

UR1987_47

1987/47. Stability assessment of a proposed subdivision at Orana Place, Riverside.

D. J. Sloane

Abstract

A proposed subdivision at Orana Place, Riverside is classified as Zone IV on the Tamar Valley Landslip Zone Map. The land is moderately to steeply sloping with an overall slope of about 13°. Topographic features of the area are indicative of old landslides.

The area is underlain by highly plastic (CH) Tertiary clays. Stability analyses of a surveyed profile indicates that the area is potentially unstable in the short term and unstable in the long term. Drainage requirements considered necessary to ensure suitable stability for subdivision and building development are extensive, expensive and impracticable.

The area is not considered suitable for subdivision and even one suitable house site cannot be recommended.

INTRODUCTION

At the request of Mr. P. Anderson of the surveying firm Peacock, Darcey and Anderson, an investigation was conducted to determine the stability of an area of land at Orana Place, Riverside. The owners, T. and R. Welsh, have proposed to subdivide the area into three lots, depending on the existence of three suitable house sites.

The allotment is approximately 1.7 ha in area with a frontage of 109 m on Orana Place and a depth of between 170 m and 146 m. The altitude ranges from about 30 m, at road level, to 70 m above sea level at the rear of the lot.

A visual site inspection indicated that the moderate to steeply sloping area was marginally suitable for subdivision and that a geotechnical investigation was required to determine the overall stability of the site.

Three seismic spreads were fired on the site and four auger holes were drilled to depths of between 7.9 m and 8.7 m. Disturbed samples and seven undisturbed drive tube samples were obtained for later laboratory determination of geomechanical properties and clay analysis. A magnetometer traverse was conducted along a surveyed profile to determine bedrock conditions.

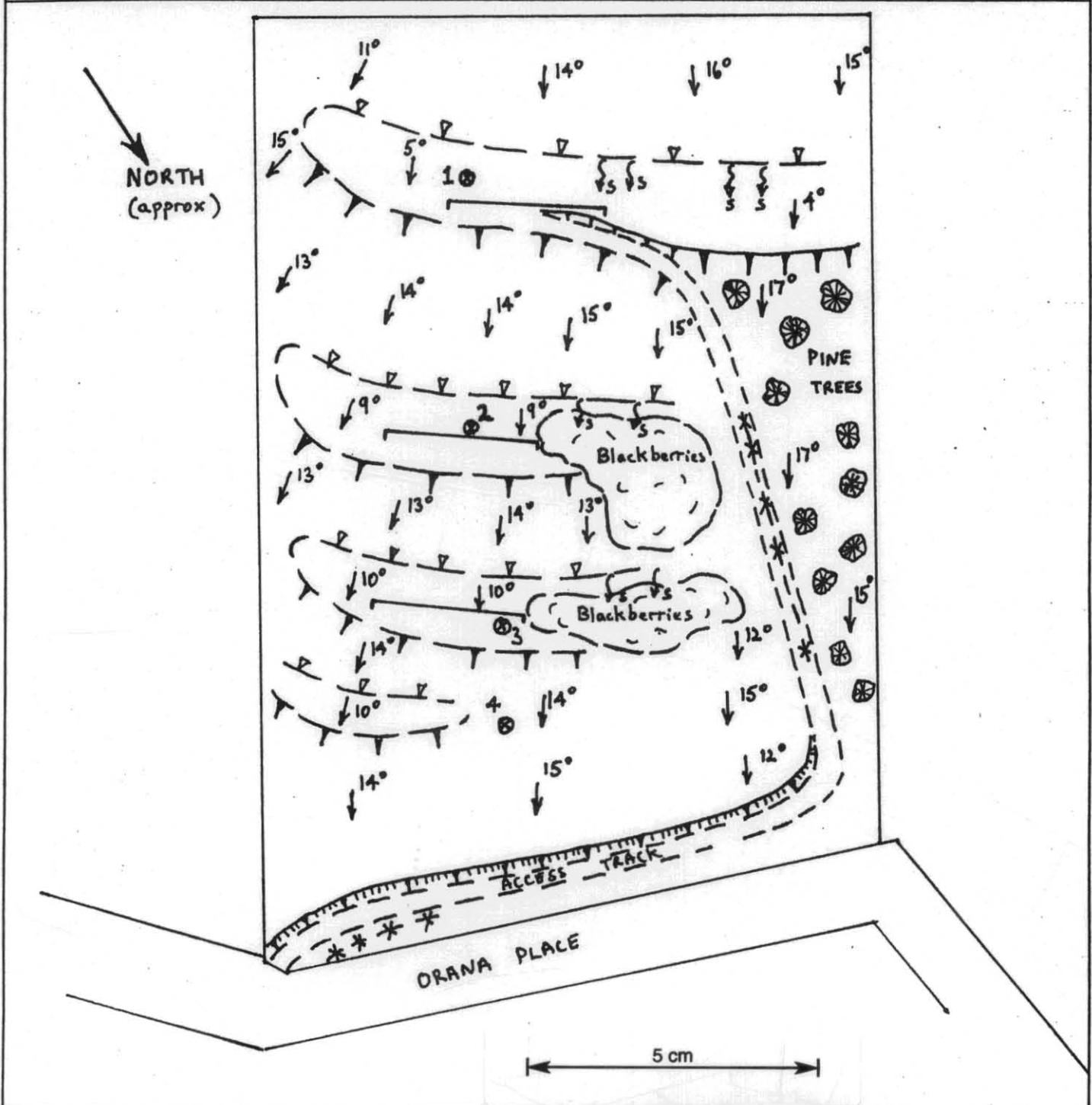
TOPOGRAPHY AND GEOLOGY

The geological map of the area (Longman, 1964) indicates that the area is underlain by Tertiary clay. The area under investigation lies close to the boundary of a Jurassic dolerite body to the west. The overall main Riverside slope represents the escarpment of a major Tamar Graben fault with an approximate northwest-southeast trend.

Surface exposures of high plasticity, brown clay (CH) can be seen in small eroded gullies and embankments adjacent to the access track. Where clay is exposed on the upper bench adjacent to Hole 1, the ground surface shows abundant desiccation cracks.

SITE PLAN

OWNER: T. and R. WELSH STREET/ROAD: ORANA PLACE GEOLOGIST: D. J. SLOAVE
 SUBURB: RIVERSIDE TOWN/CITY: LAUNCESTON DATE: 15/6/87



SKETCH PLAN OF SITE

SCALE: 0 10 20 m APPROX

Seismic Spread
 1 ⊕ Auger hole
 S S Seepage

- Convex break of slope (profile form:)
- Concave break in slope (profile form:)
- Ridge crest
- Gully

- N.A. Suitable area for building
- N.A. Suitable area for septic outfall
- 16° Slope angle and direction

The area under investigation is on the upper part of the escarpment slope. The site has an overall slope of approximately 13°. This overall slope is interrupted by three major benches (fig. 1). The lower benches have a slope of between 9° and 10° while the upper bench has a slope of about 5°. The upper bench has undoubtedly been excavated to a lower slope angle during construction of the access track, and may not be a natural feature. The slope segments which separate the benches are between 13° and 15°. The vegetation indicates that seepage occurs in places at or close to the break of slope at the rear of the benches.

The small slope benches are not laterally consistent and probably represent old landslide features. The slope has been mapped by Knights (1975) as Zone IV of the Tamar Valley Landslip Zone Map, classified as an 'old landslip and adjacent areas'. Stevenson (1972) also reported on the probable existence of a large 'old landslip' adjacent to Orana Place and extending into the northern corner of the lot.

RESULTS OF AUGER DRILLING

Four auger holes have been drilled to depths of between 7.9 m and 8.7 m. The bore logs are presented in Appendix 1. In summary, the materials encountered in the auger holes were high plasticity (CH) clays, brownish grey to yellowish brown in colour. Organic plant and stem fragments were frequently present and the clays commonly contained extremely weathered lithic fragments of coarse sand size. Small ironstone bands were also observed. Most of the samples taken had a moisture content equal to the plastic limit. No free groundwater was encountered during drilling.

The seven undisturbed, 70 mm square, drive tube samples indicated that the clays are fissured and sheared to some extent, with slickensided surfaces evident. Secondary clay cutans occur along many of the fissures and secondary iron mineral coating was observed in some samples. The fissure coatings and shear surfaces indicate that previous disruption of the sediments has occurred, with groundwater movement through the fissures subsequently occurring.

SEISMIC AND MAGNETOMETER SURVEY RESULTS

A seismic spread was fired on each of the three major slope benches. The geophone and shot point spacing was two metres. In summary the results show that bedrock does not occur at shallow depth and clay or sandy clay extends to depths of at least 10 m from the ground surface.

The first layer seismic velocities of 250 m/sec to 280 m/sec extend to depths of about one metre from the ground surface, and are considered to represent unconsolidated material such as topsoil or clay with extensive desiccation cracking.

The second layer velocities varied between 600 m/sec and 870 m/sec. These velocities are consistent with unconsolidated clay and/or sandy clay. The variation in seismic velocity is attributed to variations in the sediment density, water content, and the degree of fissuring of the underlying clay.

A magnetometer survey was conducted along a central profile of the lot, with readings taken at five metre intervals. The survey showed that dolerite bedrock was not present close to the ground surface. The recorded results were subdued, with readings between 61.8 x 10³ and 62 x 10³ gammas.

LABORATORY RESULTS

The results of laboratory testing by R. N. Woolley of the Department of Mines are presented below. Results from an investigation at 9 Orana Place (Sloane, 1987) are also presented.

Table 1. LABORATORY RESULTS

| Hole No. | Depth (m) | Liquid Limit | Plastic Limit | Linear Shrinkage | Internal Friction ϕ' r | Cohesion c' (kPa) |
|----------------------|-----------|--------------|---------------|------------------|-----------------------------|-------------------|
| 2 | 2.7 | 63 | 21 | 16 | 22 | 5 |
| 3 | 3.6 | 78 | 20 | 21 | 15 | 6 |
| <i>9 Orana Place</i> | | | | | | |
| 1 | 5.4 | 73 | 24 | 17 | 16 | 3.1 |

X-RAY DIFFRACTION - CLAY MINERAL ANALYSIS

| Hole No. | Depth (m) | Kaolinite (%) | Gibbsite (%) | Goethite (%) | Montmorillonite (%) |
|----------------------|-----------|---------------|--------------|--------------|---------------------|
| 2 | 2.7 | 75 | 20 | 5 | |
| 3 | 3.6 | 80 | 10 | | 10 |
| <i>9 Orana Place</i> | | | | | |
| 1 | 5.4 | 70-75 | 15-20 | | 5-10 |

The liquid and plastic limit results for the samples are very similar. The results reflect the highly plastic nature of the clays. Linear shrinkage results indicate high shrink-swell characteristics of the materials. These results can be taken as indicative of the clay properties over the entire site.

The laboratory results from slow shearbox testing show a variation. The sample of clay from a depth of 2.7 m in Hole 2 shows much higher results (ϕ' r = 22°, c'r= 5 kPa) than the lower sample from a depth of 3.6 m in Hole 3 (ϕ' r = 15°, c'r= 6 kPa). This latter sample has very similar properties to the sample from a depth of 5.4 m at 9 Orana Place.

The difference in properties is mirrored by the X-ray diffraction analysis results, which show that the lower samples contain 10% of the clay mineral montmorillonite. Montmorillonite has high shrink-swell characteristics and weak interlayer bonding in its structure. The presence of this clay mineral is often conducive to slope failure.

STABILITY ANALYSIS

Stability analysis has been performed on the surveyed slope profile shown on the site plan and the analysis sheets are presented in Appendix 2. The laboratory test results from undisturbed samples have been used in the analysis and the results have been shown above. Cousins Charts (1978), Bishop's (1955) simplified slip circle method, and slab failure calculations (Skempton and Delory, 1957) have been used for stability assessment. The slip circles have been chosen after careful examination of the morphology of the area. The slip circles have been chosen with toes at road level and intersecting the ground surface at the rear of each major bench.

Sheared and fissured clay has been observed in drive tube samples, and the morphology of the area indicates features of previous instability. Therefore residual strength parameters should be used in analysis. The lower values are considered appropriate to use, as any potential failure is likely to involve the weakest materials. The lower values are also favoured because of the similarity with results obtained from 9 Orana Place (Sloane, 1987) to the south.

It is interesting to note that the majority of the thirteen results from the Orana Place area are within the 15° to 19° range for the angle of internal friction. These values approximate to a mean range for the area and therefore it is reasonable to use the lower values obtained from the site, as they fall within the 'mean' range. The values from 9 Orana Place also fall within this range.

The properties used in the stability analysis are shown on the computation sheet included in Appendix 2. The results are shown as Factors of Safety (FS) in relation to pore pressure ratios (ru). A pore pressure ratio of 0.5 occurs when the assumed slip is totally saturated, and a ratio of 0.25 occurs when the slip is half saturated.

In summary, the lowest acceptable factor of safety is considered to be 1.4 to 1.5. The stability analysis results for the three assumed slip circles are shown in the Appendix. Using the residual strength parameters $\phi' = 15^\circ$ and $c' = 5 \text{ kPa}$, the results indicate that the area is potentially unstable unless fully drained conditions can be assured for each slip circle. This indicates that drainage would be required to a depth of at least ten metres. Even using the higher residual strength parameters of $\phi' = 22^\circ$ and $c' = 6 \text{ kPa}$, a suitable factor of safety can only be obtained if drainage to depths of between 4 m and 6.4 m can be assured.

In each of the above cases, drainage to the required depth is considered difficult to achieve. The construction of drains may also have a deleterious effect on stability due to removal of lateral support.

An alternative method of analysis has also been used which considers the potential for planar failure (Skempton and DeLory, 1957) and the results are shown in Appendix 3. Slab thicknesses of 4 m and 6 m have been used, together with the lower residual strength values. A suitable factor of safety can only be achieved if the area is fully drained to depths of 3.2 m and 6 m respectively. Using the higher residual strength values, drainage must still be assured to depths of 1.6 m and 2.4 m respectively.

CONCLUSIONS

Auger drilling, and seismic and magnetometer surveys indicate that the site is underlain by high plasticity (CH) clays to depths in excess of ten metres.

The stability analysis results show that the area is of doubtful stability, even when using residual strength parameters at the extreme upper end of all results from the Orana Place area.

The lower residual strength values which have been obtained from the site are considered to be 'average' values for the area. They are similar to values obtained from an adjacent area. Stability analysis indicates that the area is potentially unstable. Even using the most favourable results obtained from analysis of a 4 m thick potential slab failure, the entire site must be fully drained to a depth of 3.2 m.

When considering the stability results it must be remembered that the site has morphological peculiarities which have been mapped by the author and others as representing old landslide features. Other factors to consider are:

- The presence of fissuring and slickensides indicates previous disruption.
- The site is underlain by high plasticity clays with moderate to high shrink-swell characteristics.
- There is some evidence of seepage on the property which, together with secondary clay and iron mineral deposition along fissures, indicates the movement of groundwater within the clay.

It is also generally considered that long slopes are potentially more unstable than short slopes, and for long term stability the cohesion value should be considered as zero. If this cohesion value is used in the stability analysis, the resulting factors of safety are even lower than those determined in this report.

Previous reports by Sloane (1979, 1980, 1987) all indicate stability problems in the area.

RECOMMENDATIONS

As a result of the investigation it can only be concluded that the property is unsuitable for subdivision and even one house site cannot be realistically recommended.

REFERENCES

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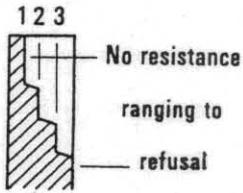
STEVENSON, P. C. 1972. Slope stability at Orana Place, Riverside.
Unpubl. Rep. Dep. Mines Tasm. 1972/14.

[16 October 1987]

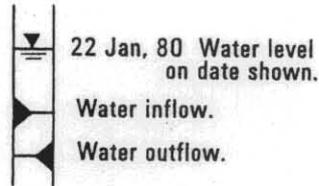
EXPLANATION SHEET FOR ENGINEERING LOGS

Borehole and excavation log

Penetration



Water



Notes - samples and tests

- U50 Undisturbed sample 50mm diameter.
- D Disturbed sample.
- N Standard penetrometer blow count for 300mm.
- N* SPT + sample.

Material classification

Based on Unified Soil Classification System. In Graphic Log materials are represented by clear contrasting symbols consistent for each project.

Moisture content

- D Dry, looks and feel dry.
 - M Moist, no free water on hand when remoulding.
 - W Wet, free water on hand when remoulding.
 - LL Liquid limit.
 - PL Plastic limit.
 - PI Plasticity Index.
- eg. M > PL - Moist, moisture content greater than the plastic limit.

Consistency

- | | | |
|-----|-------------|-------------------------|
| | | hand penetrometer (kPa) |
| VS | Very soft. | < 25 |
| S | Soft. | 25 - 50 |
| F | Firm. | 50 - 100 |
| St | Stiff. | 100 - 200 |
| VSt | Very stiff. | 200 - 400 |
| H | Hard. | > 400 |
| Fb | Friable. | |

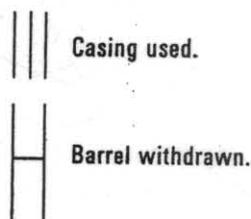
Notes: X on log is test result
— is range of results.

Density index

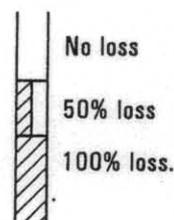
- | | | |
|----|---------------|----------|
| | | % |
| VL | Very loose. | 0 - 15 |
| L | Loose. | 15 - 35 |
| MD | Medium dense. | 35 - 65 |
| D | Dense. | 65 - 85 |
| VD | Very Dense | 85 - 100 |

Cored borehole log

Case - lift



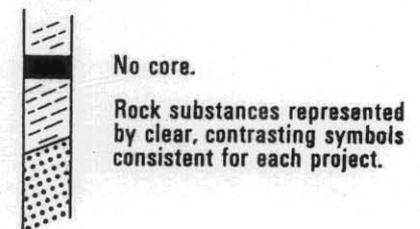
Fluid loss



Lugeons

Lugeon units (μL) are a measure of rock mass permeability. For a 46 to 74mm diameter borehole 1 Lugeon is defined as a rate of loss of 1 litre per metre per minute. 1 Lugeon is roughly equivalent to a permeability of 1×10^{-4} mm/sec.

Graphic log



Weathering

- Fr Fresh.
- SW Slightly weathered.
- HW Highly weathered.
- EW Extremely weathered.

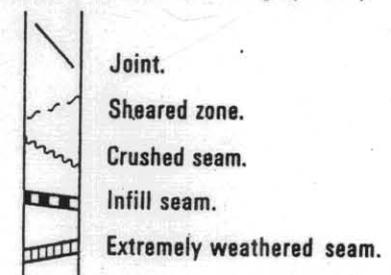
Strength

- | | | |
|----|-----------------|---|
| | | point load strength index $I_{5(50)}$ (MPa) |
| EL | Extremely low. | < 0.03 |
| VL | Very low. | 0.03 - 0.1 |
| L | Low. | 0.1 - 0.3 |
| M | Medium. | 0.3 - 1 |
| H | High | 1 - 3 |
| VH | Very high. | 3 - 10 |
| EH | Extremely high. | > 10 |

Note: X on log is test result.

Significant defects

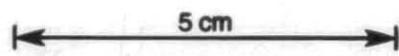
Significant defects shown graphically.



ENGINEERING LOG - BOREHOLE

| | |
|---------------------------------|---|
| project T & R. WELSH | location BORANA PLACE, RIVERSIDE |
| co-ordinates 5073 54159 | drill type TRIEFUS |
| R.L. ≈ 63m | drill method AUGER SCREW |
| inclination VERTICAL | drill fluid |
| bearing | hole commenced 31/3/87 |
| | hole completed 31/3/87 |
| | drilled by DC |
| | logged by DJS |
| | 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 25 50 100 200 400 | structure, geology |
|----------------------|---------|-------|----------------------------|-------------------------|-------------|--------------------------|---|-----------------------|------------------------------|---|--------------------|
| | | | | | | | | | | | |
| | | | | | SM | | Silty SAND: fine-medium, brownish grey | D | L | | |
| | | | D | 1 | CH | | CLAY: High plasticity, brown - brownish grey. Trace fine sand, trace organic matter. | M=PL | Vst | | |
| | | | D | 2 | CH | | CLAY: High plasticity, dull yellowish brown, greyish yellow brown. Trace fine sand, trace organic matter. | M=PL | St | | |
| | | | D | 3 | | | | | | | |
| | | | D | 4 | CH | | CLAY: High plasticity, yellowish-brown trace fine sand, trace ironstone fragments to 5mm. | M=PL | St | | |
| | | | D | 5 | | | | | | | |
| | | | D | 6 | | | | | | | |
| | | | D | 7 | | | | | | | |
| | | | D | 8 | CH | | CLAY: High plasticity, brownish-grey Trace fine sand, trace organic fragments. | M=PL | St | | |
| | | | D | 9 | | | | | | | |

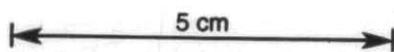


ENGINEERING LOG - BOREHOLE

project T. + R. WELSH location 13 ORAWA PLACE, RIVERSIDE

co-ordinates 5073 54159 drill type TRIEFUS hole commenced 31/3/87
 drill method AUGER SCREW hole completed 31/3/87
 R.L. ≈ 52m drilled by BC
 inclination VERTICAL logged by DJJ
 bearing 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: fine-medium, brownish grey | D | L | | |
| | | D | 1 | | CH | CLAY: High plasticity, mottled greyish yellow brown - brown. Trace fine sand. Trace ironstone fragments | M _z PL | H | | |
| | | D | 2 | | CH | CLAY: High plasticity, bright yellow-brown, brown mottles. Trace fine sand, organic matter. Some fissures. | M _z PL | Vst | | |
| | | UD 70 | 3 | | CH | CLAY: High plasticity, dull yellow orange - yellowish brown. Trace lithic fragments, fine sand and organic matter. | M _z PL | Vst | | |
| | | D | 4 | | CH | CLAY: High plasticity, dull yellow orange - yellowish brown. Trace lithic fragments, fine sand and organic matter. | M _z PL | St | | |
| | | UD 70 | 5 | | CH | CLAY: High plasticity. Dark brown. Trace fine sand and ironstone fragments to 5mm. | M _z PL | St | | |
| | | D | 6 | | CH | CLAY: High plasticity. Yellowish brown - dull yellow orange. Trace fine sand and organic fragments. Trace ironstone veins and fissures. | M _z PL | St | | |
| | | UD 70 | 7 | | CH | CLAY: High plasticity. Dark brown. trace fine sand. | M _z PL | St | | |
| | | D | 8 | | | | | | | |

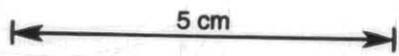


ENGINEERING LOG - BOREHOLE

project **T. & R. WELSH** location **13 ORANA PLACE, RIVERSIDE**

co-ordinates **5073 54159** drill type **TRIEFUS** hole commenced **1/4/87**
 R.L. **≈ 46m** drill method **AUGER SCREW** hole completed **1/4/87**
 inclination **VERTICAL** drill fluid drilled by **Bc**
 bearing logged by **DJS**
 checked by

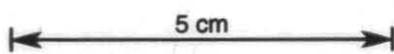
| penetration 1 2 3 | support water | notes samples, tests | metres R.L. depth | graphic log | classification symbol | material soil type: plasticity or particle characteristics, colour, secondary and minor components. | moisture condition | consistency density index | hand penetr- ometer kPa 25 50 100 200 400 | structure, geology |
|----------------------|------------------|----------------------------|-------------------------|-------------|--------------------------|--|-----------------------|------------------------------|---|--------------------|
| | | | | | | | | | | |
| | | | 0 | | SM | Silty SAND: fine-medium, brownish grey | D | L | | |
| | | | 1 | | CH | CLAY: High plasticity. Brown - brownish grey. Occasional reddish brown mottles. Trace fine sand and ironstone to 20mm. | M< PL | Vst | | |
| | | | 2 | | CH | CLAY: High plasticity. Yellow brown - dull yellow orange. Trace fine sand and organic fragments. Some EW. weathered lithic coarse sand particles. Fissures evident with secondary clay coatings. | M≈ PL | St | | |
| | | UD 70 □ | 3 | | CH | CLAY: Moderate plasticity. 20% organic frags. 30% lithic EW coarse sand particles. Dull yellowish brown. | M≈ PL | St | | |
| | | | 4 | | CH | CLAY: High plasticity. Dull yellowish brown. Trace organic matter and lithic EW coarse sand particles. Fissures evident | M≈ PL | St | | |
| | | UD 70 □ | 5 | | CH | CLAY: High plasticity. Brown. Trace fine sands | M≈ PL | St | | |
| | | | 6 | | CH | | | | | |
| | | | 7 | | CH | | | | | |
| | | | 8 | | | | | | | |



ENGINEERING LOG - BOREHOLE

| | | |
|----------------------------------|---|------------------------------|
| project T. & R. WELSH | location 13 ORANA PLACE, RIVERSIDE | |
| co-ordinates 507354159 | drill type TRIEFUS | hole commenced 1/4/87 |
| R.L. ≈ 31m | drill method ANGER SCREW | hole completed 1/4/87 |
| inclination VERTICAL | drill fluid | drilled by BC |
| bearing | | logged by DJS |
| | | 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 25 50 100 200 400 | structure, geology |
|----------------------|------------------|----------------------------|-------------------------|-------------|--------------------------|--|-----------------------|------------------------------|---|--------------------|
| | | | | | | | | | | |
| | | | 0 | | SM | Silty SAND: fine-medium, brownish-grey. | D | L | | |
| | | | 1 | | CH | CLAY: High plasticity. Brown, occ. red brown mottles. Trace fine sand and ironstone fragments to 5cm. | M _c PL | Vst | | |
| | | | 2 | | CH | CLAY: High plasticity. Greyish yellow brown - yellowish brown. Trace fine sand. Some EW lithic coarse sand particles. Some fissures | M _c PL | Vst- st | | |
| | | UD 70 □ | 3 | | | | | | | |
| | | | 4 | | CH | CLAY: High plasticity. Brown. Trace fine sand and ironstone frags. | M _c PL | Vst- st | | |
| | | | 5 | | | | | | | |
| | | | 6 | | CH | CLAY: High plasticity. Dull yellowish brown - greyish yellow brown. Trace fine sand and organic fragments. Some EW lithic coarse sand particles. Some fissures occ. with ironstone lining. | M _c PL | St | | |
| | | UD 70 □ | 7 | | | | | | | |
| | | | 8 | | | | | | | |



APPENDIX 2

Slope stability analysis computation sheets
(Bishop's Simplified method)

SLOPE STABILITY ANALYSIS - COMPUTATIONS SHEET 1 OF 1

NAME WELSH MAP REF. 5063 54158

Y axis (m)

ANALYSIS BY DJS
 DATE
 CHECKED BY P.D.W.

| INITIAL INPUT | | | | SHAPE * | | | | |
|---------------|---------------------|------|-------------------|---------|-----------------|------|----|-----------------|
| STORE | ITEM | | | STORE | ITEM | | | |
| 00 | X L.H.S. | 0 | m | 20 | Y ₁ | 2.0 | 31 | Y ₁₂ |
| 01 | Y L.H.S. | 0 | m | 21 | Y ₂ | 6.3 | 32 | Y ₁₃ |
| 02 | X R.H.S. | 105 | m | 22 | Y ₃ | 10.0 | 33 | Y ₁₄ |
| 03 | Y R.H.S. | 24.5 | m | 23 | Y ₄ | 13.5 | 34 | Y ₁₅ |
| 04 | SLICES | 7 | | 24 | Y ₅ | 17.0 | 35 | Y ₁₆ |
| 06 | GAMMA | 18 | kN/m ³ | 25 | Y ₆ | 20.0 | 36 | Y ₁₇ |
| 07 | C | | kPa | 26 | Y ₇ | 23.0 | 37 | Y ₁₈ |
| 08 | PHI | | degrees | 27 | Y ₈ | | 38 | Y ₁₉ |
| 09 | r _u | | | 28 | Y ₉ | | 39 | Y ₂₀ |
| 10 | Y _{CIRCLE} | | m | 29 | Y ₁₀ | | | |
| 11 | F ₁ | | | 30 | Y ₁₁ | | | |

* Only enter No specified

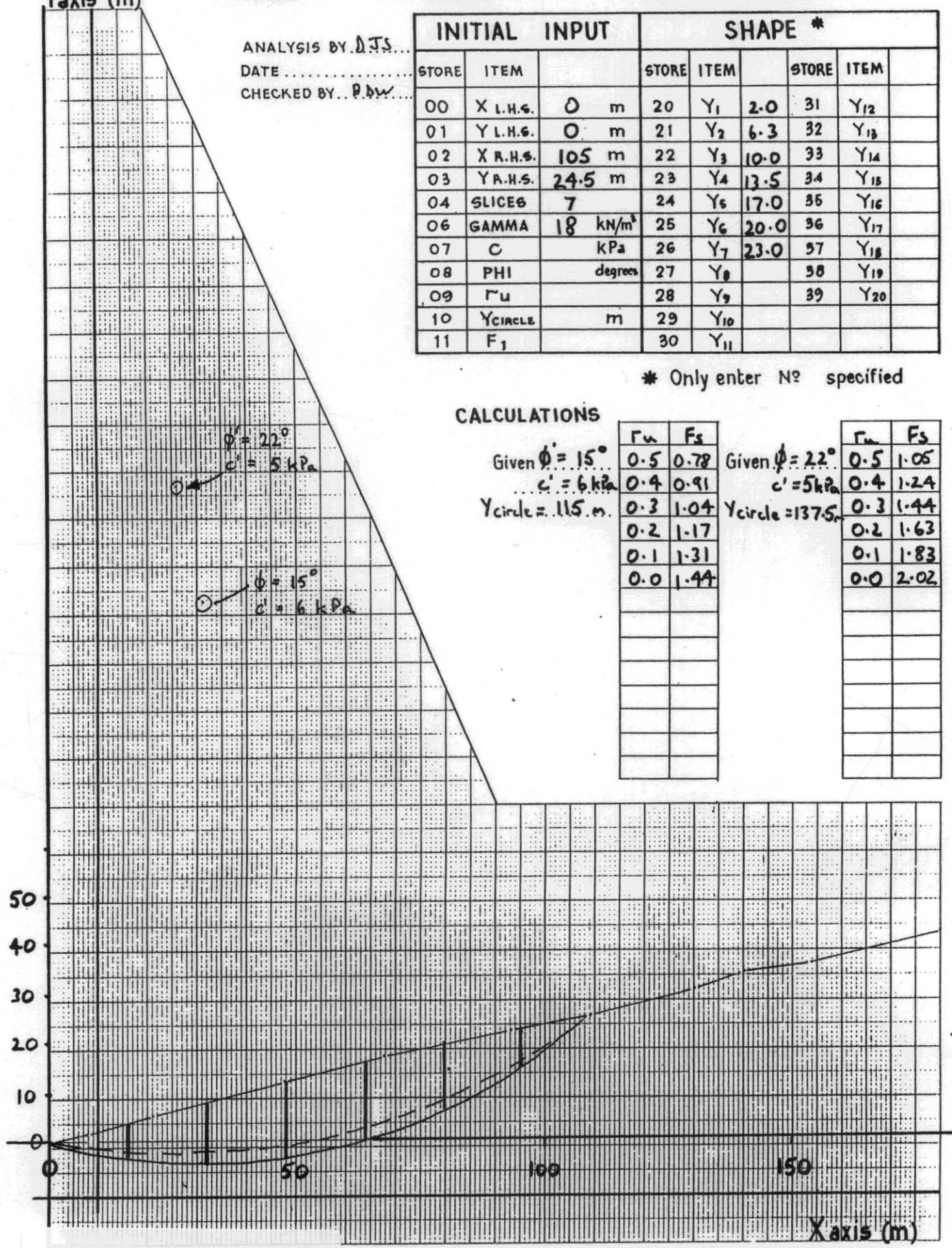
CALCULATIONS

Given $\phi = 15^\circ$
 $c' = 6 \text{ kPa}$
 $Y_{\text{circle}} = 115 \text{ m}$

| r _u | F _s |
|----------------|----------------|
| 0.5 | 0.78 |
| 0.4 | 0.91 |
| 0.3 | 1.04 |
| 0.2 | 1.17 |
| 0.1 | 1.31 |
| 0.0 | 1.44 |

Given $\phi = 22^\circ$
 $c' = 5 \text{ kPa}$
 $Y_{\text{circle}} = 137.5 \text{ m}$

| r _u | F _s |
|----------------|----------------|
| 0.5 | 1.05 |
| 0.4 | 1.24 |
| 0.3 | 1.44 |
| 0.2 | 1.63 |
| 0.1 | 1.83 |
| 0.0 | 2.02 |



5 cm

APPENDIX 3.

Stability analysis - planar failure.

Angle of internal friction = 15°
 Cohesion = 6 kPa
 Density = 18 kN/m³
 Slope angle = 13°

Depth = 6 m Depth = 4 m

| Ru | FS | FS |
|-----|------|------|
| 0 | 1.41 | 1.54 |
| 0.1 | 1.29 | 1.42 |
| 0.2 | 1.17 | 1.30 |
| 0.3 | 1.05 | 1.17 |
| 0.4 | 0.93 | 1.05 |
| 0.5 | 0.80 | 0.93 |

Angle of internal friction = 22°
 Cohesion = 5 kPa
 Density = 18 kN/m³
 Slope angle = 13°

Depth = 6 m Depth = 4 m

| Ru | FS | FS |
|-----|------|------|
| 0 | 1.96 | 2.07 |
| 0.1 | 1.78 | 1.88 |
| 0.2 | 1.59 | 1.69 |
| 0.3 | 1.41 | 1.51 |
| 0.4 | 1.22 | 1.33 |
| 0.5 | 1.04 | 1.15 |