Soil Index Methods to Predict Ground Movements

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Summary In Australia, it is current practice to select footing systems by classifying a building site using the estimation of the "characteristic ground surface movement". The Australian Standard Code AS 2870 recommends two methods for this classification; broadly they are by soil profile identification or by calculation of surface movement from laboratory tests . These tests have not yet proven reliable in accurately predicting actual site ground movements. This paper examines some of these procedures and presents alternatives which have proved successful.

1. INTRODUCTION

The cost to the community of ground movements due to expansive soils has been estimated to be well in excess of $25 billion during very severe droughts such as the 1982-83 El Nino effect. If the ground movements could be predicted with accuracy, design solutions could be devised to allow for movements. Techniques to minimize such movements could also be planned.

Examination of the swelling and shrinking of soils has shown that there are points which could be related to the change of state of the soil. A combination of the accepted index tests and these signposts has produced another method of predicting surface movement which shows signs of being more closely aligned to the actual soil behaviour.

2. CURRENT SITE CLASSIFICATION METHODS

The current site classification system in Australia is based on the "characteristic surface movement". This movement is either calculated by carrying out one of a number of laboratory tests or "assessed" from knowledge of the behaviour of identified soil profiles.

The most favoured calculation method uses soil suction variations, instability index, and the presumed depth of moisture variation. and is based on formulas which link soil shrink/swell with suction changes. The problem with this calculation method is that it gives inconsistent and unconservative results.

In 1984-85, Cameron compared field ground movements recorded over a period of 18 months at 12 test sites in Victoria, New South Wales and South Australia with predictions using 4 different test methods (Cameron, 1989). A summary of the comparisons are as shown in Table 1 below (the first three of these are the tests recommended by the Australian Standard):

Table 1. Comparison of Predicted and Actual Movements.

Test	No. of Readings	Mean Movement	Standard Deviation
Loaded Shrinkage	18	74%	33%
Core Shrinkage	11	107%	48%
Shrink/ Swell	12	79%	25%
Richards	15	141%	76%

As stated by Cameron *"the observed movements given in this table do not necessarily represent the maximum seasonal movements as suction sampling may not have coincided with peak movements".* Nevertheless .....*"the predictions from the shrink/swell tests gave inexplicably low results"*.

When one considers that this testing was carried out during relatively normal seasonal conditions it is clear that the shrink/swell test results may be grossly unconservative for the calculation of ground movements for periods up to 50 years (as required by AS 2870).

Cameron also produced a comparison of the Linear Shrinkage test with the Shrink/Swell test and found a "line of best fit" of I_{ss} = 0.25 LS; (where I_{ss} = Shrink/Swell Index, and LS = Linear Shrinkage), however he stated that..*"the scatter was considerable."*

Another formula was proposed for the calculation of soil movement, based on the change of soil suction (derived from the Aitchison formula), (Mitchell, 1981).

$$d = \Sigma \,.\, I_{pt} \,.\Delta u \,.\, \Delta h \qquad (1)$$

where: d = soil movement, I_{pt} = instability index, Δu = suction range, Δh = thickness of soil layer being considered.

This formula requires either accurate suction readings taken in extremes of dry and wet conditions or a knowledge of the I_{pt} in the various soil layers. Most researchers agree that changes in suction are very closely related to soil movements, however the measurement of soil suctions is time consuming and too costly to carry out on small building sites.

Hence a new approach based on suction "sign posts" was investigated for application to light structures on expansive soils.

3. A NEW APPROACH FOR MOVEMENT CALCULATIONS

There are a number of "sign posts" proposed by researchers in this field which relate the suction soil value to certain soil states, as shown in table 2.

Table 2 : Soil Suction "Sign Posts."

Suction (pF)	Soil State	Reference
6.5-7.0	Oven dry	Lytton,(1994) , Mitchell et al, (1984)
6.0	Air dry	Lytton, (1994)
5.5	Shrinkage Limit	McKeen, (1992)
4.5	Wilting Pt	Lytton, (1994)
3.5-3.2	Plastic Limit	Lytton , (1994)
3.0	0.4 Liquid Limit	Driscoll, (1984)
2.5-2.0	Field Capacity 0.9 Saturation	McKeen, (1992) Lytton, (1994).
2.0-1.5	Swell Limit	McKeen, (1992)
1.0	Liquid Limit	Lytton, (1994), McKeen, (1992)

To better simulate the field conditions of the distribution of soil sizes encountered, modified index tests were developed by the first author during twenty years of experience. These index tests were designated Natural Liquid Limit (L_n) and Natural Linear Shrinkage (S_n). The modified tests were carried out on the soil samples , using the normal testing procedures, but including all of the sand fraction .

Tests were conducted on 51 samples representing a very large range of soils with various Natural Liquid Limits, which related the Natural Linear Shrinkage to the various soil states indicated by the suction "sign posts".

A typical plot for an individual soil sample has been shown in Figure 1.

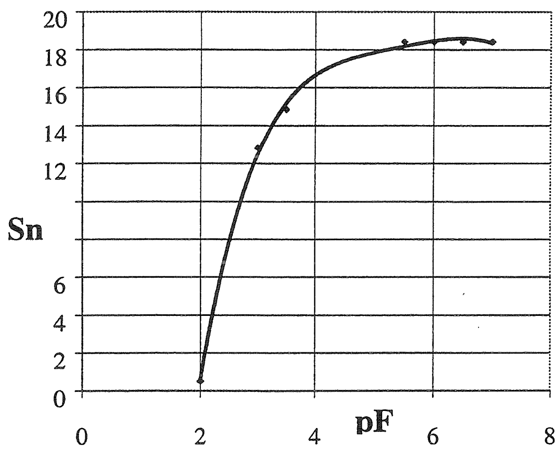

Figure 1. A Typical Plot of Natural Linear Shrinkage (Sn) Vs Suction "Sign Posts" (pF).

A family of such curves, with each curve relating to a particular Natural Liquid Limit, has been plotted in Figure 2.

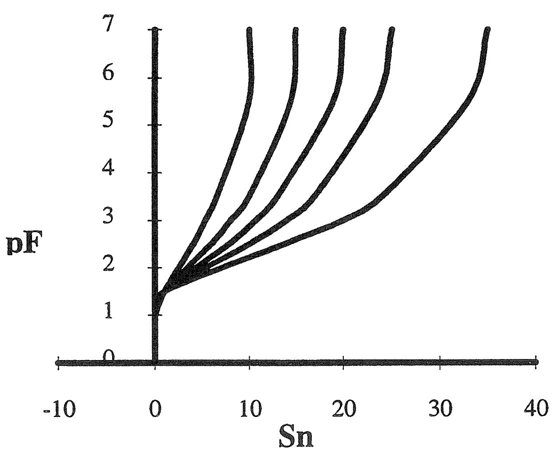

Figure 3. Plot of Suction (pF) Vs Natural Linear Shrinkage (S_n) for a range of Natural Liquid Limits.

4. SOIL SUCTION VARIATION

An interpretation of the above graphs provides the ratio of the shrinkage with suction. The above plots indicate that the I_{ps} (Shrinkage Index) values vary for different suction ranges and since this range varies with climate (among other factors) it is important to know the suction range in the soil profile being investigated.

An examination of the published suction data was made (Holden, 1995), (Cameron, 1989) with the following outcomes.

For Victorian climatic conditions as outlined in AS 2870, the maximum suction range recorded near the surface were as follows:

* Wet temperate: 2.6 - 4.4 pF (50 readings)
* Temperate: 3.2 - 5.0 pF (63 readings)
* Dry temperate: 3.5 - 4.9 pF (13 readings)

Using these ranges and selecting the appropriate curve for the Natural Liquid Limit of the particular soil, the relationship between the Natural Linear Shrinkage (S_n) and the rate of change of suction with shrinkage (I_{ps}) was found to be:

Wet Temperate: $I_{ps} = 0.30\ S_n$ (2)

Temperate: $I_{ps} = 0.19\ S_n$ (3)

Dry Temperate: $I_{ps} = 0.14\ S_n$ (4)

Taking I_{ps} as equivalent to the Instability Index (I_{pt}) used in AS 2870, a comparison has been made of predicted values, using the above Equations (2), (3) or (4) as appropriate), with Cameron's (1989) and Mitchell's (1984) results. The results are reported in the following section.

5. COMPARISON OF PREDICTED AND MEASURED VALUES OF SURFACE MOVEMENT

O'Halloran Hill (S.A.) - Mitchell (1984).
In this case, Mitchell took suction readings at various depth over a period of 18 months from which he derived the following information:
LS = 27%, Δh = 1.8 m, Δu = 2 - 5.
I_{ps} as tested by Mitchell = 5.3%
I_{ps} using Equation (4) = 5.1%.

Predicted ground movements were compared with measured movements made by Cameron (1989), in the table below.

The compared results give a mean of movement estimates of 120% of the observed value with a Standard deviation of 10%. The Melton, Flinders and Plumpton results have not been used because the high rock content in the soil profile greatly reduces the surface movement.

The predicted values, with one exception , give conservative values when compared with the measured values taken over a relatively short time span. When applied with knowledge of the climate and some experience of the site conditions, the method is viable for practical application.

Table 3. Comparison of movement predictions.

Location	Data	Measured Movement 18 month period (mm)	Max Predicted Movement (mm) using Eqn
Ballarat (Vic)	LS=16% Δh=1.5 (rock) ave. Δu=0.6	27	43 Eqn (2)
Bellarine (Vic)	LS=14% Δh=1.8 ave. Δu=0.6	49	45 Eqn (2)
Berwick (Vic)	LS=14% Δh=1.8 ave. Δu=0.6	53	45 Eqn (2)
Churchill (Vic)	LS=10% Δh=1.8 ave. Δu=0.6	32	32 Eqn (2)
Flinders (Vic)	LS=32% Δh=1.8 ave. Δu=0.6 lateritic slay	61	104 Eqn (2)
Gilles Plain (SA)	LS=24% Δh=4.0 ave. Δu=0.6	50	87 Eqn (4)
Keilor (Vic)	LS=22% Δh=2.3 ave. Δu=0.6	69	61 Eqn (3)
Shep -parton (Vic)	LS=19.5% Δh=3.0 ave. Δu=0.6	49	53 Eqn (4)
Spring- vale (Vic)	LS=7% Δh=1.8 ave. Δu=0.6	13	23 Eqn (2)
Phillip Island (Vic)	LS=23% Δh=1.8 ave. Δu=0.6	17	75 Eqn (2)
Plumpton (NSW)	LS=14% Δh=1.5 ave. Δu=0.75	10	27 Eqn (2)
Melton (Vic)	LS=25% Δh=2.3 ave. Δu=0.6	27	63 Eqn (3)

6. USE OF THE NATURAL LIQUID LIMIT

In an effort to enable the use of the Natural Liquid Limit in place of the Natural Linear Shrinkage, a study was made of the relationship of Natural Linear Shrinkage (S_n) values against the Natural Liquid Limit (L_n) on 457 clay samples collected from Victoria, the Riverina and Queensland over the past 25 years with a view to using either or both to calculate surface ground movements.

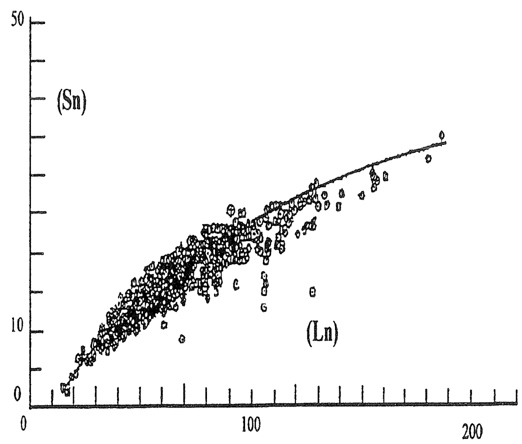

Figure 3. Plot of S_n Vs L_n

The line of best fit has the following formula:

$$S_n = \sqrt{(L_n - 30)} + 0.08L_n + 6 \quad (5)$$

7. CONCLUSIONS

The existing methods of predicting characteristic surface movement of expansive soils for the purpose of site classification have been shown to be inaccurate and not always conservative. Methods based on the change of soil suction have shown to be more accurate, but difficult to apply in practice.

This paper presents an alternative method which has been developed in practice which is relatively simple to apply and which is based on the various soil states represented by the suction " sign posts".

This method is based on the relationship between modified index tests (Natural Linear Shrinkage and Natural Liquid Limit) and the suction " sign posts". The method predicted the appropriate value of I_{ps} , the Shrinkage Index and hence I_{pt}, the Instability Index This method has predicted movements for a range of sites with results which are almost consistently conservative and reasonably close to the values measured over a short time span.

8. REFERENCES

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