

1979/45. Foundation conditions at St Anthony's School, Riverside

D.J. Sloane

*Abstract*

Two areas where extensions are proposed adjacent to St Anthony's School, Riverside, are underlain by up to 1.2 m of fill composed of silty and clayey sand (SM) which overlies yellow-brown and grey clay with reddish-brown mottles (CH) to a depth of at least 3.7 m. The clay has high plasticity and natural moisture content and has high values for Atterberg Limits. Linear shrinkage is high and the average angle of internal friction of the clay is  $7.5^\circ$  in the north-eastern area and  $17^\circ$  in the southern area.

Stability analysis indicates that both areas have short term stability, but are unstable in the long term, assuming zero cohesion and fully saturated conditions.

Care in foundation design and drainage will be required in view of the clay properties measured.

INTRODUCTION

At the request of the St Anthony's School Board of Management foundation conditions were examined on two areas adjacent to St Anthony's School at Riverside [EQ073165] where proposed school extensions are to be constructed (fig. 1). The Board requested comments concerning the general stability of the area and the geomechanical properties of the clay. This information is required to determine if any differential movement is likely to occur between the proposed extensions and the existing building.

Two Proline auger holes were drilled to a maximum depth of 3.7 m in each area. These holes were logged in detail and selected samples were taken for moisture content, Atterberg Limit, linear shrinkage and shear box testing. Two samples were taken for clay mineral identification. Vane shear tests were performed in each hole as drilling proceeded.

The school area has had a history of geological problems. A small landslide has occurred on the Fort Street boundary to the west. This landslide is a result of oversteepening the embankment and the introduction of stormwater from Fort Street and has been investigated at a request from the Beaconsfield Municipal Council. The school building has experienced problems with cracking of external walls, differential movement of surrounding pavement slabs and some movement resulting in gaps between floors and skirting boards. Insufficient foundations may be a cause, as foundations appear shallow where exposed by minor erosion along the eastern side. Problems are likely to be associated with shrinkage properties of the underlying clay and fill, and/or differential settlement of fill areas.

The two areas on which building extensions are proposed are situated to the south and north-east of the existing building (fig. 1). The former area has already been excavated and continues at the same elevation as the existing building. The cut and fill method used to construct this area implies that the eastern half of the proposed extension will be located on fill. The north-eastern area will require excavation, as a two storey extension is proposed. This will result in a two metre deep excavation below the north-eastern corner of the existing building.

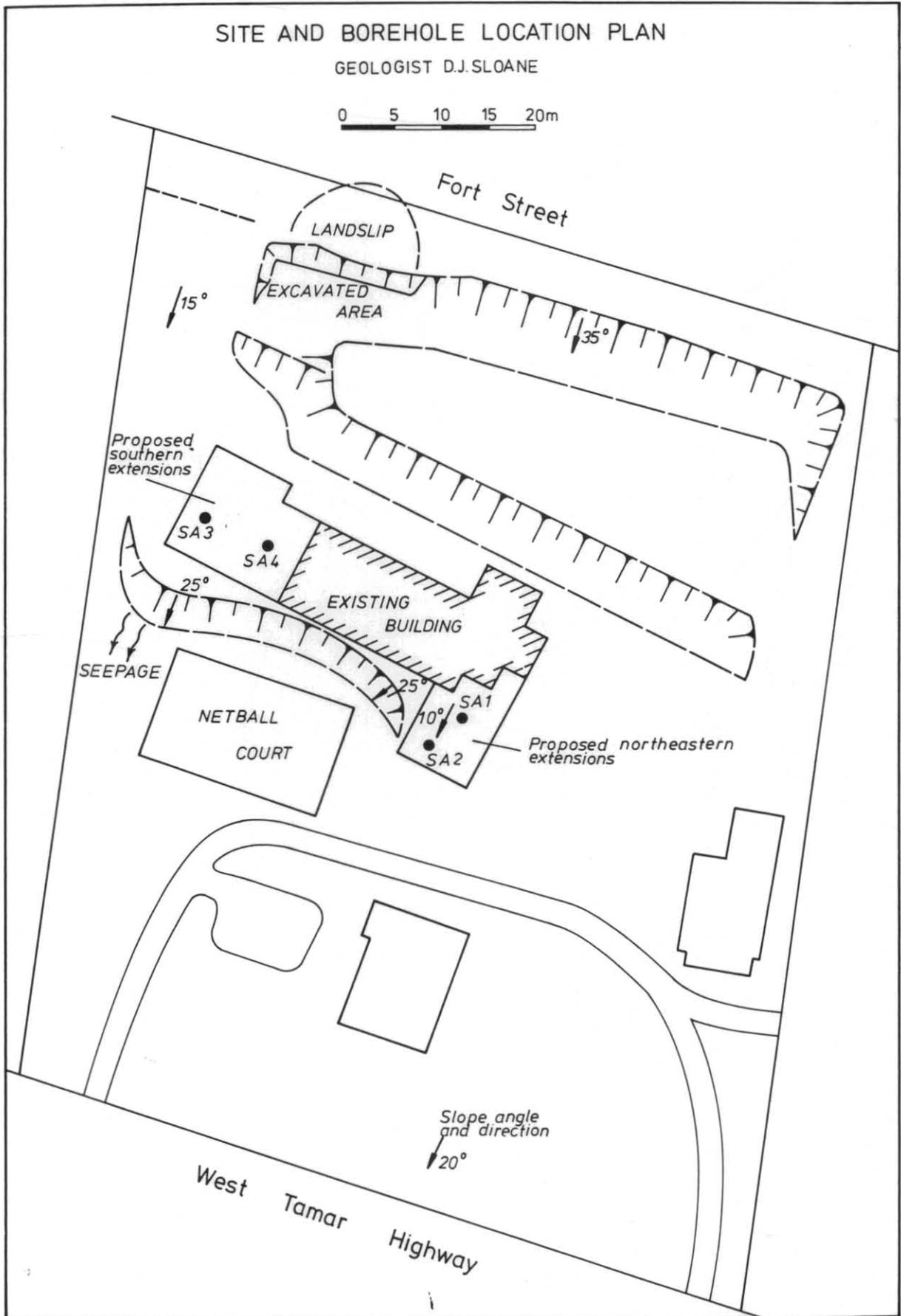


Figure 1.

5 cm

The school is situated in Zone III of the Tamar Valley Landslip Zone Map, a zone described as a potential landslip area.

#### TOPOGRAPHY

The St Anthony's School area is located towards the base of the sloping escarpment between the dolerite plateau to the west and the River Tamar floodplain to the east. Slope angles in the region vary between 10° and 20°.

#### GEOLOGY

The geological map of the region (Longman, 1966) indicates that the school area is underlain by Tertiary sediments. The plateau to the west is underlain by Jurassic dolerite and the hillslope on which the school is located is close to the dolerite-sediment boundary. The hillslope escarpment is a fault controlled topographic feature. Sediments in the area often contain laterite and bauxite with common 'buckshot' gravel, nodular concretions and layers.

#### AUGER DRILLING

Detailed logs of the Proline auger holes are presented in Appendix 1 and are summarised below.

##### *Holes SA1 and SA2, north-eastern extension*

<i>Depth (m)</i>	<i>Description</i>
0-0.75	SILTY and CLAYEY SAND (SM). Dark grey-brown. Approximately 20% plastic fines. Up to 50% medium quartz sand. TOPSOIL and FILL.
0.75-1.83	CLAY (CH). High plasticity. Brown with yellow-brown mottles. Trace medium quartz sand. Moist and stiff.
1.83-3.7	CLAY (CH). High plasticity. Grey with reddish-brown and yellow-brown mottles. Trace medium-fine quartz sand. Moist and stiff.
End-3.7	

##### *Holes SA3 and SA4, southern extension*

<i>Depth (m)</i>	<i>Description</i>
0-1.0	SILTY SAND (SM). Dark yellow-brown. 10% plastic fines. Medium sand and silt. TOPSOIL and FILL.
1.0-1.83	CLAY (CH). High plasticity. Dark brown with reddish-brown and orange-brown mottles. Some ironstone concretionary material to 20 mm diameter. Trace fine sand. Moist and stiff.
1.83-3.7	CLAY (CH). High plasticity. Grey with reddish-brown mottles. Some ironstone concretionary material to 15 mm diameter. Moist and stiff.
End-3.7	

The geology of both areas is similar, as is shown by the above summary. The main difference between the holes is in the amount of top-soil and fill present. The auger holes confirm the presence of highly plastic Tertiary clay to a depth of at least 3.7 m.

X-ray diffraction analysis of clay samples from auger holes SA1 and SA4 indicate significant differences in the clay minerals present. The clay sample from SA4 is composed of quartz and the clay mineral kaolinite, while the sample from SA1 is composed of quartz and the clay minerals kaolinite and montmorillonite. The low angle of internal friction for the area around holes SA1 and SA2 is attributed to the presence of montmorillonite.

#### CLAY ANALYSIS-GEOMECHANICAL PROPERTIES

A total of 10 samples have been tested for various properties. The results are summarised below and in Table 1.

##### *Field moisture content*

Field moisture contents (10 samples) were moderate to high and ranged from 23.6% to 39.5%, average 33.0% and are expressed as a percentage of dry weight. Clay moisture contents were generally consistent (29% to 39%) with the exception of SA3 which had a lower (average) moisture content of 24.5% (2 samples).

##### *Liquid limit*

Liquid limits (5 samples) varied from 84.9% to 172.4% and are considered to be very high. The clay can be consequently classified as of high plasticity and compressibility on Casagrandes (1948) plasticity chart classification. The majority of values (4 samples) were in the range 142.5% to 172.4%. A sample from hole SA4 at a depth of 3 m gave a much lower value of 84.9%.

##### *Plastic limit*

Plastic limits (5 samples) varied from 22% to 30.6% and are considered to be in the moderate to low range for clay.

##### *Plasticity index*

This value indicates the moisture content range over which the clay remains plastic. Values ranged from 62.9% to 141.8%. The majority of samples (4) were between 115.2% and 141.8%. The values are considered to be high and indicate high toughness and dry strength of the clay.

##### *Linear shrinkage*

Five samples tested ranged from 16% to 27% with four between 21% and 27%. These shrinkage values are considered high.

##### *Vane shear testing*

*In situ* vane shear tests provide an indication of the shearing resistance of the clay and its sensitivity. Readings from holes SA1 and SA2 were in the range 59.3 kPa to 64.2 kPa whereas those from SA3 and SA4 were much higher, between 77.4 kPa and greater than 120 kPa. The sensitivity of clay from SA4 was about 2.5 and is therefore low.

Table 1. CLAY PROPERTIES, ST ANTHONY'S SCHOOL, RIVERSIDE

Hole Number	Type of Sample	Depth (m)	Shear box moisture content (%)	Field moisture content (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)	Angle of internal friction ( $\phi$ )	
45-5	SA1	Moisture		38.6						
		Disturbed	2.30	35.2	145.7	25.5	120.2	22		
		Moisture and disturbed	2.80		36.2					
		Undisturbed	3.0	40.8	29.0	142.5	27.3	115.2	21	7°
		Moisture	3.7		34.0					
SA2	Moisture and disturbed	2.5		37.0	147.8	29.5	118.3	23	8°	
SA3	Moisture	2.7		25.3						
	Moisture	3.7		23.6						
SA4	Disturbed	1.9	43.2	39.5	172.4	30.6	141.8	27	16°	
	Moisture and disturbed	3.0	27.5	32.1	84.9	22.0	62.9	16	18°	

*Drained, slow shear box testing*

Angles of internal friction ( $\phi$ ) were determined on four samples. The results showed marked differences between the clay from the two areas investigated. Two determinations from hole SA4 indicated  $\phi$  values of  $16^\circ$  and  $18^\circ$  (average  $17^\circ$ ) but determinations from SA1 and SA2 indicated  $\phi$  values of  $7^\circ$  and  $8^\circ$  (average  $7.5^\circ$ ) with corresponding cohesion ( $c'$ ) values of 17.7 kPa and 27.25 kPa.

Clay geomechanical properties can be considered consistent in both areas except  $\phi$  and  $c'$  values which were consistent within an area but differed markedly between areas. The exception was a clay tested from a depth of 3 m in hole SA4 which shows lower values for most properties tested.

STABILITY ANALYSIS

SOUTHERN AREA (HOLES SA3 AND SA4)

The southern area has been considered as a simple embankment failure problem and is represented in Figure 2. It has been assumed that the embankment is composed entirely of clay and has the properties as measured in the laboratory. Both slab failure and slip circle cases will be considered.

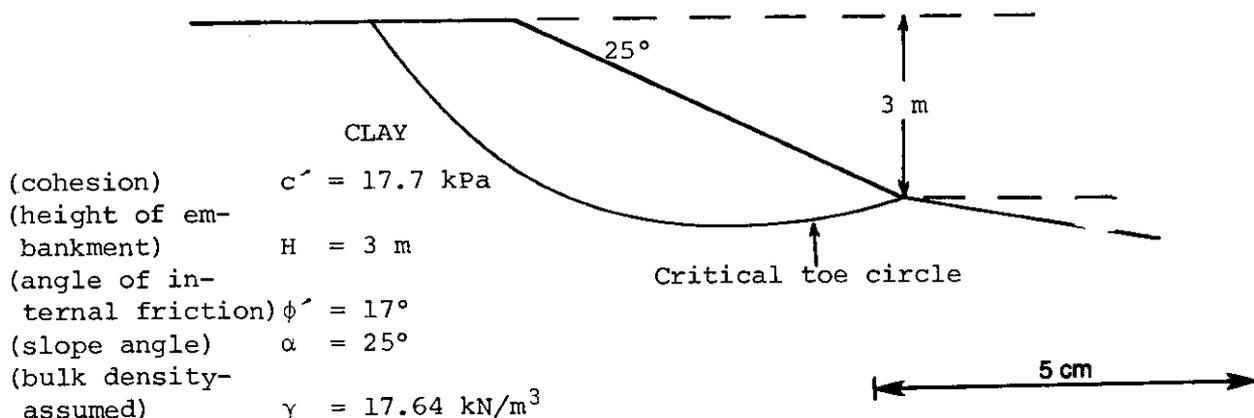


Figure 2. Diagrammatic representation, southern area

*Slab failure (Skempton and Delory, 1957)*

Assuming the above clay properties and that the clay embankment is in a fully saturated condition, calculations indicate a range of safety factors from 2.9 for a slab of one metre thickness to 1.2 for a slab of three metres thickness. The embankment is considered stable in the short term. However, for long term stability cohesion should be considered as zero and consequently the factor of safety reduces to 0.7 (dry) and 0.3 (fully saturated). This  $c'=0$  case appears a little unrealistic as natural slopes in the surrounding area are up to  $20^\circ$  to  $25^\circ$ .

*Cousins (1978) stability charts*

Assuming fully saturated conditions and assuming a toe circle failure, the charts indicate a minimum factor of safety of about 2.7 and the critical toe circle is indicated in Figure 2.

Bishop's (1955) simplified method of slices was also used to check on

the validity and accuracy of using Cousins charts. The factor of safety produced by this method for a toe circle whose centre was located close to the critical slip circle indicated above has a value of 2.75. This figure is considered close enough to the previously determined value to warrant using Cousins charts.

#### NORTH-EASTERN AREA (HOLES SA1 AND SA2)

The same assumptions have been made as those for the southern area. The embankment is represented in Figure 3.

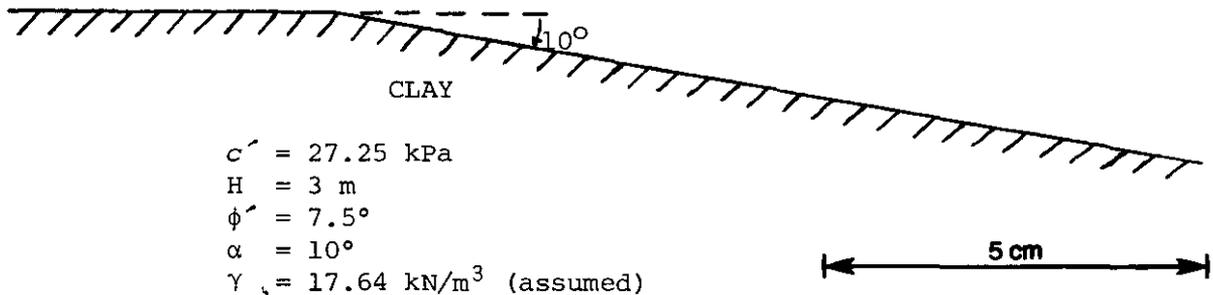


Figure 3. Diagrammatic representation, north-eastern area

*Slab failure, (Skempton and Delory, 1957)*

Assuming the same conditions as for the previous calculations on the southern area, a range of factors of safety were produced from 6.2 for a one metre depth to 2.2 at a depth of three metres, fully saturated. The embankment is thus stable in the short term. Assuming cohesion is zero the factors of safety were reduced to 0.3 fully saturated and 0.75 dry for a slab thickness of three metres. The  $c' = 0$  conditions, although considered essential for long term stability, appear unrealistic as surrounding slopes showing no signs of previous failure have slope angles generally greater than  $10^\circ$

*Cousins (1978) stability charts*

Assuming fully saturated conditions and toe circle failure, the charts indicate a minimum factor of safety of 4 and thus the area is considered stable with respect to toe circle failure.

#### SUMMARY OF STABILITY ANALYSIS

Stability calculations show that both areas are quite stable in the short term. The areas are, however, unstable in the long term assuming that the embankments are fully saturated and cohesion is zero. Regional slopes vary between  $10^\circ$  and  $20^\circ$  and failure has occurred at Fort Street on a  $15^\circ$  slope, although oversteepening of the embankment to  $35^\circ$  has been a major factor contributing to the failure. It is therefore considered that both areas should be stable if drainage is provided to prevent fully saturated conditions occurring. As a two metre vertical excavation is required to construct the north-eastern extensions, careful attention must be given to retaining wall design and drainage in view of the properties of the clay and the stability calculations.

#### CONCLUSIONS

The area is underlain by Tertiary clay and some topsoil and fill. The clay is composed of quartz and kaolinite with montmorillonite present in the north-eastern area. The clay is of high plasticity and natural

moisture content and has high values for Atterberg Limits. Linear shrinkage is high and the average angle of internal friction of the clay is  $7.5^\circ$  in the north-eastern area and  $17^\circ$  in the southern area.

Stability analysis indicates that both areas have short term stability, but are unstable in the long term when cohesion is zero and the embankments are fully saturated. The areas are considered stable provided full saturation is prevented.

Foundation design should be made by a qualified geotechnical engineer in view of the clay properties and stability analysis outlined above. An unqualified opinion is that existing foundations are unsuitable for the clay conditions and existing structural problems at the school have been caused by several factors, including differential settlement of fill areas and clay swelling and shrinkage.

Careful attention should be paid to surface drainage, footing and retaining wall design and drainage.

#### REFERENCES

- BISHOP, A.W. 1955. The use of the slip circle in the stability analysis of slopes. *Geotechnique* 5:1-7.
- CASAGRANDES, A. 1948. Classification and identification of soils. *Trans ASCE* 113:901-992.
- COUSINS, B.F. 1978. Stability charts for simple earth slopes. *J.geotech. eng.Div.ASCE* 104:268-279.
- LONGMAN, M.J. 1966. One mile geological map series. K/55-7-39. Launceston. *Explan.Rep.geol.Surv.Tasm.*
- SKEMPTON, A.W.; DELORY, F.A. 1957. Stability of natural slopes in London Clay. *Proc.4th Int.Conf.Soil.Mech.Found.Eng.* 2:378-381.

[6 November 1979]

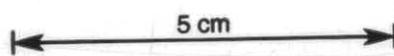
**ENGINEERING LOG – BOREHOLE**

borehole no. SA1  
sheet 1 of 1

9/12

project St Anthony's School, Riverside	location North-eastern area
co-ordinates EQ073165	drill type Proline
R.L.	drill method Auger screw
inclination vertical	drill fluid
bearing	hole commenced
	hole completed
	drilled by B. Cox
	logged by J. Sloane
	checked by

penetration	support water	notes samples, tests	metres R.L. depth	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	hand penetrometer kPa	structure, geology
1 2 3	DRY		0		SM	SILTY and CLAYEY SAND: 10%-20% Plastic fines. Dark grey-brown. Medium quartz sand and silt to 50%.	D	Fb	>129	Topsoil and Fill
			0.5							
			1.0			CLAY: Moderate to high plasticity. Brown-yellow to brown mottles. Trace medium quartz sand.	M	St		
			1.5						59.3	
			2.0			CLAY: High plasticity. Grey with reddish-brown mottles some yellow-brown mottles. Trace fine sand.	M	St		
			2.5						63.0	
			3.0							
			3.5							
			END							
			4.0							



# ENGINEERING LOG – BOREHOLE

10/12

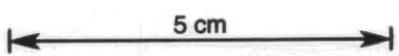
project	St Anthony's School, Riverside	location	North-eastern area
co-ordinates	EQ073165	drill type	Proline
		drill method	Auger screw
R.L.		hole commenced	
inclination	vertical	drilled by	B. Cox
bearing		logged by	J. Sloane
		checked by	

penetration	support	water	notes samples, tests	metres R.L. depth	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	hand penetrometer kPa	structure, geology
1 2 3				0		CH	CLAY: Moderate to high plasticity, dark yellow-brown with light yellow-brown mottles. Some fine sand, some ironstone gravel.	M	St	62.3	
				0.5							
				1.0							
				1.5		CH	CLAY: High plasticity. Grey with red-brown mottles.	M	F	64.2	
				2.0				PL			
				2.5						61.5	
				END							
				3.0							
				3.5							
				4.0							

TRACE

D

D, M



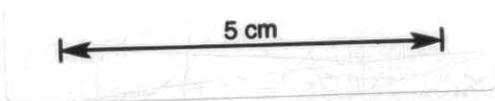
**ENGINEERING LOG – BOREHOLE**

borehole no. SA3  
sheet 1 of 1

11/12

project	St Anthony's School, Riverside	location	Southern area	
co-ordinates	EQ073165	drill type	Proline	
R.L.		drill method	Auger screw	
inclination	vertical	drill fluid	hole commenced	hole completed
bearing			drilled by	B. Cox
			logged by	J. Sloane
			checked by	

penetration 1 2 3	support water	notes samples, tests	metres R.L. depth	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	hand penetr- ometer kPa	structure, geology
			0		SM	SILTY SAND: Dark yellow-brown Medium sand (quartz) and silt. 10% plastic fines.	D	S		Topsoil and fill
			0.5							
			1.0							
			1.5		CH	CLAY: High plasticity. Dark brown, reddish-brown and orange-brown mottles. Some ironstone concretions to 2 cm dia. Trace fine sand.	M	St	77.4	
		D	2.0		CH	CLAY: High plasticity. Grey with reddish-brown and orange-brown mottles. Some ironstone concretions to 1.5 cm. Trace organic(?) particles.	M	St		
		D, M	2.5						>129	
			3.0						vSt	
			3.5							
		D, M	END							



**ENGINEERING LOG – BOREHOLE**

12/12

project	St Anthony's School, Riverside	location	Southern area
co-ordinates	EQ073165	drill type	Proline
R.L.		drill method	Auger screw
inclination	vertical	drill fluid	
bearing		hole commenced	
		hole completed	
		drilled by	B. Cox
		logged by	J. Sloane
		checked by	

penetration	support	water	notes samples, tests	metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	hand penetrometer kPa	structure, geology
1 2 3				R.L. depth						25 50 100 200 400	
				0		SM	SANDY SILT: Medium quartz sand and silt (50%) 10%-20% plastic fines. Brown.		S		Fill and top soil
				0.5							
				1.0		CH	CLAY: High plasticity. Yellow-brown. Some medium quartz sand and ironstone granules.		M		
				1.5						81.9 (33.5r)	
			D	2.0			CLAY: High plasticity. Grey with some reddish-brown and bright reddish-brown mottles.		M		
				2.5							
			D, U75	3.0						90.7 (33.5r)	
				END							
				3.5							