Case Study of an Investigation of a Damaged House in Brisbane, Australia

D.Lopes
Dip. Geology (R.M.I.T.)
M.Eng (S.U.T.) Aus.I.M.M.

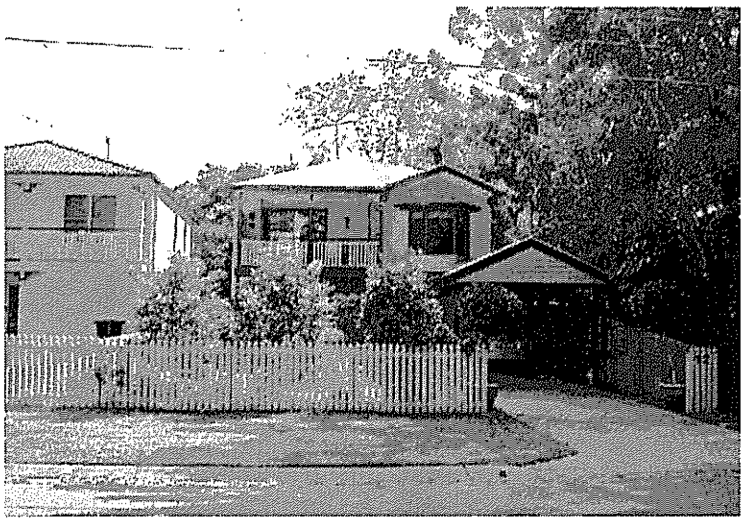
B.Hargreaves
Dip. Geology (B.I.T.)
Affil.I.E.(Aust)

Summary The growth and removal of trees or pre-existing structures causes ground movements in reactive clay profiles by changing the clay moisture content. This paper presents results of a case study carried out on a house constructed partly on an old demolished house site, which has had tree removed prior to construction on one side and continued tree growth on the opposite side. The investigation process included a desk top research of the geology, aerial photos prior and post-construction, 4 drill holes with sampling, Atterberg, Shrink/Swell and moisture tests and floor level readings. The results show the amount of movement, which can occur once a well-watered garden is established over a previously drier soil profile. The Site Classification method by the original investigator (AS2870-1996) and the likely changes to the designing assumptions are discussed. Soil parameters and the effects of prior and remaining trees is determined and recommendations made to prevent or reduce further wall and floor movement.

INTRODUCTION

A local geotechnical company was commissioned to determine the possible cause(s) of brickwork and plaster damage of a 6 year old, 2 storey town house in a Western suburb of Brisbane.and recommend appropriate remedial measures. They reported that their investigation was somewhat limited by an uncooperative owner.

The rainfall records show that the months preceding footing construction were abnormally *dry* followed by 3 months of above average rainfall and then generally drier than normal up to the time of testing. Field and laboratory tests show that the soil profiles consisted of deep high plasticity clays and that the initial investigator's predicted ground movement was underestimated. This case is further complicated by the changes in house footprints and a row of trees growing alongside one of the house walls. Floor levels and the shape of the wall cracks prove very useful in determining the problem. Soil moistures and Atterberg values help explain the mechanism of ground movement.



House under investigation (to the right) Remaining allotment with new house to the left

SITE HISTORY & DESCRIPTION

Recent History

This site is a narrow but deep low-lying, allotment, which slopes very gently to the East and is flood-prone. It is common practice for local geotechnical investigators to use a Climate Category 1 for the Brisbane area. On closer inspection of the C.S.R.I.O. Thornthwaite Index map the Brisbane C.B.D. and its western suburbs are shown in Climate Category 2. As per AS2870. the seasonal moisture variation (Hs) for Climate Category 1 is taken as 1.5 metre whereas in Climate Category 2 it is 1.8 metre.

Prior to 1997, this site (No 17) and the adjoining property to the West (No 19) were one allotment with an older style timber dwelling with a raised timber floor, straddling both allotments. There were numerous trees, some of which were >15 metre high. (Appendix 1). The new house construction began in April 1997 while the house on No 17 was commenced 3 months later. The "platform" for the town house in question has been built up to its boundary with No 15. During this development, some trees were removed, however some of the trees still remain at the rear of both No 17 and very close to its common boundary with No 15.

In No 17 there has been extensive landscaping with paths, small gardens, lawns and outdoor entertaining areas. The front garden has a lush lawn growth and an extensive system of automatic garden sprinklers. The gardens in the adjoining properties to either side appear to be less well watered.

Construction History

Original Site Classification.

A local geotechnical and engineering company carried out a "Classification" and provided a beam and slab design to meet the requirements of AS2870-1996. In a report, dated 24/7/1997, they classified this site as Class H with a "y_s" of 50-60 mm. The supporting information for this conclusion appears to be as follows:

- 2 boreholes along the East side of the old existing property.
- The proposed earthworks in the "Site Preparation Details".
- A Linear Shrinkage test as per AS1289 (20.5%)
- A site sketch showing the positions of the pre-existing house, garage and trees.

Original Footing Design.

- The footing system is a combination of a grid of beams and a footing slab poured independently.
- The edge beam has an effective depth of 550 mm.
- The internal beams are at a maximum grid spacing of 3 metre and also with an effective depth of 550 mm.
- The slab is reinforced with F82 slab mesh (top) and the beams with a row of 3 bar F12TM in the bottom.
- The slab and footings are tied together with cranked Y12 bars at 1,000 mm spacing.
- The design allowed for a 600 mm maximum of fill under the slab to lift the floor above Flood level.
- The slab was to be supported on piers, which were founded in the natural *"firm Silty Clay"*. (Appendix 2)

Footing Inspections

The documentation shows that inspections were made by the original engineering company as follows :

- 29/10/1997 Perimeter footings/pier preparations
- 17/11/1997 Slab on Footings and non structural slab preparations.
- 17/11/1997 4 Pad Footing excavations.

Investigation by 2nd Geotechnical Company

This consisted of the following :

-- Study of monthly rainfall records from the nearest Bureau of Meterology station.(not presented here)
-- Drilling of 3 bore holes (2/4/2003) drilled to a depth of 4 metre. (Appendix 1 and 4)
-- 13 grab samples were collected and tested for their moisture content values.
-- 9 grab samples representative of the soil types were selected and were tested for their Atterberg Values.
-- The Soil moisture values were compared with the Plastic Limit.
-- 6 grab samples we also selected and tested for their shrink/swell (Iss) parameters Instability Indeces (Ipt)
-- A series of floor levels (corrected for coverings and step-down) were taken with a water level. (Appendix 2)
-- Photos of noticeable wall cracks and surrounding trees were taken (not presented here).
-- Aerial photos taken in 1981, 1994, 2001 and 2002 showing the old house and tree locations (not shown here)
-- Glass slides were placed over the accessible external brickwork cracks to determine any future movement.

FINDINGS

Observations

Due to the slight West to East slope the depth of the introduced fill on the East side was 850 mm, thus creating an effective beam depth of 1,150 mm along the whole of the East wall.

The site sketch by the original investigators shows the trees, which were removed prior to construction and the position of the old house. The second investigators plotted the remaining trees and identified most of the larger ones. (Refer Appendix 1) In particular, a 20 metre high Hoop Pine was noted near the centre of the East wall of the house; also a group of Lillypilly trees near the North East corner of the rear patio. Other large trees are still growing near the rear boundary.

In early 2002 the owner complained of wall cracks to the builder who then commissioned a second geotechnical company to investigate in April 2003. During this inspection the distress noted is as follows :

External

There a number of cracks varying from 2 mm– 5 mm in the Western half of the front wall and Southern half of the West wall i.e. within 5 metre of the South West corner of the house. There is also a 2 mm crack near the North East corner of the house.

Internal

The wall cracks internally are less severe than the outside cracks and only appear near the South West corner of the house. They are all diagonal and above the front window corners.

This degree of damage is Categorized as 2 (AS2870). The largest crack is up to 5 mm and is on the Southern side of the exterior West wall. Most of the cracks are larger in the ground floor. 2-5 mm window/wall gaps were also noted at the base of the lower windows in the front wall. (Refer Appendix 1)

The floor levels show a differential of 50 mm from the North East corner to the South West corner with the sharpest change occurring closer to the South West corner. (Refer Appendix 2)

Site Investigation.

The soil geology consists of alluvial, high plasticity clays derived from the weathering and erosion of Tertiary age basalt.

The monthly rainfall figures between September 1997 (commencement of construction) and April 2003 show :
-- The first 9 months in 1997 were particularly *dry* (498 mm rainfall compared with a mean of 744 mm)
-- The last 3 months in 1997 (during construction) were slightly wetter than the mean. (400 mm/330 mm)
-- In the 3 months prior to the recent investigation the rainfall was 290 mm compared to a mean of 383 mm.

No water table was encountered during testing. The soil profile encountered is recorded on the attached log section. On the West side of the house in question the sub-floor build-up was 850 mm above the original ground level.

Laboratory Testing:

Table 1 -- Shrink/Swell Results (Iss)

		SWELL TEST			SHRINK TEST			
Test Site	Depth (mm)	"Initial Moisture	Final Moisture	Swell	Initial Moisture	Final Moisture	Shrinkage	Iss
1	500--800	28.8%	31.4%	0.04%	30.4%	0	7.6%	4.2%
1	1500-1800	24.1%	30.9%	8.0%	24.0%	0	4.8%	4.9%
1	2000-2300	23.3%	30.6%	9.0%	22.8%	0	5.9%	5.8%
2	500--800	24.8%	28.7%	1.5%	21.2%	0	0.9%	1.1%
2	1000-1300	26.6%	35.2%	4.9%	26.4%	0	6.5%	5.0%
2	2000-2300	23.6%	28.9%	2.4%	26.4%	0	9.3%	5.8%
					(Excluding	the 1.1%)	*Average:*	5.14%

Interpretation of Soil Moisture/Atterberg Values

The Atterberg Limits and soil moisture results are plotted and discussed. Of particular interest is the comparison of the in-situ moisture values with the soil Plastic Limit. Most road engineers accept that sub-grades in Wet Temperate-Sub-Tropical climates under a sealed cover, such as a concrete slab-on-ground or pavements, should be at their Plastic Limit moisture. The soil below the seasonal moisture variation depth should be approximately 2% - 6% above the Plastic Limit. (The higher difference occurring in the more plastic clays). The writers have assumed that where in-situ moisture exceed these values the soil is "Abnormally Wet" and where they are >2%-4% below the Plastic Limit they are "AbnormallyDry".

Table 2 -- Comparison of Moisture and Atterberg Limits

Test Site	Depth	In-situ Moisture	Liquid Limit	Plastic Limit	Plasticity Index	In-situ Moisture Vs Plastic Limits	Linear Shrinkage
1	500 mm	25.6%	54%	23%	31	2.6%>P.L.	14.8%
1	1000 mm	28.7%	94%	22%	72	6.7% >> P.L.	24.1%
1	1500 mm	26.3%	89%	23%	66	3.3% > P.L.	23.2%
1	2000 mm	23.5%	Similar	"	"	~ P.L.	
1	2500 mm	27.0%	Atterberg	"	"	> P.L.	
1	3000 mm	25.0%	Values	"	"	> P.L.	
1	4000 mm	24.5%	Expected	"	"	> P.L.	
2	500 mm	21.3%	45%	21%	24%	2.7% < P.L.	%
2	1000 mm	31.3%	83%	22%	61%	9.3% >> P.L.	%
2	1500mm	28.3%	85%	23%	62%	5.3% > P.L.	%
3	500 mm	28.8%	59%	21%	38%	7.8%>>P.L.	16.8%
3	1000 mm	33.2%	90%	22%	68%	11.2%>>P.L.	22.4%
3	1500 mm	31.0%	90%	22%	68%	9.0%>>P.L.	22.7%

The above values show that the soil profile in T.S. 1 is, on average slightly, wetter than the Plastic Limit and within the range of "Normal" moisture condition. From a depth of 500 mm – 1,000 mm it is and average of 5% above P.L. The soil in T.S. 2 the clay at the same depth range is somewhat wetter, being an average of 7.3% above P.L. In T.S. 3 the Clay at the same depth range 10.1% above the P.L. These latter two profiles are considered "Abnormally Wet".

Slab Floor Levels

Although there is no certainty that the floor was poured level, there is a clear trend that the South West corner has heaved. (up to 50 mm?). The East wall is almost level. The back (North wall) rises 15 mm to the West. The front (South wall) is 42 mm higher at the South West corner and the West wall is 35 mm higher to the South with most of this change occurring within 5 metre of the South West corner. (Refer Appendix2).

CONCLUSIONS

The design is a footing slab on piers with reinforced perimeter brickwork approved by a qualified and registered engineer. The pier positions appear to be unrelated to the slab beams.
The Iss, Atterberg and Linear Shrinkage results, all show that the clay profile is more "reactive" with increasing depth. The soil profile can be divided into 3 layers for simplicity.

In Layer 1, 0-1000mm - Iss = 4%, Layer 2, 1000-2000mm - Iss = 5%, Layer 3, 2000-3000mm - Iss = 6%

If these Iss and a Climate Zone 1 (Hs = 1500 mm) are used, the calculated "y_s" is in the range of 40-50 mm. If the correct a Climate Zone of 2 is used (Hs = 1800 mm) the calculated "y_s" is in the range of 50-60 mm.
If the reactive depth is deepened to 3000 mm to allow for the tree effects, the "y_s" is in the range of 90-100 mm

The original Classification was "H" and "y_s" value range quoted are 50 to 60 mm however this site should have been classified as "P" due to the presence and part removal of affecting trees. ("Abnormal Moisture" condition as per Clause 1.3.3, AS 2870-1996).

The moistures confirm the observation of a well-watered front garden. The Atterberg tests confirm a moderately high expansive clay to a depth of 500 mm followed by a very high expansive clay.

The "Abnormal Moisture" condition has been caused by the following :
-- The abnormally dry weather conditions in the months preceding the footing construction.
-- The differential drying of the on-site soils due to the growth of the original large trees.
-- The differential drying of the ventilated sub-floor area under the old house.
-- The differential in the footprint of the old house compared with the new town house.
-- The new soil cover of the new footings.
-- The retention of large trees in the adjoining property to the East.
-- The exposure of new ground to the weather.
-- The extensive watering by an automatic garden sprinkler system in the front garden.

Clause 1.3.3 of AS 2870-1996 places the footing designer in a position where he must design a footing system by "engineering principles". It is generally accepted that the full implications are "beyond current knowledge" and the standard does not provide any "Deemed to Comply" designs to cope with the conditions on this site. AS2870 warns that the impact of the trees must be considered and that the normal classifications of A to E may not be applicable. At the time of construction there was ample documentation available to indicate that trees can dry the soil profile well beyond the normal depth of seasonal moisture variation.

From the evidence provided, the original geotechnical company did not appear to have allowed sufficiently for the tree effects. A Class H design can only cope with a "y_s" up to 70 mm.

The slab appears to be designed as fully suspended on shallow piers, which are strangely located (Appendix 2). Apparently, the piers were to penetrate the old and new fill. In no way could these piers be expected to restrain a slab from any uplift since they are shallow and have no connection between the piers and the slab.

Clearly the extensive watering of the front garden (where a tree was removed) has mobilized the deeper clay "reactivity" and caused the heave in the South West corner of the house. In effect the new owner has created a new "Abnormal Moisture" condition by over-watering an area that was previously dried by a significant tree.

RECOMMENDATIONS

The remedial measures recommended were as follows:
(1) Greatly reduce the watering in the front garden.
(2) Wait for the soil moisture to stabilize (this may take many years).
(3) Monitor the floor and wall levels for 2- 3 years to establish when the floor ceases to heave.
(4) It is preferable not to fill any cracks until the monitoring period is complete however if the owner requires cracks to be filled earlier, compressible and flexible material should be used.

REFERENCES

Aitchson G.D., Richards B.G. (1965). *"Moisture Equilibria and Moisture Changes in Soils beneath Covered Areas".*

Australian Standard 2870-(1996) *"Residential Slabs & Footings"*

Australian Standard 3798-(1996) *"Guidelines on Earthworks for Commercial and Residential Developments"*

Cameron D.A., Earl I. (1982) *"Trees and Houses: A question of Function"* -- Cement & Concrete Association.

Fityus S.G. (1996) *"The Effects of Initial Moisture Content and Remoulding on the Shrink-Swell Index Iss"*, 7th Australian, New Zealand conference on Geomechanics.

Smith R.L. (1993) *"Estimating Soil Movements in New Areas".* Australian Geomechanics Society -- Seminar,

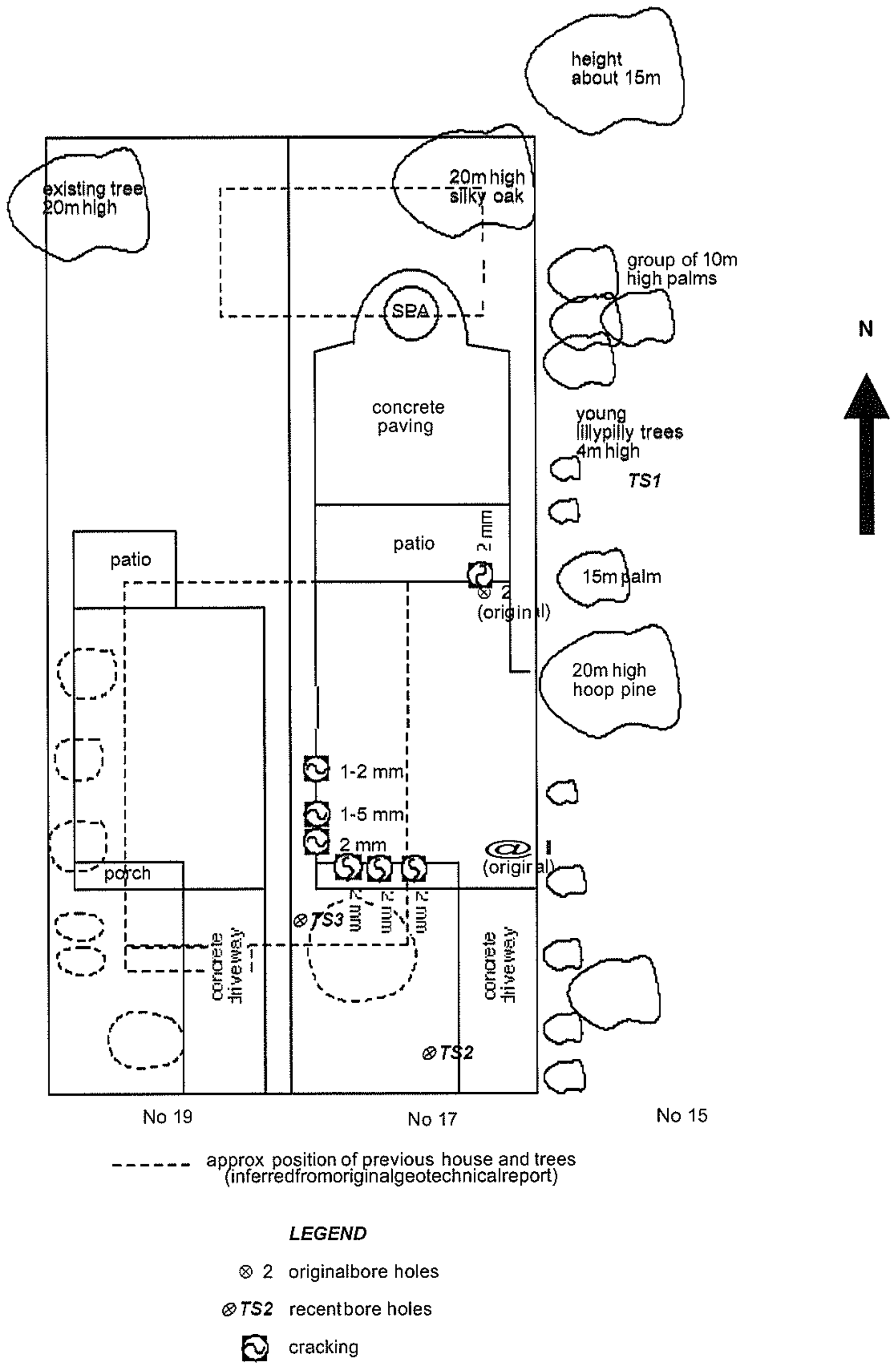
Walsh P. and Cameron D.– (1997) *"The Design of Residential Slabs and Footings"*

C.S.I.R. O. (revised August 1996) "Improving the Built Environment Information Sheet No 10-91

C.S.I.R.O,- (1996) *"Guidelines to Home Owners on Foundation Maintenance and Footing Performance.*

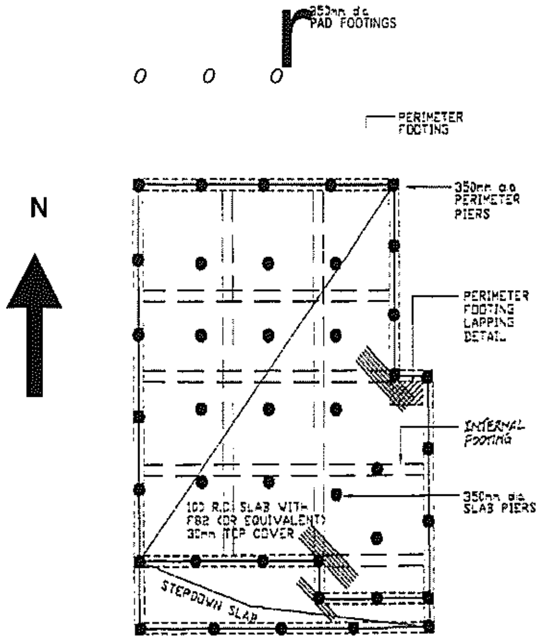
APPENDIX 1

New & Old Houses



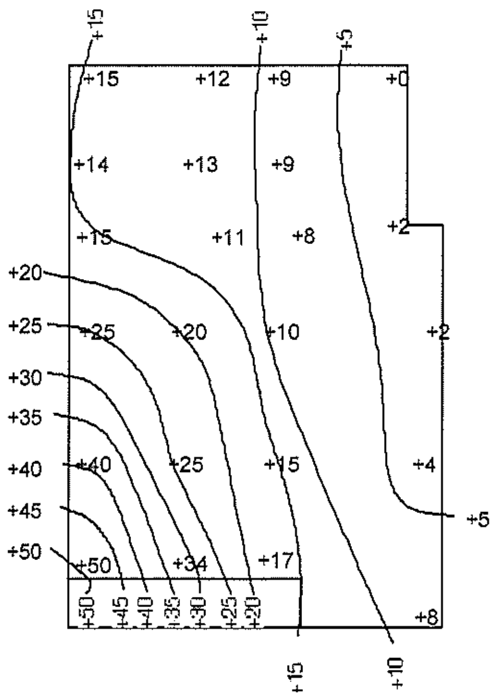
APPENDIX 2

Slab and Pier Design



APPENDIX 3

Relative Floor Levels



APPENDIX 4

Log Sections

TEST SITE 1

Depth (mm)	Description	Fill
0-300	FILL – silty clay, orange brown/grey Moist, with sand & gravels. "Uncontrolled' compaction	
300-4000	SILTY CLAY (CH) brown/orange Moist & stiff, grading to grey/orange Fine tree roots to depth of 2100 mm	
	END TEST SITE	

TEST SITE 2

Depth (mm)	Description	Fill
0-300	FILL – sandy silt, moist, brown Minor gravels "Uncontrolled, compaction	
300-4000	SILTY CLAY (CH) brown/orange With minor rounded gravels. Grading to grey orange colour. Moist & very stiff Grey – due to carbonate content at 3400 mm onwards.	
	END TEST SITE	

TEST SITE 3

Depth (mm)	Description	Fill
0-300 300-500	FILL- silty sand, brown, moist "uncontrolled" compaction FILL – silty clay orange/brown/grey With sand & gravels. Moist and "uncontrolled" compaction	
500-4000	SILTY CLAY (CH) with minor rounded gravels. Brown Very moist & stiff Gravels at 800mm Fine roots to 2,100 mm Grading to grey colour due to carbonate content at 3,500 mm	
	END TEST SITE	