Site classification and early floor movements in a new subdivision

Aaron O'Malley
Golder Associates Pty Ltd, Adelaide, SA, Australia
Don Cameron
School of Natural and Built Environments, University of South Australia, Mawson Lakes, SA, Australia

Keywords: expansive soils, footings, floor movements, level surveys, site classification

ABSTRACT

Four residential concrete house floor slabs of varying footing strengths have been monitored over a four year period in a newly established housing subdivision in South Australia. Due to Adelaide's predominantly semi-arid climate and reactive soils, the houses are founded on some of the most expansive clay sites in South Australia, which has been verified by extensive soil testing. Measured survey differences in levels across the house floors have been as high as 55 mm which has caused some cracking in the walls of the houses but the width and extent of cracking has not exceeded AS2870 damage category 2. The current movement patterns, potential causes of movements and the ongoing performance of the footings are presented in this paper.

1 INTRODUCTION

Expansive (or reactive) clays shrink or swell as moisture content changes due to climatic and environmental conditions (Holland 1979). Even relatively stable clays will move significantly if subject to extreme moisture changes. The climatic conditions of an area dictate the level of soil moisture changes at a site and therefore its site classification. Adelaide's semi-arid climate dictates that house footings should be designed based on a depth of active soil of four metres and a change in suction at ground level of 1.2 log MPa or pF (AS2870-1996).

Expansive clay sites are classified in accordance with the Australian Standard as "Slightly", "Moderately", "Highly" or "Extremely" reactive, depending on the amount of the design ground surface movement, (y_s) expected over the 50 year design period in an urban environment. The term 'y_s' is defined as 'the movement of the surface of a reactive site caused by moisture changes from characteristic dry to characteristic wet condition in the absence of a building and without consideration of load effects' (AS 2870-1996). The y_s value for a site, which is based on the soil profile and design suction changes for the area, determines the site Class.

The combination of reactive soils and a semi-arid climate in Adelaide means that houses and pavements must withstand significant soil movements due to seasonal and long term moisture changes from alteration of the site environment on expansive clay soils. It is well known that in an urban environment most trees, native or exotic, deciduous or evergreen, can add significantly to these soil movements, causing unacceptable distortions and cracking of residential structures.

Australian Standard AS2870-1996 encourages the avoidance of manageable extreme moisture changes and, in particular, does not provide guidelines for the design of trees close to dwellings. Instead the Standard recommends proximity or separation rules, which are designed to keep vegetation sufficiently far from houses to minimize the influence on ground movements, and so reduce the risk of damage to houses. For a Class E site, the Standard recommends that the planting of a single tree should be restricted to a distance from the foundation of a house of 1.5 times the mature height of the tree. An extra 50% separation distance is suggested where trees compete for moisture within a cluster, group or row. Therefore a street tree with an expected mature height of 6 m, planted on a Class E site, requires a separation distance of 9 m. In the urban environment, as housing allotments diminish in size, it is increasingly difficult to provide and maintain these separation distances.

Since the last fifteen years or so, footing designers in South Australia have applied an approach to the design of footings to accommodate additional deep drying of the soil profile by trees (Footings Group 1996). Accordingly the footings are strengthened by increasing the number of beams or the depth of beams and the steel reinforcement. The risk of damage to structures can also increase during drought periods as suffered in Adelaide during 2006.

This paper presents a background to the soil classifications at each site and the performance of four stiffened raft slabs situated on extremely reactive soils in South Australia. The monitoring of the slabs was secondary to a program of research on street trees in the subdivision, which was conducted along streets and verges over six sites (O'Malley 2006).

2 SITE DETAILS

2.1 Site Soils and Monitoring

Soil profiles and soil reactivities were found to be variable across the subdivision. At some locations the reactive clay profile extended beyond 6 m depth, while at other sites a shallow clay soil profile was underlain by sandstone or siltstone. As well, near surface layers could contain relatively low reactivity soil. The soils are generally high plasticity clays (CH) underlain at considerable depth by lower plasticity silty-clays (CI-CL), or weathered sandstone. A shallow rock layer was encountered below the higher plasticity clays at three of the four sites, namely 3LWH and 16LWH (depth of reactive profile, 3.5 m) and 8DWH (depth of 3.2 m).

Shrink-swell tests were performed in accordance with AS1289.7.1.1-2003 on soil samples from each site. Typically the shrink-swell indices were low near the surface (1% per log MPa) and quite high at depth (a maximum of 9.5% per log MPa). It should be noted that 4% per log MPa would be regarded as a highly reactive soil, 6% per log MPa very highly reactive soil, and 8% per log MPa, an extremely reactive soil.

At each site, initial soil suction and moisture profiles were determined from soil samples collected below the road verge in mid to late 2001. The first round of moisture monitoring revealed that soil suctions were not uniform across the subdivision. However it was found that the sites were generally wet to appreciable depth (2.5 m) and remained wet until mid to late 2004. Some drying of the soil profile was thought to have commenced in late 2004 or early in 2005, judging by the suction profiles gathered in this period. The unusually wet profiles before this period were believed to have been caused by overly enthusiastic irrigation throughout the subdivision to establish green verges and lawns. Irrigation was established in 1999, well before the slab monitoring had commenced in 2001.

The overwatering of the irrigated road verge at sites 3LWH and 16LWH may account for up to a 1.0 log MPa reduction in total suction in the top 2.5 m of the soil when compared to suction profiles at other non-irrigated sites.

2.2 Footing Construction

Monitored houses in the subdivision are single storey, articulated masonry veneer dwellings, supported on conventional raft slabs, which were provided with a regularly spaced grid of beams continuing from edge to edge of the building. The house footings at all the sites have been designed based on normal soil conditions, without the influence of trees.

Table 1 below provides details of the site classification and footing designs for the four monitored sites, as provided by the City of Salisbury and SA Housing Trust. Although the design details vary, the level of stiffness provided by beam depth and reinforcement were commensurate with the anticipated ground movement, except for the slab at 8DWH, which appeared to have relatively low flexural capacity in edge heave. Beam stiffness was evaluated using program CORD (v 6b), which employs Walsh's Beam on Mound analysis. Indeed the slab at 8DWH was designed using program SLOG and it is well known that the two design approaches differ when designing for edge heave.

The grillage raft at 16LWH was founded on a cut and fill site. Design drawings indicated greater beam depths and reinforcement in the cut area, to the extent that flexural stiffness was over 3 and 10 times the values for the slab in the fill area for centre heave and edge heave deformation, respectively.

Table 1: Site footing design details

House Allotment	y_s (mm)	Recommended Footing Construction					
		Slab Mesh	Beam 1 (External)		Beam 2 (Internal)		
			Depth x Width (mm)	Reinforcement	Depth x Width (mm)	Reinforcement	
8DWH	104	F72	850 x 300	3-Y16 Top 3-Y16 Bottom	600 x 250	2-Y16 Top 2-Y16 Bottom	
3LWH	100	F72	850 x 300	3-Y16 Top 3-Y16 Bottom	850 x 300	3-Y16 Top 3-Y16 Bottom	
8SWH	83	F92	750 x 200	1-Y24 Top 1-Y28 Bottom	750 x 200	1-Y24 Top 1-Y28 Bottom	
16LWH	101	F72	950 x 200 in fill area 1650 x 200 in cut area	1-Y24 Top (fill) 1-Y32/Y16 (cut) 1-Y28 Btm (fill) 1-Y32&Y16 (cut)	950 x 200 in fill area 1400* x 200 in cut area	1-Y24 Top (fill) 1-Y32* (cut) 1-Y28 Btm (fill) 1-Y32&Y12* (cut)	

*minimum

2.3 House Floor Movement Contours

Floor surveys were conducted using a dumpy level and staff, using 40 to 60 points across each floor. A network of deep bench marks had been established, which was referenced to a permanent Land Survey bench mark on a rock outcrop. Internal house floor contour movements for pertinent survey dates over the 4 year monitoring period are provided in Figures 1 to 4. An arbitrary datum point was selected at each site for the initial survey (internal centre of front door). Contour plans show differences in level at each point relative to the arbitrary datum point.

Initial surveys of newly poured floor slabs at adjacent sites in 2002 revealed a maximum difference in level of just +/-5 mm, which was believed to be attributable to construction tolerance. In the following discussion, an arbitrary North direction will be specified as up the page, to facilitate discussion.

The house at 8DWH was built in 1999 on an allotment with an expected characteristic site surface movement, y_s, of 104 mm. There was no cracking evident in the building on the first visit in September 2002. Over the four years of inspections, the house has experienced a nearly constant 10 mm heave below the front southern bedroom. More generally, patterns of movement began to become distinct by April 2005, with settlements appearing along the North side and about the South-West corner of the house. At the same time, minor cracking (≤ 1 mm) was noted next to a window in the bathroom and adjacent to the cornices between the lounge and dining areas. The patterns of settlement had extended by December 2006 at the back of the house and had receded a little at the front. A centre heave deformation was evident in the NS direction, with a differential movement of approximately 30 mm. Nonetheless the slab has performed well compared to other slabs within the subdivision, especially given the relatively lower flexural strength of the footing.

The house on site 3LWH was one of the first built in the subdivision in 1999 on an allotment with an estimated site characteristic surface movement of 100 mm. An inspection of the house on the first visit in October 2002 did not reveal any cracking; however by December 2006, minor cracking of 1.5 to 2 mm wide was noted in the cornice above the en-suite. From the first level survey, it appeared that the Northern half of the slab was undergoing heave, which had reached 40 mm near the NW corner by June 2003. The front of the house barely moved until approximately 20 mm of settlement was recorded in April 2005. By December 2006, the edge heave at the NW corner had reduced to about 20 mm and the front of the house had settled further (35 mm or so). Settlement was observed over 70% of the slab area. Fortunately there was no distinct edge or centre heave pattern. The maximum differential movement was 55 mm, and although greater than expected, its impact was lessened by tilt. There are signs however of the onset of centre heave.

The house at 8SWH was built in 2001 on an allotment with an estimated site characteristic surface movement of 83 mm. Floor slab levelling surveys were conducted in August 2002, March 2003, October 2003 and April 2005 at the site. The slab was unable to be surveyed during 2006. A skewed edge heave pattern, reaching from corner to opposite corner of the house, was clearly evident from the first floor survey. The highest differential movement in edge heave was 35 mm in March 2003, which lessened as settlement increased at the NE and SE corners. An inspection of the house on the first visit revealed minor cracking, 1 to 1.5 mm wide above two inner walls; these cracks had widened slightly to 2 to 2.5 mm by April 2005. The reason for crack widening is not apparent from the contour plots.

The house on site 16LWH was built in 1999/2000 on an allotment with an expected site characteristic surface movement of 101 mm. An initial inspection of the house revealed no cracking, however in April 2005 and December 2006, minor cracking of approximately 1 mm wide was noted in the tiled wall of the en-suite.

From the first inspection in October 2002, it was observed that the slab had heaved below the family room to a maximum value of 20 mm. The family room is at the West side of the house; a paved and rooved patio was located adjacent to this room. The upward movement continued in June 2003 and April 2005, extending further across the house, before receding by December 2006. In April 2005, an asymmetrical edge heave was evident from the SE to the lower NW corner of the house. Drying in December 2006 caused shrinkage settlement at both ends of this same section. Reduced movements were recorded around the slab, except towards the NE corner adjacent to two bedrooms, which rose approximately 10 mm. The maximum observed differential movement for this house was about 40 mm in 2006. The slab is now showing signs of progression to centre heave.

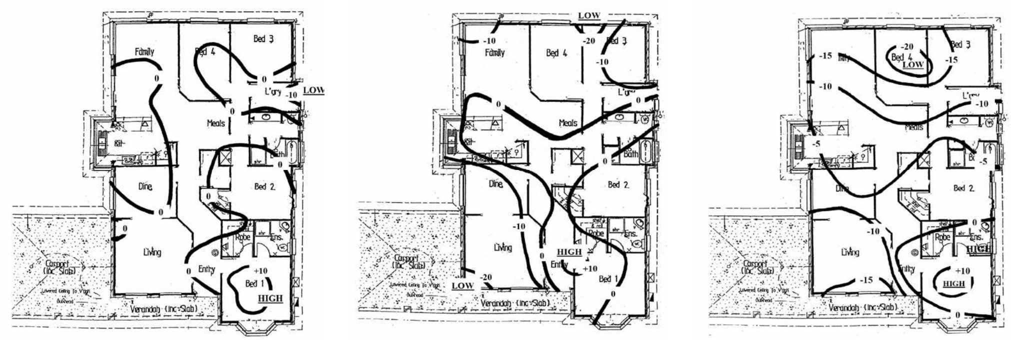
2.4 House Floor Performances

It is evident that the house contour patterns for each site are distinctively different as are the changes of the patterns of movement with time. Most of the slabs have experienced edge heave over the last four years with a trend at three of the sites of moving towards centre heave. The slab at site 8DWH is the exception. It has been shown that centre heave development beneath raft slabs can take considerable time, with edge heave persisting up to 10 years after construction (Mitchell 1988). Ultimately the pattern of slab distortion is expected to be centre heave.

Only the slab at site 3LWH was believed to have been affected by nearby vegetation. Over the monitoring period, an ornamental pear tree had almost doubled in height to 3.5 m and the tree is now relatively close to the house (proximity ratio ~ 1.0). In contrast the site at 8DWH had few significant trees or plantings; on the last visit lawn areas were thin and patchy. Two Silver Birch trees at the front of the property had not grown significantly over the monitoring period. The homeowner had not regularly watered garden areas, which is reflected in the poor growth. As already noted the slab seemed to be relatively less stiff for edge heave movements, yet this slab has performed relatively well to date.

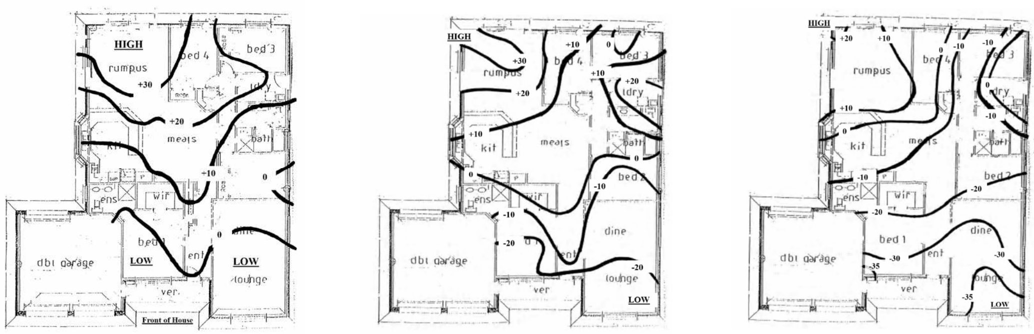
In 2006, Adelaide received less than half its long-term mean annual rainfall, leading to drought conditions and water restrictions. The drought and the restrictions may have contributed to the recently observed settlements and increasing differential movements at some sites. The footing performances to date are good in terms of observed wall cracking. The most obvious cracking was noted in the house at site 8SWH. However the level of cracking remained within the AS2870 design guidelines (Class 2) and is considered to be aesthetically unpleasing with no structural consequence.

The cylindrical mound design procedure of overlapping rectangles promulgated by AS 2870-1996 employs a maximum differential design movement, Δ_{max}, of 30 mm for spans 12 m or greater and proportionally less for lesser spans. This permissible differential deflection is associated with protecting the walls from cracking and so is measured usually along the directions of major walls, which is commonly the long and short direction of the rectangle. Observed differential movements, Δ, across the whole slab equalled or exceeded Δ_{max} in the cases presented. However Δ has not been corrected for tilt, nor has it necessarily occurred in a particular wall direction.



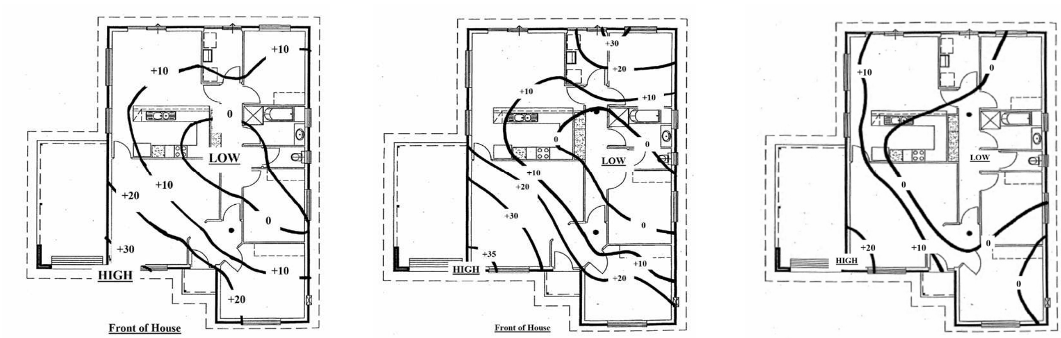
September 2002 | April 2005 | December 2006

Figure 1: 8DWH house floor movements



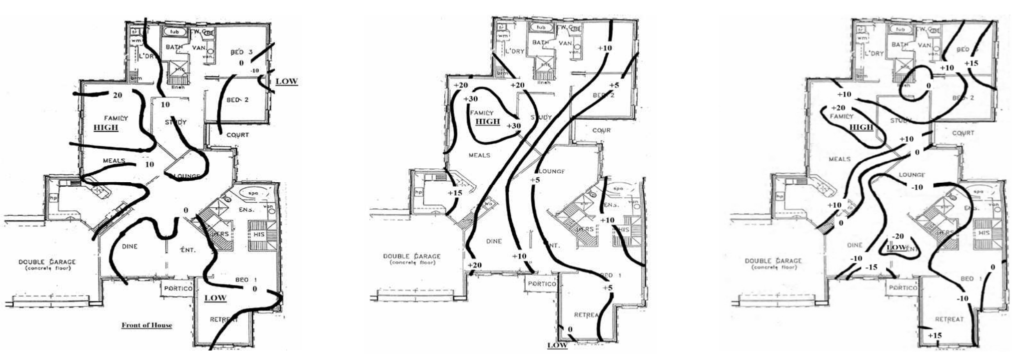
October 2002 | April 2005 | December 2006

Figure 2: 3LWH house floor movements



August 2002 | March 2003 | April 2005

Figure 3: 8SWH house floor movements



October 2002 | April 2005 | December 2006

Figure 4: 16LWH house floor movements

For example, for the slab at 3LWH in December 2006, the maximum value of Δ observed was 55 mm, occurring almost diagonally (SE to NW corners) across the floor. The maximum difference in level below the south wall (arguably suffering the worst distortion) was greater than 35 mm. This value of movement was reduced to about 20 mm when tilt was removed, a value which is well within the design limit of 30 mm

3 CONCLUSIONS AND DISCUSSION

Generally the raft slab footings have performed well over the first 4 years of monitoring on the extremely reactive sites of the subdivision, although measured differences in levels across floors have been as high as 55 mm. However differential floor deflections along sensitive walls after correction for tilt appear to have been within design guidelines for the type of house construction.

Some cracking has developed in the walls but the width and extent of cracking has not exceeded AS2870 damage category 2. The slabs are experiencing the early stages of mound development with some edge heave, which unlike AS 2870's design assumption has not been symmetrical. The transition to centre heave appears to have begun already for three of the houses.

The performances of the slabs during the centre heave stage will be exacerbated by the drying influence of surrounding vegetation, accentuating the deformation. Vegetation will have more impact in this stage as trees and shrubs develop with time. The influence of any vegetation should be evident from the level surveys and verified by soil suction profiling.

ACKNOWLEDGEMENT

This research project was kindly supported by the City of Salisbury and the Local Government Association of South Australian Mutual Liability Scheme.

REFERENCES

Footings Group. (1996). *Special Provisions for the Design of Residential Slabs and Footings*. IEAust SA, August.

Holland J. E. (1979). *Trees – How they can affect Footings*. POAV Journal, 11-14.

Mitchell, P. W. (1988). *The Actual Performance of Raft Footings on Expansive Soils*. Proc. Seminar, Australian Institute of Building Surveyors (SA Chapter), Adelaide, Feb.

O'Malley, A. (2006) Expansive Soils and Trees in the Urban Environment: A South Australian Experience, 7th Australia – New Zealand Young Geotechnical Professionals Conference, October 2006, Adelaide, South Australia, pp. 146 – 150.

Standards Australia. (1996). *Residential Slabs and Footings - Construction*. AS 2870-1996, Homebush, Sydney, NSW.

Standards Australia. (2003). *Methods of Testing Soils for Engineering Purposes - Soil Reactivity Tests - Determination of the Shrinkage Index of a Soil*. AS 1289.7.1.1-2003, Sydney.