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Determination of the True Electrical Conductivity of a Saline Clay

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ABSTRACT

The total suction of a clay can readily be measured using a dew point meter. However, of more practical use is knowledge of the matric suction. A common method of determining the matric suction of a clay sampled from the field is to measure its total suction and its electrical conductivity, using the latter to estimate its osmotic suction. The matric suction is then determined by subtracting the osmotic suction from the measured total suction. However, the true electrical conductivity of a clay is difficult to determine. There is generally insufficient pore water for extraction and direct measurement, and typically a soil paste is made using deionised water, which enables the use of a conventional electrical conductivity meter. Electrical conductivity measurements were conducted on extracts of pore water from two saline clays mixed with deionised water to various gravimetric moisture contents (or water to dry soil mass ratio pastes). The objective was to determine the true electrical conductivity of the clay at its natural moisture content from the electrical conductivity measured in pore water extracts from various soil pastes.

Keywords: electrical conductivity, gravimetric moisture content, saline clay, soil paste, soil squeezing, soil suspension

1 INTRODUCTION

The electrical conductivity of a clay is a measure of its total concentration of soluble salts, and may be obtained in pore water extracts from the clay using a portable electrical conductivity meter, as applied herein. Electrical conductivity measurements may also be taken directly in soil pastes, which results in a lower value than that taken in the pore water extract, due to the soil particles being less conductive than the pore water. Inserting the meter directly into a soil paste also runs the risk of blocking the sensor, leading to erroneous results.

The pore water of a soil sample can be extracted by various methods, such as immiscible liquid displacement, gas extraction, centrifuging, low and high pressures mechanical squeezing, and by vacuum (Rhoades and Oster 1986, Iyer 1990, Reeder and Cave 1999, de Groot 2009). The immiscible liquid displacement and gas extraction methods have been found to be useful only for sandy and silty soils. The centrifuging method works well for sands, silts, and other soils of relatively high permeability. The applicability of centrifuging to for clays is still controversial, because the capability of most laboratory centrifuges to efficiently separate clay particles from the pore water is still in question. The low-pressure mechanical squeezing method is only suitable for soft (wet) soils, such as recent marine deposits. For stiffer (drier) soils, such as overconsolidated clay, Iyer (1990) recommended using the high-pressure mechanical squeezing method. Vacuum or suction methods are commonly employed in the laboratory to extract pore water from soil suspensions.

To overcome the difficulties of obtaining pore water extracts from clays having low gravimetric moisture contents, the clay is commonly mixed with distilled or deionised water at various ratios, and electrical conductivity measurements are conducted on the resulting soil pastes (Richards 1954, Corwin and Lesch 2003). This method is commonly known as the soil suspension method. The commonly used water to dry soil ratios in the soil suspension method are 1:1, 2:1, and 5:1 by air-dried mass of clay (e.g., Richards 1954, Chi and Wang 2010), or by oven-dried mass of clay (e.g., Zhang et al. 2005, Sonmez et al. 2008).

The electrical conductivity determined using the soil suspension method however, corresponds to moisture contents much higher than natural moisture contents, and the use of distilled or deionised water dilutes the pore water salinity and may dissolve salts that have crystallised on clay particle surfaces. There is no theoretical procedure for converting the electrical conductivity measured using the soil suspension method to that of the clay at its natural moisture content, and any conversion is highly dependent on the soil type. The most reasonable procedure is to assume an inverse linear relationship between electrical conductivity and gravimetric moisture content (Krahn and Fredlund 1972). However, Iyer (1990) observed salt concentrations in the pore water extracts of soil suspensions of overconsolidated clay and clay shale to be not linearly related to the inverse of the gravimetric moisture content.

This paper presents the results of electrical conductivity tests conducted on two saline clays intended to be used as a liner for saline water storage ponds. The main objective of the electrical conductivity tests was to investigate the electrical conductivity of the saline clays at their natural moisture contents, and to establish whether the electrical conductivity measured using the suspension method (at various water to dry soil mass ratios) could provide a reliable estimate of the true electrical conductivity of the clay at its natural moisture content.

2 METHODOLOGY

Two saline clays, namely Clay 1 and Clay 2 (sourced from the same site in Central Queensland, Australia), were used in this study. The liquid limits of Clay 1 and Clay 2 were 65.9% and 44.0%, respectively, while their plastic limits were 14.8% and 18.8%, respectively. Clay 1 contained 13.7% coarse-grained particles (sand-size and coarser, passing 0.06 mm), while Clay 2 contained 27.7% coarse-grained particles. According to the Unified Soil Classification System, Clay 1 and Clay 2 were classified as a highly plastic clay, and a low plasticity clay with sand, respectively. The natural gravimetric moisture contents ($w = \text{mass of water/mass of dry solids}$, expressed as a %) of both clays were about 25%.

Deionised water was added to air-dried specimens of the clays to obtain water-soil mixtures of 25%, 30%, 40%, 50%, 70%, 100%, 200%, 500%, and 1,000% gravimetric moisture content. The water-soil mixtures of 25%, 30%, 40%, 50%, and 70% gravimetric moisture content were mixed manually using a spatula, while those of 100%, 200%, 500%, and 1,000% gravimetric moisture content, which correspond to 1:1, 2:1, 5:1, and 10:1 water to dry soil mass ratio pastes, were mixed thoroughly using a magnetic mixer. Pore water extracts from the water-soil mixtures of 500% and 1,000% gravimetric moisture content were obtained by filtering the soil suspensions using a filter paper, without the use of a vacuum. Pore water extracts from the water-soil mixtures of 100% and 200% gravimetric moisture content were obtained by applying a vacuum. Pore water extracts from the water-soil mixtures of 25%, 30%, 40%, 50%, and 70% gravimetric moisture content were obtained by a high-pressure mechanical squeezing technique. The electrical conductivities of the pore water extracts were measured using a WP-81 portable electrical conductivity meter (supplied by TPS Pty Ltd), which required a minimum 15 mL of pore water. The temperatures of the pore water extracts were measured during the electrical conductivity tests to allow correction of the measured electrical conductivity to a standard electrical conductivity at 25°C, using Equation 1 (Heimovaara et al. 1995), which was applied to all reported values:

$$EC_{(25^\circ\text{C})} = EC_{\text{measured}} / [1 + 0.0191(t_{\text{measured}} - 25)] \quad (1)$$

The mechanical squeezing technique was conducted using a 50 mm diameter, 100 mm long, thick-walled soil squeezer, which was connected to a syringe for collecting pore water extracts. The squeezer was similar to the one described by Manheim (1966). The pore water squeezing technique requires as high as possible a squeezing pressure to speed-up extraction (and limit potential evaporation of the pore water extract), without affecting the measured electrical conductivity. However, previous studies have shown that each clay has a threshold squeezing pressure which, when exceeded, may cause the salt concentration in the pore water to decrease due to the mixing of the pore water in large pores with the pore water in the diffusive double-layer of the clay particles. Manheim (1974) showed that chloride concentrations in the pore water of marine sediments extracted under a squeezing pressure in the range

from 4 to 82.7 MPa varied by less than 1%. Iyer (1990) observed that concentrations of total cations in pore water extracted from overconsolidated clays and clay shales remained constant only up to a squeezing pressure of 19.3 MPa.

Figure 1 shows that the electrical conductivity of pore waters extracted from Clay 1 at 40% gravimetric moisture content and Clay 2 at 30% gravimetric moisture content did not change significantly from 20 to 50 MPa squeezing pressure, the upper end of the range being the limit of the loading machine. Hence, a squeezing pressure of 50 MPa was adopted. Squeezing was conducted under a relatively stable room temperature and required up to 24 hours (at natural moisture content) to obtain the minimum volume of pore water extract required. By way of comparison, it required more than 2 days to obtain sufficient pore water extract from the clays at their natural moisture content using a 20 MPa squeezing pressure.

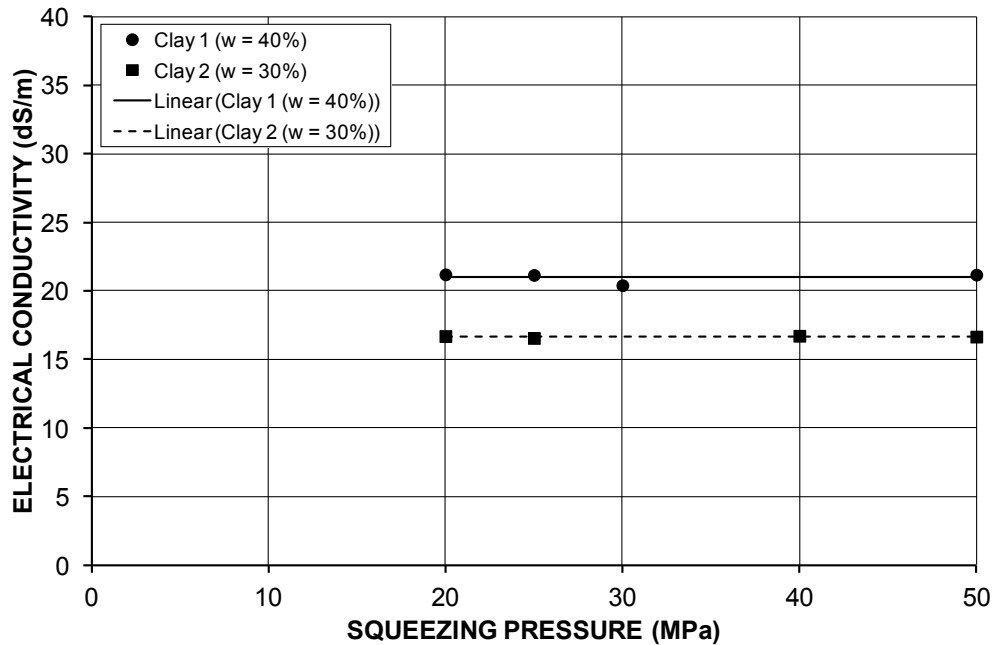


Figure 1. Electrical conductivity of pore water extracts of Clays 1 and 2 at various squeezing pressures

To assess the potential increase in the electrical conductivity of a pore water extract in the syringe due to evaporation of the liquid phase during squeezing, pore water extract was left in a syringe located next to the squeezer for 24 hours and its electrical conductivity measured over this time interval. The electrical conductivity of the pore water extract increased by less than 5% over 24 hours.

3 RESULTS AND DISCUSSION

Following previous practice, plots of the electrical conductivity of the pore water extracts from the two clays versus the inverse of their gravimetric moisture content are shown in Figure 2. Bilinear relationships are shown in Figure 2, different for each clay, with a break at the gravimetric moisture content (70% for Clay 1 and 100% for Clay 2), corresponding approximately to the change to a paste consistency. Clay 1 has higher electrical conductivities (or total soluble salt concentrations) than Clay 2. For saline clays of low gravimetric moisture content, the limited pore water volume may have reached full salt saturation and any excess salts will have crystallised on the clay particle surfaces. When deionised water is added to the clays, the crystallised salts will likely be dissolved, increasing the apparent electrical conductivity of the pore water. In this research, the salts present in both clays are likely to be completely dissolved at their natural gravimetric moisture content of about 25% ($1/[\text{gravimetric moisture content (\%)}]$ of 0.04), as indicated by the linear relationship between electrical conductivity and the inverse of gravimetric moisture content from the natural moisture state. The addition of deionised water, to obtain gravimetric moisture

contents from 30% to 1,000% ($1/[\text{gravimetric moisture content (\%)}]$ of 0.033 to 0.001), caused the total soluble salt concentration, and therefore the electrical conductivity, in both clays to decrease, as would be expected.

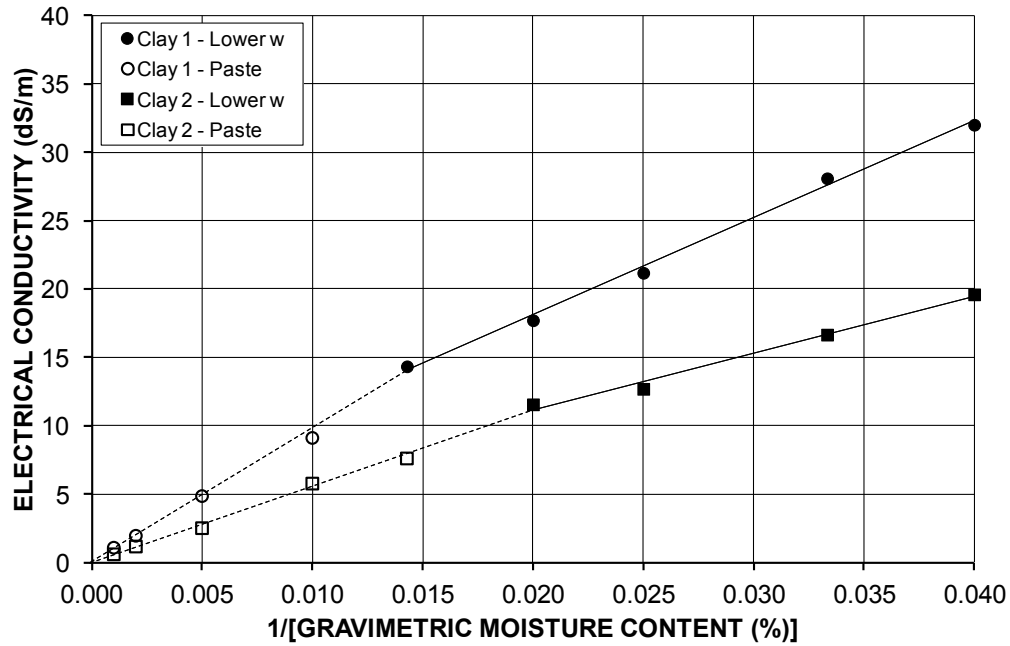


Figure 2. Electrical conductivity of pore-water extracts of Clays 1 and 2 at various moisture contents

Figure 3 shows the measured electrical conductivity normalised by the electrical conductivity at the natural moisture content of each clay, plotted against the water to dry soil mass ratio. All data, for both clays, are well represented by the power line of best fit shown, which could be used as a calibration curve.

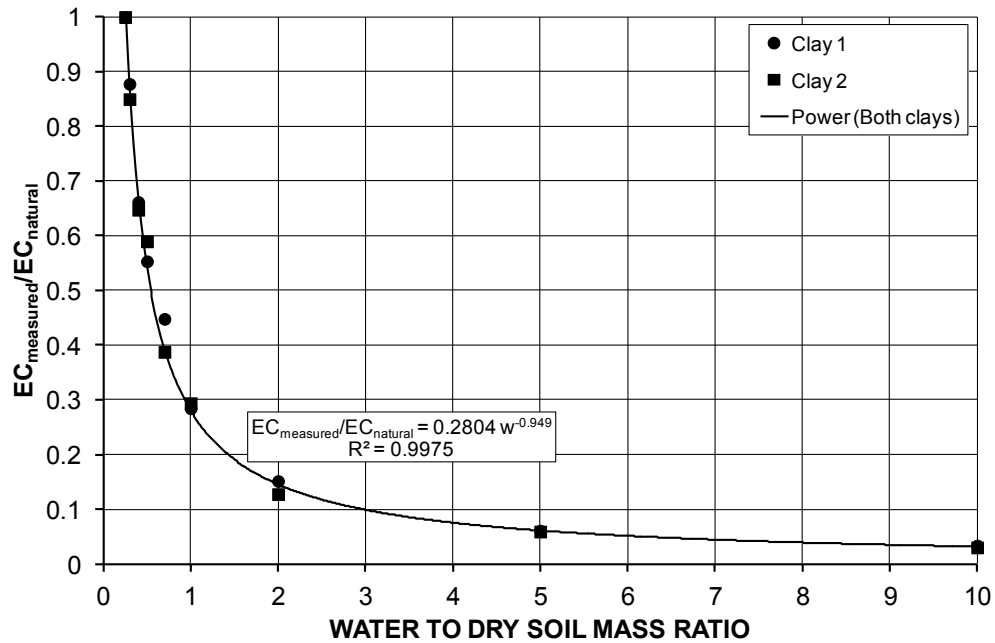


Figure 3. Normalised electrical conductivity as a function of water to dry soil mass ratio

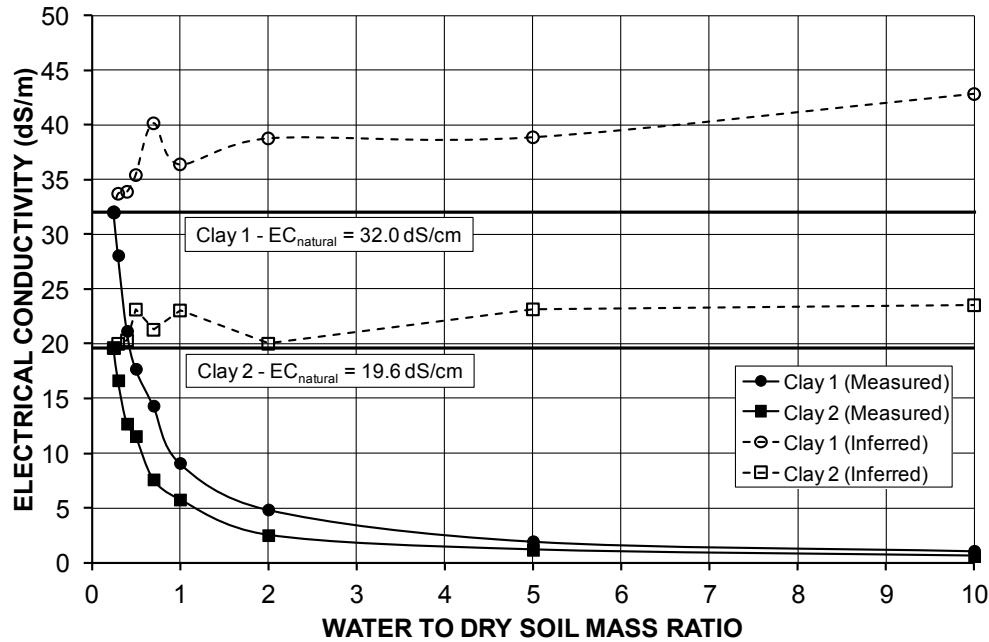


Figure 4. Measured and inferred electrical conductivities as a function of water to dry soil mass ratio

Figure 4 shows, for both clays, the measured electrical conductivities and those inferred based on a simple linear scaling of the measured values by the water to dry soil mass ratio. In general, the inferred electrical conductivities increasingly overestimate the electrical conductivity of the clays at their natural moisture content with increasing water to dry soil mass ratio. The errors are plotted in Figure 5, in which the error for the more clay-rich Clay 1 rises to almost 35%, and the error for Clay 2 rises to about 20%.

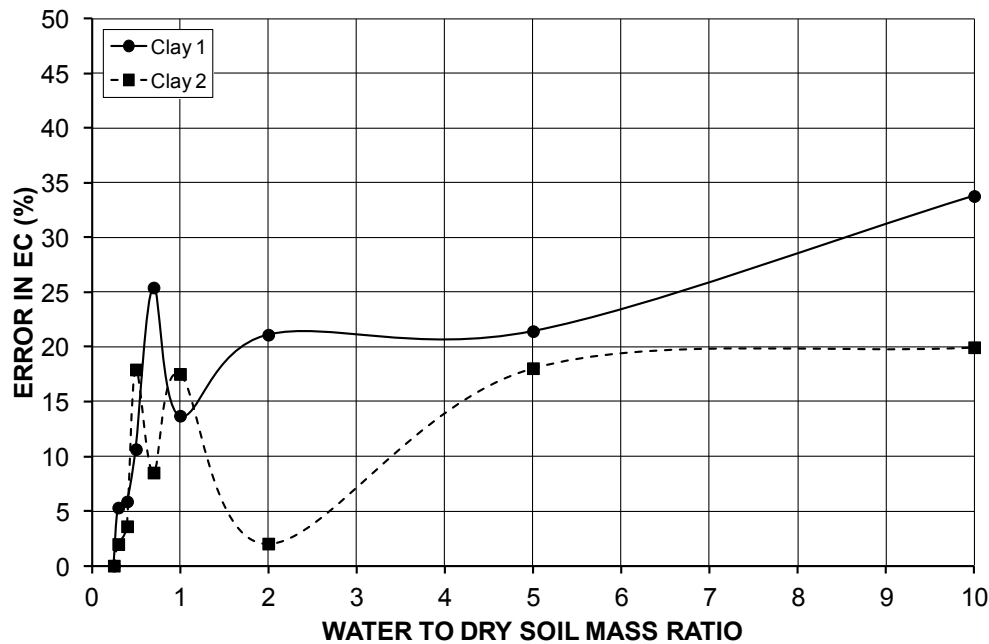


Figure 5. Error in inferred electrical conductivities as a function of water to dry soil mass ratio

4 CONCLUSIONS

The electrical conductivity of both saline clays tested was found to have a bilinear relationship with the inverse of gravimetric moisture content, different for each clay, with a break at the gravimetric moisture content (70% for Clay 1 and 100% for Clay 2), corresponding approximately to the change to a paste consistency.

The electrical conductivity data for both saline clays, normalised by the respective electrical conductivity at the natural moisture content of each clay, are well represented by a power line of best fit, which could be used as a calibration curve. For both saline clays, the electrical conductivities inferred based on a simple linear scaling of the measured values increasingly overestimate the electrical conductivity of the clays at their natural moisture content with increasing water to dry soil mass ratio. The error for the more clay-rich Clay 1 rises to almost 35%, and the error for Clay 2 rises to about 20% at a water to dry soil mass ratio of 10.

5 ACKNOWLEDGEMENTS

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