

Integration of engineering Properties of Soils in the Weathered Profile of ophiolite Suite of Rocks of South Andaman Islands, India through Vertical Electrical Sounding

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ABSTRACT

Precise determination of engineering properties of soil is essential for proper design and successful construction of any structure. The conventional methods for determination of engineering properties of soils are invasive, costly and time-consuming. Electrical resistivity survey is an alternative and attractive tool for delineating subsurface properties without soil disturbance. Statistical correlations between electrical resistivity and other soil properties will enable us to characterize the subsurface soil without borehole sampling. This paper presents the part of research on correlations of electrical resistivity with properties of soil through the application of field electrical resistivity survey (VES) and laboratory electrical resistivity measurements in the soil horizon. From the data analysis, significant correlations have been obtained between resistivity, plasticity index and angle of internal friction of the weathered profiles in the Ophiolite suite of rocks in South Andaman. Thus the high and low resistivity value provides information about subsurface of the hard and weathered rock or clay. The subsurface information is very important to make necessary arrangement for making risk and mitigation studies. Integral study of geotechnical and geophysical study is very important for structural Engineering design of building or any civil construction.

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I.INTRODUCTION

In recent years considerable efforts have been made to characterize the soil and rock conditions using Geotechnical and Geophysical methods for determining seismic design of architecture and urban planning (Kurtulus et al 2011). Precise determination of engineering properties of soil is essential for proper design and successful construction of any structure (FahadIrfan Siddiqui et al, 2012). The characterization of ground conditions necessitates the knowledge of local geology and dynamic soil properties. The conventional method of obtaining these engineering parameters is laboratory investigations performed on soil/rock samples acquired from site/field through borehole sampling are subjected to Uniaxial Compression Strength (UCS) in accordance with the American Society for Testing and Materials (ASTM). The determination of UCS is difficult and time consuming and needs regularly shaped rock samples (Kurtulus et al, 2011 and Cosenza et al, 2006). For accurate assessment of soil properties, these high-density sampling will be required but borehole sampling would be very costly and time-consuming option in such conditions (Pozdynakova and Pozdynakova, 2002). So we need the technique with less time consuming and low cost-effective. Among the various methods, geo-electrical survey is a very attractive tool for delineating subsurface properties without soil disturbance (Samoulian et al 2005). The Geophysical techniques are nowadays considered as an alternative and attractive soil testing tool for traditional geotechnical methods to characterize the geotechnical properties because the geophysical techniques are fast, cost effective, non-destructive and disturb the soil structure to least (Sudhir Bhatt et al, 2009).

Several attempts have been made by many researchers to explore the phenomenon of electrical resistivity in soils and its relationship with other soil properties; such as water content, thermal resistivity, salinity, CEC, hydraulic conductivity, ground water distributions etc. Though a large number of studies have been carried to determine the engineering and mechanical properties for the purpose of site characterization and land use, only few of studies have been carried out in Ophiolite suite of rocks (Rao and Ramana , 1974; Koumantakis , 1982 ; Paventi et al 1996 ; Chirstensen , 2004 Courtier et al 2004 ; Marino et al 2006 ; Diamantes et al ., 2009) .

The geotechnical parameters of soil such Standard Penetration Test SPT (N-value - number of blows), moisture content, plasticity index, (G.L.Yoon et al 2001; P.H.Giao et al 2003; Oh and C.G.sun, 2008; Sudha et al 2009) and the strength properties of soil (cohesion, angle of internal friction etc.). (Cosenza et al, 2006; Pozdynakova and Pozdynakova, 2002) are correlated with electrical properties of the weathered profiles of soils and rocks of Ophiolite suites in south Andaman.

II. MATERIALS AND METHODOLOGY:

2.1 DESCRIPTION OF THE STUDY AREA

The aim of this study is to assess the index properties and characterize soils in Ophiolite rocks of south Andaman Islands located in Andaman and Nicobar islands with an area of 1348 km². In Andaman Island the soil development is not well developed due to surface erosion of heavy rain fall. The south Andaman Islands generally features undulating terrain with long ranges of hills and narrow valleys. Landscapes have continuously been developed under the influence of tectonic processes. Cretaceous igneous rocks, the Ophiolite suite, marine sedimentary rocks of Paleocene to Oligocene age and recent to sub-recent beach sand, mangrove clay, Alluvium and coral rags are the major geological formation in the area. In this paper we are going to limit our study to Ophiolite suite of south Andaman Islands. The Ophiolite suite of rocks comprises a wide variety of acidic to ultra-basic plutonic rocks and their equivalent basic volcanic rocks. The rocks of this group are rendered with aquifers due to karstification. The Ophiolite rocks have undergone more phases of faulting and folding and are considered active even today. The Ophiolite suite contains a variety of minerals which were composed of serpentinized peridotites, green, dark green and green and green and light brown in color. Minerals such as Olivine and pyroxene were mainly transformed into serpentine minerals and the metamorphic reaction was accompanied by the disappearance of the textural and mineralogical characteristics of the protoliths. Serpentine is represented by sieve textured cyrisotiles. The serpentinization percentage ranges from 22 to 33%. The highly fractured Ophiolites were filled by secondary carbonates.

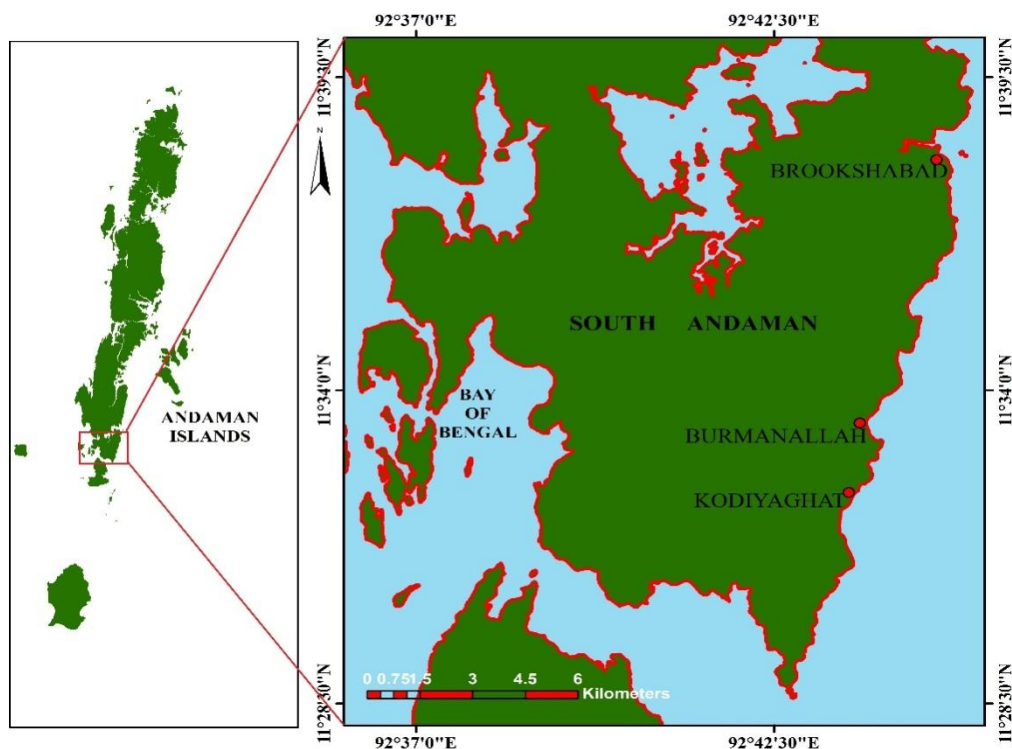


Fig1: Location map of south Andaman Islands

2.2 VERTICAL ELECTRICAL SOUNDING METHODS

To get adequate information of ground condition for making of design for the construction of foundations detailed field investigations comprise of electrical resistivity survey (VES) and soil boring using drilling set were carried. The vertical electrical sounding or 1D survey and bore hole samplings were conducted at three sites near the boreholes at Kodyaghat, Burmanallah, and Brookshabad in South Andaman using simple bore hole samples. To acquire the electrical resistivity data CRM500 Aqua meter, power source, insulated wires, measuring tapes, and stainless steel electrodes. The electrical sounding was conducted using Wenner electrode configuration with electrode spacing ranging from 2 to 6 meters. In the same set up Self Potential (SP) measurements with porcelain electrodes were also carried (Table.1, 2 and 3). The inversion process generates a layered 1D model of subsurface soil based on variation in electrical resistivity and Self potential the identification of each litho units and thickness were measured. The resistivity inversion study helps to understand the dynamic characteristic properties of features of serpentinized Ophiolite rocks for design and construction of safe foundations...

2.3 GEOTECHNICAL TEST:

2.3.1 STANDARD PENETRATION TEST:

According to Bowles(1996), standard penetration test(SPT) that was developed around 1927, is a foremost method for evaluating the geotechnical characteristics of overburden materials and been widely practiced around the world. According to Oh (2007), soil stiffness can be analyzed directly and effectively based on SPT test. The procedure for estimating standard penetration test starts with standard split spoon sampler being driven into ground at required depth by standard hammer of 63.5 kgs weight falling from a height of 75cm. Number of blows for first 15cm is not taken into consideration because of possible disturbances or presence of settled, suspended matters at the bottom of boreholes. The total number of blows for next 30cm depth of penetration is considered as SPT 'N' values. (Table.4, 5, 6 and 7)

2.3.2 SAMPLE DESCRIPTION AND PREPARATION

Soil samples from various depths were obtained by soil boring performed using percussion drilling set. Three boreholes were drilled up to the depth of 5, 8 and 15 meters respectively. The obtained samples were brought to the laboratory for soil characterization in laboratory conditions. Laboratory tests were performed on the soil samples obtained from boreholes, to determine geotechnical parameters such as moisture content, unit weight, and direct shear test as per methods suggested in Indian standards. In this study, properties of soil from geotechnical testing are compared to resistivity data at three different locations of south Andaman Islands. Each location is accompanied by a Vertical Electrical Resistivity Sounding (VES) and a matching borehole (i.e.) a borehole on the same line as the resistivity sections was used.

2.4 PLASTICITY INDEX AND MOISTURE CONTENT:

One of the universally accepted assessment technique are performing Atterberg limit tests and classifying the expansiveness based on results of the test. In this paper, we are proposing technique to develop a method to find Atterberg limit such as liquid limit and plasticity index based on electrical resistivity data (Table.8, 9 and 10). The term plasticity describes the response of a soil to changes with moisture content. When adding water to a soil changes its consistency from hard and rigid to soft and pliable, the soil is said to be exhibiting plasticity. Clays can be very plastic and silts only slightly plastic, whereas clean sands and gravels do not produce any plasticity at all.Skempton (1949) proposed an empirical relationship between compression index and liquid limit as follows:

$$\text{Compression index}=0.009(\text{liquid limit}-10) \quad \text{-- (1)}$$

Similarly, Kulhawy and Mayne (1990) proposed an empirical relationship between compression index and plasticity index as follows:

$$\text{Compression index}= \text{plasticity index}/74 \quad \text{-- (2)}$$

By combining both equations we obtain a following relationship:

$$\text{Plasticity index}=0.666(\text{liquid limit}-10) \quad \text{-- (3)}$$

Where liquid limit is the moisture content expressed without percent sign. The ratio of volume of water to the volume of soil is called moisture content. The moisture content can be easily measured in the laboratory by conducting a moisture content test (ASTM D2216) as follows:

1. Obtain a sample can to hold the soil sample and find its mass, M_c
2. Place a representative sample of the soil into the can and find the total mass, M_1 .
3. Place the soil and can into an oven with a constant temperature of $110 \pm 5^\circ\text{c}$ and leave it there until completely dried. This usually requires 12 to 16 hours.
4. Determine the mass of the dry sample and can, M_2 .

Compute the moisture content using:

$$W (\%) = [(M_1-M_2)/ (M_2-M_c)] \times 100 \quad \text{-- (4)}$$

The moisture content is obtained from relation

$$\text{Moisture content}= \text{porosity} \times \text{water saturation.} \quad \text{-- (5)}$$

The ratio of volume of voids in a soil sample to the volume of the sample is called porosity. Porosity is usually found by geotechnical engineers from using relation:

$$\text{Porosity} = \text{volume of water}/\text{total porosity.} \quad \text{-- (6)}$$

Porosity is found from electrical resistivity values by formula:

$$\text{Porosity}= \text{square root of } (1/\text{formation factor}) \quad \text{-- (7)}$$

Where formation factor is determined from resistivity of water measured from field by

$$\text{Formation factor} = \text{resistivity of water}/\text{measured resistivity} \quad \text{-- (8)}$$

2.5 SHEAR PARAMETERS

The shear strength of common engineering materials such as steel is controlled by their molecular structure. However, the physical mechanisms that control shear strength in soil are much different. Soil is a particulate materials, so shear failure occurs when the stresses between the particles are such that they slide or roll past one another. Although some particle crushing may occur, the shear strength primarily depends on interactions between the particles, not on their internal strength. We divide these interactions into two broad categories: frictional strength and cohesive strength. Frictional strength in soil is similar to classic sliding friction from basic physics. The force that resists sliding is equal to the normal force multiplied by the coefficient of friction. However instead of using the coefficient of friction, geotechnical engineers prefer to describe frictional strength using the effective friction angle (ϕ). The friction angle is usually determined by:

$$\phi = \arctan(\text{shear stress}/\text{overburden effect}) \quad \text{--(9)}$$

The effective stress (or) overburden pressure (σ) is the portion carried by soil particles.

$$\sigma = (\text{unit weight} \times \text{depth of soil layer}) - \text{pore water pressure} \quad \text{--(10)}$$

The pore water pressure (u) which is the portion carried by the pore water.

$$\text{Pore water pressure} = \text{unit weight of water} \times \text{depth below water table} \quad \text{-- (11)}$$

Where, Shear stress is the difference in weight acting on different soil layers. Some soils have shear strength when the effective stress is zero, or at least appears to be zero. Geotechnical engineers refer to it as cohesive strength, another shear parameter. Soil cohesion was calculated by the formula (Hajime Yokoi 1967):

$$c = w/A \quad \text{-- (12)}$$

Where c=cohesive strength

w=weight

A=surface area

Where weight here refers to overburden weight one over another. And the surface area was determined from porosity by using the table reproduced from (Richardson et al, 2002).

2.6 HYDRAULIC PARAMETERS:

One of the parameter used by geotechnical engineers is hydraulic conductivity. If the hydraulic conductivity is high, the necessary amount of water will escape and the soil will compress. Where there is a water column with high hydraulic conductivity, there will be a rapid drainage of excess pore water pressure. Hydraulic conductivity (K) (m/day) is found using the formula

$$K = cd^2 \quad \text{-- (13)}$$

Where c=Hazen's coefficient (0.8 to 1.2)

d=diameter of particle (m)

Diameter of particle is determined by the equation

$$D = 6/\text{surface area of particle} \quad \text{-- (14)}$$

For our geophysical measurement we have developed a relation between specific surface area and porosity. The equation relating both specific surface area and porosity is as follows:

$$\text{Specific surface area} = 869 + (3791 \times \text{porosity}) \quad \text{-- (15)}$$

Where, porosity is found by the equation (7).

III.RESULTS AND DISCUSSION

3.1 SOIL AND ROCK COMPOSITION

The litho-log layers have been interpreted from various resistivity values obtained by 1D model of subsurface soil and rocks based on variation in electrical resistivity and thickness. The litho-log types are classified based on the resistivity values obtained for different soil types. The curve obtained from the resistivity and Self- potential logs (Table.1, 2 and3) showed that many curve features are identifiable from curve to curve. Each curve features may be considered as signature of the formation. The method of correlation is based on the pattern recognition of the curve elements such as peaks and troughs. A peak is a segment of curve of which the resistivity increases with depth passes through a maximum and decreases. This peak is bound by two consecutive inflection points which define its boundaries (Vincent et al, 1979). The trough is defined in terms of derivative variation in opposite sign. The resistivity curve starts from zero line with the deflection towards right (higher deflection for higher resistivity values). But the Self-potential value has no absolute zero; the deflections can be either positive or negative. The higher (either positive or negative) the deflection, more is the Self potential value. The Self Potential value is indicated along the direction as +mV to right and -mV to left (Fig.2, 3, 4 and 5) (Arul Alphonse 2004).

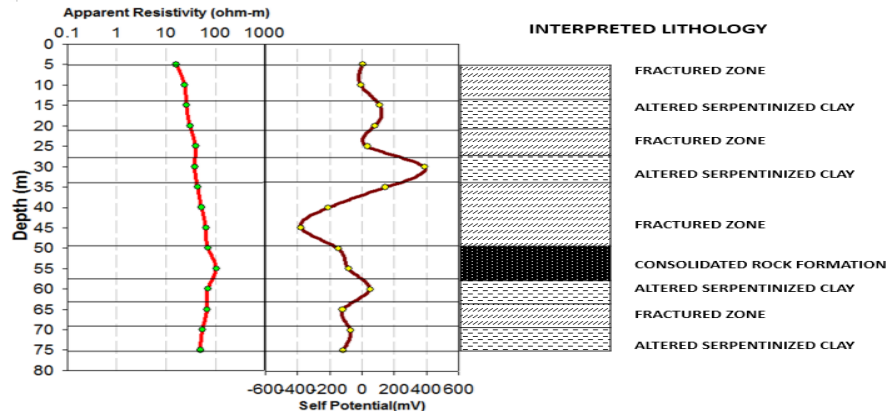


Fig 2: showing various litho-logical interpretation of Kodyaghat

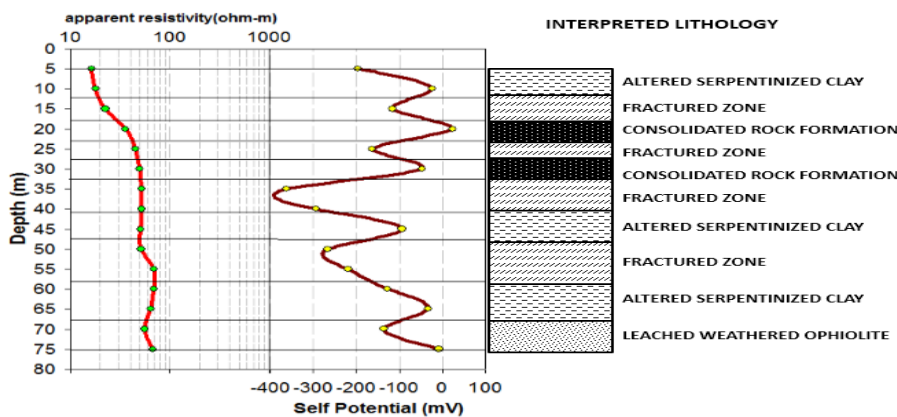


Fig 3: showing the various litho-logical interpretation of Burmanallah

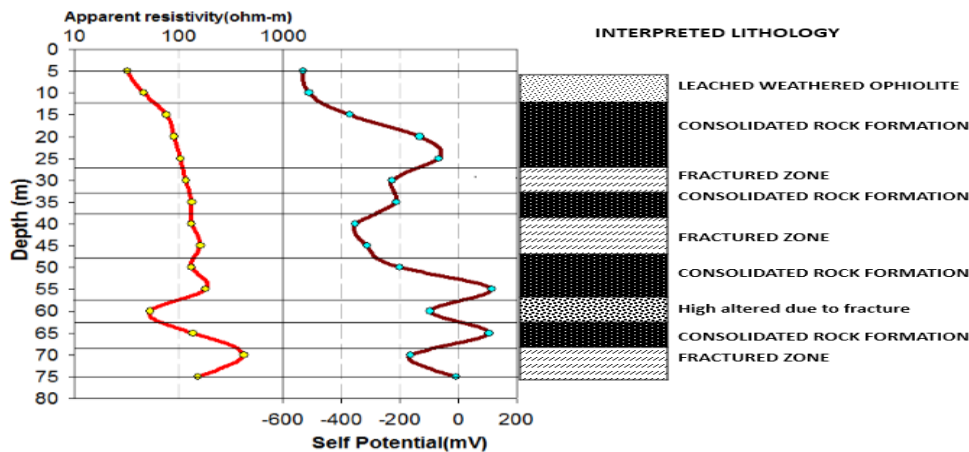


Fig 4: showing various litho-logical interpretation of Brookshabad.

After plotting three borehole locations the following combination of Self Potential and the apparent resistivity logs were obtained. The various litho-logical interpretations based on these logs are as follows:

1. Low Self Potential (trough) and comparatively low apparent resistivity values (trough) indicating leached weathered Ophiolite fragments.
2. High Self Potential (peak) and high apparent resistivity (peak) values indicating consolidated rock formation.
3. High Self potential (peak) and low apparent resistivity (trough) values indicating altered serpentinized clay.
4. Low Self Potential (trough) and high apparent resistivity (peak) value indicating fractured zone (AntonyRavindran et al; 2013).

A pie chart is prepared as shown below based on their composition of litho-logy section from the three locations in the study area. (Fig.5)

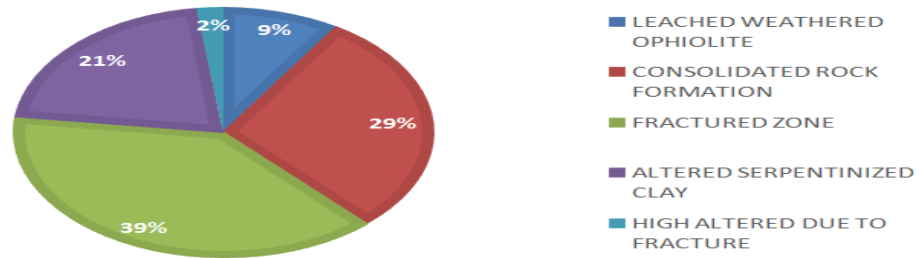
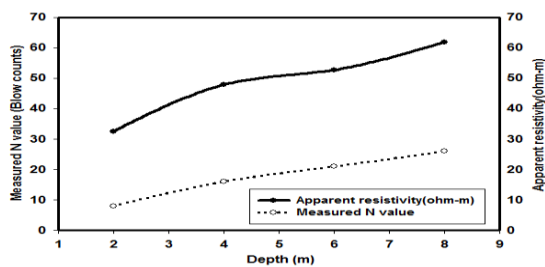


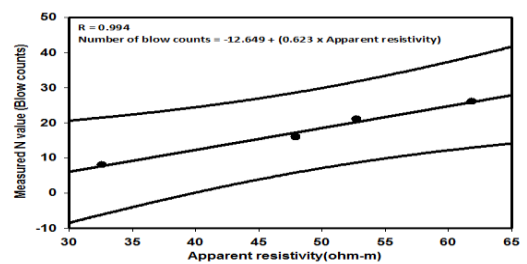
Fig 5: showing the various soil and rock compositions of Ophiolite rocks.

3.2 CORRELATION OF GEOPHYSICAL AND CALCULATED GEOTECHNICAL PARAMETERS:

The results from electrical resistivity values obtained from field tests and the geotechnical parameters calculated were analyzed to understand the factors control these values. In this attempt, the apparent resistivity values are correlated with the geotechnical parameters such as Standard Penetration Test (N = number of blows) and moisture content and logarithm of apparent resistivity with plasticity index; angle of internal friction and hydraulic conductivity. The various correlations are shown below:

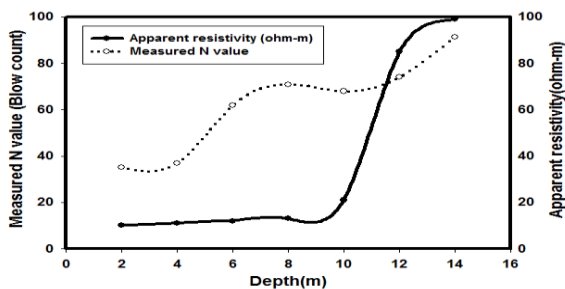


(A)

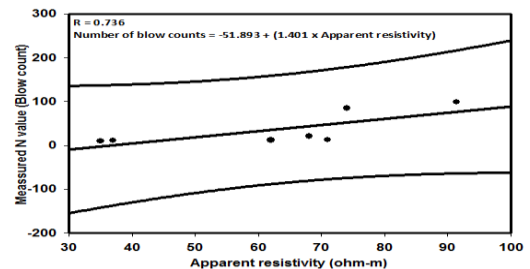


(B)

Fig.6 (A) showing the correlation between apparent resistivity and measured SPT 'N' value and 6(B) showing the comparison between measured SPT 'N' value and apparent resistivity of Burmanallah.

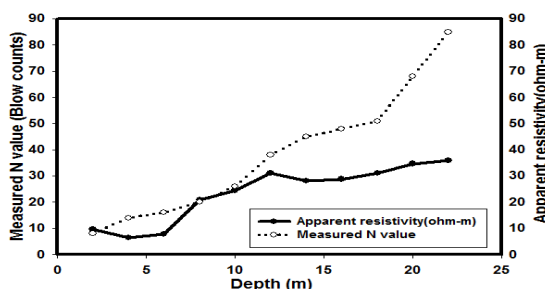


(A)

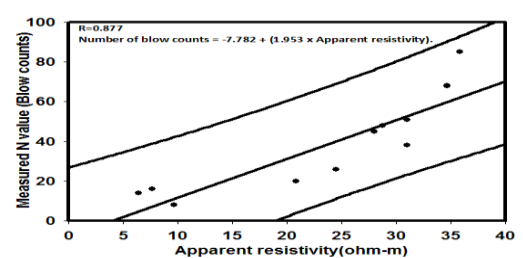


(B)

Fig.7 (A) showing the correlation between apparent resistivity and measured SPT 'N' value and 7(B) showing the comparison between measured SPT 'N' value and apparent resistivity of Brookshabad.

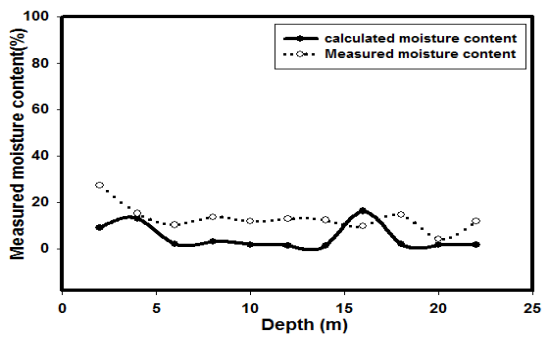


(A)



(B)

Fig.8 (A) showing the correlation between apparent resistivity and measured SPT 'N' value and 8(B) showing the comparison between measured SPT 'N' value and apparent resistivity of Kodyaghat.



(A) (B)

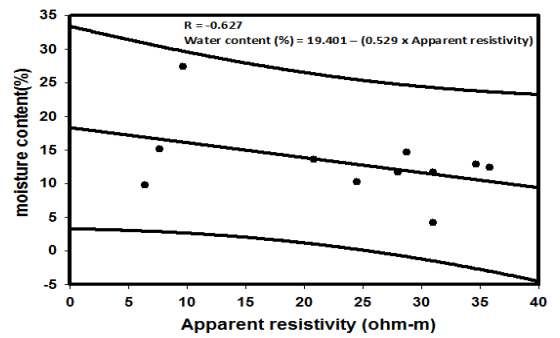
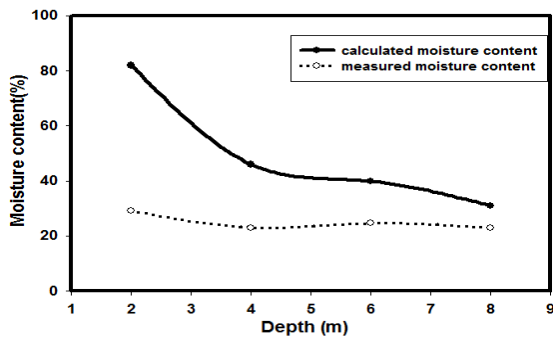
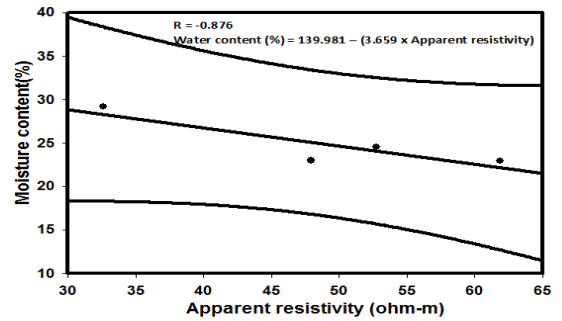


Fig.9 (A) showing the comparison between calculated and measured water content (%) and 9(B) showing the correlation between apparent resistivity and water content (%) of Kodyaghat.

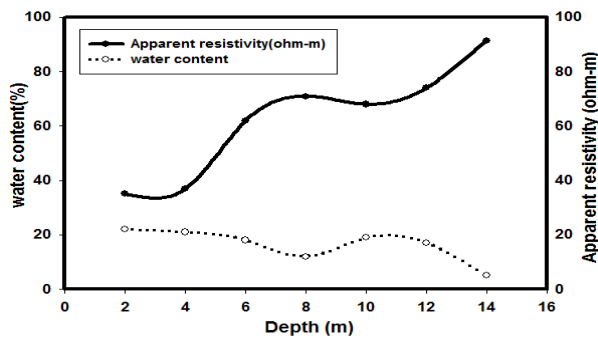


(A)

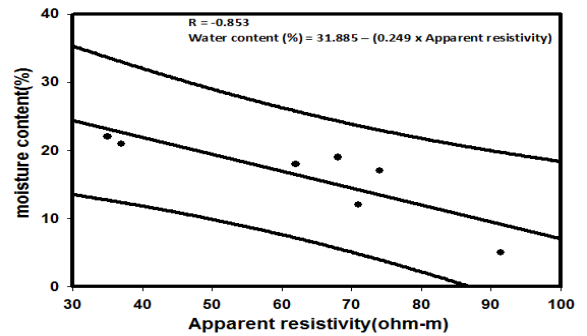


(B)

Fig.10 (A) showing the comparison between calculated and measured water content (%) and 10(B) showing the correlation between apparent resistivity and water content (%) of Burmanallah.



(A)



(B)

Fig.11 (A) showing the comparison between calculated and measured water content (%) and 11(B) showing the correlation between apparent resistivity and water content (%) of Brookshabad.

3.2.1 RESISTIVITY VS SPT (N):

Plot [Fig 8(A) and(B)](Table.4) of apparent resistivity with SPT (N) in Kodyaghat exhibit positive trends up to a depth of 13 mt, below that deviation of apparent resistivity values from the SPT (N) count and reached a maximum of N as 80 at the depth of 24 m whereas the apparent resistivity values is limited to 35 ohm. From the analysis of litho log from the 1D model of interpreted section it can be seen that weathered leached Ophiolite zone is traced up to depth of 14 mt followed by altered serpentinised clay to a depth of 20 mt underlined by fractured zone with leached out clay sized minerals up to a depth of 26mt. Up to 14 mt depth both SPT (N) and apparent resistivity data followed same positive trends, then the zone below illustrates with low resistivity values which are not accompanied by a decrease of its N value and showing a higher N value as 80. This shows very clearly the heterogeneous subsurface nature and these zone (fractured zone identified in litholog) with fracture nature contains very low moisture which are reflected by the more number of SPT (N) counts with low apparent resistivity at 20 mt depth. Correlation (Fig 8A) of

these two parameters of apparent resistivity with SPT (N) exhibit positive correlation with $R = 0.877$. The electro-stratigraphic section was carried in the Kodiyaghat region upto the depth of 75m. The SPT (N) values correlated only upto 20mt depth has followed the trend of apparent resistivity with SPT (N) blow counts. Upto 15mt depth. In the fractured zone both apparent resistivity and N counts have followed the same trend. From 14mt onwards upto 24mt resistivity value followed flat trend whereas N counts elevated steadily upwards. This may be due to presence of altered clay and fractured rocks.

For Burmanallah region (Table.6) data of SPT (N) and apparent resistivity are plotted in a plot (Fig 6 B) show the positive trends for the depth of 10 m. Measured SPT (N) varies from 10 to 28. The apparent resistivity for same zone ranges from 33 to 62 ohm. The trend of these two parameters up to 10 mt depth followed the same due availability of the homogeneous nature of subsurface. From the litholog interpretation it is seen that this zone is occupied by the altered serpentinised clay (Fig.3). Correlation (Fig 6 A) between SPT (N) with apparent resistivity values shows positive correlation, $R = 0.994$.

At Brookshabad (Table.5) showing SPT and apparent resistivity values are plotted in a plot (Fig 7 B) to a depth of 15 mt shows inconsistent trend. The apparent resistivity almost follow flat with range from 62 to 68 to a depth of 10 mt then increased to 100 ohm at 14 mt depth, whereas the SPT (N) counts fluctuate 35 to 70 in the 9 mt depth, then SPT (N) counts increased to 91 ohm-m at 14 mt. The heterogeneous nature of plot is replicated by occurrence of leached weathered Ophiolite traced upto 12 mt depth below that the occurrence of consolidated rock formation are detected from the Litholog analyses at Brookshabad region (Fig 4).

3.2.2 RESISTIVITY VS. MOISTURE CONTENT (%):

The resistivity data obtained from field and moisture content analyzed in the laboratory conditions are analyzed for three locations such as Kodiyaghat, Burmanallah and Brookshabad. Data from Kodiyaghat (Table.4) shows that the top soil within 2mt depth exhibit 27.41 % moisture content and also at 20 mt depth also moisture content nearly 4.14 %. The resistivity value for shallow depth (2mt) with high moisture content is low as 9.65 ohm and for lowest moisture content recorded at 20 mt is having 36.1 ohm-m can be seen from the analysis of electro-facies analysis of the lithology in Brookshabad (Fig.3).

At Brookshabad, the moisture content of 22 % observed at a depth of 2 mt with apparent resistivity 35.0 ohm whereas the lowest moisture content of 5% was recorded with resistivity value as 91.44 at the depth 14 mt.

Moisture content of 22.94% as minimum at 8 mt depth and recorded with resistivity value of 61.85 ohm and for highest of 29.17 % of moisture content was recorded with 32.59 ohm at Burmanallah (Table.6). In three locations the blow counts of SPT (N) recorded for the lowest moisture values have the highest number of SPT (N) counts consistently. Correlation coefficients for moisture content with resistivity calculated for three locations show negative trends $R = 0.627$; 0.876 and 0.853 for Kodiyaghat, Burmanallah and Brookshabad. This corresponds very clearly that serpentinised Ophiolite suite of rock and fractured rock containing moisture reduce the resistivity values.

The moisture contents in the soil samples measured at Kodiyaghat (Table.4) exhibit the variations from 4.14 to 27.41 %. The highest of 27.41 % of moisture was observed at 2mt depth samples, where the lowest moisture content (4.14%) was recorded at 20 mt depth samples with apparent resistivity 35 ohm. Correlation (Fig.9 A) between the apparent resistivity and moisture content (%) shows negative trends with $R = 0.627$.

Similarly the correlation for the same parameters were also carried out for the sites of Burmanallah (Table.6) and Brookshabad (Table.5). They also show the same negative trends with R values as 0.876 and 0.853 respectively. These variations of the correlation are due to the presence of moisture content and also due to different apparent resistivity values for different layers of the formation. The relationship clearly demonstrates that decrease of apparent resistivity with increase of moisture content. The higher the moisture content facilitate conduction of electric current through movement of ions in pore water (Fahad Irfan Siddiqui et al, 2012).

3.2.3 RESISTIVITY VS. PLASTICITY INDEX:

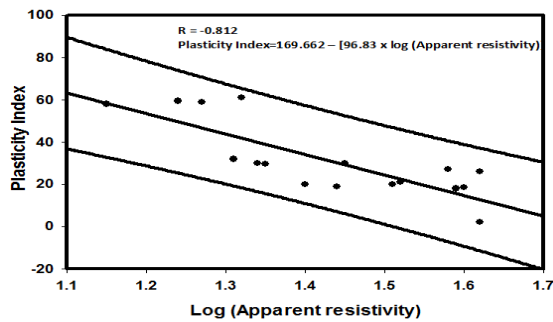
Plasticity index of the soil property vary from 1 to 63 for clay samples (Table.7) and 1 to 11.8 for sand samples (Table.8). Regression analysis in the plots for altered serpentinised clay and for leached weathered Ophiolite display negative trends with $R = 0.812$ and 0.817 correspondingly. From the analysis it can be perceived that the low plasticity would have higher resistivity. It has been reported that higher clay content more than 20% will be correspondingly to the upper limit of medium plasticity, hence the resistivity value will be low

3.2.4 RESISTIVITY VS. ANGLE OF INTERNAL FRICTION:

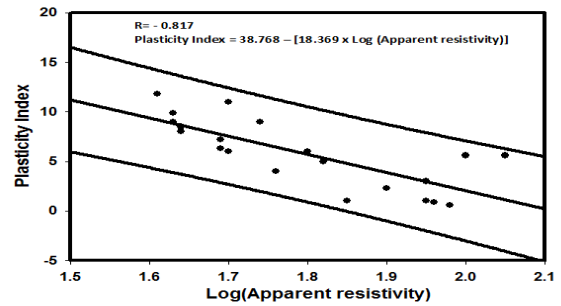
Bivariate plots between the angles of internal frictions and log of apparent resistivity were carried out for clay fraction, sand and rock separately. Though all the plots have shown positive trends with different correlation coefficient values of R values as 0.464 for clay and 0.427 for sands and 0.495 for rock samples, it is seen that the electrical resistivity increase with Angle of internal friction.

3.2.5 RESISTIVITY VS.HYDRAULIC CONDUCTIVITY:

The hydraulic conductivity and resistivity studies were conducted for serpentinised clay (Table.12), leached Ophiolite rock (Table.13) and rock (Table.14) samples. Correlation coefficient for rock exhibits the positive trends $R= 0.973$. The maximum correlation coefficient was recorded hydraulic for the parameters of resistivity of rocks vs. hydraulic conductivity in the study area. The higher hydraulic conductivity for the Ophiolite rock suit in the study area can be envisioned that accumulative of fracture opening at depth due to tectonic activity. Due to interconnectivity of the tectonic faults the accumulated water would be drained out quickly, hence the fractured rock exhibit highest correlation coefficient. The calculated hydraulic conductivity value is 0.376 m/day.

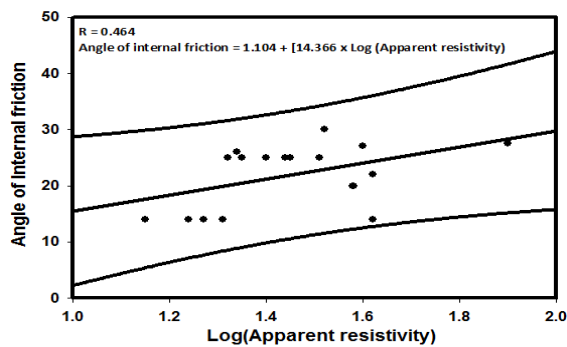


(A)

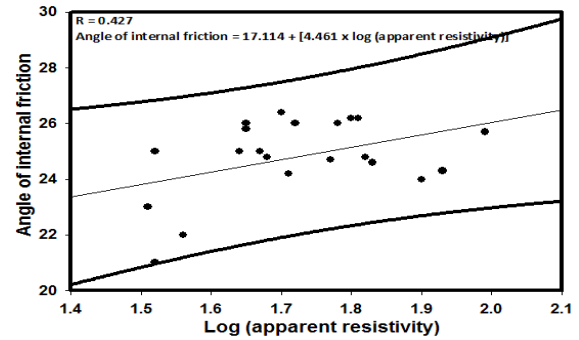


(B)

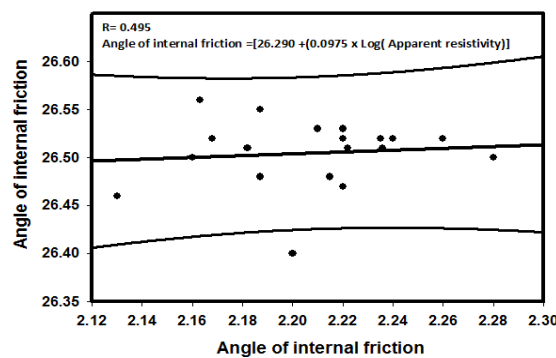
Fig. 12(A) Depicts the relation between plasticity index and apparent resistivity for altered serpentinised clay and 12(B) showing relationship between plasticity index and apparent resistivity for leached weathered ophiolite.



(A)



(B)



(C)

Fig13(A): showing the relation between apparent resistivity and Angle of internal friction for altered serpentinised clay 13(B) showing the relation between apparent resistivity and Angle of internal friction for

leached weathered ophiolite and 13(C) showing the relation between apparent resistivity and Angle of internal friction for rocks.

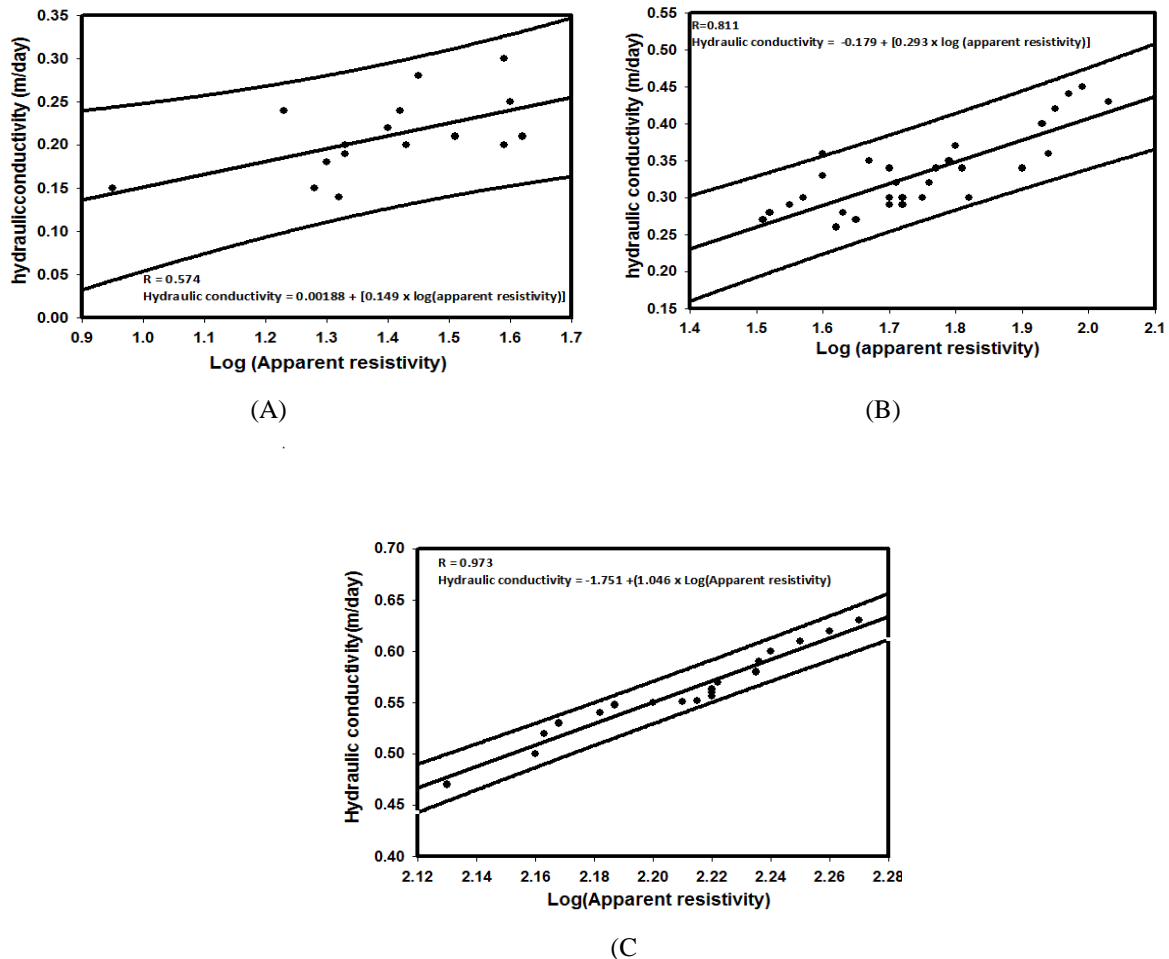


Fig.14 (A) Showing relation between Hydraulic conductivity for altered serpentinised clay, 14(B) showing relation between Hydraulic conductivity for leached weathered ophiolite and 14(C) showing relation between Hydraulic conductivity for rocks.

The number of blows measured through Standard Penetration Test as N values and resistivity values near bore well are correlated and exhibit positive correlation as $R=0.994$; 0.736 and 0.877 for Burmanallah, Brookshabad and Kodyaghat respectively. But the correlation between moisture content (%) and resistivity values showed negative correlation with $R=0.627$; 0.876 and 0.853 for Kodyaghat, Burmanallah and Brookshabad respectively. From the study it can be presumed that the high resistive zone will show a high N value.

Calculated moisture content values of soils ranged from 12.84% to 96.5% for clay with an average of 52.76 and 10.36% to 26.83% for sand with an average of 18.37%. Measured moisture content values of soils averaged 33% for clay and 20% for sand. Calculated Angle of internal friction values was 21.49° for clay which is somewhat lesser than measured angle of internal friction value of 28° by 25%. For sand these values showed 25.76° which are comparatively lower than measured value of 30° by 15%. Similarly for rocky part of the profile these parameters showed a calculated value of 26.49° which is smaller than measured value of 34° by 22%. Both measured and calculated Cohesion values produced a value of zero for both soils and rocks. The calculated hydraulic conductivity value is 0.376m/day. There is a good correlation between plasticity index and apparent resistivity with $R=0.812$ and 0.817 for clay and sand respectively. There is reasonably strong trend of reducing resistivity due to increasing plasticity. For low plasticity material the resistivity is very high. Plasticity index values of rocks produced a value of zero. There is a weak correlation between angle of internal friction and apparent resistivity with $R=0.464$ to 0.495 . The angle of internal friction depends upon the moisture content. The decrease of moisture content increases the value of resistivity. The higher moisture content facilitate

conduction of electric current ultimately reduce resistivity value. Correlation between hydraulic conductivity and apparent resistivity showed very good relationship with $R=0.973$.

III.CONCLUSION:

The objective of the study is to determine the dynamic engineering properties as well as geotechnical properties of serpentinitised Ophiolite in Andaman Island. To study this objective the Geophysical and geotechnical study linking VES, SPT (N), moisture, plasticity index, angle of internal friction, and hydraulic conductivity were carried out. This has revealed the presence of low resistivity and high resistivity zones indicating the serpentinitised clay zone, faulted and hard and compact Ophiolite rocks in the study area. Statistical correlation coefficient studies were conducted by regression analysis to evaluate the relationship between resistivity with SPT (N), plasticity, moisture, angle of internal friction and hydraulic conductivity. The delineation of clay material and hard rock identified through the Vertical Electrical Sounding indicate the presence of mechanically unstable clay and soil formation obtained from bore hole study. The presence of unstable minerals identified are inimical to the foundation of engineering structure.

In general, clay in Ophiolitic soils has slightly high swelling potential. Since clay content (%) in these sections is only about 21%, the effect of swelling potential becomes negligible altogether (Ref). Sand in these soils has low swelling potential. Usually in clayey soils internal friction angles were below 25° . Low values of angle of internal friction are due to non-drained soils in non-drained conditions. Also the presence of significant amount of clay content seems to have decreased the value of internal friction angle. Cohesion values for such soils ranged between 0 to 0.2 Mpa. Ophiolitic rocks show generally acceptable geo-mechanical behavior for any conventional excavations and foundations due to high strength properties, roughness of their contact surfaces. Due to active tectonic fault conditions, deep weathering has serpentinitised and altered the Ophiolite suite of rocks up to the depth of 75m. Hydraulic conductivity is also high due to the active tectonic faults. Weathering tends to have increased plasticity from low to intermediate and to have reduced shear strength. High resistivity zones showed consolidated formation while, low resistivity zones showed altered formations. Thus geophysical study especially, Vertical Electrical Study (VES) provide subsurface information and local geological condition and groundwater condition. These assessments are vital for risk and mitigation (Bell, 2007). The position of the water in relation to the foundation structure has an important influence on the bearing capacity. Hence integration of Geoelectrical study with Geotechnical study is an essential for any major structural design.

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APPENDIX

Table.1 shows apparent resistivity values and self-potential in Kodiyaghat

<u>s.no</u>	<u>Depth (m)</u>	<u>Apparent resistivity (ohm-m)</u>	<u>Self-potential (mV)</u>
1	5	16.21	-530
2	10	17.88	-510
3	15	22.49	-372
4	20	36.10	-132
5	25	45.15	-68
6	30	50.07	-225
7	35	52.05	-212
8	40	52.21	-352
9	45	51.22	-312
10	50	51.60	-200
11	55	69.29	115
12	60	69.21	-97
13	65	64.12	106
14	70	56.30	-164
15	75	67.15	-7

Table.2 shows apparent resistivity values and self-potential in Burmanallah.

<u>S.no</u>	<u>Depth(m)</u>	<u>Apparent resistivity(ohm-m)</u>	<u>Self-potential (mV)</u>
1	5	16.21	-197
2	10	17.88	-23
3	15	22.49	-116
4	20	36.10	24
5	25	45.15	-163
6	30	50.07	-47
7	35	52.05	-362
8	40	52.21	-294
9	45	51.22	-93
10	50	51.60	-266
11	55	69.29	-219
12	60	69.21	-127
13	65	64.12	-32
14	70	56.30	-136
15	75	67.15	-8

Table.3 shows apparent resistivity values and self-potential in Brookshabad.

S.no	Depth(m)	Apparent resistivity(ohm-m)	Self-potential (mV)
1	5	16.29	4
2	10	23.95	-7
3	15	26.36	111
4	20	30.94	83
5	25	39.84	33
6	30	38.69	389
7	35	44.08	145
8	40	52.81	-209
9	45	64.88	-380
10	50	71.34	-148
11	55	104.35	-84
12	60	71.04	50
13	65	69.06	-120
14	70	55.24	-69
15	75	50.07	-118

Table.4 shows Apparent resistivity for measured SPT 'N' value and moisture content (%) in Kodyaghat

S.no	Apparent resistivity(ohm-m)	SPT 'N' value	Depth(m)	Water content (%)
1	9.6461	8	2	27.41
2	6.4182	14	4	15.16
3	7.6490	16	6	10.27
4	20.8496	20	8	13.56
5	24.4920	26	10	11.70
6	31.0232	38	12	12.87
7	28.0088	45	14	12.35
8	28.7624	48	16	9.71
9	31.0232	51	18	14.69
10	34.6656	68	20	4.14
11	35.7960	85	22	11.70

Table.5 shows Apparent resistivity for measured SPT 'N' value and moisture content (%) in Brookshabad.

	Apparent resistivity(ohm-m)	SPT 'N' value	Depth(m)	Water content (%)
1	35.00	10	2	22
2	36.94	11	4	21
3	62.00	12	6	18
4	70.94	13	8	12
5	68.00	21	10	19
6	74.03	85	12	17
7	91.43	99	14	5

Table.6 shows Apparent resistivity for measured SPT 'N' value and moisture content (%) in Burmanallah.

S.no	Apparent resistivity(ohm-m)	SPT 'N' value	Depth(m)	Water content (%)
1	32.5967	8	2	29
2	47.9096	16	4	23
3	52.7612	21	6	25
4	61.8579	26	8	23

Table.7 shows apparent resistivity values for plasticity index values of altered serpentinised clay.

S.no	Apparent resistivity(ohm-m)	Plasticity Index
1	14.12	59
2	17.78	62
3	18.62	61
4	19.95	30
5	20.42	63
6	20.89	29
7	21.38	29
8	25.12	20
9	26.90	19
10	27.50	32
11	32.30	20
12	33.11	21
13	38.00	27
14	40.30	20
15	41.68	1
16	41.99	26

Table.8 shows apparent resistivity values with respective plasticity index values of leached weathered ophiolite.

S.no	Apparent resistivity(ohm-m)	Plasticity index
1	40.74	11.8
2	42.66	9.9
3	42.98	9.0
4	43.65	8.5
5	43.79	8.0
6	48.98	7.2
7	49.07	6.3
8	50.12	6.0
9	57.54	4.0
10	70.79	1.0
11	79.43	2.3
12	89.12	3.0
13	99.38	5.6
14	112.20	5.6
15	50.12	11.0
16	54.95	9.0
17	63.09	6.0
18	66.06	5.0
19	89.12	1.0
20	91.20	1.0
21	95.80	0.6

Table.9 shows apparent resistivity values with respective angle of friction values for altered serpentinised clay

S.no	Apparent resistivity(ohm-m)	Angle of internal friction (degrees)
1	40.74	23.0
2	42.66	25.0
3	42.98	21.0
4	43.65	22.0
5	43.79	25.0
6	48.98	25.8
7	49.07	26.0
8	50.12	25.0
9	57.54	24.8
10	70.79	26.4
11	79.43	24.2
12	89.12	26.0
13	99.38	24.7
14	112.20	26.0
15	50.12	26.2
16	54.95	26.2
17	63.09	24.8
18	66.06	24.6
19	89.12	24.0
20	91.20	24.3
21	95.80	25.7

Table.10 shows apparent resistivity values with respective angle of friction values for leached weathered ophiolite.

S.no	Apparent resistivity(ohm-m)	Angle of internal friction (degrees)
1	14.12	14.00
2	17.78	13.99
3	18.62	13.98
4	19.95	25.00
5	20.42	13.97
6	20.89	26.00
7	21.38	25.00
8	25.12	24.97
9	26.90	24.96
10	27.50	25.00
11	32.30	24.98
12	33.11	30.00
13	38.00	20.00
14	40.30	27.50
15	41.68	22.00
16	41.99	1.00

Table.11 shows apparent resistivity values with respective angle of friction values for leached weathered ophiolite.

S.no	Apparent resistivity (ohm-m)	Angle of internal friction(degrees)
1	125.89	26.42
2	138.00	26.20
3	141.00	26.55
4	147.90	26.50
5	148.00	26.56
6	151.35	26.53
7	157.29	26.52
8	159.23	26.55
9	159.50	26.48
10	164.91	26.38
11	165.51	26.53
12	167.32	26.48
13	171.29	26.63
14	172.11	26.62
15	177.28	26.57
16	181.97	26.51
17	182.00	26.48
18	186.21	26.51
19	190.50	26.53
20	194.98	26.52
21	233.87	26.53

Table.12 shows apparent resistivity values with respective angle of friction values for rocks

S.no	Apparent resistivity(ohm-m)	Hydraulic conductivity (m/day)
1	14.12	0.15
2	17.78	0.24
3	18.62	0.15
4	19.95	0.18
5	20.42	0.14
6	20.89	0.19
7	21.38	0.20
8	25.12	0.22
9	26.90	0.24
10	27.50	0.20
11	32.30	0.28
12	33.11	0.21
13	38.00	0.20
14	40.30	0.30
15	41.68	0.25
16	41.99	0.21

Table 13 shows apparent resistivity values with respective hydraulic conductivity values for altered serpentinitised clay.

S.no	Apparent resistivity(ohm-m)	Hydraulic conductivity (m/day)
1	14.12	0.15
2	17.78	0.24
3	18.62	0.15
4	19.95	0.18
5	20.42	0.14
6	20.89	0.19
7	21.38	0.20
8	25.12	0.22
9	26.90	0.24
10	27.50	0.20
11	32.30	0.28
12	33.11	0.21
13	38.00	0.20
14	40.30	0.30
15	41.68	0.25
16	41.99	0.21

Table14 shows apparent resistivity values with respective hydraulic conductivity values for altered serpentinitised clay.

<u>S.no</u>	Apparent resistivity(ohm-m)	Hydraulic conductivity (m/day)
1	40.74	0.27
2	42.66	0.28
3	42.98	0.29
4	43.65	0.30
5	43.79	0.33
6	48.98	0.36
7	49.07	0.26
8	50.12	0.28
9	57.54	0.27
10	70.79	0.35
11	79.43	0.29
12	89.12	0.30
13	99.38	0.34
14	112.20	0.32
15	50.12	0.30
16	54.95	0.29
17	63.09	0.30
18	66.06	0.32
19	89.12	0.34
20	91.20	0.35
21	95.80	0.37

Table15 shows apparent resistivity values with respective hydraulic conductivity values for altered serpentinised clay.

<u>S.no</u>	Apparent resistivity(ohm-m)	Hydraulic conductivity (m/day)
1	125.89	0.470
2	138.00	0.500
3	141.00	0.520
4	147.90	0.530
5	148.00	0.540
6	151.35	0.547
7	157.29	0.548
8	159.23	0.550
9	159.50	0.551
10	164.91	0.552
11	165.51	0.556
12	167.32	0.560
13	171.29	0.563
14	172.11	0.570
15	177.28	0.580
16	181.97	0.590
17	182.00	0.600
18	186.21	0.610
19	190.50	0.620
20	194.98	0.630
21	223.87	0.750