Duplicate testing conducted on the input parameters for the estimation of potential expansiveness of clay.

Essais dupliqués sur les paramètres d'entrée pour l'estimation du potentiel de gonflement des argiles.

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ABSTRACT – This paper presents a study conducted on three active clay soils analysed at seven commercial laboratories in South Africa. Commercial test results are often used as input parameters for prediction models used to estimate potential heave expected from active clays, especially when designing foundations for light structures. This paper briefly looks at the typical results obtained from such laboratories and comments on the correlation achieved.

RÉSUMÉ – Cet article présente une étude menée sur trois argiles actives testées dans sept laboratoires privés en Afrique du Sud. Les résultats de ces essais sont d'habitude utilisés comme paramètres d'entrée de modèles de prédiction en vue d'estimer le potentiel de soulèvement d'argiles actives, en particulier lors du dimensionnement des fondations de structures légères. Le présent article évalue les résultats typiques de ces essais de laboratoire et discute les corrélations proposées.

1 INTRODUCTION

The American Society of Civil Engineers estimates that of all homes in the United States, a quarter has had some damage caused by expansive soils. The financial loss to property exceeds that of earthquakes, floods, hurricanes and tornadoes combined.

In Africa there exists a widespread problem of providing economic housing for lower income communities. In South Africa the government is attempting to provide small subsidised houses for the very poor. Most of South Africa has semi-arid and sub-humid conditions (Weinert, 1980) which lead to generally shallow residual soils subject to seasonal saturation and aridity. Such conditions are known for giving expansive foundation problems.

Advanced mathematical solutions are available for heave prediction, but unfortunately they rely on the input Of the soil water characteristic curve (swcc) for which the typical cost is US $10 000 (Fredlund 2009) - more Than the cost of a low cost house. Besides the cost, the time needed to develop the swcc takes in excess of 6 weeks.

In practice almost all low-cost housing relies on empirical methods – estimation of heave potential based on quick, simple and economical tests. The most popular method in South Africa (Van der Merwe 1964), uses Atterberg limits and particle size distribution These tests are also known as "Foundation Indicators". Predictions of heave are only as reliable as the input parameters. This paper focuses on the reliability of these input parameters in the form of tes t results received from seven premier commercial laboratories.

2 Particle size analysis of soil samples

Particle size analysis of soil samples is a combination of grading analysis using sieves with different size apertures and hydrometer analysis which uses settlement and Stoke's law to determine the finer fractions of a soil sample.

2.1 Grading Analysis

Figure 1 shows results from a sample that was divided and sent to seven leading commercial laboratories. The results show an acceptable variance. Results are closely grouped from 13.2mm to 0.425mm. Sample preparation might have played a role in divergence of results from 0.425mm to 0.075mm. The authors have noted that details of the preparation of fines samples are critical and have a profound influence on the end result obtained.
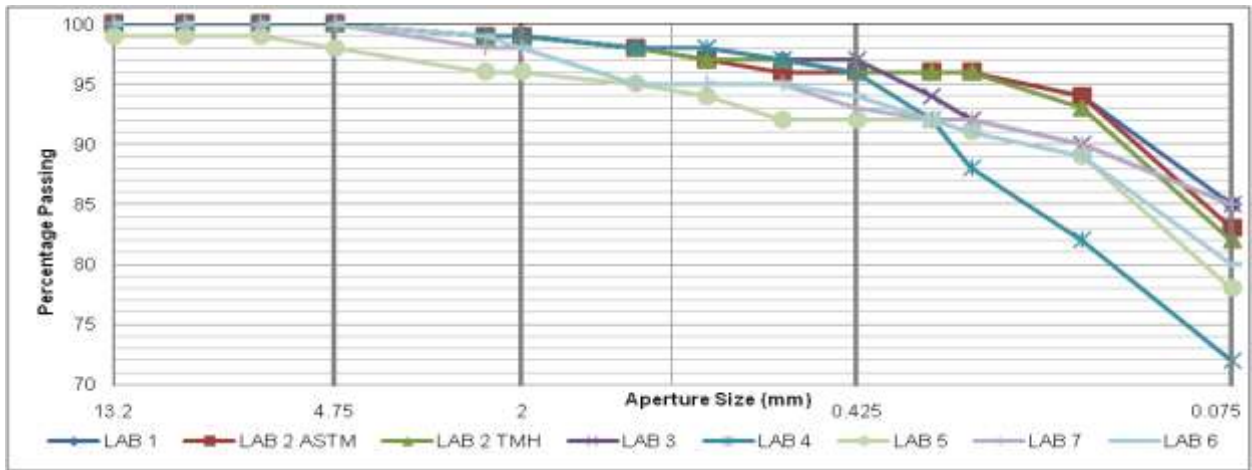
Figure 1. Grading analysis of Brandwag sample.

Six of the laboratories used in this study are accredited with SANAS and conform to the international ISO:17025 standards, suggesting that the quality is well managed and ensured.

For each of the three samples analysed, the grading analyses were reasonably consistent.

2.2 Hydrometer Analysis

Hydrometer analysis is used to determine the various fractions of fines in a sample. The method is based on Stoke's law and is flawed due to several of its assumption being dubious. Clay particles may be flakey and may have very large specific surface areas (Whitlow, 2001). Hydrometer accuracy is doubtful for four reasons (Savage 2007),: Stoke's law assumes all particles are spherical, de-flocculation may not be complete at the time of testing, clay particles are partially carried down by larger particles and a relative density of 2.65 is assumed for all particles, which may not be true. More on this in section 2.3.

Figures 2a and 2b indicate the variance obtained from different commercial laboratories. Note that the values vary between 63% and 18% on the Steelpoort sample (Figure 2b), a difference of 45%.
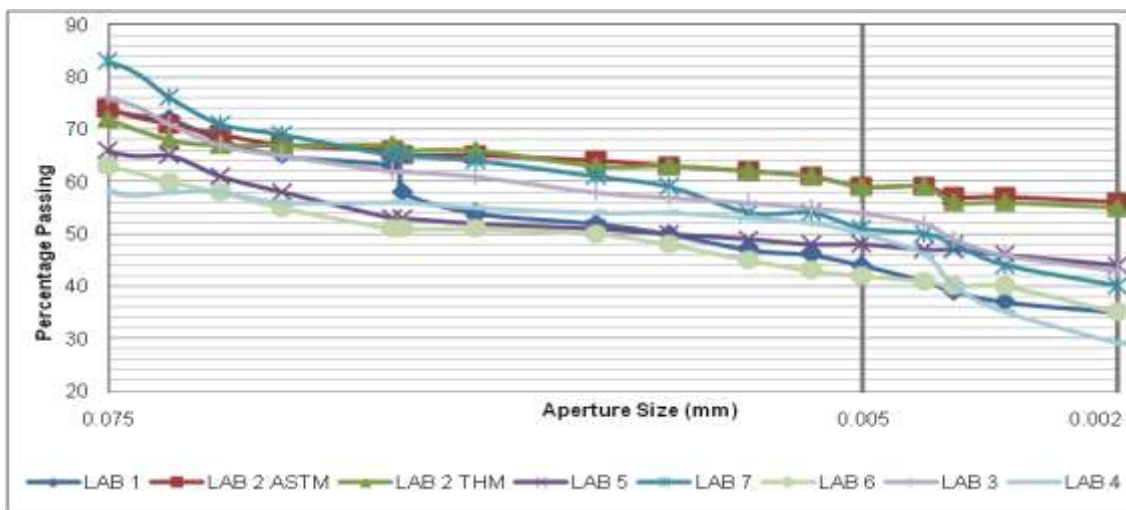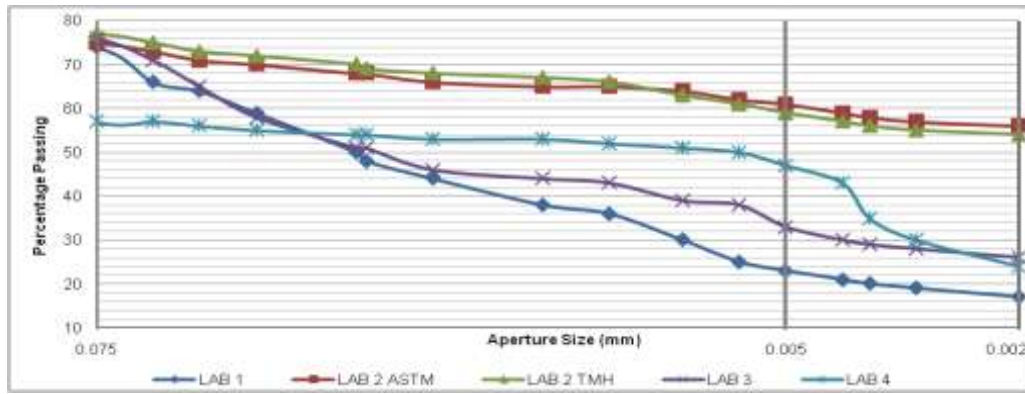

Figure 2a. Hydrometer analysis of Botshabelo Sample.

Figure 2b. Hydrometer analysis of Steelpoort Sample.

2.3 Savage's method to determine the 0.002mm fraction

Savage suggested using Skempton's activity formula to relate activity to the ratio (R) of the liquid limit (LL) to the plastic limit (PL) of a soil sample. Savage's analysis is as follows:

$$Activity = PI / P_{0.002} \tag{1}$$

Where $P_{0.002}$ refers to the percentage of material smaller than 0.002mm

Savage found an exponential relationship between the ratio LL / PL (R) from a table of the activity values for Montmorillonite , Illite and Kaolinite published by Cornell University in 1951.

$$Activity = 0.16R_{2.13} \tag{2}$$

Using formulas (1) and (2) the clay content can be established empirically as:

$$P_{0.002} = PI / Activity = PI / 0.16R_{2.13} = 6.25\ PI.R_{-2.13} \tag{3}$$

The $P_{0.002}$ value obtained is based on the PI that was tested, typically at $P_{0.425}$, and does not represent the whole sample. The equation is adjusted to reflect the entire sample (PI_{Gross}):

$$PI_{0.425}\ x\ P_{0.425} = PI_{Gross} \tag{4}$$

$$P_{0.002} = 6.25\ PI_{Gross}.R_{-2.13} \tag{5}$$

Table 1 draws a comparison between the hydrometer values for clay fraction and those derived from Savage's formula (5).

Table 1. Hydrometer $P_{0.002}$ compared to Savage $P_{0.002}$.

Sample	LAB1	LAB2	LAB3	LAB4	LAB5	LAB6	LAB7
Steelpoort							
Hydrometer	*17*	56	*24*	*26*			
Savage	*68*	44	*11*	*49*			
Brandwag							
Hydrometer	49	*58*	*33*	44	56	50	47
Savage	51	27	*18*	44	40	43	36
Botchabelo							
Hydrometer	35	*56*	29	43	44	40	35
Savage	31	*26*	22	30	31	37	34

In Table 1 it can be seen that some of the results compare favourably, while those in *italics* are unacceptable. Savage's method does not consistently predict lower or higher values and the values do not correlate well. Figure 5 shows a graphical representation of the Steelpoort sample comparison.
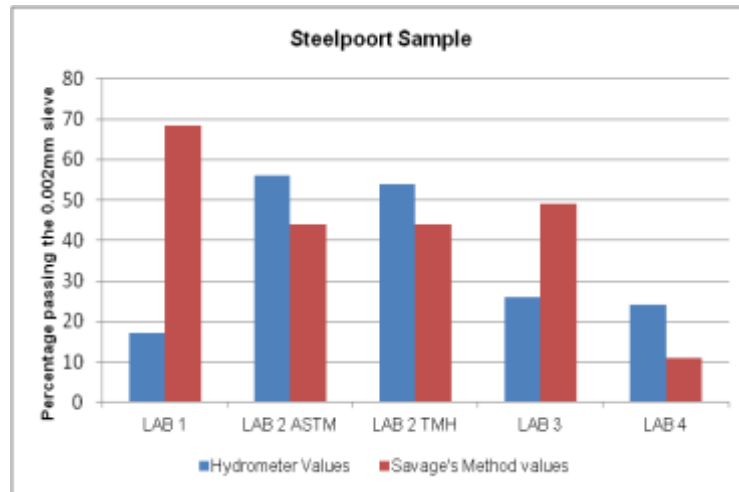
Figure 3. Steelpoort sample Hydrometers compared to Savage's values.

2.4 Atterberg limits

Atterberg limits include the Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI = LL-PL), the Shrinkage Limit (SL) and Linear Shrinkage (LS).

Commercial laboratories in South Africa make use of the Casagrande –cup apparatus and typically perform the LL test according to TMH1:1986 Method A2, which uses the same apparatus as the British Standard BS 1377-2. The authors have found that sample preparation has a significant bearing on the results, which may be responsible for the variance between the different commercial laboratories. Figure 4 illustrates typical results obtained for one of the three different active clay samples.
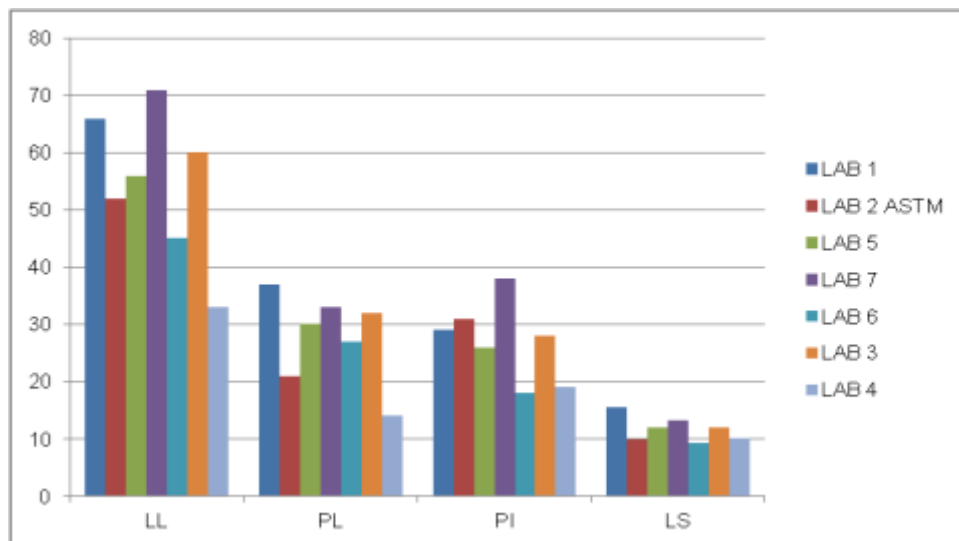

Figure 4. Liquid limit, plastic limit, plasticity index and linear shrinkage on Brandwag sample.

Based on figure 4, it is clear that the LS values are relatively consistent, with most laboratories within two percent of the average. The LL, PL and PI values show a large variance, although there is a grouping of LAB2, LAB3, LAB5 and LAB6 which seem to compare well.

Casagrande's plasticity chart, as used by the Unified Soils Classification System can be derived from the relationship between the LL and PI of a soil sample.

Figure 5 shows the relationship between the liquid limit and plasticity index for the Steelpoort sample.
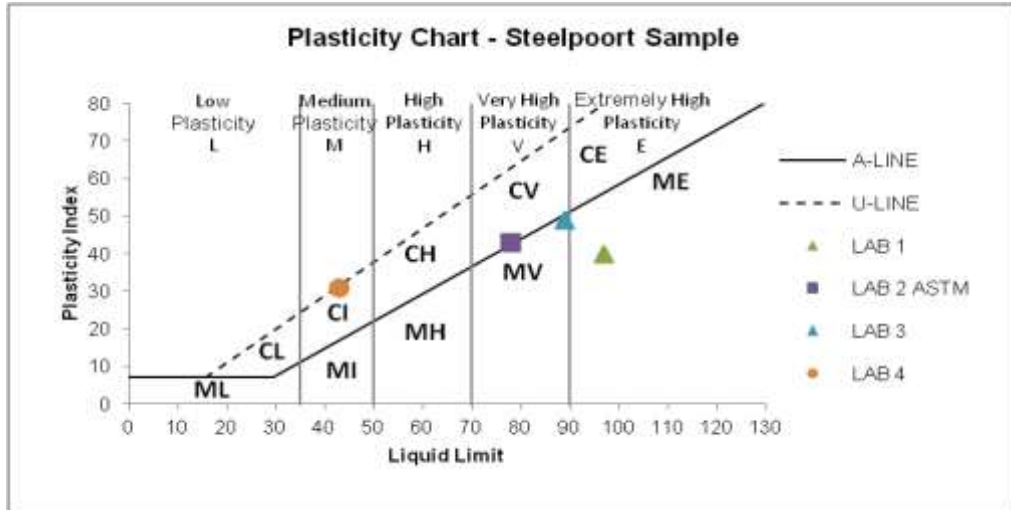
Figure 5. Casagrande's plasticity chart, Steelpoort sample.

3 Van der Merwe's empirical method for the estimation of potential heave

Van der Merwe's method relies on the PI of the gross sample and the $P_{0.002}$ fines fraction, which according to the British Classification is deemed to be the clay fraction of a soil sample. For Van der Merwe's method to give Valuable output, valuable input is required. This paper does not focus on the prediction model itself, but rather the input parameters.

For better understanding of the method, a simplified example of the process follows:

PI_{Gross} is plotted on the y-axis and $P_{0.002}$ on the x-axis as the "classification of heave potential" curve, (after Van der Merwe 1964). Figure 6 shows an example of such a plot with values obtained from various laboratories using Hydrometer analysis to obtain the $P_{0.002}$ fraction.

Table 2 and Figure 6 compare the resultant heave potential to that obtained using Savage's formula to determine the $P_{0.002}$ fraction.

Skempton suggested using the relationship between the $P_{0.002}$ fraction and the Plasticity Index to give an indication of the heave potential of soils (Skempton 1953). He suggested using slopes of less than 0.75 to refer to inactive clays, slopes of more than 1.4 would suggest active clays and everything in between would be referred to as normal clays. In figure 6 those designations have been adjusted to reflect slopes of 2.0, 1.0, 0.7, 0.6 and 0.5, with anything less than 0.5 considered inactive.

Table 2. Heave Potential: Hydrometer Analysis compared to Savage's Method

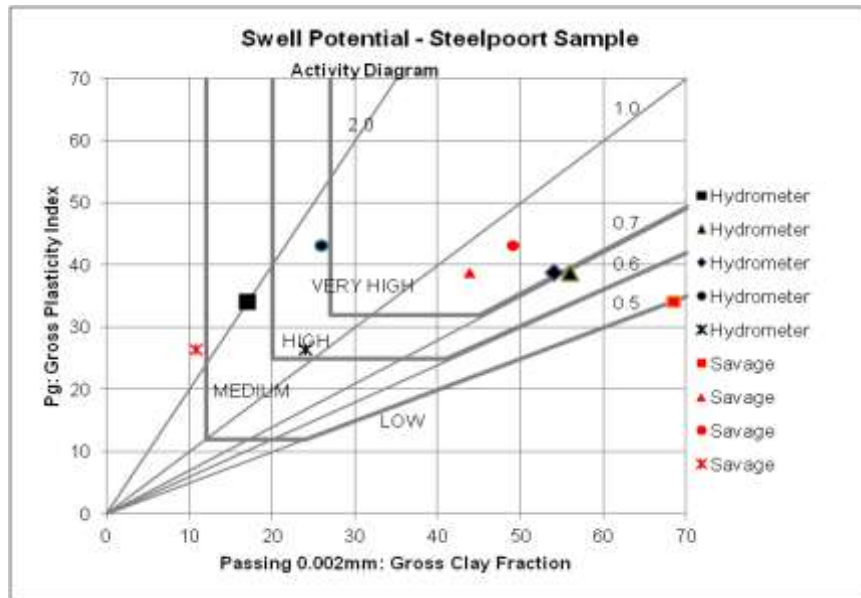| Method	LAB1	LAB2	LAB3	LAB4	LAB5	LAB6	LAB7
Hydrometer	Medium	Medium	Medium	High	Low	Very High	Low
Savage	Medium	High	Medium	Medium	Medium	Very High	Low

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Figure 6. The classification of heave potential after Van der Merwe, 1964, using Hydrometer values and Savage's values for the $P_{0.002}$ fraction with Skempton's Activity lines.

4 CONCLUSION

Seven leading commercial laboratories were tasked with performing "Foundation Indicators", which refer to the Atterberg Limits and Particle Size Analysis. Although the physical sieving provided comparable results down to the 0.425mm sieve, anything finer proved troublesome. The authors concluded that the problem probably lies with the preparation of the samples, as some details of preparation were found to have a major impact on testing done "in-house".

The Atterberg Limits were performed on fractions passing the 0.425mm sieve, and preparation might have played a role there also. A grouping of laboratories obtained results that compared well, while two laboratories found substantially different results.

The finer fractions, those passing the 0.075mm sieve, proved problematic as not all of the laboratories use the same method, although theoretically they should yield similar results. The results varied substantially and the range between the highest and lowest $P_{0.002}$ is alarming.

It can be concluded that using "foundation indicators" alone as the basis for empirical heave prediction methods is a very risky approach and that other approaches need to be identified.

REFERENCES

Fredlund D.G., (2009) Paradigm Shifts to Facilitate the Practice of Unsaturated Soil Mechanics. *8th C.W. Lovel Lecture.* Perdue Geotechnical Engineering. 26 October 2009.
Nelson J.D., Miller D.J., (1992) Expansive Soils – Problems and Practice in Foundation and Pavement Engineering. John Wiley and Sons, New York, Chicester, Brisbane, Toronto, Singapore.
Skempton, A.W., (1953) The colloidal "Activity" of clays. *Proceedings of the 3rd International Conference of Soil Mechanics and Foundation Engineering*.
Van der Merwe, D.H., (1964) The prediction of heave from the plasticity index and the percentage clay fraction of soils. *The Civil Engineer in South Africa. June 1964, pp 103-107*.
Weinert, H.H., (1980) The natural road construction materials of southern Africa. Pretoria: Academica.
Whitlow, R., (2001) Basic Soil Mechanics. *Fourth Edition, first edition published in 1983.* Prentice Hall, Pearson Education.