

UR1977\_54

1977/54. Slope stability in the Bell Bay port area.

R.C. Donaldson  
C.J. Knights

*Abstract*

The stability problems associated with the development of the Bell Bay Port area are due primarily to the general instability of the natural slopes in the area. The instability and failures are associated with the pre-basaltic moderately plastic, fissured clays. Excavations and loadings in these clays are subject to progressive failure, as the stresses are concentrated in existing weaknesses which have little cohesion and lead to failure. The sections which are now failing are probably at their fully softened state, whereas clay in the unfailed sections are closer to peak strength. Proposed excavations in the course of future development will require additional investigation to determine the exact nature of the materials present.

## 1977/54. Slope stability in the Bell Bay port area.

R.C. Donaldson  
C.J. Knights

The Port of Launceston Authority requested an investigation of the Bell Bay port area [DQ885460] following several stability problems that have arisen during the course of development. Instability is prevalent on both the natural and artificially constructed slopes, and in areas associated with fill material, causing concern to existing and proposed development (fig. 1).

## GEOLOGY

The physiography of the Bell Bay port area is characterised by an extensive plateau lying approximately 40 m a.s.l., and which terminates in a prominent escarpment with steep slopes to the River Tamar. Extensive talus and landslide debris deposits drape much of the area, obscuring the underlying geology. However both subsurface investigations (Skeats, 1922; Maunsell and Partners, 1973; Soilab, 1960) and exposed sequences in the railway cuttings and quarry on the escarpment have provided information on the stratigraphic succession in the immediate port area.

The geology of the Bell Bay area comprises a non-marine sequence of interbedded Tertiary sediments underlying up to 20 m of basalt. A veneer of unconsolidated sand, clay and gravel deposits, with associated minor laterisation, overlies the basalt.

The pre-basaltic sediments consist of an interbedded sequence of clay, carbonaceous silty clay, sandy clay, clayey sand, sand and grit. Fossil leaf impressions occur within the carbonaceous horizons. The sediments are largely unconsolidated and the upper surface crops out towards the base of the escarpment at elevations of between 20-30 m a.s.l. The beds are essentially horizontal, but show considerable local variation in attitude. Bore log interpretation has indicated lenticular bedding to be a common feature. Jointing is well developed in places, particularly in the carbonaceous silty clay horizon immediately underlying the basalt exposed in the quarry. The total thickness of the sequence is unknown. However Bore Hole 8 (Soilab 1960) penetrated sediments up to 40 m below sea level, at which depth the hole was terminated.

Basalt disconformably overlies the lower Tertiary sediments and forms the greater part of the prominent escarpment, where it acts as a resistant cap to erosive processes. The irregular relief of the pre-basaltic erosion surface has resulted in a highly variable distribution of basalt. Despite considerable lateral and vertical variation in the degree of weathering, fracturing and jointing, and overall thickness of the basalt, evidence suggests that only one flow is present.

The contact between the basalt and underlying Tertiary sediments is exposed towards the base of the quarry at approximately 19 m a.s.l. and at several other locations along the length of the escarpment. Baking of the underlying sediments at the contact is minimal, extending for several centimetres.

Generally speaking, the base of the basalt flow at Bell Bay, although locally highly irregular, lies near to or above the 16 m level (approximate R.L. of upper railway sidings) but has been noted occurring as high as 30 m a.s.l. (chainages 780 and 1170)\*. A notable exception occurs at about Ch800

\*Chainages from Port of Launceston Authority survey (fig. 1).

where basalt has infilled a narrow channel, the extension of which has been intersected in two bore holes (Soilab 6 and 9) sited near the No. 3 wharf. Basalt was encountered to depths of 10 m below sea level. Variations in the base of the flow are known to differ by as much as 40 m, with thickness ranging from 5-20+ m.

When fresh, the basalt is a dense dark blue-grey rock. Jointing is variable and irregular, ranging from massive to fractured. The rock decomposes to a blue to brown clay, the weathering being typically erratic and extending to depths of up to 20 m (table 1).

A surficial deposit of post-volcanic unconsolidated sand, clay, quartz gravel and lateritic horizons disconformably overlies the basalt and forms the present surface of the plateau. These sediments appear to have a maximum thickness of about 3-4 m.

#### GEOLOGICAL CONDITIONS IN AREAS OF POTENTIAL FUTURE DEVELOPMENT

##### RE-ROUTING OF MAIN ACCESS ROAD [Ch00-Ch300]

The proposal to re-route a section of the existing main access road leading to the Bell Bay port area has resulted from the repeated failure of sections of the pavement.

A seismic refraction survey was carried out along the alignment of the proposed new road section in an attempt to delineate the range of foundation conditions present. An assessment of the degree and depth of the weathering of the basalt was also required to ascertain the depths to which the basalt was capable of being ripped by a large machine.

A total of three spreads, two with geophone intervals of 5 m and the third at 4 m, were set out as shown in Figure 1. The results of the survey (table 1) indicate that the seismic velocities fall into three separate groups, which are considered to be indicative and consistent with the velocities expected from the materials exposed in the nearby road cutting. They also correlate well with previous seismic interpretations of the Bell Bay area (Cromer and Sloane, 1977). The three velocity groups have been interpreted as follows:

<i>Seismic velocity (m/s)</i>	<i>Geological interpretation</i>
350- 650	Dry unconsolidated sediments.
700-1150	Highly to moderately weathered fractured basalt.
3000-5000+	Slightly weathered to fresh dense basalt.

During excavation for the proposed new road, a thin sequence of dry unconsolidated sediments (gravel, sand and clay) may be expected to occur to depths of 3 m, underlain by a variable thickness (10-20 m) of weathered basalt. It is anticipated that rippable material will be present to below the estimated depths of excavation.

The interpretation of the three spreads was:

*Spread 1.* A thin veneer of dry unconsolidated sediments overlie a variable thickness of rippable weathered basalt which increases in depth towards the east to a maximum of 17 m. Below this depth is fresh basalt.

Table 1. SUMMARY OF SEISMIC REFRACTION SURVEY

Spread No.	Velocity layer	Seismic velocity (m/s)	Average layer thickness (m)	Geological interpretation
1	1	550	1.7	Dry, unconsolidated sediments.
	2	700- 950	10.9-14.4	Very weathered basalt.
	3	3000-5000	-	Relatively fresh to fresh basalt.
2	1	500- 600	1.0-1.5	Dry, unconsolidated sediments.
	2	750-1050	14.7-20.3	Highly weathered, fractured basalt.
	3	5000+	-	Fresh dense basalt.
3	1	350	2.8	Dry, unconsolidated sediments.
	2	700-1150	12.1-14.1	Weathered fractured basalt.
	3	5000+	-	Fresh dense basalt

*Spread 2.* A relatively uniform thickness of surface gravel, sand and clay to between 1-1.5 m. Weathered basalt extends to depths ranging from a maximum of 23 m (western end) up to 15 m (eastern end). An unknown thickness of fresh dense basalt is present below these depths.

*Spread 3.* Between 2-3 m of the unconsolidated sediments lie disconformably over a layer of weathered basalt extending to depths of 12-17 m below the surface gravel and sand horizon. Solid fresh basalt exists below this depth.

#### MARSHALLING YARD EXCAVATION [Ch330-Ch680]

A steep cut has been excavated behind the marshalling yard and it is proposed to cut back further to increase storage space.

The excavation is in stiff, grey, fissured clay of medium plasticity, containing minor horizontally bedded sand and ironstone of variable thickness. A thin and discontinuous capping of basalt occurs at the top of the slope. Although the cut is only one year old, the south-western two-thirds is failing badly, despite the remedial measures of surface and subsurface drainage.

Fissured clay, such as that occurring in this cutting, is difficult to deal with, as the peak strength is far greater than the residual strength and it is subject to progressive failure. The clay appears to be tough, but cohesion is low along the cleavages and reduced to near zero when wet. In cuttings in fissured clay, the stresses are concentrated in existing weaknesses until there is a localised failure; greater stress is then put on adjacent material, which in turn will fail. In this way a cutting may take years to fail, but its ultimate stability will be controlled by its fully softened state, with cohesion close to zero (Bjerrum, 1967; Skempton, 1964).

Examination of old contour plans (Skeats, 1922) show that around where the present cutting is failing, the ground used to be stepped with plateaux and steeper scarps, which suggest large landslip structures. The section which is presently stable is situated in what was a minor spur, which is

likely to have previously been stable. The section of the cutting which is now failing was probably at its fully softened state, or even residual strength, before excavation, whereas clay in the unfailed section was closer to its peak strength.

The failed section of the cutting is likely to continue to fail and to retreat, particularly following periods of extended wet weather. The unfailed section of the cutting will undergo progressive weakening and can be expected to fail eventually. It would be prudent to attempt drainage and strengthening measures now, as it will be more difficult to stabilise once failure has occurred. An investigation of the whole excavation is needed to design a safe long term slope, cut at an appropriate batter, with effective surface and subsurface drainage and possibly with retaining structures.

*Suggested investigation*

The slope should be designed on the basis of soil strength parameters and measured pore pressures. Slope stability analysis will not be of use unless there is realistic field data on groundwater conditions.

Near the failed slope section, residual  $c'$  and  $\phi'$  values should be used. Near the unfailed section residual  $c'$  and peak values of  $\phi'$  may be used.

*Drilling.* Elsewhere in the Tamar Valley, dry auger drilling supervised by a geologist has been found to be a useful and inexpensive method of investigating the clay, as it allows appreciation of the soft zones and seepages which are intercepted. Where there is free water, piezometric pressures can be measured. Sections of particular interest can be studied in undisturbed tube samples. Holes should be drilled at intervals of 7 m to 15 m along the back of the existing proposed cut.

*Surface and subsurface drainage.* By plotting the depth to wet zones and seepages intercepted by the drilling, a program of horizontal drains can be designed. A surface drain is needed along the crest of the cut and all drains should be lined.

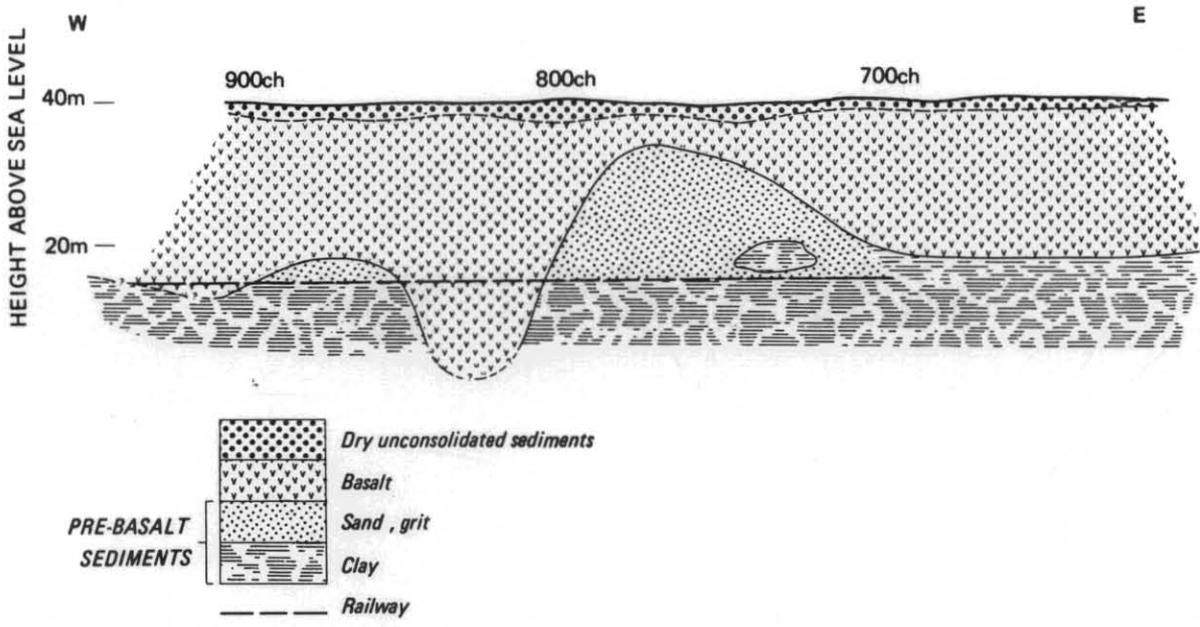
*EXCAVATION OF ESCARPMENT [Ch780-Ch900]*

Requiring additional resources for use as fill material, the Port of Launceston Authority wished to determine the nature of materials likely to be encountered in the escarpment west of the existing basalt quarry.

The 10-20 m thickness of fresh, jointed basalt exposed in the quarry face thins rapidly upwards at the western extremity, where it is reduced to a veneer of weathered basaltic clay overlying a local topographic high of pre-basaltic sand and grit (Ch720-Ch780). Exposure along the escarpment west of this point is poor, due to the extensive basalt float draping the slope.

The geological conditions considered to exist west of the quarry, are shown in Figure 2. The locally high relief of the pre-basaltic sediments exposed in the escarpment between Ch720 and Ch780 forced the basalt to flow around either side, infilling a narrow channel at about Ch800.

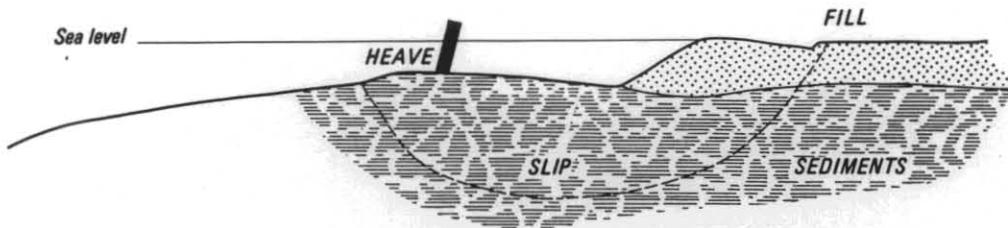
From Ch820-Ch900, there is reasonable evidence to suggest that a similar set of geological conditions to that occurring in the quarry will be encountered. At the bottom of the escarpment [R.L. 16.0 m], basalt crops



DIAGRAMATIC SECTION ALONG ESCARPMENT BELL BAY

R. C. DONALDSON

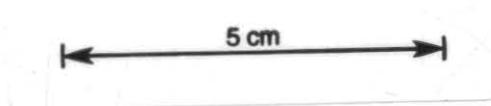
FIGURE 2



DIAGRAMATIC SECTION SHOWING MECHANISM OF FAILURE OF FILL AND MOVEMENT OF DOLPHINS

C. J. KNIGHTS

FIGURE 3



out in the northern embankment of the railway line, while it overlies sediments in the southern embankment and defines the base of the basalt flow. This indicates that the base of the basalt, although locally irregular and undulating, can be expected to occur at about this altitude during excavation.

A second interpretation of the geology west of the quarry must warrant consideration. The topography of the escarpment between Ch820 and Ch900 suggests a past history of mass movement in the form of landslip. The features are subdued by the extensive undergrowth and talus deposits. If one accepts that movement has taken place, then one may equally well argue that the basalt exposed in the railway cutting represents a massive block of displaced basalt. Thus the sediments may in fact be present at a higher elevation than suggested, and perhaps similar to the landslip situation represented at Ch1170.

It is also possible that the basalt forms a shallow flow down the slope and over the clayey sands, in which case any excavation is likely to cut back through a veneer of basalt into the underlying sediments.

Due to the extensive basalt float obscuring much of the underlying geology, it is recommended that a short drilling programme precede any proposed excavation in order to verify the actual situation.

#### *MOVEMENT OF DOLPHINS AND FAILURE OF FILL [Ch815-Ch970]*

In this zone, the mooring dolphins, which are founded in Tertiary sediments about 13 m below river level, are tilted inward towards the shore. This movement suggests a deep seated failure of the substratum, as the direction of tilt is opposed to that which would be caused by the pulling of ships.

The fill material which makes up the reclaimed land shoreward of the moving dolphins has also failed. These two factors are probably connected (fig. 3). By this mechanism, loading by the fill causes gradual displacement of the underlying sediments and a consequent heave in the adjacent zone. The rate of displacement increases as embankment failure is approached, but with time, pore pressures are able to dissipate and the situation becomes more stable.

If the movement continues, the best remedial method is to load the heaving toe area around the dolphins with boulders.

#### *PROPOSED EXCAVATIONS BEHIND NO. 5 BERTH [Ch1220-Ch1540]*

Excavation is proposed to provide more storage space near No. 5 berth. Some excavation has already been undertaken in the vicinity of Ch1370 and this shows relatively minor cutting failure in stiff silty clay and iron cemented sand.

Cutting back in the area west of Ch1370 is unlikely to present major difficulties, although there will be problems of the type already encountered at Ch1370. Care should be taken to provide good, lined surface drains and to vegetate the cut slope.

#### *LANDSLIP ZONE BETWEEN Ch1140 AND Ch1350*

Large old and recently active landslips which extend from the shoreline back to the rear escarpment occur in this area (fig. 1). The eastern part of this area has been active within the last few years, when it damaged the road to the George H. Evans berth. ~~Work on this area was undertaken by~~

Maunsell and Partners (1973).

The western part of this area consists of a large old landslide, with the typical features of a heel, a back sloping heave area and a toe. There are no signs of recent movement and the slip may have been stable for a considerable period of time, possibly thousands of years. The proposed excavation will cut back into, and therefore unload, the toe of this slip, and may well reactivate a very large area.

Little outcrop is available for detailed geological interpretation in the old slip area. However the basalt in the heel scarp appears to be thicker than that further south-east. BH 418 (Maunsell) indicates a thickness of 14 m. Sections of the basalt in the heel area are totally decomposed to a grey clay, but it is only normally weathered and oxidised in the railway cutting. This cutting shows that the base of the basalt unevenly overlies clayey silt, with large tongues of silt swept up into the basalt. Maunsell and Partners did not investigate the western landslide and the proposed excavation between Ch1230 and Ch1350 should definitely not be undertaken without a thorough stability investigation of the whole section from the storage yard to the upper plateau. Such an investigation should be designed to locate the basal failure zone of the old slip and the lesser failed zones, to locate aquifers and measure pore pressures and to study the geology and soil mechanics properties. Initial investigation below the base of the basalt can be undertaken by auger drilling in the railway cutting and by taking undisturbed samples by drive tube, where appropriate. Upslope drilling requires a method which does not need water to sample the underlying sediments. This can be done by using down-the-hole hammer to drill the basalt and then using cable tool in the sediments. Dry drilling of the sediments will allow zones of seepage and aquifers to be located. Piezometric pressures should be carefully measured, particularly those from the basal slip plane. Previous experience in the Tamar Valley indicates that the basal slip plane of large, deep landslips is marked by an aquifer containing pressure water and often by very soft materials.

From these investigations, it should be possible to assess the effect of removing the toe of the slip with some accuracy.

#### GENERAL SUGGESTIONS FOR FUTURE SUBSURFACE INVESTIGATIONS

As there are rapid facies changes within Tertiary sediments, any drilling which has continual sampling, either disturbed or undisturbed, rather than intermittent sampling, is of greater value. When core logging is undertaken by a geologist, particularly one with an overall understanding of the project, there is a far greater likelihood of being able to tie the various bore logs together and avoid the problems of mis-identification of decomposed basalt and clay, or of weathered basalt and ironstone etc. These problems have become apparent in attempting to correlate logs from previous workers in the area.

When stability problems are involved, it is necessary to obtain reasonably accurate information with regard to soft zones, seepages and groundwater. This can best be done by using dry methods of drilling, such as by augering, intact sampling or cable tool.

When groundwater is intercepted, the exact depth of interception should be recorded and slotted casing installed into the hole.

CONCLUSIONS

*Marshalling yard excavation*

The south-western two-thirds of this cutting is already failing badly and is probably located in an old slip zone. The slope should be designed using residual shear strength parameters and measured pore pressures.

The north-eastern section is presently stable, but will be subject to progressive weakening. The slope should be designed on fully softened strength parameters.

Good lined surface drainage is needed for the whole cutting, with subsurface drainage into located seepages.

*Proposed excavation of escarpment [Ch780-Ch900]*

Excavation is likely to encounter a locally undulating sequence of Tertiary sediments (sand and clay) towards the base of the escarpment overlain by a variable thickness of basalt. A deeper channel of basalt is considered to exist near Ch800.

A drilling programme should precede any excavation to verify the above interpretation.

*Movement of dolphins and failure of fill*

These two phenomena are connected, as loading of fill onto relatively weak sediments causes gradual displacement of the sediments, and consequent heave of adjacent areas.

*Proposed excavation behind No. 5 berth*

West of Ch1370, the excavation is unlikely to present major difficulties although there will be cutting failure of the type already encountered.

East of Ch1370, the proposed excavation will cut the toe off a large old landslide, thus risking large scale instability. This excavation should not be undertaken without thorough investigation.

REFERENCES

BJERRUM, L. 1967. Progressive failure in slopes of overconsolidated plastic clay and clay sheets. *Proc.Am.Soc.Civ.Engrs* 93 (SM5):1-49.

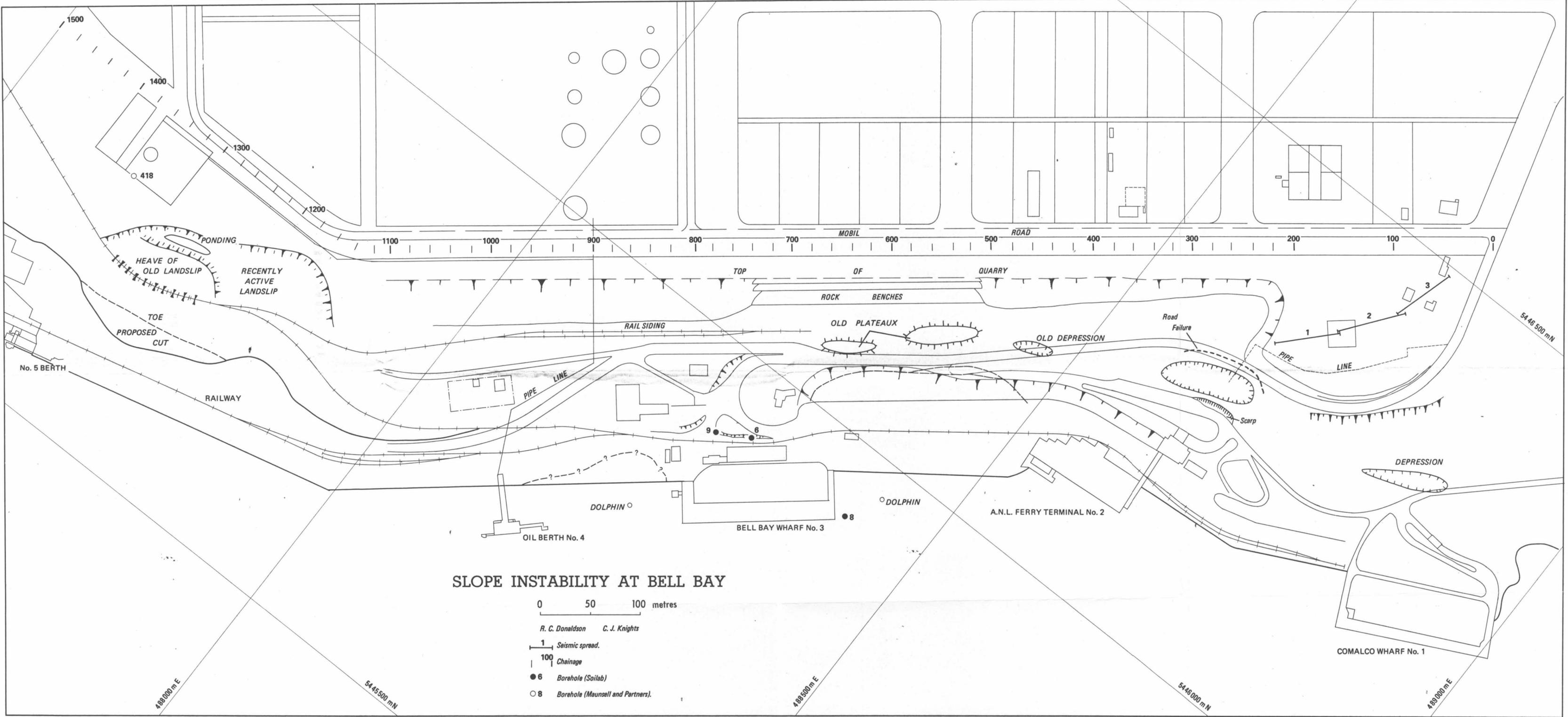
CROMER, W.C.; SLOANE, D.J. 1977. Site stability investigation for a proposed storage tank at Bell Bay. *Unpubl.Rep.Dep.Mines Tasm.* 1977/10.

MAUNSELL AND PARTNERS. 1973. *Bell Bay Railway project. Final report on investigation of slope stability at Bell Bay.* (unpubl.).

SKEATS, E.W. 1922. Report on the geological conditions at the Bell Bay site, Tamar estuary, as affecting the question of its suitability as a future deep water port for Launceston. *Daily Telegraph, Launceston* 42(161):8. (Report to Marine Board, Launceston).

SKEMPTON, A.W. 1964. Long-term stability of clay slopes. *Geotechnique* 14: 77-101.

SOILAB PTY LTD. 1960. [Logs of boreholes drilled 4 May 1960 to 31 August 1960 in the Bell Bay port and industrial area].



### SLOPE INSTABILITY AT BELL BAY

0 50 100 metres

R. C. Donaldson C. J. Knights

1 Seismic spread.

100 Chainage

● 6 Borehole (Soilab)

○ 8 Borehole (Maunsell and Partners).

5 cm

FIGURE 1

254 x 115 B142-2333