Relic Slip Verification Study – Tauranga District

D H Bell
Senior Lecturer in Engineering Geology
University of Canterbury, Christchurch

L Richards
Rock Engineering Consultant
The Old School House, Ellesmere, Canterbury

R Thomson
Consulting Geologist
Cromwell, Central Otago

Abstract: A study carried out by the authors in late 2000 using air-photo interpretation, supplemented by field checking, identified more than 2000 features of actual or probable landslip origin within the volcanic and fluviatile/estuarine deposits of the Tauranga District. Information has been transferred to the Council GIS database using a series of 1:5,000 base plans, and the data analysed to assess debris runout distances and scarp height/depth (V:H) ratios. Earlier studies had shown that a cliff zone defined by a ratio of 1V:2H effectively predicted the area of concern for slope stability assessment, and these so-called hazard zones were adopted by Council despite inevitable plotting errors. Our studies from a much more robust data set have generally confirmed the 1V:2H zone for cliff-top regression, but have also shown a significantly greater travel distance for debris runout than previously anticipated with an overall travel angle between 1V:3H and 1V:4H (18-14°). Although less than 1% of the landslips identified are currently active, the presence of relic slips remains a major issue for land development in Tauranga and reporting guidelines have been developed for geotechnical practitioners.

INTRODUCTION

The study described here was initiated by Tauranga District Council in late 2000, with the specific aims of 1) reviewing the existing landslip data on Council's GIS database; 2) carrying out a photogeological interpretation of various aerial photograph runs flown between 1943 and 1997; 3) transferring the new information to the Council database using 1:5,000 plans with 2m contour interval; and 4) assessing the geotechnical implications arising from these new data. A study by Houghton and Hegan (1980) had previously identified some 250 relic slips in the Tauranga City area which had been plotted onto a 1:40,000 base map, but subsequent errors in transferring this information to Council's GIS database had resulted in plotting errors up to 50m in plan location. The landslip features that had previously been plotted were principally located along steeper cliff lines, either those being actively undercut by wave action or forming abandoned slopes cut originally by marine or fluvial processes. The present study has focused on all landslip features identifiable using an extensive air-photo data set comprising ten different runs flown between 1943 and 1997, and the photogeology was carried out by one of the authors (R Thomson) whilst limited field checks were carried out by two of us (D Bell & R Thomson) as part of the relic slip verification process. Detailed analysis of the data obtained was then completed by the third author (L Richards) to establish vertical height:horizontal distance (V:H) relationships as part of the overall geotechnical evaluation for Council. This study integrates the new data on landslip features with the overall geology of the Tauranga area (Briggs et al, 1996), and an interpretation of landslip failure models derived from work at Maungatapu Peninsula by Oliver (1997).

PHOTOGEOLOGY STUDIES

The geology of the Tauranga area comprises a sequence of older volcanic rocks including dacites, rhyolites and ignimbrites ranging in age from about 2.5 to 0.5Ma, together with associated fluviatile and estuarine sediments of the Matua Subgroup (c.2.0-0.05Ma). Younger airfall tephras, including the Hamilton Ash (0.35-0.1Ma) and Rotoehu Ash (c.50ka), overlie the landscape and drape a series of terraces reflecting progressive basin development and sea-level fluctuations during the Quaternary. The stratigraphy of the area is complex, and for most practical purposes can be considered (from oldest to youngest) as the Matua Subgroup/Tauranga Group, Hamilton Ash, Rotoehu Ash and the Post-Rotoehu Ash Tephras, each of which has distinctive geological and geotechnical characteristics.

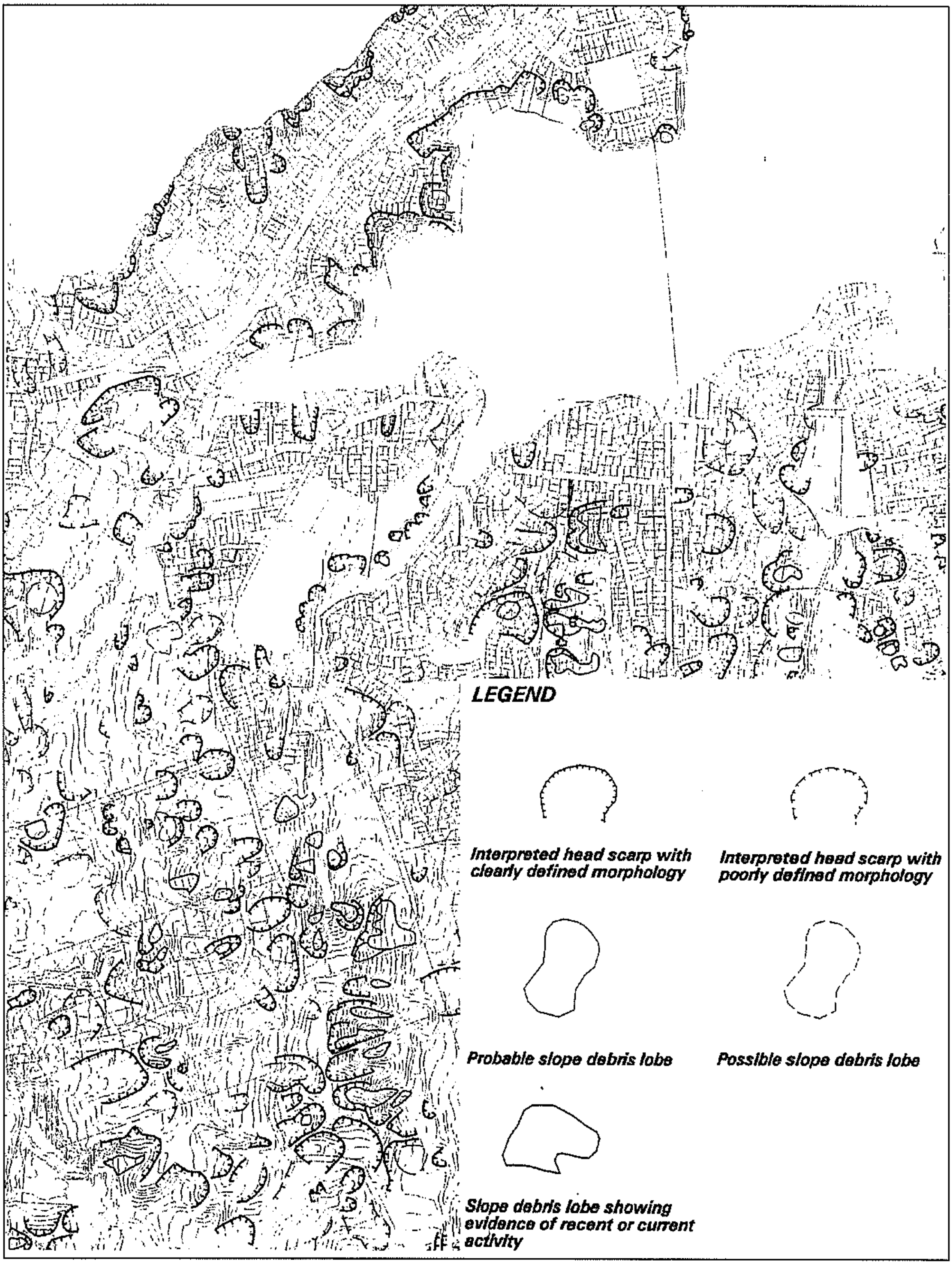

Figure 1. Part of 1:20,000 GIS Compilation for Tauranga Showing Mapping Procedure and Legend. [Note that original map is colour-coded to identify specific feature types].

A total of ten black-and-white aerial photograph sets were provided by Tauranga District Council for this study, these being flown in February 1943, January 1959, December 1971, September 1973, January and June 1975, May 1977, October 1978, March/April 1997, and March/June 1997. Many of the photo scales were between 1:2,000 and 1:6,000, and most were greater than 1:20,000, making recognition of relic landslips relatively straightforward even though many were only arcuate features from which all debris had been removed (Figure 1). The classification system used to describe the relic slips was, after field checking, recorded as follows (Figure 1):

- Possible headscarps and/or debris lobes with poorly defined morphology (~1000 features)
- Probable headscarps and/or debris lobes with clearly defined morphology (~1000 features)
- Active features with evidence for recent or current movement (13 in total)

In total more than 2,000 relic slips were recognised and mapped within Tauranga City and environs during this study, the term *relic slip* being used to mean *"the remnants of a previous landslide which has been inferred from the presence of a headscarp feature and/or hummocky slope debris"*. The above terminology was adopted in part for consistency with the earlier study by Houghton and Hegan (1980), in which they used the terms "probable" and "possible" to record a degree of subjectivity as to the certainty with which specific features had been identified as being of landslip origin.

DATA SYNTHESIS AND ANALYSIS

Specific landslide attributes were determined for each of the relic slips, which comprised more than 2,000 recognised headscarp features and over 400 slope debris lobes. Terminology used is shown in Figure 2, and typical analysed profiles based on geometry and interpreted geomorphology are given in Figure 3. The following data were formatted into an Excel™ spreadsheet to enable calculation of scarp and runout angles (the latter where possible) in relation to the 2H:1V (26.5°) hazard "zone" under investigation:

- Relic slip reference number and coordinates in terms of the New Zealand map grid.
- Scarp height, distance and width. together with scarp crest and base RLs (to nearest metre).
- Runout distance (from headscarp) and maximum width. with debris toe and top RLs.
- Slope angles for the scarp segment and the runout zone (defined from headscarp to toe).
- Geological unit data, comment on surface hydrology, and any other relevant factors.

The scarp angle, which is defined by the ratio of the vertical height to the horizontal distance from the head to the toe of the scarp, was found to average about 15° and this equates to a slope of 3.75H:1V. Tait (2002) interpreted the same data set for 2080 landslips, and found that 32% of all relic slip scarps were steeper than 25° (approximately 2H:1V), whilst 31% were flatter than 15° (3.75H:1V), with some variability due to geology. The analysed relic slips do not show the expected decrease of scarp angle with increasing slope height, and the correlation is not good between the location of mapped landslip features and Council's 2H:1V zone. Nevertheless, experience has shown that the 2H:1V criterion does provide a simple screening technique for slopes requiring specialist geotechnical input, as this is equivalent to a lower bound friction angle for the near-surface ash deposits of Tauranga and should give realistic factors of safety greater than 1.5 in conventional stability analysis.

The runout (or travel) angle, which is defined by the ratio of height difference from headscarp crest to runout toe divided by the equivalent horizontal distance, gave a similar mean of about 15° or 3.75H:1V. Four of the six slips shown in Figure 3 include runout debris, and three of these have computed travel angles in excess of 3H:1V consistent with this mean value. Given that the youngest (Rotoehu and post-Rotoehu) ashes of the Tauranga area typically have friction angles of 30° or greater, however, theoretical travel angles of about 1.7H:1V would be predicted. It is suggested that the observed values of about 4H:1V are indicative of much greater mobility of the ash materials due to their low densities at around 1200-1400 kg/m^3, with flow behaviour being induced by rainfall infiltration or saturation due to seepage.

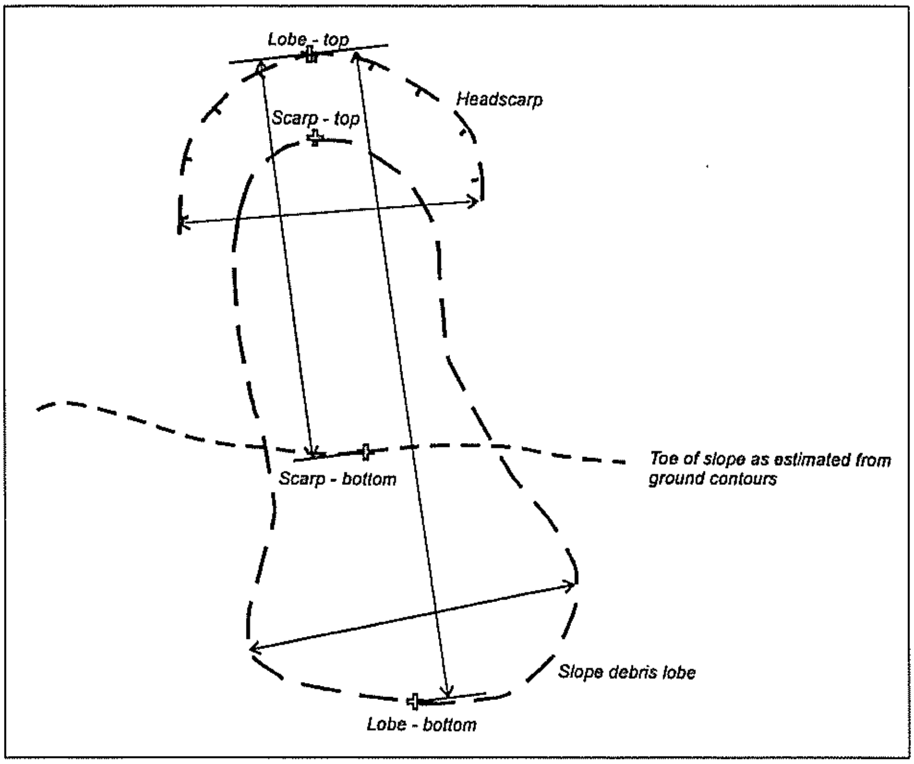

Figure 2. Basic Terminology Used to Define Landslide Attributes for Analysis.

GEOTECHNICAL IMPLICATIONS

In assessing the stability of cliffs or steeper slopes in the volcanic soils of the Tauranga area, the 2H:1V criterion has become an accepted means of identifying and administering concerns regarding slope instability in relation to residential development. Following their investigation of serious coastal instability at Omokoroa (some 10km northeast of Tauranga) in August 1979, Tonkin & Taylor (1980) concluded that slope failures would not extend beyond a 2.25H:1V limit (~24°) and they recommended a setback distance of 6m from the 2.25H:1V "hazard line". Subsequently Houghton & Hegan (1980) recommended a 2H:1V line to define the potential limit of slope instability in the Tauranga volcanic soils, which has now become widely accepted, although again their conclusions appear to have been strongly influenced by the Omokoroa study. Given that the 2H:1V criterion is based on an active-passive wedge geometry (Figure 4 (a)) in which the ash deposits fail above an aquifer within sediments of the Tauranga Group (or Matua Sub-Group) due to pore pressure effects, it is surprising that a number of practitioners continue to analyse for deep-seated circular failures in the volcanic soils of Tauranga (such as the profile shown in Figure 4 (b)).

Bird (1981), and later Oliver (1997), carefully observed and documented slope failures (especially in cliffed areas such as Maungatapu Peninsula), and it is important to reiterate that an appropriate engineering geology model is a necessary pre-requisite to quantitative stability analysis. Oliver (1997) identified four main modes of slope failure in the Tauranga area, these being 1) large-scale block failures, possibly retrogressive and typically $>10^5$ m^3 in volume; 2) piping-triggered block failures, such as those at Omokoroa and Maungatapu; 3) wave erosion-triggered block failures due to active cliff undercutting; and 4) shallow regolith or colluvium/topsoil failures. Of these, it is the piping-triggered block failures that are of particular concern in Tauranga, and there are interesting similarities with the chalk cliff failure model recognised by Hutchinson (1970) at Joss Bay in the United Kingdom. Four geometric models for this type of failure are shown in Figure 4, of which (c) and (d) are considered the most likely to describe the situation where either "blowout" or softening occurs within an aquifer unit between impermeable sub-horizontal beds in the basal Matua Subgroup with consequent steep (60°±) backscarp development in the overlying ashes and sediments.

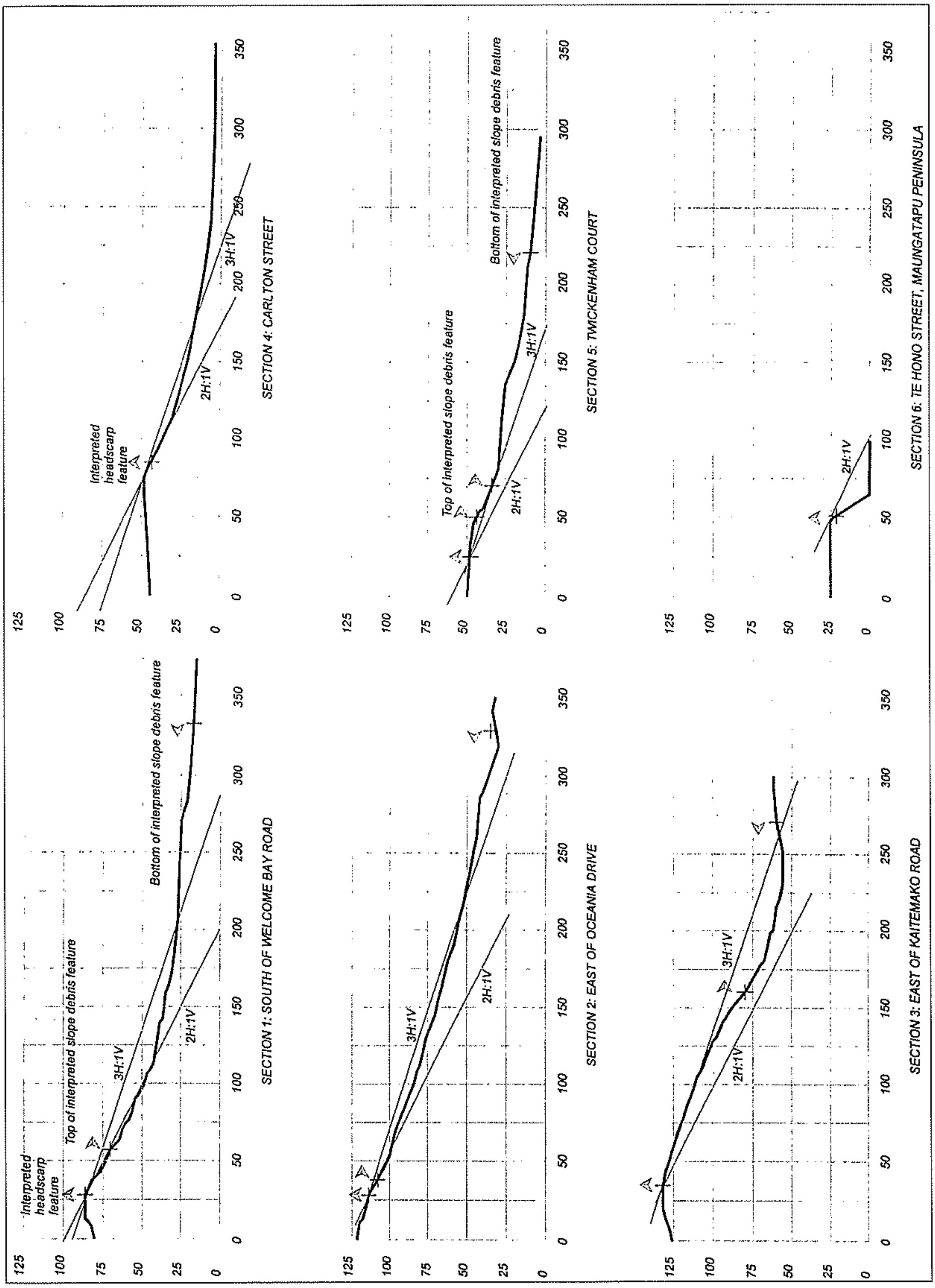

Figure 3. Six Profiles Analysed in Terms of Slope Gradient.

The relic slip verification study has generally confirmed that the 2H:1V slope criterion is still a valid approach to identifying areas where instability may occur on steeper slopes, although it can in no way replace or substitute for site-specific investigation and analysis in conjunction with detailed air-photo studies including use of the landslide inventory maps generated by this study. Instability is more likely in cases where a cliff is being actively undercut by wave erosion, while fluctuating sea-levels of the Late Quaternary have also been a factor as evidenced by the variety of terrace distributions and surface elevations. Further study of the age and development of the Tauranga landscape is clearly warranted, both from a geomorphological perspective and to assist with future urban planning in the district, and the present study has confirmed that geology does have some obvious controls on slope evolution even though that data are not presented or discussed in any detail in this paper.

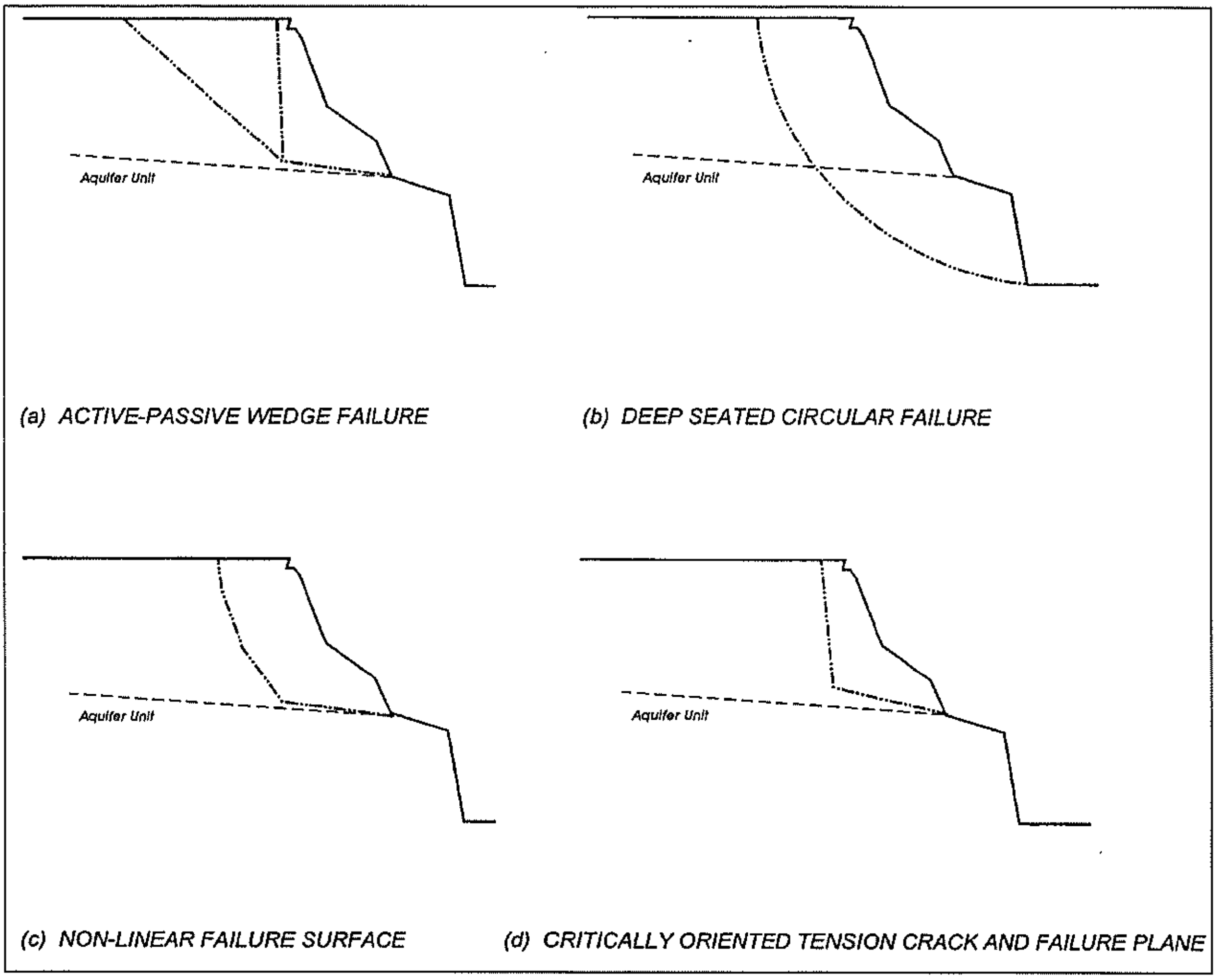

Figure 4. Possible Failure Models for Stability Analysis of Piping-Initiated Block Slides in Tauranga as Used by Local Geotechnical Practitioners. [Refer to text for brief discussion].

The scarp angle only exceeds 30° in 15% of the cases analysed (Tait, 2002), and clearly longer-term degradation post-failure will produce a significantly lower angle especially if seepage is occurring actively from the face. A realistic setback distance from the scarp or cliff top is required, and the original approach developed by Tonkin & Taylor (1980) for Omokoroa (6m beyond the 2.25H:1V hazard line) is probably still appropriately conservative in the absence of existing instability or other information. Our analyses using data from Maungatapu Peninsula suggest that a 2H:1V line from the cliff base should correspond to a factor of safety of about 2.0 for a realistic failure model, although each site must clearly be considered in its own geological, geomorphological and geotechnical context. We note again that the so-called 2H:1V "hazard line" is measured from the crest of the steeper slope segment to its ultimate base, and that the great majority of failures recorded lie within this zone and already incorporate a conservative setback distance.

The issue of toe runout from landslips in the Tauranga area does not appear to have been evaluated fully in previous studies, and the data generated by the relic slip verification study suggest that the runout or travel angle will frequently exceed 3.75H:1V (15°). The travel angle is defined from the crest of the slope to the toe of the runout debris where present (as shown in Figure 2), and this has clear implications for construction of dwellings either within former (= evacuated) landslip features or by siting them close to the toe of a steep cliff where failure might occur. The need to investigate a site well beyond the limits of the building footprint is reiterated, with air-photo interpretation offering an obvious first stage in identifying historical changes in slope geometry or position. The fact that past slope failures appear to have been significantly more mobile than expected, with an implied friction angle of about 15°, indicates that this geotechnical issue requires careful consideration especially for buildings in gully-mouth areas where debris flows could be a significant concern.

Whilst less than 1% of the relic slips studied were considered to be active, and a number have probably been removed by earthworks, one intent of the landslip inventory arising from this study is that both the Council and the practitioner will use the database to ensure that appropriate investigations are designed and carried out where there is any possible issue regarding past slope or land instability. Normal site investigation procedures (desk study; walkover; air-photo interpretation; site mapping; test pits; boreholes; etc) remain the key to successful geotechnical practice in this relatively difficult volcanic terrain, and local experience together with a knowledge of geological precedent are most important factors. We consider in fact that many sites can be at least initially evaluated from careful air-photo study and on-site geological investigation, and that much greater reliance can be placed on this information than on either numerical analyses using unsatisfactory failure models or the use of qualitative pseudo-probabilistic descriptions (for example, as outlined by the Australian Geomechanics Society Subcommittee on Landslide Risk Management, 2000).

PROFESSIONAL CONSIDERATIONS

Since May 1993 Tauranga District Council has operated an accreditation system for geotechnical specialists, whereby both engineering geologists and geotechnical engineers are evaluated in terms of qualifications, relevant experience, level of mentoring, quality of reporting, and responses at a Panel interview. Specialist (Category 1) advisers are accredited to report on any specific matter, in particular the development of steeper slopes, assessing or stabilising existing landslides, and difficult ground conditions (eg land prone to liquefaction): Category 2 specialists are accredited to deal with flatter slopes and/or ground with no evidence for landslip, and there is proviso for them to work on Category 1 sites with appropriate peer review at the client's expense. The rationale behind this approach, and the basis on which it was implemented to deal with perceived difficult ground conditions in the Tauranga area, is detailed by Petrenas (1996): he makes the point that prior to 1993 Council staff relied on their own judgement as to the ability of geotechnical specialists, but that the new system has provided greater transparency and quality assurance in terms of practitioner competence.

Arising from this study we recommend that Category 1 specialist advisers (as presently defined) be required to report on the following in terms of slope stability assessment:

- Sites with probable slope movements showing clearly defined headscarps, hummocky debris, and/or evidence for current/recent activity.
- Sites with possible slope movement features and evidence for either or both poorly defined headscarps and hummocky debris.
- Buildings located within the 2H:1V slope line (ie land steeper than about 26°) or within the 4H:1V runout distance from the slope crest.
- Sites with water seepage or discharge from the slope at any height.

Unless their work is peer-reviewed, Category 2 specialists are restricted to sites where there is no evidence of slope instability within (or in close proximity to) the existing or proposed development, and where the building is located outside the 2H:1V slope line or the 4H:1V runout distance from the slope crest. Category 3 sites are those where there is no requirement for specialist geotechnical or engineering geology data input or assessment.

The system now operating within Tauranga City and environs is designed to ensure that suitably experienced geotechnical practitioners with sound local knowledge are responsible for investigating and reporting on the more difficult sites, and that appropriate levels of mentoring and peer review are available to younger or less experienced engineering geologists and geotechnical engineers. As part of our study assessment guidelines have been developed to assist practitioners, although we do not advocate a "checklist approach" to site evaluation because of the possibility of failing to recognise unusual or critical information. Instead we strongly believe that sound engineering geology, with quality air-photo interpretation, is an essential tool within the Tauranga area and be should be used more widely to develop site-specific models prior to, and at times instead of, quantitative stability analysis. The scarp and runout angle guidelines are also simply another technique to draw attention to possible instability concerns adjacent to steeper slopes or cliff lines, whilst the relic landslip inventory that has been presented here is intended to provide additional guidance for the experienced practitioner and should not be considered definitive in its own right.

The presence or absence of groundwater within a slope, reticulation/disposal or direct infiltration of stormwater, and antecedent rainfall/threshold triggering conditions all remain issues for professional judgement and/or site-specific investigation. Further studies are clearly warranted, including long-term monitoring of groundwater levels and responses within the slopes of Tauranga City, and evaluation of the likely threshold levels of precipitation triggering both piping-initiated instability and shallow regolith failures. The recognition of past instability at a site, and knowledge of groundwater conditions and likely extremes at that site, are the keys to safe design and/or slope remediation where an appropriate engineering geology model has been developed and quantified as required. Ultimately, however, it is the competence and professionalism of the practitioners working in the Tauranga District that will ensure future geotechnical problems are identified, evaluated and remediated or avoided without loss of life or significant property damage.

CONCLUSIONS & RECOMMENDATIONS

1. The present study has identified more than 2,000 relic slip features in Tauranga City and environs, of which approximately equal numbers (~1,000 of each) have been classed as probable and possible on the basis of headscarp or debris lobe morphology: only 13 presently or recently active landslip features with clearly defined surface morphology have been recognised, representing less than 1% of the total number of relic slips.

2. The relic slip features have been recognised primarily using air-photos that were flown between 1943 and 1997, supplemented by limited field checks, and the data have been transferred to Council's GIS database using 1:5,000 field sheets with appropriate topographic and cadastral information: a 1:20,000 compilation map has also been prepared, although further work is required to identify those landslip features which have been removed by later earthworks.

3. Landslip attributes have been measured and analysed, in particular the scarp height/horizontal distance relationship and the debris lobe dimensions where this feature is preserved: our data confirm that 2H:1V (26.5°) is realistic for the scarp angle, as has previously been adopted following work at Omokoroa in 1979-80, and that a runout or travel angle (defined from scarp crest to debris lobe toe) of 4H:1V (14°) is an appropriate measure of potential landslip mobility.

4. We recommend that Council adopt these guidelines for land-use planning purposes, especially for residential building sites, and that these criteria be used in conjunction with the relic slip inventory data to plan and implement site investigations: Category 1 geotechnical specialists should be involved with land steeper than 2H:1V (as at present), within the potential 4H:1V runout zone which does not appear to have been adequately addressed in the past, and where active landslip features are present.

5. In our opinion greater use should be made of engineering geology and photogeology techniques in identifying geotechnical constraints or hazards, and in formulating appropriate site models for quantitative stability analysis where required: whilst assessment guidelines have been developed by us to facilitate such work, it is the competence and professionalism of geotechnical practitioners that is of greatest importance for future land development in the Tauranga area.

6. Future research should involve development of a geotechnical database for Tauranga and adjacent areas, including relic slip information and documentation of future landslips and debris flows as well as the distribution of specific volcanic units from exposure logging and mapping: further study of the geomorphological development of the Tauranga area is also recommended, so that better constraints can be placed on the age of specific landscape features for planning purposes.

REFERENCES

Australian Geomechanics Society Sub-Committee on Landslide Risk Management (2000) *"Landslide Risk Management Concepts and Guidelines," NZ Geomechanics News, Issue 60: 61-92*

Bell, D.H.; Richards, L.; Thomson, R. (2001) *"Relic Slip Verification Study – Tauranga District Council Environs," Unpublished Consultant Report to Tauranga District Council, March 2001*

Bird, G.A. (1981). "The Nature and Causes of Coastal Landsliding on the Maungatapu Peninsula, Tauranga, New Zealand," *Unpublished MSc Thesis, University of Waikato Library.*

Briggs, R.M.; Hall, G.J.; Harmsworth, G.R.; Hollis, A.G.; Houghton, B.F.; Hughes, G.R.; Morgan, M.D.; Whitbread-Edwards, A.R.(1996). "Geology of the Tauranga Area," *Occasional Report No 22, Department of Earth Sciences, University of Waikato.*

Houghton, B.F. and Hegan, B.D. (1980). "Preliminary Assessment of Geological Factors influencing Slope Stability and Landslipping in and around Tauranga City," *NZ Geological Survey Engineering Geology Report EG248, October 1980.*

Hutchinson, J.N. (1970). "Field and Laboratory Studies of a Fall in the Upper Chalk Cliffs at Joss Bay, Isle of Thanet," *Proceedings of the Roscoe Memorial Symposium, Cambridge.*

Oliver, R.C. (1997). "A Geotechnical Characterisation of Volcanic Soils in relation to Coastal Landsliding on the Maungatapu Peninsula, Tauranga," *Unpublished MSc Eng Geol Thesis, University of Canterbury Library.*

Petrenas, B. (1996) "Accreditation of Geotechnical Engineers and Engineering Geologists," *Proc. Tech. Groups IPENZ, Volume 22, Issue 1(G):142-151*

Tait, T.M. (2002). "Slope Stability and Land-Use Planning, Tauranga District, New Zealand," *Unpublished MSc Eng Geol Thesis, University of Canterbury Library.*

Tonkin & Taylor Ltd (1980). "Omokoroa Point Land Stability Investigation," *Unpublished Consultant Report to Tauranga District Council, May 1980.*