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Interaction between shallow foundation systems and clay shrinkage

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ABSTRACT: The consequential effects of clay shrinkage and swelling occurs in numerous centres around New Zealand, particularly in the Auckland region, where it is a common problem for houses of brittle construction (i.e. brick veneer and plaster exterior) constructed on shallow strip or pad foundations. The extent and magnitude of the shrinking and swelling of plastic clays is predominantly related to seasonal variations within the soil-moisture regime. Shrinkage can also be exacerbated by the presence of high water demand tree roots. The resultant movement can be differential settlement and building distress.

1. INTRODUCTION

It is generally accepted that movements of residential and commercial foundations and slabs, pavements and other structures are primarily related to moisture conditions. This is particularly pertinent in respect of buildings with shallow foundations bearing on clay soils which exhibit seasonal volume changes.

These clay soils are referred to in the literature as 'active', 'heavy', 'plastic', 'susceptible', 'expansive' or 'shrinkable'.

The problems associated with buildings constructed on these clay soils relate predominantly to the interaction of the foundation of the structure and movements of the clay soil.

In addition, the extent and magnitude of these movements can be magnified and markedly influenced by the presence of vegetation and/or trees close by which, by the process of transpiration, can cause depletion of the soil moisture regime from its original equilibrium situation. This process is cumulative to that by which moist clay soils lose moisture near the ground surface due to evaporation. The magnitude of this imbalance in moisture equilibrium is dependent on climatic conditions, soil type and location of the water table. The process is referred to as desiccation.

Associated foundation movements can be cyclic on a seasonal basis, progressive settlement where the vegetation is establishing a permanent soil moisture deficit, or progressive heave when such vegetation is later removed.

This paper reviews the literature relating to factors which produce volume changes in shrinkable clays, looks at the capacity of vegetation and trees to cause shrinkage and swell in clay soils and finally gives suggested design procedures and practices for minimising the effects of these movements.

2. IDENTIFICATION CHARACTERISTICS OF "ACTIVE" SOILS

Soils exhibiting significant swelling with an increase in moisture content followed by shrinkage after drying out, as a result of wetting and drying cycles corresponding to seasonal fluctuations in soil moisture conditions, are often termed as 'shrinking', 'plastic', 'expansive', 'active' or 'heaving' clays. These soils contain substantial quantities of certain minerals such as montmorillinite.

Many identifiable areas of shrinkable clays. exist in the Auckland region. The clays showing this characteristic are mainly the plastic residual soils derived from the insitu weathering of Miocene Waitemata Series sandstones and siltstones.

Professor Leonards (1962) describes the phenomena of shrinkage and swelling as:

"In regions which have well defined alternatively wet and dry seasons, susceptible soils shrink and swell in regular cycles. Beneath the centre of a building where the soil is protected from both sun and rain, the moisture changes are small and the soil movements the least. Beneath the outside walls the movements are the greatest. The result is cracking, differential movement and progressive damage."

The terms 'susceptible', 'active' and 'expansive' relate predominantly to volume change. Volume change in a soil mass due both to natural and artificial causes introduces problems to soils that are not encountered with other construction materials.

Volume decrease is caused by load; it is a function of time; it is associated with changes in water and air content; and it is produced by rolling or vibration. Volume increase is a function of load, density, water content and type of soil.

There are special terms used to describe each of these different volume change phenomena and these are listed below as given by the 'Earth Manual'.

Compression defines the volume change produced by application of a static external load.

Consolidation defines volume change that is achieved with the passage of time.

Shrinkage is the volume change produced by capillary stresses during drying of a soil.

Compaction is the volume change produced artificially by momentary bad application.

It has been claimed that shrinkage is the mirror action of expansion and that in terms of the mechanics causing building damage, the properties of both expansive and shrinkable clays are similar.

There are three recognised methods of classifying potentially expansive clays, as documented by Fu Hua Chin:

(a) Mineralogical Identifications

In this method the swelling potential of any clay can be evaluated by identification of the constituent mineral of the clay. The five techniques commonly used are:

(i) X-ray diffraction
(ii) Differential thermal analysis
(iii) Dye absorption
(iv) Chemical analysis, and
(v) Electron microscope reduction

(b) Single Index Method

Simple soil property tests can be used for the evaluation of the swelling potential of expansive soils; such tests may include:

(i) Atterberg limit tests (liquid limit, plasticity index, liquidity index),
(ii) Linear shrinkage tests
(iii) Free swell tests, and
(iv) Colloid content tests

Relation between swelling potential of clays and plasticity index can be established as follows:

Swelling Potential	Plasticity Index
Low	0 - 15
Medium	10 - 35
High	20 - 55
Very High	35 and above

Professor Teng states that expansive soils are often characterised by a high liquid limit and plasticity indicies as a result of the more active clay minerals.

(c) Classification Method

By utilising routine laboratory tests such as Atterberg limits, colloid contents, shrinkage limits and others, the swelling potential can be evaluated without resorting to direct measurement. Some of these methods are listed below:

USBR method
Activity method
Indirect measurement
PVC metre
Soil suction

Overall it is considered that the original soil consistency tests of Atterberg (1911) are the best overall guide to identifying susceptible clays. These tests give 'engineering' properties of fine grained soils in which clay minerals predominate by giving measures of the water contents at which certain changes in the physical behaviour can be observed. It should however, always be borne in mind when using the Atterberg limits for engineering purposes, that since the limit tests are performed on remoulded soils, they are at best only indicative of their physical properties of the remoulded soil and cannot accurately reflect any mechanical properties of the clay in an undisturbed state.

3. TREE INDUCED CLAY SHRINKAGE

In the process of minimising the bareness of the urban residential environment and maximising privacy, the average homeowner typically plants trees and shrubs around and beside the house, which in turn markedly and detrimentally affects the soil-moisture regime as the roots extract moisture from the soil to satisfy the water demand of the tree.

Demand for water varies according to the species, age, location and climate. Reports from the Forest Institute in Rotorua indicates that under typical New Zealand climatic conditions, a realistic estimate for a single large fast-growing tree would be at least 9,000 litres per year. There is also evidence to suggest that a mature poplar tree requires 60,000 litres per year.

'Active' tree roots, by virtue of their root growth and orientation towards moisture, create a subsoil drainage network which maintains a suction in the soil to remove water. The subsequent decrease in length of the drainage paths for the clayey soils and the lowered water table induces dissipation of pore pressures and hence induces secondary consolidation settlement or elastic compression. This increases the effective load on the soil layers below the foundations.

Indirect actions or effects by trees or buildings are recognised in the British Standard Code of Practice, BS5837 (British Standards Institution, 1980) which records that:

"Indirect action by trees results from the removal of soil moisture by tree roots. Where the soil is a shrinkage clay the changes in soil moisture are accompanied by volume changes that can cause movement of building foundations. Such action is very complex because it involves the tree, the local climate, the soil and groundwater conditions, the building, and the interaction between them. While it is seldom possible to make precise predictions of the influence of trees on building performance, some understanding of the above factors is required when making a reasonable judgement."

The common culprit of most damage in the Auckland region is the silver dollar gum tree (eucalyptus cinerea). These trees can grow from 1.0 to 1.5 metres in height per year and reach a mature height of 15 metres. These trees have a preferential lateral root development which provides stability against overturning. Observed rates of lateral root sprawl are believed to be up to 0.5 metres per year under average conditions.

"Kozlowshi (undated) credits the eucalyptus with "extensive leaf surfaces perforated with stomata and hence a tree type admirably constructed to use large amounts of water (transpiration). Since transpiration is controlled largely by atmospheric factors (e.g. light intensity, temperature, humidity, wind); influencing the vapour pressure gradient between the leaf and air, water loss tends to exceed absorption by roots and the typical eucalyptus lateral root system becomes 'aggressive'."

"With reference to the above factors which influence transpiration it can be seen that these features are frequently why the property owner plants trees. The tree (typically silver dollar gum trees) is needed to provide shade, privacy and a wind break. The equation for potential clay shrinkage and resultant house damage is satisfied".

4. BUILDING CONSIDERATIONS

The consequential effects of shrinkage and swelling of clay soils are important considerations in the design and construction of one and two storey residential and commercial buildings within the urban environment.

Settlements, and particularly differential settlements, must be kept within reasonable limits.

The main element to be considered in the design of structures on plastic clay is the foundation.

Foundations throughout the Auckland region most commonly consist of reinforced concrete strip footings. Traditionally strip footings are located below the ground surface rather than at the surface. This is to permit removal of the surface layer of organic soil, gain additional bearing capacity that usually comes from increased embedment and to place the footing below the zone of soil which experiences major volume changes because of seasonal climatic changes or other effects.

Damage to a structure can be attributable to a number of causes such as foundation movement, material drying, shrinkage, temperature contractions and expansions, structural deflections, etc.

In New Zealand there is no statutory obligation on anyone to identify a risk of shrinkage and modify foundations accordingly. To build foundations which are unlikely to be affected by shrinkage involves extra expenditure, but the cost of underpinning, should it become necessary, is considerably greater.

Frequently the problems associated with clay shrinkage are only noticed after drought conditions, generally in late autumn. However, minor blast or earthquake forces, sudden drops in temperature or an extended period of low humidity, can also cause distress cracks and damage.

Burland and Wroth (1975) described the problem of interaction between a structure and the underlying ground on which it is founded, both during construction and subsequently during service. Interaction is a complex problem because it is the combination of several different effects, some of which are time-dependent and none of which are truly linear.

These factors include:

(1) The immediate settlements caused by each increment of load.
(2) The long term consolidation settlements (both primary and secondary) which overlap with immediate settlements.
(3) The changing stiffness of the structure.
(4) The redistribution of loads and stresses within the structure due to differential settlement.

Given the complex interaction of factors involved in causing movement of building foundations, it is the writer's opinion that a compromise or equilibrium approach is an appropriate method of attempting to minimise soil-moisture changes and also to accommodate some degree of building flexibility.

To this end, the equilibrium philosophy and approach should be to:

(a) Carry out soil classification tests (Atterberg limit tests, Cassagrande classification) to determine the soils' potential for shrinkage and/or swelling.

(b) Instruct Local Authorities to identify specific districts where 'expansive' or 'active' clays occur, either at the subdivisional stage or by damage investigations. Once these areas have been identified, it is essential that designers of buildings be advised of these soil conditions.

(c) Ensure designers take specific structural design steps in areas of plastic clays to provide foundations capable of accepting seasonal volume changes of clay; minimise where possible gravity loadings of the structure; pay specific attention to detailing of elements and specification of construction procedures; and attempt overall the design of buildings to accommodate unpredictable foundation movements without damage.

These would include reinforced edge beams having significant torsional stiffness and rigidity, perimeter strip footings founded at a depth compatible with minimal soil moisture variations, bored or driven piles, etc.

It is not considered that a blanket requirement of deepening foundations would solve the problem, rather specific structural design is required.

However, in terms of structural design options, the stiffened foundation is probably more economical but is structurally indeterminate, whereas the post hole bore or driven pile approach, although more expensive, has the advantage of being structurally determinate.

(d) Enable appropriately detailed and located movement control joints to be provided for houses of brittle construction. These joints are desirable to accommodate secondary or second order movements and mainly occur due to temperature changes, drying, shrinkage, curing, building flexibility, vibration, etc.

The advantage of this mode of specific design is that it can enable dwellings such as brick and masonry structures to be constructed, rather than the traditional legislative and sterile approach of prohibition of all brittle-type construction.

(e) Remind homeowners that in areas of clay shrinkage and swell it is essential to maintain the equilibrium soil-moisture regime. Because of this, extensive areas of impervious paving and/or saturation planting of high water demand trees or shrubs should be undertaken with great caution. Of all the input variables which can lead to structural damage of buildings erected on plastic clays, it is the 'house-keeping' measures which ultimately can be the 'straw that breaks the camel's back'.

(f) Provide, with the assistance of the landscape and arbouricultural industry, a catalogue of information pertaining to suitable tree types, root growth and characteristics, tree growth rate, mature height, transpiration rates, etc. Through experience and Engineering judgement, a hierarchy of suitable trees having acceptable water demand characteristics for the urban environment could be established.

This information would naturally assist both the property owners and Authorities in establishing suitable trees to a scale appropriate to that of the soil characteristics.

5. CASE STUDIES

(1) No. 9. Hayes Place, Pakuranga, Auckland (Foundation Engineering reference number 5583)

Settlement of the south-eastern garage portion of the dwelling as a direct consequence of excessive soil moisture depletion was found to be caused by the action of the roots of three blue gum trees situated some 5 to 6 metres away in the neighbouring Council reserve.

Substantial settlement was reflected in cracks to the brick veneer exterior and in the block base wall, together with racked and jammed garage windows and doors, plus large cracks and subsidence within the adjacent concrete pathway.

Hand auger boreholes revealed that there had been a notable reduction in soil moisture content in the vicinity of the cracked portion of the dwelling.

Our recommendations to our clients included:

(i) Formally requesting that the Manukau City Council cut down the trees in the neighbouring reserve and poison the tree roots.
(ii) Observe the situation for at least 1 year and monitor any rebound that may occur as the subsoils move towards equilibrium water contents.
(iii) After approximately 1 year, assess the amount of observable damage remaining and decide whether underpinning was warranted or not.

If the observable damage is still unacceptable then we recommended they install underpinning piles at a series of positions along the affected footing.

(2) 38 Stanley Point Road, Devonport, Auckland (Foundation Engineering reference number 5497)

The dwelling on this level property comprises a 15 to 20 year old architecturally designed two level structure with a brick veneer exterior, founded on 30mm wide x 250mm deep concrete footings. Several large, mature trees were noted growing around the property.

We observed that the south-western and north-western corners of the brick veneer were moving out and down (approximately 25mm displacement).

All movements were essentially of an aesthetic nature and there was no danger to the structural integrity of the dwelling.

Although some filling was encountered in two of our three hand auger boreholes (probably associated with backfill of service trenches), there was no indication of significantly organic, compressible, or otherwise unsuitable substrata within the natural ground that could be considered to be contributing to the observed building damage.

Measured water contents were fairly low within the top metre, indicating some desiccation had occurred.

In our opinion, the principal causes of the veneer cracking were due to the shallowness of the strip footing and the effects of seasonal shrinkage and swelling brought about by soil moisture fluctuations, which have been exacerbated by the presence of several large trees growing along the western boundary.

Our recommendations included:

(i) Removal of the large tree species.
(ii) Monitoring of the cracks over the winter period when soil water contents should adjust to equilibrium conditions.

To restore the veneer back to its original condition, it was recommended that a programme of underpinning would need to be undertaken.

References

C.P. 2004:1972L British Standards Institute, "Code of Practice for Foundations".

Leonards, G.A. "Foundation Engineering", McGraw Hill Civil Engineering Series, 1962.

Kraynski, "A Review Paper on Expansive Clay Soils", by Woodward-Clyde and Assoc., Vol 1, 1967.

Teng, W.C, "Foundation Design", Prentice - Hall Inc. 1962.

Chen, Fu Hua - "Foundations on Expansive Soils", Developments in Geotechnical Engineering 12, Elsevier Scientific Publishing Company 1975.

Wesseldine, M.A. - "House Foundation Damage Caused by Shrinkable Clays", Technical Paper presented to Auckland Branch New Zealand Institute of Engineers, Nov 1980.

Kozlowshi, T.T. - "Water Relations and Tree Improvements", Research Paper, Department of Forestry, University of Wisconsin, U.S.A. (undated).

Wesseldine, M.A. – "House Foundation Failures Due to Clay Shrinkage Caused by Gum Trees", Technical Paper presented to New Zealand Institution of Engineers Annual Conference, Auckland 1981.

Burland, J.B and Wroth, D.P (1975): "Settlement of Buildings and Associated Damage", Proc. Conference Settlement of Structures.