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Prediction of Geotechnical Properties by Using Electrical Resistivity

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***Abstract:*-- Electrical resistivity is a very effective tool for the determination of geotechnical properties of soil. Electrical resistivity of a given soil decreased with increase in water content. The increasing density leads to decrease in resistivity.The resostivity of the soil changes with the nature of the soil layer.This paper mainly focusing on the predication of water content and density from the determined resistivity value.We can represent the variation of electrical resistivity with water content and density by three dimensional representation using MATLAB.**

Index Terms:- Density, Electrical Resistivity,Matlab,Water Content

I. INTRODUCTION

Electrical resistivity of the soil can be considered as an indirect method to study the spatial and temporal variability of soil physical properties. As the method is non-destructive and very sensitive, it offers a very attractive tool for describing the subsurface properties without digging.

Electrical resistivity is an intrinsic property that quantifies how strongly a given material opposes the flow of electric current. A low resistivity indicates a material that readily allows the movement of electric charge. Electrical conductivity (or resistivity) is a bulk property of material describing how well that material allows electric currents to flow through it. It is a critical factor in the design of systems that rely on passing current through the Earth's surface. Current passes through the pores in clayey soil surface charge also take part in the current transmission. The ability to transmit ions is governed by the electrical resistivity which a basic property of all the materials and has been demonstrated to be an effective predictor of various soil properties including salinity porosity and water content.

II. THEORY

For soil, electrical resistivity depends on many factors such as porosity, electrical resistivity of the pore fluid, composition of solid, degree of saturation, particle shape and orientation and pore structure. Soil resistivity is also explained by Ohm’s law. The resistance offered by the soil against the flow of current is calculated by using Ohm’s law. Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship.

$$R=\frac{V}{I} \quad (1)$$

Many resistors and conductors have a uniform cross section with a uniform flow of electric current, and are made of one material. In this case, the electrical resistivity ρ is defined as,

$$R=\frac{\rho l}{a} \quad (2)$$

A basis for most rock resistivity studies was provided by Archie (1942), who examined the relation between resistivity and porosity in sandstone cores from the U.S. Gulf Coast region. We assume that this relation is an adequate approximation in all of our analyses. He empirically established that the resistivity of fully water-saturated sediment (R_o) to be closely proportional to the resistivity of the pore fluid (R_w):

$$R_o = F*R_w \quad (3)$$

where the proportionality constant F is called the formation factor. Furthermore, by examining core samples from different formations, Archie established an exponential empirical relationship between F and the porosity (φ):

$$F=R_o/R_w=Ø^{-m} \quad (4)$$

Keller and Frischknecht (1966) extended the Archie’s law of saturated sand and rock and developed an electrical conductance model for unsaturated soil. Expressed as,

$$\rho= a\rho_w\varphi^{-m} \quad (5)$$

Where ρ w is the resistivity of the fluid and φ porosity of soil and m and a are cementation factors

III. MATERIAL AND METHODOLOGY

Soil was collected from Puzhakkal Paddy field, Thrissur at an average depth of 1.5m from the top surface.

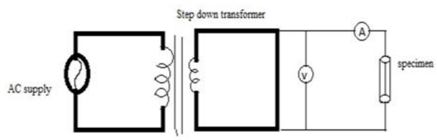

Fig. 1 Circuit diagram of soil resistivity test

Fig.1 show the circuit diagram of the experimental set up used for measuring the electrical resistivity of the soil sample. Figure 2 shows the test set up. An apparatus was constructed for measuring the electrical resistivity of the soil. A cylinder of length 10cm and diameter 5cm was used to prepare the mouldThe cylinder was constructed using poly vinyl chloride (PVC), which is an electrical insulator (electrical resistivity 1×1016□-cm).The mould filled with soil at different dry density and water content was connected to the alternating current source (AC) of 230V, frequency 50 HZ. To regulate the voltage, the source is directly connected to a step down transformer with varying voltage between 0-200V. A voltmeter of accuracy 10V is connected in parallel to the cylindrical mould. An ammeter of accuracy 0.000001A is connected in series to the specimen. AC is used because application of direct current (DC) results in electro kinetic phenomena that can cause change in water content, soil structure and pore fluid chemistry (S.Zeyad et al.(1996).

Fig. 2 Test Setup

A potential difference 10V was applied between the copper electrodes at both the ends of the cylindrical mould filled with soil. Copper electrodes of diameter 5 cm and thickness 2mm were used. The mould was filled with soil at different condition depending on the density and water content using a tamper. The current flowing through the specimen for each voltage increment was measured from the ammeter. Electrical resistance R is then computed using ohm's law. And from the electrical resistance, electrical resistivity was calculated.

Wenner four electrodes array was used to measure the electrical resistivity from the field condition. Field condition was created in a test tank made up of glass (39cm x 39xm x 70cm) This was done to check the relation between the resistivity found by using the cylindrical mould and the resistivity in the field.

Soil was filled at a known depth, water content up to 8.5cm high and 4 electrodes of diameter 4mm and length 13 cm spaced at varying distance .The inner potential electrode was connected to the volt meter and outer current electrode was connected to the ammeter. An AC source of same accuracy is used to measure the resistivity of the sample in the mould as shown in figure

Soil resistivity measured in double layer shown in Fig. 3.

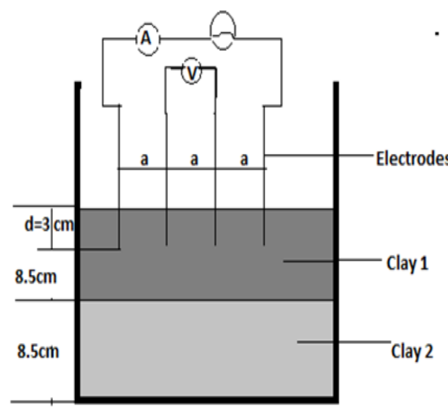

Fig. 3. Circuit diagram of field setup double- Wenner arrangement

Two soil samples are filled in different layers. Electrode spacing was charged and corresponding voltmeter and ammeter reading were measured. Using this value, the electrical resistivity was computed.

To check the accuracy of test set up a validation test was carried out. A wire of length 9.8 cm was inserted in the test mould. Voltage was applied across the copper disc and ammeter reading was measured and it was combined with the recorded value. Both the values were the same.

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IV. RESULT AND DISCUSSION

Properties of soil are given below.

Table 1 Properties of soil

Properties	Values
Specific gravity ,G	2.25
Liquid Limit ,W_L (%)	51.00
Plastic Limit, W_P (%)	31.00
Shrinkage Limit, W_S (%)	20.00
Plasticity Index, I_P (%)	20
Clay %	35
Silt %	49
Sand%	16
Soil type	MH
Optimum moisture content %	23
Maximum dry density (kN/m^3)	15.8
Unconfined compressive strength (KN/m^2)	22.20

4.1 Variation of Electrical Resistivity with Density

Fig. 4 shows the variation of electrical resistivity with density. Study was carried out under densities 1.2g/cm3, 1.3g/cm3, 1.4g/cm3 ,1.5 g/cm3 and 1.58 g/cm3. Resistivity was measured for the water content 5%, 10%, 20%, 30%, and 40%, at 5 different densities.

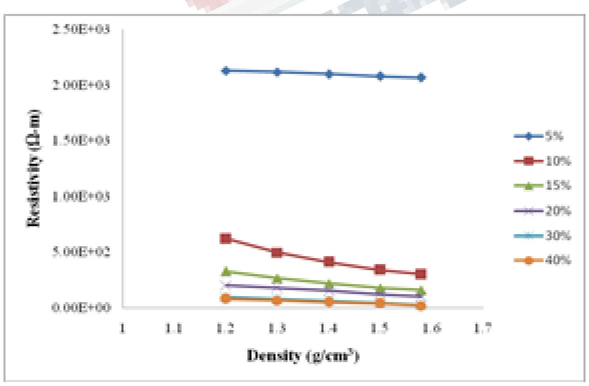

Fig. 4 Variation of electrical resistivity with density at constant water content

First line indicates the variation of electrical resistivity for 5% water content at density 1.2g/cm3, 1.3g/cm3,1.4 g/cm3,1.5 g/cm3,1.58g/cm3. Test was repeated for 5 different water contents. From the first line, for 5% water content resistivity various from 2.02 ×103 Ω-cm to 2.2 × 103 Ω-cm. The variation of electrical resistivity is less with the change in density. In all cases, increasing density leads to decrease in resistivity. But combining the 5% line and 10% line the resistivity variation is very high and from that it is clear that water content have more influence on resistivity than density. Compaction effort leads to change in the structure of soil. At higher compaction effort soil particles come closer and as a result void ratio decreases and the electric conduction increases. It leads to decrease the electrical resistivity of soil at higher temperature.

4.2 Variation of Electrical Resistivity with Moisture Content

Fig 5 shows the variation of electrical resistivity with water content. Water content varied for density 1.2g/cm3 to 1.58 g/cm3 and corresponding resistivity values were noted down. Electrical resistivity decreases with increase in water content. Up to 25% water content, the rate of decrease of electrical resistivity is high and after that it is nearly equal to its shrinkage limit. Reaching shrinkage limit most of the voids are filled with water. After that the conduction remains almost in a uniform manner. In soil the electrical charge flows through two paths. One is through the path of the water and the other is through the surface of the clay. As a result, increase in water content came to decrease in the soil resistivity. After reaching near to the liquid limit the resistivity change is insignificant. Reaching near to the liquid limit the flow of electricity is maximum independent of other variables.

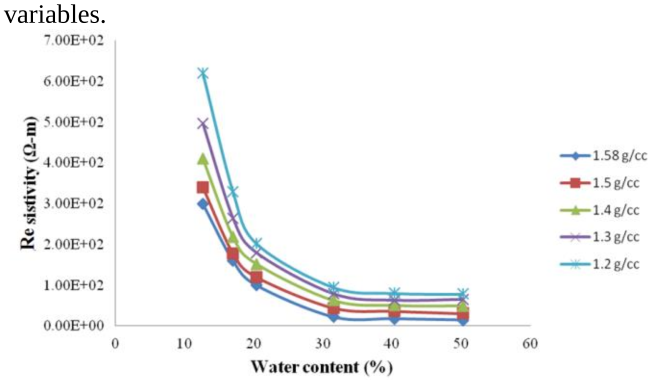

Fig. 5 Variation of electrical resistivity with moisture content at constant density

Fig 6 shows the variation of electrical resistivity with water content and density. Electrical resistivity deceases with

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increase in water content and density. Three dimension variations are shown in the figure.

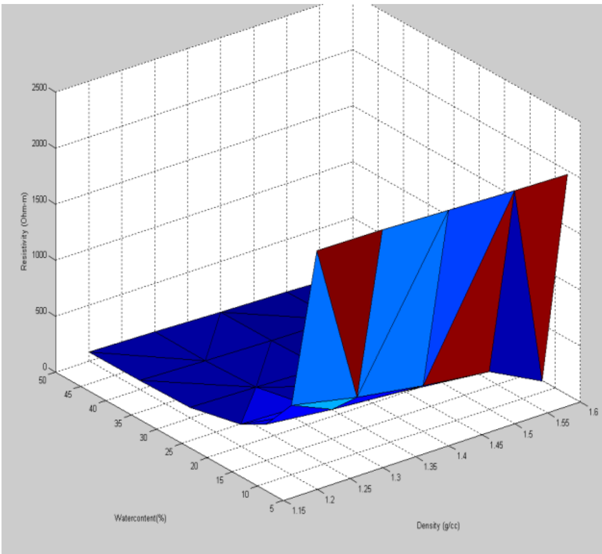

Fig. 6 Three dimensional surface arrangement of points

4.3Double Layer of Soil

Fig 7 shows the variation of electrical resistivity for the spacing 1.5 to 13.5 in equal internets of 1.5cm. First layer was filled up to 8.5 cm with soil 1. The density of the first soil layer was 1.3g/cm3 and water content 5%. Layer 2 was filled with soil 2 of density 1.3g/cm3 and water content 50% up to 8.5cm height. From figure up to 4.5 cm spacing the resistivity obtained is 2.40x 105 Ω-cm. Then it is suddenly decreased to 1.25x 102 Ω-cm at 13.5 cm spacing.

First layer was filled up to 8.5cm length. Electrode was inserted with 3cm depth. Reaching up to 4.5cm in spacing (total depth 4.5+3) it belongs to the same soil layer. So it shows the same electrical resistivity. the he layer was changed after that . After 4.5 it shows another resistivity corresponding to soil 2. From the variation of resistivity and the spacing of electrode it is easy to identify the type of soil and depth of soil.

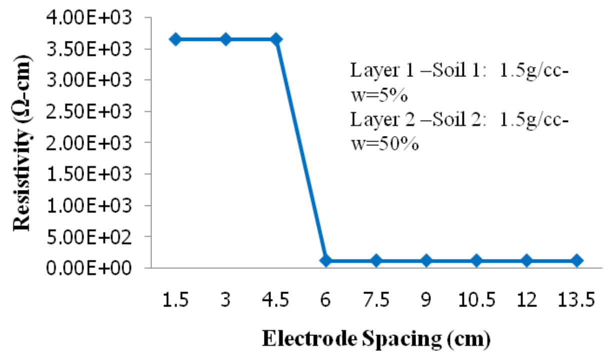

Fig. 7 Variation of electrical resistivity with spacing of electrode

In Fig 8 up to 4.5 cm spacing the electrical resistivity is 6.89 × 103Ω-cm and after 4.5cm spacing up to 13.5cm spacing electrical resistivity is 3.07 × 103Ω-cm. In this case first layer was filled with soil 2 (Coimbatore) of density 1.5g/cm3 and water content 5%. Second layer was filled with soil 1 (puzhakkal clay) of density 1.5g/cm3 and water content 50%. Electrical resistivity difference indicates the soil layer difference. Electrode spacing indicates the depth of each layer.

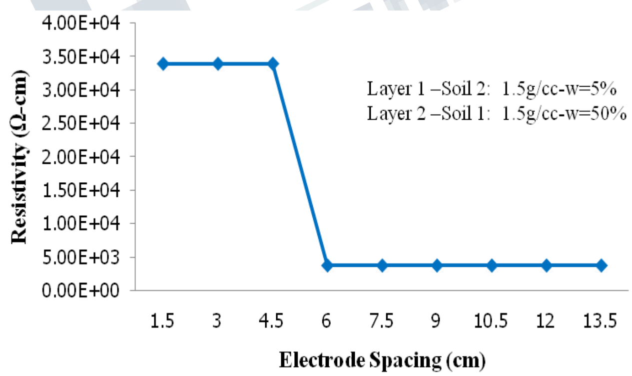

Fig. 8 Variation of electrical resistivity with spacing of electrode

In Fig 9, up to 4.5 cm spacing the electrical resistivity is 2.10 × 105Ω-cm and after 4.5cm spacing up to 13.5cm spacing electrical resistivity is 1.55 × 102Ω-cm. In this case first layer was filled with soil 1 of density 1.4g/cm3 and water content 5%. Second layer was filled with soil 2 of density 1.4 g/cm3 and water content 50%. Electrical resistivity difference indicates the soil layer difference. Electrode spacing indicates the depth of each layer.

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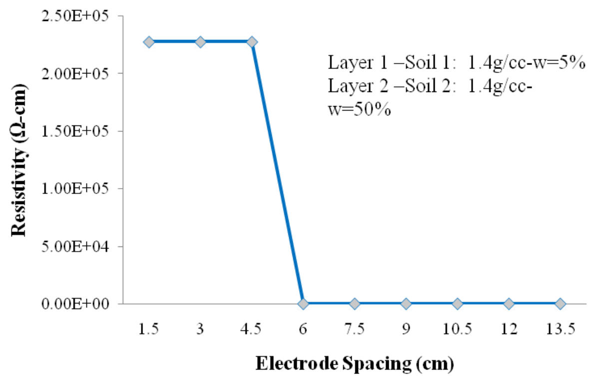

Fig. 9 Variation of electrical resistivity with spacing of electrode

In Fig 10, up to 4.5 cm spacing the electrical resistivity is 2.13 × 105Ω-cm and after 4.5cm spacing up to 13.5cm spacing electrical resistivity is 1.69 × 102Ω-cm. In this case first layer was filled with soil 1 of density 1.3g/cm3 and water content 5%. Second layer was filled with soil 2 of density 1.3 g/cm3 and water content 50%. Electrical resistivity difference indicates the soil layer difference. Electrode spacing is indicating the depth of each layer.

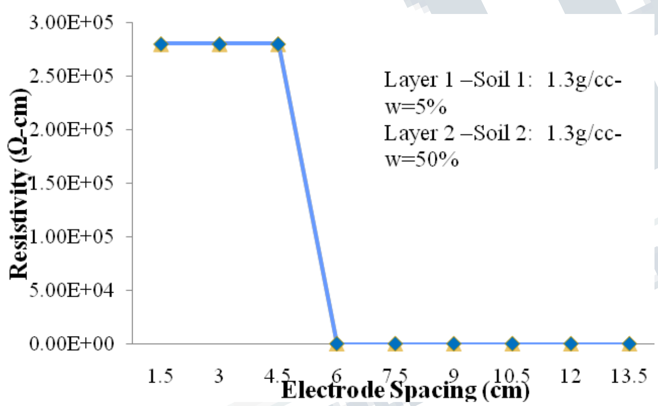

Fig. 10 Variation of electrical resistivity with spacing of electrode

In Fig .11, up to 4.5 cm spacing the electrical resistivity is 3.38 × 104Ω-cm and after 4.5cm spacing up to 13.5cm spacing electrical resistivity is 3.77 × 103Ω-cm. In this case first layer was filled with soil 1 of density 1.5g/cm3 and water content 10%. Second layer was filled with soil 2 of density 1.5 g/cm3 and water content 10%. Electrical resistivity difference indicates the soil layer difference. Electrode spacing is indicating the depth of each layer.

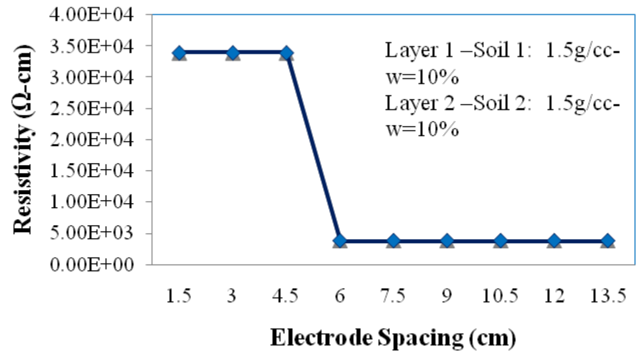

Fig. 11 Variation of electrical resistivity with spacing of electrode

In Fig .12, up to 4.5 cm spacing the electrical resistivity is 4.10 × 104 Ω-cm and after 4.5cm spacing up to 13.5cm spacing electrical resistivity is 4.55 × 103 Ω-cm. In this case first layer was filled with soil 1 of density 1.4g/cm3 and water content 10%. Second layer was filled with soil 2 of density 1.4 g/cm3 and water content 10%.

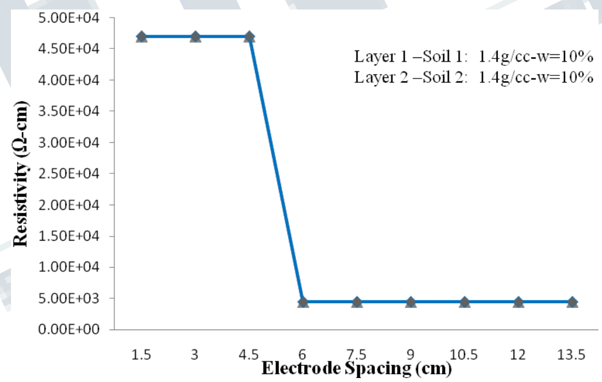

Fig. 12 Variation of electrical resistivity with spacing of electrode

In Fig .13, up to 4.5 cm spacing the electrical resistivity is 4.19 × 104Ω-cm and after 4.5cm spacing up to 13.5cm spacing electrical resistivity is 4.90 × 103Ω-cm. In this case first layer was filled with soil 1 of density 1.3g/cm3 and water content 10%. Second layer was filled with soil 2 of density 1.3 g/cm3 and water content 10%..

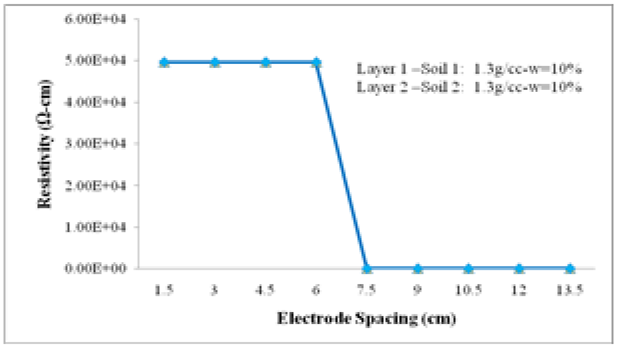

Fig. 13 Variation of electrical resistivity with spacing of electrode

Table 4.6 shows the electrical resistivity obtained from the test setup and field measurement of double layer of soils. Resistivity obtained from both the cases having almost the same. So we can use the resistivity values obtained from the cylindrical sample measurement to correlate with the field electrical resistivity.

4.4 PROGRAMME USING MATLAB FOR DIRECT MEASUREMENT OF DENSITY AND RESISTIVITY

From previous discussion it is clear that a unique relation exists between electrical resistivity, density and water content. Electrical resistivity of soils obtained from the laboratory measurement and the values obtained from the field setup almost have the equal value. So the electrical resistivity obtained from laboratory can be used as reference value. Graphs give a pattern of variation of electrical resistivity with different parameters. A programme was developed to find the value directly using the Matlab. In this programme if we are giving the resistivity value as input, then get water contentment and density get as output value.
In the programme resistivity of soil was defined by X while Y and Z defining the density and water content respectively. Looping was formed in between the X,Y and Z variables. From the preliminary studies of resistivity of soil at different conditions, a relation was formed between the variables. The same procedure was done in the case of both soils. Different steps are given below.

- Puzhakkal clay

Step 1: Defined the function
Step 2: Defined (X,Y,Z) ;X is the resistance in Ω-m
Y is the density in g/cc
Z is the water content in %
Step 3: Defined the relation between X,Y

Step 4: After getting value of y ,relation defined between x ,y and z

```
    if y>1.58
      Z= (x/33430).^-1/-2.67;
      set(handles.text2,'String',Z);
  end
  if y>1.49 & y<1.59
      Z= (x/11601).^-1/2.20
      set(handles.text2,'String',Z);
  end
  if y>1.39 & y<1.51
      Z= (x/77897)-1/-1.99 ;
      set(handles.text2,'String',Z);
  end
  if y>1.29 & y<1.41
      Z= (x/65870).^-1/-1.87;
      set(handles.text2,'String',Z);
  end
  if y<1.2
      Z= (x/62607).^-1/1.80;
      set(handles.text2,'String',Z);
  end
```

Step 5: Run the programme
A window showing space to enter the resistance value in Ω-m will appear as shown in figure 4.44.

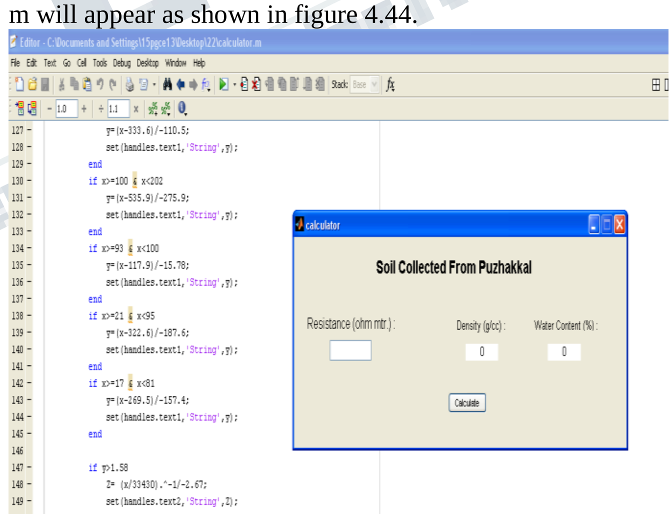

Fig. 4.44 Opening window

Step 6: Input the resistance value in Ω-m
An opening window will appear as shown in figure 4.45. Input the resistance value in Ω-m.

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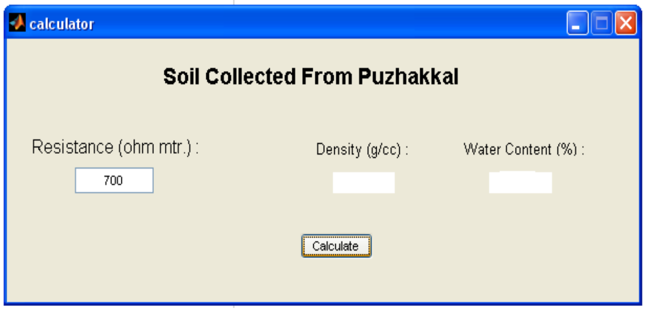

Fig. 4.45 Input window

Step 7: Get the out put value of density in g/cc and water content in %.
Output window is shown in figure 4.46.

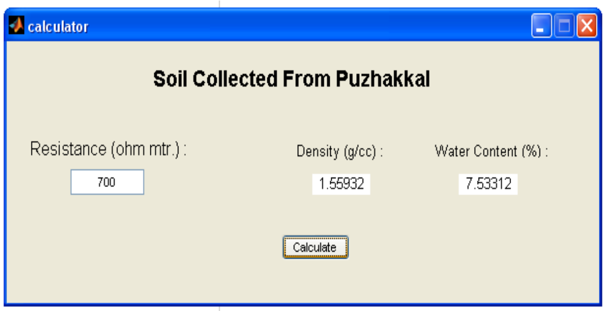

Fig. 4.46 Output window

CONCLUSIONS

The electrical resistivity of Puzhakkal clay varied from 7.85E+03Ω-cm to 2.07E+05Ω-cm. At constant density the electrical resistivity of soils decreased with increase in water content .The rate of decrease in electrical resistivity is high till the shrinkage limit is reached and after that it almost remains the same. The decrease in electrical resistivity is due to the increase in electrolytic conduction at high water contents. The variation of electrical resistivity is less with the change in density of soil at constant water content. In all causes increasing density lead to decrease in resistivity. Electrical resistivity of both the soils has inverse relation with degree of saturation. This is due to the better packing of soil particles and lower void ratio which results in better conduction.Programme was developed in Matlab to calculate the density and water content from electrical resistivity value using the existing database for the two soils. If the resistivity of soil is given as input value, then the density and water content of the soil can be obtained as output values

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