


Division of Mines and Mineral Resources — Report 1991/04

Land stability assessment of an urban block in Alexander Street, Leith

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Abstract

In 1976 the then Department of Mines assessed the suitability of a block of land at Leith for building purposes, and it was recommended that no building be permitted. In 1990 the land was reassessed and a stability analysis carried out using the results of drilling and soil laboratory testing. It is considered that the risks associated with the development of this block remain unacceptably high.

INTRODUCTION

The Division of Mines and Mineral Resources involvement in this undeveloped urban block at Alexander Street, Leith (fig. 1) dates back to 1976, when at the request of the then Devonport Municipal Council, an assessment was required as to the block's suitability for building purposes. It was recommended that no building be permitted, as the land was situated within an old landslide feature, the slopes were steep, and were therefore considered to be potentially unstable.

In 1978 the Division undertook, as part of a regional landslide risk mapping project, to drill a hole on the property in order to obtain data on the soil profile and physical characteristics of the soil. The findings have been used as a basis for the input parameters used in the stability analysis in this report.

In 1990, the Division was again approached by Mr and Mrs Kent, the owners of the land, for a re-evaluation of the land on the basis that the extensive planting of vegetation, the installation of an 'envirocycle' effluent treatment system, and the use of reinforced concrete pile footings would ensure a stable site and therefore building approval.

MORPHOLOGY

The morphological history of the Forth-Leith region is complex. One feature which remains prominent and has affected residential development in this area is landslide activity. The majority of the hillslope which rises to the east of the River Forth between the townships of Leith and Forth has been subject to extensive mass movement (landsliding) in the past. The age, type and scale of movement varies from the very old (fossil) large-scale rotational slumps to more recent, active, shallow

translatory earth flows. The latter are frequently found developed parasitically on the steeper slope segments within the fossil landslide complex.

The land under discussion is sited on the steep headscarp of a prominent old rotational landslide which exhibits the typical or characteristic features — disturbed hummocky ground, localised depressions, and back-sloping benches which are frequently associated with multiple slumping.

The basic slope segments measured on the Kent's land range from a minimum of 15° through to 26°; the surveyed profile is shown in Figure 2. Basically the land progressively steepens downslope from Braddons Lookout Road (Alexander Street) before the slope eases slightly to the bottom boundary fence, which coincides with the base of the headscarp. The slope is simple, with no pronounced micro-relief, and there are currently no obvious signs of active movement on the lot.

LANDSLIDE ZONING

Landslide activity in the Forth-Leith area has been recognised for many years. With the advent of increasing pressure towards urban development in this region in the early 1970's, the Division produced a provisional landslide risk zone map in 1974. The land was divided into areas of active or dormant movement (charted 'A' landslide zone), areas of potential movement (charted 'B' landslide zone), and stable areas. The land under discussion was placed in an 'A' landslide zone, as it lies within an area previously subject to landslide movement. Whilst no such renewal of activity has occurred in recent times, the slope is considered to be in a state of marginal stability, therefore potentially liable to movement under certain conditions.

GEOLOGY

The red-brown soils which are a prominent feature along the northwest coast of Tasmania are derived from basaltic rocks of Tertiary age. Tertiary sediments (sand, gravel etc.), usually of the order of a few metres thick, are often found interbedded with the basalt.

A hole was augered by the Division at the top of the slope on the eastern boundary of the Kent's land in 1978. This hole encountered 13 m of dark red-brown soil which

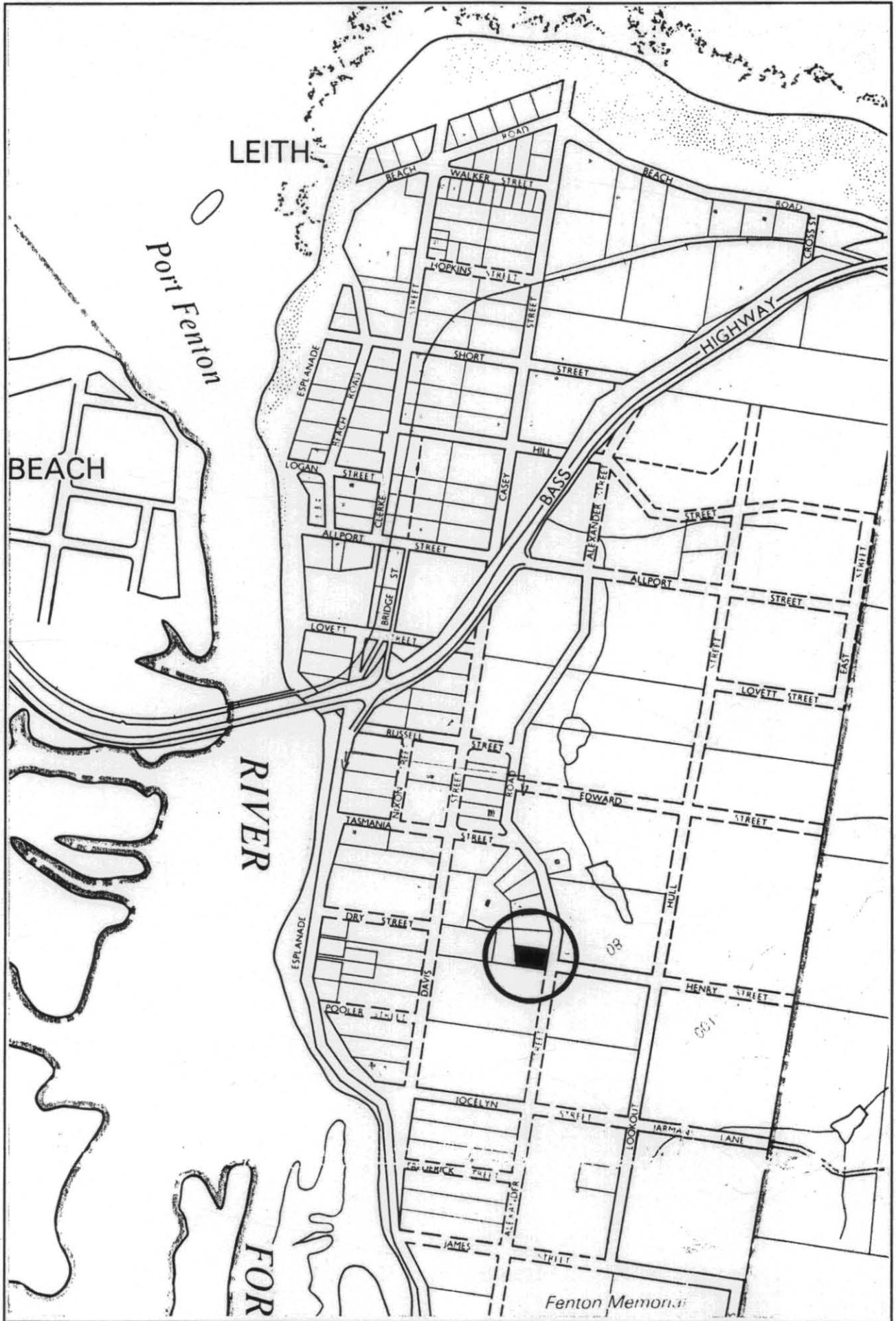


Figure 1. Location of Ken's block, Alexander Street, Leith [Scale 1:10 000]

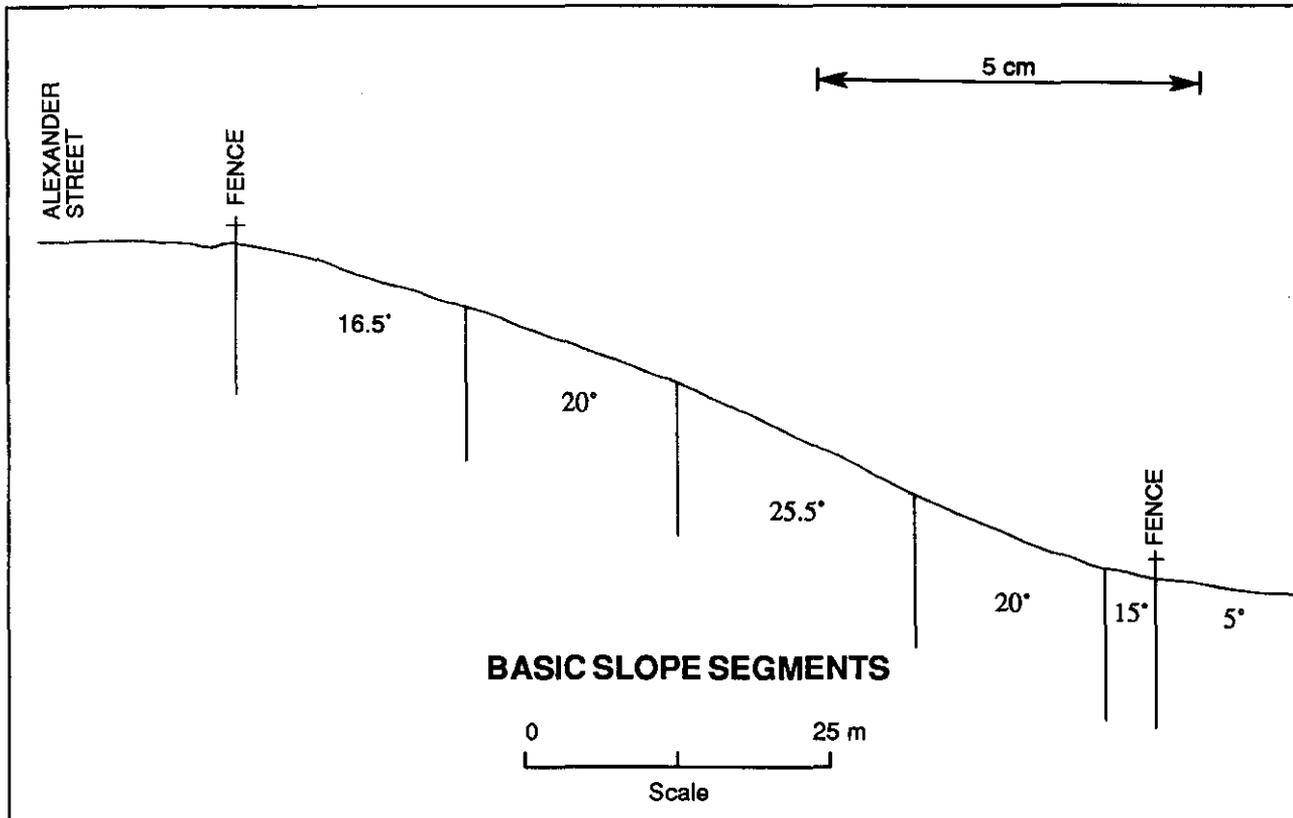


Figure 2. Surveyed profile and slope segments.

remoulds to a high plasticity clay. The profile was similar over the entire depth; there were no signs of bedrock or Tertiary sediments.

A series of test pits located in the main body of the old landslide complex below (to the west) the Kent's land were dug for the Division in 1977. These pits encountered a similar red-brown soil profile which, in some cases, graded down to an extremely to highly weathered vesicular basalt with very low strength properties.

The difference in elevation between the drill hole collar at the top of the slope and the test pits on the land below the headscarp is of the order of 25–30 metres. The actual total depth of soil overlying bedrock on the Kent's property is not known, but drilling has shown it to be greater than 13 metres.

SOIL TESTING

A series of soil tests were performed on samples obtained from the auger drilling to determine the physical properties and characteristics of the samples. The results are tabulated below.

Shear Box (Soil Strength) Determinations

Depth	ϕ'	c'
7 m	29°	2 kPa
11 m	30°	4 kPa

ϕ' = angle of internal friction
 c' = cohesion

Atterberg Limit (Plasticity) Determination

Depth	LL	PL	LS
7 m	152%	38%	26%

LL = liquid limit
 PL = plastic limit
 LS = linear shrinkage

XRD (Clay Composition) Determination

Depth	Kaolin	Goethite	Halloysite
7 m	70%	20%	10%

With respect to the soil strength values, basalt soils tend to fall into two basic groups; those relatively high-strength soils with little variance between the fully softened and residual state ($\phi' = 30^\circ$ and 28° respectively), and the lower strength, more sensitive soils with a large variance between fully softened and residual values ($\phi' = 21^\circ$ and 10°). It is evident that the soils tested from this location belong to the higher strength group of soils. This does not preclude, however, that the more sensitive soils are not present over the site.

The Atterberg Limits indicate that the soils are highly plastic over a wide moisture range and also have extremely high shrinkage–expansion characteristics.

The XRD results show a dominance of kaolin in the clay fraction of the sample. The absence of montmorillonite has possibly attributed to the relatively high ϕ' values.

STABILITY ANALYSIS

Bishop's simplified method for circular failures was used to determine the factor of safety (FS) of the slope under a variety of conditions. A profile showing the critical failure plane (i.e. slip surface associated with the minimum FS against shear failure, and derived from Figure 3) is presented in Figure 4. The maximum depth of the calculated critical slip surface is about 7 metres.

Initial input parameters (measured) were as follows:

angle of internal friction $\phi' = 29^\circ$
 cohesion $c' = 2 \text{ kPa}$
 unit weight = 19 kN/m^3
 pore pressure ratio $r_u = 0$.

Based on these initial input figures, a FS ≈ 1.5 was calculated.

A FS value less than 1.0 indicates the certainty of slope failure given the input conditions. Conversely, FS values greater than 1.0 indicate a progressively increasing level of confidence as to the stability of the slope. A FS = 1.5 has been adopted as being the minimum acceptable level to confidently predict a long-term stable house site.

On the factual information available, the land in question is on the borderline with respect to an acceptably stable building site. The calculated value of ≈ 1.5 is for an $r_u = 0$ situation. In other words, the piezometric level (or water table) is situated below the slip plane. This is the most stable situation that can exist.

Sensitivity analyses were carried out to observe the effect of varying water table conditions from the $r_u = 0$ situation to $r_u \approx 0.5$, which indicates fully saturated soil conditions. The latter can typically occur following a prolonged or short duration high-intensity rainfall period. The results are presented in Figure 5 (see discussion later).

There is sufficient documented evidence to indicate that strength contributed by tree roots is important to the stability of a slope. The contribution of tree roots to shear strength may be treated as cohesion. This 'artificial' soil cohesion provided by the roots can reportedly contribute up to 10 kPa. In response to this, a variety of c' values (up to 15 kPa) were input to observe the effect with respect to the overall FS.

Figure 5 demonstrates the interaction between varying r_u and c' values in relation to the FS. Basically the graph shows a decreasing FS with increasing pore pressure (r_u), and an increasing FS with increasing cohesion (c'). The trends are as expected, but what is of relevance is that even with $c' = 10 \text{ kPa}$ (a five-fold increase above the measured value), the end result is still only a FS = 1.0 under fully saturated soil conditions of $r_u = 0.5$.

DISCUSSION

Experience has shown that land sloping at 14° or steeper and underlain by basaltic soils is the most prone to instability. Evidence supporting this can be seen by observing the numerous shallow slides which have developed on similar slopes along the northwest coastal region. Several slides are currently active further along the slope towards the township of Forth. Thus there is the possibility that shallow-seated earth flows (say one metre or so in depth) may develop on almost any slope segment of the Kent's land at some future date.

The proposal put forward by the Kent's to plant out the slope with trees at close centres should be considered as a positive aid to increasing the overall stability. There is little doubt that trees enhance slope stability and reduce erosion rates. The mechanical reinforcement provided by the tree root systems is the major factor in increasing stability by means of 'artificial' cohesion. Trees also modify the soil moisture distribution and restrict direct infiltration of rainwater by interception and transpiration from the foliage. In other words, trees can delay the onset of waterlogged or saturated conditions in the soil.

Studies in New Zealand have shown that young forests begin to substantially increase slope resistance to shallow failures and surface erosion between 5–10 years after establishment.

The relevant point with respect to the above is the time lag factor, and that the vast majority of tree-root systems are comprised largely of a network of lateral roots which lie within a metre or so of the surface. Below this depth are the vertical tap roots which are far less numerous. In short, vegetation has certain limitations; it is effective in helping prevent shallow slope failures and reducing erosion rates after an initial period of establishment, but it is not effective in arresting deep-seated mass movements due to increased cohesion.

The stability analysis has indicated a maximum depth of about seven metres for the calculated critical slip surface, in other words, a deep-seated failure below the effect of vegetation. For deep-seated failures, the soil mass will generally be saturated, with the major cause of failure being an increase in pore water pressure (r_u) consequent to an adverse change in groundwater conditions after recharge.

Landslides on steep slopes are strongly correlated with high precipitation and storm activity. The crucial question to this whole matter is: does slope vegetation attenuate pore pressure or limit rise in piezometric levels during a major and prolonged rainfall sufficiently to make any difference, especially with respect to deep-seated failure?

The question of the effectiveness of an envirocycle effluent treatment system to avoid localised waterlogging of the soils as do conventional sewage systems and the proposed pile footings are sound in principle, but in this case will add little to ensuring a stable house site. The bottom line is that under certain rainfall conditions the site would, in our opinion, become unstable irrespective of the manner in which the sewage effluent etc. was dispersed.

CONCLUSIONS

- Field studies show that landslides are prone to develop in basaltic soils on slopes greater than about 14°. The land in question has slope angles ranging from a minimum of 15° to 26°. There is, therefore, from field evidence alone, the potential for landsliding to occur in the future.
- Vegetation does play an important role in helping stabilise soils to shallow depths. However, it is not considered to be effective to any significant degree in reducing the potential for deep-seated failures.
- Deep-seated failures are driven primarily by a rise in piezometric level as a result of groundwater recharge

following a significant rainfall event. The stability analysis shows that given the initial input parameters, the slope would become unstable ($FS < 1$) with $r_u = 0.3$ or greater. There is the potential for this situation to arise, in our opinion, following such a period of heavy rainfall.

- Finally, based on all the evidence available, there is no guarantee that in the long term the slope will maintain $r_u = 0$ conditions. As such, it is considered that there is an unacceptably high level of risk associated with guaranteeing a long-term stable house site. It is therefore recommended the land remain undeveloped.

[25 February 1991]

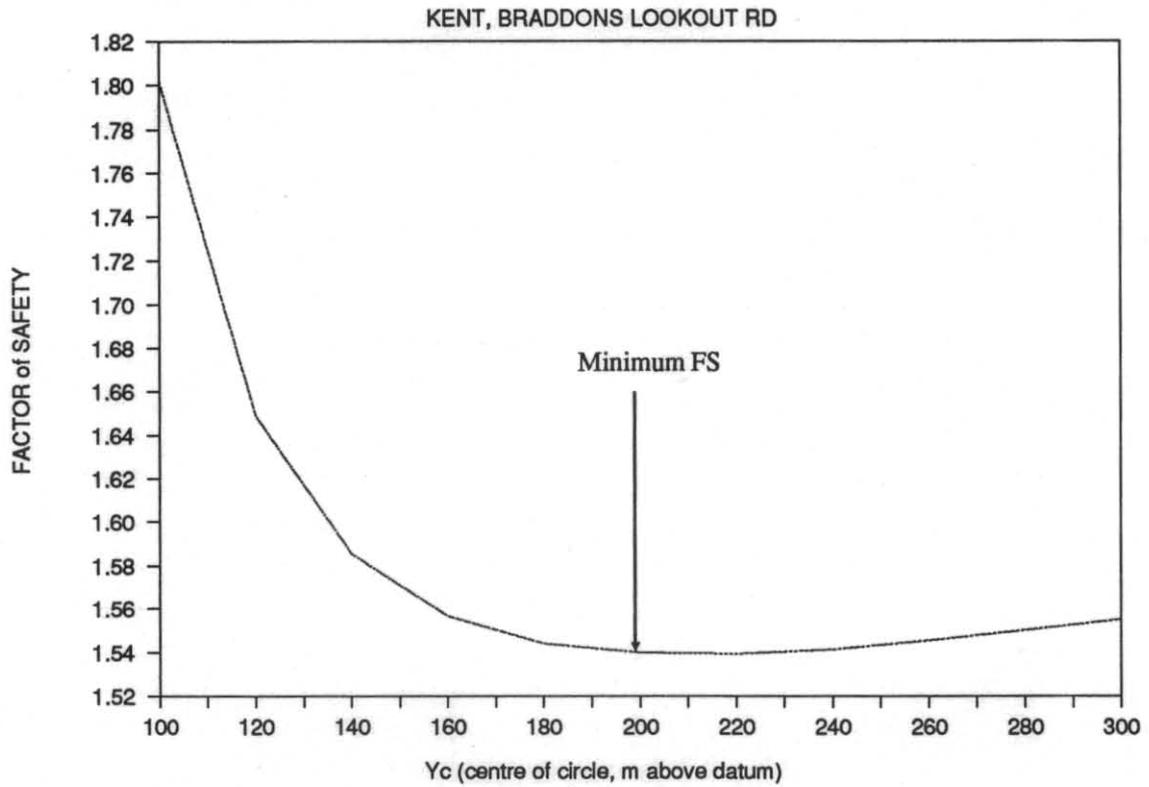


Figure 3. Y circle determination

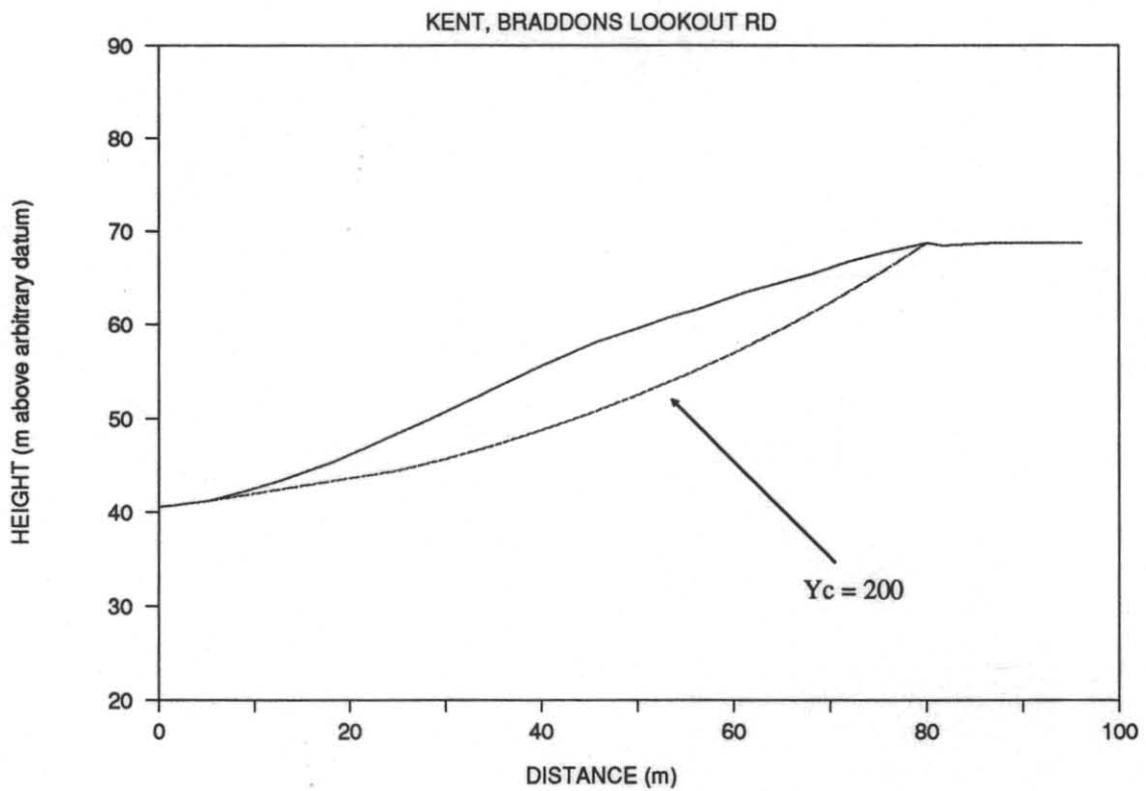


Figure 4. Profile — critical failure plane

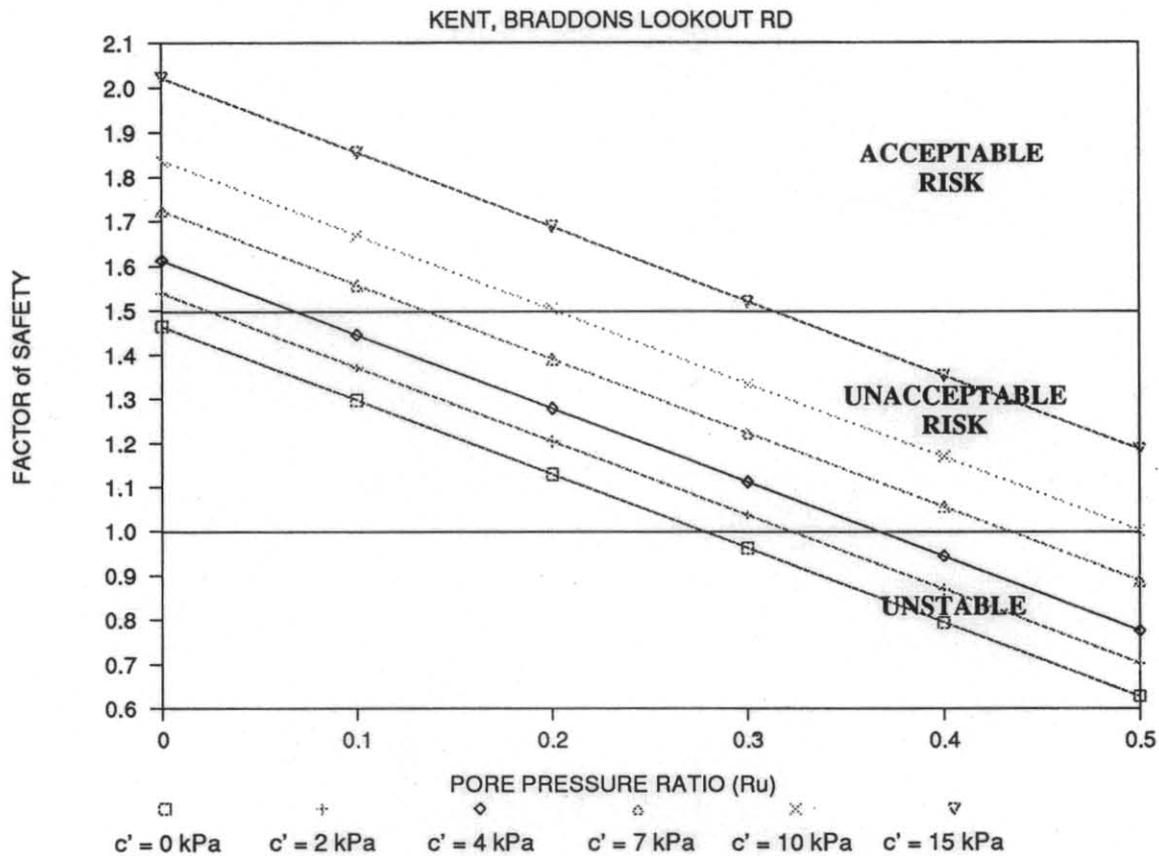


Figure 5. Sensitivity analysis, $\phi' = 29^\circ$

