A Case Study on Dispersive Soils – Saraji Mine, Dysart (QLD)

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ABSTRACT

The presence of excess exchangeable sodium ions is one of the main causes of dispersive behaviour in clayey soils. However, the presence of excess exchangeable cations other than sodium can also promote dispersion in soils. In this paper, the effect of the presence of excess exchangeable magnesium and sodium ions in dispersive soil were investigated and an assessment on the effectiveness of using the Australian Standard Emerson Class Number (AS ECN) testing standard to identify dispersive soil was undertaken. This case study was based on geotechnical investigations undertaken for the design of Coolibah Dam and Drain at Saraji Mine, Dysart. Laboratory testing undertaken on various samples collected during investigations completed for the dam and drain confirmed the presence of sodic and abnormal levels of magnesic soils. Although it's well established that sodicity is a main driver of dispersion, effect of magnesicity in soils is not well defined. Further laboratory testing suggested the presence of magnesic soil may also promote dispersion. Dispersive soil samples were treated with gypsum to reduce the amount of exchangeable sodium and magnesium based on the cation exchange capacity. Whilst gypsum treatments chemically stabilised the soil, they failed to satisfy the visual based criteria from ECN testing as defined in the Australian Standards (AS). The presence of excess exchangeable sodium and magnesium ions has been identified as a likely factor promoting dispersion. Furthermore, a review of the current AS ECN testing standard is suggested as it does not effectively amalgamate the chemical properties of soil which effect soil dispersion.

Keywords: Dispersive soil, sodic soils, magnesic soils, Emerson Class Number, Modified Emerson Aggregate Test, gypsum treatment

1 INTRODUCTION

Dispersion is the phenomenon of clay particles detaching from adjacent clay particles in a soil when exposed to wet conditions. This detachment causes the clay aggregates to structurally breakdown which presents a plethora of problematic properties in the soil. High erodibility can create rill and gully erosion on surfaces, piping and tunnel erosion below the surface, poor soil stability, chemical imbalances in the soil resulting in low soil fertility and extremely poor plant growth (vro.agriculture.vic.gov.au, 2019).
Research has clearly identified that the presence of excess exchangeable sodium ions in clayey soils results in the phenomenon of dispersivity. According to Northcote and Skene (1972), soils with an Exchangeable Sodium Percentage (ESP) greater than 6% of the Cation Exchange Capacity (CEC) are known as 'sodic soils' and those with an Exchangeable Magnesium Percentage (EMP) excess of 15% are 'strongly sodic soils'. According to data published by the Queensland Government (2014), sodic soils are known to be problematic throughout North and Central QLD and approximately 45% of soils in QLD are considered to be sodic.

Similar to sodic soils, soils with an EMP greater than 25% of the CEC are known as magnesic soils. It has been further identified that magnesic soils can also become unstable under wet conditions and have the potential to promote dispersion when the magnesium ion concentration is high in relation to other cations. Although the contribution of magnesic soils towards soil dispersion has been identified, it has not been defined to the level of the effects of sodic soils (Upjohn et al., 2005).

To reduce the effects of sodic soils it is generally recommended that the cation balance be altered by increasing the relative proportion of calcium in the soil while reducing the relative proportion of exchangeable sodium. This is usually achieved by the introduction of gypsum ($CaSO_4.2H_2O$) into the problematic soil, which is favoured due to its solubility, low price and it does not alter the soil pH (vro.agriculture.vic.gov.au, 2019).

The Emerson Aggregate Test (EAT) (Emerson, 1967) which in its current Australian Standard form in AS 1289.3.8.1: 2017 titled "Determination of Emerson Class Number" (AS ECN) is the most common test referred by engineers for identifying dispersive soils. Although the determination of CEC and Exchangeable Cations (i.e. ESP and EMP) are the most accurate chemical testing methods to identify sodic, magnesic and potentially dispersive soils, AS ECN testing is commonly used as a cheaper screening method to identify whether the soils are likely to be dispersive and therefore identify a need for further, more expensive chemical testing to confirm soil dispersivity.

The degree of dispersion in the EAT test depends not only on ESP, but also on the relative Exchangeable Calcium Percentage (ECP) and EMP (Emerson, 1983). Furthermore, sodic soils with high EMP are more susceptible to dispersion than those with high ECP. Loveday and Pyle (1973) refined Emerson's test by subdividing the classes and taking the rate and degree of dispersion into account. Their test was highly correlated with ESP. However, their testing was limited to soils from certain areas of Central West NSW and did not correlate ESP to Emerson's original classes.

Numerous other researchers have related observed dispersion to ESP (Emerson, 1983). However, all of these studies were conducted on a small range of soils or on artificially prepared soils with specific ESP, mineralogy and solution composition.

2 METHODOLOGY

Samples from the footprints of the Coolibah Dam and Drain were obtained during geotechnical investigations undertaken in 2018 during the design phase of the project. The investigation comprised five (5) test pits excavated within the proposed Coolibah Dam footprint and four (4) test pits excavated along the Coolibah Drain alignment. All the test pits were excavated to a target depth of 4m. The collected samples were subjected to four phases of laboratory testing as described below.
Phase 1 of the laboratory testing included AS ECN and Particle Size Distribution (PSD) testing and was used to identify whether the soils were likely to be susceptible to dispersion and erosion. Two (2) samples each from the Coolibah Dam and Drain sites were used for this phase of testing. Results of Phase 1 testing identified that all the soil samples had an AS ECN of 2 and were therefore likely susceptible to dispersion. Further testing was required to understand the cause/s of the observed AS ECN values.

Phase 2 of the laboratory testing included chemical testing in addition to the AS ECN and PSD testing, specifically: Exchangeable Cations, CEC, Chloride Content, Electrical Conductivity (EC) and pH Value. These chemical tests were used to determine the chemical properties of the soil samples which demonstrated likely dispersive characteristics. Nine samples, namely one from each test pit were submitted for Phase 2 testing. An additional 27 gypsum treated samples (created by mixing the soils with gypsum at rates of 0.5%, 1.0% and 1.5% (by mass) were subjected to the same suite of chemical testing. The gypsum dosage rates were initially calculated based on the requirement to neutralise the ESP (based on the total CEC of the soil) which was initially thought to be the dominant factor which promotes dispersion in a soil. The mixing of gypsum with the relevant soil samples was undertaken using minimal amounts of water to make small, plasticine-like aggregates for testing. Results of Phase 2 testing indicated that the addition of gypsum showed minor improvement in the AS ECN of the treated soil samples. Out of the total nine (9) samples tested during this phase only two (2) samples showed a significant improvement where the AS ECN increased from 2 to 4. According to the results of Phase 2 testing, it was understood that it is likely that the added amount of water may not have been the optimal amount required for the gypsum to properly dissolve in order to facilitate the migration of calcium ions into the soil sample and/or to react with adequate amounts of sodium ions on the colloidal surfaces. Also, the duration assigned for the reaction to take place during the experiment may not have been sufficient for the gypsum to completely react during this phase of testing. These shortfalls were rectified in the next two phases of laboratory testing.

Phase 3 of the laboratory testing was undertaken by using the same gypsum rates with a more rigorous mixing procedure to better enable the chemical reactions to take place. This was also undertaken to replicate the possible field methodology used during the construction phase of the project. The material was initially broken down to <2mm particle size and then the gypsum was added to the soil along with enough distilled water to create a slurry. The soil was then soaked for 3 days, mixed with a hydrometer mixer in an effort to speed up the gypsum–water–soil chemical reactions and allowed to sit for a minimum of 24 hours prior to drying in a 45°C oven for a day. After the slurry had dried, some of the sample was broken apart for AS ECN testing. In addition to AS ECN testing, the same suite of chemical testing undertaken during Phase 2 was carried out at this phase. Gypsum addition rates of 1.0% and 1.5% (by mass) were trialled during this phase. Also, samples subjected to AS ECN tests were photographed to enable further visual based analysis of the dispersive behaviour of soil. The results of

Phase 3 indicated only minor improvement in the AS ECN, even after following the more vigorous mixing methodology. However, the chemical testing undertaken during this phase revealed that all the gypsum treated samples were within the accepted criteria for chemically stable and productive soils (detailed further in Section 3) and therefore likely non-dispersive. Although chemical tests revealed the soils were chemically stable and productive and likely non-dispersive, soil samples were put through a final phase of testing (Phase 4) to gain further understanding of the dispersive behaviour still observed in the AS ECN testing on the gypsum treated samples.

Phase 4 laboratory testing was undertaken by using the same rigorous mixing procedure whilst increasing the gypsum addition rates to 2.5%, 5.0% and 10.0% (by mass). The AS ECN results of these samples increased to 4 for the samples which were mixed with 10% (by mass) gypsum. As the chemical composition of samples tested in Phase 3 were within the acceptable range for non-dispersive soils, additional chemical testing was not undertaken in this phase of testing. Similar to Phase 3 testing, samples subjected to AS ECN tests were photographed to enable further qualitative visual based analysis of the dispersive behaviour of soil. A visual assessment was undertaken using the photographs of the samples from Phases 3 and 4. The assessment was based on the modified EAT classification method provided in the Queensland Department of Transport and Main Roads (QDTMR) Road Drainage Design Manual (RDDM) from June 2002 (now superseded) which provides three additional subclasses for AS ECN 2 and two additional subclasses for AS ECN 3. The probability of sodicity occurring within these sub-classes are in the following order: 2(3) > 2(2) > 2(1) > 3(4) > 3(3) > 3(2) > 3(1).

3 DISCUSSION

Results obtained from the chemical testing were compared based on a set of desirable common indicators utilised to define chemically stable, non-dispersive and productive soils (soils which supports plant growth) which were developed from the data of Reuter and Robinson (1997), Peverill et al. (1999), Standards Australia (2003), Incitec Pivot Ltd (2008), Hazelton and Murphy (2007) and QDTMR (2017). Table 1 provides a summary of the desirable values of the indicators utilised to define stable productive soils. It should be noted that the analysis undertaken for this case study was based only on the main indicators which influence the characteristics of stable productive soils. Other indicators such as Electrical Conductivity (EC), Chloride Content and soil pH have not been taken into consideration during the assessment undertaken within this case study.

Table 1: Desirable values of the indicators (i.e. Exchangeable Cations (ESP and EMP), CEC and AS ECN) for stable productive soils.

Parameter		Desirable range	Unit
Exchangeable Cations Proportions	Exchangeable Sodium percentage (ESP)	<6	%
	Exchangeable Magnesium percentage (EMP)	15 – 25	%
Exchangeable Cations Abundance	Cation Exchange Capacity (CEC)	>6	meq/100g of soil
	Exchangeable Magnesium	>0.2	meq/100g of soil
Australian Standards Emerson Class Number (AS ECN)		≥4	-

3.1 Exchangeable Cations

3.1.1 Exchangeable Sodium Percentage (ESP)

Results of Phase 3 testing obtained from untreated samples showed high ESP values which lay well outside the desirable range for ESP < 6% for a non-dispersive soil. These high ESP values in untreated soil suggested that soils from the Coolibah Dam and Drain sites are highly sodic. Hence, the treatment of soil with gypsum was introduced, in order to reduce the high ESP values to obtain non-dispersive characteristics and to chemically stabilise the soil. Figure 1 shows the variation of ESP of multiple samples with gypsum treatment rates varied between 0.0%, 0.5%, 1.0% and 1.5% by mass added to the soil to determine the optimum amount of gypsum required. The results shown in Figure 1 suggest that the ESP of the majority of the samples are reduced to the desirable range at a gypsum treatment rate of between 0.5% and 1.0%.

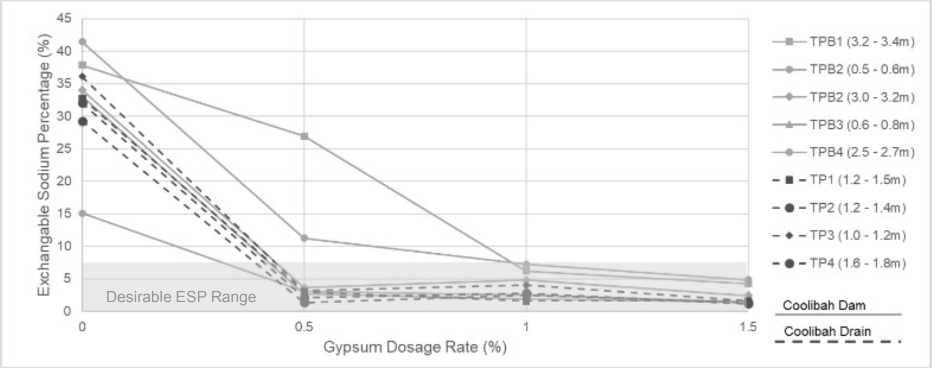

Figure 1. ESP vs Gypsum Rate

3.1.2 Exchangeable Magnesium Percentage (EMP)

Untreated soil samples at Coolibah Dam and Drain showed EMP values above the recommended range for non-dispersive soils which support plant growth. This indicated that the soils are highly magnesic and that the presence of high levels of exchangeable magnesium could also be a cause soil dispersion (in addition to the more common cause attributed to high ESP which is further discussed in Section 3.2). The variation of EMP of the soils with gypsum treatment rates of 0.0%, 0.5%, 1.0% and 1.5% by mass are depicted in Figure 2.

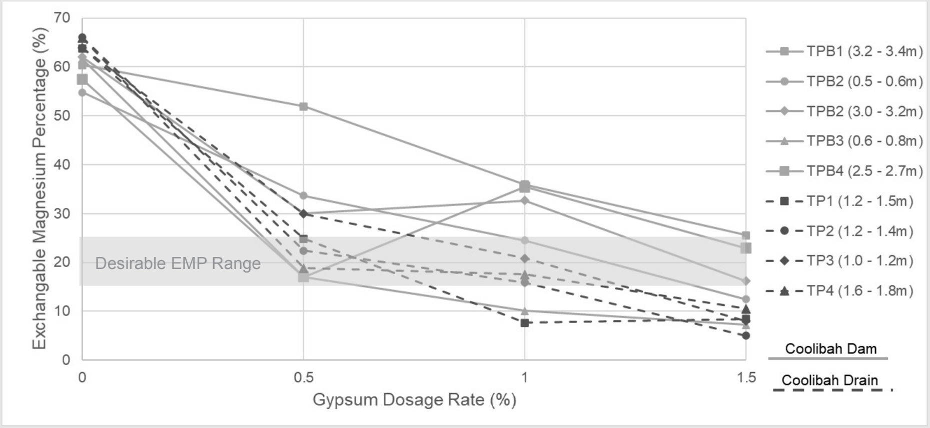

Figure 2. EMP vs Gypsum dosage rate.

With the application of gypsum, the EMP of the soil samples reduced significantly. The EMP of the majority of the soil samples fell below the desirable range by a gypsum rate of 1.5%. Although the EMP fell below the desirable range at this gypsum rate, a conclusion could not be categorically made that the ameliorated soil would not support plant growth because the exchangeable magnesium abundance requirement for non-dispersive soils which supports plant growth (being >0.2meq/100g) was fulfilled in all instances based on the laboratory test results. Accordingly, the optimum gypsum dosage rate (considering only ESP and EMP criteria for non-dispersive soils) to reduce excess sodium and magnesium in these soil samples lies between 1.0 and 1.5%. It should be noted that the results for cation abundance testing are not presented due to page limit limitations of this paper.

3.2 Cation Exchange Capacity (CEC)

CEC is the total capacity of a soil to hold exchangeable cations. According to the laboratory results shown in Figure 3, the results indicated that the CEC which was previously below the desirable range in many samples could be improved to be within the desirable range by the treatment with 1.5% (by mass) gypsum to the soil samples being assessed.

As discussed in Section 3.1, the ESP of the soil samples were reduced to the recommended range at a gypsum treatment rate of 1.0% (by mass). Although the ESP levels were satisfied, as shown on Figure 3, the CEC of some of the soil samples at this gypsum treatment rate did not necessarily lie within the recommended range. This suggested the presence of additional exchangeable cations which influenced the CEC of the soil other than sodium in some of the soil samples. In this case it was quite evident that the additional exchangeable cations were the excess magnesium observed in these samples of soil. Hence, it was understood that the excess magnesium and sodium present in the soil were likely factors promoting dispersion.

This was further validated by analysing the CEC and EMP levels at a gypsum rate of 1.5% (by mass). With the reduction of excess magnesium in the soil samples at a gypsum rate of 1.5% (by mass), the CEC of the samples improved to the recommended range as shown in Figure 3. Subsequently, it appeared that a gypsum treatment rate of 1.5% (by mass) was necessary to achieve the desirable criteria for ESP, EMP and CEC to produce chemically stable and productive soils (that are also likely to be non-dispersive).

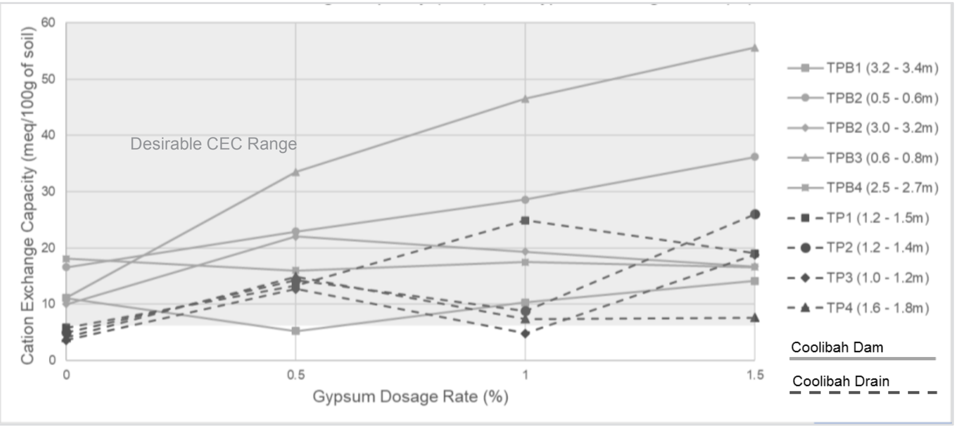

Figure 3. Cation Exchange Capacity vs Gypsum Rate.

3.3 Emerson Class Number (ECN)

The AS ECN tests undertaken on the natural soil samples as well as those treated with gypsum by up to 5.0% (by mass) showed little or no improvement from their original dispersive state with AS ECN values of 2 which suggested the soil was susceptible to dispersion. Only under the application of an abnormally high gypsum dosage rate of 10% (by mass) did the AS ECN of each of those samples improve to 4 (which suggests the treated material is non-dispersive at this dosage).

The AS ECN test results for soils treated with various gypsum dosages when compared with the visual-based assessment using the modified EAT classes, resulted in many of the test results having a lesser likelihood of being sodic and therefore a less damning view on the degree of dispersion. Further interrogation of Phase 3 AS ECN testing indicated that at a gypsum rate of 1.5%, the soil samples showed a modified EAT of 2(2) or 2(1). According to the modified EAT definitions describing the likelihood of being sodic, the samples were highly likely to be sodic (2(2)) or might be sodic (2(1)). Phase 4 testing revealed that the modified EAT of 50% of the samples treated with 2.5% gypsum (by mass), improved to 3(1) or 4 and the remaining samples improved to 2(1). Overall, the results indicated that 50% of the samples are unlikely to be sodic whilst the rest of the samples might be sodic, thus showing minimal dispersive characteristics. With an increase of the gypsum treatment to 5.0% gypsum (by mass), the percentage of samples with an EAT of 3(1) or 4 increased to 80%, which means most of the samples can be classified as 'unlikely to be sodic'. Treating the samples with 10% gypsum (by mass) resulted in all modified EAT results becoming 4 or 3(1) which indicated that all the treated soil samples were 'unlikely to be sodic' and likely non-dispersive.

As discussed in Section 3.2 the exchangeable cation data following gypsum treatment offers evidence of the soils becoming non-sodic and non-magnesic. This outcome further validates observations made by the modified EAT assessment, that a 2.5% gypsum (by mass) dosage is likely to largely reduce the dispersion and the likelihood of the soil being sodic from 'highly likely' or 'almost certainly' to 'might be' or 'unlikely'. It is therefore apparent that the inclusion of the modified sub-classes provides a more practical outcome which can be better corelated to the chemical properties of the soil than the AS ECN testing standard which is currently in use.

4 CONCLUSION

An assessment was undertaken to identify the percentage of gypsum (by mass) required to provide a chemically stable and productive soil that may also show non-dispersive behaviour. The initial assessment indicated that the soils were not only sodic but abnormally magnesic as well. Chemical testing showed that treatment with 1.5% gypsum (by mass) was likely to be optimal for providing a chemically stable and productive soil which is likely to be non-dispersive. The assessment indicated that the presence of excess cations such as sodium and magnesium are likely to promote soil dispersion. It is acknowledged that whilst there is more information regarding sodic soils nowadays, further research is required with regards to magnesic soils and the testing done during this study is only based on a limited number of samples.

Whilst the chemically tested gypsum treated soil samples (to 1.5% gypsum (by mass)) indicated that the soils were likely to be desirable in terms of being chemically stable, productive and non-dispersive, the AS ECN testing on the same treated samples indicated that there was no apparent change from testing undertaken on the untreated samples (an AS ECN of 2). In fact, the AS ECN test results on the soils only increased to the desired value of 4 after the addition of 10% (by mass) gypsum. However, further careful visual assessment undertaken with consideration of the modified EAT classes (presented on the now superseded QDTMR (2002) Road Drainage Manual) in conjunction with the evidence of desirable chemical testing results (of ESP, EMP and CEC etc), revealed that the soil could be deemed non-dispersive with less gypsum additive (2.5% by mass).

The results indicated that the removal of the sub-classes and associated visibly descriptive behaviours from the modified EAT classes (from QDTMR (2002) Road Drainage Manual) to the current day test method that further identify the degree of dispersion and likelihood of being sodic as being a significant factor which prevents the current day AS ECN test method from providing practical outcomes. Indeed, the ability for a soil to be chemically stable and productive for the purpose of providing vegetative cover is equally as important (if not more) for the soil to be non-dispersive. Therefore, the importance of undertaking quality chemical testing trials in addition to the ECN testing (incorporating the modified EAT classes) are vitally important to achieving practical and beneficial outcomes on projects where dispersive (and sodic) soils are a problem.

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