imaged because their properties do not differ sufficiently from those of the encompassing strata.

2.8 The Site Characterization Problem

The single most critical issue we face in site evaluation work is accurately characterizing the site's geology and hydrogeology. If we can achieve an accurate understanding of a site's geology and hydrogeology, predicting the engineering performance of a site will be reasonably straightforward. However, the frequent lack of understanding of site geology and hydrogeology is often responsible for the structural and environmental failures that occur. [9]

If all sites were simple (horizontally stratified geology with uniform properties), site characterization would be easy. Data from just one boring would be sufficient to characterize the site. However, in most geologic settings, this will not be the case. Even at sites where the geology appears to be uniform, one must be alert to often-subtle variations that can cause significant changes in structural or hydrological properties. [9]

Traditional approaches to subsurface field investigations commonly rely only upon the use of direct sampling methods such as: [9]

- Borings for soil and rock samples;
- Monitoring wells for gathering hydrogeologic data and water samples;
- Laboratory analysis of discrete soil, rock and water samples to provide a quantitative assessment of site conditions; and
- Extensive interpolation and extrapolation from a limited number of data points.

Soil and rock sampling programs and the placement of borings and wells are done mainly by educated guesswork. The accuracy and effectiveness of such an approach is heavily dependent upon the assumption that subsurface conditions are uniform. Numerous pitfalls are associated with this approach that can result in an incomplete or even erroneous understanding of site conditions. These oversights are the cause of many structural and environmental failures. [9]

A variety of surface geophysical methods can be used to characterize natural soil and rock conditions. Soil types along with their spatial extent and thickness can often be assessed. Depth to the water table and rock can be determined as well as the depth and thickness of soil and rock layers. Larger structural features such as synclines, folds and faults can be located and mapped. Smaller localized features such as, the degree of weathering, existence of sand and clay lenses, fracture zones, buried relic stream channels, cavities, sinkholes and other geologic hazards can be located, mapped and assessed. [9]

Surface geophysical methods can be used to assess soil and rock properties and for the non-destructive testing of man-made structures. They are also frequently used for archeological investigations. Geophysical methods can be used for geotechnical forensics in which the cause of a structure failure is investigated. [9]

Soil and Rock Properties

- Corrosion measurements of soil;
- Elastic properties of soil and rock;
- Rippability and dredgeability of rock.

2.9 Review of AASHTO, ASTM D 420-98

AASHTO standard practice recommended the following to be included in conducting subsurface investigations and other techniques may be applied as appropriate as per the site condition: reconnaissance of project area, exploration plan, geophysical exploration, sampling, insitu testing, determination of subsurface investigation, and interpretation of results.

2.9.1 Reconnaissance of Project Area

a. Available technical data from the literature or from personal communication should be reviewed before any field program is started. This includes, but is not limited to, topographic maps, airphotos, satellite imagery, geologic maps, statewide or county soil surveys and mineral resource surveys, and engineering soil maps covering the proposed project area. Reports of subsurface investigations of nearby or adjacent projects should be studied.

   Note —While certain of the older maps and reports may be obsolete and of limited value in the light of current knowledge, a comparison of the old with the new will often reveal valuable unexpected information.

b. In areas where descriptive data are limited by inadequate geologic or soils maps, the soil and rock in open cuts in the vicinity of the proposed project should be studied and various soil and rock profiles noted.

c. Where a preliminary map covering the area of the project is desired, it can be prepared on maps compiled from aerial photography that show the ground conditions. The distribution of the predominant soil and rock deposits likely to be encountered during the investigation may be shown using data obtained from geologic maps, landform analysis, and limited ground reconnaissance. Experienced airphoto interpreters can deduce much subsurface data from a study of black and white, color, and infrared photographs because similar soil or rock conditions, or both, usually have similar patterns of appearance in regions of similar climate or vegetation.

   Note —This preliminary map may be expanded into a detailed engineering map by locating all test holes, pits, and sampling stations and by revising boundaries as determined from the detailed subsurface survey.

d. In areas where documentary information is insufficient, some knowledge of subsurface conditions can be obtained from land owners, local well drillers, and representatives of the local construction industry.

e. Review of past land use (tax maps, fire insurance records, etc.) or changes to local contours, or both, may indicate the possible presence of buried materials that may result in remediative efforts.

2.9.2 Exploration Plan

Available project design and performance requirements must be reviewed prior to final development of the exploration plan. Preliminary exploration should be planned to indicate the areas of conditions needing further investigation. A complete subsurface soil, rock, and groundwater investigation should encompass the following activities:

a. Review of available information on the geologic history, rock, soil, and groundwater conditions occurring at the proposed location and in the immediate vicinity of the site;
b. Interpretation of aerial photography and other remote sensing data;
c. Field reconnaissance for identification of surficial geologic conditions, mapping of stratigraphic exposures and outcrops, and examination of the performance of existing structures;
d. On-site investigation of the surface and subsurface materials by geophysical surveys, borings, or test pits;
e. Recovery of representative disturbed samples for laboratory classification tests of soil, rock, and local construction material. These should be supplemented by undisturbed specimens suitable for the determination of those engineering properties pertinent to the investigation;

f. Identification of the position of the groundwater table, or water tables, if there is perched groundwater, or of the piezometric surfaces if there is artesian groundwater. The variability of these positions in both short and long time frames should be considered. Color mottling of the soil strata may be indicative of long-term seasonal high groundwater positions;
g. Identification and assessment of the location of suitable foundation material, either bedrock or satisfactory load-bearing soils;
h. Field identification of soil sediments, and rock, with particular reference to type and degree of decomposition (for example, saprolite, karst, decomposing or slaking shales), the depths of their occurrence, and the types and locations of their structural discontinuities;
i. Evaluation of the performance of existing installations, relative to their foundation material and environment in the immediate vicinity of the proposed site; and
j. Determination of the possible presence of buried hazardous material that may result in remediation efforts.

2.9.3 Geophysical Exploration

a. Geophysical or remote sensing techniques may assist in mapping of the areal extent of geological formations and for evaluating variations in soil and rock properties.

    i. Satellite and aircraft spectral mapping tools may be used to find and map the areal extent of subsurface materials and geologic structure. Interpretation of aircraft photographs and satellite imagery may locate and identify significant geologic features that may be indicative of faults and fractures. Some ground control is generally required to verify information derived from remote sensing data.

b. Geophysical survey methods can be used to supplement borehole and outcrop data and to interpolate between holes. Seismic, ground penetrating radar, and electrical resistivity methods can be particularly valuable when distinct differences in the properties of contiguous subsurface materials are indicated.

c. Shallow seismic refraction/reflection and ground penetrating radar techniques can be used to map soil horizons and depth profiles, water tables, and depth to bedrock in many situations, but depth penetration and resolution vary with local conditions. Electromagnetic induction, electrical resistivity, and induced polarization (or complex resistivity) techniques may be used to map variations in water content, clay horizons, stratification, and depth to aquifer/bedrock. Other geophysical techniques such as gravity, magnetic and shallow ground temperature methods may be useful under certain specific conditions. Deep seismic and electrical methods are routinely used for mapping stratigraphy and structure of rock in conjunction with logs. Cross-hole shear wave velocity measurements may provide soil and rock parameters for dynamic analyses.

i. The seismic refraction method may be especially useful in determining depth to, or rippability of, rock in locations where successively denser strata are encountered.
ii. The seismic reflection method may be useful in delineating geological units at depths below 3 m (10 ft). It is not constrained by layers of low seismic velocity and is especially useful in areas of rapid stratigraphic change.
iii. The electrical resistivity method may be similarly useful in determining depth to rock and anomalies in the stratigraphic profile, in evaluating stratified formations where a denser stratum overlies a less dense stratum, and in location of prospective sand-gravel or other sources of borrow material. Resistivity parameters also are required for the design of grounding systems and cathodic protection for buried structures.
iv. The ground penetrating radar method may be useful in defining soil and rock layers and manmade structures in the depth range of 0.3 to 10 m (1 to 30 ft).
v. Airborne thermal infrared line scanning is useful in locating seepage areas on hills and earthen water impounding structures.

Note —Geophysical investigations can be a useful guide in determining boring or test hole locations. If at all possible, the interpretation of geophysical studies should be verified by borings or test excavations.

2.9.4 Determination of Subsurface Conditions

a. Subsurface conditions are positively defined only at the individual test pit, hole, boring, or open cut examined. Conditions between observation points may be significantly different from those encountered in the exploration. A stratigraphic profile can be developed by detailed investigations only where determinations of a continuous relationship of the depths and locations of various types of soil and rock can be inferred. This phase of the investigation may be implemented by plotting logs of soil and rock exposures in walls of excavations or cut areas and by plotting logs of the test borings. Then one may interpolate between, and extrapolate a reasonable distance beyond these logs. The spacing of these investigations should depend on the geologic complexity of the project area and on the importance of soil and rock continuity to the project design. Exploration should be deep enough to identify all strata that might be significantly affected by the proposed use of the site and to develop the engineering data required to allow analysis.

Note —Plans for a program of intrusive subsurface investigation should consider possible requirements for permits for installation and proper closure of boreholes and wells at the completion of the investigation.

b. The depth of exploratory borings or test pits for roadbeds, airport paving, or vehicle parking areas should be to **at least 1.5 m (5 ft) below the proposed subgrade elevation**. Special circumstances may increase this depth. Borings for structures, excavations, or embankments should extend below the level of significant stress or groundwater influence from the proposed load as determined by a subsurface stress analysis.

2.9.5 Interpretation of Results

a. Interpret the results of an investigation in terms of actual findings and make every effort to collect and include all field and laboratory data from previous investigations in the same area. Extrapolation of data into local areas not surveyed and tested should be made only for conceptual studies. Such extrapolation can be done only where geologically uniform stratigraphic and structural relationships are known to exist on the basis of other data. Cross sections may be developed as part of the site characterization if required to demonstrate the site conditions.

   i. Cross sections included with the presentation of basic data from the investigation should be limited to the ground surface profile and the factual subsurface data obtained at specific exploration locations. Stratigraphic units between the locations of intrusive explorations should only be indicated if supported by continuous geophysical studies.

   ii. Cross sections showing interpretations of stratigraphic units and other conditions between intrusive explorations but without support of continuous geophysical profiles should be presented in an interpretive report appendix or in a separate interpretive report. The interpretive cross sections must be accompanied by notes describing anomalies or otherwise significant variations in the site conditions that should be anticipated for the intended design or construction activities.

   Note —Additional exploration should be considered if there is not sufficient knowledge to develop interpretive cross sections, with realistic descriptions of anticipated variations in subsurface conditions, to meet project requirements.

b. Subject to the restrictions imposed by state licensing law, recommendations for design parameters can be made only by professional engineers and geologists specializing in the field of geotechnical engineering and familiar with the purpose, conditions, and requirements of the study. Soil mechanics, rock mechanics, and geomorphological concepts must be combined with knowledge of geotechnical engineering or hydrogeology to make a complete application of the results of the soil, rock, and groundwater investigation. Complete design recommendations may require a more detailed study than that envisioned by this standard practice.

c. Delineate subsurface profiles only from actual geophysical, test hole, test pit, or cut-surface data. Interpolation between locations should be made on the basis of available geologic knowledge of the area and should be clearly identified. The use of geophysical techniques as discussed is a valuable aid in such interpolation. Geophysical survey data should be identified separately from sample data or *in situ* test data.

2.10 Review of National Highway Institute (U.S. Department of Transportation Federal Highway Administration) Publication

This manual is the reference text used for the FHWA (Federal Highway Administration) NHI (National Highway Institute) on Subsurface Investigations and reflects current practice for such. The planning, execution, and interpretation of geotechnical site explorations in natural soil and rock are presented with regard to the design and construction of transportation facilities. [10]

This manual presents the general state of the practice of subsurface exploration and focuses on the scope and specific elements of typical geotechnical investigation programs for design and construction of highways and related transportation facilities. The manual presents the latest methodologies in the planning, execution, and interpretation of the various exploratory investigation methods, and the development of appropriate soil and rock parameters for engineering applications. It is understood that the procedures discussed in the manual are subject to local variations.

2.10.1 Project Initiation

In general there are two types of subsurface investigation that new construction may require; the first being a conceptual subsurface investigation, or route selection study, where the geotechnical engineer is asked by the designers to identify the best of several possible routes or locations for the proposed structures, or to evaluate foundation alternatives. This type of project generally does not require a detailed subsurface investigation. It is normally limited to geologic reconnaissance and some sampling, field identification of subsurface conditions to achieve generalized site characterization, and general observations such as the depth to rock or competent soils, presence of sinkholes and/or solution cavities, organic deposits in low lying swampy areas, and/or evidence of old fill, debris, or contamination. Conceptual study investigations require limited laboratory testing and largely depend on the description of subsurface conditions from boring logs prepared by an experienced field engineer and/or geologist. Properly performed exploratory investigations, in cases where the designers have flexibility in locating the project to take advantage of favorable subsurface conditions, have the potential for resulting in substantial savings by avoiding problematic foundation conditions and costly construction methods.

The second and more common type of subsurface investigation is the detailed investigation to be performed for the purpose of detailed site characterization to be used for design. Frequently, the design phase investigation is performed in two or more stages. The initial, or preliminary design, stage investigation is typically performed early in the design process prior to defining the proposed structure elements or the specific locations of foundations, embankments or earth retaining structures. Accordingly, the preliminary design investigation typically includes a limited number of borings and testing sufficient for defining the general stratigraphy, soil and rock characteristics, groundwater conditions, and other existing features of importance to foundation design. Subsequently, after the location of structure foundations and other design elements have been determined, a second, or final design, phase investigation is frequently performed to obtain site specific subsurface information at the final substructure locations for design purposes and to reduce the risk of unanticipated ground conditions during construction. Further investigation stages can be considered if there are significant design changes or if local subsurface anomalies warrant further study. When properly planned, this type of multi-phase investigation provides sufficient and timely subsurface information for each stage of design while limiting the risk and cost of unnecessary explorations.

Prior to planning and initiating the investigation, the geotechnical engineer needs to obtain from the designers the type, load and performance criteria, location, geometry and elevations of the proposed facilities. The locations and dimensions of cuts and fills, embankments, retaining structures, and substructure elements should be identified as accurately as practicable. Bridge locations, approaches, and types of bridge construction should be provided in sufficient detail to allow a determination of the locations, depths, type, and number of borings to be performed.

2.10.2 Existing Data Source

The first step in the investigation process is the review of existing data. There are a number of very helpful sources of data that can and should be used in planning subsurface investigations. Review of this information can often minimize surprises in the field, assist in determining boring locations and depths, and provide very valuable geologic and historical information which may have to be included in the geotechnical report.

Following is a partial list of useful sources of geological, historical, and topographic information.

- Prior subsurface investigations (historical data) at or near the project site.
- Prior construction and records of structural performance problems at the site. Some of this information may only be available in anecdotal forms. The more serious ones should be investigated, documented if possible, and evaluated by the engineer.
- Geological Survey (GS) maps, reports, publications, and websites.
- Flood zone maps.
- Soil Conservation Service (SCS) Soil Maps - It should be noted that they only provide detailed information for shallow surficial deposits. They may show drainage characteristics, soil types, and agrarian data.
- Local university libraries and geology departments.
- Earthquake data, seismic hazards maps, fault maps, and related information.
- Road Maps
- Aerial Photographs.

- Remote Sensing Images.
- Site Plans showing locations of ditches, driveways, culverts, utilities, and pipelines.
- Maps of streams, rivers and other water bodies to be crossed by bridges, culverts, etc., including bathimetric data.

2.10.3 Site Visit/ Plan-in-hand

It is imperative that the geotechnical engineer, and if possible the project design engineer, conducts a reconnaissance visit to the project site to develop an appreciation of the geotechnical, topographic, and geological features of the site and become knowledgeable of access and working conditions. The plan-in-hand site visit is a good opportunity to learn about:

- Design and construction plans
- General site conditions
- Geologic reconnaissance
- The geomorphology
- Access restrictions for equipment
- Traffic control requirements during field investigations
- Location of underground and overhead utilities
- Type and condition of existing facilities (i.e. pavements, bridges, etc.)
- Adjacent land use (schools, churches, research facilities, etc.)
- Restrictions on working hours
- Right-of-way constraints
- Environmental issues
- Escarpments, outcrops, erosion features, and surface settlement
- Flood levels
- Water traffic and access to water boring sites
- Benchmarks and other reference points to aid in the location of boreholes
- Equipment storage areas/security

2.10.4 Communication with Designers/Project Managers

The geotechnical engineer should have periodic discussions with the field inspector while the investigation program is ongoing. The geotechnical engineer should notify the project or the design engineer of any unusual conditions or difficulties encountered, and any changes made in the investigation program or schedule. The frequency of these communications depends on the critical nature of the project, and on the nature and seriousness of the problems encountered.

2.10.5 Subsurface Exploration Planning

Following the collection and evaluation of available information, the geotechnical engineer is ready to plan the field exploration program. The field exploration methods, sampling requirements, and types and frequency of field tests to be performed will be determined based on the existing subsurface information, project design requirements, the availability of equipment, and local practice. The geotechnical engineer should develop the overall investigation plan to enable him or her to obtain the data needed to define subsurface conditions and perform engineering analyses and design. A geologist can often provide valuable input regarding the type, age and depositional environment of the geologic formations present at the site for use in planning and interpreting the site conditions.

Frequently, the investigation program must be modified after initiating the field work because of site access constraints or to address variations in subsurface conditions identified as the work proceeds. To assure that the necessary and appropriate modifications are made to the investigation program, it is particularly important that the field inspector (preferably a geotechnical engineer or geologist) be thoroughly briefed in advance regarding the nature of the project, the purpose of the investigation, the sampling and testing requirements, and the anticipated subsurface conditions. The field inspector is responsible for verifying that the work is performed in accordance with the program plan, for communicating the progress of the work to the project geotechnical engineer, and for immediately informing the geotechnical engineer of any unusual subsurface conditions or required changes to the field investigation.

Generally, there are five types of field subsurface investigation methods, best conducted in this order:

1. Remote sensing
2. Geophysical investigations
3. Disturbed sampling
4. In-situ testing
5. Undisturbed sampling

2.10.5.1 Remote Sensing

Remote sensing data can effectively be used to identify terrain conditions, geologic formations, escarpments and surface reflection of faults, buried stream beds, site access conditions and general soil and rock formations.

2.10.5.2 Geophysical Investigation

Some of the more commonly-used geophysical tests are surface resistivity (SR), ground penetrating radar (GPR), and electromagnetic conductivity (EM) that are effective in establishing ground stratigraphy, detecting sudden changes in subsurface formations, locating underground cavities in karst formations, or identifying underground utilities and/or obstructions. Mechanical waves include the compression (P-wave) and shear (S-wave) wave types that are measured by the methods of seismic refraction, crosshole, and downhole seismic tests and these can provide information on the dynamic elastic properties of the soil and rock for a variety of purposes.

2.10.5.3 Disturbed Sampling

Disturbed samples are obtained to determine the soil type, gradation, classification, consistency, density, presence of contaminants, stratification, etc. Disturbed samples may be obtained by hand excavating methods by picks and shovels, or by truck-mounted augers and other rotary drilling techniques.

2.10.5.4 In-Situ Investigation

In-situ testing and geophysical methods can be used to supplement soil borings. Certain tests, such as the electronic cone penetrometer test (CPT), provide information on subsurface soils without sampling disturbance effects with data collected continuously on a real time basis. Stratigraphy and strength characteristics are obtained as the CPT progresses in the field. Since all measurements are taken during the field operations and there are no laboratory samples to be tested, considerable time and cost savings may be appreciated. In-situ methods can be particularly effective when they are used in conjunction with conventional sampling to reduce the cost and the time for field work. These tests provide a host of subsurface information in addition to developing more refined correlations between conventional sampling, testing and in-situ soil parameters.

2.10.5.5 Undisturbed Sampling

Undisturbed samples are used to determine the in place strength, compressibility (settlement), natural moisture content, unit weight, permeability, discontinuities, fractures and fissures of subsurface formations.

2.10.6 Frequency and Depth of Borings

The location and frequency of sampling depends on the type and critical nature of the structure, the soil and rock formations, the known variability in stratification, and the foundation loads. While the rehabilitation of an existing pavement may require 4 m deep borings only at locations showing signs of distress, the design and construction of a major bridge may require borings often in excess of 30 m. Table below provides guidelines for selecting minimum boring depths, frequency and spacing for various geotechnical features. Frequently, it may be necessary or desirable to extend borings beyond the minimum depths to better define the geologic setting at a project site, to determine the depth and engineering characteristics of soft underlying soil strata, or to assure that sufficient information is obtained for cases when the structure requirements are not clearly defined at the time of drilling.

Table 2-3: Minimum Requirements for Boring Depths

Area of Investigation	Recommended Boring Depth
Roadways	Extend borings a minimum of 2 m below the proposed subgrade level.
Cuts	Borings should extend a minimum of 5 m below the anticipated depth of the cut at the ditch line. Borings depths should be increased in locations where base stability is a concern due to the presence of soft soils, or in locations where the base of the cut is below groundwater level to determine the depth of the underlying pervious strata.
Embankments	Extend borings a minimum depth equal to twice the embankment height unless a hard stratum is encountered above this depth. Where soft strata are encountered which may present stability or settlement concerns the borings should extend to hard material.

The frequency and spacing of borings will depend on the variability of subsurface conditions, type of facility to be designed, and the investigative phase being performed. For conceptual design or route selection studies, very wide boring spacing (up to 300 m, or more) may be acceptable particularly in areas of generally uniform or simple subsurface conditions. For preliminary design purposes a closer spacing is generally necessary, but the number of borings would be limited to that necessary for making basic design decisions. For final design, however, relatively close spacings of borings may be required, as suggested in Table 2-4 below.

Table 2-4: Guidelines for Boring Layout

Geotechnical Features	Boring Layout
Roadways	The spacing of borings along the roadway alignment generally should not exceed 60 m. The spacing and location of the borings should be selected considering the geologic complexity and soil/rock strata continuity within the project area, with the objective of defining the vertical and horizontal boundaries of distinct soil and rock units within the project limits.
Cuts	A minimum of one boring should be performed for each cut slope. For cuts more than 60 m in length, the spacing between borings along the length of the cut should generally be between 60 and 120 m. At critical locations and high cuts, provide a minimum of three borings in the transverse direction to define the existing geological conditions for stability analyses. For an active slide, place at least one boring upslope of the sliding area.
Embankments	A minimum of one boring should be performed for each embankment slope. For embankments more than 60 m in length, the spacing between borings along the length of the embankment should generally be between 60 and 120 m. At critical locations and high embankments, provide a minimum of three borings in the transverse direction to define the existing geological conditions for stability analyses. For an active slide, place at least one boring upslope of the sliding area.

Subsurface investigation programs, regardless to how well they may be planned, must be flexible to adjust to variations in subsurface conditions encountered during drilling. The project geotechnical engineer should at all times be available to confer with the field inspector. On critical projects, the geotechnical engineer should be present during the field investigation. He/she should also establish communication with the design engineer to discuss unusual field observations and changes to be made in the investigation plans.

2.11 Review of the Republic of Kenya, Ministry of Transport and Communication Roads Department Manual

Road design may be divided in to three stages, namely feasibility study, preliminary design and final design. The following part describes the materials sampling and testing programmes applicable to each stage of the design. [11]

2.11.1 Preliminary Design

2.11.1.1 Alignment Soils, Sampling

At least one sample shall be taken per kilometre of anticipated alignment, with more frequent samples where there are major changes in soil type.

To this end, pits shall be dug mostly in anticipated out areas, if possible down to at least 0.5 m below the expected formation level. Further, in the case of a new alignment, the depth of any pit shall in no case be less than 1.5 m, unless rock or other material impossible to excavate by hand is encountered.

2.11.2 Final Design

2.11.2.1 Earthworks and Subgrade, Sampling

At least one sample shall be taken per 500 metres along the length of the proposed alignment, with more frequent samples where necessary to record changes of soil type or to provide an adequate assessment of the subgrade strength. A good knowledge of the materials to be cut is also essential.

For these purposes, holes shall be excavated mostly in proposed cut areas, down to at least 0.5 m below the anticipated formation level, unless rock is encountered. The position of each test hole shall be accurately determined and reported. In hilly or mountainous terrain, deep holes will be required to accurately determine the materials to be cut. It is sometimes impossible to dig trial pits to the depth of the anticipated formation level. It is then recommended to use a hand or power auger to drill holes to the depth required.

To assess the quantities of the various earthwork categories (i.e. rock, rippable or normal material), it will in some cases be necessary to drill boreholes. This type of investigation may advantageously be supplemented by a seismic survey or a resistivity survey.

2.12 Review of the United Republic of Tanzania, Ministry of Works Manual

This describes the methods for subgrade evaluation for structural pavement design of new roads and conventional sampling. Subgrade strength is classified on the basis of CBR values. Strength indicators other than CBR may be used provided they are adequately correlated to CBR values and are approved at project level. [12]

2.12.1 Design Depth

The design depth is defined as the depth from the finished road level to the depth that the load bearing strength of the soil no longer has an effect on the pavement's performance in relation to traffic loading.

Table 2-5 gives the design depth values in relation to design road type.

Table 2-5: Design Depth

Road Type	Design Depth (m)	
	General Requirements	Heavy Load Classes
Paved trunk roads	0.8	1.2
Other roads	0.6	1.0

2.12.2 Centreline Soil Surveys

A desk study shall always be carried out to gather available information about previous investigations, topography, climate, geology, soils, known material sources, road type, design standard and expected traffic load conditions (i.e. whether large number of very heavy axle loads are likely). Issues related to slope stability and foundation of structures shall be addressed separately.

Subgrade soils and their properties, including strength, shall be classified based on soil surveys by the use of trial pits excavated along the road line.

2.12.3 Depth of Investigations

Soil surveys shall be planned and conducted in a manner that classifies all materials according to their suitability in load bearing layers within the zone of the design depth. A preliminary vertical alignment shall be assumed at the time of the soil survey in order to ensure that soil samples for subgrade classifications are actually taken at levels that fall within the design depth of the road.

Investigations shall be extended to below design depth as required to detect problems that need special consideration. These include:

- Presence of problem soils
- Unfavourable subgrade conditions
- Features associated with slope and embankment stability

Excavation of sample pits may be impractical in cuts deeper than 3 metres, which special equipment may have to be employed. If possible, postponement of sampling until the time of construction should be considered under such conditions.

Evaluation of subgrade strength in embankment areas shall be based on the best possible information about likely sources of earthworks fill materials for use within the design depth.

2.12.4 Materials Testing Frequency

Test pits shall be excavated for the purpose of sampling the subgrade along the road line, and materials testing carried out at a minimum average frequency as shown in Table 2-6.

Table 2-6: Minimum materials testing frequency

Road Type	**Indicator Testing**	**CBR Strength Testing**	**Minimum number of CBR tests for any homogeneous section**	
			Minimum for statistical analysis	**Absolute minimum**
Paved trunk roads	Min. 4 per km	Min. 2 per km	5	3
Other paved roads	Min. 2 per km	Min. 1 per km		
Gravel roads	Min. 2 per km	Min. 1 per 2 km		

The testing frequencies in Table are minimum averages and shall be increased as required according to site conditions.

The test pit locations may be distributed un-evenly along the road line to capture changes in soil conditions and as required for optimum use of resources allocated for investigations.

2.13 Review of South African National Roads Agency Limited Manual

2.13.1 Site Investigation

In the case of many cut slopes, successful design depends on a thorough site investigation. The site investigation should provide adequate information to: [13]

- Define fully the surface and subsurface geology over the area in which the cut will be constructed;

- Define the ground-water regime in terms of flow paths, porewater pressures, permanent and temporary (perched) water tables and adjacent water sources under the worst possible expected conditions;
- Define the geological and mechanical properties of the materials involved in the cut, regarding both the stability and excavation aspects;
- Define the subsurface geological structure in order to identify possible planes of failure and
- Assess the probable failure mechanisms, if any.

The figure 2-5 below shows an idealized site investigation process. Depending on the proportions and importance of the cut, this decision chart should be followed to a greater or lesser extent.

2.13.2 Geology

The surface geology should be mapped to a fairly large scale (1:1000 to 1:2500). Note should be taken of outcrops, different soil types and geological structure where exposures permit. From these data an estimate of the subsurface geology can be made. With this knowledge in mind, a subsurface exploration programme can be drawn up to confirm any assumptions in the initial estimate. It is often useful to excavate a trench or pit to get a direct view of the material and the geological structure.

A seismic refraction survey can be used to delineate the soil/rock or soft rock/hard rock boundaries. It is useful as a rough indicator of excavation properties when combined with geological input but is of little use in stability estimates other than defining material boundaries. However, a seismic survey is of invaluable assistance in the design of the boring or drilling programme as unexpected variations in the soil/rock contact can be investigated directly. It is always necessary to confirm seismic refraction data by means of drilling.

The layout and spacing of the borings will depend on the anticipated subsurface geology, the configuration and dimensions of possible unstable areas and the anticipated mechanism of failure. The practice of specifying a minimum number of boreholes per unit length of cut is both undesirable and uneconomical. The drilling programme should be designed on a sound geotechnical basis, and may be done in two stages: a few holes initially followed by a more detailed programme later.

Usually it is not economical to carry out a site investigation so thoroughly that the possibility of unforeseen factors being discovered during the actual investigation for the cut is completely eliminated. Both the designer and the supervisory staff should be aware of this. The actual excavation of the cut should therefore be regarded as the final phase of the site investigation.

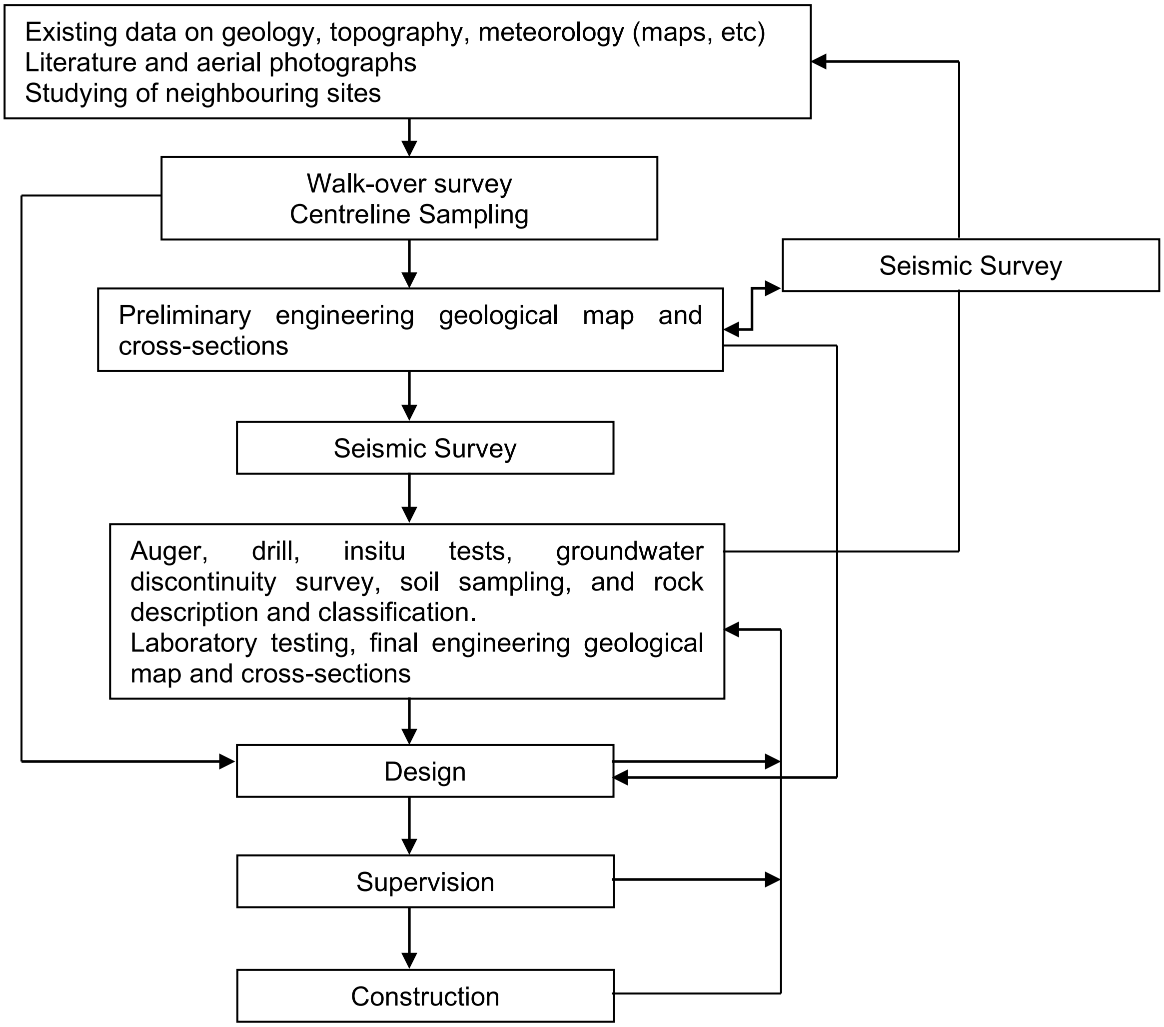


Figure 2-5: Site investigation flow diagram for cut

2.14 Review of Ethiopian Roads Authority (ERA) Manual

As it is worth demanding to review ERA manual on the issue, the following important points are taken from ERA Site Investigation Manual, 2002. [7]

2.14.1 General

As mentioned in Chapter 2 of the Site Investigation Manual, investigations for road design are often conducted in two stages (feasibility and preliminary stage, final stage), depending on the terms of reference. Where two stages are chosen or specified, the frequency of sampling and testing during the preliminary stage is significantly less than that for the final design. An indication of the types of tests and testing frequency for road design is as follows:

Table 2-7: Sampling Frequency

Investigation Stage	Test Description	Frequency of cumulative Sampling
Feasibility/ Preliminary	Identification	1 km
	CBR	2 – 5 km
Final	Identification	0.5 km
	CBR	1 km

Notes:
1. The frequency of sampling is cumulative, i.e. the frequency indicated in the final stage is a cumulative total of both the preliminary stage and final stage sampling.
2. As mentioned in Section 4.1, if major emphasis is on the preliminary stage, the frequency of sampling shall be as indicated for the final stage.
3. The sampling should insure at least two tests per each soil group along the alignment.

The field exploration in the preliminary and final stage should be of such extent as to have sufficient data for the road design. The explorations and testing, which are costly and time-consuming, should serve the obvious needs of civil and structural design. The design phase data must have sufficient accuracy, coverage and applicability to support design analysis and decisions. It should also permit reasonably **accurate estimates of material quantities and construction costs**.

Common investigations include (in-situ) test pits and hand auger probes, and occasionally borings. It is sometimes impossible to dig trial pits to the depth of the anticipated formation level. It is then recommended to use a hand or power auger to drill holes to the depth required.

For the purpose of taking representative samples, pits shall be dug mostly in anticipated cut areas (since these cuts will expose the subgrade support of the future pavement and provide embankment materials), if possible down to at least **30 cm below the expected subgrade level**. Further, in the case of a new alignment, the depth of any pit **should in no case be less than 1.5 m unless rock or other material impossible to excavate by hand is encountered**. The engineer in charge of planning the investigations should make every effort to locate the test pits (along the alignment as well as within the lateral extent of the anticipated excavation) in order to optimize the representativity of the material excavated from the test pit.

If deep cuts are proposed through materials indicated to be variable by test pits and a study of the geological maps, consideration is to be given to **drilling the cuts** at the final design stage when the potential hard stone sources are being investigated.

The position (in plan and elevation) of each test pit must be accurately determined and recorded. This implies that geotechnical and topographical tasks must be coordinated in the field. In every test pit, all layers, including topsoil, shall be accurately described and their thicknesses measured. All layers of more than 30 cm (except topsoil) shall be sampled. This will promote a proper assessment of the bulk of the materials excavated in cuts and to be used in embankments. The sample shall be taken over the full depth of the layer by taking a vertical slice of material.

The road design requires and shall include the following geotechnical studies:

- **Soils and rock conditions** as they pertain to earthworks operations and subgrade conditions as pavement support. As far as possible, the **interface between soil (or rippable rock) and unweathered rock should be identified** in order to optimize the alignment and profile. Also, an assessment of the subgrade strength is required at this stage to conduct the pavement design, together with a definition of the conditions of compaction and reuse of excavated materials into embankments.

2.14.2 Special Investigations

Special investigations relate to such items as deep cuts, embankments over soft and compressible soils, expansive soils and natural slopes.

2.14.2.1 Deep Cuts

This deals with additional considerations regarding cuts if common investigations for the earthworks and subgrade have revealed particular problems (e.g. significant rock excavation) and also with considerations regarding the side slopes to be considered.

Regarding the investigations of **deep cuts**, it is desirable to conduct specific test **pits, borings, auger probes and/or geophysical investigations**, since significant cost overruns can result from erroneous estimates of rock excavation (as opposed to unclassified or earth excavation).

The potential for water resurgence in deep cuts should also be investigated. The stability of cut sections needs to be detailed, including provision of cut-off and interface drainage, and treatment of other slope stability issues. When new horizontal alignment is required, or when the vertical alignment is changed, required new cuts should be designed and existing cuts deepened. It is very important to avoid rocky cuts whenever possible.

If additional, possibly expensive, tests are deemed necessary, such as **seismic tests or drilling**, a program should be proposed to ERA for approval, describing the scope, intent, and price of the tests. Specific drainage systems must also be designed to protect slopes prone to mud slides from rainfall runoff.

The following factors should be considered with respect to deep cuts:

- Type of material to be excavated, volume and position of different materials.
- Level and flow of water table and springs
- Stability of slopes

- Drainage and protection against erosion

The type of material to be excavated influences its suitability as embankment material, as developed in the section regarding subgrade strength class determination. As indicated before, it is important to **determine the volume of rock, rippable and normal material in each deep cut**. Dynamic penetration and seismic tests may usefully supplement borings for this purpose (see the section below).

The depth and degree of weathering may be very variable within short distances. Laterization may also be present. The determination of the rock level is important not only to estimate quantities and costs, but also because its interface with the overlying soil may provide an opportunity for the presence of a perched water table. Springs may also be a problem, depending on the type of rock and its structure.

2.14.3 Engineering Geophysics

Geophysical techniques applied to geotechnical investigations can be categorized into two general groups-investigations conducted from the ground surface and those conducted in boreholes. Each group is further separable into two basic modes of data generation; measurement of either existing earth fields (passive) or measurement of fields induced deliberately for the purpose of the investigations (active). Investigations conducted from the ground surface typically provide information about the subsurface both laterally and to some depth, while most of the borehole investigations, with some exceptions, provide detailed information about materials only in the immediate vicinity of the borehole or between boreholes.

The existing energy fields and induced energy fields represent those most useful in terms of the engineering requirements, but others exist that might be used under special circumstances (e.g., randomly-occurring seismic events, ground tilt, and natural electromagnetic fields). Those particularly applicable to the Ethiopian environment included herein are limited to seismic and electric techniques.

The interest in passive energy fields occurs because the strength of the field at any particular point and reflect the geological conditions present between the point and the source of the field, such as proximity of bedrock, varying stratigraphic or hydrologic conditions, or mineral changes indicative of the stratigraphy present.

Geophysical methods that rely upon the reaction of subsurface materials to induced energy are typically much more versatile for geotechnical purposes. These active geophysical techniques can be tailored to the needs of particular investigations. The appropriate equipment can be selected, the locations for investigation chosen, and the parameters measured in accordance with the specific project requirements (within the ability of geophysical techniques to provide such measurements).

Fundamental to the entire process of making geophysical measurements is selection of the method or methods appropriate to measure or derive the needed parameters, based on knowledge of how the resulting data are to be used. In general, a single geophysical technique may not always provide the information needed for engineering investigations. A combination of several complementary methods usually provides more information and detail. The purpose and limitations of any particular investigation should be clearly understood before selecting the approach to be used. A cost-effective investigation can often be designed so that the need for later geophysical surveys can be avoided.

2.14.3.1 Use of Data

The data derived from geophysical investigations usually have to be interpreted by experienced geophysical analysts prior to use by engineering geologists or geotechnical engineers.

The results of geophysical investigations should always be supported by direct observation of subsurface conditions by means of borings, test pits, trenches, outcrops and other geological information. Such direct measurements will assure that subsurface conditions not measured by the geophysical methods are discovered and support or negate interpretations made on the basis of geophysical methods. Awareness of the potential for error must be recognized and anticipated so that proper “calibration” of the results is possible.

Induced-field geophysical techniques are more widely used than passive techniques. **Seismic refraction and electrical resistivity** are the techniques most familiar to the geotechnical community. While many other geophysical techniques are available in certain types of investigations, these represent methods that have been demonstrated effective in geotechnical investigations. Computerized treatments of data collected at ground surface (seismic and resistivity) are constantly in a state of improvement. Additional use of geophysical techniques for geotechnical applications can be expected as improvements in both field procedures and analytical/interpretation approaches develop.

Selection of the method used in the induced case can be based upon a need for depth of coverage versus the specific type of information needed. Resolution capability is also selectable to some degree, with resolution increasing as the density of observation points or rate of observation is increased.

Table 2-8 indicates which geophysical methods can be used to investigate geologic conditions which may be important in the siting of transportation routes. Limitations of some of the methods make some of those shown less useful than might be initially expected, and some comments regarding actual usefulness are reflected in the discussions of the following sections.

2.14.3.2 Scheduling

Geophysical investigation techniques are generally applicable to some degree throughout a project lifetime, ranging from the initial investigative phases through the final design phase.

The widest use of engineering geophysics occurs as an integral part of the initial site explorations, especially in phased investigations or to generally provide information between widely spaced “point” observations (i.e., boreholes, test pits, outcrops, etc.). Preliminary geophysical explorations (following a review of geological and topographical conditions) can lead to realignment or site rejection or can indicate the need for additional explorations. Table 2-8 is helpful in determining when various engineering geophysics techniques should be used (i.e., at what point in time a particular parameter must be known in the decision process). The need for some methods is sometimes also identified during the investigation of a site by other geophysical techniques.

Table 2-8: Uses of Engineering Geophysics in Geological Investigations of Transportation Routes

Geological Conditions to be investigated	Useful Geophysical Techniques	
	Surface	Subsurface
Stratified rock and soil units (depth and thickness of layers)	Seismic Refraction	Borehole Logging
Depth to Bedrock	Seismic Refraction, Electrical Resistivity	Borehole Logging
Depth to Groundwater Table	Seismic Refraction, Electrical Resistivity	
Location of Highly Fractured Rock and/or Fault Zones	Electrical Resistivity	Borehole TV Camera
Bedrock Topography (troughs, pinnacles, fault scarps)	Seismic Refraction	
Location of Planar Igneous Intrusions	Seismic Refraction	
Solution Cavities	Electrical Resistivity	Borehole TV Camera
Isolated Pods of Sand, Gravel, or Organic Material	Electrical Resistivity	Borehole Logging
Permeable Rock and Soil Units	Electrical Resisitivity	Borehole Logging
Topography of Lake or River bottoms	Seismic Reflection	
Stratigraphy of Lake or River Bottom Sediments	Seismic Reflection	
Lateral Changes in Lithology of rock and Soil Units	Seismic Refraction, Electrical Resistivity	

For major projects, use of geophysics is ordinarily defined before the field investigations begin since the role of the eventual results is well known in the design process. On smaller projects the use of geophysical methods is sometimes deferred until it is determined that more traditional investigations cannot provide the required information, or that geophysical technique will provide the needed information on a more timely or more cost-effective basis.

3. DATA COLLECTION, PRESENTATION AND DISCUSSION OF RESULTS

In the practiced detail design of roads using ERA site investigation manual, in order to ascertain the strength characteristics and quantity of earthworks and sub grade soils as well as the thickness and quality of the surface (overburden) material, sampling and testing using hand dug test pits of not more than 1.5m depth at an interval stipulated in the specific design standard is undertaken.

Thus, the data collection and analysis is done with the aim of whether the practiced site investigation technique is enough for proper design of roads or further investigation is necessary.

3.1 General

Soil samples must be obtained as part of any geotechnical site investigation to characterize subsurface conditions, determine geotechnical properties such as strength and compressibility, and corroborate the findings of in situ tests. A variety of techniques ranging from test pits to block sampling can be used depending on the use and desired quality of the samples. Important issues include the different methods used for obtaining soil samples, sample disturbance, and sampling intervals.

As can be seen from the details of the review, all the manuals/ publications contain the reconnaissance and existing data source review, exploration planning, geophysical investigation, and detail site investigation, though applied differently.

Geophysical methods, as stated on most of the manuals reviewed, are useful as an indicator of excavation properties in combination with geological inputs such as test pits and boreholes. Since geophysical methods are fast and economical testing technique which is applicable to both soil and rock, it can be used as an integral part of detail site investigation. But it is not practically used by the design offices in Ethiopia for the design of road.

Though the practices on the developing countries show that the required attention is not given on using geophysical methods, the developed countries are using the technique to assist in mapping areal extent, evaluating variations in soil and rock properties, to interpolate between test pits and boreholes, to map soil horizons, stratification, depth profiles & depth to bed rock, as a useful guide in determining boring or test pit locations.

Consequently, on the basic investigation stage, i.e. detail investigation for final design, all the manuals/ publications provide different minimum standards as summarized in table 3-1. The reason behind the difference is economy.

All the manuals/ publications reviewed, including ERA Site Investigation manual, state that depth of any test pit for determination of subgrade strength shall be dug down to at least below the design subgrade level. However, practically this is not the case as the site investigation usually is conducted before any of the alignment of the road is designed. Furthermore, on the practiced site investigation, usually test pits are dug 1.5 m below the natural ground level for the entire alignment of the road to be designed, including deep cut sections. Even though the main reason of limiting the investigation depth is limiting the risk and cost of unnecessary exploration, such investigations are causing expenses which have of no use as input to the design of the road.

In addition, the different manuals/ publications reviewed propose different spacings of test pits along the alignment of a road for subgrade strength determination and earthwork classification & quantity determination.

The aim of geotechnical investigation is to convey information on surface and sub-surface ground conditions (so far as they can be ascertained) sufficient to satisfy the requirements for preliminary and/or detailed design, while avoiding expensive ground investigation.

Considering the erratic nature of the subsurface on some locations and homogeneity on another location of a country, specifying a minimum standard spacing of test pits is uneconomical and not logical.

Thus, by studying the area of interest with respect to the required subsurface investigation, planning an exploration technique on a sound geotechnical basis using the test pits supplemented by geophysical technique would bring cost effective result with better accuracy.

3.2 Data Collection

Data has been collected on the extent of site investigation based on three terms of study; namely:

1. collected data of sample road projects that are victims of the insufficient site investigation
2. collected data on the currently used site investigation technique for estimation of earthwork
3. collected data using geophysical investigation on sample locations of project road

3.2.1 Collected Data of Sample Road Projects that are Victims of the Insufficient Site Investigation

Records of some substantially completed or road projects that are under construction with earthworks are almost completed, are assessed of the earthwork quantities and item costs at the beginning and end of the project from Ethiopian Roads Authority, as shown in Appendix B. The selected projects are roads that made the client, Ethiopian Roads Authority, to pay a variation amount for a discrepancy from the original contract amount.

The data were collected from the regional directorates of the Ethiopian Roads Authority. The study considered 13 road projects of such type: three from the Northern Regional Directorate, two from the Southern Regional Directorate, five from the Central Regional Directorate, and three from the Western Regional Directorate. The following are the road projects taken for the study:

Northern Region

i. Dima – Fiyel Weha Road Project
ii. Endaselassie – Dejena – Dansha Road Project, Contract 3: Dansha – Dejena – Adiremet
iii. Afdera – Abala Road Project, Contract 1: Hawusewa – Abala – Irebti

Southern Region

i. Arba Minch – Jinka Road Project, Contract 3: Delbena – Jinka
ii. Nazareth – Assela – Dodola and Shashemene – Goba Road Upgrading Project, Contract 2: Dodola Junction – Goba

Central Region

i. Dera – Mechara Road Project, Contract 2: Magna – Mechara
ii. Modjo – Ijere – Arerti – Gobensa Road Project, Contract 2: Arerti – Gobensa
iii. Ziway – Butajira – Gubre Road Project, Contract 2: Butajira – Gubre
iv. Gindeber – Gobensa Road Project
v. Gedo – Bako – Nekempt Road Upgrading Project, Contract 2: Bako – Nekempt

Western Region

i. Tongo – Begi – Mugi Road Project, Contract 2: Gidami – Mugi
ii. Jimma – Mizan Road Upgrading Project
iii. Wacha – Maji Road Project

The data collected has been analysed using the original contract quantity/amount, the executed (revised) contract quantity/amount, variation occurred and reason for the variation, and is presented in section 3.3.1 of this report.

3.2.2 Collected Data on the currently used Site Investigation Technique for Estimation of Earthwork

Questionnaire has been prepared to be filled by some of the local consultants selected randomly who are currently participating in major contracts of road projects with Ethiopian Roads Authority. The questionnaire is distributed to Best Consulting Engineers, Beza Consulting Engineers and Architects, Core Consulting Engineers PLC, Engineer Zewdie Eskinder and Co. PLC, MH Engineering PLC, SABA Engineering PLC, Transport Construction Design Share Company and United Consultants.

The questionnaire includes some of the basic input for design of road as: the method/technique used by the consultant to calculate/estimate the volumes of soil and rock at deep excavations; whether the alignment soil extension report is used for the sub grade and earthwork volume determination or not; providing the maximum depth of test pits dug for the provision of soil extension; whether the soil extension provides the estimate of soil and rock excavations to the required degree of accuracy or not; and, if the soil extension survey couldn’t bring the required degree of accuracy, what methods do the consultant recommend for the relatively best accuracy of soil and rock excavation on road design. The questionnaires filled by the consultants are attached in Appendix C of this report.

The results are discussed in section 3.3.2 of this report.

3.2.3 Collected Data using Geophysical Investigation on Sample locations of Project Road

In order to have sufficient data for the study, records of design data of already designed road that is under construction are collected from reliable sources (Ethiopian Roads Authority and International and Local consulting offices). The site which is selected for the study is the Sawla-Maji road project; Lot I: Sawla-Laska. Records of the design data of the project is collected from the International Consulting Office, Finnroad Ltd and the local consulting office SABA Engineering PLC. Data verification or comparison at selected sections (deep cut sections) of the project road using geophysical investigation (seismic resistivity) in the field is performed from March 13 to

March 18, 2013. Vertical Electrical Sounding (VES) was used with a digital read out resistivity meter to acquire data in the area.

The stations selected for the test are heavy cut sections, which are not yet cut but will soon be cut. These stations are km 23+000 – 23+200 (average cut depth of 21 m), km 24+500 – 24+720 (average cut depth of 23 m) and km 33+000 – 33+140 (average cut depth of 17 m).

The resistivity data including the coordinates and elevations of electrode stations is shown in Appendix A.

Seismic refraction method would have been preferable for this particular study; however, since the depth of investigation is more than 15 m, which needs a seismic source of energy like explosive that wouldn't be affordable for this study, and the equipment wouldn't be easily available.

Therefore, Electrical resistivity method is selected for two reasons:

1. It can provide a subsurface geological succession, determining the thickness and nature of the overburden material and estimating the depth to the sound bedrock and the quality of the rocks as defined by their resistivity values, which is adequate for the study. Therefore, it may assist in supplying subsurface information indirectly, which are useful during the designing of the route.

2. It is easily available for the study of the thesis.

3.2.3.1 Instrumentation and Field Procedure

3.2.3.1.1 Instrumentation

The instrument used during the investigation was a portable integrated resistivity meter, known as SARIS (Scintrex Automated Resistivity Imaging System). It has a digital (LCD) readout and stacking features, powered by internal rechargeable 24V battery. The instrument is capable of making 2D resistivity (imaging) survey, and unlike the former resistivity instruments it calculates and displays the apparent resistivity values.

3.2.3.1.2 Field survey method and measurement procedure

The typical setup of a 2-D survey with 15 electrodes along a straight line using Wenner electrode arrangement is shown on Figure 1. The actual number of electrodes used is determined based on the actual profile length on the field. The spacing between the adjacent electrodes is "a"=10m. For the first measurement, the 1st, 2nd, 3rd and 4th electrodes are used. This is repeated down the line until

12th, 13th, 14th and 15th electrodes (the last measurement with “1a”=10m spacing) are used. Note that for a system of 15 electrodes there are 12 = (15-3) possible measurements.

After completing the sequence of measurements with “1a” spacing, the next sequence of measurement with “2a” spacing is made. For the first measurement the 1st, 3rd, 5th, and 7th electrodes are used because the spacing between them is “2a”. This process is repeated down until 9th, 11th, 13th and 15th electrodes (the last measurement with “2a”=20m spacing) are used. Note that for a system of 15 electrodes there are 9 = (15-2*3) possible measurements. The same process is continued for measurements with “3a”, “4a”, “5a” and “6a” spacing. When the electrode spacing increase, the number of measurements obtained are decrease. The degree of decrease depends up on the type of the array used.

Different arrays have their own advantage and disadvantage. The Wenner array is the robust array relatively sensitive to vertical changes (Griffith and Turnbull 1985, Griffith, Turnbull and Olayinka 1990). Many of the 2-D surveys were carried out with this array. Other common arrays used are Dipole-dipole, Schlumberger, Pole-pole, and Pole-dipole arrays.

In this particular case we use four electrodes by moving along the survey lines with a=10, 20, 30 & 40 meter and with 10 meter observation interval.

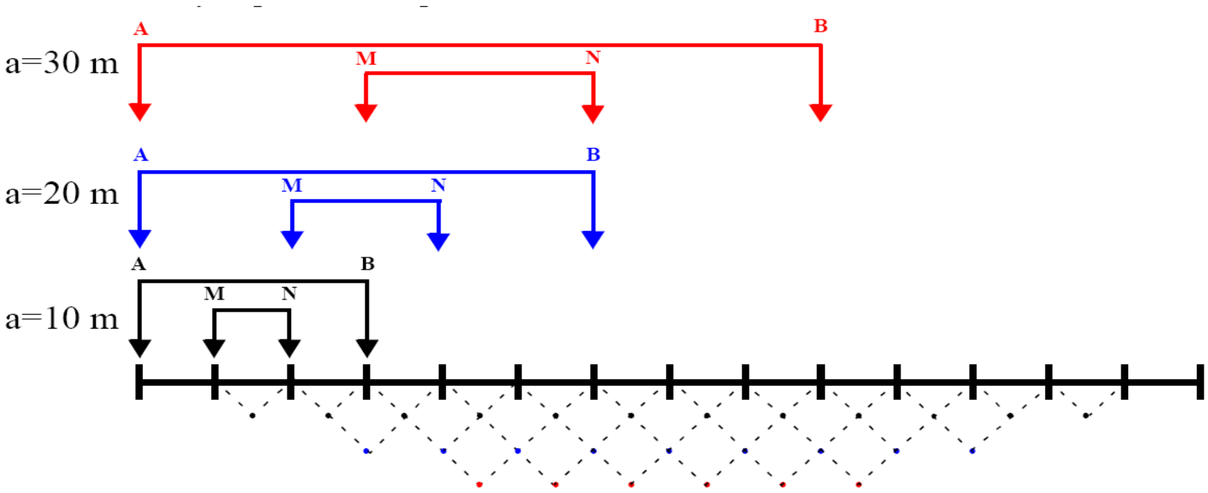


Figure 3-1: The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo-section.

3.2.3.2 Data Processing and Presentation

The data obtained from a 2-D imaging survey is plotted using the pseudosection contouring method. The horizontal location of the point is placed at the mid-point of the set of electrodes used to make the measurement (Figure 1). The vertical location of the plotting point is placed at the distance which is proportional to the separation between the electrodes. This plotting arrangement makes nearly 45˚ angle to the horizontal. This doesn't imply the current flow or isopotential lines have a 45˚ angle with the surface. The pseudosection gives a very approximate picture of the true subsurface resistivity distribution, and as an initial guide for further quantitative interpretation. Another practical application of the pseudosection plot is for pick out bad resistivity measurements manifested by extremely high or low values.

The location of the electrodes and apparent resistivity values must be entered into a text file which can be read by the RES2DINV program. To interpret the data from a 2-D imaging survey a 2-D model for the subsurface which consists of a large number of rectangular blocks is usually used. A computer program is then used to determine the resistivity of the blocks so that the calculated apparent resistivity values agree with the measured values from the field survey. The computer program RES2DINV.EXE will automatically subdivide the subsurface into a number of blocks, and it then uses a least-square inversion scheme to determine the appropriate resistivity value for each block. The median depth of investigation for the Wenner array is about 0.5 times the maximum "a" used.

3.3 Presentation and Discussion of Results

3.3.1 Analysis of data on the Projects that are Victim to Limited Site Investigation

In the construction of road projects in Ethiopia, one of the main factors for the delay and increase in cost of road construction projects is huge variation of earthwork item and quantities, which is mainly due to insufficient/limited geotechnical field investigation.

The following tables (Table 3.2a-d) present the variation of earthworks with the possible reasons, and the impacts of such variations are also shown.

The reason in almost all of the projects is soil/rock classification.

Table 3.2:

Three sample road projects are selected for discussion from the above tables (Tables 3.2a-d): Ziway – Butajira – Gubre Road Project, Contract 2: Butajira – Gubre, Gindeber - Gobensa Road Project and Wacha – Maji Road Project. The selection is made in order to show the different outcomes and the affected party. Note also that almost all the other projects fall in one of the three discussions.

3.3.1.1 Ziway – Butajira – Gubre Road Project, Contract 2: Butajira – Gubre

It can be seen from Table 3.2c that the quantity of soil excavation to be spoiled as per the design is 638,057.70 m^3; whereas the executed quantity of soil excavation is 1,765,727.68 m^3, which is increased by 176.73 % from the design quantity. In addition, the quantity of rock excavation to be spoiled as per the design is 1,577,337.84 m^3; whereas the executed quantity of rock excavation is 559,564.51 m^3, which is decreased by 64.52 % from the design quantity. The cause for such variation in this particular project is purely limitation of site investigation to the top 1.5m only. The total reduced contract value of the project due to this variation is Birr **85,403,400.21**, which is **13.4** % of the total original contract amount.

3.3.1.2 Gindeber - Gobensa Road Project

It can be seen from Table 3.2c that the quantity of soil excavation to be used for fill as per the design is 1,564,900.00 m^3; whereas the executed quantity of soil excavation to be used for fill is 230,265.27 m^3, which is decreased by 85.29 % from the design quantity. The total reduced contract value of the item due to this variation is Birr **57,562,795.90**, which is **7.62** % of the total original contract amount.

In addition, the quantities of soil, intermediate (material in between soil and rock, like highly weathered material) and rock excavations to be spoiled as per the design are 752,960.00 m^3, 2,425,825.00 m^3 and 0 m^3, respectively; whereas the executed quantities of soil, intermediate and rock excavation are 1,673,032.47 m^3, 3,546,781.64 m^3 and 271,023.88 m^3, respectively, in which the soil and intermediate excavations are increased by 122.19 % and 46.21 %, respectively from the design quantities while forced to add a new cost item and rate for the rock excavation. The major cause for such variation in this particular project is realignment of the route due to inadequate site investigation. In addition, classification of soil and rock due to limited site investigation to the top 1.5m only contributed for the variation. The total increased contract value of the project due to this variation is Birr **127,346,973.33**, which is **16.86** % of the total original contract amount.

3.3.1.3 Wacha – Maji Road Project

As can be seen from Table 3.2d, the quantity of soil excavation to be spoiled as per the design is 4,947,500.00 m^3; whereas the executed quantity of soil excavation is

9,646,049.74 m^3, which is increased by 94.97 % from the design quantity. In addition, the quantity of rock excavation to be spoiled as per the design is 674,600.00 m^3; whereas the executed quantity of rock excavation is 985,105.55 m^3, which also is increased by 46.03 % from the design quantity. The total increased contract value of the project due to this variation is Birr **112,928,820.71**, which is **20.04** % of the total original contract amount. The cause for such variation in this particular project, **from the technical audit report prepared by the design consultant, SABA Engineering PLC,** as per the request for clarification from Ethiopian Roads Authority, is presented as follows:

The estimation of quantity for earth work is very challenging. This challenge comes from sub-surface soil investigation whose scope is limited to 1.5 m depth. For a deep cut section the result of such limited investigation would leave designers to apply their engineering judgment. Thus the estimation of quantity for common and rock excavation is based on judgment and experience. The possibility of introducing errors in this regard is very clear. Thus we believe that Common and rock excavation should be considered in totality for the reason mentioned above.

In addition, we have attempted to find the reasons and found out that the following to be the main causes for the discrepancy:

1. *The discrepancy between the quantity given in the Bill of Quantity and the quantity that can be obtained from the drawings given in the design review stage*
2. *Change of back slope during construction stage from what has been given in the design review x-section*
3. *Centreline shifting in several locations during construction stage*
4. *Difference between natural ground given during design review stage and construction stage in some locations.*
5. *The data collection interval during the design stage and the interval applied for quantity computation during construction.*

The actual facts and their outcomes for each cause are elaborated in the technical audit report in detail.

As indicated above, one of and the main reason for such variation is limited site investigation. The technical audit also presents: *in several locations of the project where the excavation depth is significant and where cut benching is provided, the design review x-section indicates back slope of 1H: 2V where as these ratio is modified to 1H:1V in most of the cases during the construction stage, which is the right decision from stability point of view. This change has brought about significant quantity increment. In addition to this, the audit conducted on the sections which significantly contributed to the increased earthwork quantity, it was noticed that the construction of these sections was well carried out as per the approved templates. However most of the heavy cut sections, despite having rocky formations, were constructed with the requirement soil back slopes ratio.*

This shows how the limited site investigation makes the construction works so complicated.

The general outcomes of these variations, which may be for one or all of the three projects detailed above, include:

i. The contractor has entered in to the contract assuming the quantities in the contract are fairly good estimates and wouldn't expect a huge variation; and would prepare all the necessary resources (equipment, manpower and materials) based on these design quantities. Therefore, when such variation occurs, the contractor definitely claims and/or suffers of such variations.
ii. The first to be blamed, as per the trend now, for such cases is the design consultant, which may lead the design consultant to be accounted and punished. Though the design manual states that it is desirable to conduct specific test pits, borings, auger probes and/or geophysical investigations at deep cut sections, no provisional sum amount or other means of handling such investigations is provided in the Terms of References.
iii. The client (in this case, Ethiopian Roads Authority) will be in headache managing the problems and claims from such variations rather than engaged in other duties. This also will cause the client to budgetary problems and untrustworthiness on the design consultants.
iv. When the section in deep cut that is assumed to be rock is changed to soil, there will also be a back slope design change from (5:1 to 2:1 in rock) to (1.5:1 to 1:2 in soil) (V:H), which in turn increases the soil excavation volume.
v. When the section in deep cut that is assumed to be rock is changed to soil, it might be accompanied by slope stability problem, as the section is assumed to be rock no stability analysis would be performed during the design stage.
vi. The stipulated construction time in the contract document will not be enough, and will cause time and cost overrun.
vii. As the contractor is not aware of the rock excavation, equipment and/or material needed for the rock excavation should be mobilized (even it may need import of the equipment/material) to the site, which will cause time overrun.

3.3.2 Analysis of data on the Technique of Site Investigation

From the distributed questionnaire, which is filled by the local consultants, all the consultants have pointed that the currently employed site investigation technique is very limited. The filled questionnaires are summarized as presented in the following table:

Table 3.3: Summarized Table of Questionnaire

As can be seen from summarized table 3.3, all the consultants have pointed out that the soil extension survey with the test pit dug for a depth of maximum of 1.5 m couldn't provide the estimate of soil and rock excavation to the required level of accuracy.

The same table also shows that all the consultants, as expected, have the opinion that additional site investigation technique has to be employed for a better accuracy of earthwork volumes and sub-grade strength, though different techniques.

Knowing that the practiced site investigation technique has such limitations, all the concerned parties; the Ethiopian Roads Authority, the design consultants and the contractors are still using the same technique on the current ongoing design road projects.

3.3.3 Analysis of data from Site conducted using Geophysical Investigation

With the goal of mapping the bedrock-soil interface in mind, the P-wave refraction method would have been selected as being most appropriate and cost effective. As mentioned earlier, however, due to the unavailability of the equipment for this study, Seismic Resistivity has been selected.

As indicated in the manual '*Application of Geophysical Methods to Highway Related Problems, September 2003*', which was prepared in cooperative effort of the Central Federal Lands Highway Division (CFLHD) and Blackhawk GeoServices, Inc., USA, the resistivity method can be used to find bedrock depths if the overburden and bedrock have different resistivity, which is usually the case.

The measurement of resistivity, or more correctly apparent resistivity (since the value read may include several layers each with different resistivity), are measured using four electrodes placed into the ground. The electrodes are simply metal stakes about 0.3 m long that are hammered vertically into the ground.

Current is passed into the ground using the two electrodes labelled A and B. The voltage that results from this current is then measured using electrodes M and N. Using the amount of current passed into the ground along with the voltage and a geometric factor for the electrode layout, the resistivity of the ground is calculated. The electrode array is then expanded, making the current penetrate deeper into the ground and another reading is taken. This procedure is repeated for many electrode spacing, providing a set of resistivity values for different electrode spacing. The resistivity curve is interpreted using software that provides a resistivity model (depths and resistivity) whose resistivity calculations match the field data.

When the electrode spacing is small, the measured resistivity approaches that of the upper layer, and when the electrode spacing is large, the measured resistivity approaches that of the lower layer.

Performing a resistivity survey is a moderately labour-intensive procedure, largely because four electrodes have to be inserted into the ground at each station. The first step is to decide the electrode array dimensions to use. This will depend on the depth of investigation and on the geologic section.

Usually no processing of the data is needed. The resistivity data are plotted to form a pseudosection in which data from small electrode spacing are plotted near the top of the plot (ground surface), and data from the large electrode spacing are plotted some distance vertically beneath the surface line, thus simulating a plot of resistivity against depth for the whole traverse.

Interpretation of the data is usually done with resistivity modelling software, which produces a plot of the interpreted resistivity against depth. The resistivity of the soil and the rocks determines the expected contrast. Usually, air-filled voids in the soil will have a higher resistivity than the rocks. However, if the voids in the soil are water-filled, its resistivity may be similar to that of the rocks.

Unlike the seismic refraction method, which requires that each successive layer have a higher velocity, the resistivity method works whether the deeper layers become more or less resistive. However, because electrodes need to be placed in the ground, the method is difficult to use in areas where the surface of the ground is hard, such as concrete or asphalt-covered areas. In addition, if the ground is dry, water may need to be poured on the electrodes in order to improve the electrical contact between the electrode and the ground. Generally, the separation between the current electrodes will need to reach a maximum of about three times the investigation depth. Thus, if the bedrock is 15 m deep, the current electrodes will need to be spaced up to 45 m apart. Lateral variations in resistivity can affect the accuracy of the depth interpretation, or grounded metal objects near the sounding site may also influence the data.

Usually little data processing is applied to the data, apart from removing any bad data points.
Data from the conducted resistivity systems are interpreted by using software that calculates the theoretical resistivity data from a resistivity/depth model, thus enabling a model to be developed that produces data that matches the field data, a process called inversion.

Resistivity method of geophysical site investigation technique is conducted at selected stations of Sawla-Maji road project, Lot-I: Sawla-Laska section. The stations at km 23+000 – 23+200, km 24+500 – 24+720 and km 33+000 – 33+140, from the design document of the project road, are accompanied by deep cuts of average depths 21 m, 23 m and 17 m respectively.

3.3.3.1 Station km 23+000 – 23+200

Mineral grains comprised of soils and rocks are essentially nonconductive, except in some exotic materials such as metallic ores; so the resistivity of soils and rocks is governed primarily by the amount of pore water, its resistivity, and the arrangement of the pores. To the extent that differences of lithology are accompanied by differences of resistivity, resistivity surveys can be useful in detecting bodies of anomalous materials or in estimating the depths of bedrock surfaces. Generally, since the resistivity of a soil or rock is controlled primarily by the pore water conditions, there are wide ranges in resistivity for any particular soil or rock type, and resistivity values cannot be directly interpreted in terms of soil type or lithology. Commonly, however, zones of distinctive resistivity can be associated with specific soil or rock units on the basis of local field or drill hole information, and resistivity surveys can be used profitably to extend field investigations into areas with very limited or nonexistent data. Also, resistivity surveys may be used as a reconnaissance method, to detect anomalies that can be further investigated by complementary geophysical methods and/or drill holes.

Although the resistivity of materials can be a good indicator of the type of subsurface material present, it is not a unique indicator. While the resistivity method is used to measure the resistivity of earth materials, it is the interpreter who, based on knowledge of local geologic conditions and other data, must interpret resistivity data and arrive at a reasonable geologic interpretation.

Materials with either a low effective porosity or that lack conductive pore fluids have a relatively high resistivity (>1000 Ωm). These materials include massive lime stones, most unfractured igneous rocks and unsaturated unconsolidated materials.

Materials that have high porosity with conductive pore fluids or that consist of or contain clays usually have low resistivity. These include clay soil and weathered rock. Materials whose pore water has low salinity have moderately high resistivity.

If the area was saturated, particularly at greater depths where there is no option of visualization, then the resistivity contrast with the host rocks will likely be smaller. This problem can be solved by conducting Seismic Refraction technique of geophysical investigation.

From the geological map of Ethiopia shown in figure 4 of Appendix D, the project area is characterized predominantly by Cenozoic volcanic and subordinate Quaternary superficial deposits. The Cenozoic volcanic rocks (Pjb and Pjr) are represented by thick succession of basalt, rhyolitic and trachytic domes and flows. The Quaternary superficial deposits are characterized by clay, silt, sand, and gravel mixed in various proportions.

Consequently, as shown in the resistivity pseudosection in figure 3-2 below, the resistivity contrasts between different layers are shown as contour-colored image. The bluish portion, that is the topsoil consisting mainly of silty sandy CLAY as confirmed on the test pit log of the project, shows zone of low resistivity. This portion extends to an approximate depth of 8-10 m. When conducting the site geophysical investigation, it was raining on the project area. Thus, the top portion was wet, which contributed for the low resistivity. The rest portion is also characterized by low resistivity, which will be wet to moist clayey sand/ Gravel or highly weathered rock.

However, this analysis at some point contradicts with the assumption made by the design consultant. The design consultant assumed from the geology of the area using geological map and visual assessment that, at approximately 15 m depth a hard rock will be encountered on this section of the project road, which is not the case in the above analysis from the geophysical investigation.

As per the confirmation received from SATCON Construction PLC project office, the excavation work at this station is executed and rock is not encountered to the entire depth of the cut section, which resembles the result found from Electrical Resistivity Survey conducted at the site.

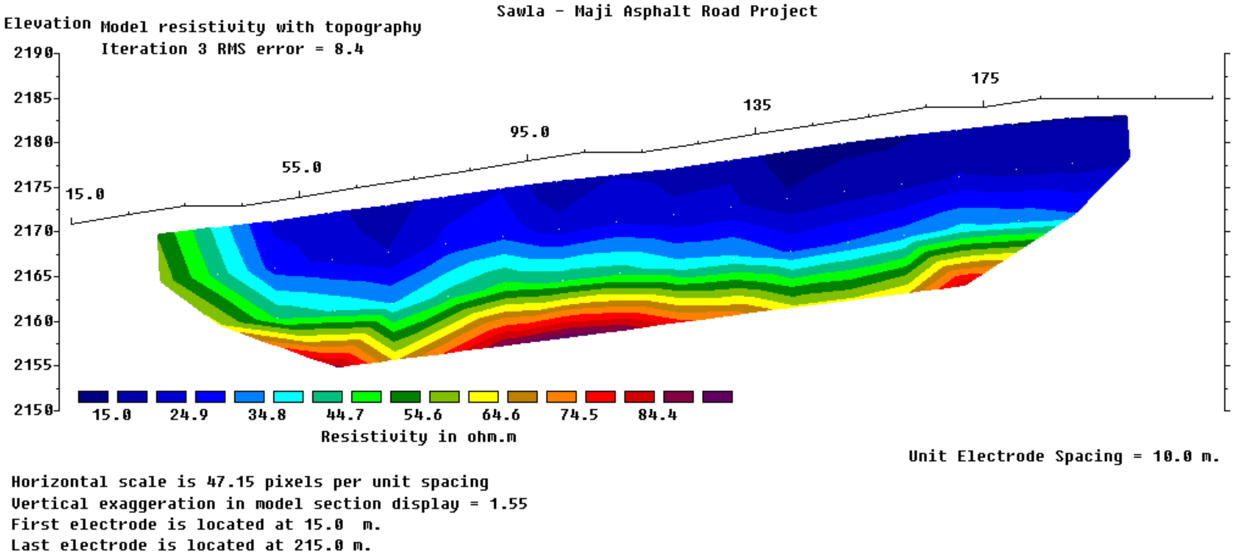


Figure 3-2: Resistivity result at Station 23+000-23+200

3.3.3.2 Station km 24+500 – 24+720

As shown in the resistivity pseudosection in figure 3-3 below, the physical properties of the soil of this stretch have erratic nature though all with low resistivity values. From the information received from the local people, there is spring water on the locations indicated in the pseudosection with blue. Therefore, since the whole portion is characterized by low resistivity, it will be wet to moist clayey sand/ Gravel or from highly weathered rock at the top to slightly weathered at the end of investigated depth.

However, this analysis at some point contradicts with the assumption made by the design consultant. The design consultant assumed from the geology of the area using geological map and visual assessment that, at approximately 15 m depth a hard rock will be encountered on this section of the project road, which is not the case in the above analysis from the geophysical investigation.

As per the confirmation received from SATCON Construction PLC project office, the excavation work at this station is executed and rock is not encountered to the entire depth of the cut section, which resembles the result found from Electrical Resistivity Survey conducted at the site.

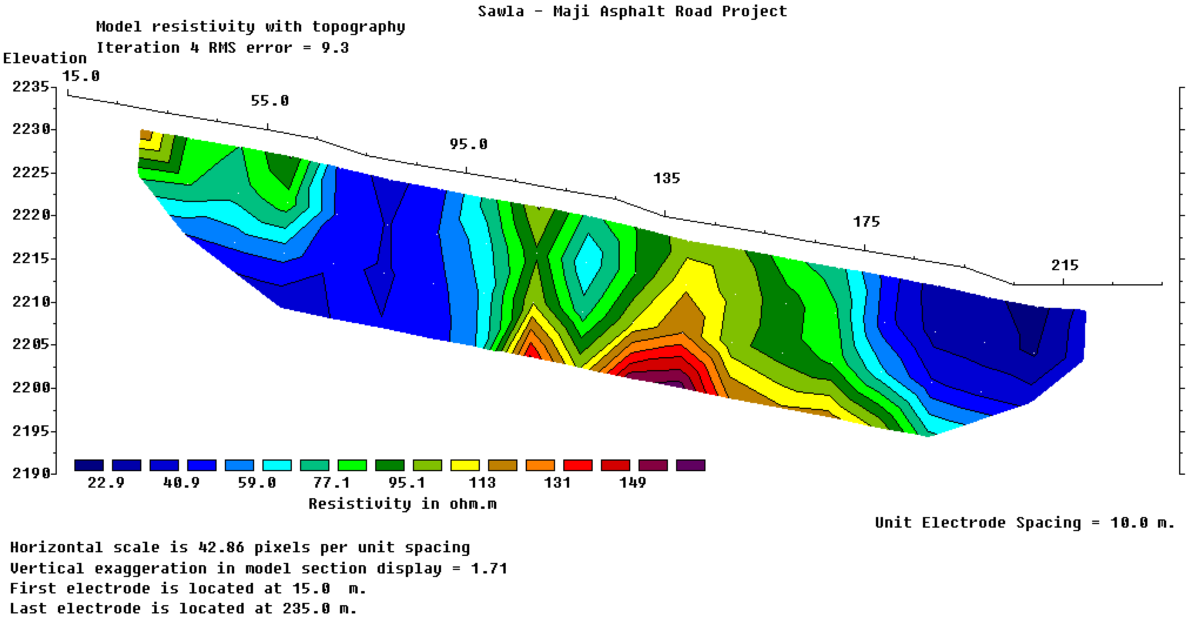


Figure 3-3: Resistivity result at Station 24+500 – 24+720

3.3.3.3 Station km 33+000 – 33+140

As shown in the resistivity pseudosection in figure 3-4 below, the bluish portion, which is the whole investigated depth (approximately 20 m) soil, consists mainly from silty CLAY as confirmed on the test pit log of the project to wet to moist Clayey Sand/ Gravel or highly weathered rock, shows zone of low resistivity. When conducting the site geophysical investigation, it was raining the previous day on the project area. Thus, the top portion was wet, which contributed for the low resistivity.

However, this analysis at some point contradicts with the assumption made by the design consultant. The design consultant assumed from the geology of the area using geological map and visual assessment that, at approximately 12 m depth a hard rock will be encountered on this section of the project road, which is not the case in the above analysis from the geophysical investigation. From the previous two sections results, it can also be concluded that rock would not be encountered to the entire depth of the cut section, which would resemble the result found from Electrical Resistivity Survey conducted at the site.

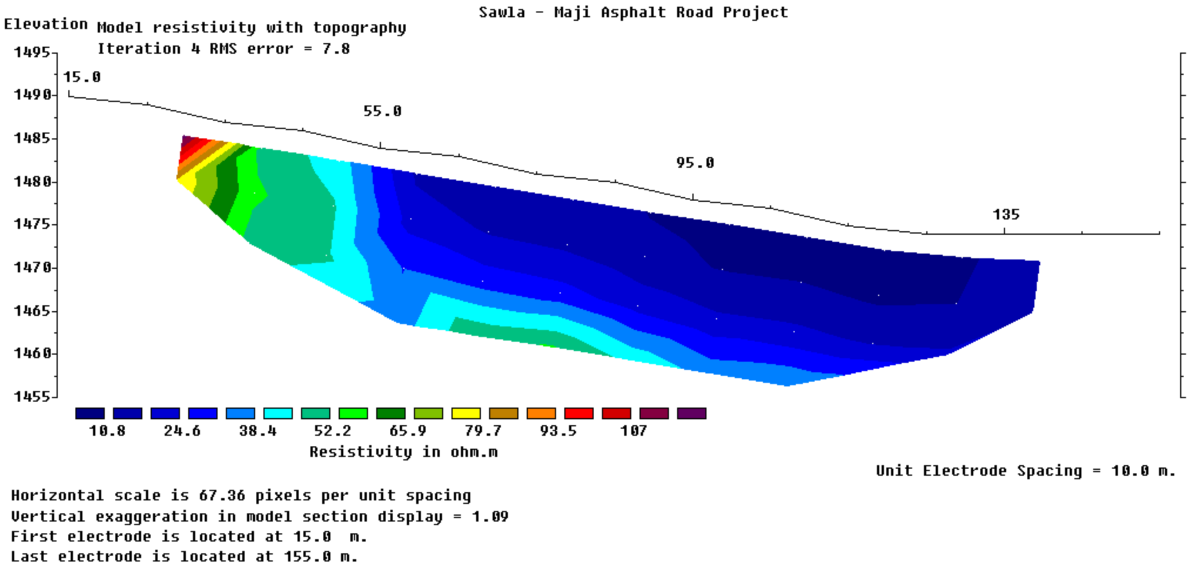


Figure 3-4: Resistivity result at station 33+000 – 33+140

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Earthworks always form a significant part in the cost of road construction, as even a simple road in flat terrain involves the excavation of ditches, and the formation of a small embankment. When the terrain is not flat, cuttings are required, and their design can greatly affect the cost of earthworks.

In developing countries, geotechnical investigations for roads are usually limited to shallow sub-surface exploration using manual excavation and hand-portable equipment. Specialist drilling investigations are usually only cost-effective and practicable at major bridge sites.

The aim of geotechnical investigation is to convey information on surface and sub-surface ground conditions (so far as they can be ascertained) sufficient to satisfy the requirements for preliminary and/or detailed design, while avoiding expensive ground investigation.

Considering the erratic nature of the subsurface on some locations and homogeneity on another location of a country, let alone digging test pits 1.5 m below the natural ground level for the entire alignment of the road to be designed including deep cut sections, specifying a minimum standard spacing of test pits is uneconomical and not logical.

Based on the results found from the data presentation and discussion, it is observed that lack of detailed site investigation using appropriate method caused major cost overrun and delays in several road projects.

This practice will leave clients for untrustworthiness of the design documents and the consulting offices, and punishing them of their performances. However, punishing the consulting offices wouldn’t be the prime solution though it flares some awareness.

The burden of these additional costs can fall on several parties, including owners, engineering design firms, and construction contractors.

From the points stated in the manuals/ publications reviewed, it can be understood that the necessary investigations are discussed in all the manuals; however, the problem lies on the application of the manual.

Geophysical surveys can offer considerable time and financial savings compared with borehole investigations. Furthermore, site access is usually easier and the work causes less damage to the site surface. At an early stage of site investigation, it may be beneficial to undertake a reconnaissance geophysical survey to identify areas of the site which should be investigated by drilling, if any, i.e. those where anomalous results are obtained. Alternatively, geophysical surveys can be used to interpolate between test pits and boreholes after detail site investigation. Further geophysical surveys, both within and between the boreholes and on the ground surface, can be used to determine the geological and geotechnical properties of the ground mass in which the engineering construction is taking place.

Broadly speaking, geophysical surveys are used in one of three roles:

1. To allow a choice to be made rapidly and economically between a number of alternative alignments for a proposed project, prior to a detailed design.

2. To complement a programme of drilling and trial pits as part of the detailed site ground investigation at the chosen site.

3. To assist in mapping areal extent, evaluating variations in soil and rock properties, to interpolate between test pits and boreholes, to map soil horizons, stratification, depth profiles & depth to bed rock.

4.2 Recommendation

Subsurface investigations require use of equipment to gain information below the ground surface. Most of these exploration techniques are relatively expensive and, therefore, should be carefully planned and controlled to yield the maximum amount of information possible. The quality of the information produced can vary significantly. If procedures are not followed carefully and data not interpreted properly, radically different conclusions can be reached. For example, poor drilling techniques could produce samples that might yield lower strength values. Therefore, only competent, senior geotechnical personnel should be charged with planning a subsurface investigation, and only qualified geotechnical professionals and technicians should do the pitting and data collecting, reducing, analyzing, and interpreting.

1. The client shall take the leading role in minimizing such discrepancies by using:

   i. Before floating the road project for design, the client, by its own Engineers shall conduct a site visit in order to preliminarily point out the necessary investigations to be carried out during the design stage for the TOR.
   ii. A guideline procedure of the geotechnical investigation required, which incorporates the necessary minimum investigations need to be carried out for the specific assignment/ project, shall be included in the TOR. A plan of the site investigation technique to be applied can be prepared/ revised by the consultant for the client's approval after reconnaissance survey is conducted.
   iii. In the TOR, the client should specifically determine the necessary investigations to be carried out, such as for the need of drilling and/or geophysical investigations by putting a provisional sum amount specifying the purpose of the same.
   iv. Building the capacity of the Client's, consultant's and contractor's professionals, and knowledge transfer between them (by presentation of the services accomplished). The

capacity building of the professionals can be achieved by providing them with further education, workshops, etc.

v. By taking in to account the extent of work to be performed, since the allocation of design time for a project, and allotted time for a geotechnical engineer in the design time are usually undermined by the client, it is recommended to be given serious attention.
vi. To include Engineering Geophysist with the required man-month in the key personnel of the design work.

2. The design consultant should take the full responsibility of the site investigation by using the guideline prepared by the client. The consultant should also be responsible for modifying the guideline to be fit with the specific project, in consultation with the client.

   The consultant should also be responsible to perform the site investigation using his experience and different methodology to the best accuracy required for the design.

   To further reduce the risk, the consultant should also go beyond presenting raw data by preparing to include a Geotechnical Report.

Engineering geophysics should be considered as a cost effective means to reduce the exposure of responsible parties to financial risk. When used in conjunction with test borings, trenching and soil testing, the combined knowledge and resulting geologic picture can be used to avoid costly mistakes, and provide the information needed for better designs.

In addition to aiding engineering design, the geophysical interpretation leads to a better understanding of hazards that may exist, such as the risk of landslides.

Employing an engineering geophysist to work with the design team at the beginning of the investigation enables the team to learn from each other to the project's continuing benefit. This helps to prevent mistakes, rather than seeking advice when things go wrong. With the engineering geophysist on the design team from the start, the risk of adopting an unsuitable technique diminishes as each stage of the work progresses. This does not imply continual involvement, which would generally be unnecessary and certainly expensive, but access to an engineering geophysist on a when-required basis. This can be a cost-effective solution and the choice of such a person is critical.

All projects ought to begin with a desk study at the feasibility stage. In too many cases there is no desk study, or it is prepared inadequately. A desk study can have several purposes, but it is usually focused specifically on a particular construction project. It should present a summary of the historical development of the site. The study should collect together the geological, hydrogeological and geotechnical information about the site and its surroundings. This should include reference to the most recent, largest scale geological plan of the area and to other information held by the Geological Survey. It should identify the likely implications of the ground and groundwater conditions for the design and the construction of the project, as well as the impact of the project on the adjacent area.

Thus, by studying the area of interest with respect to the required subsurface investigation, planning an exploration technique on a sound geotechnical basis using the test pits supplemented by geophysical technique would bring cost effective result with better accuracy.

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Appendices

Appendix A

Data Collected from Site

Appendix B

Data Collected from Ethiopian Roads Authority

Appendix C

Questionnaire filled by Consultants

Appendix D

Geology of Project Area

Appendix E

Photographs

Submitted By

______________ ______________

Signature Date

Approved By

1. Samuel Tadesse (Dr.-Ing.) ______________ ______________

Advisors Signature Date

2. ______________________ ______________ ______________

Chairman, Dept.'s Signature Date

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Associate Dean's
for Research & Graduate Signature Date