The effect of sample remoulding on the shrink-swell test

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ABSTRACT

The shrink-swell index test (AS 1289.7.1.1-2003) has become a widely utilised and effective tool for estimating the reactivity of expansive clay soils. Whilst AS1289.7.1.1:2003 specifies the use of an undisturbed sample in the shrink-swell test, it is understood that the use of a remoulded specimen for site classification (AS 2870-2011) has increasingly become utilised by local consulting geotechnical engineers in the event that an undisturbed sample is unable to be obtained. This gives rise to the possibility that incorrect conclusions in site classification and characteristic ground movement are drawn, based on inaccurate shrink-swell index values.

This paper assesses the validity of using a remoulded specimen to determine a site classification. A number of shrink-swell tests were performed, using undisturbed and remoulded samples, obtained from an alluvial and a residual soil sequence in Newcastle, NSW. The results indicated a significant increase in shrink-swell index when using a remoulded soil specimen. These results have significant implications for the assessment of site classification based on remoulded shrink-swell tests.

Keywords: expansive soils, swelling clays, shrink-swell test, site classification

1 INTRODUCTION

Expansive soils, commonly known in Australia as reactive clays, are a very common and often direct cause of damage to infrastructure and engineering works around the world. Reactive soils are soils that exhibit significant volumetric change due to a change in moisture content. This extreme volume change due to moisture variation is typically attributable to a high proportion of certain types of clay minerals present in the soil, such as those of the smectite group, influencing the soil behaviour (e.g. Johnston et al., 2014, Johnston et al., 2015).

It is estimated that the costs associated with damage caused by reactive soils around the world is in the billions of dollars annually (eg. Zhao et al., 2013, Siemens and Blatz, 2009). They are ranked as one of the most significant natural hazards to building performance (Karuiki et al., 2002), and are also widely distributed throughout the world. Estimates of the quantity of reactive soils in Australia that could be classified as medium to highly reactive are as much as 20 percent of the total surface soils (Richards, 1983).

Preliminary experimental methods to quantify expansive soil movements due to reactive clays specific to Australia are detailed by Cameron and Walsh (1984). In their paper, several test methods were used to derive an instability index, used as a qualitative measure of a soil's reactivity. The instability index is used as input into the calculation of the free surface movement due to reactive soils expected at a particular site. Of these early test methods, the shrink swell test has been most widely adopted as a measure of soil reactivity due to its reliability, relative simplicity and practicality.

In Australia, the shrink-swell test (AS 1289.7.1.1-2003) has become used as part of standard practice by local consulting geotechnical engineers in order to measure clay reactivity. This is subsequently used, together with an estimated depth of soil suction change at a site, to estimate a characteristic surface movement for input into structural foundation design. This characteristic surface movement is also commonly used to assign a site classification as a result of its inclusion in the Australian Standard for Residential Slabs and Footings (AS 2870-2011).

In the shrink swell test, a clay soil's reactivity is determined by measuring the change in volume exhibited by the clay, from field moisture content to both the fully saturated and fully desiccated moisture condition. By this method, the testing procedure aims to negate the initial suction and water content as factors in the assessment of the reactivity of the soil (Fityus et.al, 2005).

Whilst some studies have been completed comparing the use of remoulded and undisturbed samples in expansive soil behaviour, these have not reached consensus, with some showing an increase in the reactivity of the soil (Erguler and Ulusay, 2002, Livneh and Livneh, 2002, Livneh and Livneh, 2012), a decrease (Attom et al., 2006) or little to no impact (Fityus, 1996). None of these studies have tested the remoulding procedure used as common practice by local geotechnical engineers, and thus cannot be used to determine the validity of remoulded samples for the classification of undisturbed sites.

Typically, samples used in testing are undisturbed and obtained using 50mm thin-walled push tubes in accordance with AS 1289.7.1.1-2003. However, under certain soil conditions, such as hard soils or soils with a high sand and/or gravel content, obtaining an undisturbed sample may be difficult to accomplish. In these cases, bulk disturbed soil samples obtained in the field are often used for testing, typically being broken down and re-compacted using standard/modified proctor compaction. Whilst this has become common practice, to date, a comparison of this method of determining a soil's reactivity after remoulding has not been fully tested.

2 METHODOLOGY

2.1 Sampling

Samples were obtained from two field sites in Newcastle, NSW, Australia. A summary of the location, soil type and origin of the samples used in this study is given in Table 1 below.

Table 1: Location and Origin of Tested Soils

Location	Mayfield	Eleebana
No. Samples	10 undisturbed, 11 disturbed	8 undisturbed, 13 disturbed
Soil Type	Residual Silty Clay, trace sand	Alluvial Silty Clay with sand, trace gravel
Origin	Residual soil, Tomago Coal Measures	Quaternary Alluvial Clay Deposit
Sample Depth	0.4m to 0.7m	0.4m to 0.7m

Undisturbed 50mm thin wall tube samples and bulk disturbed samples were obtained from each field site for the testing program. Both thin wall tube samples and bulk disturbed samples were taken in close proximity to each other (from the same test pit) and at similar depths (as given in Table 1) to minimise the potential for soil variability influencing the test results.

Samples were taken from the base of hand-excavated and machine-excavated test pits. Thin wall samples were taken using a slide hammer to drive sample tubes into the ground. After the thin wall samples had been taken and removed, bulk disturbed samples were taken of the clay soil between and immediately surrounding the thin wall samples, within the same test pit and at the same depth as the undisturbed samples.

After excavation and sampling, thin wall tube samples were carefully sealed to an air tight condition at both ends. Bulk disturbed samples were sealed in buckets to await final testing.

2.2 Testing

2.2.1 Sample Preparation

Undisturbed 50mm thin-walled tube samples were extruded from their sampling tubes via a manual jacking device in preparation for testing.

Disturbed samples were prepared for testing by being broken up and homogenised, by being forced through a 19mm sieve. No material from the samples tested was retained on the 19mm sieve. The resulting homogenised soil was then compacted using a 2.4 litre compaction test mould. The mould was filled with 3 layers of soil and compacted with 50 blows per layer of a 2.7kg rammer falling 300mm. Several compaction regimes were trialled, with the selected regime found to be sufficient to remove macroscopic air voids from the compacted samples, while maintaining approximately the same average dry density as the undisturbed samples.

A 50mm thin wall sample tube was driven into the resulting compacted soil while still in the mould to obtain a remoulded soil core. This specimen was then extruded using the same jacking device as the undisturbed samples.

2.2.1 Laboratory testing

Both the undisturbed and remoulded soil core specimens were tested in accordance with AS 1289.7.1.1-2003.

The swell potential of each sample was measured using a one dimensional consolidation cell. The sample was cut into a rigid ring measuring approximately 24mm in height and 45mm in diameter and placed between two porous plates. The ring and plates were placed in the consolidation cell under an initial applied load of 5kPa. An additional load of 20kPa (to correspond with an estimated overburden pressure of 25kPa) is then applied for 30 minutes to expedite any initial settlement. The swelling strain (ε_{sw}) of the specimen was measured as the total increase in height of the specimen while inundated under the applied load, expressed as a percentage of initial specimen height.

The shrinkage potential of the soil was determined by fully drying a subsection of each clay core sample. The subsection measured a length 1.5 to 2.0 diameters, in conformance with AS 1289.7.1.1-2003. Samples were initially air dried before being placed in an oven at 105°C to fully desiccate. The total shrinkage strain (ε_{sh}) was measured for each sample as the decrease in length of the specimen induced by fully desiccating from its initial moisture content, expressed as a percentage of the initial specimen length.

The shrink-swell index (I_{ss}) was calculated for each sample in accordance with AS 1289.7.1.1-2003, using equation (1).

$$I_{ss} = ((\varepsilon_{sw} / 2) + \varepsilon_{sh}) / 1.8 \quad (1)$$

3 RESULTS

The physical properties of the undisturbed and remoulded samples (mean moisture content and dry density) and mean initial void ratio are shown in Table 2. These were calculated using the initial height, diameter and mass readings from the shrinkage specimen, and volume and mass reading from the swell specimen. The Mayfield clay had the highest in situ moisture content, whilst Eleebana clay had the highest in situ dry density. The compaction regime used resulted in the mean remoulded dry densities and initial void ratio being approximately equal to the corresponding mean in situ dry density and initial void ratio.

Table 2: Mean in situ and remoulded physical parameters of soils

Properties	Unit	Mayfield Clay	Eleebana Clay
In Situ Dry Density	kN/m^3	13.2	15.9
In Situ Moisture Content	%	36.2	24.1
In Situ Initial Void Ratio	%	0.94	0.61
Remoulded Dry Density	kN/m^3	13.3	15.6
Remoulded Moisture Content	%	35.9	24.8
Remoulded Initial Void Ratio	%	0.94	0.65

The Atterberg limits (Liquid Limit, Plastic Limit and Plasticity Index), Linear Shrinkage and Particle Size Distribution of both soils are shown in Table 3.

Table 3: Properties of soils

Properties	Unit	Mayfield Clay	Eleebana Clay
Gravel content (19mm-2.36mm)	%	0	9
Sand content (2.36mm – 75 µm)	%	12	27
Silt content (75 µm – 2 µm)	%	34	28
Clay content (<2µm)	%	54	36
Specific Gravity (Gs)		2.614	2.608
Liquid Limit	%	73.3	39.2
Plastic Limit	%	24.8	14.6
Linear Shrinkage	%	16.4	11.2
Plasticity Index	%	48.5	24.6
Unified Soil Classification		CH	CL-CI
Clay Activity		0.90	0.68

Based on the soil test results presented in Table 3, the residual clay obtained from Mayfield was assessed according to AS 1726-1993 as a silty clay of high plasticity with a trace of sand, whilst the alluvial clay obtained from Eleebana was assessed as a silty clay of medium plasticity with sand and a trace of gravel. It can be seen in Table 3 that the Eleebana sample has greater amounts of non-clay material than the Mayfield sample.

The results of the Mayfield and Eleebana clay soils' undisturbed vs. remoulded shrink-swell tests and corresponding dry density are shown in Figure 1. It can be seen from Figure 1 that once remoulded both the Mayfield and Eleebana clay soils tested in this study exhibited a consistent, significant increase in shrink-swell index compared to when tested in their undisturbed states. The Mayfield clay soil experienced an increase of 21%, whilst the Eleebana clay soil experienced an increase of 129%.

Results of Eleebana and Mayfield clay soils in situ vs. remoulded dry density and in situ vs. remoulded initial void ratio are shown in Figures 2 and 3 respectively. It can be seen that whilst there is variance in the results, overall, there is little difference between the average in situ and average remoulded values of dry density and initial void ratio.

In the Mayfield clay's case, a small amount of variation was noted in the value of shrink-swell index produced by both remoulded and undisturbed samples, with standard deviation of the data sets being 0.25% and 0.27% I_{ss} respectively.

In the Eleebana clay's case, the undisturbed shrink-swell index had more significant variation, with results ranging from 0.9% to 2.4% and a standard deviation of 0.56% I_{ss}, whilst the shrink-swell index obtained using a remoulded sample was more consistent, with a standard deviation of 0.49% I_{ss}.

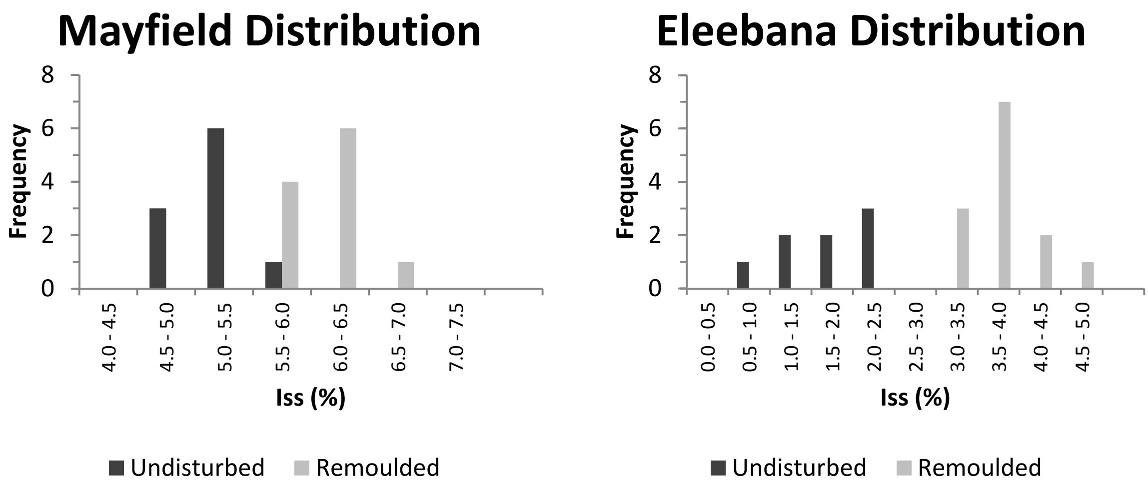

Figure 1. Histograms showing frequency of calculated I_{ss} for tested soils

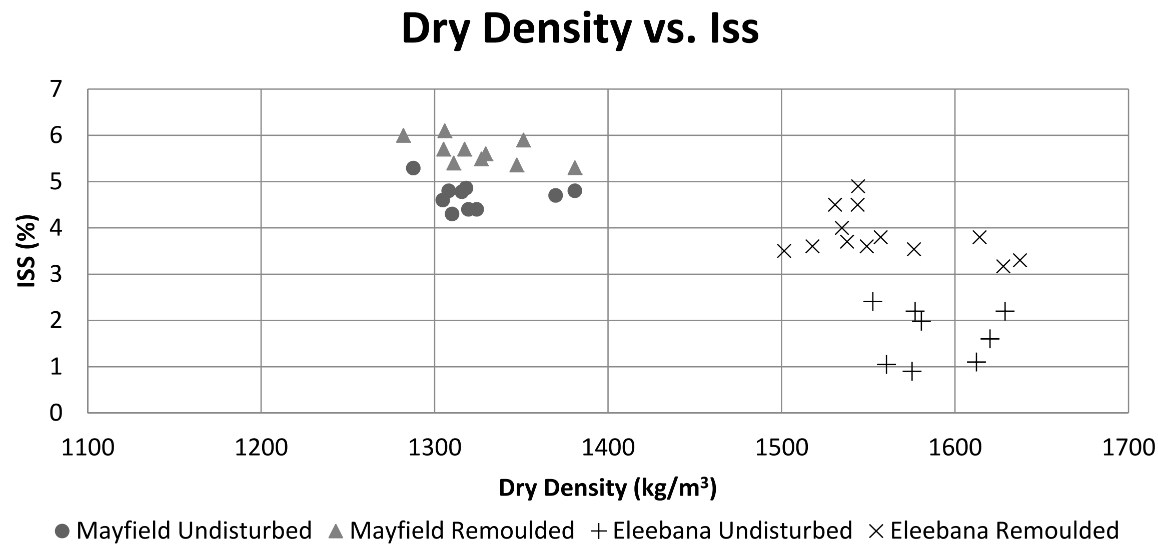

Figure 2. Plot of calculated dry density vs. I_{ss} for tested soils

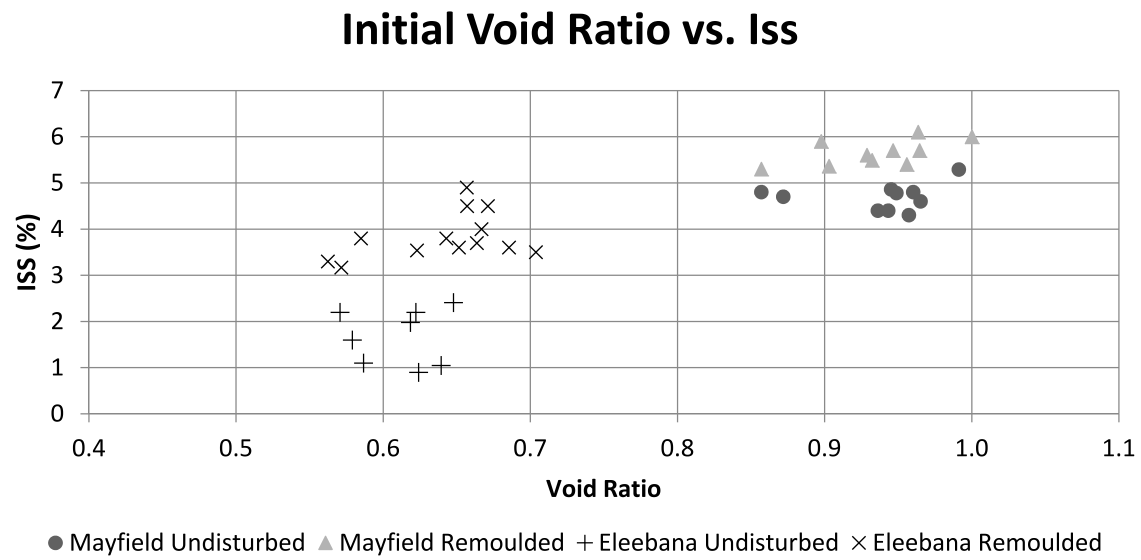

Figure 3. Plot of calculated initial void ratio vs. I_{ss} for tested soils

4 DISCUSSION

The results of this study suggest that remoulding a clay soil significantly affects the measurable shrink-swell index when compared to the shrink-swell index obtained from an undisturbed sample. In both cases, the measurable soil reactivity increased after being remoulded, with the most significant increase being in the alluvial Eleebana clay. In both cases, if the shrink-swell index obtained using a remoulded soil sample were used in the determination of a site classification, it would change the result, producing a higher estimate of characteristic surface movement, and consequently a more conservative site classification.

The result of this study agrees well with Livneh and Livneh (2012), who found that the measured vertical swell of a remoulded clay soil was up to 100% greater than the swell exhibited by its in situ counterpart. Likewise, Erguler and Ulusay (2003) found that the reactivity of a clay soil significantly increased when remoulded.

Although we are only able to speculate on the cause of this apparent increase in reactivity, it has been postulated that when reactive clay soils are remoulded to the same physical parameters (density, void ratio and water content) as their in situ counterparts, they tend to exhibit a higher degree of reactivity due to the destruction of the soil structure (eg. Livneh and Livneh, 2012, Kassiff et al., 1969). It is possible that the aggregated structure of the in situ clay deposit, formed over a considerable time period, being significantly restructured in the process of remoulding the sample, affects the soil's measured shrink-swell index.

Whilst the measured shrink-swell results of the Mayfield clay soil used in this study are relatively consistent (with a standard deviation of 0.25% to 0.27% I_{ss} for undisturbed and remoulded samples respectively), the results of the Eleebana clay have significant variation when testing undisturbed samples. It is thought that this may be due to the inherent nature of its alluvial deposition rather than any systemic or gross errors in the testing method. It is noted that once remoulded, the Eleebana clay produced a more consistent set of results, indicating a degree of homogenisation involved in the remoulding process.

It is interesting to note that whilst the object of this study was not to match the in situ physical properties of the clays, once remoulded, minimal difference was measured between the resulting dry densities for both undisturbed and remoulded samples, with the Mayfield residual clay increasing and Eleebana alluvial clay decreasing in dry density. As the shrink-swell test effectively negates initial water content in the measurement of soil reactivity, the influence of initial suction and water content is thought to be minimal.

5 CONCLUSION

In this study, the undisturbed and remoulded shrink-swell indices of one residual and one alluvial soil were measured and the results compared. It was shown that testing a remoulded clay soil sample will give a significantly increased shrink-swell index when compared to testing an undisturbed sample. The magnitude of this change is thought to be significant enough to warrant a discussion on whether basing characteristic surface movement and site classification derived from remoulded shrink-swell tests is valid.

Despite there being a significant increase in recorded shrink-swell index, the magnitude of this change was not consistent, with the shrink-swell index of the residually-derived soil tested in this study increasing by 21% whilst the alluvial soil's shrink swell index was increased by 129%.

Based on this study, if shrink-swell indices derived from remoulded soils were to be used to estimate a characteristic surface movement, the potential to influence the final site classification is significant. For both the Mayfield and Eleebana clay sites, this could lead to a more conservative site classification with resulting higher construction costs.

It follows that if undisturbed shrink-swell index tests were used to assess soil reactivity for earthworks such as building pads and platforms, there is the potential to underestimate the site classification of such works. This would seem to confirm what good engineering practice would dictate: that it is always best to perform tests on the actual soils being loaded, in their service condition.

Also apparent from this study was that significant variability exists in the measured physical properties and shrink-swell indices of the alluvial clay. It is possible that the typical method of obtaining a single undisturbed shrink-swell index of this type of clay deposit may not be adequate for use in the determination of an accurate estimate of characteristic surface movement or consequent site classification.

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