1977/35. House damage in the Taroona area.

C.J. Knights

Abstract

Expansive clay, combined with change of moisture content and inadequate foundations is the major cause of house damage in the area studied. Less commonly, damage may be caused by dispersion and settlement of the clays, by consolidation of peaty layers, or through landslip.

Moderate to extensive structural damage is common in this area, where most houses have been constructed on footing foundations. Most of the damaged houses are situated on brown or black clay. The brown clay is very plastic with PI = 58-84% and the clay-silt size fraction is comprised of over 60% montmorillonite. Expansion pressure is known to be well over 255.5 kPa which can easily lift a house. Volumetric expansion is 0.8-1% volume change for each 1% of moisture content.

In the cited case studies damage was facilitated by the following causes: Localised soil drying by shrubs and trees, drying by installation of drains, soil drying combined with matting of tree roots, change of water regime through upslope housing development, broken service pipes producing localised wetting, seasonal moisture variations in situations exposed to the weather.

General recommendations for the construction and maintenance of buildings in this area are included.

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House damage is very common in the Taroona area and ranges from minor structural cracks to major distortion of buildings, which require extensive underpinning and strengthening to make them habitable. In many instances serious disruption does not commence until many years after construction.

The area dealt with during this survey lies between Flinders Esplanade and the Channel Highway, including Norwood Avenue, Belhaven Avenue and Meath Avenue. Of the houses in this zone 46 show no structural damage, 22 exhibit light structural damage, and 15 have had major damage requiring extensive and expensive repair work.

The basic cause of the damage lies in the nature of the underlying subsoil, and in the house foundations, which are often inadequate for these soils. The situation is either eased or worsened by location variations in the sediments, by drainage conditions and by the location of paths, gardens, trees etc. For any particular house the mode of damage tends to be complex so that it is difficult to determine the specific factors involved.

NATURE OF THE UNDERLYING SEDIMENTS

The sediments consist mainly of plastic clay, but there is also silt, sand, volcanic tuff, boulder beds and peaty soil. There are rapid variations from one material type to another, so that a house may have one side situated on sandy tuff, and the other side on many metres of plastic clay.

Rapid lateral variation indicates a sedimentary environment where there were periods of active channel erosion followed by infilling.

The sediments may be divided into three types which may reflect a real age difference in their origin.

Type 1. Mixed layered clay with tuff, silt and sand which can be seen cropping out in cliffs to the north of the Taroona High School, where they dip to the south-west. Variously coloured clay, often green-grey, yellow or brown occurs in layers which range from thin laminae to beds several metres thick. The clay is smooth and very plastic. The interlayered tuff and sand appears to be tough and dry *in situ,* however when it is worked with water it becomes plastic.

Quartz pebbles commonly occur, also mineral veins and ironstone bands. These indicate that the sediments are derived from both the dolerite and the Permian rocks which crop out upslope. In a number of places Type 1 underlies Types 2 and 3, indicating that it is older. Type 1 material does not reach the surface in the area surveyed.

Type 2. An apparently homogeneous, brown clay underlies much of the area, in some places as a layer less than one metre thick, but in others it has been proved to 10 m, and may be much thicker. The clay is chocolate brown with white flecks but although it appears to be homogeneous and unlayered there are variations in quartz sand content and in plasticity.

Type 3. Black clay is present in localised patches, and was only seen in the top 1-2 m. The black colour is probably due to the large amount of organic material which it contains.

GEOTECHNICAL PROPERTIES AND COMPOSITION OF THE CLAYS

For explanation of symbols see Appendix 3.

Composition

Clays of Types 1, 2 and 3 have 60-90% of particles less than 20 µm in size. These fine particles are composed of quartz and clay minerals, montmorillonite being the dominant clay mineral.

Details of the composition as determined by X-ray diffraction are given in Appendix 2.

Atterberg limits

Atterberg limits were determined for eight samples (Table 1). These show the general range of plasticity present in the sediments, and in particular points out the variation in material properties in the visually similar brown clay, (Type 2). A high plasticity index and a high linear shrinkage are both indicators of expansive clay.

Dispersion

Samples of the brown clay (Type 2) showed moderate dispersion in the Emerson crumb test. Samples of the black clay showed slight dispersion. During a test for expansion potential on a sample of brown clay from Hole P8 a noticeable amount of the sample escaped from its container through joints and pin-holes into the water tray. This occurred during a period of 10-12 days, and again indicates that this clay is dispersive.

Expansion pressure

Expansion pressure is the uplift pressure exerted by the clay when it is wetted.

One successful test was carried out on Sample 3 from Hole P8. During the test, water was allowed access through porous plates, and weights were added to load the sample and keep its height within 0.05 mm of the starting height. The test was taken to the maximum available load of 255.5 kPa (5340 lbf/ft^2). At this load expansion still took place.

Potential volume expansion

Tests for potential expansion under a small load were undertaken on two samples of brown clay (Type 2) from Hole P8.

Results

Sample 2 from a depth of 850 mm, at natural density.

An expansion pressure test was started, then abandoned at a load of 138 kPa. Whilst under this load the sample expanded by 0.3 mm before it was unloaded. The sample was unloaded and allowed to swell for 6 days (fig. 1).

Initial height 25 mm	Initial m 35%
Final height 27.03 mm	Final m 45.8%
	Total swell 8.2%

A small seating load of 6.9 kPa was applied throughout.

Table 1. ATTERBERG LIMITS OF CLAY SAMPLES FROM TAROONA

Material	Location		LL	PI	LS
Brown plastic clay	Hole P14	1.8-2.7 m	71	58	25
Brown plastic clay	Hole P11	1.1 m	103	84	27
Dark brown plastic clay	High school playing fields	0.8 m	96	78	25
Black organic clay	High school playing fields	1.5 m	65	45	19.5
Black organic clay	Hole P9	0.8 m	83	65	26.5
Grey, light sandy clay	Hole P5	5.4-6.3 m	51	38	14
Lithic sand (tuff)	Hole P18	2.7 m	83	55	-

Atterberg limits by Department of Construction, soil testing laboratory.

Sample 3 (undisturbed, air dried) from a depth of 800 mm was loaded during the expansion pressure test to 255.5 kPa, it expanded by 0.32 mm before it was unloaded. The test was undertaken in three stages (fig. 1).

(*a*) Unloaded at $t = 0$ to a load of 72.5 kPa and allowed to swell for 24 hours. The expansion was 3.8%.

(*b*) Unloaded to 45.2 kPa and allowed to swell for 24 hours. The expansion was 2.4%.

(*c*) Unloaded to 6.9 kPa and allowed to swell. After 24 hours the expansion was 4.6%.

Swelling was allowed to continue for 10 days:

Initial height 25 mm	Initial m 24.4%
Final height 28.575 mm	Final m 45%
	Total expansion 19.2%

For both tests a standard 60 x 60 mm shear box container was used, with porous plates at top and bottom.

Consolidation

A sample of brown clay (Type 2) from Hole P8 at a depth of 800 mm was tested. The test was undertaken in a 60 x 60 mm shear box container and is therefore non standard.

The graph (fig. 2) shows that this clay is normally consolidated, with a small preconsolidation equivalent to about 3 m of overburden. m_v = 0.435 x 10^{-3} (kPa). Therefore a double brick dwelling with 0.5 m wide foundations is unlikely to settle more than 4 mm.

During the site investigation for the Wrest Point Casino at Sandy Bay, consolidation tests were undertaken by Foundation Engineering Pty Ltd, on Type 1 material. These tests also showed no overconsolidation. The highest consolidation recorded by the engineers was from a sample of stiff grey fissured clay from 0.27 m with (m_v = 0.109 x 10^{-3} kPa).

Black clay (Type 3) contains organic material, sometimes as peaty layers up to 10 mm thick. A sample of this material from Hole P9 at a depth of one metre was compressed under a load of 136 kPa (2840 lbf/ft^2) and in four days had decreased in volume by 8%. Brick houses constructed on this material may suffer unacceptable settlement.

Soil strength

Soil strengths were assessed using a Torvane *in situ*, and on undisturbed samples which were still in the sample tube. Undrained tests were also done in a shear box.

For brown clay (Type 2), peak strength determined by the vane method is generally 50-70 kPa. Residual strengths are in the range of 20-35 kPa, (Appendix 1). A sample of this material in saturated condition (m = 45%) was tested in the shear box. C_{qu} = 17.5 kPa (peak strength = residual strength).

Black clay (Type 3) has a lower peak strength than *in situ* brown clay. A sample from Hole P9 (depth one metre) has a vane strength of 35 kPa peak and 19.3 kPa residual (m = 44%). A similar sample tested in the shear box had C_p = 38 kPa C_r = 35 kPa.

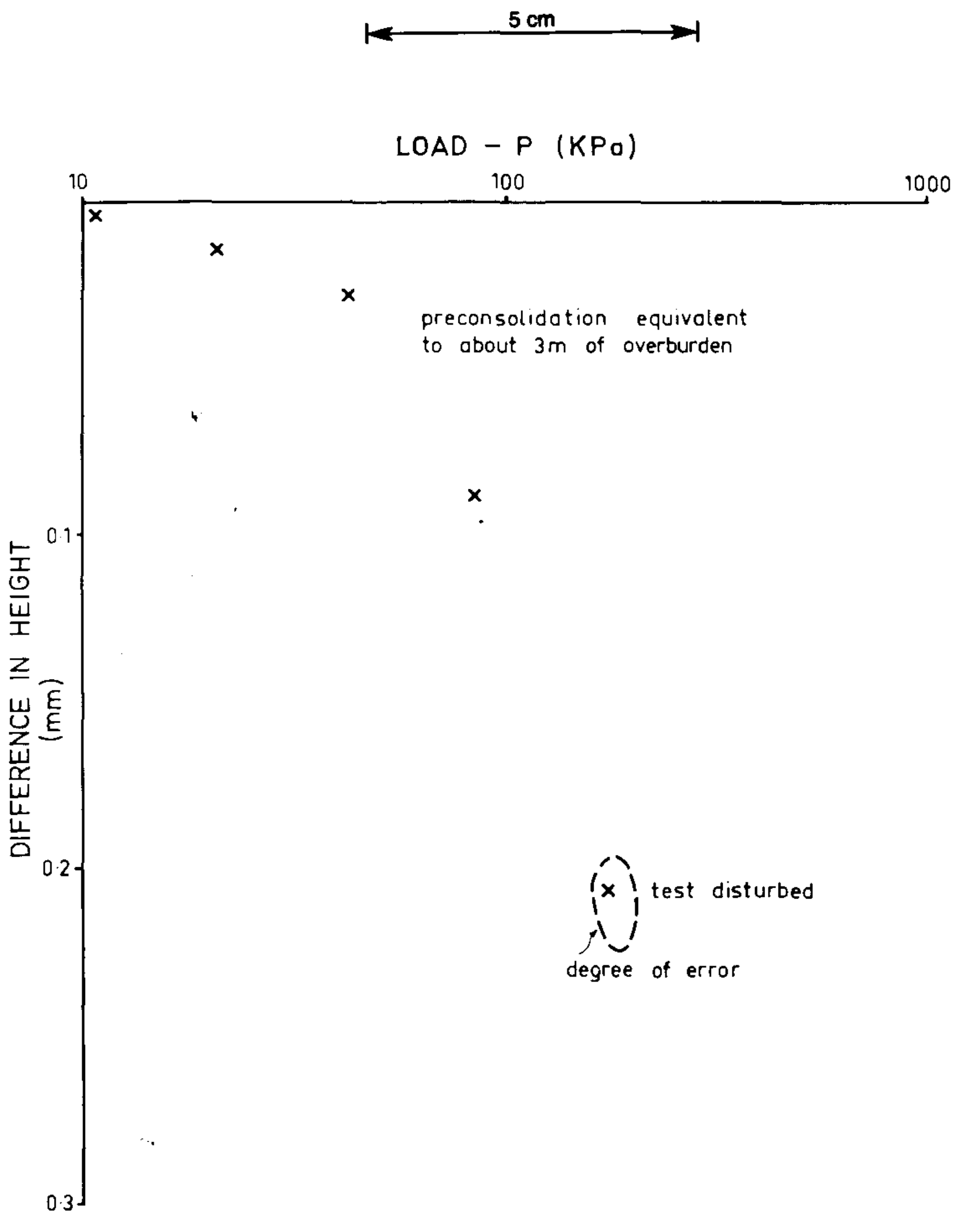


Figure 2. *Consolidation test on a sample of brown clay from 14 Norwood Avenue, Taroona. Sample from hole P8, depth 0.85 m.*

In view of the deep cracks which affect these soils in the summer it is appropriate to use residual strengths in assessing whether a near surface soil failure is likely to occur under load. Calculations for a double brick house exerting a pressure of 95 kPa (2000 lbf/ft^2) indicates that failure is unlikely to occur under normal conditions but may occur in exceptionally wet material.

Moisture content (see Appendix 1)

The moisture content of the clay varies between sites, between bore holes and within each soil profile. Variations depend on the drainage conditions, on depth below surface and on the clay composition.

The samples were taken in June, after there had been substantial rainfall, even so, particularly in unshaded positions, the top metre of clay is 4-9% dryer than the deeper material.

Clays from 4 and 6 Norwood Avenue are more moist than those from 116 Channel Highway. Also samples from the south side of the houses in Norwood Avenue are wetter than those from the north and east. As the effect of shading from the sun does not extend below about one metre, it appears that this part of Norwood Avenue is a particularly wet zone. There used to be a creek in this vicinity which has been piped, but there is probably still a seepage zone near the line of the old creek.

Samples of black clay from 17 Meath Avenue are very moist (m = 39-47%). This site is known to have contained a pond before it was developed.

Summary of geotechnical information

The clays contain a high proportion of montmorillonite which is a well known expansive mineral.

The clays have a high plasticity.

Black clays contain organic particles and peaty layers.

Brown clays are dispersive in water.

The expansion pressure of the brown clays is known to be greater than 255.5 kPa (5340 lbf/ft^2).

Expansion takes place readily under a load of 72.5 kPa which is adequate to lift a house.

Volumetric expansion is in the range of 0.8-1% for a 1% increase in moisture content. Therefore an increase in moisture of 10% beneath a building with footings to 0.5 m depth which has a subsoil dried to a depth of one metre, may cause the building to lift 50 mm.

Under load from a normal dwelling the brown clay is unlikely to consolidate sufficiently to cause damage. However the black clay contains compressible peaty layers which may cause difficulties.

Soil strengths are such that failures may occur in particularly soft locations under the load of a brick house.

The moisture content of the top metre of soil was 4-9% dryer than the deeper soil in June, and this difference would be greater in summer.

Average moisture content below one metre:

Channel Highway	m = 32%
Norwood Avenue	
N and E side of houses	m = 38.6%
S side of houses	m = 41.7%
15 Meath Avenue	m = 43.6%

MECHANISMS OF HOUSE DAMAGE

In the Taroona area the major cause of house damage is the alternate expansion and shrinkage of the clay subsoil due to wetting and drying.

Localised damage is caused by three minor mechanisms:

(1) Dispersion of clay particles may cause localised subsidence.

(2) Compression of peaty layers in the black soil may cause settlement under load.

(3) Clay failure can occur under concentrated loads, or where the subsoil is particularly wet.

Landslip damage also occurs and is discussed in Unpublished Report 1977/36.

Expansion-shrinkage of clays

When the moisture content of an expansive clay is increased, sufficient uplift pressure and volumetric expansion is produced to lift a house by several centimetres. Conversely, drying of the clay causes shrinkage and settlement. Most damage is caused by differential movement.

For any particular house it is difficult to determine the exact processes operating. Some of the processes and factors involved are:

Wetting of subsoil beneath the foundations. The moisture content will increase beneath footing foundations from the following causes:

(1) Alteration of drainage flow by the house being built.

(2) Concentration of water by downpipes or drains.

(3) Broken service pipes, possibly damaged by the seasonal change of the subsoil.

(4) Recessed gardens by house walls which become ponds in wet weather.

(5) A general rise in moisture content due to upslope activities.

(6) A particularly wet season.

Beneath a slab foundation the presence of the slab itself induces moisture migration beneath it, accompanied by heave.

Under differential loading, heave due to increased moisture will have differing effects, *e.g.* a more heavily loaded main wall will rise less than a connected porch, so that stresses are set up between the two.

Shrinkage of subsoil. Shrinkage is generally considered less likely to cause damage than is swell, however damage does occur.

Under well ventilated houses with footing foundations the soil becomes very dry and cracked which can cause the supporting piers beneath the house to lower, and lessen support to the structure.

Shrinkage beneath footings can be caused by the following:

(1) Change of groundwater conditions due to upslope activity.

(2) The installation of drains.

(3) Localised drying produced by transpiring trees and shrubs can be particularly damaging.

(4) Prolonged dry weather.

Seasonal swelling and shrinking

In several cases damage is restricted to the northern side of the house. When other causes have been accounted for, this suggests that the house is under stress from seasonal moisture changes at the edges of the foundations. One householder reported that seasonal changes effected the rise and fall of a pier under the centre of the house.

Dispersion of clays

At 4 and 6 Norwood Avenue ground settlement of several centimetres has been noticed in their gardens. As these sites have a wetter subsoil which may be associated with an old stream path, and as the clays from this site are dispersive, it is possible that the ground subsidence is caused by loss of subsoil by dispersion. Future workers in this area should note the presence of any tunnelling.

Consolidation and subsoil failure

If damage occurs to a brick house, situated on black peaty soil, then consolidation should be considered as a possible cause.

In several instances householders reported that part of their building 'sunk' after the ground around their house became wetter. In practice it is difficult to know whether one part of a building has settled, or another part has risen. However, if the reports of sinking are accurate, then clay failure may occasionally occur in particularly wet patches.

CASE STUDIES

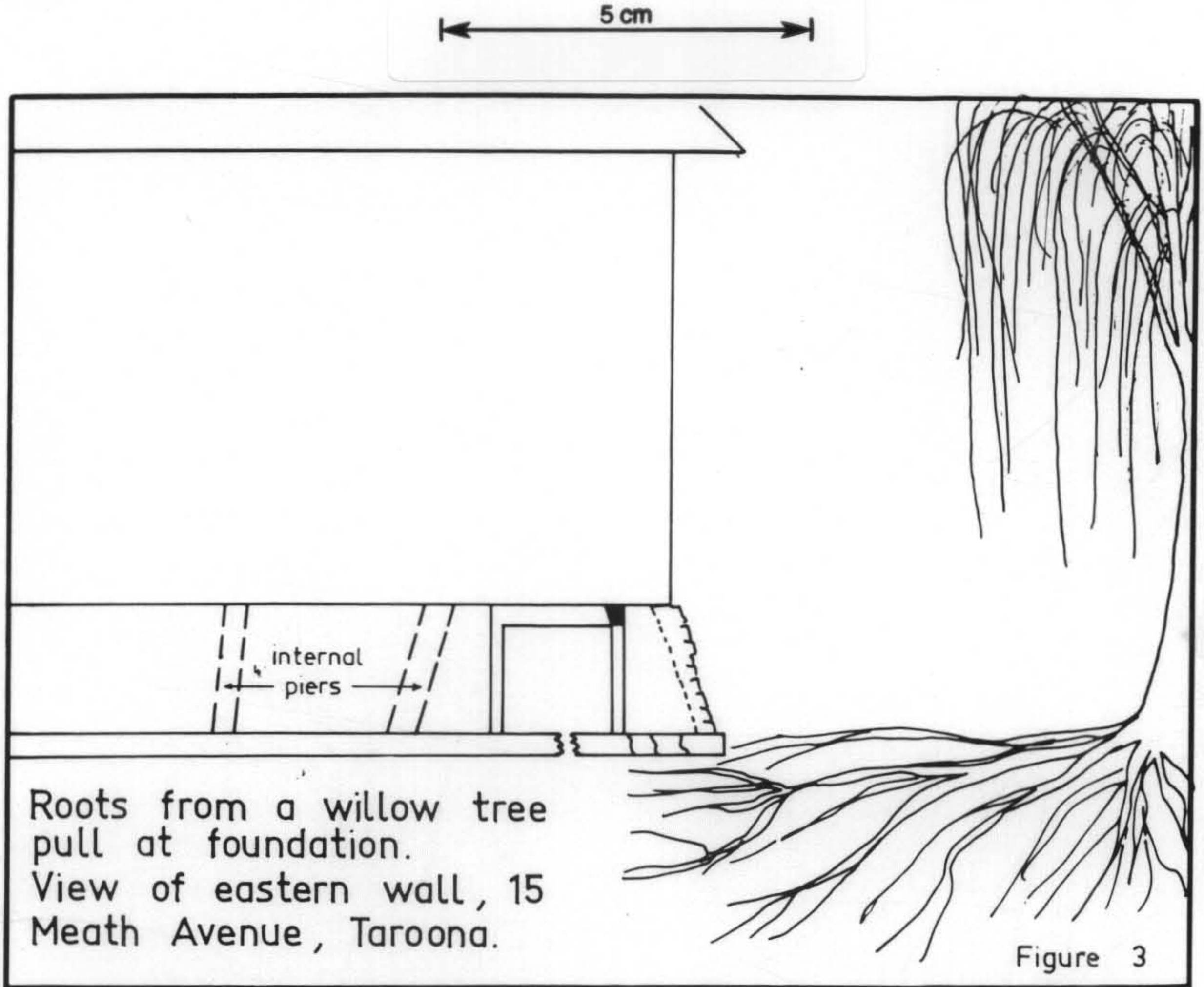
15 Meath Avenue. Effect of tree roots.

This weatherboard house has single brick foundation walls one metre high, founded on moist, black peaty clay (m = 38-44%). Serious damage commenced in 1973 and is restricted to the northern half of the house. It appears that the footings beneath the northern wall have been pulled outwards, away from the house, so that the foundation wall leans in towards the weatherboard above it (plate 1). On the east side of the north-east corner there is a hatchway leading under the house. Here the footings have an open crack several centimetres wide, and the top of the hatch is pulled apart by about 30 mm (plate 2), again suggesting that the northern foundations are being pulled away (fig. 3). Excavation of the corner footings show them to be 46 cm deep and 46 cm wide at the top, narrowing downwards. The internal piers tilt towards the damaged wall.

The mode of failure of this house is most unusual, as it seems that

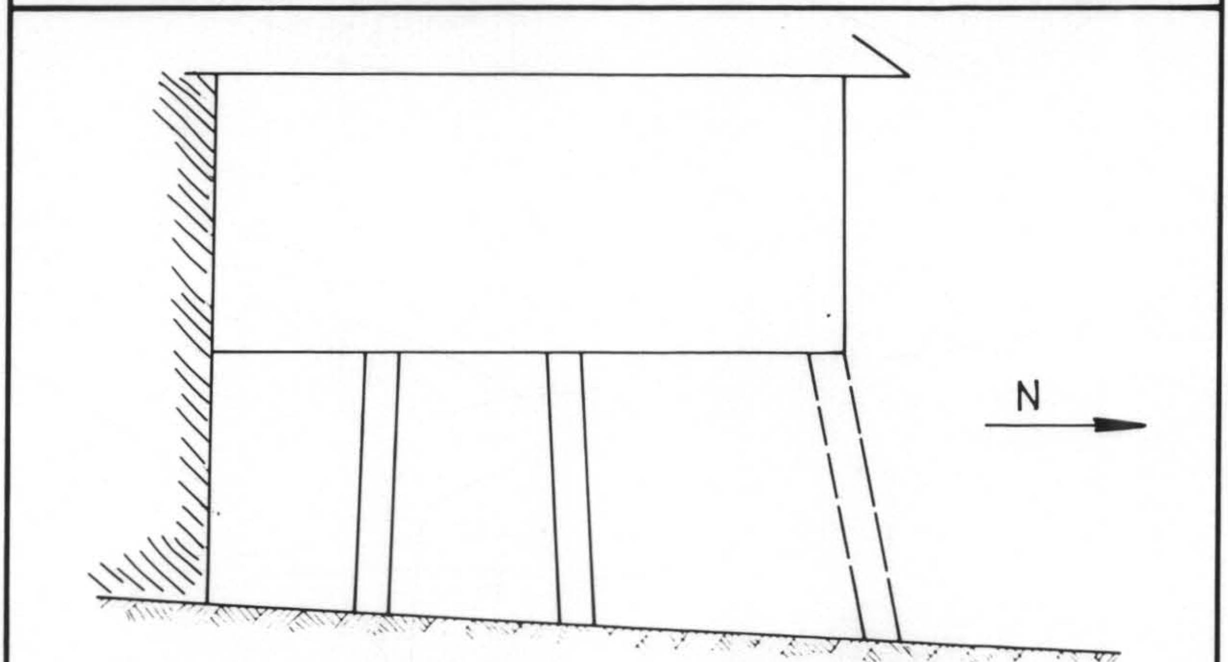
Plate 1. *15 Meath Avenue. View of northern wall. Footings have moved outward, causing wall to lean.*

Plate 2. *15 Meath Avenue. View of hatchway in eastern wall. Note tension crack in footing and separation of hatchway frame from brickwork.*



Roots from a willow tree pull at foundation. View of eastern wall, 15 Meath Avenue, Taroona.

Figure 3



Brick pillars beneath an extension are moved by seasonal moisture changes of the subsoil, 4 Belhaven Avenue, Taroona.

Figure 4

the foundation has been laterally moved outwards. In the front garden there is a large willow tree with roots extending to the house footings. Roots from this tree form a mat which interacts with the clay so that in summer suction by the roots causes dessication, but also the interwoven roots allow the whole front wall to be moved.

Apart from the action of the tree, the footings are insufficiently deep for an expansive clay area.

Although the subsoil is moist and compressive the light loads exerted by a weatherboard house are unlikely to cause difficulties.

2 Belhaven Avenue. Rise of groundwater.

This brick home, which is about 25 years old, is situated at the top of Belhaven Avenue, below the Channel Highway. For both this house, and for 3 Belhaven Avenue it is reported that damage commenced subsequent to the upslope development of Harrow Place in 1972 or 1973.

The building is founded on dark brown plastic clay containing large dolerite boulders. During foundation repair it was noted that part of the footing rests on a large boulder. The clays were reported to be quite wet.

There has been extensive structural damage to the house, which has been underpinned on two corners. The failure of the walls is reported to have taken place by bulging, and further cracking has occurred since underpinning. The owners associate the damage with increasing wetness of their block, and have recently installed french drains.

Householders at 2 and 3 Belhaven Avenue associate the commencement of house damage with increased wetness since the upslope development. Other householders in the avenue also commented on increasing wetness. Damage to No. 2 began just before the present stormwater drain was constructed and continued to worsen. This drain now runs up the centre of Belhaven Avenue to Harrow Place, and continues upslope to service a considerable area of upslope development. Old aerial photographs show that there are no natural drainage channels in the Belhaven Avenue area. The drain carries a heavy flow of water during wet weather, and towards the top of Belhaven Avenue it is reported to have repeatedly fractured. As the drain lies in expansive clay it is probable that it has other minor leaks.

In view of the reported moisture increase of the ground, and the timing of the house damage the upslope development has probably brought about a change of groundwater conditions. Clearing of trees and redirection of stormwater can cause changes in the water regime. Pipe fracture, minor leaks or winter overflow may contribute to the increase in groundwater.

In the heavy clay only a small change of moisture content will produce considerable movement. For example a rise of the water table and its capilliary fringe so that 3 m of clay has a moisture increase of 2% is sufficient to cause 60 mm of uplift. As No. 2 is partially founded on a large boulder the uplift would be differential, which is a particularly damaging situation.

The installation of french drains should help towards halting future moisture increase. The main stormwater drain should be checked to ensure that it is not leaking, and that it is of adequate size for storm runoff. Trees planted a safe distance from the house will help to dry the site.

4 Belhaven Avenue. Seasonal moisture change.

This brick house has a weatherboard extension supported on brick pillars on the northern side of the house.

Most of the damage is caused by movement of the pillars supporting the extension. The main building is structurally sound. The pillars which are about 3 m high, appear to have moved down the slight incline away from the house so that they tilt inwards towards the extension (plate 3), they also have a sideways lean. Most movement is in the pillars furthest away from the main building (fig. 4).

Ground beneath the extension is open to the changing elements. In winter it becomes damp and swells, in summer the sun can dry the ground out so that it shrinks. These seasonal alternations cause the pillars to rise and fall and there is also a downslope creep so that the pillars become damaged and tilted.

If a concrete slab is laid to cover the ground and for one metre outside the extension, then seasonal moisture variations will be subdued. Such a slab is likely to lead to a long term moisture increase beneath it which will produce lifting of the pillars. This lifting will take place over several years and may be allowed for by using removable wedges.

6 Norwood Avenue. Shrinkage and settlement of clay.

This is a brick house built over 20 years ago which is situated on brown clay (Type 2). Tests to determine the geotechnical properties of this clay were discussed earlier. For many years the owners have had problems with water running onto their block in winter, so that the garden became boggy, and a pond of water accumulated under the north-east corner of the house. In late 1975 the owners installed french drains to collect water coming onto their land, subsequently the water beneath the house dried up.

Damage has occurred on the north-west and east sides of the house, but is most serious on the north-east corner. Prior to 1976 the damage consisted of major cracking in the back verandah, but there were also minor structural cracks in the walls. In late 1976 major cracks occurred in the north-east corner and it appears that this corner has dropped downwards away from the rest of the house.

Ground on the southern side of this building is very moist, as is discussed in the section on moisture content, however house damage has been on the north, west and east sides. This suggests that the damage is caused by seasonal changes, with water pouring onto the block in winter and the sun drying it out in summer. Major cracking, in the form of settlement, occurred after the water which used to collect under the house had dried up subsequent to drains being built. It is probable that the settlement was caused by drying out and shrinkage of the clays in this corner, a process which would be aided by transpiration from the shrubs growing close to the wall.

The corner will have to be underpinned, after this shrubs should not be replanted. A concrete apron, which must be well maintained could be laid to prevent further drying out of this corner.

6 Belhaven Avenue. Broken service pipes.

In 1973 sewerage outlets from this house fractured. Wetting caused

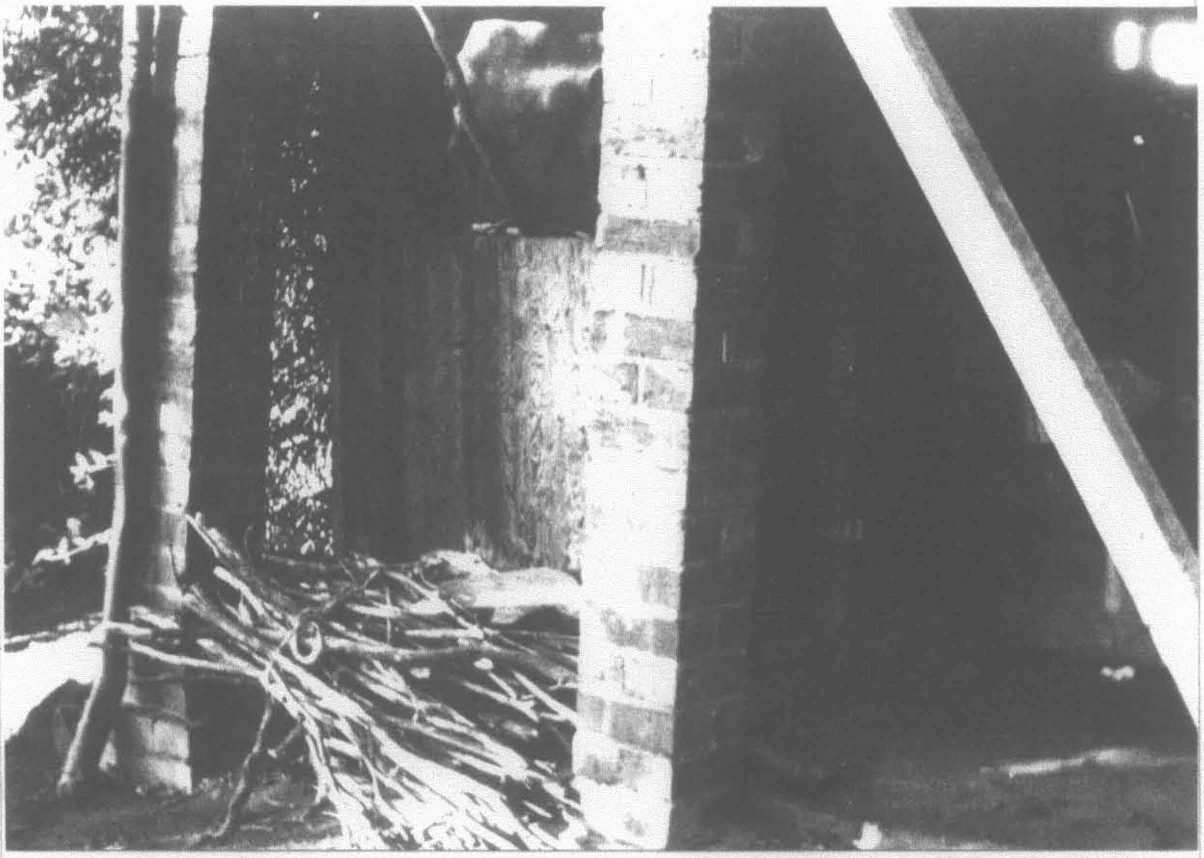


Plate 3. *4 Belhaven Avenue. Supporting pillars beneath north end of extension have a strong lean due to stress imposed by seasonal heave and shrinkage of underlying clay.*

by this produced structural damage to the extent that a corner had to be underpinned. No further damage has been noticed.

GENERAL RECOMMENDATIONS FOR LIGHT BUILDINGS

Parts of the Sandy Bay-Taroona area are situated on expansive clays, which can be recognised by their high plasticity, very high dry strength and by the deep cracks which cross the ground in summer. When houses are built on this subsoil their foundations need to be designed to withstand these special conditions.

(1) Footings should be founded below the zone of seasonal moisture change. The depth of this zone is not known in detail and will vary with aspect, however one metre is the suggested depth.

(2) Footings should be strongly reinforced.

(3) Short reinforced concrete piles may be preferable.

(4) Reinforced raft foundations may be used.

(5) In some cases slip joints in the building construction are appropriate.

In dealing with new sites, or with existing buildings the general principle is to maintain the soil moisture conditions at a stable level. The following precautions will lessen the risk of damage.

(1) Large trees, especially water loving trees should be kept away from buildings. For poplars and willows the suggested minimum distance is 7.5 m (British Building Code, 1948).

(2) It is inadvisable to grow shrubs next to a house, particularly on the north, west and east sides.

(3) Recessed gardens adjacent to house walls trap water in winter and promote transpiration in summer, thus causing damage (plate 4).

(4) Gardens near a house should be well watered in summer.

(5) Concrete aprons may be necessary to subdue seasonal changes (plate 5).

(6) Storm drainage should be taken well away from the home, taking care not to release it above a neighbour's house.

(7) If any unusual water ponding is noticed, then service pipes and other water sources should be checked immediately, and the cause corrected.

(8) The effect of a general water rise in an area may be alleviated by means of subsurface drains.

(9) Backfill into an excavation adjacent to a foundation wall needs to be well compacted to prevent it being a permeable path to the foot of the foundations.

[25 August 1977]

Plate 4. *Cracked wall and recessed garden. Recessed gardens encourage seasonal moisture variations below footings.*

Plate 5. *Concrete apron around house reduces seasonal moisture variations below footings.*

APPENDIX 1

Proline holes to investigate house damage at Taroona, June 1977.

Depth	Description	Sample data: Depth (cm)	m (%)	C_{up} (kPa)	C_{ur} (kPa)	δ (t/m^3)	δ_d* (t/m^3)
	Hole P8. Front garden south side, 6 Norwood Avenue.						
0-30	Dark brown plastic clay.	30	30				
30-55	Dark brown silty clay.	55		53	26		
55-107	Very plastic brown and orange clay.	107	40.1				
107-170	Softer brown and orange clay.	170	42				
170-210	As above. Some gritty oxidised material at 190 cm.	210	41				
	Hole P8A. East side of house, northern end						
0-120	Dark brown plastic clay,	35		81	26		
	some with high per-	75	31.6	83	21	1.85	1.4
	centage of siliceous	85		89.7	26		
	grains.	120	38	93	26	2.01	1.46
	Samples were taken from this hole for a consolidation test, an expansion pressure test and for potential volume expansion tests.						
	Hole P9. North side of house, in front garden about one metre from house wall, 15 Meath Avenue.						
0-90	Soil over soft black clay	50		50	31		
	with layers of peaty material.	100	44	35	19.3	1.75	1.19
90-180	Black clay grading into very plastic dark grey clay, becoming paler with depth.	180	47				
	From sample at one metre C_{qu} = 38 kPa/35 kPa. The black organic clay is spongy and compressible. Under a load of 136 kPa (2840 lbf/ft^2) volume decreased by 8% in 4 days and δ increased from 1.75 to 2.48. Samples taken for the determination of Atterberg limits and for XRD analysis.						

*δ_d = apparent dry density calculated from dry weight/original wet volume.

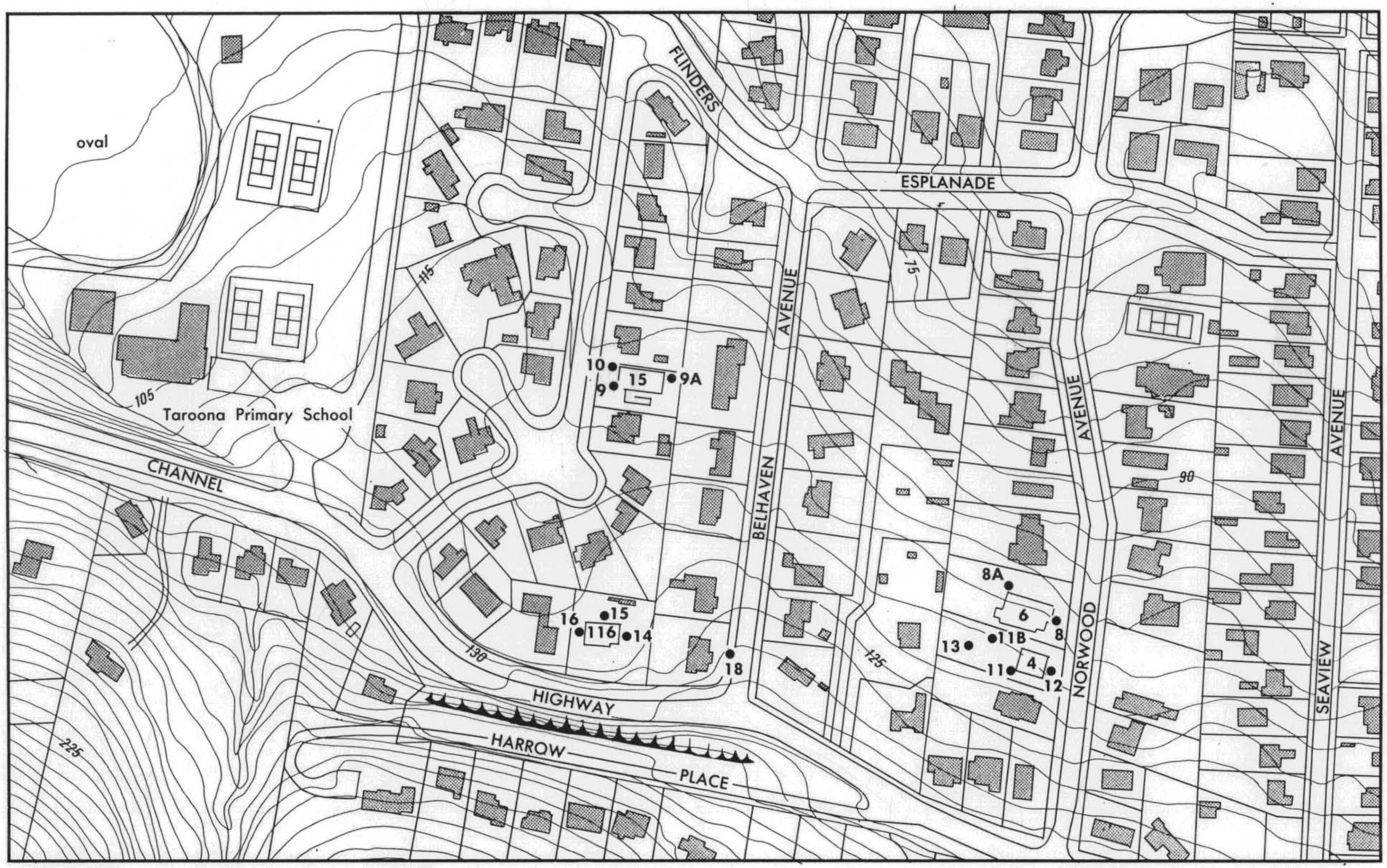
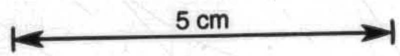


Figure 5. *Location of proline holes.*



Depth	Description	Sample data					
		Depth (cm)	m (%)	C_{up} (kPa)	C_{ur} (kPa)	δ (t/m^3)	δ_d* (t/m^3)
	Hole 9A. South side of house, 15 Meath Avenue						
0-80	Moist black medium soft clay.	50	44.7				
		76	39				
	Hole P10. In front garden.						
0-90	Soft black humic clay.						
90-180	Softer grey clay, highly plastic.						
180-270	Moderately firm plastic clay with grit. Fawn and black colour plus white fragments.						
270-370	Firm, moderately plastic green clay with white fragments.						
370-550	No return on auger. Water. Stiff plastic green clays and sand.						
	Water was intercepted between 370 and 460 cm. Rose in hole to 58 cm; a rapid initial rise.						
	Hole P11. North side of house near west corner, 4 Norwood Avenue.						
0-270	Stiff brown plastic clay with white siliceous fragments.	90	26				
		180	37				
	Hole P11A. Adjacent to Hole P11.						
57-107	76 mm diameter sample.	53		55	28		
		90	39			1.66	1.19
		100		43	21		
107-150	50.8 mm diameter sample.	106	38			1.76	1.27
		120	40.8			1.81	1.28
	Samples were taken for the determination of Atterberg limits for XRD analysis.						
	Hole P11B. Located north side of house, east corner.						
0-270	Similar to above.						
	Hole P12. Front garden, south side.						
0-107	Soft brown plastic clay.	58	38			1.81	1.31
		76	43.7			1.74	1.21

*δ_d = apparent dry density calculated from dry weight/original wet volume.

Depth (m)	Description	Sample data Depth (cm)	m (%)	Cup (kPa)	Cur (kPa)	δ (t/m³)	δ_d* (t/m³)
	Hole P13. Back garden approx. 20 m from house, 4 Norwood Avenue.						
0-90	Soft brown plastic clay.						
90-180	Firm brown plastic clay.						
180-270	Hard, orange lithic sand (?tuff).						
	Hole P14. South side of house, 116 Channel Highway.						
0-90	Moist, medium firm, dark brown plastic clay.	50	34.3	43	27		
90-135	50 mm diameter sample. Material as above.	100	35.7	54	21.4	1.86	1.37
		127	33	63	33.5	1.9	1.44
135-180	Homogeneous brown plastic clay.	180	35.3				
180-270	As above.	270	30.6				
	Samples were taken for the determination of Atterberg limits and for XRD analysis.						
	Hole P14A. Adjacent to Hole P14.	15		57	21		
		46		57	33.5		
		80		57	38		
	Hole P15. East side of house.						
0-45	Brown plastic clay, sea-shell layer.	45	23.9	78†	48		
45-90	Medium soft brown clay with pebbles.	90		56	31		
90-135	50 mm diameter sample.	100	27.8			1.75	1.28
		125	36.4	62	27	2.17	1.69
125-270	Homogeneous brown plastic clay.	145		59	24		
		180	30.7				
		270	29				
	Hole P16. North side of house.						
0-270	Homogeneous brown plastic clay.	35	26.6	67	36		
		90		55	31		
	50 mm diameter sample	100	32	53	19	1.87	1.42
		125	33.6	55	19	1.86	1.4
		140		67	31		
		190	32.3				
		270	35.2				

†Vane affected by sea shells.
*δ_d = apparent dry density calculated from dry weight/original wet volume.

APPENDIX 2

Composition of clay at Taroona

W.L. Matthews

The composition of five samples of clay from areas in Taroona where damage to structures has taken place, has been examined. The combined silt and clay size fractions of each sample was subjected to X-ray diffraction to determine the mineralogy. From the diffractograms an estimate of the quantity of each component has been made. Sample No. S1A was black with a crumby texture while P9 30" was black and plastic. The remainder were brown and plastic.

Table 2. X-RAY ANALYSIS OF COMBINED CLAY AND SILT SIZES

Sample No.	Montmorillonite	Kaolinite	Quartz
P11 40"	70%	15%	15%
P9 30"	80%	12%	8%
P16 30"	80%	20%	trace
S1A	60%	30%	10%
P20 5'-6'	85%	15%	trace

Montmorillonite has been identified as the mineral producing a peak on the diffractogram with a d spacing of about 15 Å, which on glycolation expands to about 17 Å. This material could contain some mixed layer minerals (*e.g.* montmorillonite and illite) but no other treatment was undertaken to determine this. Peaks indicating illite as discrete mineral particles were absent from the diffractograms. Similarly, kaolinite was identified from peaks with d spacing of about 7.2 Å and 3.58 Å. Again these peaks could be partly due to chlorite but no further tests were made. Heat treatment on Tamar clays suggest that little or no chlorite is present in those clays.

The percentages of the various minerals given can only be regarded as a guide to the actual proportions. Under the best circumstances such determinations from X-ray diffraction are only approximate. The usual weightings for peak area have been applied (*i.e.* 2 x kaolinite peak area : 1 x montmorillonite peak area). The preparation of the above samples involved settling suspensions on to glass slides; usually montmorillonite particles are smaller than kaolinite and concentrate on the surface of a slide so prepared. The result is a greater calculated proportion of montmorillonite than would be obtained if the minerals are evenly distributed throughout the sample. Quantitative methods are usually applied to the clay size particles whereas in these preparations, at least the finer silt size fraction has been included. This could result in further inaccuracy of the calculated proportions.

ANALYSIS OF THE >63 μm FRACTION

Each of the samples were wet sieved to separate the sand size and larger particles from the finer material. The following percentages of the coarser material were contained in the samples: P11 40", 16%; P9 30", 52%; P16 30", 19%; S1A 22% and P20 5'-6', 13%.

In the case of P9 30", complete separation of the two fractions may not have taken place although a large proportion of the coarser fraction is made up of carbonaceous material. Carbonaceous material was also present in S1A in fragments up to 5 mm across.

Quartz grains are the dominant mineral in all of the coarser fractions. These range up to 3 mm across and some of the larger grains are milky (vein quartz?) and others are clear. The majority of the quartz grains are in the fine sand size range. The finer grains tend to be angular while the coarser grains are angular to rounded.

A black magnetic mineral (ilmenite and/or magnetite) comprises less than 1% of the coarser fraction. In most cases this is shiny black and in angular fragments ranging in size from <0.1 mm to 0.3 mm. In S1A, dull brown magnetic material also occurs and is probably magnetite.

ORIGIN OF THE CLAY SEDIMENTS

The high percentage of montmorillonite suggests that its most likely source is from weathering of dolerite, basalt or tuff. It is possible that it may have been derived from Permian and Triassic sediments (very thin beds of montmorillonite are known to occur in the Permian in the Hobart area) but this is a less likely source. The quartz particles are probably derived from weathering of the Permian and/or Triassic sediments. The most likely source of ilmenite /magnetite is from dolerite weathering although Triassic sediments are known to contain concentrations of it.

DISPERSON TESTS

Dispersion tests as described by Ingles and Metcalf (1972) were undertaken on the five samples. This is a modified procedure for the classification of dispersive properties as originally developed by Emerson (1967), P16 30" dispersed on contact with distilled water and could be placed in Classes 1 or 2 (Emerson). All disperse when remoulded *i.e.* the remainder could be classified as Class 3. All produce cloudy water when shaken, with P16 30" and P11 40" producing very cloudy water and can be considered to be more dispersive than the other samples.

REFERENCES

EMERSON, W.W. 1967. A classification of soil aggregates based on their coherence in water. *Aust.J.Soil Res.* 5:47-57.

INGLES, O.G.; METCALF, J.B. 1972. *Soil stabilisation principles and practice.* Butterworth.

APPENDIX 3

Symbols and abbreviations

C_p	Peak strength
C_{qu}	Strength, quick undrained test
C_r	Residual strength
C_u	Strength, undrained test
kPa	kilopascal ($N/m^2 \times 10^3$)
LL	Liquid limit
LS	Linear shrinkage
m	Moisture content
m_v	Coefficient of volume expansion
XRD	X-ray diffraction

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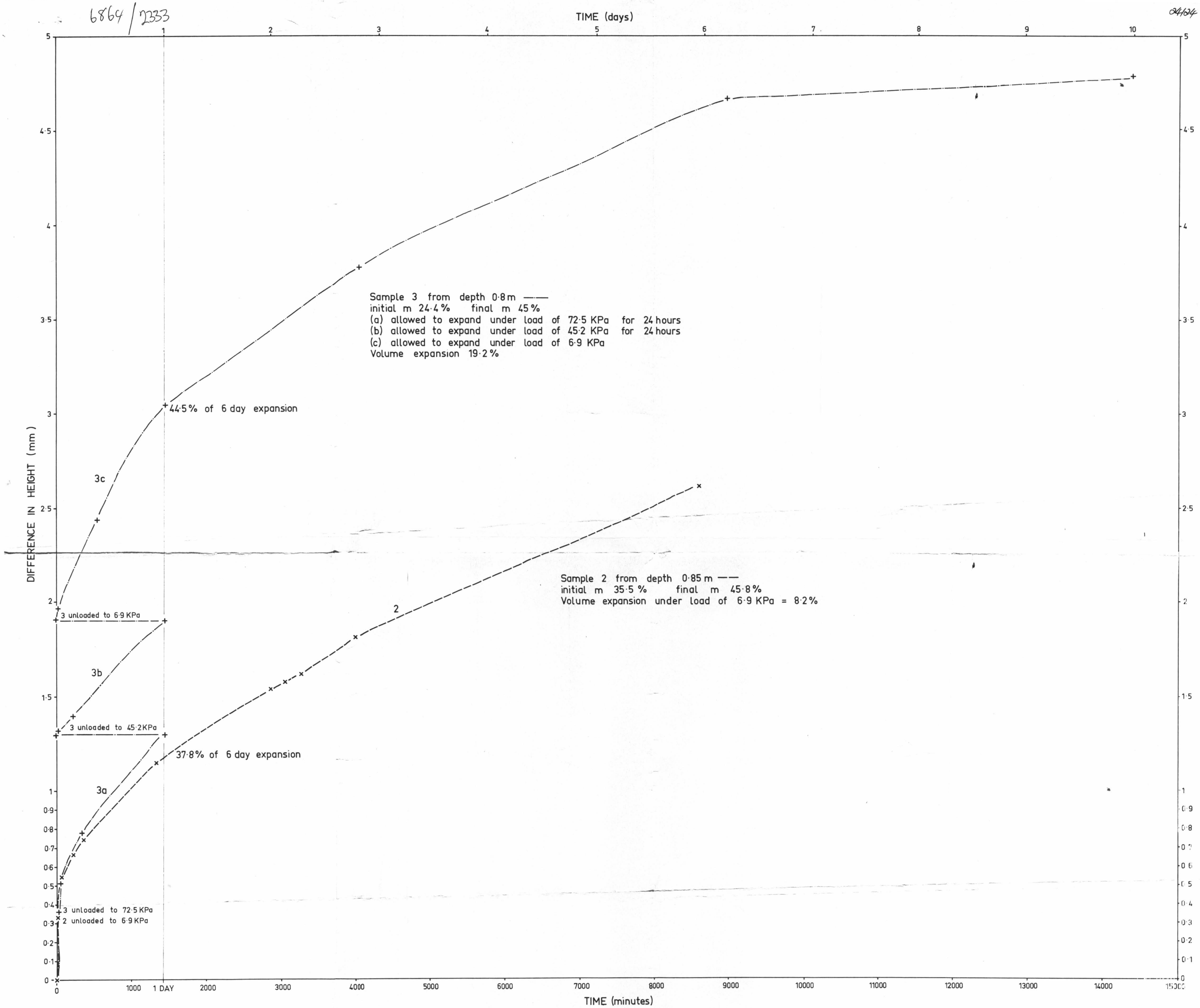

VOLUME EXPANSION OF CLAYS FROM TAROONA

Figure 1

5 cm

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