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Full Length Research Paper

Correlation between electrical resistivity and soil-water content: Istanbul and Golcuk

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Soil is a heterogeneous medium which consist of liquid, solid, and gaseous phases. The solid and liquid phases play an essential role in soil spontaneous electrical phenomena and in behavior of electrical fields, artificially created in soil. Soil air can be considered as a dielectric. Soil electrical properties are the parameters of natural and artificially created electrical fields in soils and influenced by distribution of mobile electrical charges, mostly inorganic ions, in soils. Geophysical methods of vertical electrical sounding were used for measuring soil electrical properties and tested in different soil studies. For our aim, study area is selected in Istanbul (Yesilkoy, Florya, Basinkoy) and Golcuk. In this area, the electrical resistivity is measured by VES (Vertical Electrical Sounding) and in many points of this location by McPHAR resistivity equipment. For geotechnical purposes, on the soil samples from borings, it was applied soil mechanics laboratory procedures and the soil water contents are determined from these samples. Relationships between soil water content and electrical parameters were obtained by curvilinear models. The ranges of our samples are changed between 1 - 50 ohm .m (for resistivity) and 20 - 60 %(for water content). For this range, the relation between resistivity (R) and water content (W) of soils is found to be given as $W = 49, 21e^{-0,017R}$.

Key words: Soil electrical resistivity, water content, Istanbul and Golcuk (Turkey).

INTRODUCTION

Engineering properties of geomaterials are very important for civil engineers because almost everything they build; tunnels, bridges, dams and others are in, on or with soils or rocks. For geotechnical engineers, the strength, the stress-deformation behavior and the fluid flow properties of earth materials are of primary concern and form the conventional framework of the geotechnical discipline (Mitchell, 2004). Conventional techniques for the determination of these engineering properties can be generally divided into three categories; laboratory tests, *in-situ* tests and geophysical methods. Of these, geophysical methods have been least developed as regards to their suitability for specific quantification of soil properties (Liu, 2007). Laboratory tests have the advantages of directly measuring the specified engineering properties under controlled boundary conditions and different environmenttal conditions. However, soil samples are usually disturbed during the drilling and sampling processes, which may make the measured engineering properties, deviate from their actual values (Liu, 2007).

Natural geomaterials whose skeletons form the primary structure to supports loadings consists of various solid mineral particles with diverse size, shape and arrangement, while multiple phases of pore fluids fill in their voids, such as air, water and solutions (Dong, 2006).

Many kinds of electrical fields and potentials are often simultaneously observed in natural soil; thus, it is difficult to know what mechanism is responsible for their formation (Semenov, 1980). Electrical conductivity and resistivity of soils have been investigated in a large number of studies, which can be divided into three groups. The first group includes laboratory studies of electrical conductivity and dielectric constant of different dispersed media (including soils) with electromagnetic waves (Jumikis, 1977; Palmer and Blanchar, 1980; Campbell, 1990). These studies help to develop relationship between electrical parameters, quantitative and qualitative compositions of electrolytic solutions (Chang et al., 1983). The relationships were enhanced by the studies of soil electrical parameters with constant electrical field (Rhoades et al., 1976).

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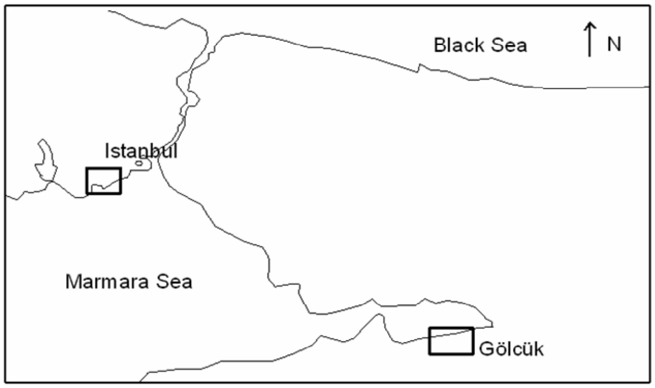

Figure 1. Location map of study areas.

For some diluted soil solutions and groundwaters, the methods are developed to calculate electrical conductivity from the solution compositions. Electrical conductivity of the extracted soil solutions have been studied vigorously (Cambell et al., 1948; Larsen and Widdowson, 1965; Rhoades et al., 1976; Rhoades et al., 1990). The second group of studies is devoted to laboratory measurements of surface electrical conductivity. The surface electrical conductivity is a major parameter describing structure of electrical double layer and its ion composition. There is only limited special research with experimental measurements of surface electrical conductivity in soils (Troizhky, 1979).The third group of studies includes measurements of electrical conductivity of soils, rocks, and sediments *in situ* with various geophysical methods (Pozdnyakova et al., 1996; Pozdnyakova, 1999).

In the literature the various models proposed to describe relationships between electrical parameters and soil water content, temperature, or salt content. Electrical conductivity and resistivity are usually measured as electrical parameters in laboratory and field conditions. Relationships between soil water content and electrical parameters were measured in field and laboratory conditions and mostly curvilinear models were obtained. Curvilinear relationships were also proposed between electrical resistivity and temperature (Raisov, 1973; Wells, 1978). But, Ananyan (1961) derived and experimentally proved exponential relationship between electrical resistivity, soil temperature, and water content based on a series of experiments.

The assessment of soil water content variations more and more leans on geophysical methods that are non invasive and that allow a high spatial sampling. Among the different methods, Direct Current (DC) electrical imaging is moving forward. DC Electrical resistivity shows indeed strong seasonal variations that principally depend on soil water content variations (Robain et al., 2003). Although there are many studies between electrical resistivity and water content of agricultural soils, on geotechnical or engineering soils there are little attentions (Asci et al., 2004a, b; Ozcep et al. 2005; Liu et al., 2006).

Background and objective of this study intends the relationships between electrical resistivity and soil-water content in context of electrical properties of coarse-grained (sandy) soils and to develop practically applicable relation for the determination of soil water content from geoelectrical measurements (in some sites in Turkey). In this study, our analysis is conducted to set the relationships between soil electrical resistivity and water content.

STUDY AREAS

Our study area is located in Istanbul (Yesilkoy, Florya, Basinkoy) and Golcuk areas). Location map of study areas are given in Figure 1. Since the 1999 Izmit and Düzce earthquakes in northwest Turkey, many seismic hazard studies have focused on the city of Istanbul. An important issue in this respect is local site effects: strong amplifications are expected at a number of locations due to the local geological conditions (Sorensen et al., 2006). The Izmit earthquake of August 17, 1999 destroyed the masonry houses, and residential and office buildings in the northwest area of Turkey. In Golcuk, Kocaeli Province, in particular, a large number of medium-rise buildings sustained either partial or complete collapse typically of a soft first story. The concentration of the building damage could be due to the effects of surface geology on ground motions, that is, so-called “site effects.” In fact, most of the northern area of the main street is located on a plain while the south is on a hill, where the building damage was slight (Arai and Pulido, 2006). One example is the heavy damage to buildings in Avcilar, west of Istanbul, which is relatively far (150 km) from the source (Cranswick et al., 2000).

RESEARCH METHOD

In geotechnical engineering, water content determination is a routine laboratory test to determine the amount of water present in a quantity of soil in terms of its dry mass (Bowles, 1992). As a definition,

$$W = MW / MS \times 100\%$$

Where MW is the mass of water present in soil mass (g) and Ms is the mass of soil solids (g). On the other hand, electrical resistivity of any material is defined as the electrical resistance of a cylinder with a cross section of unit area and with unit length. In most earth materials, porosity and chemical content of water filling the pore spaces are more important in governing resistivity than is the conductivity of mineral grains of which the material itself is composed (Dobrin, 1988).

Electrical resistivity is measured by VES (Vertical Electrical Sounding) in 210 points of this location by McPHAR resistivity equipment in a microzonation project (Bayat, 2000). For geotechnical purposes, boring was carried out in this region and it was applied soil mechanics laboratory procedures on the soil samples from borings, and the soil water contents is determined from these samples. Soil samples are selected from only sandy soils. In Figures 2, 3 and 4, the obtained relations are given.

RESULTS AND DISCUSSION

The electrical properties of soils are the parameters of

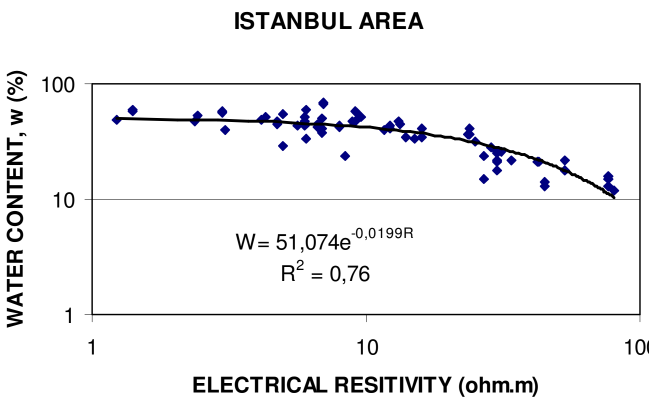

Figure 2. Relationships between soil electrical resistivity and water content for Istanbul Area (Turkey).

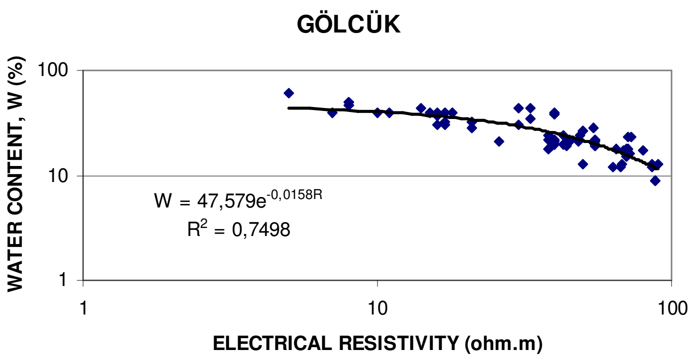

Figure 3. Relationships between soil electrical resistivity and water content for Golcuk Area (Turkey).

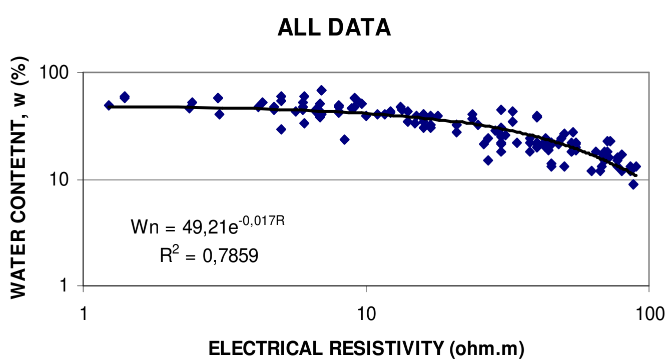

Figure 4. Relationships between soil electrical resistivity and water content for all data.

natural and artificially created electrical fields in soils and influenced by distribution of mobile electrical charges, mostly water content, in soils.

Based on the laboratory and in geoelectrical data, by choosing the appropriate relationship, development of a relation that provides an estimation of soil water content from electrical resistivity data of soils have been accomplished for study areas. Applications of the electrical measurements for studying soil water content provides useful tool for geotechnical engineering.

In our study area located in Istanbul (Yesilkoy, Florya, Basinkoy) and in Golcuk, the electrical resistivity is measured by VES (Vertical Electrical Sounding) in many points. In the other hand, on the soil samples from borings, it was applied soil mechanics laboratory procedures and the soil water contents are determined from these samples. The ranges of our samples are changed between 1 - 50 ohm m (for resistivity) and 20 - 60% (for water content). For this range, the relation between resistivity and water content of soils is found as; $W = 51,764e^{-0,0188R}$. In the estimated volumetric water contents, regression coefficient (R^2) fall approximately 78%.

The relationship model developed in this study provides a very useful tool to relate the water content of a soil that is, its fluid behavior. The model can only be used for soil-water mixtures carefully.

As Robain et al. (2003); Ozcep et al. (2005) point out; solid soil components are generally electrical insulators, the conduction of electrical current only lies on phenomenon occurring in water. Volume conduction controlled by the electrolyte concentration in water and the geometrical characteristics of macro voids network. For the water contained in macro voids the preeminent phenomenon seems to be volume conduction while for the water contained in micro voids, it seems to be surface conduction.

In the future, several possible applications are:

a) To study the effects of load effect on soil hydraulic conductivity and strength.
b) To study the electromagnetic properties of soils in context of the water content.
c) To study the effect of temperature on soil water content and resistivity.

This study has shown that the obtained model has the capability of investigating the effects of water content on soil resistivity. More work needs to be done by measuring the electrical properties of other type of soils (for example clay and silts) at different locations, so that how the water content changes the soil resistivity.

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