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Effect of Insitu Moisture Content in Shrink-Swell Index

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Abstract Expansive soils (also called reactive soils) undergo heave and settlements due to moisture changes and could result in differential movements in light weight structures. Hence, an estimation of potential ground movement is essential for designing footings for such structures. Shrink-swell index (I_{ss}) is commonly used as a measure of soil reactivity and it is used in Australian standard of residential footing design to calculate ground movement. The shrink-swell test estimates the strain change per unit suction of an undisturbed soil sample; assuming the strain is independent of the insitu moisture content. In this study, 14 undisturbed soil samples were collected from an expansive soil site at different times over a two-year period. The sample locations were very close to each other. The samples had different insitu moisture contents varied from 22 to 37%. Test results indicate that increase in insitu moisture within that range resulted about 50% increase in I_{ss}. Similar increment was observed in a set of samples obtained from another expansive soil site. The impact of insitu moisture content on I_{ss} could lead to incorrect site classification. Consequently, the results of this study indicate that if the site is tested during different times of the year, it will result in different footing recommendations.

Keywords Expansive · Soil · Shrink-swell · Moisture

1 Introduction

In general, the expansive soils cause a greater damage to the light weight structures (i.e., residential buildings) and significant financial loss to property owners. As Fig. 1 shows, approximately 20% of the surface soils in Australia are found to be moderate to highly expansive (Richards et al. 1983). These expansive soils are more frequently found in all the populated areas. Expansive soils around Australian states contain Montmorillonite clays that are capable of absorbing water and increase in volume. This change in volume can exert enough force on a building or other structure to cause damage.

In order to minimize the damages induced by ground movement, designing of residential slabs in Australia is entirely based on the reactivity of the site (AS2870 2011). The sites are classified from slight to extreme reactive based on characteristic ground movement (y_s) as shown in Table 1. The standard—

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Fig. 1 Distribution of expansive soils (Richards et al. 1983)

AS2870 2011 subsequently provides appropriate footing details for each site class. Moreover, for extremely reactive sites, footings must be designed using engineering principles based on y_s. Therefore, an accurate estimation of y_s is a vital part of footing design.

y_s is calculated using Eq. (1) given in AS2870 (2011). As it shows, y_s depends on three variables; surface suction change (ΔU), design depth of suction change (H_s) and the instability index (I_{pt}). AS2870 (2011) defined ΔU as a constant 1.2 pF for Australian sites. H_s is defined based on climate zone such that, higher the aridity of the area the higher the H_s. I_{pt} is defined using lateral restraint factor (α) and reactivity index as shown in Eq. (2).

Table 1 Site classification by characteristic surface movement (AS2870 2011)

y_s (mm)	Site classification	Reactivity
$0 < y_s \leq 20$	S	Slight
$20 < y_s \leq 40$	M	Moderate
$40 < y_s \leq 60$	H1	} High
$60 < y_s \leq 75$	H2	
$y_s > 75$	E	Extreme

$$ys = \sum_{0}^{Hs} (I\text{pt} \times \Delta U \times h) \quad (1)$$

$$I_{pt} = \alpha \times reactivity\ index \quad (2)$$

The lateral restraint factor depends on crack depth of the area. As suggested in AS2870 (2011), reactivity index is a constant for a soil type. Based on these definitions, y_s is a constant for a given site which represent the expected ground movement during the design life of a structure.

Apart from the constants given in AS2870 (2011) model, the reactivity index is the only site-specific parameter that represent the soil behavior. Therefore, it is playing the key role in site classification. This paper reveals some drawbacks of the reactivity test prescribed in AS2870 (2011). The paper also points out how this ignorance of the reactivity index can result in misclassification of sites and incorrect footing designs.

1.1 Reactivity index of soil

Reactivity index can be obtained using different tests mentioned in AS2870 (2011) such as core shrinkage test, loaded shrinkage test and shrink-swell test. The shrink-swell test (AS1289.7.1.1 2003) is the most appropriate test among them and recommended in the hand book of AS2870 (2011) (Walsh and Cameron 1997). The reactivity index obtained from this test is called Shrink-swell index (I_{ss}).

Reactivity indices represent the volume change of expansive soil per unit suction change. In shrink-swell test, shrinkage and swell strains are measured separately. There are two tests to measure shrinkage and swell strains; both start at the insitu moisture content of the same undisturbed sample. The shrinkage strain (ε_{sh}) is measured from core shrinkage test, whereas the swell strain (ε_{sw}) is measured from one-dimensional swell test. The swell test is performed using a confining cell so that only the vertical strain is allowed. A surcharge of 25 kPa is applied during the swelling process to account for the effect of the weight of the footing. The detailed procedure of shrink-swell test procedure is described in AS1289.7.1.1 (2003).

The shrinkage sample is unconfined and hence accounts for the three-dimensional strain, while ε_{sw} is a one-dimensional strain due to lateral restraint applied by the ring. Those two strain values cannot be added together without correcting the dimensional inequality. Cameron and Walsh (1984) concluded that the unrestrained vertical strain of the soil is commonly 0.3–0.6 of vertical strain of the laterally restrained soil. This effect must be accommodated in the context of the results of the one-dimensional swelling taken from the laboratory tests. Therefore, the swell strain is divided by a factor of two (Eq. 3) to convert it to unconfined strain before adding to the shrinkage strain (AS1289.7.1.1 2003). This factor has been investigated in many studies (Cameron 1989; Fityus et al. 2005; Leong et al. 2002) and was subsequently accepted for use in AS1289.7.1.1 (2003).

Since the instability index accounts for the strain per unit suction, the suction change during the test must be obtained. An advantage of using the shrink-swell test is to bypass the measurement of suction. Since this test considers the total strain of the soil sample between saturated condition and oven dry condition, an approximated value is defined for the suction change during the volume change process. The researchers have suggested to use of the suction difference between wilting point and saturation point of the soil (Fityus et al. 2005). This concept assumes that only a negligible amount of volume change will occur beyond the limits of the wilting point and the saturation point. Observations suggest that the wilting point suction varies around 4.0–4.4 pF for clay soil and the total suction at saturation is about 2.2–2.5 pF (Cameron 2001; Fredlund and Rahardjo 1993; Wray 1998). Therefore, researchers have agreed to use an approximate suction difference of 1.8 pF and hence it is defined in the relevant standard of the test (AS1289.7.1.1 2003) as shown in Eq. (3).

$$I_{ss} = \frac{\frac{\varepsilon_{sw}}{2} + \varepsilon_{sh}}{1.8} \quad (3)$$

It is assumed that the I_{ss} is a constant for a soil sample irrespective of the starting moisture content of the test (AS1289.7.1.1 2003). However, certain investigations revealed that I_{ss} changes due to different insitu moistures (Lopes 2017; Lopes and Karunarathne 2017). Therefore, this study focuses on investigating the sensitivity of I_{ss} to initial moisture content. Shrink-swell test was conducted for expansive soils collected from Braybrook - a typical basalt clay soil site in Melbourne. Soil samples were collected at different times of the year. As a result, the samples had different insitu moisture contents. The results of those tests were used to calculate y_s and then to classify the Braybrook site. The effect of in-suite moisture content in I_{ss} was quantified and compared with y_s calculations. The conclusions from Braybrook soils were confirmed by test results from another site in Burnside Heights, Melbourne.

2 Initial investigation

According to AS1289.7.1.1 (2003), shrink-swell test starts from the insitu moisture content. The shrinkage part of the test continues to the oven dry state. Contradictorily, the swell part of the test has a termination point defined in AS1289.7.1.1 (2003). It states that the measurements may discontinue when the swell amount in 3 hours reaches less than 5% of the total swell of the specimen. Interestingly, most of the soils reach this limit at the end of the linear section of the strain variation and therefore, swell after this point is not considered in I_{ss} calculation. Authors have experienced that a significant swelling can be occurred after the above-mentioned limit and swelling may continue for many days. Figure 2 shows sample results from a tested site in Wyndham Vale, Melbourne, Australia. Even though the standard neglects strain beyond this limit, it could be a significant amount compared to the total strain. In fact, in Fig. 2, it reached about 30% beyond that limit in 5 days. Authors have experienced similar phenomena in moderate to highly expansive clay soils collected from most of the western suburbs of Melbourne. Such

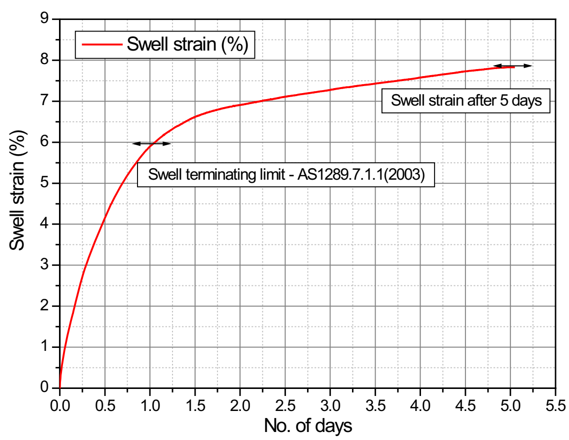

Fig. 2 Swell strain versus time measured in one dimensional swell test—Wyndham Vale soils

termination can result lower swell strain for wet soils and hence a lower I_{ss}. Furthermore, I_{ss} value will result in a lower ground movement than the actual situation.

In order to understand the strain variation with moisture content, a core shrinkage test was performed starting from very wet condition, where swell strain is zero. As shown in Fig. 3, soil strain versus suction has a curvilinear variation. I_{ss} is the slope of this curve. Figure 3 suggests that the relationship has an "S" shape with three different stages. The main stage is the darkened area which has a linear variation with a steep slope. Therefore, soils in this section experience significant strain for a small suction change. Very wet soils and very dry soils represent either side of that area, as illustrated in the Fig. 3. These two sections of the curve have mildly changing slopes implying that less strain change will be observed for a given suction change.

Since the relationship of suction and strain has variable slopes at either side, shrink-swell tests started at different insitu moistures (samples from a same site) can produce different I_{ss} results. The purpose of the study described in this paper is to investigate the influence of starting moisture content on I_{ss}.

3 Experimental procedure

Undisturbed soil samples at different insitu moisture contents were used to observe the above-mentioned phenomenon. Soil samples were collected from an expansive soil site in Braybrook—located in west Melbourne, Victoria, Australia. The natural soil type

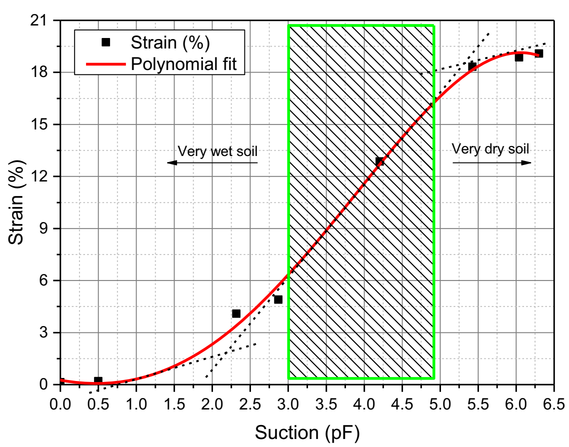

Fig. 3 Vertical strain and suction relationship (Braybrook soil)

of Braybrook is mainly Clay, the local geology being mainly Quaternary Basalts. The samples were taken at different times between 2012 and 2013 and hence the insitu moisture contents were different due to climate conditions. These samples were taken within a two-meter radius and therefore, appeared identical to each other. Basic soil properties of Braybrook site are shown in Tables 2 and 3. More details about Braybrook site can be found elsewhere (Karunarathne 2016).

Where, LL is the liquid limit, PL is the plastic limit, PI is the plasticity index and LS is the linear shrinkage of soil.

In addition to the Braybrook site, this phenomenon was investigated in another site in Burnside Heights, Victoria, Australia. Burnside Heights is also a western suburb of Melbourne, where geology being mainly Quaternary Basalts. Red-brown clay soil was found within the top layer of this site. Atterberg test of these soils resulted a liquid limit of 89% and plastic limit of 31%. This site was investigated as a part of forensic investigation regarding abnormal moisture issue (pipe leakage). The site had a damaged house due to differential moisture condition. Soils with different moisture contents were found nearby and away from the pipe leaks.

Shrink-swell test was performed for the sample collected from above mentioned sites and the results are shown below.

4 Experimental results

Shrink-swell test results together with sampling dates and insitu moistures of Braybrook soils are presented in Table 4.

Sample calculation of I_{ss} using values given in Table 4 is presented below.

Date 02/08/2012 at 0.5–1.0 m depth,

Swell strain (ε_{sw}) = 2.35% Shrink strain (ε_{sw}) = 8.75%

From Eq. (3),

$$I_{ss} = \frac{\frac{2.35}{2} + 8.75}{1.8} = 5.51$$

Within the period of sample collection, March 2013 was recorded as the driest month whereas August 2013 was the wettest. Moisture contents of the top soil varied by more than 15% between these two

Table 2 Soil profile at Braybrook

Depth (m)	Soil description
0.0–0.3	Clay (CH), Dark Brown, Soft, Root fibres present
0.3–0.5	Clay (CH), Dark Brown, Stiff, Root fibres present
0.5–1.0	Clay (CH), Brown, Stiff, Slightly calcareous
1.0–1.5	Clay (CH), Brown to dark grey, Stiff, Slightly calcareous
1.5–2.0	Clay (CH), Dark grey to light grey, Very stiff, Slightly calcareous
2.0–2.5	Clay (CH), Light grey, Very stiff, Slightly calcareous
2.5–3.0	Clay (CH), Light grey, Very stiff
3.0–5.0	Clay (CH), Light grey, Very stiff

Table 3 Basic properties of Braybrook soils—average values of three locations

Depth range (m)	LL	PL	PI	LS (%)
0–0.5	74.3	27.7	46.6	18.5
0.5–1.0	76.4	22.6	53.8	18.9
1.0–1.5	73.8	23.1	50.7	18.7
1.5–2.0	71.1	21.9	49.2	18.2
2.0–2.5	77.0	21.2	55.7	18.3
2.5–3.0	76.6	23.0	53.6	17.1
3.0–3.5	78.0	21.8	56.2	18.1
3.5–4	75.6	21.5	54.1	18.3

conditions. However, the soil moistures below 1.5 m were stable. Table 4 shows the different I_{ss} results obtained corresponding to different moisture contents particularly for soils up to 2.0 m. Due to the high variation of moisture, top soils show greater difference in I_{ss}.

The changes of shrink, swell strains and I_{ss} are shown in Fig. 4. Shrinkage strain becomes increasingly higher when insitu moisture content is increased. Swell strain varies as opposed to shrinkage. According to the calculation based on those two strains, I_{ss} increased with insitu moisture content. Interestingly, I_{ss} changed by more than 2 for a change of soil moisture of 15%. This is about 50% increase of I_{ss} from dry to wet soil.

Similar scenario was observed in Burnside Heights as shown in Table 5 and Fig. 5. There is a considerable increase in I_{ss} with the increase in moisture content. Hence, these results suggest that I_{ss} can be dependent on insitu moisture content.

Table 4 I_{ss} test results from different samples—Braybrook site

Sample date	Depth (m)	Insitu mc (%)	Shrinkage (%)	Swell (%)	I_{ss} (%)
02/08/2012	0.5–1.0	28.53	8.75	2.35	5.51
	1.5–2.0	26.78	8.83	2.70	5.65
	2.5–3.0	26.06	8.86	1.45	5.33
26/03/2013	0.5–1.0	21.86	3.95	7.20	4.19
	1.5–2.0	26.01	7.92	3.25	5.30
	2.5–3.0	24.26	8.53	3.10	5.60
20/06/2013	0.5–1.0	32.15	9.89	0.25	5.56
	1.5–2.0	25.02	7.93	5.10	5.82
08/08/2013	0.5–1.0	37.12	11.54	0.16	6.46
	1.5–2.0	30.83	9.14	5.91	6.72
	2.5–3.0	25.42	8.70	3.78	5.88
21/10/2013	0.5–1.0	34.42	10.29	1.45	6.12
	1.5–2.0	25.86	7.90	3.51	5.37
	2.5–3.0	25.30	7.99	2.66	5.17

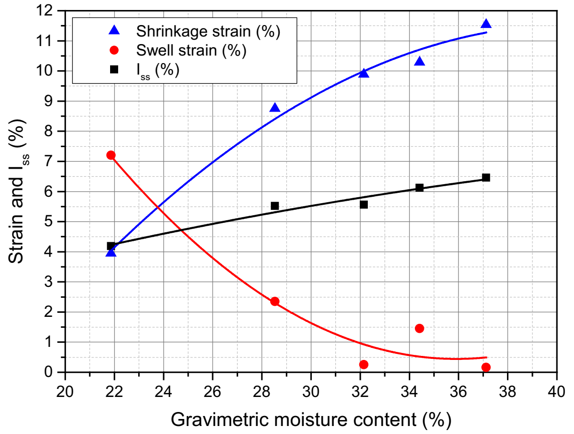

Fig. 4 Shrink, swell strains and I_{ss} variation with starting moisture content for soils at 0.5–1.0 m depth in Braybrook

Table 5 I_{ss} results of Burnside Heights samples

In situ moisture content (%)	Shrinkage %	Swell %	I_{ss} %
27	8.9	3.9	6.1
41	13.2	0	7.4
46	15.9	0.1	8.9
49	17	0	9.4

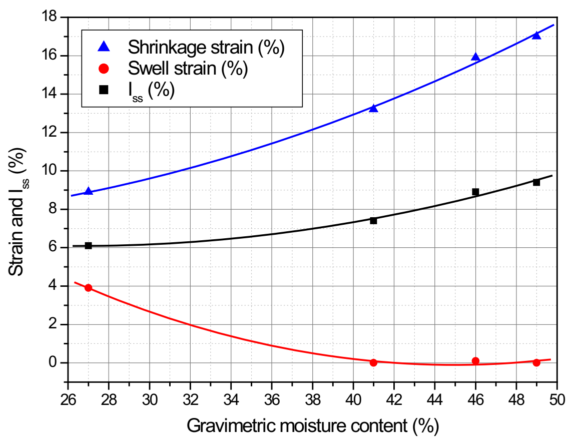

Fig. 5 Shrink, swell strains and I_{ss} variation with starting moisture content for soils in Burnside Heights

5 Discussion and conclusion

The experiment results suggest that different I_{ss} values can be obtained for a particular site, if the samples are collected at different times. In order to observe the effect of varying I_{ss} on site classification, y_s was calculated using measured data. Based on AS2870 (2011), H_s is 2.3 m and the crack depth is 0.75H_s for the western suburbs of Melbourne. ΔU is specified as 1.2 pF. The y_s was calculated from I_{ss} obtained at three different periods representing wet, dry and moderate soil moisture content, as shown in Table 6.

The Braybrook site was classified based on the classification given in Table 1. As a result of different y_s values obtained at different periods, this site can be classified as class E in moderate to wet soil moisture conditions whereas H2 in dry condition (Table 6). Hence, a footing design performed at different times of the year would result in different types of slabs.

Similar calculation was performed for the second site at Burnside Heights and it is shown in Table 7. The higher the insitu moisture the higher the I_{ss} and hence higher the y_s. At the lowest tested moisture content (27%), the site predicts 87 mm of y_s which is higher than the upper limit of site class H2. Therefore, the site classification remained at class "E" for all 4 results (refer y_s values in Table 1 and Table 7). However, a significant increase in y_s is observed with increase in moisture content. It is indicated that a greater stiffness of footings will be demanded, if the site is tested at higher moisture content.

When the soil is wet, shrinkage part of the test has a broader range to release moisture, whereas swell part has a narrow range to further absorption until the defined limit is reached. Therefore, wet soils record high shrinkage strain and low swell strain which result in higher I_{ss} based on Eq. (3). When soil is dry, swell part records a higher strain by absorbing more moisture and shrink part archives lower strain as the soil has a little moisture to be released. However, since measurement of swell strain terminates at the defined limit in AS1289.7.1.1 (2003) and also divide by two before calculating total strain, it can result in a lower I_{ss}. The presented results of Braybrook and Burnside Heights indicate the dependency of I_{ss} on starting moisture content of the test.

The results of the experimental investigation contradict with the specifications given in AS2870 (2011) and AS1289.7.1.1 (2003). AS2870 (2011) defines y_s using three variables; H_s, ΔU and the reactivity index. H_s and ΔU are constants for a given area. But the presented variations of I_{ss} could make differences in y_s and cause miss-classification of sites. AS2870 (2011)

Table 6 Calculation of y_s using different I_{ss} values—Braybrook

Depth (m)	ΔZ (mm)	Average ΔU (pF)	α	I_{ss} (%) at different soil moisture condition			y_s (mm)		
				Wet (08/08/2013)	Moderate (02/08/2012)	Dry (26/03/2013)	Wet (08/08/2013)	Moderate (02/08/2012)	Dry (26/03/2013)
0–1.0	1000	1.026	1	6.46	5.51	4.19	66.3	56.5	43.0
1.0–1.5	500	0.591	1	6.46	5.51	4.19	19.1	16.3	12.4
1.5–1.725	225	0.378	1	6.72	5.65	5.3	5.7	4.8	4.5
1.725–2.3	575	0.2	1.62	6.72	5.65	5.3	12.5	10.5	9.9
						Total y_s	103.6	88.1	69.7
						Site class	E	E	H2

Table 7 Calculation of y_s using different I_{ss} values—Burnside heights

In situ moisture content (%)	I_{ss} %	y_s (mm)	Site class
27	6.1	87	E
41	7.4	106	E
46	8.9	127	E
49	9.4	135	E

provides appropriate footing details for each site classification; such that the higher y_s values demand deeper and stronger slabs. Therefore, incorrect classification of sites will result in under or over designs of footings.

I_{ss} can be a good measure for soil reactivity, however the way it is currently used needs to be improved to recognize its reliance on starting moisture condition. Further research and more experimental data are required to improve the use of it. Alternatively, specific relationships (I_{ss} versus moisture content) can be developed for commonly found expansive soils.

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