Variability of Expansive Nature of Clay on a Site

K. McManus, AM
RFD, MEngSc, BE, CPEng, FIEAust
Deputy Head, School of Civil Engineering and Building, Swinburne University of Technology, Australia.

S. De Marco
B.Eng. (Hons), Grad. I.E. Aust., P.Eng.
Graduate Student, School of Civil Engineering and Building, Swinburne University of Technology, Australia.

Summary Methylene blue adsorption tests have been conducted on a series of sites close to Melbourne, Australia to assess the clay mineral type which is present in the soil and therefore give an indication of the likely degree of relative movement in the soil. The findings from these tests show that there can be considerable variation in the proportion of active clay mineral across a site whose residual soil has the same geological origin.

1. INTRODUCTION

The Australian Standard (S.A.A AS2870, 1988), implies that the movement of a soil is uniform across a residential building site. The soil characteristics of these residential building sites often have been determined from the tests conducted on samples from only a single borehole. The classification of a site for the design and construction of footing systems for residential buildings was established from these tests, and foundation design is based on these results. The assumption that this set of test results is characteristic of the total site so far seems to remain unchallenged.

Swinburne University of Technology conducted a study which showed that, although a soil may have the same geological origin, the proportion of the active clay mineral in the soil can vary, resulting in significant differential movement of a light structure constructed on that site. This paper proposes a simple method to determine this site variation to assist in the foundation design.

2. CLAY MINERAL VARIATION

Case studies have found that the movement of existing structures not only varies across a site, but also across a region whose residual soil has the same geological origin. Agricultural science sources confirm these findings by showing that the distribution of soil could not be expected to be uniform. For example, in figures 1 and 2, Shouse et. al., (1990) and Nash et. al., (1989) illustrate the variation of clay minerals which have been measured at a particular site. The proportion of the clay was not found to be uniform throughout the site and hence expansive movement could also not be uniform. Depending on the location of a single borehole, different, classifications of the site could be possible.

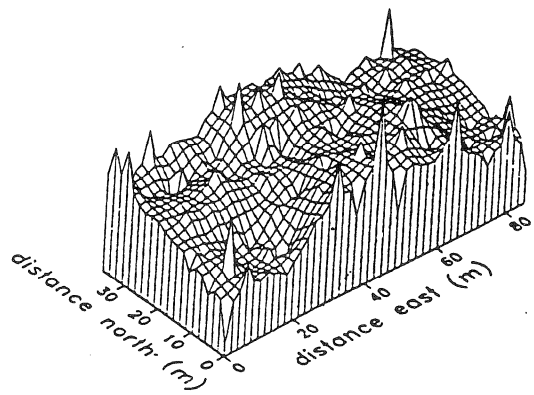

Figure 1. The variation in clay content over the site (Shouse et. al., 1990)

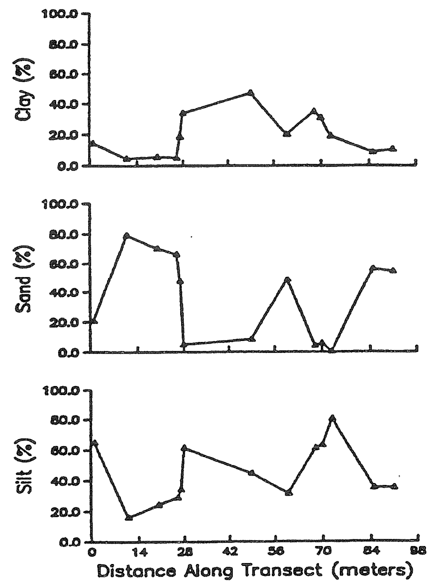

Figure 2. Variation in clay, sand and silt content at 0.6m depth with distance along a transect (Nash et. al., 1989).

3. CASE STUDIES

An analysis of a series of individual sites located in the Quaternary Basalt Deposits of the Melbourne Region was made to determine the extent and effect of the variable nature of the soil (Case and McInnes, 1994).

3.1 McGrath Rd. Wyndham Vale

The McGrath Rd investigation site was located on the Quaternary Basalt soils of Western Melbourne (Figure 3). Levels on the slab were taken around the perimeter of the property to show the extent of differential movement that had occurred. Movements of up to 55mm were recorded on the west side of the house.

Boreholes were drilled down to a depth of 3.2m at the locations shown as (1), (2), (3) and (4). Four to five samples were taken from each borehole for testing.

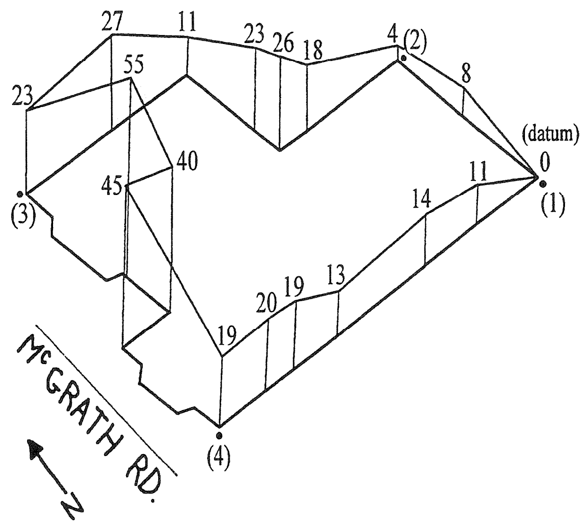

Figure 3. Slab levels for McGrath Rd site (mm) and borehole locations (shown in brackets), (Case & McInnes, 1994).

Methylene blue adsorption (MBA) tests were conducted on the soil samples from each borehole. This test indicates the apparent surface area (ASA) of a soil sample. Results obtained from this test are shown in Table 1.

Table 1. Average apparent surface area (ASA) over total depth and movement for McGrath Rd site.

Borehole No.	Movement (mm)	ave.ASA (m^2/g)
1	0 (datum)	102
2	4	107
3	23	252
4	19	163

From these results, it was seen that the average apparent surface area for each borehole is roughly related to the movement of the structure. Samples from boreholes (1) and (2) showed the least ASA and were associated with the least slab movement. The ASA measurements for boreholes (3) and (4) were greatest with the largest amount of slab movement.

Looking at the results from each individual borehole, Case and McInnes (1994) found that the variability of the ASA results not only occurred across a site, but also with depth as shown in Figure 4.

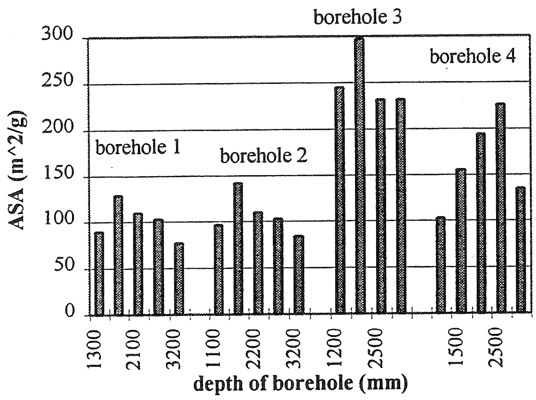

Figure 4. ASA compared to depth of borehole at the McGrath Rd Site

3.2 Keilor Sites

The Heatherlea Cres. and the St. Bernards Dr. investigation sites in Keilor were both located in the Quaternary Basalt area of North West Melbourne, and were about 1km apart. One borehole was taken at each site and the variation of ASA with depth was found (Figure 5).

From the results, the conclusion was reached that the reactivity of the clays was not uniform in the Keilor area. Depending at what depth a single sample was taken, a site classification could have been adopted which would not have been representative of the whole depth of profile and probably over the whole site.

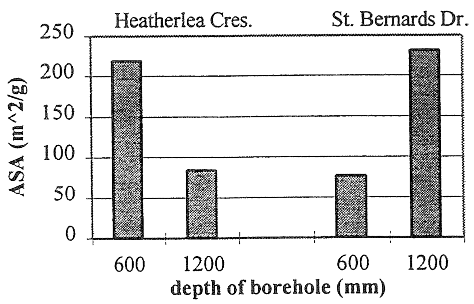

Figure 5. ASA at the Keilor Sites.

4. METHYLENE BLUE ADSORPTION TEST (MBA).

The swelling and shrinking of clay soils has been related to the surface area of a soil, which determines its ability to take up water. Measurement of this surface area has been used as a guide by Swinburne University of Technology to characterise these soils.

The apparent surface area data from the above sites was found using a relatively simple laboratory test called methylene blue adsorption (MBA), proposed by Xidakis and Smalley (1980). This is a qualitative test and has the potential for use in the field.

When a solution of Methylene Blue Dye (dissolved in water) is brought into contact with a soil, the dye molecules form an adsorbed monolayer over the clay particles. When the monolayer is formed, any excess dye is not adsorbed by the soil, but gives a colouration to the supernatant liquid.

The point where the monolayer is complete is detected by the dye being shed from the clay sediment when placed on a filter paper. The formation of a light blue 'halo' around the drop of sediment displayed the presence of the excess dye indicating the "end point". By relating the amount of methylene blue dye used to reach the end point, and taking the effective area of the dye molecule as 107 $Å^2$, the apparent surface area (ASA) of the soil can be found by the following simplified equation. (Xidakis & Smalley, 1980).

$$ASA_{107} = Vd/C * 6.45 \ m^2/g \quad (1)$$

Where Vd is the volume in cm^3 of 0.01 M methylene blue standard solution required to reach the end point; C is the mass of soil used in the test in grams.

The methylene blue adsorption test is subjective in that the end point can differ depending on who is conducting the test. Provided consistent determination of the halo is adhered to, the results obtained from the MBA test will provide a relative measure of surface area. This gives guidance to the relative reactivities of parts of a site.

The surface area of a soil is defined as the sum of the external and internal surface areas of the clay minerals present in the sample. Table 2 describes the size and specific surface of soil particles for various clays.

Table 2. Size and Specific surface of Soil Particles.

Soil particle	diameter (mm)	specific surface area (m^2/g)
Sand grain	1	0.002
Kaolinite	0.3 to 3^{-3}	10 to 20
Illite	0.1 to 2^{-3}	80 to 100
Montmorillonite	0.1 to 1^{-3}	800

A soil with a high surface area will more readily attract larger volumes of water enabling it to swell to a larger degree than soils with lower surface areas. This is due to the fact that each part of the clay mineral can attract a water molecule. The more water the mineral could attract, the more the volume of the mineral would increase.

4.1 Comparison of MBA apparent surface area and true total surface area.

To compare the MBA surface area with the true surface area of the clay mineral, a test developed by VicRoads in Victoria, called Total Surface Area (TSA) was used. This was a fairly long and complex test, but the accuracy of the results were very good. The equipment was calibrated using samples with known surface areas. The TSA test is based on the retention of Ethylene Glycol Monoethyl Ether (EGME) on the clay minerals by assuming a monomolecular layer adsorption on the surface of the clay mineral (VicRoads, 1980).

To check the accuracy of the methylene blue test, the results from 390 TSA and cation exchange capacity test samples (using methylene blue adsorption) conducted in 1980 by the VicRoads technical staff were analysed.

The relationship between Surface Area of a clay mineral using methylene blue, and cation exchange capacity, is shown in equation (2) (Hang and Brindley, 1970)

$$\text{Surface area} = M_f * A_m * 6.02*10^{-2} \ m^2/g \quad (2)$$

Where M_f is the milliequivalents of methylene blue absorbed per 100 g of clay (cation exchange capacity); and A_m is the effective area per dye molecule in $Å^2$ on the clay surface. [= 107 $Å^2$ as recommended by Xidakis and Smalley (1980)].

The results of the MBA test showed a consistent relationship with the results of the TSA (Figure 6). Therefore, the approximate surface area of a clay mineral could be found by multiplying the methylene blue result by 1.8.

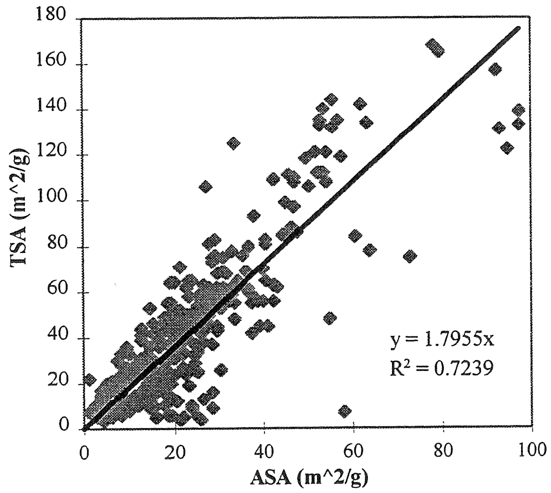

Figure 6. MBA apparent surface area vs. Total Surface Area (TSA)

From a practical point of view, it was deemed sufficient that the MBA test was a consistent indicator of the relative reactivities of the soils on various parts of a site. The determination of absolute specific surface areas was not seen as significant in practice.

4.2 Comparison of Liquid Limit and ASA.

According to Muhunthan (1991) and Fairbairn et. al., (1956), there is a linear correlation between the liquid limit and the surface area (SA) of a soil. The relationship used by Muhunthan (1991) is shown in equation (3). The values of β and λ reported by Muhunthan (1991) are shown in Table 3.

$$1/LL = \lambda(1/SA) + \beta \qquad (3)$$

Table 3. Values of β and λ for each set of test data (Muhunthan, 1991)

Test data	method used	β	λ	correlation R^2
Sridharan et al., 1988	water adsorption	0.006	1.127	0.8652
Farrar & Coleman, 1967	water adsorption	0.006	0.795	0.5799
De Bruyn et al., 1957	glycol retention	0.0085	0.752	0.9318

Table 4 presents the results of the liquid limit and MBA tests on some Victorian soil samples. The inverse of the Liquid Limit and ASA, was plotted (Figure 7).

Table 4. Liquid Limits and Surface Areas of Some Melbourne Soils

No.	sample	LL	ASA (m^2/g)
1	Tulla-red/brown	67	77
2	Tulla-tank test	59	65
3	Tulla-white	75	90
4	Tulla-grey	68	90
5	Glenrowan	56	77
6	Wangaratta	33	39
7	Mitchelton	28	26
8	Mhyree	37	19

Note that the location for sample numbers 1-4 are from the Tullamarine freeway at the 20km post (airport bound lane) at varying depths. The names of these samples were chosen by their colour, ("Tank Test" was a soil formed from a combination of all the Tullamarine samples).

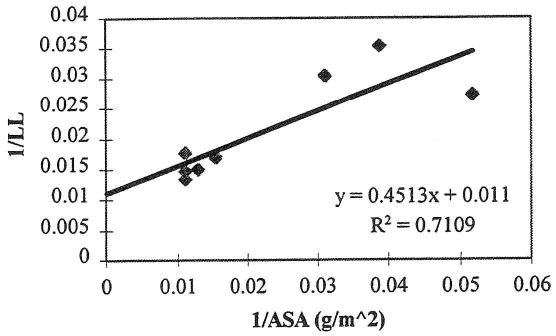

Figure 7. Relationship between Liquid Limit and Surface area for some Victorian Soils.

These results gave values of β=0.011, λ=0.4513 and r^2=0.7109 for the Victorian region tests. These values were in general agreement with the figures quoted by Muhunthan (1991).

5. CONCLUSIONS.

The assumption that residual clay soils derived from the same geological unit had the same reactivity has been shown to be misleading. Experience from Agricultural Science has illustrated the extent of the variability in the proportion of clay minerals in the soil across a site.

The reactivity has varied also with the proportions for the various clay minerals in the clay. Case studies have shown that the reactivity has changed significantly across individual sites and the variation in reactivity has influenced the differential movement of light structures founded on reactive sites. This has a significant impact on the assumptions of the Australian Standard, AS2870, (1988), for light structures on swelling soils.

A simple test (MBA test) has been used to measure the relative reactivities of the soils on a site. The results of the test showed good correlation with the performance of a light structure on site. The test results also showed that it was consistent when compared with a true measure of the surface area of clay (TSA test).

The results of the MBA test correlated well against the results of the Liquid Limit test. The Victorian region test results agreed reasonably with the published relationships for liquid limit and surface area of the soil, found by other testing methods.

The results obtained from the MBA test were shown to be of practical value in guiding the classification of sites and in predicting the performance of light structures on expansive sites.

6. ACKNOWLEDGMENTS

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