The examination of a possible relationship between the liquid limit (LL%) and soil shrink index (*I*ps)

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ABSTRACT

Although SAA HB 28-1997 (section 2.6.1) clearly states that movement estimates of reactive clay soil profiles by the computation method is the least preferred method of classifying a site in accordance with AS 2870-1996, there is a growing trend by legislators and the legal fraternity to prefer and even insist on its use to classify a site. The other methods (visual assessment and profile identification) are considered too subjective and in legal situations, the equation generally prevails. AS 2870-1996 gives no alternative laboratory test to the Shrink/Swell (Iss) test to derive a Soil Shrinkage Index (Ips), and provides no concessions where for various reasons a suitable tube sample cannot be retrieved, or in remote areas where shrink/swell apparatus is not available.
This paper will use Kay 1990 "Use of Liquid Limit for Characterization of Expansive Soil Sites" as a starting point, but where Kay endeavoured to derive a Site Classification directly from a liquid limit test, this paper will attempt to derive a Soil Shrinkage Index (Ips) from the Liquid Limit (LL) test, which if successful, will allow the equation in AS 2870-Supp1-1996 (Clause C2.2.3(c)) to be used to derive a y_s, and hence a site classification.

1 INTRODUCTION

The writer has been aware of the Kay (1990) paper since the early 1990's but prior to AS 2870-1996 had been using an in-house method to derive a ground movement figure via the linear shrinkage test (LS) and post 1996, the shrink/swell (Iss) test. After reading SAA HB28-1997,(in which Kay (1990) Figure 1 was reproduced) the writer was interested by the coincidence that in Section 2.7.1 the table presented showed Liquid Limit ranges between moderate, highly and extremely expansive (see Table 1).

Table 1: Description of expansive soil and liquid limit range (Kay 1990)

Description	Liquid Limit Range
Moderately Expansive	Less than 40%
Highly Expansive	40% to 70%
Extremely Expansive	Greater than 70%

The coincidence which attracted the writer's attention was the alignment of the table to the ys values in AS 2870-1996 (see Table 2)

Table 2: Site classification, Ys value and soil description by AS 2870-1996

Class	Y_s Range	Description
A	0-10mm	Stable
S	10-20mm	Slightly Reactive
M	20-40mm	Moderately Reactive
H	40-70mm	Highly reactive
E	Greater than 70mm	Extremely Reactive

By late 2006, the writer had also noted that at least two major geotechnical consultants on each side of the country (Perth and Rockhampton) had decided to use the Kay (1990) table to arrive at a site classification method.

The AS 2870 formula of;

$$y_s = 1/100\int_o^{Hs} I_{pt} \Delta u \Delta h \qquad (1)$$

where y_s = characteristic surface movement, *I*pt = instability index, Δu = suction change at depth (h) from the surface, expressed in pf units, Δh = thickness of soil layer under consideration, in metres.

was derived from earlier work by Aitchison and Mitchell & Avalle (1984) besides others.

The instability index (*I*pt) varies with depth, and is related to the soil shrinkage index (*I*ps) by the formula *I*pt = α *I*ps. The accepted relationship between the *I*ps and *I*ss is that *I*ss = *I*ps. Difficulties occur where suitable samples cannot be obtained for the Iss test, or where the Iss apparatus is not available. It is therefore desirable to find the relationship between *I*ps and LL so that the AS 2870-1996 formula can be used in conjunction with the Liquid Limit (LL) test.

2 THE KAY (1990) METHOD

Kay (1990) proposed the relationship between liquid limit and site classification shown in Table 3.

Table 3: Liquid limit range and site classification by Kay (1990)

Liquid Limit Range	Site Classification
<20	S (slightly expansive)
20-40	M (moderately expansive)
40-70	H (highly expansive)
>70	E (extremely expansive)

Kay (1990) gave the following equation for ground movement:

$$M = (LL_{wa}/2)-10 \qquad (2)$$

where M = ground surface movement and LL_{wa} = liquid limit (weighted average).

The liquid limit (weighted average) was the weighted average of a soil profile where it had layers of different strata, with differing liquid limit values. This allowed Kay (1990) to derive a geotechnical model where it could be assumed that the strata was homogeneous to a depth equal to or greater than Hs. Kay then proposed that the ys value should be taken as a value as somewhere between y_s = 2 x "M" and Ys = 3 x "M". Kay (1990) used a Hs of 2 metres but his method appeared to bypass the need to consider either a cracked zone or suction change (Δu) as neither were mentioned. Kay (1990) preferred the Laboratory Cone Penetration method over the classical Casagrande device to determine the liquid limit, as he considered that it reduced the operator error.

Kay (1990) stated "It is believed that although the plasticity index may well be an inherently better indicator of expansive properties, the errors introduced in the highly operator-dependent plasticity limit determination override any possible inherent advantage that may exist over liquid limit." Kay (1990) concluded "The fact that test results would appear to justify the use of this simple procedure implies that the liquid limit is a sufficiently good indicator of shrink-swell response for natural soil in spite of the fact that the test is conducted on remoulded soil." and "The results presented provide evidence to indicate that serious consideration might be given to use of the liquid limit test for direct characterization of expansive soil sites. For the wide range of sites tested, use of the liquid limit as determined by the laboratory cone penetration test appears to provide at least equally high quality information at considerably lower cost than methods used in accordance with the current (1986) Australian code."

Kay (1990) however qualified his conclusions by stating "It should be noted that the proposed method for site classification includes no consideration of differences in climatic influences for different localities. It simply describes the nature of the site soils. Differences in the environmental influences such as those associated with climatic extremes must be treated as a separate matter in the design problem."

3 EXTENDING KAY (1990) TO DERIVE AN *I*ps

3.1 Hs

In this paper an Hs of 2 metres has been used to keep consistency with the Kay (1990) work, although Table D1 of AS 2870-1986 clearly indicates that a Hs of 4 metres is appropriate for Adelaide (where his paper was focussed).

3.2 Change in Suction (Δu) and cracked zone

Although the Kay (1990) method did not take into consideration either of these parameters, 1.2_pF and 0.75 Hs have been used, both of which are consistent with AS 2870-1986 and AS 2870-1996 for Adelaide

3.3 Y_s as per Kay 1990

Various y_s values were calculated using the Kay (1990) method and using a geotechnical model comprising homogenous clay from surface to 2 metres and various weighted liquid limits from 25% to 130%.

3.4 Deriving a relationship between the liquid limit and soil shrinkage index

Various back-calculations were carried out using a spreadsheet table, similar to those shown on page 22 of SAA HB28-1997, but using the following input;

Hs = 2 metres
Δu = 1.2pF
Cracked zone = 0.75 Hs
*I*ps = various values

These back-calculations were carried out until the value which coincided with the target upper or lower limit of the y_s range derived by the methodology in 3.3 above was found. M=2 was used for the lower limit and M=3 was used for the upper limit. The results were plotted as liquid limit (weighted average) vs soil shrinkage index (*I*ps) for both M=2 and M=3

4 DERIVING NEW EQUATIONS

Table 4 was derived using Kay (1990) Equation 2.

Table 4: Ground movement by Kay (1990)

LL_{wa}	M	Y_s M = 2	Y_s M=3
25%	2.5mm	5mm	7.5mm
40%	10mm	20mm	30mm
55%	17.5mm	35mm	52.5mm
70%	25mm	50mm	75mm
85%	32.5mm	65mm	97.5mm
100%	40mm	80mm	120mm
115%	47.5mm	95mm	142mm
130%	55mm	110mm	165mm

The soil shrinkage index (Ips) was then back-calculated and LL_{wa} vs Ips tabulated (see Table 5).

Table 5: Relationship between liquid limit and *I*ps

LL_{wa}	M	*I*ps M = 2	*I*ps M=3
25%	2.5mm	0.4	0.6
40%	10mm	1.6	2.4
55%	17.5mm	2.8	4.2
70%	25mm	4.0	6.0
85%	32.5mm	5.2	7.8
100%	40mm	6.4	9.6
115%	47.5mm	7.6	11.4
130%	55mm	8.8	13.2

Figure 1 shows the plot of the relationship between *I*ps and liquid limit.. Results were then sought from sources other than Kay (1990) to test the validity of the relationships. Forty samples were sourced from various published external sources comprising Cameron (1989), Jaksa et al (1997), McInnes (2003), Jayasekera & Mohajerani (2003) where both liquid limits and shrink/swell (Iss) results from the same sample were available, as well as our own unpublished samples from S-E and Central Queensland. The plot of the forty samples with Kay's M = 2 plot and Kay (1990) M=3 plot are shown on Figure 2.

Figure 1: Relationships between *I*ps and liquid limit

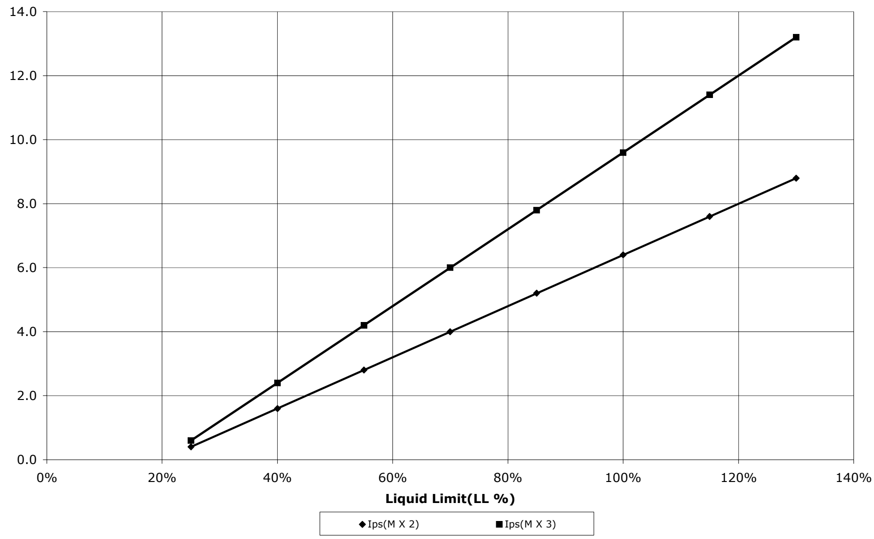
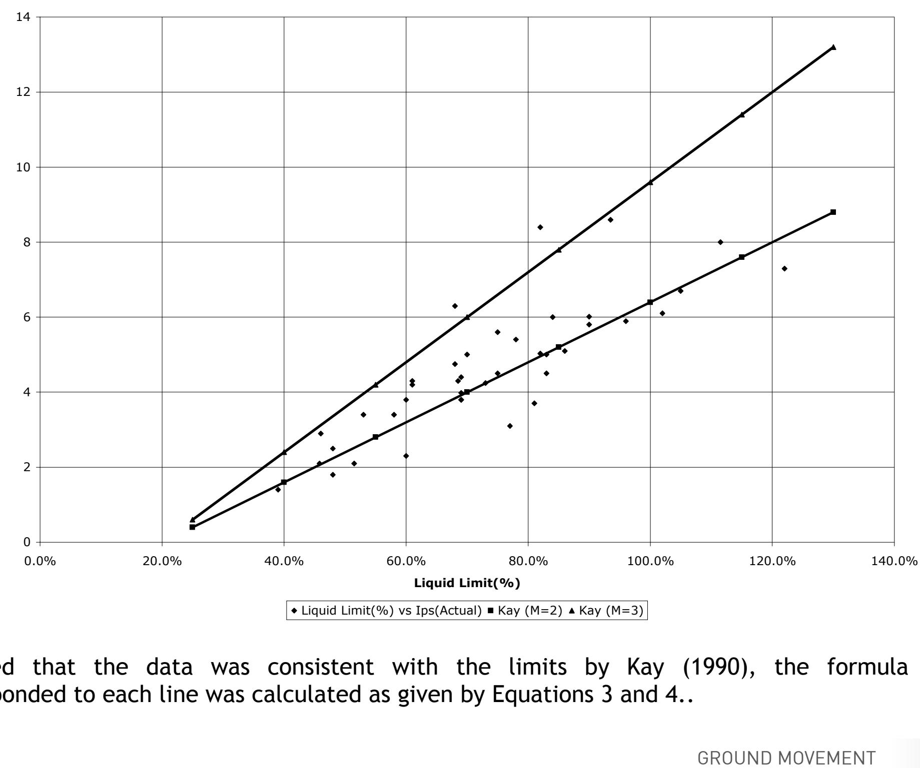


Figure 2: Measured values of Ips and liquid limit and comparison with Kay (1990)



Satisfied that the data was consistent with the limits by Kay (1990), the formula which corresponded to each line was calculated as given by Equations 3 and 4..

For M = 2 $\quad I_{ps} = 0.08LL-1.6 \quad$ (3)

For M = 3 $\quad I_{ps} = 0.12LL-2.4 \quad$ (4)

Using the geotechnical model in 3.3, the liquid limit values of 40% and 70% were used to determine the Kay (1990) predicted ground movement, with the following results;

Table 7: Ground movement by Kay (1990) for LL=40 and LL=70

LL	Y_s M=2	Y_s M=3
40	20 mm	30 mm
70	50 mm	75 mm

Using Equations 3 and 4 and liquid limit values of 40% and 70% the following Tables 8 to 10 were developed, based on a geotechnical model comprising homogeneous clay to the full depth of Hs; Hs = 1500 mm, 1800 mm, 2300 mm, 3000 mm and 4000 mm; cracked zones 0.5Hs and 0.75Hs; suction range 1.2pF and 1.5pF.

Table 8 - For 0.5 Hs and Suction Range 1.2pF

Hs	Liquid Limit = 40%		Liquid Limit = 70%	
	y_s M=2	y_s M=3	y_s M=2	y_s M=3
1500 mm	15 mm	25 mm	45 mm	65 mm
1800 mm	20 mm	30 mm	50 mm	75 mm
2300 mm	25 mm	40 mm	65 mm	95 mm
3000 mm	35 mm	50 mm	85 mm	125 mm
4000 mm	45 mm	65 mm	105 mm	160 mm

Table 9 - For 0.5 Hs and Suction Range 1.5pF

Hs	Liquid Limit = 40%		Liquid Limit = 70%	
	y_s M=2	y_s M=3	y_s M=2	y_s M=3
1500 mm	20 mm	30 mm	55 mm	80 mm
1800 mm	25 mm	40 mm	65 mm	95 mm
2300 mm	30 mm	50 mm	80 mm	120 mm

Table 10 - For 0.75 Hs and Suction Range 1.2pF

Hs	Liquid Limit = 40%		Liquid Limit = 70%	
	y_s M=2	y_s M=3	y_s M=2	y_s M=3
1500 mm	15 mm	25 mm	40 mm	55 mm
1800 mm	20 mm	25 mm	45 mm	70 mm
2300 mm	25 mm	35 mm	55 mm	85 mm
3000 mm	30 mm	45 mm	75 mm	110 mm
4000 mm	40 mm	60 mm	100 mm	145 mm

Comparing Tables 8 to 10 with Table 7 indicates that a wide range of ys values result depending on the geotechnical model adopted, rather than by the predictions by Kay (1990).

5 CONCLUSIONS

Figure 2 in this paper supports the Kay(1990) conclusion that "serious consideration might be given to use of the liquid limit test for direct characterization of expansive soil sites. For the wide range of sites tested, use of the liquid limit as determined by the laboratory cone penetration test appears to provide at least equally high quality information at considerably lower cost than methods used in accordance with the current (1986) Australian code."

One of the Kay (1990) qualifications was "It should be noted that the proposed method for site classification includes no consideration of differences in climatic influences for different localities. It simply describes the nature of the influences such as those associated with climatic extremes must be treated as a separate matter in the design problem".

The equations 3 and 4 developed in this paper extend the Kay (1990) principles by providing an equation to link the liquid limit to an *I*ps. This has allowed for the climatic influences to be considered in the ys calculation.

Section 4 of this paper and Tables 8, 9 and 10 were an attempt see, when using this method, if reporting y_s ranges rather than specific values would be an advantage, however this writer considers the range would be too wide to aid in economic design and Figure 2 also shows that the M=2 plot may not be conservative.

Section 4 and Table 7 of this paper may show that the arbitrary boundaries by Kay (1990) plotted on his Figure 1 (which may have been appropriate for Kay's purposes at the time) may also lead to y_s values which cannot be substantiated by other means.

Equations 3 or 4 may be used to determine Ips from the liquid limit, particularly when either a tube sample cannot be retrieved or time or cost constraints prevent the completion of a full Iss test. In our increasing litigious society, it would be expected that most consultants would choose equation 4 over equation 3.

The sample size used is small, but the test results have been derived from various locations around Australia and tested by different laboratories. Although Figure 2 shows an obvious relationship, it is this writer's contention that with a large sample size it may be possible to achieve greater refinement, particularly if the sample size is sufficient to group the samples according to their geological origins.

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