UR1984_59 1/16

1984/59. Subsurface movement in expansive clay: An alternative explanation for house cracking at Sandown Road, Launceston

W.R. Moore

Abstract

A trench dug on Block 23, Sandown Road, exposed river terrace deposits of unconsolidated sandy silt with minor gravel beds and boulders, with a cemented horizon at the base. These deposits were underlain by clay of the Launceston Beds of Tertiary age. A sandy clay lens in the clay was present at the base of the trench. The clay, in contrast to the sandy silt, is highly plastic, expansive and gave a low friction angle when shear box tested. The sandy silt has a low plasticity, is non-expansive, and has a high friction angle but is permeable.

Two old landslides occur in the vicinity of Sandown Road. Although the area is considered a potential landslide risk, slope failure appears only likely to occur under very adverse and rare combinations of conditions.

The cause of the recently reported house cracking in Sandown Road is thought to be from shrinkage in the underlying clay resulting from the prolonged drought of 1982-84. This explanation is preferred to that of translational downslope movement resulting from the beginning of a landslide. To prove the expansive clay hypothesis would require a considerable amount of trenching which is impossible in an already built up area. Long term monitoring of house cracking and movement in this area is unlikely to be acceptable to the house owners.

INTRODUCTION

At the request of Mr J.R. Adams a slope stability investigation of a block at 23 Sandown Road, Launceston, was undertaken. After auger drilling was not successful, a pit was dug on the block with a backhoe. Samples from the pit were collected for testing in the Department of Mines soil testing laboratory. Atterberg limits testing, grain size analysis, X-ray diffraction analysis, linear shrinkage testing, and slow shear box testing of over two weeks duration were undertaken on the clay and sandy silt samples. Soil testing was undertaken by R.N. Woolley.

The initial reason for Mr Adams' concern over the block's stability was that several houses in the area were cracked and that this cracking was thought to be caused by movement downslope as a result of the beginning of a landslide. Sandown Road is in a Zone III (potential landslide) area, and this fact and the widespread knowledge of local house cracking made it difficult to sell the block. As a result the Department of Mines was asked to investigate the potential of the slope for slope failure.

The writer had previously examined another block in Sandown Road near its junction with Queechy Road and had observed cracking in nearby houses. The cracking of houses in Sandown Road (as observed from the road) is scattered. There is no obvious pattern in crack distribution, whereas if the cause was the beginning of a landslide some concentration and pattern should be visible. A similar problem exists at Legana where four houses have been badly cracked; these house cracks have been monitored since 1982. The Legana houses are in a Zone III (potential landslide) area and are underlain by expansive clay with a low shear strength, as occurs at Sandown Road.

TOPOGRAPHY

Sandown Road is a loop road at the end of Queechy Road and is built on the north-facing slope of a spur. This spur is a NE-trending extension of a flat-topped ridge, and is an eroded remnant of a 35-45 m high terrace of the North Esk River. The existing terrace was trimmed to its present ridge form by former meanders of the North Esk River (fig. 1).

Block 23 is situated on the lowest part of Sandown Road and is situated on the toe of the slope [EQ146115]. The northern boundary of the block is approximately 5-7 m above the North Esk River flood plain. The block slopes away from the road with a uniform 15° slope 21 m long and then flattens to 10° with a sharp change in slope. At the change in slope is a wet area. The 10° slope is 18 m long to the northern boundary of the block, from where the land falls steeply (22°) for 16 m to the river flood plain. The overall slope of Sandown Road above the block is 7°, with a slope length of 225 m to the junction with Queechy Road. The steep section of 15° on Block 23 is small when compared with the overall length of the Sandown Road slope (fig. 2).

GEOLOGY

Surface geology

The Launceston geological map sheet (Longman *et al.*, 1964) shows the area of Sandown and Queechy Roads to be underlain by the Launceston Beds of dominantly clay, capped along the ridge by quartzite gravel.

There are no exposures on the block but on a neighbouring block are several large spoil heaps of material excavated from the foundations of an extensive retaining wall. No clay so characteristic of the Launceston Beds was present in the spoil heaps, the excavated material being dominantly silt and silty-sand with fine quartz pebbles, with an organic silty clay soil. Such material is unlikely to fail and cause landslides or expand and shrink to cause the house cracking occurring in Sandown Road.

As housing covers most of the area the only outcrop seen was on the steep cliff-like section west of the Sandown-Queechy Road junction where some brown silt, sandy-silt and what appeared to be gravel is exposed amongst the blackberry and undergrowth covering most of this steep area. Though the growth prevented a detailed examination of this outcrop, from a distance these sediments appear to be similar to those found in the top horizon of the trench dug on Block 23.

Subsurface geology

A trailer-mounted Triefus auger drill was used to investigate the subsurface geology but it could only penetrate to less than one metre before being stopped by boulders. A backhoe dug a pit to 2.1 m depth (Appendix 1). This pit was located eight metres from the road on the 15° slope and was near the solitary large tree in the middle of the block.

The trench exposed a surface layer of sand fill which is underlain by the original surface clay soil layer of 0.6 m thickness. In the clay soil were boulders and fine gravel. Beneath this soil layer was 0.6 m of soft, unconsolidated, friable sandy silt, at the base of which was a

Figure 1. *Location map of Sandown Road area.*

5 cm

SECTION THROUGH SLOPE - SANDOWN ROAD, NORWOOD

W. R. MOORE

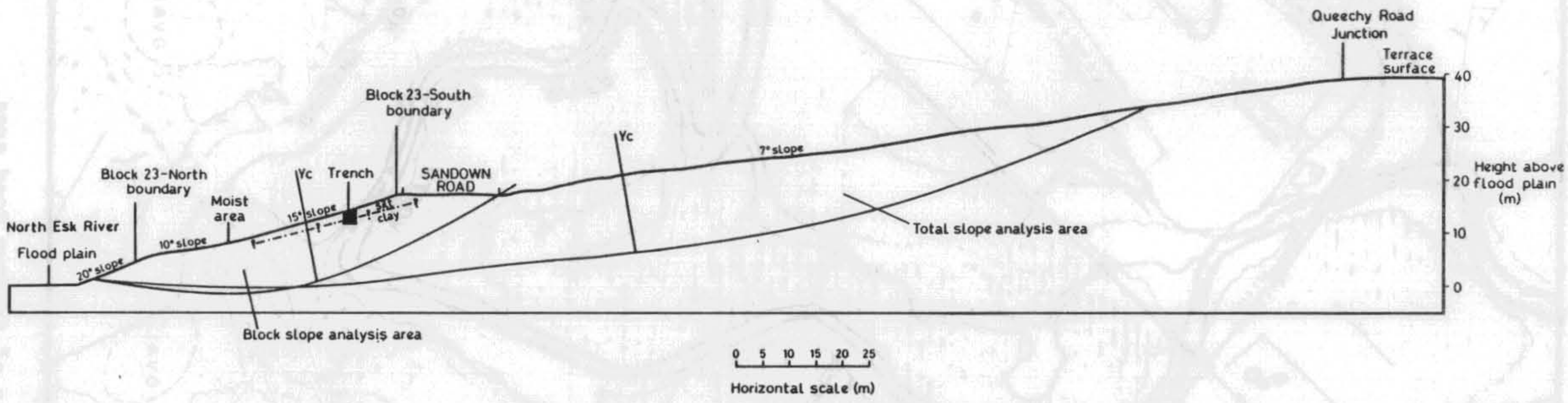

Figure 2.

59-4

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200 mm thick cemented hard pan. In the cemented band was a fine gravel layer and some boulders. The sandy silt and gravel are considered to be river terrace sediments of Pleistocene age.

Below these river terrace sediments was 1.2 m of brown and orange-grey mottled clay of the Launceston Beds of Tertiary age (Longman, 1966). These clays were highly plastic and moist but with no visible shearing. A hard, sandy clay layer was exposed at a depth of two metres on the south side of the trench. Without moving the backhoe to another position it was not possible to dig beyond 2.1 m depth because of the slope and a large root crossing the trench. The sandy clay layer did not continue across the trench and appeared to be a lens but may have been continuous below the depth dug.

In Appendix 1 is a cross section of the trench showing the varying lithology and the depth at which samples were collected. Sample 1 was collected from the clay topsoil and Samples 4 and 5 were collected from the clay and sandy clay lens. These samples were tested in the soil laboratory for moisture content, Atterberg limits and linear shrinkage. Samples 1 and 4 were analysed for composition by X-ray diffraction. The clay of Sample 4 was slow shear box tested for over two weeks to obtain a residual value of the angle of friction. Samples 2 and 3 (silt and cemented basal horizon) were grain size analysed and Sample 2 (the unconsolidated silt) was also slow shear box tested.

LABORATORY RESULTS

The laboratory results (Table 1) confirm that the surface soil (Sample 1) is a low plastic clay with a plastic index of 12 and linear shrinkage of only 5%. The clay component (kaolinite) was only minor. The grain size analyses show Samples 2 and 3 to be identical in composition with 60% fine silt, 20% fine sand and 20% medium to coarse sand. The difference in hardness is thought to be due to a groundwater precipitate and cementing horizon (hard pan) above the low permeable clay layer. The silt horizon was dry except for a moist, soft layer immediately below the surface soil. Small gravel lenses and boulders were present throughout these beds. The surface soil and underlying subsoil layer of sandy silt would be sufficiently friable and permeable to allow surface water to reach the underlying clay. The Tertiary age clay and sandy clay lens were both moist, with moisture contents of 32% and 28% respectively. The clay, in contrast to the sandy clay, was highly plastic with a plastic index of 91 and linear shrinkage of 24%. Kaolinite was present in moderate amounts and the expansive montmorillonite was present. The sandy clay had a low plasticity with a liquid limit of only 34, compared with 118 for the overlying clay.

Two weeks slow shear box testing of the clay gave an angle of friction (ϕ) of 21° with a rather higher value than anticipated for cohesion (C') of 7.5 kPa. A slow shear box test gave a far higher angle of friction of 39° for the sandy silt compared with the clay.

INTERPRETATION OF THE LABORATORY RESULTS

(1) The shear box tests confirm the field evidence that any slope failure is likely to occur within the Tertiary clay.

(2) The linear shrinkage and plastic index show that if the moisture content of the clay fluctuated sufficiently, either seasonally or over longer periods such as in the recent drought, vertical shrinkage movement would be reflected in the overlying surface sediments on which most house foundations are probably built in Sandown Road.

Table 1. SOIL LABORATORY TESTS, BLOCK 23, SANDOWN ROAD

Sample	Depth (m)	Moisture content (%)	Liquid limit (%)	Plastic limit	Plasticity index	Linear shrinkage (%)	X-ray diffraction mineralogy
1	0.5	10	30	18	12	5	Kaolinite (very weak)
4	1.4	32	118	27	91	24	Kaolinite (moderate) montmorillonite (very weak)
5	1.8	28	34	-	-	-	-

SHEAR BOX TESTING

Sample 2 0.8 m Angle of friction (ϕ) = 20° Cohesion (C') = 7.5 kPa
Sample 4 1.4 m Angle of friction (ϕ) = 39°

GRAIN SIZE ANALYSIS

	Sample 2 Depth 0.8 m		Sample 3 Depth 1.2 m		
Seive	*mass (%)*	*cum% retained*	*mass (%)*	*cum% retained*	
+2.36 mm	6.5	6.5	6.8	6.8	Gravel
+1.18 mm	6.7	13.2	5.7	12.5	
+600 µm	3.7	16.9	3.9	16.4	Sand
+300 µm	4.5	21.4	5.6	22.0	
+150 µm	21.3	42.7	23.3	45.3	
+75 µm	16.6	59.3	17.8	63.1	
+38 µm	8.2	67.5	9.3	72.4	Silt
-38 µm	32.5	100.0	27.6	100.0	

Grading curves of samples are given in Figure 3.

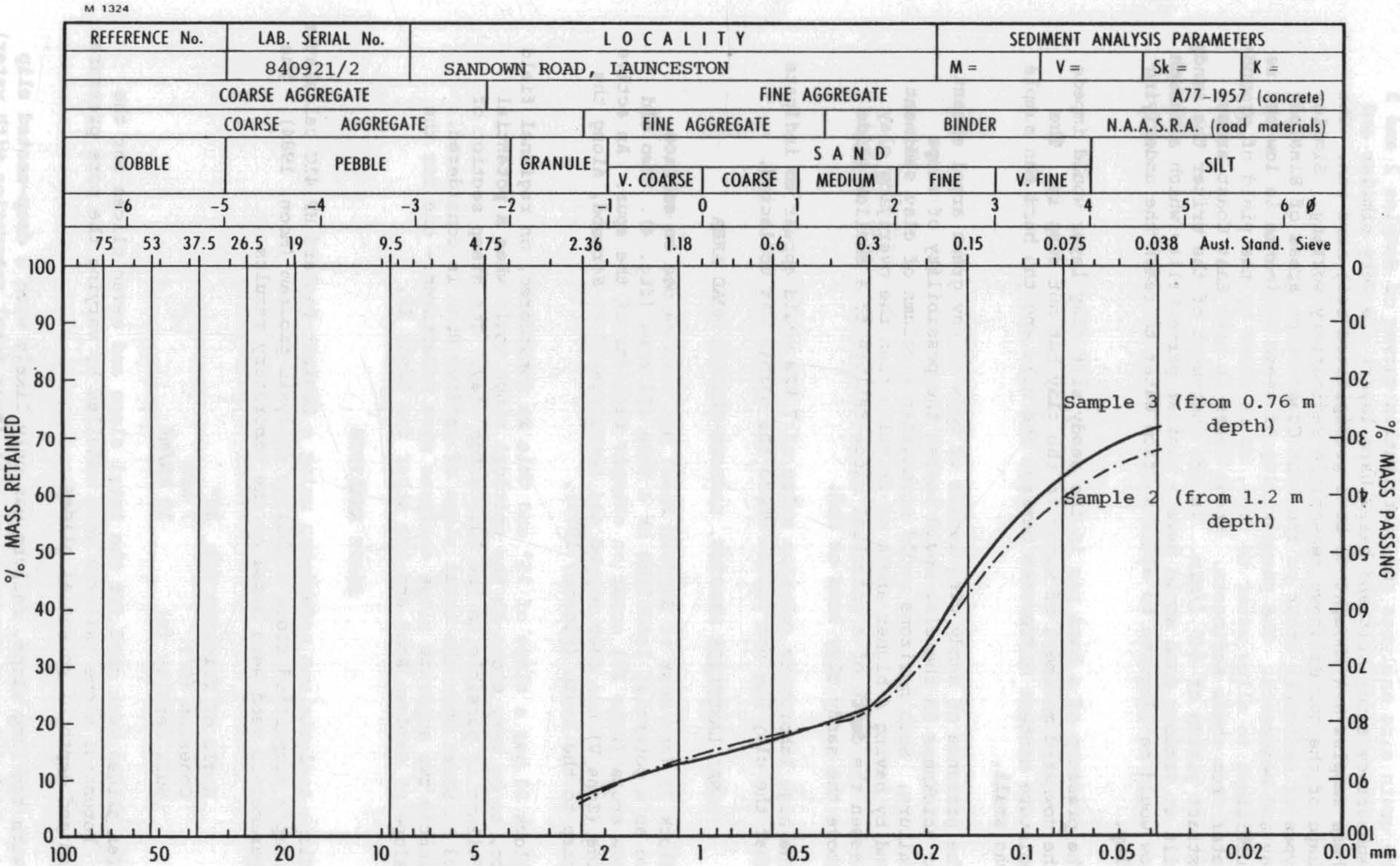

Figure 3. *Grading curves of Samples 2 and 3.*

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(3) The grain size analyses and distribution curves of Samples 2 and 3 (subsurface sandy silt and basal hard layer) are very similar and these samples are thought to be a precipitated soil hard pan. The shape of the curves shows reasonable sedimentary sorting. Similar types of sediments occur on the East Coast beach areas of Binalong Bay and Beaumaris. The permeability of these sediments is low but is sufficient to allow water to flow, as is shown by the yield of groundwater from these sediments. Spear bores in both East Coast areas extract yields of 4-8 *l*/min. In the judgement of the writer the sandy silt at Sandown Road would have a similar permeability which although low would be adequate to allow surface water to reach the underlying clay.

(4) The presence of a hard pan in the sandy silt clay layer would impede the downward movement of water to the clay but not stop it. The moisture content difference between the silt and the hard pan sample was small.

(5) The presence of sandy clay lenses or beds of any great areal extent or thickness in the clay would lessen the possibility of slope failure. Such horizons would strengthen a column of clay sediment and by having a higher angle of friction than the overlying clay lessen the depth of a potential slope failure to a shallow slide above the sandy clay lens or bed.

(6) The high laboratory cohesion value of 7 kPa would appear to indicate that the clay has not failed where the sample was collected.

ZONAL LANDSLIDE MAPPING, SANDOWN-QUEECHY ROAD AREA

Block 23 (and most of Sandown Road) has been mapped on surface evidence as a potential landslide or a Zone III area (fig. 4). Two old landslide areas (Zone IV) occur on steeper sections of the spur. An active landslide (Zone V) has been mapped and investigated at Norwood, along the same scarp to the south (Sloane, 1979).

Block 23 has a slope of 15° and this is considered, on regional field evidence, to be very close to the critical slope angle when a potential slope failure is possible in the Launceston clay. The steep section of Block 23 is short when the total slope of Sandown Road is considered. Consequently two separate slope analyses were undertaken:- one for the total slope of Sandown Road and the other for Block 23.

SLOPE ANALYSIS

Slope analysis was undertaken using a Hewlett-Packard HP 41C calculator and Bishop's simplified slope stability analysis program (Moon, 1984). The slope parameters used were based on the laboratory results.

Angle of friction (ϕ)	20°
Cohesion (C')	7 kPa
Bulk density (γ)	19 kN/m^3

Ten slices were used for the total slope and seven slices for the block. Potential slope failures were modelled by varying the pore pressure, cohesion and depth of potential slides.

With the long slope, failure was only likely with a deep-seated slip plane in which the pore pressure was high (near total saturation with water)

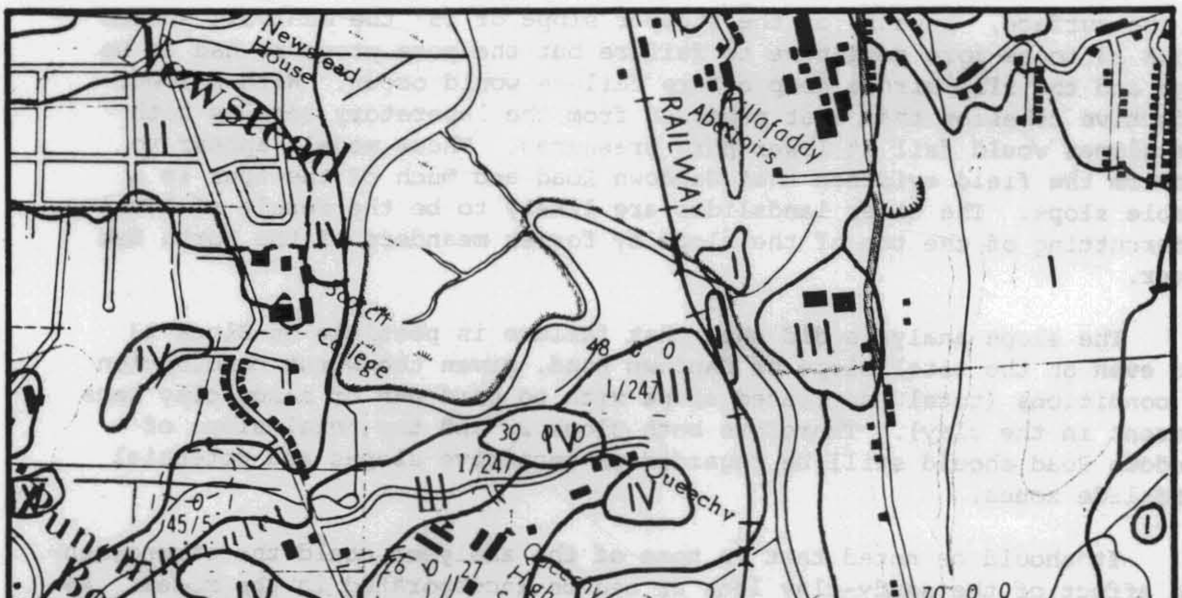

Figure 3. *Landslip zone map, Sandown Road area.*

Zone V - Active landslips and adjacent areas.
No building without specialised investigation and design.

Zone IV - Old landslips and adjacent areas.
No building without specialised investigation and design.

Zone III - Potential landslip areas.
Building methods in accordance with a special code.

Zone II - Stable ground, but on soft rocks.
Strict adherence to existing building code.

Zone I - Stable ground on hard rocks.
No abnormal problems or risks.

5 cm

at the surface. Because of the steeper slope of 15° the analysis showed Block 23 to be more sensitive to failure but the pore pressure had to be high and the slip circle deep before failure would occur. With a lower effective cohesion than that produced from the laboratory results both the slopes would fail at lower pore pressures. These models appear to confirm the field evidence that Sandown Road and much of the spur is a stable slope. The older landslides are likely to be the result of local undercutting of the toe of the slope by former meanders of the North Esk River.

The slope analysis did show that failure is possible on Block 23 and even on the total slope of Sandown Road, given the worst combination of conditions (total saturated slope with no hard pan or sandy clay lens present in the clay). Therefore both Block 23 and the total slope of Sandown Road should still be regarded as sensitive slopes and potential landslide zones.

It should be noted that in none of the analyses could the strengthening effect of the sandy-clay lens or bed be incorporated in the model. As well as strengthening the clay, such a lens would limit the thickness of clay and would also stop the deeper slip circle slides developing which, because of their greater weight, have more potential to slide.

A sandy clay lens has been observed in a building block in Queechy Road by the writer and similar sediments have been reported in the Launceston clays from nearby Norwood (Sloane, 1979). They are probably the major geological reason for many of the steeper slopes not failing around the Sandown and Queechy Road area.

AN ALTERNATIVE HYPOTHESIS TO LANDSLIDE MOVEMENT FOR THE CRACKING OF HOUSES

With an adequate permeable surface horizon as exists at Sandown Road, surface water would reach the underlying clay. As the clays are expansive, seasonal swelling and shrinking would be transferred through the overlying silt and soil to the house foundations. The normal seasonal summer shrinkage would be accentuated by the drought of 1982-84. During this drought similar clays have caused widespread house cracking elsewhere in Launceston (Moore, 1983). Expansive subsurface clay appears to be a more feasible explanation than landslide movement for the cracking of the houses in Sandown Road.

The random distribution of the house cracking, given the variability of the construction of house foundations, is also possibly influenced by the distribution of the cemented hard pan at the base of the silt. If, as is common for hard pans, they are discontinuous horizons, the water reaching the underlying clay would be more concentrated in areas where no hard pan is present.

The presence of sandy clay layers close to the clay/silt interface would also affect the amount of movement in the clay. Even though the moisture content of the sample from the sandy clay layer was only marginally lower than that of the overlying clay, the linear shrinkage was low (5%) compared with the clay (24%). If this clay was of a limited thickness (600 mm as at Block 23) the total movement would be small compared with areas where there is no sandy clay component.

If both the silt hard pan and sandy clay are missing at a particular locality, greater movement could be anticipated in the clay. As both the

the hard pan and silty clay horizons are probably lenses and discontinuous, their distribution could affect the pattern of cracked houses in Sandown Road. Differential movement in an individual house is also possible as the result of the distribution.

CONCLUSIONS

(1) From the trench dug at 23 Sandown Road the sandy silt sediments with minor gravel and boulders, even though soft and unconsolidated, did not possess the field properties to be the direct cause of the house cracking in the area. The sediment had a low plasticity, was non-expansive and a high angle of friction was anticipated. Even with a hard pan present the sandy silt appeared to have sufficient permeability to allow water to reach the underlying clay.

The underlying clay has all the field properties for potential slope failure as well as being expansive if the moisture content fluctuates sufficiently. It is these clay sediments that are probably the direct cause of the house cracking. The presence of a sandy clay lens or bed in these clays (as in the bottom of the trench) would reduce the risk of deep slip circle failures, and shallow translational slope failure is likely to be the mode of any failure at Block 23.

(2) The laboratory results show that the river terrace sandy silt has a plastic index of only 12, a linear shrinkage of 5% and angle of friction of 39 degrees.

In contrast, the Tertiary clay has a plastic index of 98, linear shrinkage of 24% and an angle of friction of 20° and cohesion of 7 kPa. The sandy clay horizon in the clay has a low liquid limit of 28, and would have a low plastic index and linear shrinkage.

Therefore any potential slope failure or differential movement is likely to be in the underlying clay rather than the near-surface sandy silt and gravel.

(3) The presence of a sandy clay lens or bed in the Tertiary clay would add stability to the area and would make a deep slip circle type of failure unlikely. Shallow translational movement is the potential risk.

(4) Using the Bishop's simplified effective stress analysis for the total slope of Sandown Road, based on the laboratory results of the clay, shallow slope failures are difficult to model unless high pore pressures with deteriorated cohesion values are used. Deep slip circle failures could be generated without altering any of the laboratory results. As would be anticipated the slope analyses show the steep 15° section of Block 23, at the toe of the total slope, to be more prone to failure than the total slope with an average slope of seven degrees. Failures in the models occur when the pore pressures are very high with the slope completely saturated and clay to the surface.

Such models do not fit the geology. They ignore the surface terrace silt, which is thought to have sufficient permeability to drain down slope, and the strengthening effect of the sandy clay lenses or beds in the underlying clay.

The analyses reflect the geological evidence that where undercutting of the toe area has taken place failures have occurred, but the total slope has not failed. The steeper sections (such as Block 23) should be treated as sensitive slopes which have not failed but which have the potential to fail given the combination of high pore pressure, deteriorated cohesion, and the absence of sandy clay lenses.

(5) Sandown Road has, with the exception of the two old landslides, been mapped as a Zone III area, one of potential landslide risk. The subsurface investigation and soil testing indicate this classification is correct and does not warrant being altered.

(6) The house cracking in the Sandown Road area is thought to be the result of excessive shrinkage in the highly expansive underlying clay, due mainly to the recent 1982-84 drought.

(7) The lack of any obvious pattern to house cracking in Sandown Road, as well as reflecting structural strength differences between houses, could be a reflection of the areal distribution of the hard pan in the terrace sandy silt and the sandy clay lens in the clay of the Launceston Beds.

(8) Unfortunately as Sandown Road is almost a completely built up area it is difficult to test the expansive clay hypothesis by further trenching or drilling. The detailed house crack monitoring and precise levelling required is not financially possible for the Department. Such a monitoring programme is not likely to be acceptable to the house owners of the area because of the effect on the resale values of properties in Sandown Road. Such a problem is now occurring in Legana, where only four houses are involved and where monitoring was welcomed and very acceptable at the beginning of the programme in 1982.

RECOMMENDATIONS

(1) Although Block 23 is on the steeper section of Sandown Road, a house with properly designed foundations and adequate drainage could be erected on the block.

(2) Such a house appears to be in no greater risk from landslide than one in any other Zone III area of the Tamar Valley, which includes a large proportion of Launceston city. Adherence to the Building Code Regulations, Part IV Division 5, 1980, dealing with building on landslide areas is advised.

(3) The house foundations should be designed by a competent engineer to withstand the movements anticipated from the underlying highly plastic clay. Drainage of the terrace silt, particularly above the house site, and of the wet area at the change of slope on the block should be given priority.

(4) If any retaining walls are to be built these should be adequately drained. The effectiveness of such walls is well illustrated in the neighbouring house, especially where they are loading the toe area of the block. This large split level house appears to have no visible cracks, even though the wooden retaining wall along the front is bowed slightly after being filled behind.

(5) The oversteepening of the 15° slope by cutting into the bank should be kept to a minimum.

(6) The growth of trees and shrubs should be encouraged to keep the moisture content of the silt and underlying clay to as low a level as possible, and to reduce the seasonal fluctuations.

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[30 August 1984]

APPENDIX I

TASMANIA DEPARTMENT OF MINES

ENGINEERING LOG – EXCAVATION

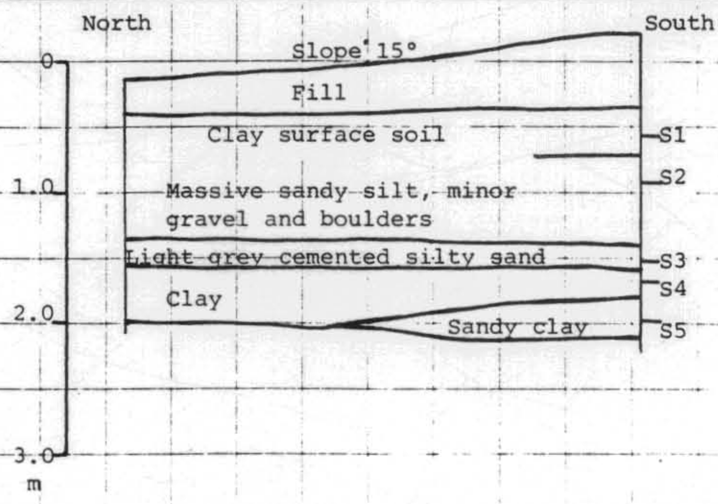
excavation no. 1
sheet 1 of 1

project	Slope and expansive soil subsurface investigation	location	23 Sandown Road, Norwood		
co-ordinates	EQ148115	exposure type	Pit	pit commenced	5.6.84
		equipment	Backhoe	pit completed	5.6.84
R.L.	15 m			logged by	W.R.M.
excavation dimensions	2 x 1 x 2.1 m	operator	Not known	checked by	R.C.D.

penetration 1 2 3	support	water	notes samples, tests	metres R.L. / depth	classification symbol	material soil type: plasticity or particle characteristics, colour secondary and minor components	moisture condition	consistency density index	structure, geology	
	None	None			SP	SAND AND FILL brown-yellow mortar, sand and brown sand	D	L	Fill	
			S1	0.5	CL	CLAY with boulders and gravel. Dark brown. Roots. Low plasticity. Depth irregular	M	St	Surface soil	Recent
			S2	1.0	ML	SANDY SILT. Silt 60%, fine sand 20%, uniform texture. Dark brown, well sorted, sedimentary. Very soft layer beneath surface clay.	D	F	Silt — River terrace sediments	Pleistocene?
			S3		SP	SAND WITH SILT. Light grey, fine, cemented with gravel and pebbles 70-100 mm	D	D	Hard pan	
			S4	1.5	CH	CLAY brown, highly plastic. Some mottled grey-orange. Occasional pebbles.	D	H	Clay - Launceston Beds	Tertiary
						SANDY CLAY lens. Fine grey sand and grey-orange clay.	D	H		
			S5	2.0		Trench stopped by large root across trench and slope on which machine was working.				

hand penetrometer kPa: 25 50 100 200 400

sketch

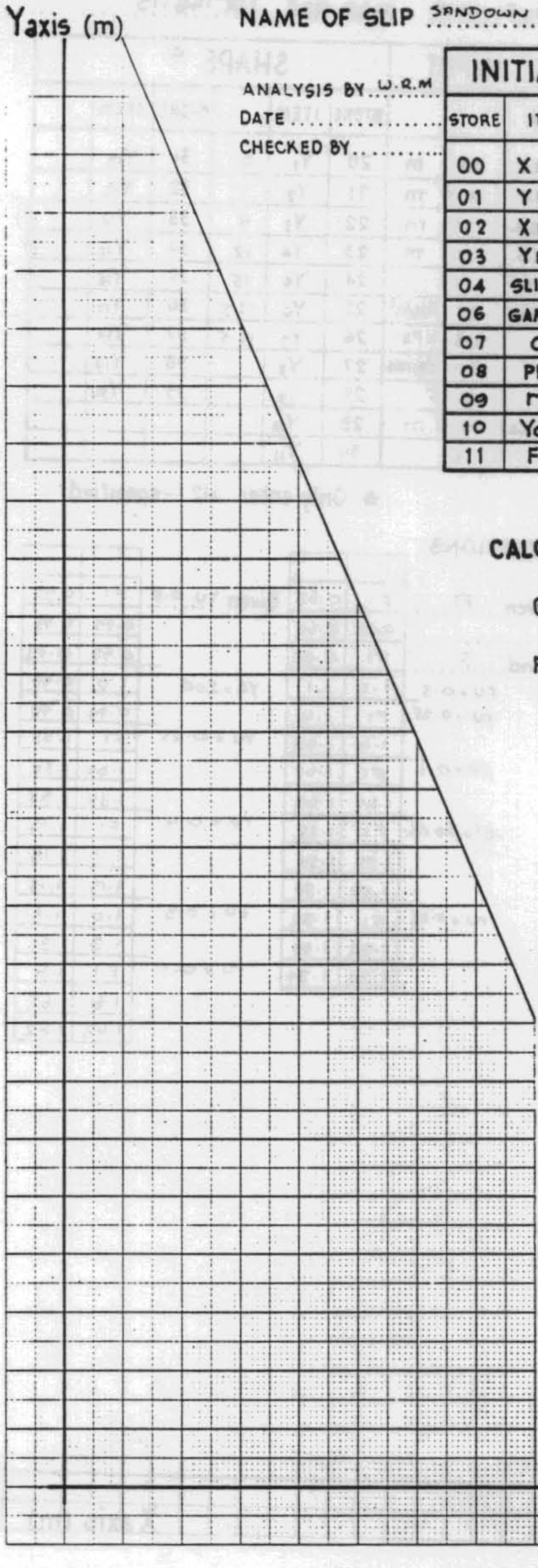


5 cm

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF 1

NAME OF SLIP: SANDOWN ROAD - TOTAL SLOPE MAP REF: EQ 148 115

ANALYSIS BY: W.R.M
DATE: ....
CHECKED BY: ....



INITIAL INPUT			SHAPE *					
STORE	ITEM		STORE	ITEM		STORE	ITEM	
00	X L.H.S.	10 m	20	Y_1	6	31	Y_{12}	
01	Y L.H.S.	2.5 m	21	Y_2	10	32	Y_{13}	
02	X R.H.S.	200 m	22	Y_3	15	33	Y_{14}	
03	Y R.H.S.	35 m	23	Y_4	17	34	Y_{15}	
04	SLICES	10	24	Y_5	19	35	Y_{16}	
06	GAMMA	19 kN/m³	25	Y_6	21	36	Y_{17}	
07	C	7.5 kPa	26	Y_7	24	37	Y_{18}	
08	PHI	20 degrees	27	Y_8	27	38	Y_{19}	
09	ru	0.75	28	Y_9	29	39	Y_{20}	
10	Y CIRCLE	200 m	29	Y_{10}	32			
11	F_1	1	30	Y_{11}				

* Only enter Nº specified

CALCULATIONS

Given F1	1.0	0.9
	0.9	0.89
Find F	0.89	0.89
yc = 200 ru = 0.5	F1	0.99
	0.99	0.99
yc = 200	F1	0.84
	0.84	0.83
yc = 100	F1	0.96
	0.96	0.96
ϕ = 25° yc = 200	F1	0.96
	1.01	1.01
ru = 0.5 ϕ = 20° yc = 200	F1	1.5
	1.5	1.53
ru = 0.25 ϕ = 20° yc = 200	1.0	2.2

	F1	1.5
Given ru = 0.5	1.5	1.54
	1.54	1.54
ru = 0.5	F1	1.5
	1.5	1.54
	1.54	1.54
ru = 0.25	1	2.13
	2.13	2.13
ru = 0.5 yc = 600	F1	1.59
	1.59	1.62
	1.62	1.62
ru = 0.25	F1	2.19
	2.19	2.25
	2.25	2.25
yc = 600 ru = 0.5 c′ = 5 kPa	F1	1.46
	1.46	1.48
	1.48	1.48
ru = 0.5 c′ = 3 kPa	1.0	1.35
	1.35	1.37
	1.37	1.37
yc = 600 ru = 0.5 c′ = 1.5	F1	1.28
	1.28	1.29
yc = 200 ru = 0.5 c′ = 5.0	F1	1.45
	1.45	1.43
	1.43	1.43

5 cm

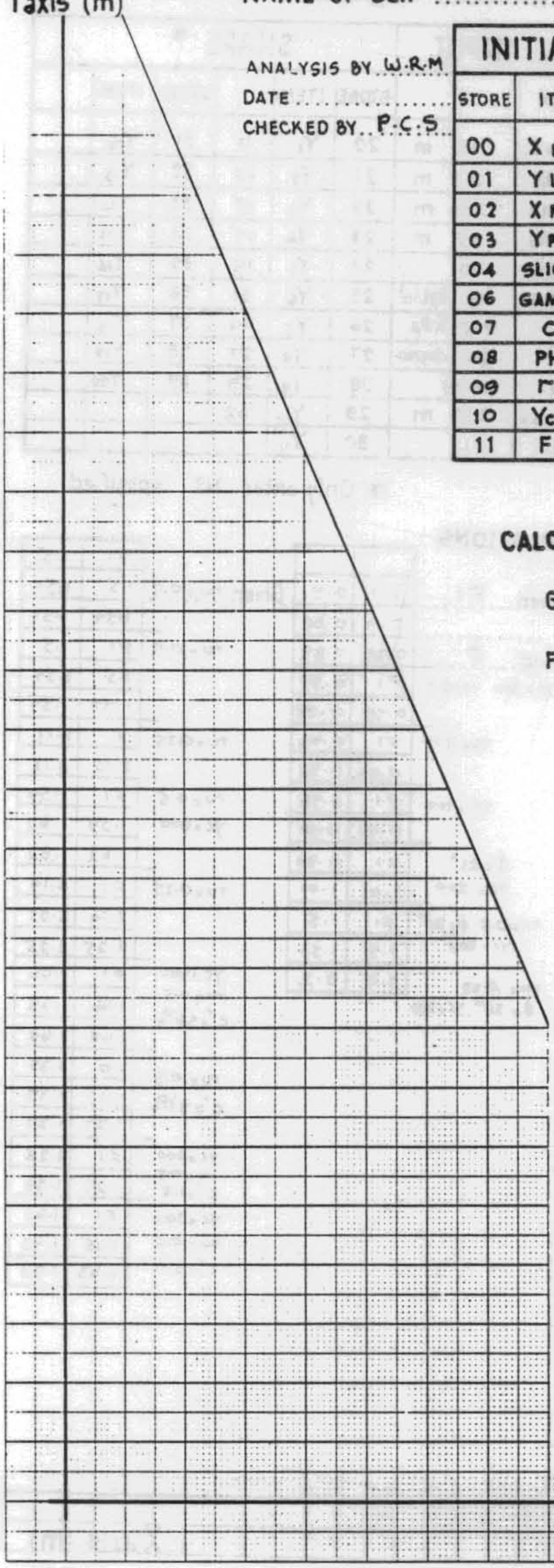
SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF 1...

NAME OF SLIP SANDOWN RD, BLOCK 23 MAP REF. EQ 148115

ANALYSIS BY W.R.M

DATE ....

CHECKED BY P.C.S



INITIAL INPUT			SHAPE *					
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00	X L.H.S.	10 m	20	Y_1	6	31	Y_{12}	
01	Y L.H.S.	2.5 m	21	Y_2	7	32	Y_{13}	
02	X R.H.S.	70 m	22	Y_3	9	33	Y_{14}	
03	Y R.H.S.	17 m	23	Y_4	12	34	Y_{15}	
04	SLICES	7	24	Y_5	15	35	Y_{16}	
06	GAMMA	19 kN/m³	25	Y_6	17.5	36	Y_{17}	
07	C	7.5 kPa	26	Y_7	17.5	37	Y_{18}	
08	PHI	20 degrees	27	Y_8		38	Y_{19}	
09	ru	0.75	28	Y_9		39	Y_{20}	
10	Ycircle	78.5 m	29	Y_{10}				
11	F_1	1	30	Y_{11}				

* Only enter Nº specified

CALCULATIONS

Given F1	F1	0.63
....	0.63	0.63
Find F	F1	0.95
ru = 0.5	1.1	1.1
ru = 0.25	F1	1.4
	1.4	1.43
ru = 0.1	F1	1.67
	1.67	1.68
c' = 50 kPa	F1	1.55
	1.55	1.59
	1.59	1.59
ru = 0.25	F1	1.32
	1.32	1.34
	1.34	1.34

Given ru 0.5	F1	0.95
	0.95	0.93
	0.93	0.93
yc = 200	1.0	0.99
	0.99	0.99
ru = 0.25	F1	1.35
	1.35	1.38
	1.38	1.38
ru = 0.4	F1	1.14
	1.14	1.15
	1.15	1.15
ru = 0.3	1.0	1.3
	1.3	1.31
ru = 0.1	F1	1.6
	1.6	1.62
	1.62	1.62

5 cm