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PRE-FOUNDATION COMPETENCY AND CORROSSIVITY STUDY: A CASE STUDY OF CANAL VIEW ESTATE, ISOLO, LAGOS

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Constant separation traversing and Vertical Electrical Sounding (VES) techniques have been used in Canal View Estate, Isolo, Lagos, Southwest Nigeria to determine subsurface competency and corrosivity evaluation for structural development and other civil engineering applications such as underground pipeline for sewage and petroleum product transportation in the area. Twelve vertical electrical soundings (VES) and five 2D Wenner data were acquired from five different traverses established in the study area. Models obtained from 1D inversion of each traverse were used for construction of geo-electric sections which exhibit the main geo-electric characteristics of the geological units present in the area. Data obtained for each of the traverses in the 2D Wenner array were used to present Inverse Model Resistivity Sections. The interpreted results showed that the geoelectric sections consist of four to five geoelectric layers namely: the topsoil, clayey sand, clay, sandy clay and sand. The investigation revealed the fourth and fifth layers, interpreted as Sand, to be most competent and essentially non corrosive unit for shallow foundation for small to medium engineering structures and buried pipelines. These layers have thickness values that range between 9.8m to 44.0m and resistivity values of about 234.8Ωm to 6844.5Ωm.

Keywords: Inversion; soil competence; soil corrosivity; engineering structures; canal view.

1. INTRODUCTION

Geophysical investigation is one of the methods used in probing the soil and/or the subsurface for engineering structure applications [1]. With the growing demand for site development and unpleasant experiences of building failure, there is growing need for site investigations to reveal possible subsurface problems [2]. Therefore, geophysical investigations are important in evaluating the physical properties of the subsurface in terms of its soil type, soil competence, soil corrosivity, depth to bedrock and lithological sequence [3,4,5]. The deduced soil characteristics can be used as preliminary information to determine the suitability of a site for proposed engineering structure. In the absence of such investigation, concealed geologic features within the subsurface may precipitate excessive total or differential settlement leading to sinking, failure or collapse of such engineering structures [6].

Site engineers, for reasons of cost and other considerations such as assumptions in structural design, sometimes fail to incorporate pre-construction

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investigations in their job schedule. The importance of geophysical investigation cannot be over emphasized as it reveals possible future subsurface problems and proffer possible solutions before the erection of structures [2].

Since nearly every civil engineering structure must be erected on the surface of the earth, it is important that enough information on the strength and the fitness of the host earth materials must be ascertained before the actual construction work commences, hence the need for this exercise. The performance of an infrastructural element or facility is considered good if it performs as designed and provides an acceptable level of service over its intended life [7].

Geophysical methods can provide information on materials in the subsurface such as overburden thickness, horizontal and vertical lithological extents, depth to water table, fault zones etc. Electrical resistivity and seismic exploration methods are the most commonly used techniques for these purposes [8,9]. (Susan, 2004).

The application of electrical resistivity survey has become a prime choice as a result of the cheap cost that is involved and the fact that it saves time and easy to carry out, and can also be used to determine geological structures [10]. Engineering applications of electrical resistivity include the bridge, dam and building/structural foundation investigations [11,12] (Adeoti *et al*., 2009;). Apart from engineering applications, electrical resistivity can also be of great importance in ground water investigation, determination of contamination source and impact of leachate [3, 13, 14, 15].

The incessant incidence of foundation failures of structures is becoming alarming in Nigeria. These failures have been attributed to a number of factors such as inadequate information about the soil and the subsurface geological material, poor foundation design and poor building materials. This has led to loss of life, goods and properties worth millions of Naira.

The necessity for site characterization for construction purposes has therefore become very vital so as to prevent loss of valuable lives and properties that always accompany such failure. Some general reasons why buildings may be susceptible to collapse have been advanced which include poor quality of building materials, salinity, and old age of buildings. Less frequently mention is the subsurface conditions of the ground on which the buildings are sited. The design of a structure which is safe, durable and has low maintenance costs depends upon an adequate understanding of the nature of the ground on which such building is located. The structural failures range from settlement, differential settlement, upthrust and total collapse [16].

Some earth materials, due to their nature, cannot support solid and rigid structure among these materials are clays and clay-bearing earth. On the other hand, earth materials such as sands and fresh basement rock provide firm support for solid foundation. Site characterization usually provides subsurface information that assists civil engineers in the design of foundation of civil engineering structures. The primary purpose of all site investigations is to obtain the data needed for analysis and design. The most challenging part of these investigations is to collect only those data needed with the least amount of money and in the least amount of time.

To this end, geophysical methods besides geotechnical approaches are routinely used for foundation investigation. The geophysical methods that suites such investigation are the electrical resistivity, gravity and seismic refraction methods [17] (Olorunfemi *et. al*., 2004 Rahaman, 1976). The electrical resistivity method usually furnishes the engineers with information about the depth to the bedrock, the composition of the geologic layers and the trend/nature of geological fissures that can jeopardize or threaten the life span of the structure.

One important concept in civil engineering practice is competence of the earth materials employed in construction processes [18]. However, topsoil thickness also plays an important role in foundation design. Competence (or strength) of any geological material is influenced by several factors such as the mineralogy, the character of the particle contacts and the agent of weathering [19]. Every civil engineering structure is seated on geological earth materials hence, it is imperative to conduct pre-construction investigation of the subsurface of the proposed structures to ascertain the strength and the fitness of the host earth materials as well as the timed post-construction monitoring of such structure to ensure its integrity [20]. Correlated ranges of apparent resistivity values with subsoil competence and corrosivity are presented in Table 1 and 2.

This study is necessary because as the population of Lagos increases, the demand for shelter and housing also increases. The study area is a new and developing residential area which is an extension of Jakande Estate, Isolo, Lagos in which there are several ongoing building constructions and a lot of people are relocating into the area. However, the area is a sedimentary terrain characterized by surrounding

Table 1. Soil Competence Rating (Idornigie and Olorunfemi, 2006.)

Apparent Resistivity (Ωm)	Lithology	Competence Rating
< 100	Clay	Incompetent
100 – 350	Sandy Clay	Moderately Competent
350 – 750	Clayey Sand	Competent
> 750	Sand/ Laterite/ Bedrock	Highly competent

Table 2. Soil corrosivity rating

Soil Resistivity (Ωm)	Corrosivity Rating
> 200	Essentially non-corrosive
100 – 200	Mildly Corrosive
50 – 100	Moderately Corrosive
30 – 50	Corrosive
10 – 30	Highly Corrosive
< 10	Extremely Corrosive

(http://www.corrosion-doctors.org/cp/soil-resist.htm)

swamps and canal into which waste materials are deposited by the occupants of the area. These swamps and canal pose a significant threat to the competence of the subsoil for engineering construction purposes and the extent of the subsoil corrosivity for locating underground materials such as pipes, earthings and steel [21, 22]. The soil competency and corrosivity was investigated in streets adjoining or closer to the canal and swamps which is the major source and origin of the nature of the surrounding soil.

In this study, non-destructive geophysical technique involving Vertical Electrical Sounding using Schlumberger array and 2D Wenner array were adopted to investigate the conditions of the subsoil layers in terms of their corresponding depth, thickness and resistivity values at Canal View Estate, Jakande, Isolo, Lagos. This provides a means of investigating the competency and corrosivity of each of the subsurface layers.

2. METHODOLOGY

Electrical resistivity method of geophysical survey was used in the study area with the aim of determining the competency and corrosivity of the soil subsurface. 2-D Wenner array and Vertical electrical sounding (VES) involving the Schlumberger array were used to obtain field data using Pasi resistivity meter. Other instruments include; metal electrodes, measuring tape, Sledge hammer (used in driving the electrodes into the ground), connecting cables (reference cables) and Global Positioning System GPS.

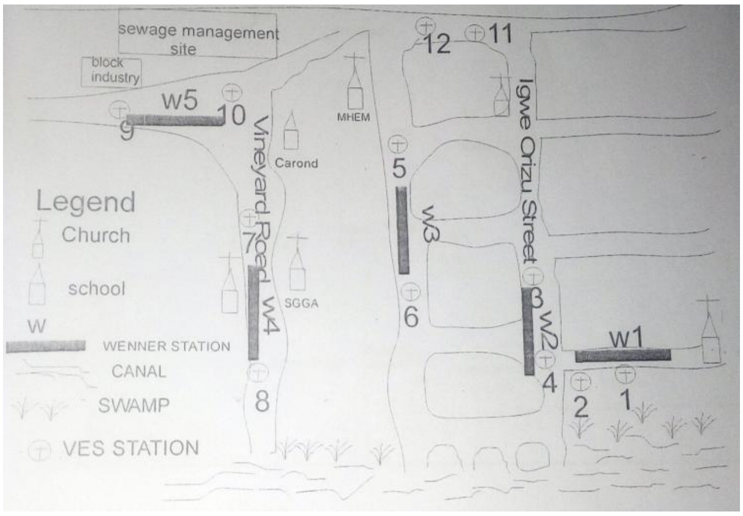


Fig. 1a. Base map of the study area showing VES 1-12

Fig. 1b. Satellite view of the investigated area showing VES points

Five (5) 2D-Wenner data were acquired along the five traverses established in the study area with two vertical electrical soundings (VES) on each traverse making a total of twelve (12) VES. The Pasi resistivity meter measures the response of the earth to the flow of electrical current by passing an electrical current using current electrodes (AB) through the ground and two potential electrodes (MN) allow us to record the resultant potential difference between them, giving us a way to measure the electrical resistance of the subsurface material. Data are termed apparent resistivity because they are averages over a complex current path but are associated with a single depth point in the survey plane. A maximum electrode separation (AB/2) of 400m and potential electrode separation (MN/2) maximum of 10m were utilized in the survey using the schlumberger electrode configuration.

The wenner array method used is such that constant electrode spacing is maintained between the adjacent electrodes as the whole spread is traversed [23]. This wenner array method was used to obtain data on five (5) traverses. The electrode spacing between the adjacent electrodes is assigned “a” with initial spacing of 10m and subsequent spacing being multiple of 10. The maximum electrode spacing used was 60m over a survey line of 200m.

3. DATA PROCESSING AND INTERPRETATION

The calculated resistivity values obtained in the field VES data were plotted against the electrode spacing (AB/2) on bi-logarithmic graph sheets, using a transparent tracing paper superimposed on the log-log paper and later curved matched on a standard master curve in order to estimate the number of layers in each VES to build a resistivity model for iteration on the WINRESIST software. From the final calculation, the resistivity, depth and thickness of the different geoelectric layers were plotted using the WINRESIST software. The VES data was used to determine the lithology and resistivity of the subsurface in the study area.

The interpretation of the sounding curves was done both qualitatively and quantitatively. The qualitative interpretation entails observation of the sounding curves as plotted on log-log graph paper. Quantitative interpretation of the VES data was carried out in stages as follows: (a) plotting and smoothing of the apparent resistivity field data curve and removing the noise appropriately; (b) curve matching the smooth curve on tracing paper using master curves and auxiliary curves, (c) initial geoelectrical model (thicknesses and resistivities) emerging from the previous stage was prepared, and (d) entering the geoelectrical model into the inversion package and the iteration was achieved using WinResist software at a minimum root mean square error.

Also, the apparent resistivity values calculated from the measured resistances in each traverse for 2D imaging was uploaded onto a notepad and inputted into the RES2DINV software in order to produce profile pseudo-sections. The contoured pseudo-sections were inverted to plot the apparent resistivity against true vertical depth. The profiling data are presented as contoured pseudo-sections.

4. RESULTS AND DISCUSSION

In this section, the interpreted results for the VES and 2DWenner are presented in order to identify competent/non-corrosive zones.

4.1 Results

The VES results are presented as sounding curves (Fig. 2.1a-Fig. 2.1l) and geoelectric sections (Fig. 2.2a-Fig 2.2d). Also, the results of 2D Wenner array are presented as 2D Inverse Model Resistivity Sections Fig. 3.

The interpreted data for schlumberger configuration with twelve (12) VES plotted on a graph with apparent resistivity against electrode spacing (AB/2) are presented in the Fig. 2.1a to Fig. 2.1l with their corresponding layers resistivity, thickness and depth. The summary of the interpreted VES results is shown in Table 3. Fig. 3 shows the 2D inverse model resistivity section for traverse 1-5. The resistivity values are contoured using different colors.

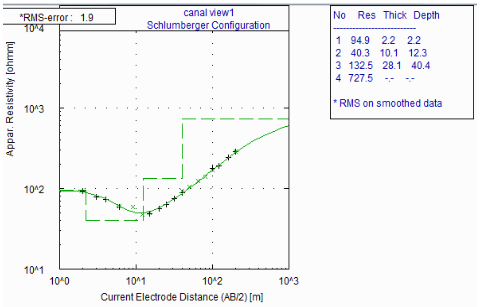


Fig. 2.1a. Computed iterated graph for VES 1

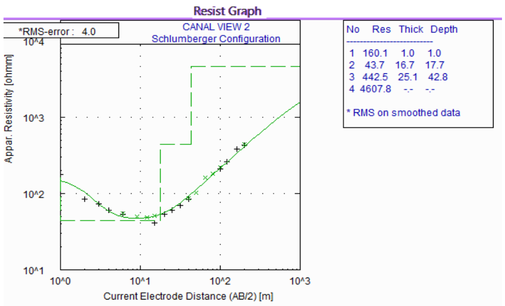


Fig. 2.1b. Computed iterated graph for VES 2

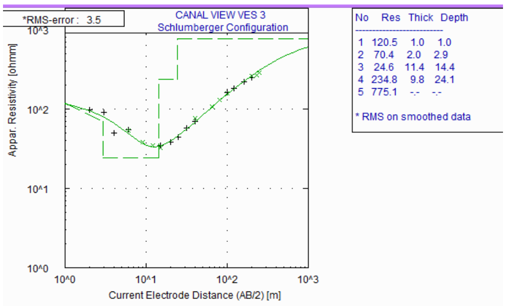


Fig. 2c. Computed iterated graph for VES 3

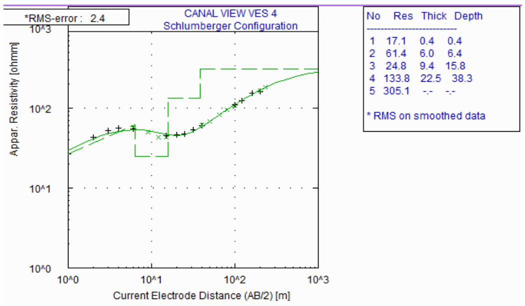


Fig. 2d. Computed iterated graph for VES 4

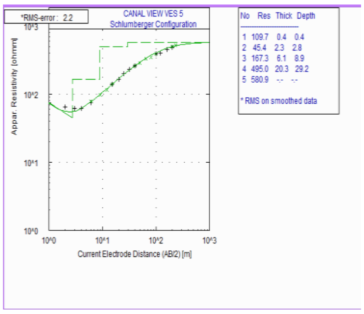


Fig 2e. Computed iterated graph for VES 5

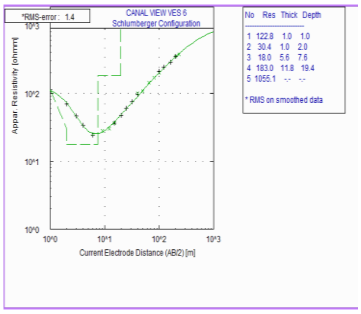


Fig. 2f. Computed iterated graph for VES 6

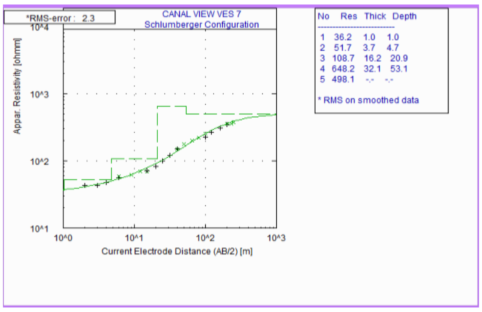


Fig. 2g. Computed iterated graph for VES 7

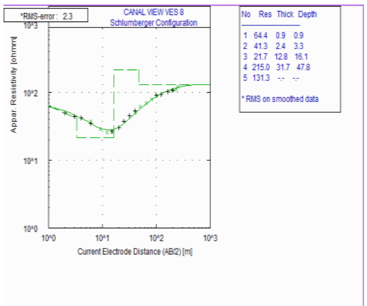


Fig. 2h. Computed iterated graph for VES 8

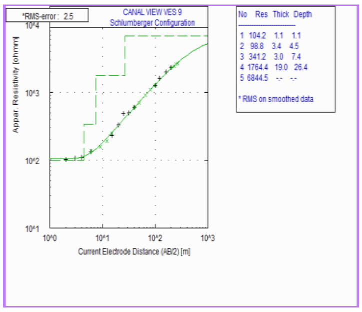


Fig. 2i. Computed iterated graph for VES 9

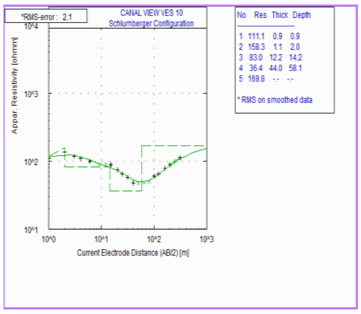


Fig. 2j. Computed iterated graph for VES 10

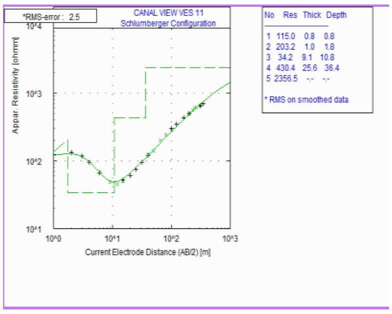


Fig. 2k. Computed iterated graph for VES 11

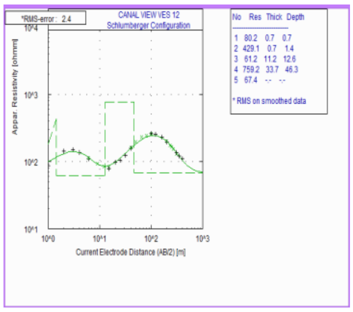


Fig. 2l. Computed iterated graph for VES 12

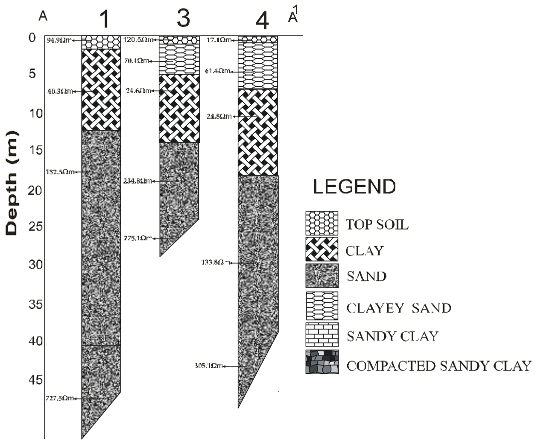


Fig. 2.2a. Geoelectric section for VES 1,3&4

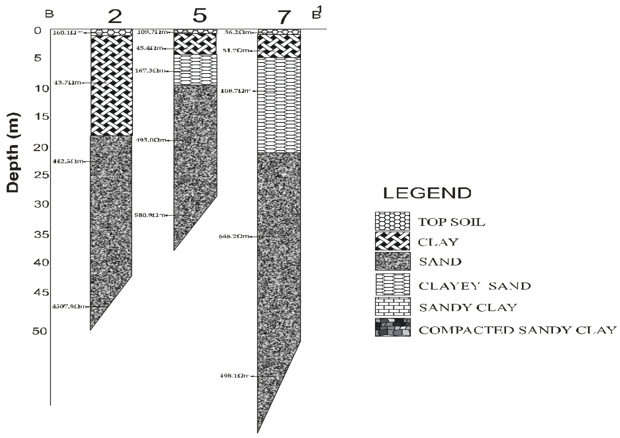


Fig. 2.2b. Geoelectric section for VES 2,5&7

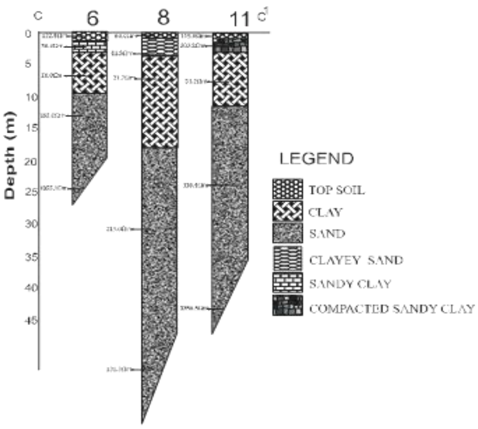


Fig. 2.2c. Geoelectric section for VES 6,8&11

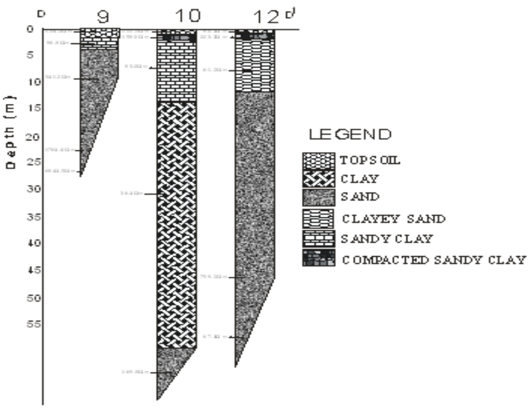


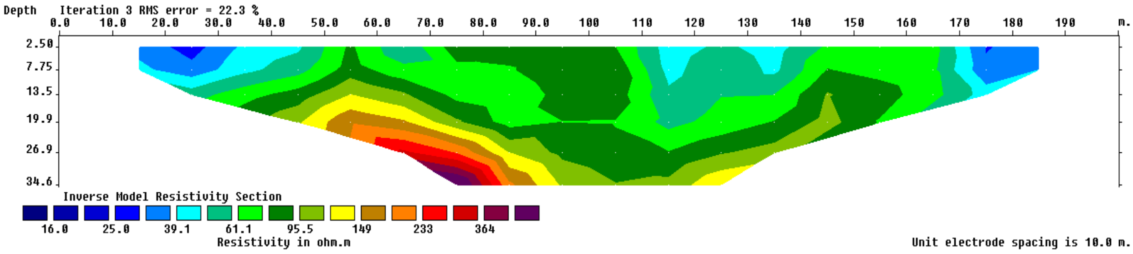
Fig. 2.2d. Geoelectric section for VES 9,10&12

Table 3. Summary of VES results

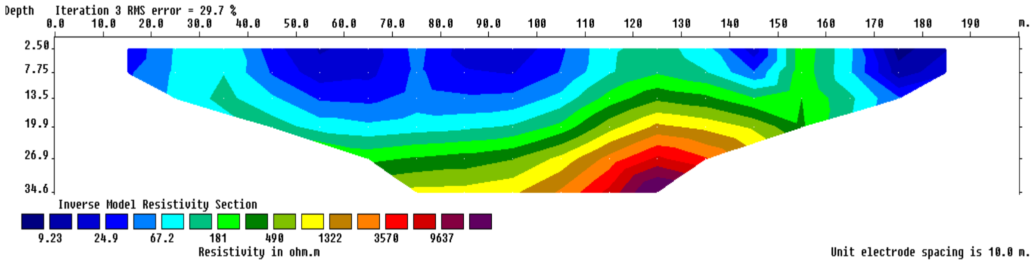
TRAVERSE	VES	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	LITHOLOGY	CURVE TYPE	CORROSIVITY	COMPETENCY
1	1	1	94.9	2.2	2.2	Top soil	HA	Moderately corrosive	Incompetent
		2	40.3	10.1	12.3	Clay		Corrosive	Incompetent
		3	132.5	28.1	40.4	Sand		Mildly corrosive	Moderately competent
		4	727.5			Sand		Essentially non corrosive	Highly competent
	2	1	160.1	1.0	1.0	Top soil	HA	Mildly corrosive	Moderately competent
		2	43.7	16.7	17.7	Clay		Corrosive	Incompetent
		3	442.5	25.1	42.8	Sand		Essentially non corrosive	Competent
		4	4507.8			Sand		Essentially non corrosive	Highly competent
2	3	1	120.5	1	1	Top soil	H	Mildly corrosive	Moderately competent
		2	70.4	2	2.9	clayey sand		Moderately corrosive	Incompetent
		3	24.6	11.4	14.4	Clay		Highly corrosive	Incompetent
		4	234.8	9.8	24.1	Sand		Essentially non corrosive	Moderately competent
		5	775.1			Sand		Essentially non corrosive	Highly competent
	4	1	17.1	0.4	0.4	Top soil	A	Highly corrosive	Incompetent
		2	61.4	6	6.4	clayey sand		Moderately corrosive	Incompetent
		3	24.8	9.4	15.8	Clay		Highly corrosive	Incompetent
		4	133.8	22.5	38.3	Sand		Mildly corrosive	Moderately competent
		5	305.1			Sand		Essentially non corrosive	Moderately competent
3	5	1	109.7	0.4	0.4	Top soil	H	Mildly corrosive	Moderately competent
		2	45.4	2.3	2.8	Clay		Corrosive	Incompetent
		3	167.3	6.1	8.9	clayey sand		Mildlycorrosive	Moderately competent
		4	495	20.3	29.2	Sand		Essentiall y non corrosive	Competent
		5	580.9			Sand		Essentially non corrosive	Competent
	6	1	122.8	1	1	Top soil	H	Mildly corrosive	Moderately competent
		2	30.4	1	2	Sandy Clay		Corrosive	Incompetent
		3	18	5.6	7.6	Clay		Highly corrosive	Incompetent
		4	183	11.8	19.4	Sand		Mildly corrosive	Moderately competent
		5	1055.1			Sand		Essentially non corrosive	Highly competent
4	7	1	36.2	1	1	Top soil	A	Corrosive	Incompetent
		2	51.7	3.7	4.7	Clay		Moderately corrosive	Incompetent
		3	108.7	16.2	20.9	clayey sand		Mildly corrosive	Moderately competent

TRAVERSE	VES	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	LITHOLOGY	CURVE TYPE	CORROSIVITY	COMPETENCY
		4	648.2	32.1	53.1	Sand		Essentially non corrosive	Competent
		5	498.1			Sand		Essentially non corrosive	Competent
	8	1	64.4	0.9	0.9	Top soil	H	Moderately corrosive	Incompetent
		2	41.3	2.4	3.3	clayey sand		Corrosive	Incompetent
		3	21.7	12.8	16.1	Clay		Highly corrosive	Incompetent
		4	215	31.7	47.8	Sand		Essentially non corrosive	Moderately competent
		5	131.3			Sand		Mildly corrosive	Moderately competent
5	9	1	104.2	1.1	1.1	Top soil	A	Mildly corrosive	Moderately competent
		2	98.8	3.4	4.5	Sandy Clay		Moderately corrosive	Incompetent
		3	341.2	3	7.4	Sand		Essentially non corrosive	Competent
		4	1764.4	19	26.4	Sand		Essentially non corrosive	Highly competent
		5	6844.5			Sand		Essentially non corrosive	Highly competent
	10	1	111.1	0.9	0.9	Top soil	H	Mildly corrosive	Moderately competent
		2	158.3	1.1	2	Compacted sandy clay		Mildly corrosive	Moderately competent
		3	83	12.6	14.2	Sandy Clay		Moderately corrosive	Incompetent
		4	36.4	44	58.1	Clay		Corrosive	Incompetent
		5	169.8			Sand		Mildly corrosive	Moderately competent
6	11	1	115	0.8	0.8	Top soil	H	Mildly corrosive	Moderately competent
		2	203.2	1	1.8	Compacted sandy clay		Essentially non corrosive	Moderately competent
		3	34.2	9.1	10.8	Clay		Corrosive	Incompetent
		4	430.4	25.6	36.4	Sand		Essentially non corrosive	Competent
		5	2356.5			Sand		Essentially non corrosive	Highly competent
	12	1	80.2	0.7	0.7	Top soil	KHK	Moderately corrosive	Incompetent
		2	429.1	0.7	1.4	Compacted sandy clay		Essentially non corrosive	Competent
		3	61.2	11.2	12.6	Clayey sand		Moderately corrosive	Incompetent
		4	759.2	33.7	46.3	Sand		Essentially non corrosive	Highly competent
		5	67.4			Sand		Moderately corrosive	Incompetent

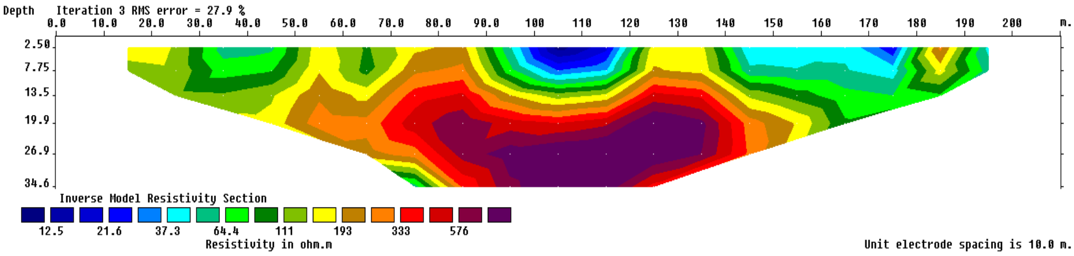
Traverse 1



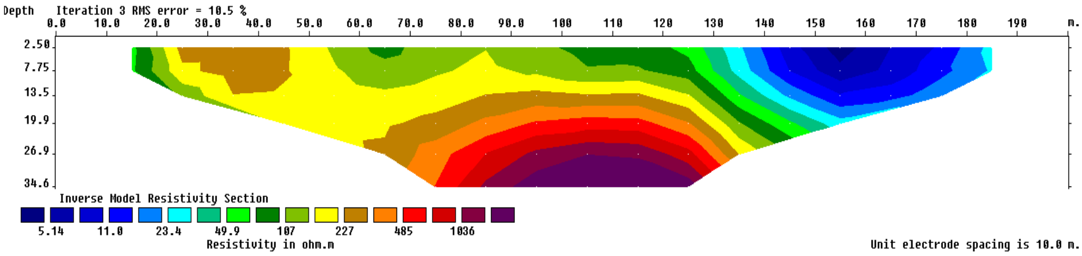
Traverse 2



Traverse 3



Traverse 4



Traverse 5

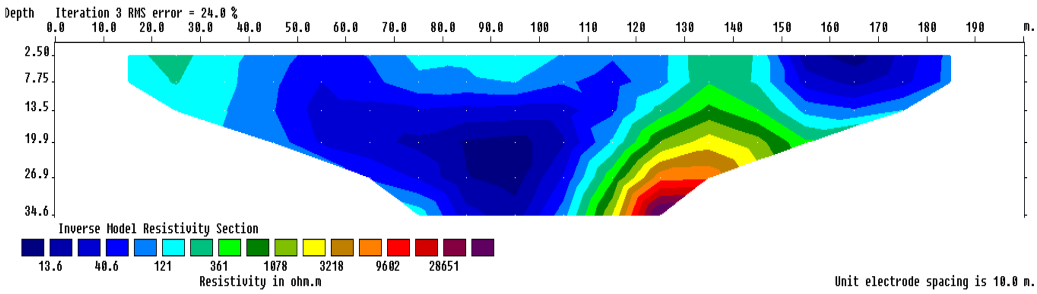


Fig. 3. 2D Inverse Model Resistivity Section for traverse 1-5

4.2 Discussion

The interpreted results of the VES data show a system of four to five geo-electric layers which comprises of topsoil, clay, clayey sand, sandy clay and sand. The sounding curve reveals the following different curve types: HA, QHA, KAA, HAA, AAK, QHK, KQH, KHA, KHK. Out of the 12 VES sounding curves, KAA, AAK, QHK, KQH, KHA and KHK curves occupies about 8.33% each, while HA, QHA, HAA has about 16.67% each. The root-mean-square error of the graphs obtained ranges from 1.9 to 4.0.

The VES interpreted results shows that the first layer which is characterized by low resistivity of about 17.1Ωm to 160.1Ωm is incompetent and moderately corrosive due to their thin thicknesses (0.4m to 2.2m) and probably due to sand filling of the study area.

The second and third geoelectric layer is incompetent for building constructions and corrosive to underlying materials due to its very low resistivity values and high corrosivity which might probably be due to the accumulation of clay material and possibly other contaminants in this layer.

Sand which represents the fourth layer with high resistivity and thickness values reveals that this particular layer is competent for building purposes and mildly corrosive to underground structures. This layer can therefore be considered to be competent for small to medium engineering structures due to its thickness of about 9.8m to 44.0m and high resistivity.

The last layer is considered as the essentially non corrosive and highly competent layer for all purposes with the highest resistivity values.

2D Inverse Model Resistivity Sections obtained along Traverses 1 to 5 are presented in Fig. 3 above with root-mean-square error of about 10.5% to 29.7%. The lateral extent of the traverses is from 1 to 200m.

The 2D Inverse Model Sections interpreted for Traverse 1 at a depth of about 2.50m to 7.75m with low resistivity characterized with the blue color which is diagnostic of clay material is incompetent for building construction and also corrosive for underground materials. Depth of about 13.5m to 34.6m with higher resistivity values is highly competent and mildly or practically non corrosive for construction and underground materials.

Traverse 2 show that moderately competent and essentially non corrosive layers can be obtained at a depth of about 20m to 34.6m while the uppermost layers of about 2.5m to 16m is incompetent and corrosive for building construction and underground materials as also shown in the VES results.

The topmost layer in Traverse 3 is incompetent, mildly corrosive at the beginning of the traverse and corrosive at the midpoint of the traverse as represented by the blue color code in the model sections shown above with a depth of about 2.50m to 8.90m. The highly competent and essentially non corrosive layer is at the depth of 13.50m to 34.60m represented by orange and purple color codes in the model figure.

From the beginning of the Traverse 4, at a lateral extent of about 130m, and depth of about 2.5m to 16m, the layers are moderately competent and mildly corrosive while at the same depth and lateral extent of 140m to 180m the layers are incompetent and corrosive represented by the blue color in the model section which might be characterized by clay soil. Competent and essentially non corrosive layers can be obtained at a depth of about 19.9m to 34.6m.

Traverse 5, at a lateral extent of about 120m and depth of about 2.50m to 34m, the layers are moderately competent and corrosive which might be probably due to accumulation of clay soil or pollutants within the soil structure. Highly competent and essentially non corrosive layer is obtained at a lateral extent of about 130m to 160m and at a depth of about 19m to 34.6m as shown in the resistivity model section obtained.

5. CONCLUSION

One of the keys to successful development of a site is the understanding of the subsurface formation during the planning stages. Measurement of electrical resistivity is one of the most widely used geophysical surveys in this respect. Vertical electrical sounding can afford a relative means of determining inherent environmental and engineering effects of the subsurface variations.

The application of electrical resistivity method has been employed in delineating the various lithological units at Canal view estate, Isolo. It has been established in this study that the electrical resistivity method is useful in determining the competence and corrosivity of the study area. The geoelectric sections and 2D Inverse resistivity model sections were used to categorize the area into different soil competence and corrosive layers. Based on the twelve (12) VES measurements taken, five major geoelectric layers were delineated from the study area which comprise of topsoil, clay, sandy clay, clayey sand and sand. The soil condition in the area was categorized as incompetent, moderately competent, competent and highly competent layers based on the soil resistivity. The depth of the competent layer ranges from 12.6m to 53.1m and a resistivity of about 442.5Ωm to 6844.5Ωm due to the presence of sand thickness and the incompetent layer ranges from 0.4m to 10.8m and a resistivity of about 18.0Ωm to 341.2Ωm. The depth of the corrosive layer ranges from 0.4m to 20.9m and the essentially non corrosive layer is within the range of 24.1m to 46.3m. The study concluded that the study area was underlain by highly competent to incompetent soil layers and essentially non-corrosive to highly corrosive soil layer.

6. RECOMMENDATION

Based on the conclusion stated above, the following recommendations have been proposed:

(i) Ground treatment such as dewatering and in-situ compaction should precede use of reinforced concrete during the construction of shallow foundation.
(ii) Depending on the size of structures to be erected, the use of piling may be necessary for the structures to rest directly on the competent bed.
(iii) It is important to take into cognizance all other engineering construction criteria that may be relevant considering the geological nature of the site.
(iv) Further geological and geotechnical analysis should be carried out on the soil sample of the study area. Further studies in this respect, could adopt integrated geophysical methods and increase in area of coverage in other to enhance accurate delineation of the stratigraphic layers of the subsurface in the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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