Correlation between Electrical Resistivity and Suction for Unsaturated Coastal Saline Soil

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Abstract. An experimental research on joint application of engineering-geological and geophysical measurements is presented in this paper. Experimental results obtained from the filter paper method and four electrode resistivity measurements were presented to characterize unsaturated saline soil samples collected in a test area in Lian Yungang City (in Jiangsu Province), which aimed at defining both soil suction and electrical resistivity curves versus water content at different salt contents. From the matching of the experimental data, the relationships between electrical resistivity and suctions were retrieved for the investigated soil. It was concluded that suctions increase with the increase of electrical resistivity and the increase of soil salt content. The outcomes of the study would provide proper understanding about the influence of physical characteristics of unsaturated soils on their electrical responses.

1. Introduction

The unsaturated soil, which is located above the groundwater table and composed of soil particles, water and air, exhibit more complex properties due to negative pore water pressure described as suction when compared to saturated soil. In engineering practice, soil suction is composed of two components: matric and osmotic suction [1]. The sum of matric and osmotic suction is called total suction. Matric suction comes from the capillarity, texture, and surface adsorptive forces of the soil. Osmotic suction arises from the dissolved salts contained in the soil water. If the salt content in a soil change, there will be a change of osmotic suction.

A soil-water characteristic curve (SWCC) which relates the water content of a soil to suction is an important relationship for the unsaturated soil mechanics. The SWCC essentially shows the ability of an unsaturated soil to retain water under various suctions. There are many soil suction measure techniques and instruments in the fields of soil science and engineering. Most of these instruments
have limitations with regard to the range of measurement, equilibration times, and cost. The filter paper method is a soil suction measure technique, which can cover the practical suction range, be adopted as a basis for routine testing, and is inexpensive.

The situ testing, the laboratory testing and the geophysical methods are three ways to measure soil's properties. Recently, the interest in introducing electrical resistivity measurement to measure the properties of soil has increased markedly. The electrical resistivity measurement is a non-destructive testing technology and a very convenient tool for describing water content, porosity, saturation, type and mineral compositions of soils, which has a great significance in theory and application prospects due to the great technical, continuous, rapid and economic advantages. It has been used to predict the matrix suction of unsaturated soil as an effective tool to recognise the hydrological state of larger and more representative soil volumes and to improve early warning of dangerous slope movements [2].

Soil suction and resistivity strongly depend on the degree of soil saturation and; therefore, both are used for estimating water content variations; it is reasonable to ask if they are correlated. However, the laboratory studies of electrical resistivity on unsaturated soils such as shedi soil, shedi soil blends with river sand, silty soil, white clay, pyroclastic soils, Berea sandstone, quartz and limestone rock specimens have been carried out [2-7], but saline soil is rarely reported.

Soil samples were collected and were investigated for geotechnical and electrical resistivity studies by adding different percentage of water to them. The laboratory analyses were aimed at defining both soil water retention and electrical resistivity curves versus water content, establishing a direct relationship between electrical resistivity and suction for the unsaturated coastal saline soil.

2. Test material and apparatus

2.1. Text material
The coastal saline soil in the current study was collected from Lian Yungang, which is located in Jiangsu Province, a district near to Huanghai. The results of the geotechnical tests conducted as per the IS Specification are presented in Table 1.

Table 1. Physical properties of coastal saline soil

| Parameter | Specific Gravity | Sand (%) | Silt (%) | Clay (%) | Plastic limit(%) | Liquid limit(%) | Plasticity index(%) | USCS |
|-----------|-----------------|----------|----------|----------|------------------|----------------|---------------------|------|
| Specification | 2.633 | 4       | 23.14    | 72.86    | 24.23            | 48.59          | 24.36               | SCL  |

2.2. Text apparatus
2.2.1. Soil suction measurements. The filter paper method has long been used in soil science and engineering practice, and it has recently been accepted as an adaptable test method for soil suction measurements because of its advantages over other suction measurement devices. The test principle of it is shown in Figure 1. Basically, the filter paper comes to equilibrium with the soil either through vapour (total suction measurement) or liquid (matric suction measurement) flow. At equilibrium, the suction value of the filter paper and the soil will be equal. After equilibrium is established between the filter paper and the soil, the water content of the filter paper disc is measured. Then, by using a filter
paper water content versus a suction calibration curve, the corresponding suction value is found from the curve.

The "Shuangquan" No.203 quantitative filter paper of Hangzhou Xinhua paper mill was used in the test. The total suction and matric suction of saline soil were obtained by the contact method and the uncontact method from the calibration curve of the filter paper [8]. Both metric and total suction measurements can be performed on the same soil sample in a glass jar as shown in Figure 2. A testing procedure for matric suction measurements using filter papers can be outlined as suggested by ASTM Standard Test Method [1].

![Figure 1. Principle of suction measurement](image1.png)

![Figure 2. Total and matric suction measurements](image2.png)

2.2.2. Electrical resistivity measurement equipment. The apparatus for measuring the electrical resistivity of soils in the laboratory is based on the Wenner array experimental setup (Figure 3). Measurements of the voltage and current were taken directly from the WDDS-1 digital resistivity instrument produced by Chongqing Pentium Numerical Control Technology Research Institute. The electrical resistivity was then evaluated using an equation derived from Ohm’s law [9].
3. Results and discussions

3.1. Relation between suctions and water content

The tests described in the previous section were carried out on the saline soil. The variation of the total suction with volumetric water content at different percentages of salt content for saline soil was shown in Figure 4. The relationships indicate that a decrease of total suction with an increase of volumetric water content and a decrease of soil salt content.

![Figure 4](image-url)  
**Figure 4.** Relationship between the total suction and volumetric water content at the different salt content

The same trend was observed in Figure 5 for the relationship between the osmotic suction and volumetric water content.
Figure 5. Relationship between the osmotic suction and volumetric water content at the different salt content

Figure 6 was for the relationship between the matric suction and volumetric water content. The curve basically coincides between matric suction and volumetric water content at different salt content. It was noticed that when salt exists in the soil, there was a noticeable increase in both total suction and osmotic suction. But there was little change in matric suction. That is the same conclusion as the study of S. De’an [10], but differ from those of M. Y. Fattah.

3.2. Relation between electrical resistivity and water content

Based on the analysis of the test data, the electrical resistivity of the unsaturated coastal saline soil sample as a function of the volumetric water content was shown in Figure 7. As it can be seen, experimental data show the increasing behaviour of electrical resistivity with the decreasing of the volumetric water content, for the samples at the salt content of 4.6%, electrical resistivity varies from a maximum value of 15.213Ω·m to a minimum value of 2.182Ω·m. The smallest values of electrical resistivity were reached for the volumetric water content of 38.142%; the largest values of electrical resistivity were reached for the volumetric water content of 14.713%. The correlation between them filed the exponential function. For the samples at the salt content of 3.7%, the electrical resistivity decrease from 89.55Ω·m to 3.5Ω·m as volumetric water content increase from 15.66% to 40.284%, and the samples at the salt content of 1.5%, as the volumetric water content increase from 17.3% to 42.689%, the electrical resistivity decrease from 232.975Ω·m to 8.75Ω·m, both were fit for exponential function. Experimental electrical resistivity results show a hierarchy of values dependent on sample salt content [11].
Figure 6. Relationship between the matric suction and volumetric water content at the different salt content

Figure 7. Relationship between volumetric water content and electrical resistivity of saline soil at the different salt content

There are many factors affecting the electrical resistivity of the soil. Generally considered, electrical resistivity of unsaturated soil is influenced by pore water from three aspects, which are 1) affecting the cross sectional area of conductive path and charged ions in solution viscosity, 2) affecting the original charged ions type and quantity in pore water, and 3) affecting the type and quantity of charged ions in soils. When the volumetric water content is lower, most pore space is filled with air, which decreases the effective sectional area of conductive path and the amount and type of charge ions in aqueous solution, so unsaturated soil is primarily dependent on the conductivity of soil particle surface, and the electrical resistivity is very large. When the volumetric water content increases, especially when salt content increases, water form a sort of fluid conduction channel, which increases
the sectional area of conductive path and the amount and type of charged ions in water and reduces the solution viscosity, so the electrical resistivity is decreased. When the volumetric water content increases further, the water is in continuous state and has little effect on the electrical resistivity due to it is a conductor, so for the coastal saline soil studied in this paper when volumetric water content larger than 40% the change of the electrical resistivity tends to be stable, and reaches to a constant [12].

3.3. Relation between electrical resistivity and suctions
The correlation between electrical resistivity and soil suction has been investigated on saline soil samples. The relationships between electrical resistivity and suctions were shown in Figure 8 to Figure 10. Graphical correlations shown complex nonlinear relationship between suctions and electrical resistivity that was an increase of suction with an increase of electrical resistivity and an increase of soil salt content.

Figure 8. Relationship between total suction and electrical resistivity at the different salt content

Figure 9. Relationship between matric suction and electrical resistivity at the different salt content
Figure 10. Relationship between osmotic suction and electrical resistivity at the different salt content

We notice when the salt content was 4.6%, the saline soil shows the largest variations in total suction, matric suction and osmotic suction when electrical resistivity value smaller than 10 Ω·m, basically conform to the power function relationship (Figure 11). When the salt content was 1.5%, the electrical resistivity of saline soil shows slow increasing with the increase of suctions, especially when the resistivity was greater than 100 Ω·m (Figure 12). It was also worth noticing that for the salt content of 3.7%, the relationship between resistivity and suction was between the two salt levels (Figure 13).

Figure 11. Relationship between suction and electrical resistivity at the salt content of 4.6%
It can be seen from the above research results that the relationship between resistivity and suction changes significantly at high salt content.

4. Conclusions

In conclusion, the results presented in this paper demonstrated that an integration of engineering geological and geophysical methods can provide useful information for the saline soil response to different water contents. In particular, our analysis reveals the existence of a possible link between the geotechnical and geophysical approaches for the study of coastal geology analysis. This paper studies the properties of unsaturated saline soil. Research shows that the suction increases with the decrease of the volumetric water content at different soil content. The increasing behaviour of electrical resistivity with the decreasing of the volumetric water content. And suction increases with increases in electrical resistivity and decreases in soil salt content.
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