Fourth Australia - New Zealand
Conference on Geomechanics,
Perth, 14-18 May 1984

A Study of House Foundations at Elizabeth East, South Australia

K.C. PILE

Senior Lecturer, School of Civil Engineering, South Australian Institute of Technology

SUMMARY The results of observations extending over 17 years on the foundations of 16 houses are presented. The houses are of brick veneer construction with timber floors, built on shallow strip external footings and internal dwarf walls. The soil is an expansive red-brown clay 12 metres deep. It is concluded that the movements of external walls are mainly due to soil moisture changes resulting from domestic activities such as gardening, and that the pattern and magnitude of movements are unpredictable. An attempt is made to assess the relevance of the currently used methods for footing design proposed by Walsh and Mitchell. It is found that these methods do not model the observed long-term soil deformations accurately. Nevertheless for the soil deformations at the 16 sites in the study, footings properly designed by either of the above methods would perform satisfactorily.

1 INTRODUCTION

The problem of the design and construction of a stable footing system for houses built on expansive clays has concerned geotechnical engineers in arid regions of Australia for at least 30 years. In this time, the two footing types most commonly used have been either piers founded at a depth where the soil is stable and supporting beams clear of the soil surface, or relatively shallow footings built on stabilized soil or, more recently, designed as structural beams.

In 1966, the South Australian Housing Trust (SAHT) constructed 30 experimental houses at Elizabeth East, with the objective of finding out which of the footing types being used at that time was best. Fourteen houses had pier and beam footings and 16 had shallow footings with minimal reinforcing steel. The foundation soil profile was a red-brown clay. All houses were of brick-veneer construction with timber floors. On completion, the houses were rented, and thus the heaves and settlements observed since construction have occurred under environmental conditions including normal domestic activities, such as paving, building additions and gardening, including tree planting.

In recent years, deep beam or grillage raft footings with substantial reinforcement have come into wide use. A major problem in their design is estimating the deformation of the soil surface beneath the house or building and hence determining the distribution of upthrust on the base of the footings. For the 16 houses at Elizabeth East with shallow footings, the vertical displacements observed may be assumed to be similar to the deformation of the soil surface, due to the low strength and stiffness of the footings. Thus a comparison between actual deformations and those assumed by current design methods can be made.

Whereas the use of stiff-beam footings on reactive clays has increased, the use of pier and beam footings in the Adelaide area has decreased. It is now known that many reactive soil profiles are of great depth, and also that long-term swelling or shrinking may occur well below the zone of seasonal moisture change. As a result, piers to stable strata tend to be expensive, and in addition are rather difficult to construct properly. Thus the most useful information gained from the Elizabeth East project is probably the performance of the houses with shallow footings, which will be the main topic of this paper.

2 SITE CONDITIONS AND SOIL PROPERTIES

2.1 The Site

The site of the 30 experimental houses is bounded by Marshalsea and Seatown Roads, Elizabeth East, approximately 25 kilometres north-east of Adelaide. The area is an outwash plain, having an average fall of 1 in 40 from the south-east to north-west Prior to construction of the houses, the land had been cleared of trees and was used for grazing.

2.2 Soil Profile

The soil profile was investigated by the SAHT in 1965, with several bores to a depth of 3.6 metres. In 1980, the S.A. Institute of Technology (SAIT) became involved with a follow-up and review of the project and six deep boreholes were put down, the maximum depth being 12 metres. All boreholes disclosed similar clay strata, as shown in Figure 1. However, four of the six deep bores encountered gravel layers of thickness up to 2 metres, which appeared to be old stream-bed deposits. The depth of the layers was random, ranging from 2 to 8.5 metres. Ground-water was not found in any of the bores of 1965 and 1980/81. Even at 12 metres the soil was very stiff and low in moisture content, suggesting that natural ground-water level is much deeper.

Of the 1980/81 deep boreholes, three were in a park opposite the houses in Seatown Road. They were put down well away from trees, in order to obtain soil samples representative of conditions prior to development of the area for housing. The other three boreholes were in the front gardens of houses.

2.3 Laboratory Soil Tests

Laboratory testing of the soil was carried out by the SAHT in 1965 and the SAIT in 1980/81.

The SAHT tests, in keeping with practice at the

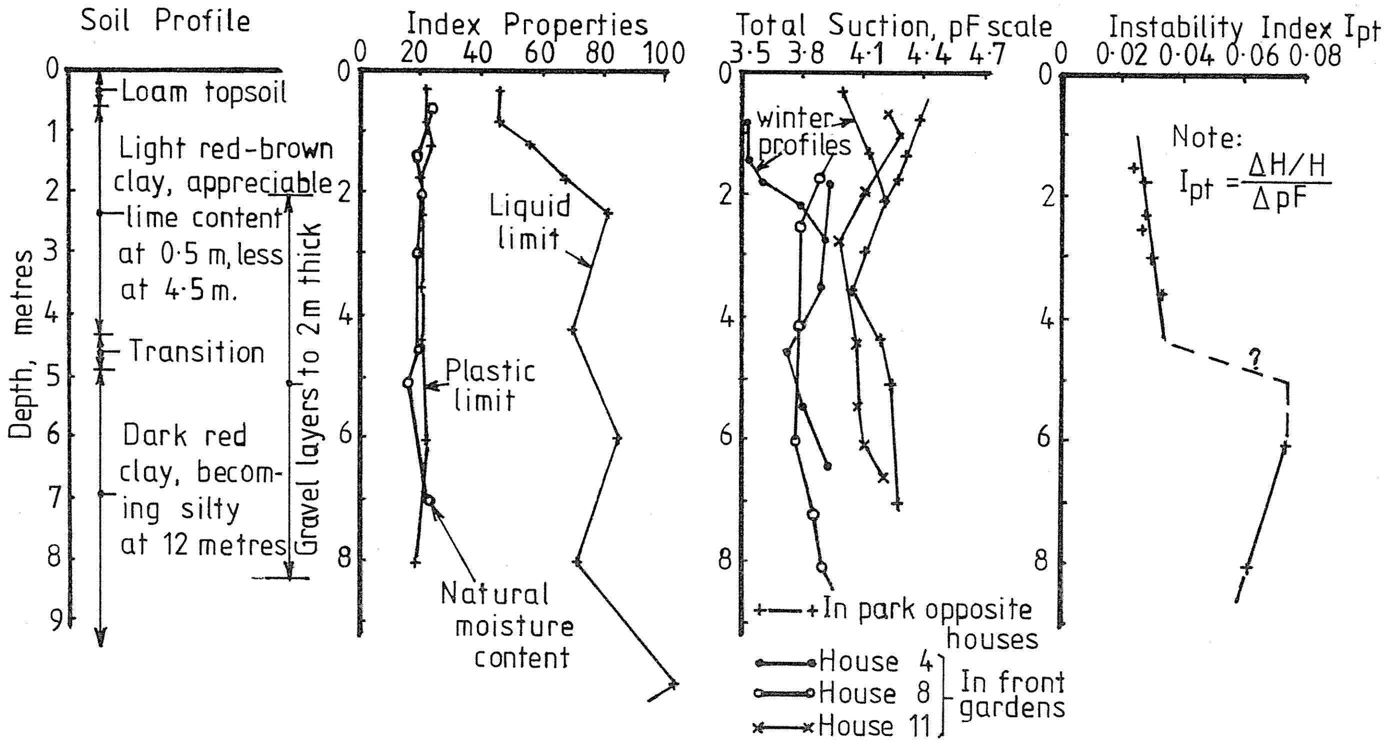

Figure 1 - Soil Profile and Properties

time, included determination of liquid and plastic limits (W_L and W_P), plus volumetric shrinkage. The W_L and W_P results are plotted in Figure 1.

The SAIT soil tests included measurements of total suction, and both swell pressure and magnitude of swell as a result of saturation in an oedometer. The latter showed that the entire soil profile to 12 m is in a desiccated state and is capable of swelling under overburden pressure on wetting. A few tests for instability index were made by drying to controlled suction values, as well as some additional liquid and plastic limit tests. Figure 1 shows suction profiles for the soil in the park and in the gardens of three houses and also some instability index results.

3 HOUSE FOOTINGS AND INSTRUMENTATION

3.1 Foundation Treatment

Of the 16 houses with shallow footings, 12 sites had lime-stabilizing treatment. One was a lime-raft, while 11 had drill-lime stabilization, carried out either before or after the footings were constructed. The lime-raft process consisted of mixing hydrated lime with the soil in the top 150 mm and re-compacting. The drill-lime process involved drilling a large number of holes to a depth of 1.5 m at each house and filling with hydrated lime slurry. The treatment at the 16 sites is shown in Table 1.

3.2 Footings.

The 16 houses with shallow footings have 380 mm wide concrete strips for the external walls, reinforced with three 12.7 mm dia. mild steel bars top and bottom. The overall depth is 300 mm for houses No. 23 and 29, and 380 mm for all others.

Internal footings consist of brick dwarf walls founded just below the soil surface.

3.3 House Construction

As previously noted, all houses are of brick veneer construction with timber floors. External walls are either masonry blocks or clay bricks, as shown in Table 1. All of the houses have roofs of cement-concrete tiles.

3.4 Instrumentation

Each house had 9 or 10 levelling points fixed to the external footings. Three 9 m deep benchmarks were put down at different locations around the housing estate to provide a datum for precise levelling. In addition, two water-levelling points were installed under the timber floors near the centre of each house, to record vertical displacement of the internal dwarf walls. Also, most houses had three installations of type FFF gypsum blocks, two beneath the interior floors and one at the external footing. The depths of blocks were 0.3, 0.9, 1.5, 2.1, 2.7 and 3.6 metres.

3.5 Site Development

The observed vertical movements of the external walls appear to be influenced by such factors as tree planting and garden development, as well as the reported state of soil moisture at the time of construction. Some notes on the individual sites are included in Table 1.

4 RESULTS

The following results were recorded for the period 1966-1982 :

4.1 Vertical Movements of External Walls

For the 16 houses with shallow footings, vertical displacements of the outer walls are shown in Figure 2. Some houses have moved at a fairly uniform rate since construction, especially Nos. 8 and 9, which have large heaves with relatively small differential movements. For others, such as No. 1, differential settlement became apparent several years after construction, probably due to the establishment of large trees.

Level checks at different times of the year have shown that seasonal variations of movement are small.

TABLE I

FOUNDATION AND HOUSE DATA

House No.	Foundation Treatment	External Wall Constr'n	Site Notes
1	None	Besser blocks	Large eucalyptus tree 9 m from levelling point 5
2	Drill-lime 211 holes	Besser blocks	Large eucalyptus trees in garden all round house.
3	Drill-lime 58 holes	Besser blocks	Surface of site wet at time of construction due to poor drainage.
4	Drill-lime 216 holes	Besser blocks	Surface of site wet at time of construction due to poor drainage.
5	Drill-lime 59 holes	Clay bricks	Large eucalyptus tree in front garden
6	Drill-lime 62 holes	Clay bricks	Large eucalyptus tree in front garden
7	Drill-lime 61 holes	Besser blocks	Lawn front and back, no trees
8	Drill-lime 67 holes	Clay bricks	No large trees in garden
9	Drill-lime 216 holes	Besser blocks	
10	Drill-lime 208 holes	Clay bricks	
11	Drill-lime 203 holes	Clay bricks	Large eucalyptus tree in front garden
21	Drill-lime 240 holes	Clay bricks	
23	None	Besser blocks	Large eucalyptus tree on boundary nr. levelling Pt1
24	Lime-raft	Clay bricks	
26	None	Clay bricks	
29	None	Clay bricks	

4.2 Soil Moisture Beneath Floors

Gypsum blocks are now known to be a somewhat unreliable measure of in-situ suction. Nevertheless it is believed that the installations at Elizabeth East do indicate the general trend of soil drying beneath the timber floors. Readings have been consistent over the 16 years since construction, and have shown that all profiles have become drier except at houses No. 3 and 4, where the average soil suction has undergone little change. In general, drying out at the surface occurred soon after construction, and extended downwards over many years. By 1982, the soil 3.6 m below floor level had dried out very slightly.

4.3 Internal Levels

The water levelling points beneath internal floors have not proved to be completely successful. Some tubes became broken and a number were probably disturbed during levelling of floors by wedging up from the dwarf walls, for which no records have been kept. However, the points which appear to be working properly indicate that the internal dwarf walls have only settled by 10 to 20 mm with respect to the external footings.

4.4 Damage to Houses

The SAHT made regular inspections and kept records of defects in the houses for five years following construction. All houses had some damage, although in a few cases it only amounted to minor cornice cracking. By 1983, some houses (e.g. No. 11) had fairly severe cracking of external walls and significant damage to interior walls, but in no case was it necessary to carry out reconstruction. The most common repair jobs were patching interior walls and levelling timber floors by wedging up the joists.

4.5 Houses with Pier and Beam Footings

The 14 houses with pier and beam footings all underwent some vertical deformation, but the results are not reported in this paper due to interpretation difficulties. There were various construction problems, such as loose soil in pier holes, partial collapse of sides and water draining into pier holes before pouring concrete. Also the piers were cast in-situ with no attempt made to isolate them from the surrounding soil. Hence, it is not possible to relate measured displacements to soils data, or to draw any accurate conclusions. However, the fact that all pier and beam houses had some vertical movement is an indication that swelling or shrinking of the foundation soil occurred below the pier depth of 3.6 metres.

5 ANALYSIS OF DATA

5.1 Vertical Movement of Outer Walls

The movements plotted in Figure 2 show a wide variation of deformation patterns, especially considering that the houses are similar in size and design, and the soil profile is relatively uniform. Table II attempts to categorize the movements. One fairly obvious conclusion is that the houses on lime stabilized sites (Table I) moved as much or more than those on untreated sites, suggesting that the stabilization was either not deep enough or not effective in distributing the lime through the clay.

TABLE II

SUMMARY OF DEFORMATION PATTERNS

House No.	Pattern	Actual Deflection Ratio
11	Heave of short sides, total movement 50 mm. Brick walls severely cracked.	$\frac{1}{300}$
1,23	T shaped houses with settlement of one leg. Hogging at re-entrant corner	$\frac{1}{930}$
2,6,7,21, 24,26,29.	Overall twisting deformation. External walls generally with negligible bending deflection.	$\frac{1}{1000}$ max.
3,4,5,8, 9,10.	Houses stable, or experienced planar tilting.	$\frac{1}{1500}$ or less

5.2 Vertical Movement of Internal Walls

The gypsum block installations indicated soil drying to 3.6 metres beneath the interior of most houses, suggesting vertical shrinkage.

The water level points suggest that the internal dwarf walls have settled by 10-20 mm with respect

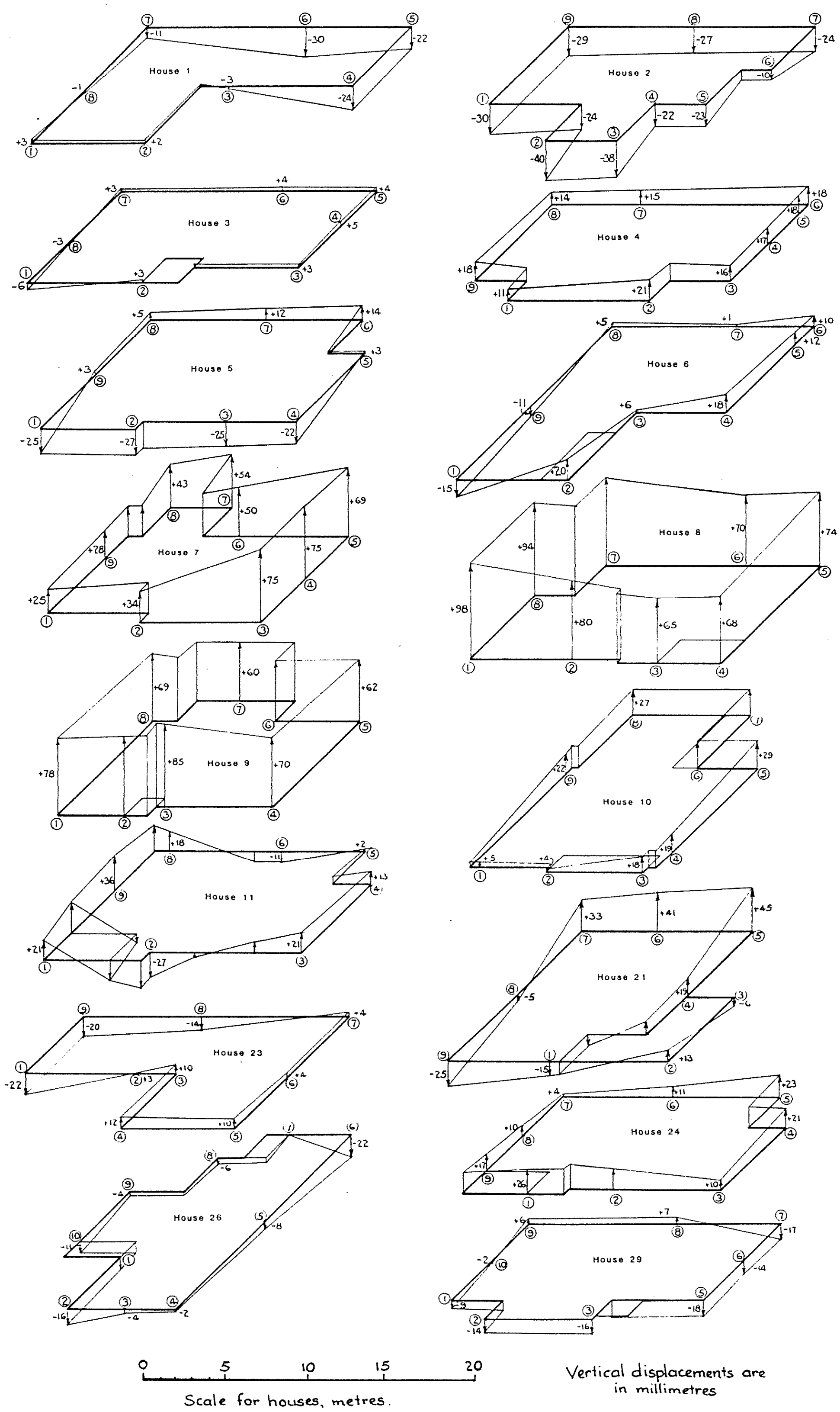

Figure 2 - Vertical Movements of External Walls

to the outer walls. Thus, for houses with large heaves, i.e. No. 7, 8 and 9, the dwarf walls have heaved by up to 80 mm, even though the soil just below them has dried out. It is concluded that the large heaves have deep-seated origins and are due either to wetting up of the very reactive clay from 4 to 12 metres in depth, or to a slow geological movement. If the latter is true, house No. 11 may be on a discontinuity in the underlying outwash plain material.

5.3 Comparison with Current Design Methods

The methods being used in Adelaide at present for the design of footings on reactive clay sites are those proposed by Walsh (1978) and Mitchell (1979). Each assumes deformations of the soil surface due to centre heave or edge heave in the long and short directions of a rectangular footing. The magnitude of soil movement that would normally be assumed at Elizabeth East is approximately 70 mm.

From Figure 2 and Table II, only one of the 16 houses has deformed in an edge heave pattern, i.e. No. 11 which has a differential movement of 50 mm. Two houses, Nos. 1 and 23 have a hogging shape, probably due to settlement caused by trees. Seven houses have twisting type deformations which have resulted in cracking, even though the external walls have little bending deflection. The remaining 6 houses have undergone planar displacement with differential movements much smaller than current design values.

6 CONCLUSIONS

From the results of the Elizabeth East study, the following conclusions may be drawn :

(a) The vertical movement of external footings and walls of houses on expansive clays may have many different patterns, and is virtually impossible to predict. The reason is that significant variations of soil moisture content occur around the perimeter of houses due to domestic activities such as gardening.

(b) Only one house (No. 11) had a deformation pattern similar to those assumed by the Walsh and Mitchell methods of design. This was the most severely distorted house of the 16 in the study. Current design methods may be viewed as assuming the worst soil movement that <u>might</u> occur rather than what <u>will</u> occur at each house.

(c) Twisting, or non-planar deformation of the external footings, occurred in seven of the 16 cases. The outer walls had only small bending deflections along their length. Twisting may be regarded as being caused by a doming of the soil surface beneath the house, in which the axis of the dome is not aligned with the external walls.

(d) It may be inferred that the stiff grillage and stiffened slab house footings now in common use often function to resist twisting deformations rather than the bending deformations which are the basis of design.

(e) A high proportion of the houses in the study had distortions smaller than assumed by current design methods. The present philosophy of design is to consider the worst case of soil movement that can be foreseen. Clearly footings designed on this basis will be larger and more expensive than necessary for many houses. As more field records become available, an investigation of footing strength versus probability of failure appears worthwhile.

(f) The centres of houses with timber floors undergo settlement with respect to the external walls due to soil shrinkage. The depth of drying out appears to be at least 3.6 metres.

(g) Although the deformations observed are not generally similar to those assumed by the currently used Walsh and Mitchell methods of design, it is apparent that footings designed by these methods would cope with the actual movements for all of the 16 houses.

7 REFERENCES

MITCHELL, P.W. (1979). The Structural Analysis of Footings on Expansive Soil. <u>K.W.G. Smith and Associates</u> Research Report No. 1.

WALSH, P.F. (1978). The Analysis of Stiffened Rafts on Expansive Clays. <u>CSIRO Division of Building Research</u> Technical Paper No. 23.