Small Scale Variability of Reactive Soils in Western Sydney

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SUMMARY The Australian Standards AS2870 deal with the design of slabs and footings for residential construction, several methods of site classification are countenanced by these standards. One such method is the estimation of the maximum ground surface movement (y_s) and this is often based on shrink-swell index (I_{ss}) test results. The standard provides no guidance on the number of tests that should be completed. The paper describes a detailed site investigation on one site in western Sydney aimed at determining the small scale variability of the shrink-swell index. The site was selected with a view to minimising this variability. A comprehensive programme of laboratory testing was completed on samples obtained during the site investigation. The results of this programme were then analysed to determine the variability across the site. The results indicate that the variability is such that a single shrink-swell test result can be a very poor indicator of site reactivity even for this "low variability" site. In general at least two to three tests are required to classify a site with even low confidence. A detailed geotechnical log increases the value of test results almost three fold. For the site with relatively low variability two or three tests and a detailed log result in a site classification which is also relatively low in variability.

1 INTRODUCTION

Soils may be considered reactive or expansive if they undergo significant volume changes as the degree of saturation changes. Large variations of soil moisture conditions in the Australian environment mean that when reactive soils are present, they can have a severe effect on overlying light weight structures. Australian geotechnical practice has adopted methods to deal with reactive soils that are relatively sophisticated compared with those adopted in many other parts of the world.

As more information has become available, it has become apparent that the variability of these soils must be taken into account in site characterisation. The variability occurs over all scales including that of a typical Australian residential allotment even when conditions would appear to indicate that soil behaviour should be reasonably uniform (Moss and Bone, 1988).

This variability results in the extent of the site investigation required being uncertain as there is a conflict between cost and extent. This paper presents the results of an investigation to establish the least variation in reactivity that might be expected over a typical residential site. It also attempts to define the site investigation that would be adequate to establish representative values of surface movement.

2 AUSTRALIAN PRACTICE

The first Australian Standard that covered design of footings and slabs over reactive soils was released in 1986 (Standards Australia, 1986). This standard has been complimented by a commentary and map and subsequently revised and split into two parts (Standards Australia, 1988a, 1988b, 1988c and 1990). The potential for surface movement depends on two factors: (i) the potential for moisture change and (ii) the soil profile. The approach adopted in the Australian standards is to classify the site rather than the soil, in this manner both of the above two factors can be taken into account.

The various standards describe differing methods to classify a site, the language varies between standards and it is not always clear exactly what was intended by the drafting committee. Nevertheless three methods of classification are appropriate for reactive clay sites, these are:

* Visual assessment and interpretation of performance of existing buildings.
* Soil profile identification and classification from extablished data.
* Computation of predicted surface movement, y_s.

In general the determination of the predicted surface movement depends on (i) soil sampling and testing to provide Instability Indices for the soils encountered, and (ii) information on the design change in soil suction versus depth. The Instability Index, I_{pt}, is defined as the percent vertical strain per unit change in suction (in pF units), it is therefore like a modulus but is not constant. The standards provide a range of methods of determining I_{pt} by testing undisturbed samples. The standards also provide a set of recommended suction versus depth profiles for various places within Australia. Thus given an appropriate site investigation it is possible to predict the surface movement on a site and therefore to classify the site.

The standards do not give any indication of the scope of site investigation considered appropriate to classify a site. In a given area, for example Sydney, the site classification is almost entirely dependent on the value or values obtained for the Instability Index. With this in mind it was decided to investigate the variability of this property.

3 SITE SELECTION

It was intended to investigate the variability of the Instability Index for a given soil profile and therefore it was desirable for the selected site to satisfy as many of the following criteria as possible:

* Soil behaviour typical of the reactivities encountered in western Sydney. Thus this required an expected Moderate reactivity (i.e. Class M site).
* Low expected variability across the site so that the underlying variability could be established. Thus preferable sites would be flat with expected consistent subsurface conditions and away from the boundaries of profile units shown on available maps.
* Information already available regarding soil reactivity. Thus if possible sites that had been established by the CSIRO in Blacktown City would be ideal.
* Easy access for investigation, thus a co-operative owner, easy physical access and a minimum of subsurface services would be ideal.

Five sites were chosen from those detailed in Coffey and Partners (1985) and Moss and Bone (1988) and from discussions with the Government Architects Branch. Preliminary site visits were then completed.

There are two map series that may be used to assist with profile identification in the Sydney Region. The first is the Soil Associations of the County of Cumberland map, first published in the early 1960s by the N.S.W. Department of Agriculture and re-issued by Standards Australia (1988b). This map was intended for agricultural purposes but was indicated by the 1986 Standard to be useful for site classification. The second is a series of Soil Landscape maps published recently by the Soil Conservation Service (Chapman & Murphy, 1989; Bannerman & Hazelton, 1990). These maps were used to assess the potential for lateral variation across the site, and it was thus considered desirable to find a site which was well within a given unit on both series of maps and thus not near any map unit boundaries.

On the basis of the site visits, review of the maps and other information available for each site, it was decided that a site at Plumpton Park was almost ideal. This site was selected.

4 SITE DESCRIPTION

The selected site had many advantages for this investigation, amongst these were:

* The site was in the Cumberland Soil Association and the Blacktown Soil Landscape Unit and away from the boundaries of these map units. These are very extensive units which are typical of western Sydney and are expected to be Moderately reactive.
* The site was very flat with no large trees and no obvious activity by man except having been cleared some time ago. Thus access was easy and no subsurface services were expected.
* The site was apparently owned by the Blacktown City Council and awaiting future subdivision, so permission could be obtained to complete a site investigation.
* Immediately adjacent to the chosen site was a Ground Movement Station (not currently operating) and there was considerable data already available about the subsurface soils and their reactivity. In fact Coffey and Partners (1985) had estimated the surface movement at the site as between 32 and 36mm, i.e. Class M.

5 FIELD WORK

The field work consisted of three simple stages:

* A site visit was completed as part of the site selection process. The surface features of the site were recorded during this visit.
* Seven boreholes were augered on the site on the 12th July 1990. These bores were located on the two arms of an "L" shaped pattern, one arm extending north along the slope and the other east down the gentle slope. Holes were located at the intersection of the two arms and at 5 and 30 m along each arm, two holes were redrilled for better logging and to provide some redundant samples. Undisturbed samples were obtained almost continuously for the first 2 metres. In general samples were started at 0.15, 0.60, 1.10 and 1.60m depths.
* Three test pits were excavated with a backhoe on the 8th August 1990, these enabled some large disturbed samples to be obtained and for the profile to be better established.

6 LABORATORY WORK

In general shrink-swell tests were completed on each of the samples. Sometimes more than one test could be completed on a sample and other times more than one shrink or swell stage could be completed.

These tests were completed in accordance with the methods outlined in the Draft Australian Standard DR89116 "Methods of testing soils for engineering purposes - Method G1.3: Soil reactivity tests". The test basically consists of obtaining two undisturbed sub-samples and measuring the shrink strain, ε_{sh}, from in-situ conditions on one and the swell strain, ε_{sw}, from in-situ conditions under a light surcharge on the other. A shrink-swell index, I_{ss}, is then determined from assumed values of the change in soil suction and ratio between the slope of the shrink (unrestrained) and swell (restrained) strain versus moisture content relationship.

A limited program of laboratory suction measurements was completed using psychrometer and filter paper techniques. Finally classification testing was undertaken, this included linear shrinkage, Atterberg limits and particle size analyses.

7 FACTUAL RESULTS

The soil profile is shown on Figure 1, and consists of:

* A clayey silt topsoil to a depth of between 0.2 and 0.3 metres, overlying
* A mottled red-brown and grey silty clay of intermediate plasticity with shale and siltstone fragments to 70mm and rare ironstone bands, this is layer 2 and 3 on Figure 1. This graded at approximately 1 metre depth to
* A grey silty clay of intermediate plasticity with rock fragments to 200mm diameter, which inturn graded to
* Grey siltstone at between 1.8 and 2.8 m depth.

The profile was relatively consistent across the area investigated, the depths at which one layer changes into an-

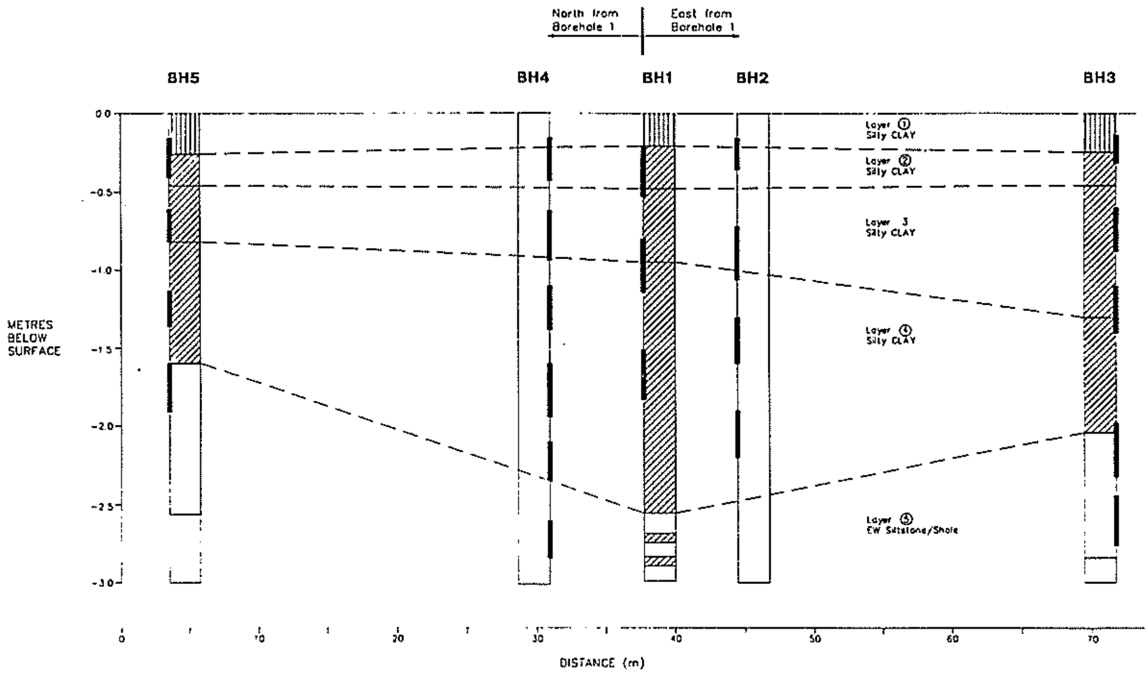

Figure 1 Geotechnical section through the site investigation

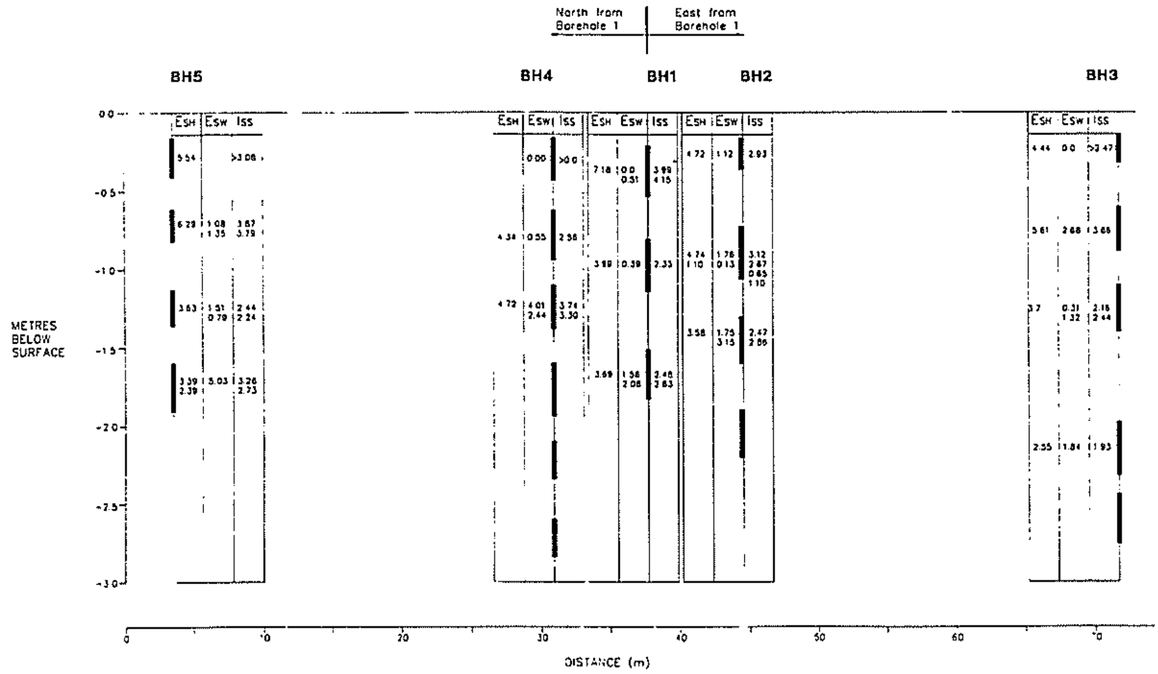

Figure 2 Summary of factual data

other are a little arbitrary as all boundaries were gradational.

The results of the shrink-swell tests are presented on Figure 2, this shows all ε_{sh}, ε_{sw} and I_{ss} results. Where two shrink or swell stages were completed on a sample, these have been combined to produce more than one I_{ss}. In all 28 results for I_{ss} were determined.

8 ANALYSIS OF RESULTS

There are a number of approaches that can be adopted to determine site reactivity given the 28 I_{ss} results obtained from 5 boreholes. These different approaches and the implications are discussed in the following sections.

8.1 Single Test

In some site investigations a single shrink-swell test may be completed and used to characterise the site reactivity. The results of this current investigation can be used to simulate 28 single test investigations on the basis that any one of the samples or tests may have been undertaken to characterise the site. For this series of tests the mean I_{ss} was 2.69% with a standard deviation of 0.97%. This is equivalent to an average y_s of 41.4mm in the Sydney region and the site would be classed on the average as (low) Class H, i.e. virtually on the boundary with Class M.

If it is assumed that I_{ss} is normally distributed, which is not unreasonable, then a single shrink-swell test would result in the site being classified as Class S 7.6% of the time, Class M 39% of the time, Class H 51% of the time and even Class E 2.7% of the time. Similar values are determined if the percentages are estimated simply from the raw data. The conclusions do not alter very much even if the obviously unreliable result from BH 4 at 0.15m of 0% and the deep result from BH 3 at 2.5m are ignored. In which case the percentages are 3.4, 36, 59 and 2.0 respectively.

The above indicates that there is considerable variability associated with the use of only one shrink-swell test even on this site which was selected because it was expected to have low variability.

A more reasonable assessment of a one test site classification may be based on the 17 results obtained from between 0.6 and 1.3m depth, i.e. below the topsoil and above the level at which suction changes are small. These tests have a mean of 2.68% and a standard deviation of 0.91% and thus the site classifications obtained would be Class S 6.4%, Class M 40%, Class H 51% and Class E 2.0%. These are almost identical to those discussed above.

8.2 Single Borehole

The information can be viewed as five separate boreholes, from each of which several shrink-swell test results have been obtained. In this case the site could be classified from each of these boreholes by a number of different methods. Firstly the shrink-swell behaviour of the soil at any depth could be taken as that obtained from the sample nearest to it, i.e. boundaries to each layer are taken as the mid-point between each pair of samples. This may be the approach adopted if the borehole had not been carefully logged. The classifications of the site obtained using this method are given in the "mid-point" row of Table I.

An alternate is to use the borehole information and engineering judgement to decide the extent of each layer, the result of this method is given in the "geotechnical" row of Table I. Finally it is usual practice to remove the topsoil prior to constructing a residential slab, in this situation the suction changes that are applicable to the site are those occuring over the depth of influence below the topsoil, results of this method, adopting geotechnically based layers, are given in the "topsoil removed" row of Table I.

From the above it is apparent that in this case the midpoint method (mean 46.4mm, s.d. 6.43mm) over estimates the thickness of the reactive soils compared with the geotechnical assessment (mean 38.6mm, s.d. 3.78mm) and therefore over estimates the site reactivity. In addition it is clear that removing the topsoil can have a large influence on the expected surface movement (mean 54.4mm, s.d. 6.35mm) and should be taken into account when classifying a site.

TABLE I
SURFACE MOVEMENT BY BOREHOLE PROFILE

Method	BH 1	BH 2	BH 3	BH 4	BH 5
Midpoint	51	45	42	36	48
Geotechnical	37	40	33	40	43
Topsoil removed	46	62	51	59	54

Surface movement in mm

With the midpoint method layer thickness is purely a function of sample location and as would therefore be expected results in considerably larger scatter than the geotechnical assessment of layering. This indicates the importance of accurately logging the borehole and not just using it as a means of obtaining samples. It can be seen that multiple tests in a single borehole produces relatively low variability in the resulting site classifications.

8.3 Multiple Tests

One potential method of classifying the site would be to undertake more than one shrink-swell test and adopt the mean I_{ss} to characterise the site. An approximate idea of the classifications that would result from repeated such investigations can be obtained by random sampling from the existing test base (ignoring the two outriders). Table II shows the frequency that would be obtained for each class for varying numbers of tests.

TABLE II
FREQUENCY OF VARIOUS CLASSIFICATIONS

No of tests	Site classification			
	S	M	H	E
1	3.4	36	59	2.0
2	-	36	64	-
3	-	32	68	-
5	-	28	72	-
10	-	20	80	-

8.4 Variability

One useful way of assessing the relative merits of different site investigation procedures is to determine how often a particular method would predict the surface movement, y_s, to within, say, plus or minus 5mm of the mean as this is roughly half a class. Following this criterion, the following results are obtained:

Method	Percentage y_s within $\pm$ 5mm
Single test	30
Midpoint	56
Geotechnical	81
Two tests	42
Three tests	50
Five tests	61
Ten tests	78

As can be seen from the above:

* A single test results in a very poor classification.
* Three to five tests represents a significant improvement in reducing the variability but at a cost.
* The variability for the midpoint method (which used about five test results for each hole) and for random sampling using five tests is about the same.
* The simple measure of completing a detailed log of a borehole results in the same increase in accuracy of classification as almost trebling the number of tests completed (i.e. in this case the midpoint method is equivalent to about four tests, while the geotechnical method is equivalent to greater than 10 tests).

9 RECOMMENDATIONS AND CONCLUSIONS

The investigation indicated that if a single test is undertaken there is very large variability in the resulting site classification even on this site which was selected because of its expected low variability. Other sites which were not as geotechnically uniform would presumably show considerably more variability.

The best method of classifying a site based on shrink-swell test results is to accurately log a borehole and complete a few, at least two and three is considerably better, tests and then determine y_s from these results. It should be noted that the extra information obtained from a detailed log means that this is not the same as just completing three tests on a site and taking the mean I_{ss} to characterise the site. In fact this approach yields the same level of confidence in the classification as randomly completing over 10 shrink-swell tests. In addition detailed logging will alert the investigator to the presence of fill on the site, which is known to cause many problems with reactive soils in Sydney.

10 ACKNOWLEDGEMENTS

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11 REFERENCES

1. Bannerman, S.M. and Hazelton, P.A. (1990) "Soil Landscapes of the Penrith 1:100 000 Sheet" Soil Conservation Service of New South Wales, Sydney (and accompanying map).

2. Chapman, G.A. and Murphy, C.L. (1989) "Soil Landscapes of the Sydney 1:100 000 Sheet" Soil Conservation Service of New South Wales, Sydney (and accompanying map).

3. Coffey and Partners Pty Ltd (1985) "Sydney Swelling Soils Study - Analysis of Data" Report No. S7032/2-AD prepared for the N.S.W. Builders Licensing Board (Unpublished).

4. Moss, D. and Bone, L. (1988) "Reactive Clays in the Sydney Region" Final Year Project, School of Civil Engineering, University of New South Wales, Sydney (Unpublished).

5. Standards Association of Australia (1986) "AS2870-1986 Residential Slabs and Footings" SAA, Sydney.

6. Standards Association of Australia (1988a) "AS2870 Supplement 1-1988 Commentary - Residential Slabs and Footings" SAA, Sydney.

7. Standards Association of Australia (1988b) "AS2870 Supplement 2-1988 Soil Associations of the County of Cumberland Map (Sheets 1 to 3) - Residential Slabs and Footings" SAA, Sydney.

8. Standards Association of Australia (1988c) "AS2870.1-1988 Residential Slabs and Footings, Part 1: Construction" SAA, Sydney.

9. Standards Association of Australia (1989) "DR89116 Methods of Testing Soils for Engineering Purposes - Method G1.3: Soil Reactivity Tests" SAA, Sydney.

10. Standards Australia (1990) "AS2870.2-1990 Residential Slabs and Footings, Part 2: Guide to Design by Engineering Principles" Standards Australia, Sydney.