Identification of potentially expansive clay soils from soil structure

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ABSTRACT: Potentially expansive clay soils are probably the most commonly encountered problem soils in southern Africa and careful examination of the soil profile is the first essential in any site investigation. The importance of shattering and slickensiding as field indicators of such soils and their correlation with laboratory indicator test results are reviewed. Consideration of 43 typical South African recorded soil profiles revealed laboratory indicator test results on 18 shattered and 19 slickensided soils, indicating that a minimum plasticity index of 12 is required for shattering and 17 for slickensiding. The lower limit of 12 for a potentially expansive soil should probably be lowered to 10 when multiplied by the fraction passing 425 µm as in the modified Williams-Van der Merwe activity chart. However, the test methods used to derive all of these limits differ somewhat from the methods most often used today and must therefore be applied with caution.

1 INTRODUCTION

In spite of over 50 years of local research and experience, expansive soils probably still remain the most extensive problem soils in South Africa. The identification of such profiles in South Africa has traditionally been made on the basis of local experience in the particular area, a close inspection of the soil profile, and laboratory tests on disturbed or undisturbed samples, or both.

Shattering and slickensiding give evidence of heaving conditions (e.g. Williams 1985, Williams et al. 1985) and it is the purpose of this paper only to review the use of such structural aspects of the soil profile and their relation to the results of laboratory indicator tests on disturbed samples.

2 LOCAL EXPERIENCE

Expansive clays are so widespread in South Africa that, over most of the country "the designer should ask himself why should I not encounter expansive conditions" (Williams 1985, Williams et al. 1985). The maps provided by them, Brackley (1985) and the Department of Public Works (DPW) (2007) show practically the whole country as well as all of Lesotho and parts of Botswana, Namibia and Swaziland) to be affected, whilst that of Fey (2010) shows vertisols - the most active with a plasticity index (PI) exceeding 32 - to cover much of north-eastern South Africa.

Indeed, whilst it is common knowledge that soils derived from basic rocks and mudrocks of all kinds including some tillites, whether residual or transported, are liable to heave; less well known are cases on Cape granite and soils leached from sandstone (Brackley 1985). Knowledge of local experience in the area is therefore always an essential part of the decision as to whether or not there is a problem. In this connection, whilst it usually takes several years for the maximum heave (e.g. Jennings & Williams 1960) - or settlement due to shrinkage - to take place, damage may be evident after the first rainy season, in the laboratory expansive clays reach maximum volume within 24 hours (Williams 1991) and the same author reported 300 mm of heave of the edge of a new road near Kimberley within a few days caused by a leaking fire hydrant.

3 THE SOIL PROFILE

Careful examination of the soil profile has long been an essential part of the evaluation of a potentially expansive soil (e.g. Jennings & Brink 1961, Jennings et al, 1973, Brink & Bruin 2002). In particular, the moisture condition, colour (often black, dark grey, mottled yellow-grey, sometimes red but seldom brown or white – Williams 1985), structure, soil texture (usually a clay: silty, sandy – or even gravelly – Davis 1999), origin, inclusions (e.g. of roots or calcrete nodules) and the depth to the water table(s) are particularly relevant to the expansive clay problem.

The term 'structure' indicates the nature and presence (or absence) of discontinuities and other features. The term 'intact' is used to confirm the absence of structure, and it is important not to forget this descriptor.

The term 'soil' is used here in its usual engineering sense to mean a particular horizon which is at least visually distinguishable from the adjacent layers. This differs from the definition used in pedology where it refers to the whole profile.

4 SOIL STRUCTURE

The type of structure referred to in this paper is the macrostructure i.e. that which is easily visible to the naked eye. The microstructure, perhaps better called fabric, is only briefly considered here. The structure and fabric – including any bonding – accounts for the different behaviour of many soils after they are disturbed, even after recompaction to the same density. Thus, swell and/or shrinkage tends to be highest after remoulding, when the clay is dispersed and normal to any preferred orientation of platy clay minerals (Mitchell 1993). However, as highly expansive soils tend to have a remoulded structure in situ, such soils exhibit the same swell on undisturbed and remoulded samples (Brackley 1985).

Whilst the presence of fissures in South African soils usually indicates a clay heaving condition (e.g. Jennings et al 1973), other possible causes include additional loading during consolidation, rebound due to reduction in loading, syneresis, chemical changes during weathering, tectonic movements, landslides, inheritance from bedrock, shrinkage due to drying out, and high lateral stresses (summarized by Williams & Jennings 1977), crystallization and growth of calcrete or gypsum (e.g. Williams 1991, 1992).

The term 'fissured' is used to describe the presence of closed joints. The term 'slickensided' describes fissures which are "highly polished or glossy and frequently striated" (Jennings et al. 1973, DPW 2007). This definition of slickensides differs from that in geology (American Geological Institute 1962, Whitten & Brookes 1972) and United States pedology (Soil Survey Division Staff 1993) which requires the surface to be both polished and striated, but coincides with that used in South African pedological practice which allows either, and occurs only in clayey materials with a high smectite content (Soil Classification Working Group 1991, Van der Watt & Van Rooyen 1995). However, more recent pedological practice (e.g. Turner & Van der Walt 2007, Fey 2010) appears to require both polishing and grooving. In this connection slickensides should not be confused with the cutans (clay skins) of pedology which only indicate a deposition of clay in the fissure.

The term 'shattered' is used for fissures which have opened up and are filled with air – the desiccation crack of geology. 'Microshattering' is a small-scale shattering the size of sand grains.

5 THE TYPICAL SOUTH AFRICAN EXPANSIVE SOIL PROFILE

When not covered by a sand blanket the typical South African expansive soil profile in the dry season consists of three main structural elements (mostly after Blight & Williams 1971, and Williams & Jennings 1977):

- a thin mulch of microshattered clay often only a few cms thick, masking
- a shattered horizon with mostly vertical shrinkage cracks extending to a metre or more, grading downwards into
- the major clay horizon with mostly inclined, often slickensided fissures caused by passive horizontal pressure failures during swelling, which may extend to a depth of several metres.

Shattering on drying may run throughout the depth of a vertic material and even into the upper subsoil (Fey 2010) and shattering down to 7.9 m under 1.2 m of sand, with the water table at 8.2 m was recorded by Jennings & Kerrich (1962). No laboratory test criteria for shattering appear to have been published.

In discussing the black and red smectitic clays, Harmse & Hattingh (1985) stated that slickensiding can be expected in soils with PIs greater than 30, and a PI greater than 32 is used in South African soil science as one criterion to distinguish a vertic from a melanic A horizon (Soil Classification Working Group 1991). The bar linear shrinkage (BLS) of vertic horizons is also usually greater than 12. A more recent evaluation of a large number of South African soil profiles (Turner & Van der Walt 2007) confirmed that "the regular occurrence of slickensides ceases at around 30 PI units". Their definition of slickensides required the presence of shiny, grooved faces.

Further criteria for slickensiding are (Williams & Jennings 1977):

- both a PI and a < 2µm clay fraction greater than 30 % and, apparently,
- an Activity (A) greater than 0,7, or
- a 'very high' or possibly 'high' degree of potential expansiveness when plotted on Williams' (1958) Activity chart, and
- clay minerals largely those with an expansive lattice.

Slickensides have been recorded to depths of more than 15 m, usually above the water table, are an indication of seasonal movement (Brackley 1985), and their occurrence also requires a suitably adequate seasonal rainfall (Williams & Jennings 1977). They cited Mariental in Namibia as an example, where the dry climate had led to the expansive soil profile almost only exhibiting shrinkage cracks and practically no slickensides. Similarly, little or no shattering would be expected in a continuously wet climate or during the wet season in a seasonal climate.

Shallow vertical horizons may lack slickensides as they apparently require a minimum depth or volume of soil in which to form (Soil Classification Working Group 1991, Fey 2010). The optimum depth for the formation of slickensides in Israeli vertisols is about 1.5 - 2 m (Yaalon & Kalmar 1978).

6 A NEW EVALUATION

6.1 *The data base*

Accepting that shattering, fissuring and slickensiding provide an important indication of the activity of the soil profile (e.g. Williams 1985) an attempt was made to determine the soil constants of such soils more closely. The 43 typical South African soil profiles compiled by Winterbach (1961) were mostly used for this purpose (Table 1). Of those profiles, 21 contained 35 soils described as shattered and/or slickensided. Of these, 18 profiles had 30 associated sets of indicator test results, which included at least a liquid limit (LL) and PI. However, only 5 results for "clay" (< 2μm) content were provided.

All soils were described as clays with at least 50 % passing 2 μm, or silty or sandy clays containing 30–50 % passing 2 μm. These profiles had a variety of origins and parent materials and were in climates with Weinert's climatic N-values ranging between 1–2 and 5–10, but mostly 2–5. (The N-values shown were only given as minima and maxima (e.g. 2–3), were calculated by an earlier method and may differ slightly from Weinert's (1980) later work.) Although all profiles were not fully described according to the method of Jennings & Brink (1961) the terms 'shattered; 'fissured' and 'slickensided' but not 'intact' were used. The depth of the water table was not given and it has been assumed that it was not encountered.

Table 1. Typical South African profiles with shattering and/or slickensiding

Test Results Yes / No	Shattering alone or with slickensiding				Slickensiding alone or with shattering				Both together			
	Profiles No.	Soils No.	Depth (m)	N-Value	Profiles No.	Soils No.	Depth (m)	N-Value	Profiles No.	Soils No.	Depth (m)	N-Value
Yes	18	19	0-17	1-2–5-10	18	19	0-14	2-10	13	9	0.6-6.4	2-3–5-10
No	3	5	0-7.5	2-3–5-10	3	4	1.5-24	2-3–3-4	3	3	1.5-5.5	2-3
Total	21	24	0-17	1-10	21	23	0-24	2-10	16	12	0.6-6.4	2-3–5-10

6.2 *Shattering*

Shattering was recorded from all depths from the surface in climates with Weinert's N-values of 1 - 2 at Weza in Kwazulu-Natal – and frequently under N-values of 2-5 – up to 5-10 near Taung to a maximum depth of 17m in a diabase profile on the West Rand with an N-value of 3. Shattering was recorded in this profile from the surface down to 16.8 m but not from 16.8 to 24.4 m where only slickensides were reported. Inclusions of "lime" (calcrete) were not reported but "laterite" (ferricrete) from the surface down to 7.6 m. Laboratory test results were only reported for the 7.6 - 16.8 m layer, e.g. a PI of 12 and 25 % clay. The second and third deepest occurrences of shattering were 7.0 m with a PI of 13 with an N-value of 4 - 5, and 6.5 m with a PI of 37 and N-value of 2 - 3. Depths of down to 5 - 7 m were often recorded in the profiles.

The presence of nodules of calcrete is usually taken to indicate seasonal drying and ferricrete seasonal wetting.

Calcrete was reported in 10 and ferricrete in 13 out of the 35 soils from the surface at all depths down to 10.1 and 7.6 m, respectively with N-values of between 2 - 3 and 5 - 10. Calcrete was present in 10 out of the 24 shattered soils at all depths down to 7.0 m and in 6 out of the 23 slickensided soils at all depths down to 6.4 m. Ferricrete was present in 9 out of 24 shattered soils at depths of down to 7.6 m and in 8 out of the 23 slickensided soils at all depths down to 6.9m.

In 5 out of the 35 soils they occurred together, i.e. in the same horizon, with N-values of 2 - 3 to 4 - 5.

Although only one profile with a surface layer of microshattered clay (with a PI of 14 and 48 % clay) was recorded, the general structural feature of a shattered horizon overlying a slickensided one was found in nearly every case. The deepest recorded shattering, from the surface to 17 m, and the deepest slickensiding, between 17 and 24 m, were both recorded in the same residual diabase profile on the West Rand with an N-value of 3.

The delay between excavating the hole and profiling was not stated, and it has been assumed that the structure refers to the freshly exposed profile.

Both shattering and slickensiding occurred together in 16 out of the 21 profiles and together in the same soil horizon in 12 out of the 35 soils, at depths between 1,1 and 6,4 m in climates with N-values between 2 - 3 and 5 - 10.

Table 2 shows a summary of the details of 19 shattered soil horizons from the 18 profiles for which test results were shown. Also shown are the individual results for the five soils with the lowest LL, PI or linear shrinkage (LS).

Table 2. Summary of indicator test results on 19 shattered soils in 18 profiles

Crite-rion	Also slicken-sided Results (No.)	LL %	PI %	LS %	SL %	SR %	SI %	Clay (<2µm) %	A	Potential Expansiveness Van der Merwe (1976)	Potential Expansiveness Wilson (1976)	Unified Class	Depth m	N-Value
Min.–Max.	Yes (9)	49–70	25–51	10–17.0	7.5–4.5	1.8–1.9	6.5–16	25;33	1.0; 1.2	High; Very high	High – Very high	CL-CH	0.6–6.5	2–3 – 5–10
	No (8)	32–66	12–50	5.5–17.0	7.5–21	1.5–1.9	0.5–21	25;48	0.29;48	Low; low / med.	Med. – Very high	ML-CH	0–17	1–2 – 4–5
	Yes (1)	51	25	–	–	1.8	–	25	1.00	High	High	CH	0.6–2.1	5–10
	No (1)	40	22	5.5	17.5	1.7	0.5	–	–	–	Med.	CL	5.2–5.8	2.6
	No (1)	53	14	–	–	1.6	–	48	0.29	Low	Med.	MH	0–0.9	1–2
Min. LL	No (1)	32	13	6	13	–	6	–	–	–	Med.	CL	4.3–7.0	4–5
Min. PI	No (1)	48	12	5.5	21	1.5	15	25	0.48	Low/med	Med.	ML	7.6–17	3

As no values for the percentage passing 425µm (P425) were given these results are all unweighted (i.e. multiplied by the fraction passing 425 µm) and the classifications are also on this basis. However, it is presumed that the clay contents refer to the whole sample. As the three lowest PIs were 12, 13 and 14 it appears that about 12 represents the minimum PI required for shattering. This sample also had a liquid limit (LL) of 48, a LS of 5.5, a clay content of 25 % and an activity of 0.48. As two of these five samples, with PIs of 12 and 14, clay contents of 25 and 48 % and activities of 0.48 and 0.29 respectively classified as of low potential expansiveness according to the Williams (1958) – Van der Merwe (1964, 1976) modified activity chart, but as medium using the Wilson (1964, 1976) criteria it seems safest to prefer the latter. If the PI is weighted assuming the soil (described as 'clay' had a P425 of 80 - 90 %) then a minimum WPI of 10 results.

Although a minimum PI of 12 is the simplest criterion for shattering, it can also be said that it is also likely when the LL equals or exceeds 32, the PI 12, or the LS 5,5. As the shrinkage limit (SL) of the sample with a PI of 13 is much lower than the SL of the one with a PI of 12 it is actually a potentially more expansive (and shrinkable) soil than is indicated by its much lower LL and the closeness of the PIs. The PI of the 7 soils which were only shattered ranged between 12 and 50 but between 25 and 51 when slickensiding was also present and the SL was 7.5 or less. The depths over which shattering only was recorded ranged between 0 and 17 m and the climate between N-values of 1–2 and 5–10.

Examination of indicator test results on 3 intact clayey sands with PIs of 14 – 17, five shattered clayey sands with PIs of 19 – 28 and 7 sandy or silty clays with PIs of 16 – 28 from 11 profiles in Mariental in Namibia (N-value about 32) showed that 11 out of the 12 shattered soils all possessed a PI of at least 19. A minimum PI of 17 would have provided a separation in 13 out of the 15 soils. The reason for these minima being higher than the 12 derived from the Winterbach (1961) data base is not clear – it may be due to the extremely dry climate (although one would then expect shattering at a lower rather than a higher PI) – or simply due to the well-known poor reproducibility of the test (e.g. Jacobsz and Day 2008). In either case it seems safest to assume a PI of at least 12. The minimum and maximum depths of shattering were 0.2 and 5.8 m respectively, and calcrete nodules and/or gypsum were often present. Most of these soils contained 80 – 90% passing 425 µm.

6.3 *Slickensiding*

Slickensiding was recorded from all depths from the surface near Taung with an N-value of 5–10, but usually starting at depths of more than 1–2 m and in climates with N-values ranging between 2–3 in Kwazulu-Natal and Gauteng and 5–10 near Taung down to 24 m in residual diabase on the West Rand with an N-value of 3.

Slickensiding from the surface was only recorded in one profile out of 19. This was from 0–0.6 m in a clay horizon with a PI of 21 described as moist and overlying a clay horizon described as dry and shattered. The next shallowest recorded depth of slickensiding was 0.6 m with two cases both with a PI of 25. Depths exceeding 1–2 m were more usual. The dates on which these profiles were recorded were not given, but it is presumed that this anomaly must have been due to closure of the cracks caused by swelling after wetting by rainfall.

Table 3. Summary of indicator test results on 10 slickensided only soils in 18 profiles

Criter-ion	Results	LL	PI	LS	SL	SR	SI	Clay (< 2µm)	A	Potential Expansiveness		Unified Class. (ASTM 2017)	Depth	N-Value
										Van der Merwe (1976)	Wilson (1976)			
	No.	%	%	%	%	%	%	%					m	
Min.–Max.	10	35–66	17–41	6.5–14.5	4.5–16.0	1.5–1.9	2–17	32	0.66	Med.	Med. – Very high	MH – CH	0–13.9	2–10
	1	49	25	10.0	12.5	1.9	11.5	–		–	High	CL	0.6–1.4	2–3
	1	48	25	10.0	11.0	–	12	–	–	-	High	CL	0.6–1.7	2–3
	1	48	24	9.0	10.2	1.8	–	–	–	-	High	CL	0.9–4.9	2–3
	1	38	21	–	–	1.9	–	32	0.66	Med.	Med.	CL	0–0.6	5–10
Min.	1	35	17	6.5	16.0	1.6	2	–	–	–	Med.	CL	8.3–9.3	2.6

A summary of the details of 9 slickensided soils which were only slickensided from the 18 profiles for which test results were provided together with the actual results on the five soils with the lowest PIs are shown in Table 3. The PIs recorded for those soils which were not also shattered ranged between 17 and 41.

The lowest PIs were 17 at a depth of 8.2–9.3 m in the Port Elizabeth area and 21 from 0–0.6m in an alluvial soil at Taung. The next lowest were three of 24 and 25. It thus appears that the minimum PI required for slickensiding is about 17 although this is less definite than the minimum of 12 required for shattering. This soil was from a depth of 8.3 to 9.3 m in the Northdown area of Port Elizabeth with an N-value of 2.6 and was described as sand with clay lenses. The layer above with a PI of 33 was also slickensided up to a depth of about 5.8 m, above which the silt and clay were shattered.

Except for one MH all the soils which were only slickensided classified as CL or CH in the ASTM D2487 Unified classification and as medium to very highly expansive according to the Wilson criteria.

The depths over which slickensiding only were recorded ranged between 0 (with a PI of 21 and 32 % clay) 9.3 m (with a PI of 17) and 24 m (no test results) and the climatic N-values between 2–3 and 5–10. These five soils all plotted above the A-line as CL or CH.

The PIs of 12 clay soils which were not described as shattered or slickensided from 9 well-described profiles ranged between 11 and 51 (usually about 15 – 45) at depths of about 1–10 m, but usually at depths in excess of about 5 m. Such soils usually occurred below shattered or slickensided horizons.

If it is accepted that shattering is a good indicator of a potential significantly heaving and shrinking condition, then the minimum Kantey & Brink (1952) PI limit of 12 (but probably a weighted PI of 10) for a potentially heaving soil is supported. However, the PIs of slickensided soils of down to 17 (with four of 21 – 25) are lower than the 30 found by Williams & Jennings (1977) in general and by Turner & Van der Walt (2007) for vertisols.

The occurrence of usually deeper horizons of apparently intact clays with higher PIs does not of course mean that they are not potentially expansive.

7 LABORATORY TEST METHODS

As far as can be ascertained the test methods used to obtain the results quoted here – as well as those used by Kantey & Brink (1952) and Van der Merwe (1964, 1976) – employed air-drying, pulverization with a rubber-covered pestle, dry sieving, an ASTM D423-type LL device, and a three-point flow curve LL method without presoaking (W.H. Luwes, D.H. van der Merwe, A.B.A. Brink 2002, pers. comm.). Nearly all of the clay samples had at least 90 % finer than 420 µm (ABA Brink 2002, pers. comm.).

The closest modern methods would therefore be TMH1 Methods A1(b) for soil preparation (without the dispersant for the grading), A2 three-point for LL, A3 for PL and PI (NITRR 1986) and A4 for LS (NITRR 1979), and their new SANS equivalents.

The shrinkage factors including possibly the linear shrinkage were probably determined according to the ASTMD 427-39 volumetric method (ASTM 1942) which was only revised in 1961. The linear shrinkage determined according to this method may differ from that determined by the bar method, which is that usually used in South Africa.

Similar test methods employing only air-drying for soil preparation should therefore be used when the Kantey-Brink or Van der Merwe criteria are to be applied. The use of dissimilar methods will add to the existing reproducibility problem (e.g. Jacobsz & Day 2008).

8 CONCLUSIONS

A good soil profile description showing the presence or absence of shattering, fissuring and slickensiding remains an important method for the recognition of a heaving or shrinking condition.

When describing slickensides, it should be recorded whether or not they are also striated.

Shattering due to shrinkage on drying out indicates a minimum PI of about 12 and fissuring and slickensiding a minimum of about 17. Possible equivalent PIs weighted (multiplied by) for the fraction passing 425µm might be 10 and 14, respectively.

The methods used to test the soils from which these limits – as well as those of Kantey & Brink (1952) and Van der Merwe (1964, 1976) – were derived were those formerly used at the CSIR and differ in some respects from those most commonly used today. Caution and engineering judgement remain therefore, as always, essential.

9 ACKNOWLEDGEMENTS

The kind permission of the Director of the CSIR Division of Built Environment for the use of unpublished information is acknowledged. However, the opinions expressed are those of the author and not necessarily those of the CSIR.

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