SUPPLEMENTING CONVENTIONAL SITE INVESTIGATION TECHNIQUES OF EARTHWORKS AND SUB-GRADE SOILS WITH GEOPHYSICAL INVESTIGATION IN ROAD DESIGN

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ABSTRACT

In the construction of road projects in Ethiopia, one of the main factors giving rise to significant delays and both increases and decreases in project cost is the huge discrepancy in earthworks quantities between the design and the construction phases. This causes budgetary uncertainties and questioning of design documents. The aim of this paper is to assess the benefits of geophysical investigations in reducing the earthworks discrepancies.

Records have been collected of projects at the design stage and projects under construction, particularly drawing on information along sections of deep cut. The findings from three projects are discussed in detail and geophysical investigations have been undertaken in the field along three sections of a selected project to allow reassessment of earthworks quantities.

It is concluded that lack of detailed site investigation is a major reason for cost imprecision and delays in several road projects as a result of discrepancies in earthworks quantities. It is further concluded that careful planning and implementation of ground investigations supplemented with results from a geophysical investigation would yield cost effective results and reduce the uncertainties by greatly improving earthworks predictions at the design stage.

Key Words: Earthwork, Sub-grade, Geophysics, Site Investigation

INTRODUCTION

Because of Ethiopia's economic status, it has been categorized among the highly indebted poor countries (HIPC). In order to effectively tackle poverty, the improvement of infra-structure, transportation, and communications within the country, the construction and improvement of roads has become one of the major objectives of the Ethiopian Government since the mid-1990s.

The Ethiopian Highlands form the largest continuous area of mountainous terrain in the whole continent, with little of its surface falling below 1500m, while the summits reach heights of up to 4550m. The Ethiopian Plateau, which occupies 66% of the land, consists of a central area that is bisected by the Great Rift Valley to the west and the Somali Plateau to the east. Constructing roads in such rugged mountainous terrain necessitates large volumes of earthworks. Adopting appropriate field geotechnical investigation techniques is essential to economic design and construction. Geophysical investigation is one such tool that allows exploration of the subsurface environment (strata sequence, material type and thickness) at minimum cost.

In the design of roads in Ethiopia, the scope of site investigation for earthworks and sub-grade soils is usually limited to test pits dug to not more than 1.5m below natural ground level. For deep cut sections, the result of such limited investigation leaves designers with no option but to apply their engineering judgment. Thus the estimation of quantity for soil and rock excavation is frequently assessed from the known geology of the area, surface observations and experience. The possibility of introducing errors in this regard is evident.

While it must be recognised that the value of a clear, visual examination of the ground in trial pits and boreholes should not be underestimated, geophysical investigations, particularly in areas of deep cut, provide valuable supplementary data below and between intrusive investigation points. The benefits of using geophysics in reducing uncertainties in earthworks quantities, particularly in soil and rock cut quantities, and reducing overrun in project costs, is the subject of this paper.

GROUND INVESTIGATION TECHNIQUES AND APPROACHES

Data on earthworks on a number of road projects have been collected and analysed with the aim of identifying whether current site investigation practice in Ethiopia is adequate for the proper design of roads, or whether the projects would have benefited from a geophysical investigation.

A geophysical investigation is recognised in earthworks manuals around the world as a useful indicator of the strata to be exposed in excavation operations, particularly when used in conjunction with geological input from intrusive test pits and boreholes. There are a number of geophysical techniques of investigation available, all with different efficacies in different situations, but they are generally recognised as a fast and economical investigation technique, which is applicable to both soil and rock. But it is not an approach currently employed in Ethiopia in the design of roads. Developed countries use geophysical techniques regularly as an integral part of detail site investigation to assist in mapping the extent of strata and evaluating variations in ground properties, as well as providing a useful guide in determining where more detailed investigation by boring or test pitting would be warranted.

The manuals and publications reviewed (Ref 5, 8 to 11), including the Ethiopian Roads Authority Site Investigation manual, state that the depth of any test pit for determination of sub grade strength should be to at least below the design sub grade level. In practice, in Ethiopia, pits are usually taken to 1.50m depth along the line of the proposed road. Frequently only a single phase of investigation is carried out, often prior to the final road alignment being determined. Accordingly, where deep cuttings are proposed, the investigation gives no indication of the materials likely to be encountered between the base of the investigation and the proposed formation level. Such investigations frequently lead to disputes and claims with delays in earthworks operations.

There are also wide disparities in the different manuals and publications on the appropriate spacing of test pits along the alignment of a road for sub grade strength determination, earthwork classification and quantity determination. Here filling the gaps between intrusive investigation positions using geophysics would also be of value.

The aim of geotechnical investigation is to convey information on surface and sub-surface ground conditions sufficient to satisfy the requirements for the design. While there is inevitably a requirement to avoid excess cost associated with unwarranted investigation, it is generally recognised that savings associated with limiting a ground investigation are relatively small in relation to the costs associated with claims for unexpected and adverse ground conditions that may necessitate amendments to the design. In more developed countries, investigations are frequently carried out in stages generally in accordance with the following, though the terminology may differ:

- Desk Study with a walk over survey to identify the geology and appropriate locations and frequency of boreholes and trail pits, as well as the appropriate investigation equipment and access requirements.
- A tertiary investigation that hopefully proves sufficient for the design of the works.
- Supplementary investigation(s) where there are still uncertainties in relation to the design and strata to be encountered.

Within this context, geophysical investigations can play an important role at either the preliminary or subsequent investigation stages and are recognised as frequently saving in the scale of intrusive investigation and accordingly saving costs.

DATA COLLECTION AND DISCUSSION ON FINDINGS

The following outlines were used for the research strategy:

- Collection of data from a number of road projects that appear to have been the subject of inadequate site investigation, and where there has been significant cost divergence between the design and construction stages.
- Collection of data on current site investigation approaches in determining earthworks quantities.
- Collection of supplementary data using geophysical investigation at three deep cut sections on a selected road project to show how there can be a significant improvement in the assessment of earthworks quantities.

Collected Data from Road Projects

Records of thirteen substantially completed road projects, or ones where earthworks operations were substantially complete, have been studied. An assessed of the earthworks quantities and item costs at the beginning and end of the projects have been obtained from the Ethiopian Roads Authority. The projects are roads that the Ethiopian Roads Authority has had to pay variation amounts through the contract because of differences between earthworks quantities predicted from the site investigation and the actual conditions encountered. Of the thirteen projects studied, three sample road projects (discussed below) have been selected for detailed discussion. Of note is that almost all the remaining projects studied comply closely with one or other of the three sample projects.

Sample Project 1: Ziway – Butajira – Gubre Road Project, Contract 2: Butajira – Gubre

The quantity of soil to be excavated and taken to spoil as per the design was 638,058m^3; whereas the quantity of soil actually excavation was 1,765,728m^3; an increase of 176.7% from the design quantity. In addition, the quantity of rock excavation as per the design was 1,577,338m^3; whereas the quantity of rock excavation was 559,565m^3; a decreased by 64.5% from the design quantity. The cause for such a large variation in quantities was purely due to the limitation of the site investigation depth to 1.5m. The total reduced contract value of the project due to this variation was Birr 85,403,400, which is 13.4% of the total original contract value.

Sample Project 2: Gindeber - Gobensa Road Project

The quantity of soil excavation to be used for fill as per the design was 1,564,900m^3; whereas the quantity of soil excavated and used for fill was 230,265m^3; a decreased of 85.3% from the design volume. The total reduced contract value of the item due to this variation was Birr 57,562,796, which is 7.6% of the total original contract amount.

In addition, the quantities of soil, intermediate material (material between soil and rock) and rock excavated and to be taken to spoil as per the design were 752,960m^3, 2,425,825m^3 and zero respectively. The actual executed quantities of soil, intermediate material and rock excavation were 1,673,032m^3, 3,546,782m^3 and 271,024m^3 respectively. The soil and intermediate material excavated showed an increase of 122.2% and 46.2%, respectively from the design quantities, while it was necessary to add a new cost item and rate to the contract for the rock excavation. The major cause for the large variations in earthworks quantities for this project was realignment of the route due to inadequate site investigation prior to the design. The investigation was limited to 1.5m depth in areas of cut. The total increased contract value of the project due to the variations was Birr 127,346,973, which is 16.9% of the total original contract value.

Sample Project 3: Wacha – Maji Road Project

The quantity of soil excavated and to be taken to spoil as per the design was 4,947,500m^3. The actual quantity of soil excavated was

9,646,050m^3; an increase of 95.0% from the design volume. In addition, the quantity of rock excavation to be taken to spoil as per the design was 674,600m^3; whereas the executed quantity of rock excavation was 985,106m^3, an increase of 46.0% from the design quantity. The total increased contract value of the project due to the variations was Birr 112,928,821. This was 20.0% of the total original contract value. The Ethiopian Roads Authority requested a Technical Audit Report from the design consultant to identify the reasons for the cost overrun. The report blamed the inadequate estimation of quantities on the limited depth of investigation of 1.5m in areas of deep cut and the need to assess the quantities based on judgement; the change of back slope during the construction stage from that of the design due to variation in strata encountered; centreline shifting at several locations during the construction stage as the design was adjusted; and discrepancies in natural ground levels.

Uncertainties and Problems with Current Practices

Inadequate ground investigation is a prime cause of the earthworks quantity disputes and the cost variations encountered in the highway projects studied. This is the view of both consultants and contractors and a conclusion of this paper. 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 allowed for in the contract or terms of reference. Current practice of excavating pits to only 1.5 m depth in areas where deep cuts are proposed leads to a design based on inadequate geotechnical information. Accordingly quantities of earthworks materials to be excavated and handled have to be modified and designs have to be significantly changed as work progresses.

In areas of deep cut, slope inclinations in rock and soil have to be modified, roads realigned, sub grade strength re-evaluated and delays ensue. The contractor is forced to modify his approach to excavation, construction plant employed and staffing. The Ethiopian Roads Authority is left uncertain of financial requirements and contracts are fraught with disputes and claims.

Collected Data using Geophysical Investigation

The site selected for the geophysical study was the Sawla-Maji road project; Lot I: Sawla-Laska. Existing data was collected for three selected sections of deep cut and geophysical investigations (seismic resistivity) carried out in the field over a period of 5 days in March, 2013. Vertical Electrical Sounding (VES) was used with a digital read out resistivity meter to acquire data in the area. The approach allows the subsurface geological succession to be assessed including the thickness and nature of the overburden material; the depth to sound bedrock; and the quality of the rocks as defined by its resistivity values.

Interpretation of the data was carried out with resistivity modelling software, which produces a plot of the interpreted resistivity against depth. The resistivity of the soil and the rocks determines the response contrast though errors can occur. Usually, air-filled voids in a soil have a higher resistivity than rock. However, if the voids in the soil are water-filled, its resistivity may be similar to that of rock. Materials with either a low effective porosity or lack of 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.

The resistivity approach was employed at the following three selected stations of the Sawla-Maji road project, Lot-I: Sawla-Laska section:

km 23+000 – 23+200; km 24+500 – 24+720; and km 33+000 – 33+140. These are the design document designations for the project road and are areas of deep cut of average depths 21m, 23m and 17m respectively.

Published geological information for the areas of geophysical investigation indicates that it is characterized predominantly by Cenozoic volcanic and subordinate Quaternary superficial deposits. The Cenozoic volcanic rocks (Pjb and Pjr) are represented by a 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.

Station km 23+000 – 23+200

As shown in the resistivity pseudo section in Fig.1, the resistivity contrasts between different layers are shown as contour-colour horizons. The bluish portion, that is the upper layers, consists mainly of silty sandy CLAY, as confirmed on the test pit log for the area, and is a zone of low resistivity. This portion extends to an approximate depth of 8-10m.

Rain at the time of the geophysical investigation is considered to have contributed to the wetness of the soil and the low resistivity. The remainder of the section is also characterized by low resistivity and is interpreted as comprising wet to moist clayey sand/gravel or highly weathered rock.

The design consultant assumed from the published geology of the area and visual assessment that at approximately 15 m depth hard rock would be encountered. This is not the case indicate by the geophysical investigation and was not the case encountered during excavation which complied with the results from the geophysical survey.

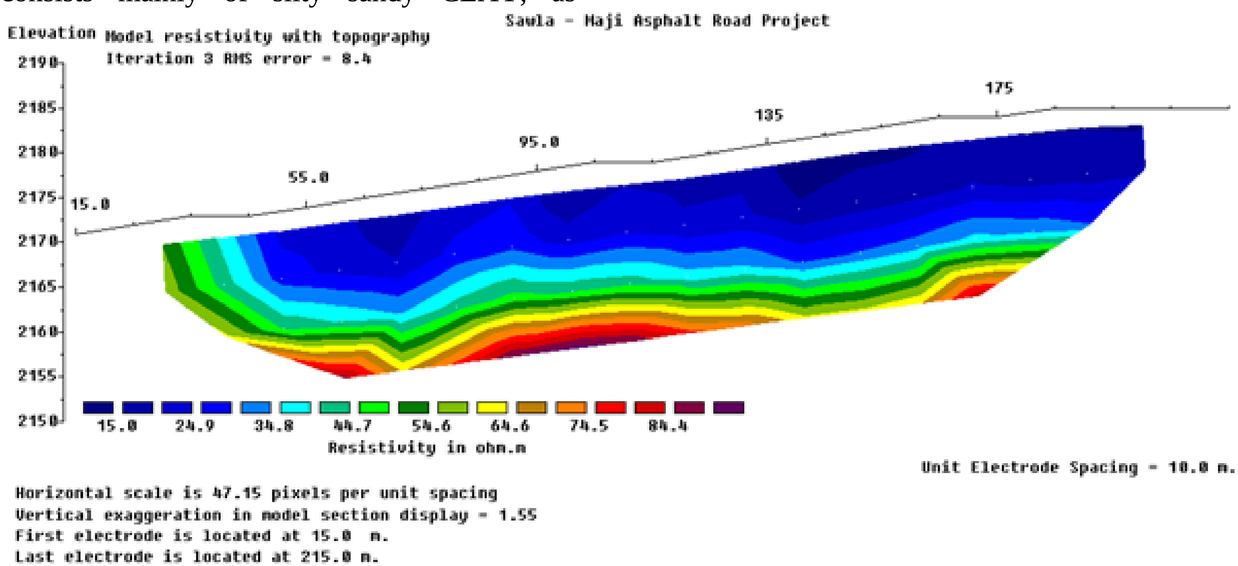

Fig. 1: Resistivity Result at Station 23+000-23+200

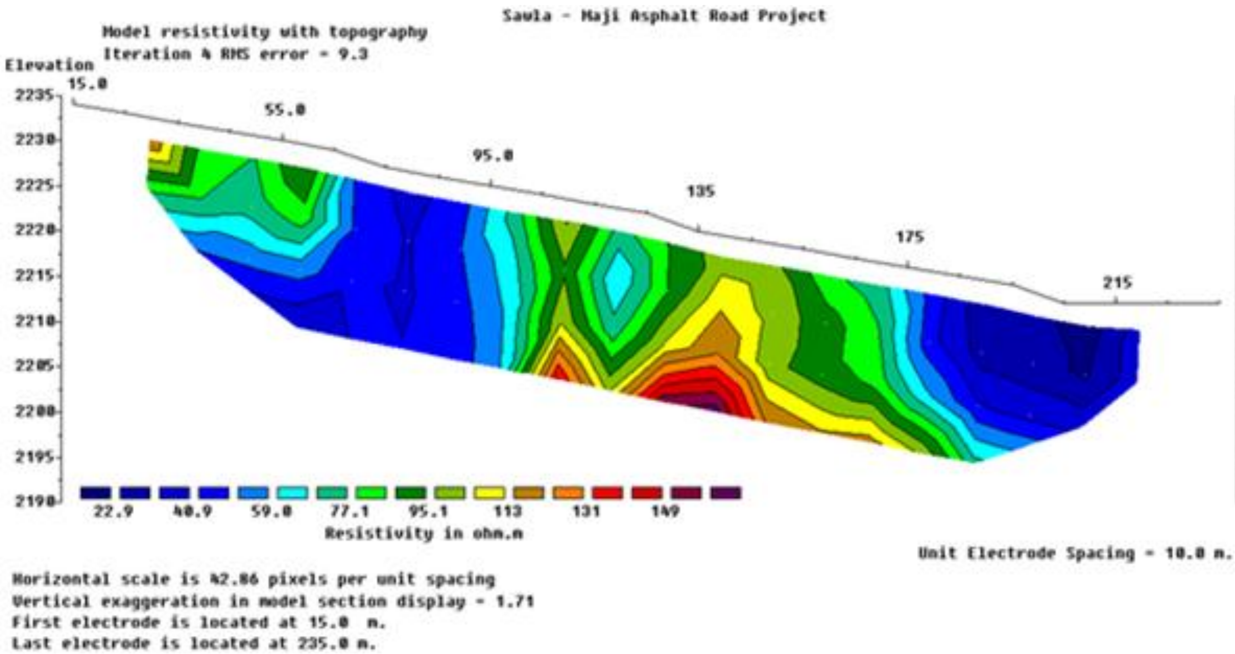

Fig. 2: Resistivity Result at Station 24+500 – 24+720

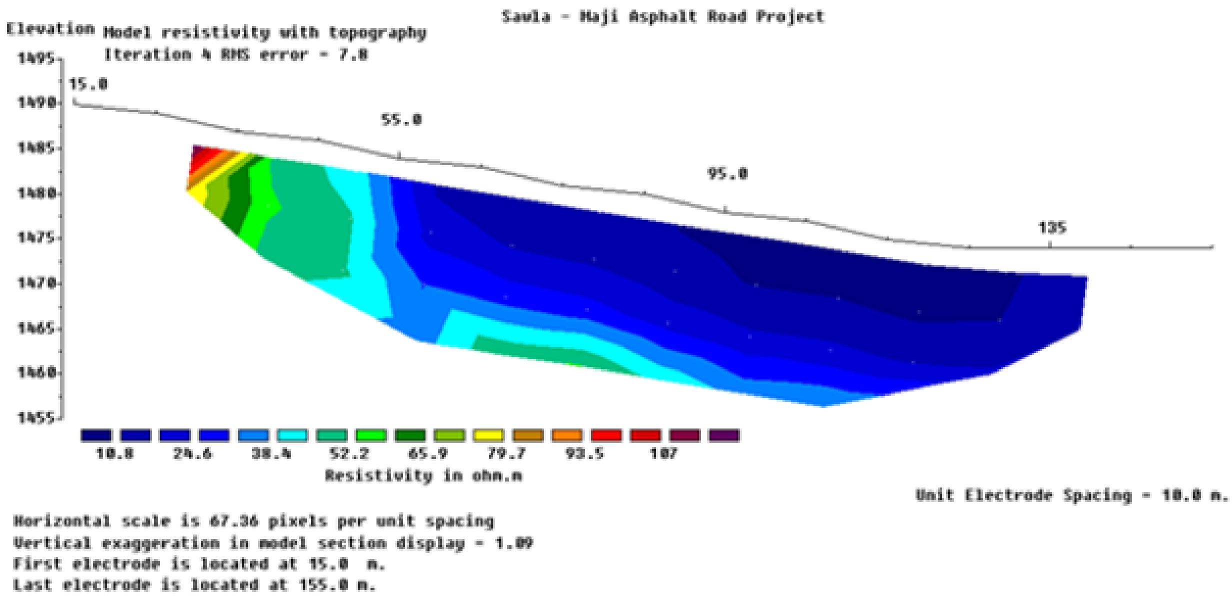

Fig. 3: Resistivity Result at Station 33+000 – 33+140

Station km 24+500 – 24+720

As shown in the resistivity pseudo section in Fig.2, the physical properties of the soil have an erratic nature though all have a low resistivity. Local information suggests spring water in this location consistent with the blue, low resistivity, on the pseudo section. The whole section is characterized as wet to moist clayey sand/gravel or highly weathered rock, giving way to slightly weathered rock at depth.

The design consultant assumed from the geology of the area that, at approximately 15m depth hard rock would be encountered. The results from the geophysical analysis have been confirmed by excavation of the cutting which did not encounter rock.

Station km 33+000 – 33+140

As shown in the resistivity pseudosection in Fig. 3, the bluish portion, which extends to the whole investigated depth (approximately 20 m), is a zone of low resistivity. This is interpreted as a silty clay (confirmed by a test pit log in the area), on wet to moist clayey sand/gravel or highly weathered rock, When conducting the site geophysical investigation, it rained the previous day contributing to the low resistivity.

The design consultant assumed that at approximately 12m depth hard rock would be encountered. This was not the case suggested by the geophysical investigation.

CONCLUSIONS

Earthworks generally form a significant component in the cost of road construction projects, particularly when the terrain is undulating or mountainous.

The findings of this study in the highlands of Ethiopia confirm the importance of detailed and appropriate site investigation and the significant cost implications associated with earthworks quantities, redesign, road re-alignment and delays if the investigation is inadequate. The supplementing of traditional investigation techniques of boreholes and trial pits with geophysical investigation offers the following benefits and advantages:

- The approach is quick and offers considerable financial savings compared with more conventional intrusive investigations.
- It may be used within a staged programme of investigation to maximise the information obtained at the chosen site.
- It can be used to identify anomalies and areas of uncertainty where targeted intrusive investigation would be of benefit.
- It can be used to interpolate between test pits and boreholes and below the depths penetrated.
- It allows the mapping of the areal extent of both soil and rock horizons, the evaluation of strata variations and properties, stratification, anomalous ground conditions and depth to bedrock.
- It may be used as an economic aide in the investigation of a number of alternative routes or alignments prior to detailed design.

An appraisal of various road projects with significant cost variations between the design and construction stages has been made. The cost variations were directly attributable to inadequate investigation. Three sections on a selected site where deep cutting was proposed were investigated by a resistivity geophysical approach. This has highlighted that considerable insight and accurate prediction of the strata sequence and thus more accurate budgetary predictions can be gained economically and rapidly by supplementing conventional investigation by a geophysical survey.

REFERENCES

[1] Pavel Bláha, RNDr. D.Sc. and Roman Duras, “*Methods of a Geophysical Survey for Road Design*”, Czech Republic.

[2] American Association of State Highway and Transportation Offices (AASHTO), “*Standard Specifications for Transportation Materials and Methods of Sampling and Testing*”, Twenty-Ninth Edition, 2009.

[3] US Army Corps, “*Geotechnical Investigation Manual EM 1110-1-1804*”, January 2001.

[4] Neil Anderson, Neil Croxton, Rick Hoover and Phil Sirles, “*Geophysical Methods Commonly Employed for Geotechnical Site Characterization*”, Transportation Research Circular, Number E-C130, October 2008.

[5] Ethiopian Roads Authority, “*Site Investigation Manual*, 2002.

[6] W. Ed Wightman, Frank Jalinoos, Philip Sirles, Kanaan Hanna, “*Application of Geophysical Methods in Highway Related Problems*”, September 2003.

[7] Technos Inc, “*Surface Geophysical Methods*”, Volume I, Fall 2004.

[8] Paul W. Mayne, Barry R. Christopher and Jason DeJong, "*Sub Surface Investigations - Geotechnical Site Characterization*", Publication by National Highway Institute (U.S. Department of Transportation Federal Highway Administration) Publication No. FHWA NHI-01-031, Reference Manual, May 2002.

[9] Republic of Kenya, Ministry of Transport and Communication Roads Department Manual, "*Part III, Material and Pavement Design Manual for New Roads*", August 1987.

[10] The United Republic of Tanzania, Ministry of Works Manual, "*Pavement and Materials Design Manual*", 1999.

[11] South African National Roads Agency Limited, "*Technical Recommendations for Highways, TRH 18– The Investigation, Design, Construction and Maintenance of Road Cuttings*", January 1993.

[12] McDowell P W, Barker R D, Butcher A P, Culshaw M G, Jackson P D, McCann D M, Skipp B O, Matthews S L and Arthur J C R, "*Geophysics in engineering investigations*", Publication by Geological Society/ Engineering Geology Special, Ciria C562, 2002.

[13] Burt G. Look, "*Handbook of Geotechnical Investigation and Design Tables*", Consulting Geotechnical Engineer, October 2006.

[14] American Society for Testing and Materials, "*Standard Guide to Site Characterization for Engineering Design and Construction Purposes*", West Conshohocken, USA.

[15] Zulfadhli Hasan Adli, Mohd Hafiz Musa, M. N. Khairul Arifin, "*Electrical Resistivity of Subsurface: Field and Laboratory Assessment*"; by World Academy of Science, Engineering and Technology 45, 2010.

[16] ASTM D6431-99, "*Standard Guide for Using the Direct Current Resistivity Method for Subsurface Investigation*", 2010.

[17] John Milsom, "*Field Geophysics, The Geological Field Guide Series*", Third Edition, 2003.