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Assessment of clays by small-scale suction **tests**

Évaluation des argiles par des essais de succion à petite échelle

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ABSTRACT - The relationship between suction and water content gives crucial information about a soil. The time and cost of determining the full soil water suction curve make it not feasible for small projects like economic housing. A considerable range of soil suctions can be determined easily and within a reasonably short time by using small samples, simple suction control and a high precision balance. It appears that in this way it may be possible to estimate heave potential and variability of soil properties at reasonable cost in an acceptable time.

RESUME - La variation de la succion en function de la teneur en eau (courbe de rétention) donne des informations importantes à propos du sol étudié. Toutefois, pour des projets de gamme moyenne, notamment les maisons économiques, la détermination de la courbe de rétention n'est pas toujours possible en raison du cout et du temps. L'utilisation d'un dispositif précis de mesure de succion pour des petits échantillons de sols, nous a permis de contourner ce problème. En effet, il est possible en utilisant ce dispositive de déterminer raisonnablement le potentiel de soulèvement et les variations des propriétés du sol en termes de cout et de temps acceptables.

1. INTRODUCTION

The tests here presented aim to address problems with the current commercial methods for foundation indicator tests. Usually such tests involve procedures primarily intended for road construction materials and they frequently give poor estimates of heave potential for high clay-content soils. Preoccupation with economy points to a need for simple tests with minimum skilled labour content, minimum opportunity for short-cuts and straightforward interpretation of results. Tests should directly relate to heave potential, rather than general properties. Suction potential gives an indication of how readily a soil can draw in water. Change in water content is the cause of volume change. Suction potential should be a good indicator of swell potential.

2 INDICATION OF SHRINK/SWELL POTENTIAL

Kassa (2005) found that Atterberg limits are not a reliable indicator of volume change under load. Sridharan and Prakash (2000) found that Atterberg limits can sometimes indicate heave potential significanty higher or significantly lower than reality. Atterberg limits remain, however, the most popular indicators of heave potential. The Linear Shrinkage test performed on raw soil samples and allowed to air-dry slowly, gives a graphic indication of the extent to which a soil may change volume with water content, but does not indicate the likely pressures involved in this change of volume.

Clays expand when they draw in water. The force which can be exerted in this expansion depends on the strength with which they can suck in water. The suction of clays has long been recognised as a cardinal indicator of heave potential, but it is one of the least convenient indicators to measure. The plot of suction from saturation to desiccation is known as the soil water characteristic curve (swcc). The swcc is an indispensable part of a full unsaturated analysis, but it requires much time and skill to measure.

3. RECENT ADVANCES AND CURRENT PRACTICE IN SUCTION MEASUREMENT

Three papers presented at the International conference on Soil Mechanics and Geotechnical Engineering in Paris 2013 deal with advances in techniques of suction measurement. Two other papers deal with measuring suction in practical engineering projects.

Advances in dew-point potentiometer technology point to extending the range of suctions measurable by this type o f instrument (Macek et al 2013). The use of micro-porous membranes may allow quicker suction

Measurement in the 0-30 kPa suction range (Nishimura 2013). The use of a centrifuge may speed up measurement in the 0 to 900 kPa range (Reis et al 2013).

But in practical use, for assessing lime treatment on London Clay (Mavroulidou et al. 2013) and for modeling the impact of climate changes on embankments and cuttings (Mendes and Toll 2013), Whatman No.42 paper remained the method of choice. This time-honoured system takes two to six weeks for a suction measurement and requires careful laboratory technique.

4. SMALL SCALE SUCTION POTENTIAL MEASUREMENT

A more limited indication of suction potential can be found by allowing samples to reach equilibrium at known temperature and humidity. Soil samples can be brought to equilibrium with saturated solutions of various salts (Blight 2013). Blight's tests took typically 90 days. Although the equipment was cheap and unsophisticated, and the skilled labour component not large, the time frame is not feasible for normal engineering practice. The authors have modified the procedure to give quicker results, making enquiry into some important questions feasible.

The procedure involves using small pieces broken from a soil specimen. Breakage usually occurs along planes of existing weakness; the micro-structure and fabric of the soil are not greatly disturbed. Samples are placed in small glass weighing bottles with ground-in lids. When firmly closed, little air or water vapour leaves or enters in the time taken for weighing. Samples are weighed on an analytical balance and then placed with lids open in a container at controlled temperature and humidity. Equilibrium moisture content is a measure of the suction potential of the soil under those conditions. Samples can be weighed periodically by closing the ground-glass lid and removing from the controlled atmosphere to the analytical balance. For most of the tests performed in this investigation suctions corresponding to saturated solutions of KCl and NaCl were used, though a number of tests used both higher and lower suctions.

Figure1 shows curves of moisture content against time at constant suction for samples of 30 clayey soils from housing developments in central South Africa. The masses of the samples range between 25g and 35g. Starting water contents were arbitrary. The equilibrium moisture contents at 22MPa suction (corresponding to a saturated solution of KCl at 20^{0}C) vary from 3.6% to 12.6%. There appears to be a correspondence between moisture content and possible heave potential. Those with the highest water contents have Plasticity Index close to 40, which would normally be considered an indication of high heave potential. Those with the lowest water content have PI below 15, normally taken as an indication of low heave potential.

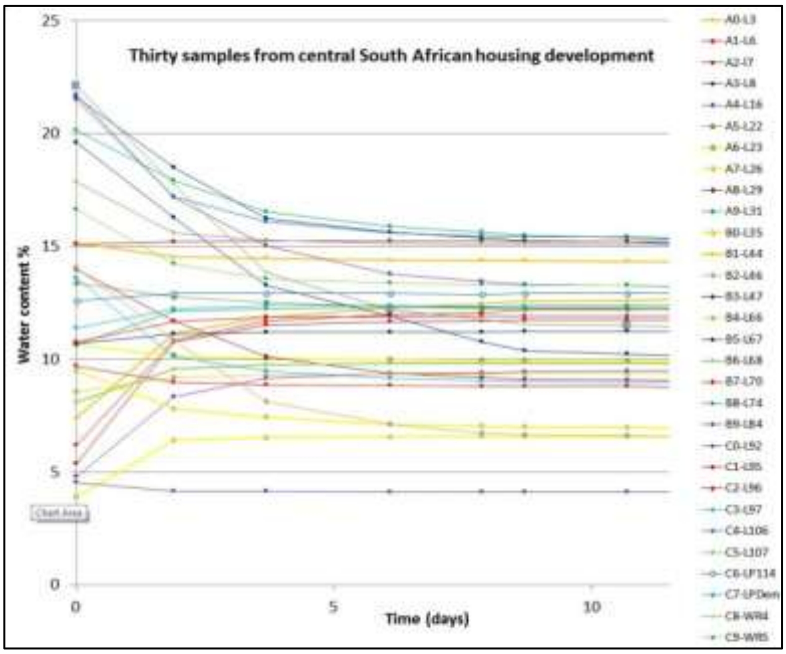

Figure 1 30 samples at 22MPa suction

These same samples were used to probe questions concerning differences of behaviour in wetting and drying, and the possibility of permanent change in properties due to oven drying. Figures 2 to 4 show these 30 samples being tracked from equilibrium moisture content at 22MPa, through oven drying and re-wetting by absorption of water from the air (Figure 2), wetting by the addition of a small amount of die-ionised water and re-equilibrating at 22 MPa (Figure 3), saturation with de-ionised water and re-equilibrating at 22 MPa (Figure 4).

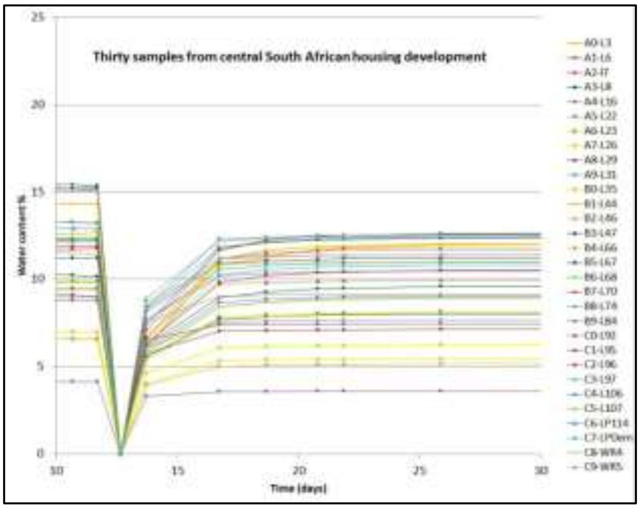

Figure 2 30 samples after oven drying

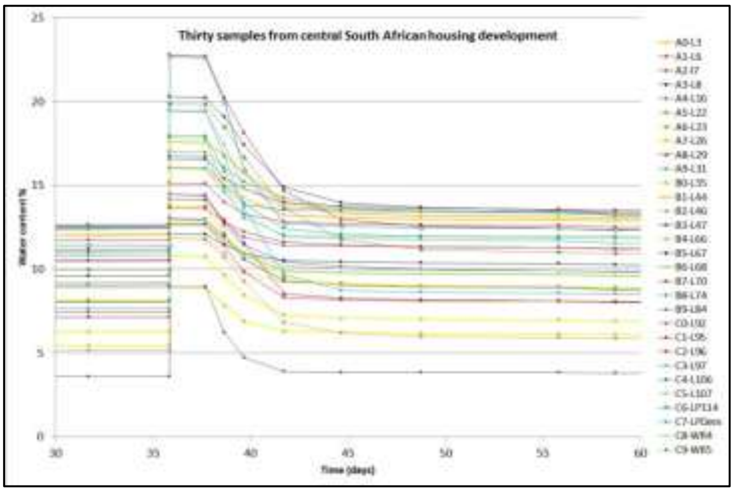

Figure 3 30 samples after wetting

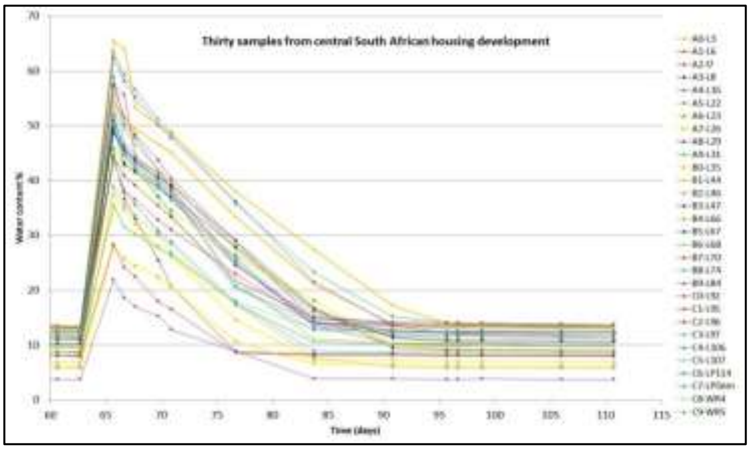

Figure 4 30 samples after saturation

From initial moisture content the low-suction samples reached equilibrium moisture content after about 4 days, the high-suction samples reached constant water content after about 9 days. After oven drying and returning to 22MPa suction conditions all samples reached equilibrium after about 5 days. In most cases the equilibrium water content was significantly lower than that reached before oven drying. After wetting to water contents close to or somewhat higher than the original values and re-stabilising at 22MPa almost all of the samples reached moisture contents higher than the value after oven drying, but substantially less than the original values.

After saturation most of the samples reached equilibrium at slightly higher moisture content, but again lower than that reached before oven drying.

Figure 5 shows moisture content changes as a bar chart. Samples whose initial water content was very low are grouped predominantly on the left side.

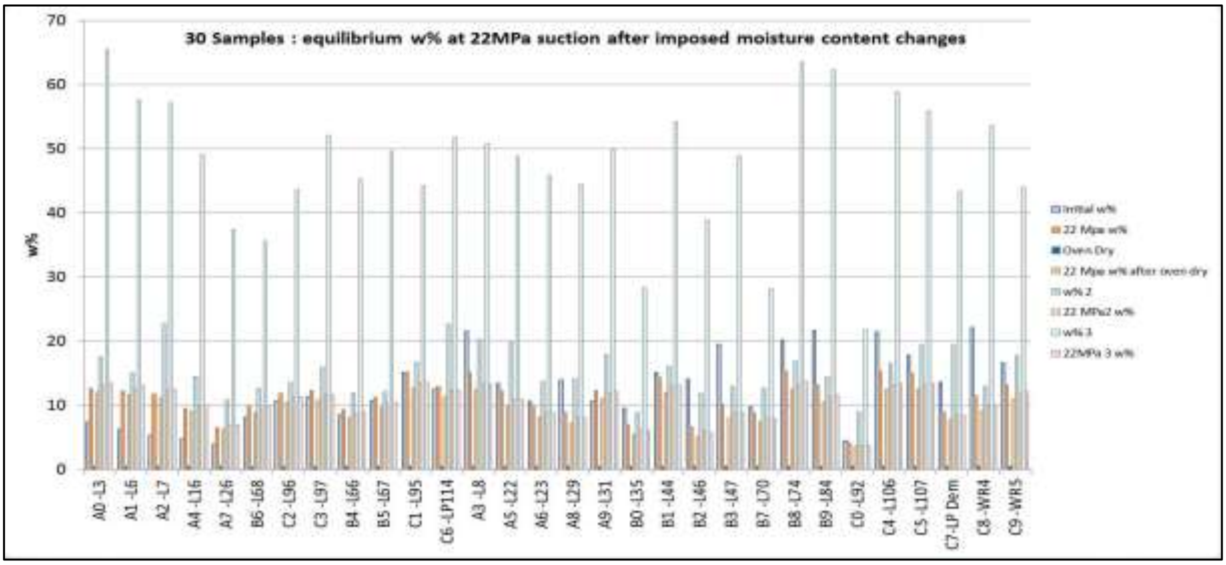

Figure 5 Water content reached by 30 samples at 22MPa from initial moisture content after oven drying, wetting and saturation

Where the initial water content of the soil was well above its 22MPa value, oven drying significantly reduced the soil's subsequent suction potential, and even saturation did not restore the original suction potential. Where the initial water content was well below the 22MPa value, the soil was not so greatly affected by oven drying and saturation could lead to higher retained moisture content at 22MPa. This suggests that Blight's contention (Blight 2012) that air drying can lead to permanent changes in some residual soils may commonly apply to many clayey soils. Alternatively it may be a consequence of the well-known hysteresis property of clays and a very high degree of saturation may be needed to regain the original drying curve.

This test also suggests that in the majority of cases, whatever suction changes take place, the ratios of water content between the various samples remain substantially the same.

The possibility of consistent relationship over a range of suctions was tested with 20 samples which were brought to equilibrium at 37 MPa then 10 MPa and then 2 MPa. Figure 6 shows that almost all of the samples maintained a consistent relationship throughout this range of suctions. They also maintain this relationship after oven drying. This suggests that a single determination at one suction may allow estimation of suction potential over a considerable range of suctions.

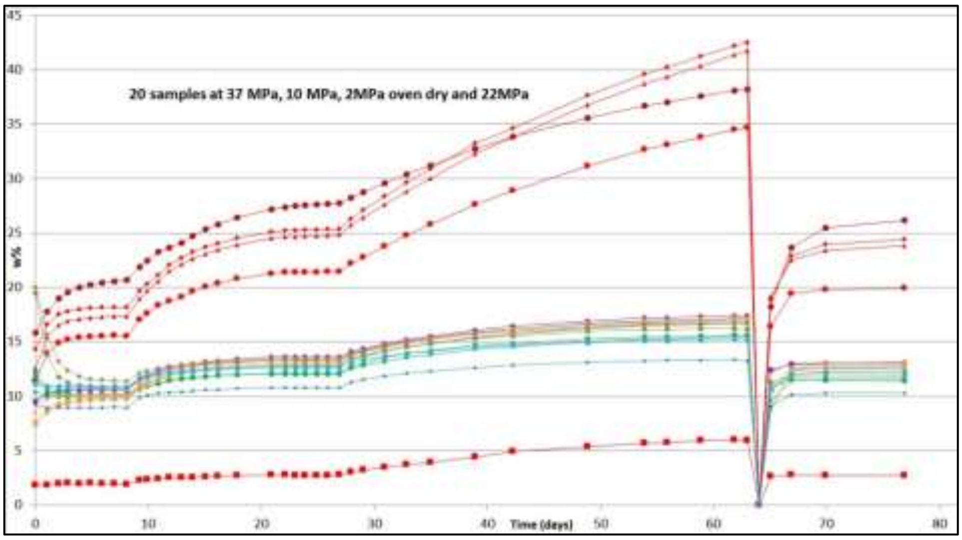

Figure 6 20 samples : equilibration of water content at 37 MPa, 10 MPa, 2 MPa and at 22 MPa after oven drying

4.1. Reducing the time of testing.

It could be expected that smaller samples would take less time to reach equilibrium. Figure 7 shows plots of moisture content against time for seven different-sized small samples of the same clay (PI = 40). The sample masses vary from 0.71g to 8.4g. All seven samples reached equilibrium water content in approximately one day. The equilibrium value reached by the 7 samples averaged 13.56% with standard deviation of 0.30%. The correlation coefficient with sample-size was 0.17, suggesting that there is no significant correlation between sample size and test outcome for this range of sample masses.

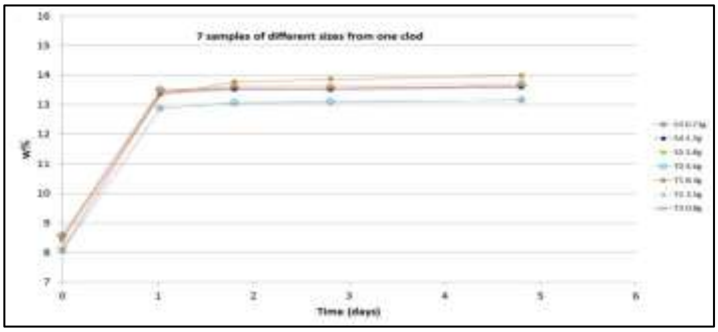

Figure 7 Equilibration of 7 samples (8g to slightly less than 1g) at 22 MPa suction.

5 ASSESSMENT OF VARIABILITY OF SOIL PROPERTIES

Soil is highly variable, and testing procedures usually lay stress on the need to take a sample of adequate size from which a representative portion is obtained by systematic mixing and division. The intent is to give characteristic median values. Reliability analysis is an increasingly accepted technique for accounting for uncertainties in various aspects of geotechnical analysis (Phoon 2008). Reliability analysis needs an estimate of standard deviation as well as a median value of soil properties. The procedure described above allows a direct assessment of the variability of a soil by using a number of different small samples. The difference in time involved in testing one, five, or even twenty samples is small, since the samples are just weighed and put into a container where they are left to reach equilibrium.

Preparation time is minimal - specimens are simply selected from any preferred location in the sample. There is little scope for short-cuts in preparation. The soil micro-structure remains substantially intact. For samples smaller than about 10g, a time of only one or two days may be needed to reach equilibrium when suction is 20 MPa or more. The weighing procedure is quick compared to the time taken to reach equilibrium - each weighing takes only a few seconds.

Table 1. Mean and standard deviation for 5 samples of 6 different soils

	Average w% at 22 MPa	**Standard Deviation**
S1 Light brown clayey sand	7.12	0.23
S2 Dark brown clay	11.92	0.29
S3 Black clay	12.4	0.18
S4 Brown clay	13.86	0.32
S5 Light yellow silty clay	6.06	1.22
S6 Light brown sandy clay	11.09	1.76

Table 1 shows results for five specimens each of 6 widely different soils. The first four show only small standard deviation, suggesting that variability is small and a single test result would probably give a good representation of the properties of the soil. The results for the fifth and sixth samples show substantial standard deviation. Sample S5 is a kaolinitic clay presenting little problem for heave. Sample 6 was taken from a subsidy housing project site where results of foundation indicator tests suggested low heave potential but significant heave was in fact, encountered.

Ten more samples of the soil S6 were tested. The results for the two tests were:

7.98, 12.22, 11.67, 12.02, 11.58	Average 11.09, S.Dev. 1.76
11.63, 11.72, 11.37, 11.23, 11.98, 8.11, 11.50, 11.76, 11.13, 11.37	Average 11.13, S.Dev. 1.11

Most of these results give equilibrium water content at 22 MPa close to 12%, indicating the probability of medium to high heave potential. There are, however, two very different results, one in each set. Both are close to 8%, indicating far lower heave potential.

These results suggest that in a very restricted area there is the possibility of major variation in properties for some soils. They suggest the possibility that a single laboratory determination of heave potential may give a misleading value and this could be the cause of the damage which occurred in this case.

6. CONCLUSIONS

The testing technique described here, using very small samples subjected to easily-controlled suctions, may provide a more convenient means of assessing probable heave potential than current commercial methods. Very little sample preparation is involved and there is little scope for short-cuts. A large enough number of test samples can be used to gain insight into the variability of the soil concerned without greatly increasing the testing time or labour cost.

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