Possible errors in dispersivity testing due to free salts in the pore water

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ABSTRACT: During dispersivity testing, a high concentration of dissolved salts (free salts) in the pore water of a soil could lead to errors in the results. Two possible errors are considered. Firstly, the free salts will cause the clay particles to flocculate, thereby inhibiting dispersion, leading to errors in the double hydrometer, crumb and pinhole tests. Secondly, in the determination of the exchangeable sodium percentage (ESP) and cation exchangeable capacity (CEC) of the soil using the ammonium acetate method, both the bound and unbound cations will be extracted, leading the errors in the exchangeable cation value and the ESP and CEC values calculated. The former can be resolved by removing the free salts prior to testing, but further research on the methodology to this is required. A method to correct the error in the exchangeable cations determined in the ammonium acetate leaching test is recommended.

1 INTRODUCTION

Dispersive soils is one of the five problem soils identified in South Africa (Jones 2008). If not identified prior to construction, their presence could influence the susceptibility to piping in earth embankment dams (Gerber & Harmse 1987) or the erodibility of capping layers or other surface soils. However, there is currently no single method, standard or procedure for the determination of dispersive soils (Jones 2008).

Paige-Green (2008) recommended that the Bell & Walker (2000) rating system (hereafter referred to as the Bell & Walker rating system) be used to identify dispersive soils. The rating system is based on the following laboratory tests:

- Pinhole test
- Crumb test
- Evaluating the exchangeable sodium percentage (ESP) and cation exchange capacity per 100 g clay (CEC 100 g^{-1} clay) according to the chart developed by Gerber & Harmse (1987)
- Determination of the sodium adsorption ratio (SAR)
- Evaluating the percentage sodium in the pore water and the total dissolved salts (TDS) according to Sherard et al. (1976).

In the Bell & Walker rating system, each test result is given a weighted rating, and the degree of dispersivity is determined based on the sum of the ratings. It is important to note that the five tests evaluate the three components of the soil dispersion process, namely the properties of the soil particles, the pore water and the eroding fluid.

The pinhole and crumb tests are usually carried out by geotechnical laboratories. However, the determination of the ESP, CEC percentage sodium and TDS are done based on tests generally carried out by agricultural soil laboratories. As these are not standard geotechnical laboratory tests, it is the author's experience that in practice, the results are often received from the agricultural laboratory and used without a proper understanding of what they mean.

A particular aspect that is often not accounted for, is the effect of soluble salts in the pore water, referred to as free salts, on the dispersivity test results. According to Gerber & Harmse (1987), the results of the pinhole, crumb and double hydrometer tests (the latter is not included in Bell & Walker rating system) are invalid if the quality of the water used in the test and the presence of free salts are not considered.

This paper seeks to address possible errors in dispersivity tests due to the influence of free salts in the pore water. Two possible ways in which the free salts could influence the results are discussed:

- A high concentration of free salts causes flocculation, which will inhibit dispersion and lead to incorrect results.
- In the determination of the ESP and CEC, the sample is leached with ammonium acetate to determine the exchangeable cations on the surfaces of the clay particles. If the free salts are not removed beforehand or accounted for, they will be leached

as well, resulting in incorrect values of the ESP and CEC.

Although not yet evaluated experimentally, recommendations are given, some based on literature, on how the influence of free salts can be accounted for.

2 FREE SALTS INHIBIT DISPERSION

2.1 *The influence of free salts on dispersion*

When soil is brought into contact with water, its particles, and in particular the clay particles, either flocculate or disperse. As stated by Harmse (1980), the reason for the flocculation is the suppression of the double diffused layer around clay particles by the dissolved cations in the pore water. As the concentration of dissolved cations in the pore water decreases, the suppression is reduced, and the particles are dispersed. According to Bell & Maud (1994), the boundary between the flocculated and deflocculated state depends on the SAR, salt concentration, pH and mineralogy.

Gerber & Harmse (1987) listed three categories of soil based on their CEC values, with the CEC values linked to clay mineralogy:

- Soils with CEC values ranging between 40 – 150 me /100 g clay include hydromica, vermiculite, chlorites and smectites
- Soils with CEC values ranging between 5 – 40 me /100 g clay include kaolinite and halloysite
- Soils with CEC values between 1 – 5 me /100 g clay include oxides, hydrous oxides and hydroxide of iron and aluminium where dispersion is expected to be non-existent.

Gerber & Harmse (1983) carried out a range of soil tests and developed three boundary lines between the flocculated and dispersed state, as indicated in Figure 1. The boundary lines are influenced by the SAR and TDS (both of which are properties of the pore water) and the CEC, expressed per 100 g of the clay fraction of the soil, which is determined by the clay mineralogy. The CEC reflects the total negative charge on the surface of the clay particles, which influences dispersion.

The first observation from Figure 1, is that when a soil is placed in water, the clay fraction will either flocculate or disperse depending on the SAR and the concentration of salts in the pore water, both of which are properties of the pore water. The implication is that a soil that is dispersive under certain conditions, can appear to be non-dispersive if the free salt concentration is too high.

The second observation is that a soil of which the clay particles are flocculated due to the high salt concentration in the pore water, can be rendered as dispersive if the salt concentration decreases. Several authors, including Elges (1985) and Harmse (1980) also confirmed this, and referred to it as the soil becoming dispersive when the free salts are leached. One example of this phenomenon is the seepage of dam water through an earth embankment. If the dam water has a much lower salt concentration than the pore water in the embankment, the soil may become dispersive. Another example is the erosion of soils during a heavy rainfall event following a prolonged period of drought as described by Jones (1981).

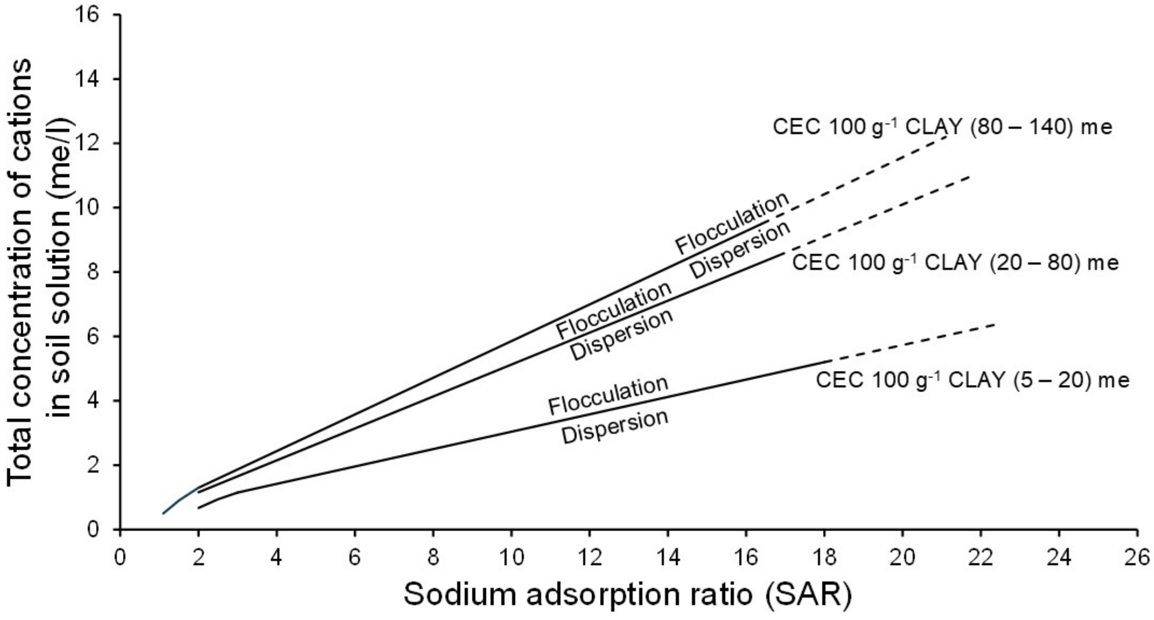

Figure 1. The influence of free salts on the flocculation and dispersion for different ranges of CEC (Gerber & Harmse 1983)

The influence of free salts was further illustrated Gerber & Harmse (1983), who noticed that samples of dispersed soil that were left for a long period of time, started to flocculate as the water evaporated, leading to an increase in the free salt concentration.

Furthermore, Sherard et al. (1976) stated that the evaluation of dispersivity using the percentage sodium vs. TDS chart, is only valid if the TDS of the eroding fluid is less than 0.5 me/l, meaning that if the eroding fluid has too much free salts, the particles will remain flocculated.

Based on the above, it is evident that the presence of free salts could have an influence on the results of dispersivity tests, especially the double hydrometer, crumb and pinhole tests. The procedure for the pinhole test requires distilled water to be used. Nevertheless, Gerber & Harmse (1987) observed that the results of the pinhole tests could be influenced by free salts.

In practice, how does one account for the presence of free salts during laboratory testing to ensure that the test results are accurate?

2.2 *Removal of free salts prior to testing*

The solution to prevent the presence of free salts influencing the dispersivity tests, is to remove the free salts before the tests are carried out.

Based on a limited literature review of dispersion related testing, no clear guideline on the removal of free salts prior to testing could be found.

Gerber & Harmse (1987) stated that in the development of their ESP vs CEC chart, they used double hydrometer tests done on samples from which the free salts were leached beforehand. However, they do not give an indication as to how the leaching was done.

Harmse (1980) recommended that a saturated paste be prepared with distilled water at 15°C, and the conductivity of the paste be determined. If the conductivity is more than 250 µS/cm and the SAR greater than 6, there could be sufficient free salts present to render the soil dispersive if the free salts are leached. No further comment was given on how the free salts are removed in preparation for other laboratory tests.

Gerber & Harmse (1983) referred to the leaching of free salts with alcohol as part of a laboratory testing programme investigating the relationship between ESP and SAR. No further information was given on how the leaching with alcohol was done. They also stated that before determining the ESP, they ensured that the free salts were removed.

If the soil sample is simply leached with distilled water, how does one ensure that any of the clay particles are not leached out as well?

It is recommended that the methodology for the removal of the free salts prior to testing be investigated further. Once the method has been identified, it could be used in combination with the conductivity criterion given by Harmse (1980). If the conductivity is more than 250 µS/cm, the free salt concentration is significant and needs to be taken into consideration and removed. If the conductivity is less than 250 µS/cm there is no requirement for the free salts to be removed prior to testing, as the concentration is low enough. It will not mean that the soil is non-dispersive, and the normal testing procedure should still be carried out.

3 FREE SALTS INFLUENCING THE ESP AND CEC DETERMINATION

3.1 *Possible error in the ESP and CEC determination through the ammonium acetate test*

In the general chemical analysis of a soil, as is typically done by agricultural soil laboratories, two tests are carried out.

The first test is the determination of the exchangeable cations on the surface of the clay particles, also referred to as the bound cations. The cations are attracted to the clay particle surface due to the negative charge of the clay particles. The exchangeable cations are determined by leaching the sample with ammonium acetate, as described by Schollenberger & Simon (1945). The result of the test is measured in units of electrical charge, called cmol, and is expressed per mass of soil (i.e. cmol/kg), since it is a property of the clay particles. The values of the ESP and CEC are calculated from the result of the exchangeable cations determination.

In the second test, a soil sample is saturated with distilled water, and a saturated paste is formed from which the fluid is extracted. The dissolved cations in the pore water is determined, and from these results the SAR and TDS values are calculated. The results are also measured in terms of electrical charge, but are expressed as me/l because it is a measure of the concentration in the fluid.

In the author's experience, the results of the above tests are generally received from the agricultural soil laboratory and then used to calculate the ESP, CEC, SAR and TDS values.

However, there is a potential pitfall in the above procedure that could influence the test results, as was alluded to by Maharaj (2013) and Schollenberger & Simon (1945). When the sample is leached with ammonium acetate, the extracted cations will include both the bound and unbound cations, i.e. both the cations that were attracted to the clay particle surfaces and the cations dissolved in the pore water (free salts) will be extracted. If the ESP and CEC are calculated from these values, the results will be incorrect.

3.2 *Proposed method to correct for free salts*

Schollenberger & Simon (1945), in their description of the ammonium acetate method to determine the exchangeable cations, stated that small amounts of free salts are "customarily neglected" and are included with the exchangeable cations. If the amounts are significant, the free salts are to be removed through preliminary leaching. However, no methodology was given on how the leaching is to be carried out. It is presumed that this is the reason why Gerber & Harmse (1983) first removed the free salts from the soil before the ESP and CEC values were determined.

Maharaj (2013) stated that for cases where the free salt concentration is significant (indicated if the resistance is less than 460 Ω) the water-soluble cations can be determined separately and then subtracted from the extracted cations to determine the exchangeable cations.

The problem is that this subtraction cannot be done using the regular data received from the agricultural laboratories, because the soluble cations are measured in me/l (from the saturated paste extract) and the exchangeable cations in cmol/kg as determined from the ammonium acetate leaching. Because the units are different, the values cannot be subtracted.

However, if the mass of soil used for the saturated paste extract is recorded by the agricultural laboratory, the me/l value can be converted to a cmol/kg value, and the subtraction can be made. This will require a specific instruction to the laboratory for the mass of soil to be reported in addition to the standard results.

The author has not applied this correction to ammonium acetate leaching test results as yet.

4 CONCLUSION & RECOMMENDATIONS

The presence of free salts in the pore water during dispersivity testing can lead to errors in the test results. In the pinhole, crumb and double hydrometer tests, a high concentration of free salts causes the clay particles to flocculate, thereby inhibiting dispersion and leading to errors in the results.

It is recommended that the conductivity of a saturated paste be measured, and if above 250 μS/cm, the free salts be removed before the tests are carried out. However, further research is required on the method of removing the free salts.

A high concentration of free salts could also lead to errors in the determination of the ESP and CEC using the ammonium acetate leaching method, as the unbound cations will be extracted with the bound cations.

It is recommended that when the saturated paste extract is analysed, the mass of soil used be recorded, so that the concentration of free salts can be expressed in cmol/kg. Thereafter, the value can be subtracted from the cations extracted through the ammonium acetate leaching, to calculate the exchangeable cations and the correct ESP and CEC. The author has not yet applied the method in practice.

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