The continuing problems associated with expansive and collapsing soils

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ABSTRACT

Challenging problems associated with expansive and collapsing soils are described. In the presence of trees, even considerably strengthened and stiffened raft footings on expansive soils can suffer excessive distortions. The complex pattern of soil suction changes due to tree effects under a building must be considered. It is emphasised that the design of stiffened footings for the effects of trees under all possible circumstances remains outside current engineering expertise, and building owners should be warned of this.

Collapsing soils are found in a range of soil types, so that all unsaturated soil should be viewed with suspicion. The conditions for collapse are described. Geotechnical solutions comprise water proofing, pre-wetting, piling to a stable underlying layer, and densification. A design for the magnitude of typical collapse settlement should consider a differential deflection of at least 75 mm, together with drainage provisions and flexible plumbing connections.

For both expansive and collapsing soils, the importance of a geological understanding of the site is emphasised.

1 INTRODUCTION

Damage to structures constructed on soils that undergo deformation independent of external loading continues to be a problem encountered throughout the world. Such soils include expansive and collapsing soils. Despite the wide use of codes of practice, such as AS2870-1996, these soils continue to be a challenge to geotechnical engineers.

This paper summarises some of the difficulties associated with expansive and collapsing soils, and suggests some techniques that can be used to minimise the more damaging effects of these soil types.

2 EXPANSIVE SOILS

Expansive soils are clays that undergo volume changes with a change in soil suction. Common problems associated with this soil type include the instability of excavations (Figure 1) and the cracking of buildings (Figure 2). Although this paper is confined to footing designs on expansive soils, design solutions to problems associated with other geotechnical structures such as road pavements, excavations and retaining walls on expansive soils are far from being resolved.

Figure 1: Instability of an excavation in expansive clay

Figure 2: Expansive soil effects on domestic structure

Problems associated with expansive soils were traditionally regarded as being more significant in the semi-arid regions of Australia, such as west of the Great Dividing Range as shown in Figure 3 (Richards et al. 1983). The recent extended drought encountered in regions normally regarded as being in a more humid climate, such as large parts of the Eastern Australian seaboard, has resulted in widespread damage in areas usually regarded as not being prone to significant expansive soil effects. It must now be assumed that any site containing clay has the potential to develop appreciable expansive soil movements.

It must always be appreciated that a thorough understanding of the geological background of a site is important in any successful footing design. This is especially the case for difficult sites such those containing gilgai (Figure 4), where the variable nature of the soil layering renders an investigation of the site by boreholes alone very difficult, and the non-homogeneity of the profile can lead to non-uniform soil distortions.

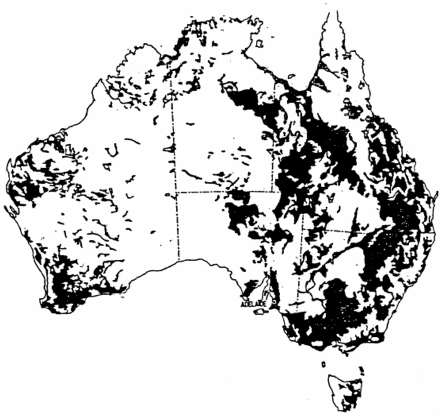

Figure 3: General distribution of Expansive soils

Figure 4: Gilgai structure in a Black Earth profile

The writer is of the opinion that the greater use of geotechnical design procedures for footings on expansive soil since the 1970's (such as the procedures of AS2870 'Residential slabs and footings' code introduced in 1986) has led to a lower incidence of problems associated with expansive soils. One area of improvement has been the greater acceptance of gridding (i.e. footing beams placed continuously across the structure in the longitudinal and transverse direction) such as the sub-beams of the raft footing shown in Figure 5, and for the strip footing layout shown in Figure 6. Adequate gridding, together with an increase in the reinforcement content in the footing beam, to improve the footing ductility, has greatly reduced the incidence of problem cases.

Figure 5: Gridded raft footing

Figure 6: Gridded strip footing (for suspended flooring)

This improvement in design methods can be demonstrated by Figure 7, which shows an example of a typical raft footing constructed in the 1970's. The lack of a suitable gridded layout and low sub-beam ductility contributed to the footing failure mechanism shown in Figure 8. A 'hinge' developed across the house whereby two sections of the structure underwent an appreciable differential distortion.

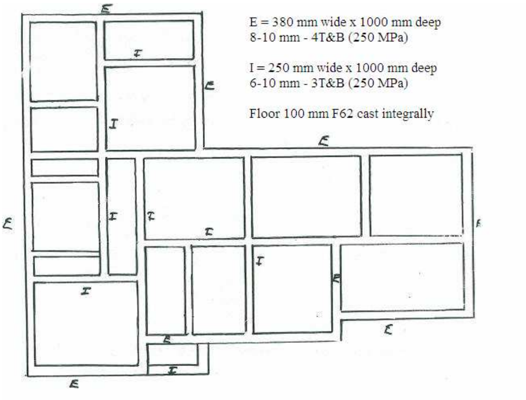

Figure 7: Typical 1970's raft design

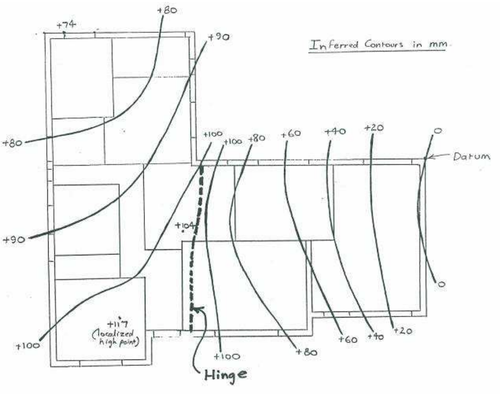

Figure 8: Distorted shape of raft

Improvements in the design methods have meant that if a cost-effective footing constructed on an expansive soil is subjected to the characteristic soil movement for the site (as defined by AS2870-1996), then the footing design will have a satisfactory probability of success. Problems continue, however, when the footing is subjected to tree effects.

3 EFFECTS OF TREES ON BUILDINGS

3.1 Design principle

It is well known that trees located in close proximity to structures have the potential to cause damage to the structure. This is because trees require water for their growth and survival, this water being drawn from the subsoil by means of their fibrous root systems. When the soil is expansive, this reduction in subsoil moisture results in an increase in soil suction, leading to shrinkage of the soil. Footings of buildings overlying the soil profile can undergo settlement in response to this soil shrinkage. The footing settlement can be sufficient to distort and crack a structure if it is incapable of accommodating this movement.

Figure 9 shows typical crack patterns associated with a house deformed into convex bending by a tree which has created a differential soil settlement across the structure.

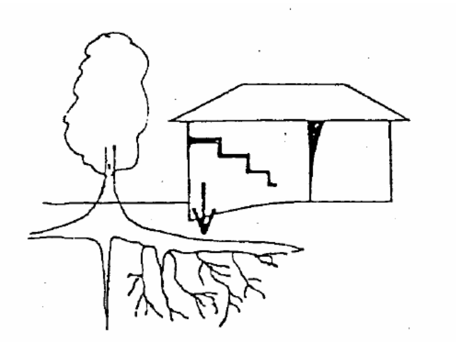

Figure 9: Footing in convex shape due to nearby tree

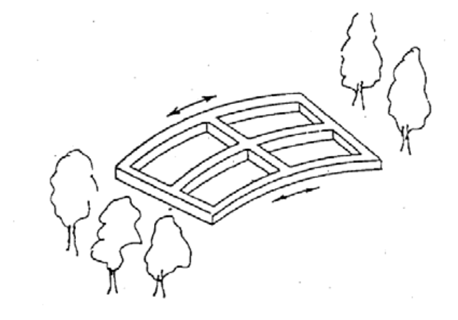

Figure 10: Principle of shallow stiffened footing

One type of footing used to overcome the effects of trees on buildings consists of the pier-and-beam (or pier-and-slab) footing, where the piers are designed to found the structure on a stable soil layer below the zone of expansive soil movements. However, as this system requires the piers to extend to a considerable depth and the floor slab needs to be suspended above the expansive soil surface, a piered footing can be expensive.

The stiffened raft footing (Figure 10) is also widely used to overcome the effects of trees on buildings. This type of footing is designed to be of a sufficient structural capacity to limit the magnitude of footing deformation, caused by expansive soil movements, to values permissible for the superstructure.

3.2 Adequately designed raft footing distorted by trees

Figure 11 shows the footing layout and construction details of a raft constructed over an extremely expansive soil profile. The raft design had a very high strength and stiffness, incorporating a much higher design surface movement and using much greater reinforcement in an attempt to cater for the effects of trees.

Despite the high raft strength and stiffness, cracks had developed in the building a few years after construction, with one crack being 25 mm wide. A differential corner settlement of 80 mm was measured (Figure 11). The settlement was due to the effects of young eucalypt trees growing near the settled corner.

Despite the raft footing having a very high strength and stiffness, the raft still suffered excessive distortion. This case example, and other similar cases seen by the writer, illustrates how the effects of trees in some instances can be very severe, and there are no reliable design procedures to allow for all their potential effects.

These cases justify the inclusion of warnings to future building owners, such as those warnings adopted in South Australia (IE Aust 1996), where it is stated that "….*due to the complex tree root geometry, variable moisture extraction by the tree and the difficulty in predicting future tree growth, a precise design for the effects of trees is outside current knowledge. The owner must be aware that although precautions have been taken for the effects of trees in [the footing] design, some distortion must be expected*".

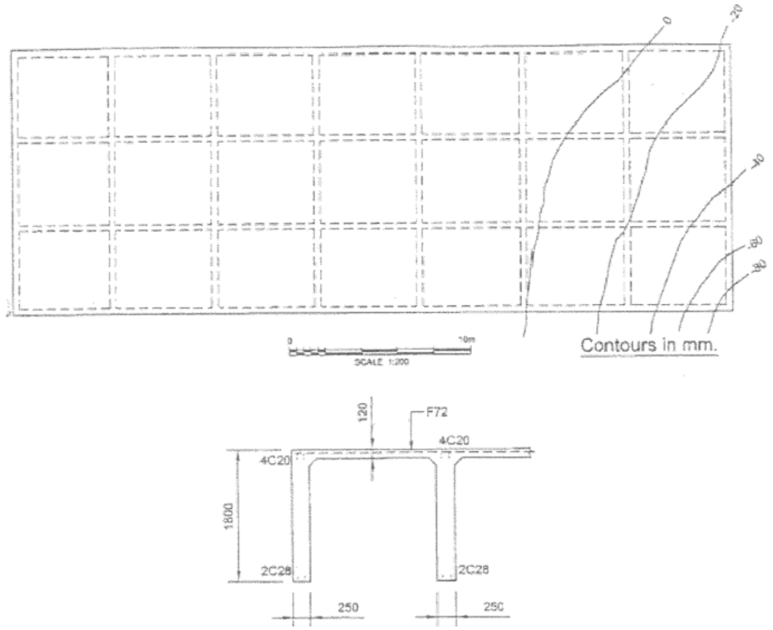

Figure 11: Footing layout showing distortion pattern and details for a well designed raft

3.3 Soil suction changes and footing distortion by trees

Figure 12 shows the measured soil suction under a structure and the induced building settlement due to nearby trees. The soil suction contours are in terms of pF and were inferred from measured values on soil specimens taken from various depths in several boreholes.

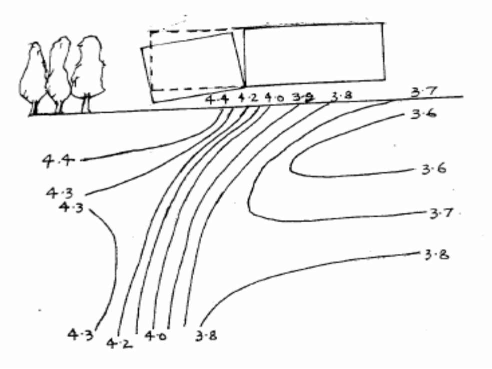

Figure 12: Example of tree-induced soil suction under building

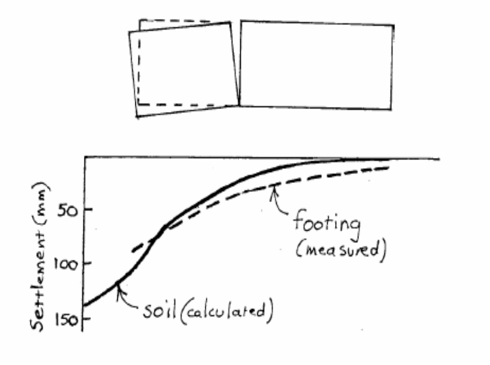

Figure 13: Inferred settlement profile induced by soil suction of Figure 12

It can be seen that in the area of the structure affected by the trees, the gradient of soil suction change is very high as indicated by the closely spaced soil suction contours. This means that the curvature of the settled soil surface induced by the large changes in soil suction is very severe.

Figure 13 shows the calculated deflected shape of the soil surface due to the soil suction distribution in Figure 12. The measured footing deflection is also indicated in Figure 13.

Although current design methods enable a footing to be designed to accommodate the soil movement and the measured deflected shape of the footing shown in Figure 13, the prediction of this footing shape at the time of design of the footing is not possible. In particular, the prediction of the pattern of the soil suction changes under the structure shown in Figure 12, and the prediction of the resulting angular distortion of the footing in the zone of severe soil suction changes, remains outside current knowledge.

The difficulties in the prediction of the observations shown in Figures 12 and 13 at the time of footing design further support the need to emphasize the uncertainties in the design process for the effects of trees as outlined in Section 3.2 above.

4 COLLAPSING SOILS

Collapsing soils are soils that lose strength and settle when wetted up, as illustrated in Figure 14 (after Schwartz 1985). A typical distortion pattern of a dwelling undergoing corner settlement due to a nearby underground leaking service in collapsing soils is shown in Figure 15 (photograph courtesy of Mr J. Goldfinch). Examples of problems associated with collapsing soils have been described by Nuntasarn et al (2007), Jaksa (2007), Wawryk (1983a, 1983b), Stapledon (1971), Selby (1982) and Schumann & Chugg (1970).

Collapsing soils can be easily misidentified by inexperienced persons. AS2870-1996 (Supplement clause C2.4.4) warns the reader that *'it is important for the problem sites to be correctly identified as in some cases they can appear to be similar to stable sites. For example, collapsing soils have a high bearing capacity when dry, but a much lower bearing pressure when wet, and hence need to be classified as a soft foundation'*.

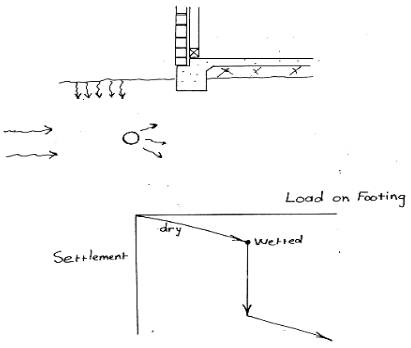

Figure 14: Principle of collapse settlement

Figure 15: Example of house distorted by collapsing soil movement

A simplified representation of the soil structure of a collapsing soil is shown in Figure 16. Collapsing soils often comprise coarse granular particles (sand or clay lumps) with a weak intergranular bond that can comprise water, silt, clay, calcium carbonate and a soluble salt. With the introduction of water, a break-down of the intergranular bond occurs, resulting in a collapse of the soil structure.

In Australia, collapsing soils commonly occur in arid and semi-arid regions (Figure 17, after Selby 1982). Collapsing soils commonly occur in South Australia, especially in the Riverland, the mid north, the Mallee, and Yorke and Eyre Peninsulas. Charters (2006) describes a collapsing soil (loess) that blankets the volcanic bedrock of Port Hills and Banks Peninsula, Canterbury, New Zealand.

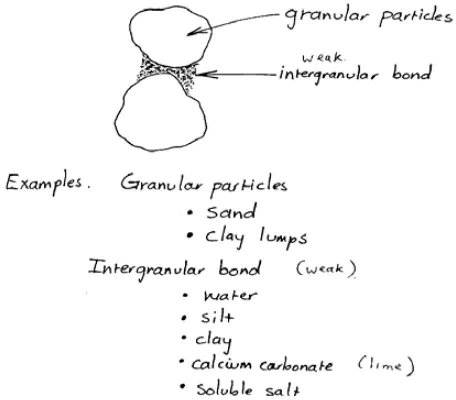

Figure 16: Structure of collapsing soil

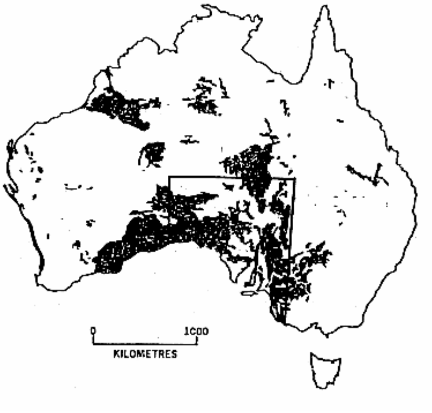

Figure 17: General distribution of collapsing soils

The conditions for collapse to occur require the following factors (Schwartz 1985):

- The soil needs to be partly saturated,
- The soils have a low dry density. Soils with a dry density less than about 1.55 t/m^3 should be regarded with suspicion, and
- An increase in moisture content occurs (the "trigger" for collapse), with hydration of the material binding the grains resulting in a rapid loss of strength.

It therefore follows that geotechnical solutions for the treatment of collapsing soils include water-proofing the site to prevent the "trigger" occurring, pre-wetting to pre-collapse the soil, densification by an impact roller or sand or gravel piling, or piling to an underlying stable layer. These solutions can be expensive and sometimes difficult to implement.

As in any successful geotechnical solution, an understanding of the geological background is important for a successful design on a collapsing soil site. A collapsing soil may be of an aeolian origin such as dune sand in Figure 18. A collapsing soil may originate from a debris flow, such as a torrential stream deposit, gully wash, or hillwash. A collapsing soil may be caused by the effects of burrowing animals, earthworms or decayed roots leading to a type of biotic soil. A common collapsing soil occurring world wide is that induced by human activity, such as uncontrolled fill in Figure 19.

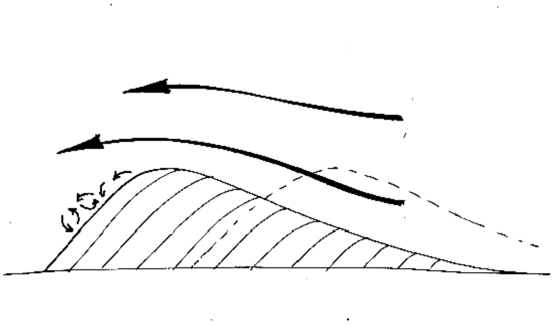

Figure 18: Formation of an aeolian soil type

Figure 19: Human-induced collapsing soil

Experiences with structures constructed on the collapsing soils located in the Riverland of South Australia are summarised in Table 1 (information courtesy of Mr. M.S. Humphris and Mr. P. Gunson). Experiences such as those shown in Table 1 indicate that it would be unwise to design a footing for a differential deflection of less than about 75 mm. Combined with this design requirement is the provision of adequate drainage, and flexible plumbing connections.

Table 1: Examples of problem buildings on SA Riverland soils

House Type	**Footing Type**	**Type of distortion**
Single storey, brick veneer	310 mm deep waffle raft	25 mm edge settlement
Single storey, brick, heavy loads	125 to 175 mm slab over separate strip footing	119 mm edge settlement
Single storey, solid brick	Strip footing	50 mm edge settlement
Single storey, brick veneer	430 mm deep raft sub-beams	94 mm differential movement
Single storey, solid brick	Strip footing, separate floor	75 mm differential movement

5 CONCLUSIONS

Improvements in the design procedures have evolved since the 1970's so that a cost-effective footing design on expansive soils, using procedures such as those of AS2870-1996, has a high probability of success.

Problems occur when attempting to consider the effects of trees. Even considerably strengthened and stiffened raft footings can suffer excessive distortions. The complex pattern of soil suction changes under a building must be considered. It is emphasised that the design of stiffened footings for the effects of trees under all possible circumstances remains outside current engineering knowledge, and building owners should be warned of this.

Collapsing soils are found in a range of soil types, so that all unsaturated soil should be viewed with suspicion.

These soils can be easily misidentified by inexperienced persons. The conditions for collapse of a collapsing soil are described. Geotechnical solutions comprise water proofing, pre-wetting, piling to a stable underlying layer, and densification. A design for the magnitude of typical collapse settlement should consider a differential deflection of at least 75 mm, with drainage provisions and flexible plumbing connections.

For both expansive and collapsing soils, the importance of a geological understanding of the site is emphasised.

REFERENCES

AS 2870-1996. Standards Australia. *Residential slabs and footings – Construction*. 5 June 1996.

Charters, N. (2006) *Development on Loess Soils in Canterbury, New Zealand*. 7th ANZ Young Geotechnical Professionals Conference. pp 21-26, Adelaide, October.

IE Aust (The Institution of Engineers, Australia SA Division 1996) *Special Provisions for the Design of Residential Slabs and Footings for South Australian Conditions*, The Footings Group, 1 August 1996.

Jaksa, M. B. (2007) *Transportable House Failure in Collapsing Soils at Port Broughton, South Australi*a. Australian Geomechanics. Vol. 42, No. 2, pp 13-24, June.

Nuntasarn, R., Cameron, D. A., & Mitchell, P. W. (2007) *South Australian Collapsing Soils*. Australian Geomechanics. Vol. 42, No. 2, pp 1-12, June.

Richards, B.G., Peter, P. & Emerson, W.W. (1983) *The Effects of Vegetation on the Swelling and Shrinking of Soils in Australia*. Geotechnique, vol. 33, no. 2, June.

Schumann, E.E. & Chugg, R.I. (1970). *Some Observations on Collapsing Soils*. Unpublished Paper to Symposium on Soils and Earth Structures in Arid Climates, Australian Geomechanics Society. Adelaide, May.

Schwartz, K. (1985). "Collapsible Soils" in *Problems of Soils in South Africa – State of the Art*. The Civil Engineer in South Africa, pp 379-393, July.

Selby, J. (1982). Engineering Geology of Collapsing Soils in South Australia. Proceedings 4th International Congress of the International Association of Engineering Geology. India. December, pp.I469-I475.

Stapledon, D. (1971). Renmark Television Mast, Investigation of Settlement. Prepared for Electric Power Transmission Pty Ltd. Coffey and Hollingsworth Report No. A28/1-1, Progress Report No. 1, 19 July.

Wawryk, S. (1983a). Formerly Public Buildings Department of South Australia. Unpublished data on Gawler High School.

Wawryk, S. (1983b). Formerly Public Buildings Department of South Australia. Unpublished data on Loxton High School.