Slope Failure in a Complex Volcanic Terrain Opito Bay, Kuaotunu, Coromandel Peninsula

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The Ohinau Drive slope failure has occurred at the northern base of the volcanic Tahanga Hill, Opito Bay. The failure has affected a recent subdivision on Ohinau Drive situated immediately adjacent to the hill.

The slide is a complex, variable depth failure encompassing several differing geological units. It extends a distance of 170m from headscarp to toe with an estimated maximum width of 130m. It comprises both shallow seated and deep seated failure mechanisms to a maximum depth of approximately 20m.

In the winter of 1996 slope instability was recognised following development of a headscarp and ongoing disturbance to kerbing and manholes.

Investigations undertaken revealed complex geological conditions generally comprising hydro-thermally altered andesite partially overlain by basaltic debris and weathered basalt lava. Artesian water pressures were encountered within the andesite. The investigation results indicate that both a deep seated failure through the underlying andesite and a shallow seated movement involving the basalt debris were recently active.

A geotechnical model was constructed along 2 cross sections with computer aided stability analyses undertaken. Target groundwater levels were determined to achieve a satisfactory Factor of Safety to allow future subdivision development. Drainage installation and monitoring is yet to be established following liaison with Council.

1 INTRODUCTION

The Ohinau Drive slide is located at Opito Bay in the eastern extent of Kuaotunu Peninsula, north eastern Coromandel Peninsula. (Figure 1) The slope failure has developed largely beneath vacant lots of a recent subdivision extending southward into a Pine plantation covering Tahanga Hill (Figure 2).

At the time of the author's involvement the failure presented as a non-catastrophic event, but one which, if left, might progress to damage far more seriously the existing roading and drainage infrastructure, and to damage future houses that might, if permitted at all, be built on the subdivision. The purpose of the author's involvement was to analyse the failure and to provide advices upon possible stabilisation measures to achieve geotechnical factors of safety consistent with the territorial authority's expectation for issue of house building consents without restraint or restriction.

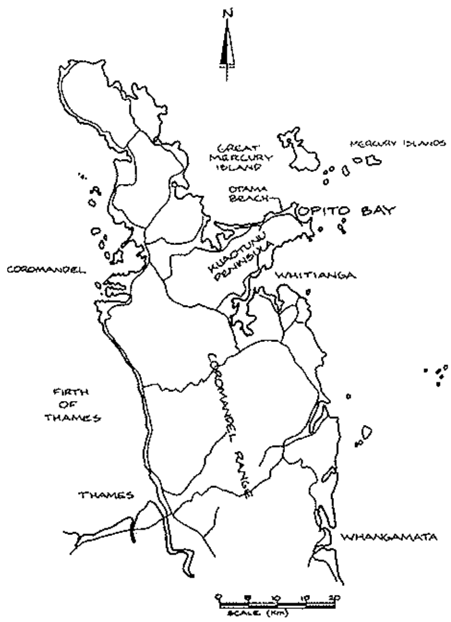

Figure 1 – Locality Plan

Subdivisional earthworks were undertaken in the late 1980's removing up to 5.0m from an existing ridge line at the base of Tahanga Hill for the purposes of forming Ohinau Drive and the subdivision. However the subdivision was not completed until 1993-1994 and the first signs of ground movement are reported as having occurred in the latter part of 1995 when minor displacements in concrete were put down to poor civil works construction.

However in 1996 concrete work displacements were more pronounced, and a significant headscarp developed about 40 metres upslope from the nearest residential lot boundary. Closer inspection disclosed ground heave 170m downslope from the headscarp plus a variety of evidence of very small amounts of relative movement within the street works as if the road was being shunted over a considerable length but without incurring massive overt damage.

Upon a surveyor's check lot boundary pegs placed in 1993 were shown to have undergone lateral movements of up to 0.5 metres. By using GPS survey methods useful comparisons of the original boundary peg positions with their displaced positions were able to be made, and these were periodically rechecked at approximately six monthly intervals. This provided information on the extent and direction of the slide, revealing a somewhat fan shaped effect.

It included an unexpected movement in one survey mark at the centre of a quite deep local gully (labeled western gully in figure 2) indicative of deep seated movement sufficient to carry the whole overlying topography as a block.

By agreement with the owner the local authority imposed S.36 (2) Building Act encumbrances on all land titles deemed to be affected, to remain until such time as the land could be satisfactorily stabilized.

Section 36(2) of the Building Act 1991 allows territorial authorities to issue building consents on properties subject to subsidence provided the building work will not accelerate, worsen or result in subsidence. Such an encumbrance typically detrimentally affects the property value and insurance cover.

2 LANDSLIDE INVESTIGATION

Whilst a complete definition of the lateral extent, depth and interfaces between the various units has not been determined, a geological/geotechnical model was developed with a reasonable degree of confidence.

Two phases of investigation were undertaken. An initial investigation in 1997 was performed by Worley Consultants Ltd (1997). The second stage of investigation was undertaken by Riley Consultants Ltd (RCL) in 2000. Results of the second stage were presented in Riley Consultants Ltd (2001).

The initial RCL investigation comprised a review of existing information including borehole logs, piezometer and land survey monitoring records. From this a preliminary subsurface investigation programme was planned. During the investigation the location of boreholes and test pits were altered as the exploration continued.

A total of 5 machine boreholes, 4 hand auger boreholes and 5 test pits were drilled and excavated over these two phases of investigation conducted by WCL and RCL.

A walkover appraisal and review of pre-earthworks topographical plans was also undertaken.

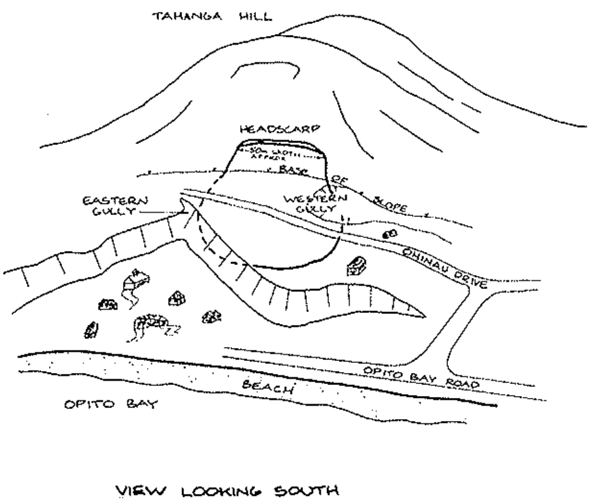

Figure 2 – Perspective View

No s dertaken adjacent to the headscarp as permission from the neighbouring land owners was not forthcoming.

The objective of the investigations was to assess the subsurface conditions and identify possible failure surface(s).

3 GEOLOGY AND SUBSURFACE CONDITIONS

The geology of the general area has been described by Skinner (1976) and in more recent times Hawthorn (1996). The area generally consists of the basaltic Tahanga Hill surrounded by a mixture of basalt lava/plugs and thick andesite lava deposits.

Geology of the area investigated was found to be more complex than shown on available geological plans with several materials encountered north of the basaltic Tahanga Hill (Figure 3). In stratigraphic (chronographic) order the following units were encountered:

Fill
Encountered adjacent to the eastern gully. Inferred to be remnants of a stockpile created during earthworks. Typically firm to very stiff silt with topsoil layers.

Alluvium
Firm to very stiff clay and silt, found beneath the fill within the eastern gully.

Surface Debris
Consisting of basalt gravels, cobbles and boulders in a silt/clay matrix. Encountered at the northern base of Tahanga Hill and interpreted to extend beneath the adjacent Ohinau Drive. This material was encountered to a depth of nearly 11.0m.

Weathered Basalt
Highly weathered products of basalt lava, very stiff to hard inferred to be filling an ancient palaeovalley.

Lacustrine Deposits
Stiff silts and clays encountered forming a "buttress" at the landslide toe. These deposits included minor quantities of coarse quartz/flint and rounded mudstone.

Hydrothermally Altered Andesite
Underlying the basalt and outcropping north of Ohinau Drive, the andesite was typically of stiff to very stiff consistency.

Andesite
Basement rock inferred to underlie the entire subdivision. This is hydrothermally altered and whilst typically of very weak rock strength, is sheared and of soil strength in places. Artesian water pressures were encountered in this material in 1997.

Failure Planes
Failure surfaces are often not easily detected in recovered core however a distinct failure surface was encountered in drillhole R1 at the base of the basaltic debris where it contacts the underlying andesite consisting of a striated slickenslide. A failure surface was also observed in a test pit excavated in the toe heave zone, with movement of highly weathered hydrothermally altered andesite over lacustrine deposits.

4 LANDSLIDE CHARACTERISTICS

4.1 Geomorphology

Topography near Ohinau Drive is dominated by the 212m elevation basaltic peak and associated lava flows. A concave depression is evident on the steep sided slopes with a hummocky landscape below. A review of the topographical plan from 1974 (prior to earthworks) indicates a large "tongue" of material below (north) of this concave depression and the most recent scarp. This "tongue" feature has been obliterated by recent earthworks.

North of Ohinau Drive consists a flat to gentle graded area created by earthworks where up to 5.0m was cut from a pre-existing ridge line. A heave zone of approximately 150mm height is evident in this area.

4.2 Failure Surface

From the earlier study by Worley Consultants Ltd it was postulated in the RCL report (2001) that either of two failure mechanisms could exist: a) a shallow failure surface involving movement of the surface debris, b) a deep failure through the underlying andesite. However, a failure along either one of the surfaces alone was not entirely consistent with the surficial expressions of movement (eg deflection of boundary pegs, location of tension cracks etc). Despite this inconsistency the combination of borehole information and surface observations did not indicate any plausible alternative failure scenarios.

Accordingly it is concluded that the movement was attributed to one or a combination of the following two basic failure mechanisms.

- **Surface Debris Failure**
  Reactivation of ancient slip debris moving over the underlying andesite. This failure explains relatively large boundary peg movements (in the order of 0.5m) in Lots adjacent to Tahanga Hill and the development of a tension crack in the basaltic material at the base of Tahanga Hill. However, this failure mechanism does not explain the andesite toe heave north of Ohinau Drive or movement at the andesite western gully base.

- **Andesite Failure**
  Deep failure within the andesite along shear zones or clay seams as identified in cores. This failure mechanism is thought to have been active in winter of 1996 and is consistent with toe heave.

  Both failure surfaces are shown on Figure 4.

4.3 Recent Movement and Groundwater

The 1996 mass movement appears to have been strongly influenced by highly localised artesian groundwater pressures in combination with subdivision earthworks that removed approximately 5.0m of earth from the toe area. Two boreholes drilled into the andesite in 1997 encountered artesian water pressures, although 3 others did not. It is inferred that the location of such water pressures is dependant upon defects within the andesite, some of which were evident in drill core recovered. Water levels within the surface debris were also found to be high (within 2.5m of ground surface during winter months, probably at or close to ground surface at the time of failure).

5 DRAINAGE

A single horizontal bored drain was installed in mid 1997 with an outlet in the eastern incised gully. The 65m long bored drain targeted the zone of andesite artesian water pressure located centrally below the landslide mass. The effect of this drain was a substantial reduction in groundwater levels; approximately 1.7m and 8.7m within the surface debris and andesite respectively. However, the effect was localized to the central area and other areas showed no significant drops in water level that can be directly attributed to the bored drain.

Upon completion of the initial drainage relief bore, which comprises 75mm steel casing, the driller's bucket-measure estimate of flow was 27,000 litres/hour. At 4 months later a careful bucket-measure established a flow of 8,000 litres/hour, and 3 years later the flow had reduced to a steady 2,400 litres/hour and which rate continues. Unrelieved pressure from an artesian source of this magnitude in moderately steep topography is clearly a major destabilizing factor. However since the installation of that first relief bore no discernable ground movement has occurred.

6 STABILITY ANALYSES

A series of computer assisted stability analyses were undertaken for both failure surfaces. Effective stress strength parameters were determined from back analysis of the existing slope movement and considered judgment of soil characteristics. Effective stress strength parameters assumed for the failure plane within the andesite were c'=2kPa and Ø'=15°

The analyses indicate that groundwater pressures within the underlying andesite are critical to the slope stability.

It was determined that lowering sub-basal (andesite) groundwater levels to between 5m and 7m below ground surface will achieve a the Factor of Safety between 1.4 and 1.5. As often occurs with large scale failures, such as through the andesite, relatively large changes to groundwater levels are required to achieve significant changes in the Factor of Safety.

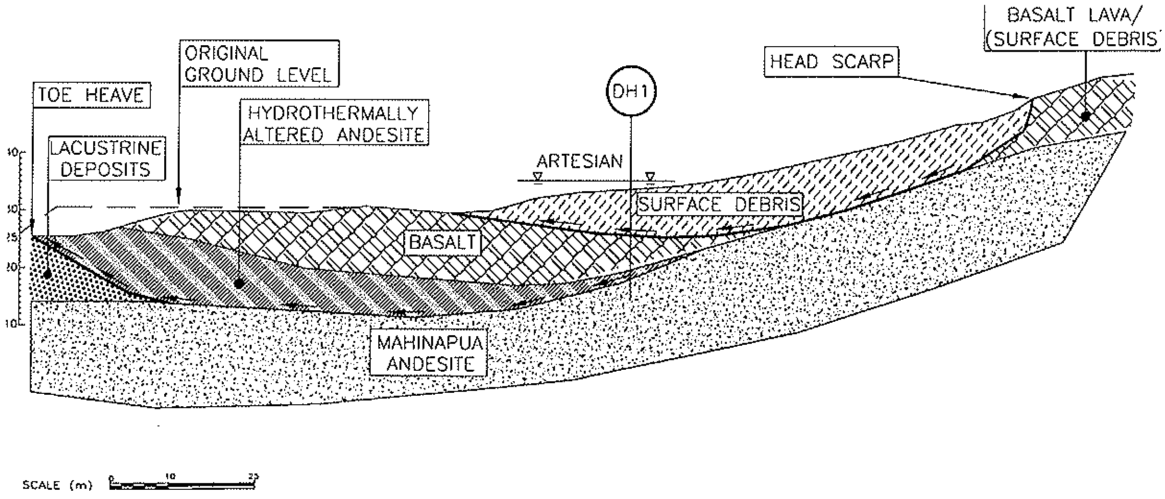

Figure 4 – Geological Cross Section of Ohinau Drive Failure

Within the shallow basaltic debris an assessed FOS exceeding 1.5 can be achieved by lowering groundwater levels below 4.0m from ground surface.

7 FUTURE DEVELOPMENT

It is proposed to install counterfort (buttress) drains within the surface debris to minimize the risk of saturation and achieve a Factor of Safety in excess of 1.5.

Large diameter bored drains are the preferred drainage method for the andesite drilled from the slope toe. Achieving a Factor of Safety in excess of 1.5 for the underlying andesite is considered impractical given the slope gradients and depth of drawndown required. A Factor of Safety of 1.4 is the recommended objective. With no dwellings with the main movement area, nor immediately adjacent, any settlement caused by drainage is considered unlikely to affect existing structures.

Alternative methods of stabilization have been considered, such as toe buttressing. However, these are generally impractical and/or provide insignificant improvements in the Factor of Safety.

Successful performance of the drainage systems is essential in order to maintain groundwater at depressed levels consistent with acceptable factors of safety. The local authority is expected to be concerned with the manner in which the drainage is monitored long-term, but it may be reluctant to carry out such monitoring function itself. Methods of involving the property owners, perhaps by means of a special body corporate, are being considered whereby the groundwater levels (using the existing piezometers) are regularly checked and reported upon. In return for the proposed extra drainage measures and an acceptable ongoing monitoring arrangement it is intended that the local authority lift the S.36 Building Act title encumbrances.

Even though the artesian water source is, and presumably will be, ever-present within the affected land it need not limit the usefulness of the building sites now that the local geology and the predictive geotechnical stability have been established. On this basis this particular slope failure, fortunately caught before extensive damage could occur, will have been successfully resolved.

Maintenance of the piezometers and bored drains could be carried out by a body corporate.

8 CONCLUSION

A large, deep seated failure within complex volcanic terrain has affected a recent subdivision in Ohinau Drive, Opito Bay. Investigation of the movement indicates possible multiple failure mechanisms following heavy rain and removal of toe weight.

Stability analyses indicate that satisfactory Factors of Safety can be achieved by subsurface groundwater drainage. It is proposed to install a combination of counterfort and bored drains.

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