Shrink-Swell Testing in the Sydney Region

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Summary Laboratory test results from over 300 sites within the Sydney region have been studied. Correlations of shrink-swell index, moisture content, liquid limit, plastic limit, plastic index and linear shrinkage have been attempted. Trends in the results have been examined and compared to other published data.. No obvious correlations exist between the shrink-swell index and other common soil indices. Results of the shrink-swell tests have been reviewed and compared with the classification of Sydney clays contained in Appendix D of AS 2870 Residential slabs and footings.

1. INTRODUCTION

The aim of site classification is to estimate the expected soil movement due to extreme moisture changes. There are three methods given in the Australian Standard AS 2870 for determining the site classification, namely:

- visual assessment of the performance of existing buildings,
- identification of the soil profile and established data,
- computation of the characteristic soil movement.

Recent published information in Australia (Woodburn, 1996) suggests that the usual method for establishing a site classification is the computation of the characteristic soil movement using the Instability Index, I_{pt}. The shrink-swell test is the common method for establishing the Instability Index.

Over three hundred soil index laboratory test results on soils have been collected from Douglas Partners' records within the Sydney region to compare with other published data and with the recommendations given in AS 2870.

2. GEOLOGY

The greater metropolitan area of Sydney lies approximately in the central portion of the Sydney Basin. Most of the Sydney area is covered by rocks of the Triassic Hawkesbury Sandstone and Ashfield Shales of the Wianamatta Group. Most of the clays in the Sydney region are generally residual having weathered from the parent rock. There are some alluvial clays also present.

3. SHRINK-SWELL TEST

The shrink-swell test involves the measurement of axial strain of soil samples between extreme moisture limits. The result assumes a linear rate of axial strain per unit change in suction.

Where an undisturbed sample is used in the test, the samples is divided into sub samples for separate procedures. The shrinkage, ε_{sh}, is obtained by using an unloaded core shrinkage test to measure the axial strain component of the sample dried from the natural moisture content of the sample to the oven dried condition. The result is a measure of the axial strain component of a sample undergoing strains in three dimensions.

The swell, ε_{sw}, is assessed by measuring the swell of the sample placed in a consolidation cell apparatus. In the test, the sample is confined in the lateral direction, thus the measured axial strain is equal to the volumetric strain.

Taking into account the incompatibility of the strain measurements of the two separate tests, the shrink-swell index is obtained by the following formula:

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

There is a potential problem in cases where relatively dry samples are tested. Dry samples placed in the consolidation cell could actually compress rather than swell. Cases have been recorded where the swell has been measured as negative. Possible reasons for this settlement include seating movements of non-swelling soils, soil softening and compressing upon saturation or operator equipment error. In cases where there is a "negative" swell due to soil softening, the swell component is ignored in the above equation. This could therefore give rise to a different instability index compared to the same sample tested at a higher initial moisture content which has compressed prior to saturation.

The cases where a negative swell was recorded were generally samples taken in prolonged periods of relatively dry weather and which had a low initial moisture content.

4. SOIL PROPERTIES

Various soil index testing had been carried out on the samples in accordance with AS 1289. The results of the following tests have been used for comparison purposes:

- Moisture content
- Atterberg limits
- Linear shrinkage
- Shrink-swell index.

Most of the samples tested are from soils derived from a shale parent rock.

A summary of the results are given in Table 1.

Table 1. Summary of Laboratory Test Results.

Test	No of tests	Minimum	Maximum	Mean
Moisture content	301	2.6	72.4	21.2
Plasticity limit	145	10.0	46.0	20.1
Liquid limit	145	4.3	108.0	53.4
Plasticity Index	145	4.0	84.0	34.0
Linear shrinkage	131	1.0	23.5	12.3
Shrink-swell	181	0.1	5.9	2.3

Using these results, various correlations are shown on Figures 1 to 4.

The instability index plotted against moisture content in Figure 1 indicate a large spread of results. The pattern of results is similar to those reported by Fityus et al (1996) but has a smaller range.

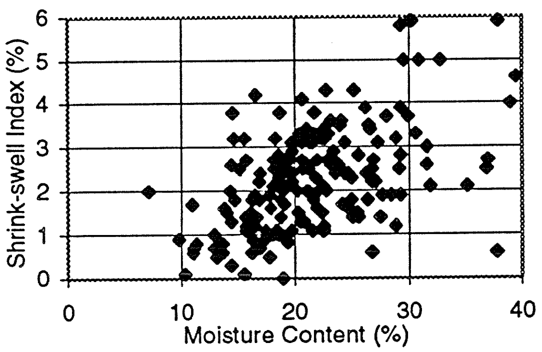

Figure 1. Instability index versus moisture content.

Figure 2 shows a Casagrande plot and indicates that the samples tested are generally medium to high plasticity non-organic clays. There are good correlations between liquid limit and linear shrinkage as shown in Figure 3.

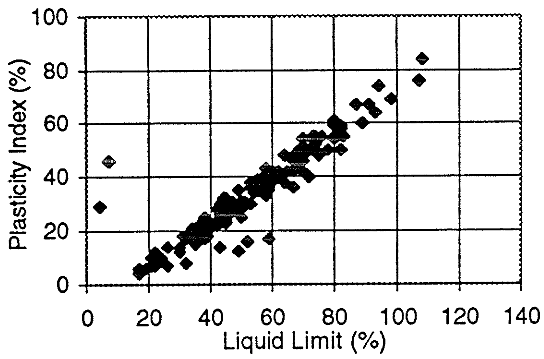

Figure 2. Plasticity Index versus liquid limit.

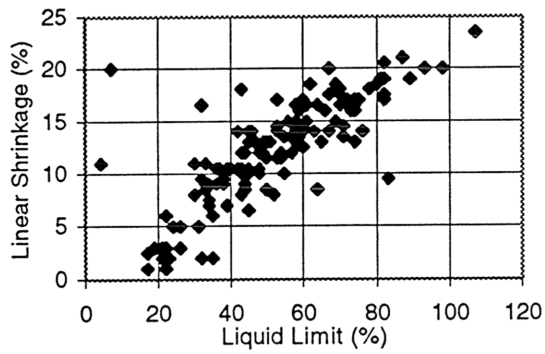

Figure 3. Linear shrinkage versus liquid limit.

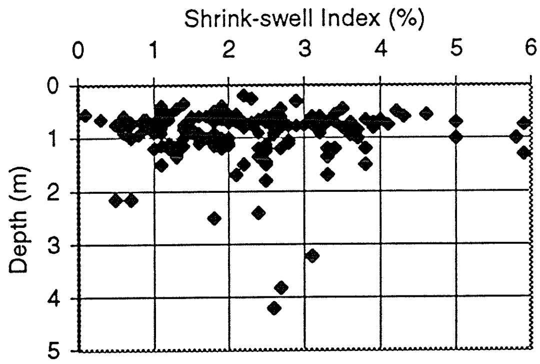

Figure 4. Instability versus depth.

There is no correlation of the instability index with depth as shown in Figure 4.

Delaney (1996) commented that in Newcastle there is a poor correlation between plasticity index and instability index. Mitchell (1996) observed that there was considerable scatter of results, however, in general the higher the plasticity index, the higher the instability index. Mitchell implied that if the plasticity of a soil is assessed in a qualitative way such as the visual-manual method, then from experience and with local knowledge, the instability index may be estimated with reasonable accuracy.

The above findings are in general agreement with those reported by Delaney (1996). Good correlations exist between various Atterberg limits and linear shrinkage. However, the correlation of shrink-swell index with other soil indices is not as well defined.

5. SITE CLASSIFICATION

For the design of residential slabs and footings in accordance with AS 2870, a site classification is used to determine the footing types and sizes which can be adopted. The site classification, except for Class P sites, is determined by one or more of the following methods:

- identification of the soil profile and either established data on the performance of houses or interpretation of the current performance of existing houses on the soil profile,
- estimation of the characteristic surface movements.

Estimation of the characteristic surface movement (y_s) is often used to determine the site classification. In Table 2 characteristic surface movement ranges are given for the various site classes:

The characteristic surface movement (y_s) is a function of the instability index (I_{pt}), depth of design suction change (H_s) and change in suction (Δu) as given below.

$$y_s = \frac{1}{100}\int_0^H I_{pt}.\Delta u.dh \qquad (2)$$

To obtain the instability index from test results, AS 2870 recommends the following correction in the absence of exact information:

$$I_{pt} = \alpha . I_{ps} \qquad (3)$$

where α is a factor to correct reactivity for soil cracking and overburden pressure. The index, I_{ps}, may be taken as equal to the shrink-swell index, I_{ss}.

Using the recommended values as given in AS 2870 for Sydney, the change in suction of 1.5 pF, the depth of design suction change of 1.5 m, depth of cracked zone of $0.5H_s$ and the values for α, the ranges of I_{ss} for the different site classes are given in Table 2.

The ranges of I_{ss} in Table 2 do not apply where rock and/or groundwater are within 1.5 m of the surface.

Table 2. Characteristic surface movements and shrink-swell indices for various classes.

Characteristic Surface Movements (mm)	Class	Range of Shrink-Swell Index (%)
$y_s < 20$	S	$I_{ss} < 1.5$
$20 < y_s < 40$	M	$1.5 < I_{ss} < 3.0$
$40 < y_s < 70$	H	$3.0 < I_{ss} < 5.2$
$70 < y_s$	E	$5.2 < I_{ss}$

Using the results of the shrink-swell tests given above and assuming that the results are typical of the variability that can be obtained from clay sites, it was found that 74% of the shrink-swell results are Class S and M. A further 24% were Class H and the remaining 2% were Class E.

It is noted that the estimation of surface movements has to be based on sufficient soil data to adequately describe the soil profile. Using a single test result to describe a full soil profile may be misleading.

An alternative method of providing a site classification is based on the depth of clay in a profile as given in Table D3, AS 2870. For sites where the depth of clay is less than or equal to 2.5 m, the site classification is S or M. Where the depth of clay is greater than 2.5 m, the site classification is given as H.

6. DISCUSSION

The two methods given above for determining the site classification by estimating the characteristic surface movement and by determining the depth of clay do not appear to be related. If the results of the shrink-swell tests given above are taken to be typical of soils in Sydney, it could be concluded for a site where the clay depth is 2 m, that there is approximately 25% risk that the site classification using the two methods is different.

The shrink-swell test result appears to be the common method for estimating the characteristic surface movement and hence the site classification. There are some problems with the shrink-swell test especially testing of relatively dry samples which have been recorded as having no swell component. The same sample with a higher initial moisture content would probably have a higher shrinkage component resulting in a higher instability index. This is confirmed by Fityus (1996) who has stated that the initial moisture content does affect the shrink-swell index. For the Maryland clays which were tested by Fityus, testing at a higher moisture content resulted in a higher shrinkage index.

There appears to be little correlation of the instability index with other easily measured soil index properties. This is consistent with other published results.

McManus (1996) has presented case studies which show that the reactivity can change significantly across individual sites. This implies that a particular site could have different site classification. AS 2870 recognises this possibility by noting that the estimate of surface movements shall be based on sufficient soil data and that basing the estimate on one test result could be misleading.

Another method for providing a site classification is the established data on the performance of houses on the soil profile. Soil Conservation Service of NSW (1989) have published maps which show characteristics of the soil within each landscape in terms of composition and distribution of soil materials as well as soil classification. These maps could be used to provide a site classification based on generalised information only. Like the other methods mentioned above, there is a risk of an inaccurate site classification using this method as the information does not account for individual and variable site conditions.

7. CONCLUSION

Based on recent published data, the shrink-swell test appears to be the common method for estimating characteristic surface movement and thus the site classification. The shrink-swell test on samples from a particular site attempts to reproduce in the laboratory the potential field conditions. There is not a single site classification applicable to the Sydney region.

No obvious correlation exists between the shrink-swell index and other common soil indices such as linear shrinkage, liquid limit, plastic index and moisture content.

It is noted, however, that there is a potential problem with the shrink-swell test in that the result could be influenced by the initial moisture content.

Due to the potential variability of reactivity of a clay across a site, a site classification should be based on a number of tests. It is realised that commercial pressure does not encourage several tests being carried out on a particular site and therefore there is a risk of an inaccurate site classification being given.

Classification of a site based on the depth of clay could be misleading as it does not account for the variability of the clay.

The use of soil maps is a quick method for providing a generalised site classification which carries a risk of not being applicable to a particular site.

In conclusion, there are different methods for determining the site classification and the three methods discussed above have their limitations. Considering these limitations, simpler methods such as identification of the soil profile and local experience which take into account soil variability may be more appropriate.

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