NZGS SYMPOSIUM 2021
Good grounds for the future
24-26 March 2021 • Dunedin • New Zealand

Identifying and classifying expansive soils in New Zealand – time to find a better way?

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ABSTRACT

Expansive soils are present across the wider Auckland region and in many other parts of New Zealand, where residential buildings are increasingly supported on shallow slabs and footings in clay-rich soils subject to shrinking and swelling behaviour. Currently NZS3604 provides first-line guidance on the identification of these so-called expansive soils, based on the use of Atterberg Limits and Linear Shrinkage. Since 1999, NZS3604 has codified the use of Australian Standard AS2870 to guide residential foundation design which requires the classification of a site based on the expected ground surface movement.

There are several limitations in the application of AS2870 to New Zealand conditions, which have been known about for some time, yet still remain unresolved today. Of even greater concern, however, is the unreliability of the shrink swell test for New Zealand soils. If the test results are unreliable, then so too must be the site soil classification from which it is derived. Apart from New Zealand, no other country (besides Australia) has adopted the shrink swell test to classify expansive soils.

Internationally there are alternative methods available to systematically identify and classify expansive soils for the purposes of foundation design, including the Volume Change Potential approach used in Britain. Without the shrink swell test, AS2870 cannot be practically applied in New Zealand. This paper reviews the known problems associated with NZ's current approach to identifying and classifying expansive soil, comparing it with some international alternatives and poses the question: Is it time to ditch AS2870 from the New Zealand Building code?

1 INTRODUCTION

1.1 Consideration of expansive soil in NZ increasingly important

In New Zealand, as in Australia, the trend in residential construction in recent decades has been towards increasingly routine use of shallow foundations, in particular stiffened raft slabs and waffle raft slabs, for residential buildings. Traditional subfloor systems such as short timber piles and suspended timber floors seen in yesteryear have given way to slab-on-grade flooring systems, particularly for buildings in new subdivisions on relatively level ground.

A significant portion of the new housing stock recently constructed, and currently under construction, in the greater-Auckland area especially, is on lithologies dominated by highly plastic and clay-rich soils. In these areas the “expansive” properties of the soil, (i.e. soil shrinking and swelling) warrant close attention by the foundation designer. The issues related to expansive soils in Auckland have been known about since the early 1970s when drought conditions caused damage to new buildings in Pakuranga. Harvey et al (1982) provided guidance on these issues, and Wesseldine (1980, 1981) estimated that such damage-causing droughts might have a return period of about 20 years.

Without the correct identification and foundation design detailing, shallow footings and slabs constructed on expansive soil can cause costly damage to the structure due to the shrinking and swelling movements of the supporting ground. Furthermore, in some parts of the country future climate change effects are expected to manifest in the form of more frequent and more severe droughts. Foundations constructed on expansive soils therefore need to be designed with the appropriate degree of resilience to withstand such events.

1.2 The need for robust procedures

The standard methods and code requirements for identifying and designing foundations on expansive soils are a critical part of the residential building construction process. But the procedures need to be finely balanced. The required investigation and reporting should be sufficiently comprehensive whilst not producing overly conservative outcomes that add significant cost to the construction process (e.g. an over-assessment of risk leading to very deep embedment of footings over many houses in a large subdivision). A robust and accurate procedure is the clear objective.

A closer examination of the procedures currently used in New Zealand reveals a litany of inconsistency and error, both in the technical methods used and the building code framework that requires use of those particular methods. It is the contention of the authors that the time has come to review the methods required for identifying and classifying expansive soils and drawing on experience from overseas to decide on the path New Zealand should take in future.

Geotechnical practitioners around New Zealand should take an interest in this regardless of where they currently practice. Engineers and geologists need to have confidence in the processes required to be used because if there are potential flaws in those methods they could leave practitioners open to liability when building damage occurs. While expansive soil issues might be expected to arise most frequently within Auckland and Northland, they are not restricted to those regions.

2 IDENTIFICATION AND ASSESSMENT OF EXPANSIVE SOIL IN NEW ZEALAND

2.1 NZS3604

Since 1990 the New Zealand Standard for Timber-framed buildings NZS3604 and its predecessor code have required identification and assessment of expansive soil. The overall philosophy of NZS3604 is to provide for standardised design of low-rise timber framed buildings without the need for specific design. The geotechnical threshold for non-specific design is to establish the site conditions in accordance with the definition of “good ground”. Expansive soils are excluded from the definition of good ground. In NZS 3604:2011 expansive soils are defined as those with:

- Liquid Limit, LL > 50% (as tested by NZS4402.2.2:1986)
- Linear Shrinkage, LS > 15% (as tested by NZS4402.2.6:1986).

Changes to NZS3604 have essentially transformed these tests into a first line screening tool, with further classification and design to be undertaken in accordance with AS2870. However, prior to those changes, if the soil was not expansive and passed other tests it could be classified as good ground and standard foundation designs could be applied to lightweight timber framed buildings.

2.2 Incorporation of AS2870 into New Zealand practice

In 1999 NZS3604 was updated to require designers to classify the site in accordance with AS2870 ‘Residential slabs and footings’ where the definition of good ground for expansive soil was not met (Section 17).

First prepared in 1986, AS2870 was most recently updated in 2011 and provides for classification of the site based on the assessed ‘reactivity’ (i.e. expansivity) into one of six classes as shown in Table 1. The classification is typically established by calculation of a ‘characteristic surface movement’ based on certain assumptions about the soil suction profile, cracked soil depth, climatic zone, and an Instability Index parameter usually determined via one of three laboratory tests (see section 3 below).

Table 1: Classification of Site Reactivity (AS 2870-2011).

Class*	**Relative Reactivity**	**Characteristic surface movement, y_s (mm)**
A	Sand and rock sites with no ground movement from moisture change	-
S	Slight	$0 < y_s \leq 20$
M	Moderate	$20 < y_s \leq 40$
H1	High	$40 < y_s \leq 60$
H2	Very High	$60 < y_s \leq 75$
E	Extreme	$y_s \leq 75$

* A ‘Class P’ classification also provides for sites where ground movement would be significantly affected by factors other than reactive soil movements due to normal moisture conditions (e.g. soft ground, collapsible soil, landslide instability etc).

The standard provides guidance and typical values for crack depth and soil suction profiles for various locations in Australia. No guidance is provided for New Zealand soils or climatic conditions.

The question of whether AS2870 is applicable to New Zealand conditions at all (and if so, what modifications would be required) was canvassed within the geotechnical community immediately following the publication of NZS3604:1999. The question does not appear to have been ever satisfactorily settled (Grayson, 2000, and NZGS, 2001), and the guidance that emerged (research under the auspices of BRANZ 2002 - 2008, see section 5 below) seemed to implicitly accept that AS2870 could be applied to New Zealand conditions.

2.3 Place in NZ regulatory framework

Design based on NZS3604:2011 is considered compliant with the New Zealand building code, and it is estimated that over 90% of homes and other low-rise timber framed buildings in New Zealand are designed to this standard. The 1999 changes to NZS 3604 effectively brought the usage of AS2870 formally into the building code framework.

Recently the government has used amendments to Building Code Clause B1 Structure – Verification Method VM1 General as an omnibus mechanism to modify standards including NZS 3604, without updating the standards documents themselves. In 2019 amendments to B1/VM1 brought the site classification provisions of AS2870 directly into the building code (albeit using the older 1996 version of site classes in AS2870 1996), and included provisions for standard footing designs for various expansive soil site classes. This raises questions about whether expansive soil is still considered outside the definition of good ground, and the status of testing in terms of Liquid Limit and Linear Shrinkage as a basis for establishing good ground (see section 5.2 below for further discussion).

Since 1999 various local authorities have also incorporated into their engineering standards the requirement for geotechnical professionals to classify sites in terms of AS 2870. For example, Section 2.6 of Auckland Council's *Code of Practice for Land Development and Subdivision* (version 1.6, September 2013) requires the geotechnical report to:

> *"...identify any specific design requirements which would necessitate the building design deviating from NZS3604.*
>
> *The expected level of site movement from reactive soil (expansive soils) under AS2870:1996 shall be identified by their respective class and included in the geotechnical completion report (GCR). The soil properties used in determining the class are to be recorded in the report."*

Thus it can be seen that in spite of the widespread usage of AS2870 in New Zealand, inconsistencies are present in its application, and questions remain as to its applicability to New Zealand soil and climatic conditions.

3 THE SHRINK-SWELL INDEX TEST

3.1 Overview

There are three tests in AS1289 which produce index values that can then be used as a basis to estimate the characteristic ground surface movement. Of these, only the shrink-swell Index test (AS1289.7.1.1 (2003) has been found to have a practical application in determining the characteristic ground surface movement (Xi, Sun et al, 2017). The earlier tests (AS1289 7.1.2 and 7.1.3 (1998) either took too long (8 weeks), were not suitable if the soil was too dry or had difficulty with soil suction measurements.

The shrink swell test is a simplified procedure developed to determine the shrinking and swelling properties of the soil without the need to measure soil suction. The test combines the measured soil shrinkage and swelling strains to produce an index value. In calculating the index value it was assumed that magnitude of soil suction to volume change is 1.8pF for all tests. Also, since the swelling component of the test is confined within the oedometer ring, and due to concerns that the swelling strain would be overestimated, the swelling strain is divided in half (Fityus et al, 2005).

Thus the Shrink Swell Index is defined as:

$$I_{ss} = \frac{\epsilon_{shrink} + \frac{1}{2}\epsilon_{swell}}{1.8} \qquad (1)$$

3.2 Initial moisture content

One of the fundamental rationales for the adoption of the shrink swell test (in addition to its speed and low cost) was that it tested an undisturbed soil sample over the full moisture content range, and therefore removed the initial moisture content bias which beset core shrinkage tests alone.

Apart from a limited amount of testing to demonstrate that this is in fact true (e.g. Fityus 1996), it is surprising that this assumption has not been subject to closer scrutiny, given the fact that it forms the basis of determining a soil's site classification, and therefore foundation design. Even in the seminal paper on the shrink swell test, Fityus et al (2005) stated that, *"to the authors' knowledge, a general assessment of the effectiveness of the shrink swell test, and its associated application in routine geotechnical practice, has not been undertaken formally in any quantitative way."*

On the assumption that the shrink swell test is reliable, considerable research effort has gone into attempting to find correlations between the shrink swell index and other simpler, and more widely used, soil parameters such as Atterberg limits. Where little correlation has been found, it has been the Atterberg limits that have been concluded to be unreliable for identification of expansive soil.

Some researchers had been concerned that the shrink swell test does not in fact remove the initial moisture content bias (e.g. Hargreaves, 2017). It was not until researchers in New Zealand[1] undertook a critical analysis of over 1000 shrink swell test results was it found that not only did the shrink swell test not remove the initial moisture content bias, but that the swell test generally contributed little if anything to the shrink swell index values, thus producing an overwhelming shrinkage strain bias. The risk in using the test is that samples collected in summer with relatively lower moisture content may return low index values, when in fact the soil may be highly expansive. The shrink swell index test is considered by the authors to be fatally flawed.

4 METHODS USED INTERNATIONALLY

4.1 Overview

Given that expansive soils are present in many countries and major cities, and are a major geohazard for residential buildings, it is important to look at how other countries are practically dealing with the problem of expansive soils. Approaches in the UK, the US and South Africa are surveyed here briefly.

Nelson and Miller (1992) note that the various rating and classification schemes in use around the world provide only an indication of the true soil expansion and results often differ considerably from actual field conditions, mainly due to local variations and issues with sampling and testing. Practitioners should be familiar with the soil type and conditions used to develop the particular classification system, otherwise results can be misleading, and "*if used with design options outside the region where the rating was established cause significant difficulties".*

A wide range of approaches have been developed around the world that attempt to universally classify shrinking and swelling. There is some difficulty in direct comparison since there is no standard definition of swelling potential (Nelson and Millar 1992).

4.2 United Kingdom (UK)

Two approaches are in common usage across the UK, a method based on the assessment of a 'modified plasticity index (I'_P) advanced by the Building Research Establishment (BRE), and a very similar 'volume

[1] Research undertaken by Tonkin + Taylor, currently planned to be published in the June 2020 edition of NZ Geomechnics News.

change potential' classification advanced by the National House-Building Council (NHBC) which utilises the modified plasticity index.

The BRE method involves adjustment of the Plasticity Index (I_P) based on particle size, the fraction passing the 425µm sieve.

$$I'_P = I_P \times \frac{\% < 425\mu m}{100\%} \quad (2)$$

Thus soils are able to be classified into one of several categories, with corresponding design recommendations provided in the issued guidance. The BRE guidance clearly emphasises that the risk is related to the clay minerology and clay content of the soil, with the risk to foundations being related to changes in soil moisture (BRE, 1993).

Table 2: 'Clay volume change potential' (BRE, 1993)

Modified Plasticity Index, I'_P (%)	**Volume change potential class**
> 60	Very high
40 - 60	High
20-40	Medium
< 20	Low

Among the recommendations by BRE for building foundation design they note:

> *"Work carried out by BRE in the 1940s showed the need for a minimum foundation depth of 0.9 m; below this, seasonal wetting and drying, and the influence of minor vegetation, produced no significant ground movement. This depth has become the accepted minimum for foundations on most clay soils."*

This is twice as deep as the minimum embedment (450mm) required by NZS3604 before it was removed in the 1999 update.

With the usage of the BRE or NHBC approaches it must be remembered that the calculated values indicate potential swelling and shrinkage movement, which are dependent on changes to in-situ moisture content. In contrast to the AS2870 philosophy, there is no suggestion that the values calculated represent intrinsic properties of the soil, or that there is a need to precisely calculate the in-situ swelling and shrinkage movements (which are themselves based on a set of assumptions). Usage of this method requires judgement and careful design allowance for the appropriate range of conditions expected to eventuate onsite, and a focus on the amount and type of clay in the soil as the potential sources of uncertainty.

4.3 United States of America (USA)

Perhaps unsurprisingly there is no agreed method of expansive soil determination across all the states in the USA. In terms of soil types and climate, parts of California share some similarities to those of Auckland.

California developed a method (ASTM D-4829) for determining the Soil Expansion Potential which was designated as Uniform Building Code (UBC) test standard in 1994. According to ASTM, the Expansion Index (EI) has been determined to have a greater range and better sensitivity of expansion potential than other indices (such as Atterberg limits). This is essentially a swell test, but the soil is remoulded and conditioned and then compacted into a 100mm diameter mould prior to wetting and measuring the volumetric strain.

EI = 100 x percent swell x %passing the No 4 sieve

Table 3: Soil Expansion Potential (ASTM D-4829)

Expansion Index, EI	**Expansion Potential**
10 to 20	Very Low
21 to 50	Low
51 to 90	Medium
91 to 130	High
130+	Very High

The UBC mandates that "*special (foundation) design consideration*" be employed if the EI is 20 or greater.

4.4 South Africa

The approach to expansive soils in South Africa appears to be guided by a method developed by Van der Merwe (1964). Originally based on observations of building heave in Free State clays, it provides an empirical classification framework using standard particle size gradings and Atterberg Limits to predict ground heave.

The method is applied by classifying the potential expansiveness of the soil in accordance with the chart in Figure 1. The potential expansiveness class is related to unit heave using a correlation table and correction for depth, and the potential heave value is evaluated for a hypothetical 3m thick stratum comprising three layers of differing potential expansiveness.

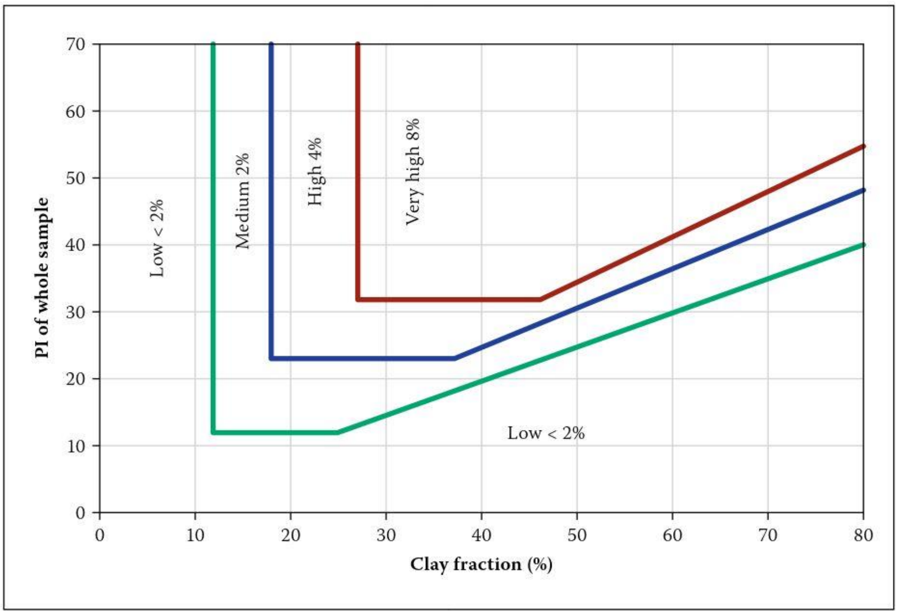

Figure 1: Van de Merwe plasticity chart reproduced from Jones (2017).

Jones (2017) pointed out that the distinction between Van der Merwe's maximum potential heave calculation and the realistic or probable heave was often ignored by practitioners, and the "accuracy of this prediction will be governed by the actual moisture changes that occur in the soil". Jones (2017) proposed some modifications to the original method to adjust the heave prediction to what were deemed more realistic results.

The South African experience over some 50 years usage of Van der Merwe's method suggests that there is a place for a local empirical classification framework for expansive soil. Although in comparing it to New Zealand conditions it is important to recognise that the expansive properties of clay soils in the upper North Island tend to be dominated by shrinkage rather than swelling for the Free State clays, a likely reflection of climatic differences as much as geologic differences. Jones and Jefferson (2012) note that whilst high swelling soil will manifest high index properties, the converse does not always seem to hold true.

4.5 Australia

The issues around the AS1289 tests have been set out in this paper.

A new approach for characterising expansive clay soils has been developed by Dr Dominic Lopes. (HEDRA 2019).

The fundamental aspects of this new Conditioned Core Shrinkage (CCS) test is that it is commenced at a 'fixed' suction (3-3.3 pF) and does not have the problem of the AS1289 tests which are tested in their field condition and hence at various field suctions and moistures.

The CCS test does not need a swell test, as the full test range is in the shrink mode. In the CCS test, suctions are measured at a range of 3-3.3pF, 3.5-4.5pF, 4.5-5.5pF and 6pF. 100% shrinkage is measured at 7 pF.

The shrink index values (Ips) are calculated along the appropriate suction range and used to calculate the (y_s). The laboratory test can be carried out in 4-7 days depending on the type of soil and the soil moisture during which the samples are taken.

Like all testing for soil expansivity, the CCS test results will need to be critically analysed over a range of soil types before it can be adopted as a reliable basis for site soil characterisation.

4.6 Observations regarding various approaches

The fact that there is no internationally agreed test method for soil expansivity attests to the extreme difficulty of trying to predict soil shrinkage and swelling with any precision. The various methods essentially fall into two main approaches:

Those based on traditional soil classification tests such as Atterberg Limits, or

Those that determine an index classification, usually based on core tests, which may be on undisturbed or remoulded samples, and may involve measuring shrink strains, or swell strains, or both.

5 NEED FOR CHANGE IN NEW ZEALAND

5.1 Research involving expansive soils

The BRANZ research study (Brown et al, 2003, and Brown et al, 2008) is the only recent major publicly funded study of expansive soils in NZ, but this was based on a very limited set of data and was focussed on Auckland soils.

That study essentially concluded that the AS2870 approach was suitable for NZ practice, but based on a clear set of assumptions, and with numerous suggestions and opportunities for improvement. Since the BRANZ research findings were published in 2008, there has been no further research undertaken on expansive soils in NZ. Due to the unreliability of the shrink swell index test, those findings have now been called into question.

5.2 Building code regime

The 2019 amendments to the Building Code relating to expansive soil introduced two areas of inconsistency:

5.2.1 Inconsistency with NZS3640 and AS2870

- In 2019 provisions included in B1/AS1 requiring assessment of expansive soils in terms of AS2870, however the site categories do not align with the latest version of AS2870-2011.
- The use of amendments to B1/AS1 the effectively modify standards such as NZS3604, when in fact the standards themselves should be amended and updated.
- The overarching philosophy of NZS3604 that provides for non-specific design of timber-framed buildings has been compromised by the recent amendments via B1/AS1. Buildings designed in compliance with NZS3604 are permitted so long as the ground conditions meet the definition of "good ground". However for sites where expansive soil is present, specialist engineering advice is required to determine the site classification in terms of AS2870.

5.2.2 Performance requirements for drought conditions

The building code has until recently effectively required compliant building performance on expansive soil for an SLS drought event of 1 / 300 years (AS 2870 is calibrated to a 5% exceedance in 50 years). The recent amendment to B1/VM1 introduced the AS 2870 framework directly to the building code provisions for the first time. With that introduction it appears that the value ranges for characteristic movement for each soil class have been scaled compared to original values. The scaling factor adopted would correspond to a 1 / 500 year drought event in accordance with the BRANZ research. The reasons why this was done are unclear, as no commentary or guidance on this point was release by MBIE with the amendment. Without a clear researched basis for the change, it is unclear whether even the new 500-year SLS level provides sufficient protection from projected future drought conditions of climate change.

Furthermore, as future drought effects to be experienced around the country are unlikely to be uniform, one would expect there to be location-specific adjustments based on local conditions to adjust the design and embedment of foundations on expansive soil. In the absence of further explanation, it is assumed that MBIE have used the drought scaling factors determined for Auckland and determined that they are applicable across New Zealand.

6 CONCLUSIONS

The Shrink-Swell Index test, and thus the AS 2870 method of site classification, has been shown to be unreliable at accurately predicting the expansive potential of soils at various sites in the upper North Island. This is because the test does not in fact remove the bias for initial moisture content as it was designed to do. Geotechnical practitioners will need to exercise caution when providing engineering advice regarding the determination of expansive soils. Accordingly, there is currently no reliable basis for determining a site soil class. If the shrink swell test is unreliable, then we need to look for other measures of soil expansivity.

The advantage of the approaches that utilise traditional soil classification based tests (plasticity, particle size distribution) is that they keep the focus, and the thinking of the engineer on the identification of the soil and mineral type in question, rather than on the "black box" determination of an index value. Various methods have been canvassed that could provide an alternative basis for identification and classification of soils, albeit with their own limitations. These need to be evaluated as a replacement for the current codified method of expansive soil classification.

Until changes are made to various codes, it is suggested that geotechnical reports with expansive soils include additional commentary regarding aspects such as the proportion of clay in the soil, and the presence of known expansive clay mineral types, in addition to the NZS3604 requirements for LL and LS values. PI is clearly also identified in many other countries as a reliable measure of soil expansivity.

Recent building code changes have simply added confusion and inconsistency into an already problematic area of New Zealand geotechnical practice. The authors of this paper encourage MBIE to carefully review the recent building code amendment, and release additional commentary regarding the change in return period drought. As there is no basis for reliably determining a site soil class, AS2870 cannot be used for foundation design in New Zealand.

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