

TAURANGA STORM EVENT OF 18 MAY, 2005: LANDSLIP ISSUES

INTRODUCTION

This report presents the results of a survey of the slips that occurred in Tauranga City on 18th May, 2005, as a result of the severe rain storm at that time. The survey has consisted primarily of visual inspections of all the major slips, together with a review of relevant literature, some limited soil testing, and conversations with affected residents. The purpose of the survey has been to identify the main cause of the slips, and any contributing factors, and make recommendations as to how the likelihood of further slips in the future could be eliminated or reduced.

PRIME CAUSE (OR CAUSES) OF THE SLIPS

The prime cause of the slips was (rather obviously) the extreme rainfall event of 18th May. Our understanding of this event is that it was approximately a 100 year event, which is a very severe event. We have been informed that there was also a period of heavy rain early in May, which was probably a significant contributing factor. Recent preceding rain would tend to saturate the ground and raise water levels, and thus increase the likelihood of slips during the storm that followed on 18th May. Verbal reports of local residents who observed the storm from their properties speak of large “rivers” and “waterfalls” on their properties, which appear to confirm the very extreme nature of the rainfall at the time.

Of almost equal significance is the fact that New Zealand, including Tauranga, is a very young country geologically, and slips and soil erosion are part of the natural processes occurring throughout the country. There are probably few areas in the North Island of New Zealand that are not susceptible to slip damage to some extent in the event of severe rainfall storms. Tauranga appears to be particularly vulnerable to rainfall induced slips because of the prevalence of steep slopes consisting almost entirely of soil susceptible to the weakening influence of rainfall. These slopes are the remains of sea cliffs formed by erosion and follow the old foreshore boundary.

Very few of the slips we inspected could be considered surprising or unusual given the general steepness of the topography where they occurred. They generally appear to have occurred in places likely to be vulnerable to intense rainfall. This is not to say that they could be predicted with any certainty. There are a great many other slopes of rather similar characteristics that did not fail during this storm event.

Mechanism of Failure and Influence of Local Geology

The slopes in which the slips have occurred consist of a sequence of volcanic ashes, most of which have undergone weathering over many centuries to form soils. In very general terms the volcanic ash sequence (from the surface downwards) consist of the pale brown coloured “younger ashes” including the very sandy Rotoehu Ash which overlies the chocolate brown Hamilton Ash. Below the Hamilton Ash are the Pahoia Tephra, which include creamy white fine grained rhyolitic ash. A number of paleosols (old ground surfaces) separate the various ash falls and these layers are generally of low permeability. The properties of the ash layers vary considerably and they influence to some extent the way failures occur. At Otumoetai there are no true “basement” rocks and the ash sequence extends down to sea level. Elsewhere within Tauranga city, variably weathered ignimbrite and weakly cemented volcanoclastic sediments underlie the ash sequence.

The upper layers, in particular the younger ashes and the Hamilton ash, often contain random vertical fissures or cracks through which water can easily enter the slope and seep through it. Other

layers (especially “rhyolite” ashes) appear somewhat weaker than other layers and failure seems more likely to occur in or on these layers than other layers. These layers also rapidly lose strength once slip movement occurs, which helps explain why some slips move a great distance once slip commences.

The Hamilton ash is believed to be derived from andesitic parent material, while the lower layers are derived from rhyolitic ash. The properties of these two types of ash are significantly different; Appendix 1 to this report provides comments on the geotechnical properties of these two types of ash, together with the results of limited soil testing that has been carried out on samples of the rhyolitic ash taken from one of the current slips.

A further complication is that the volcanic ash layers are generally air-fall deposits and while following the original topography tend to mask it somewhat. Thus there are now paleo-valleys (ancient buried valleys) hidden beneath the existing smoothed-out recent topography. These old valleys are capable of concentrating groundwater seepage and bringing it out to the present cliff face at specific locations.

The effect of rainfall on a slope is to induce increased infiltration into the soil, and a consequent rise in water (or seepage) pressures in the void space between soil particles. This has the effect of weakening the soil; if sufficient weakening occurs the soil “fails” and a slip takes place. This effect can occur in all types of soil, although it occurs more rapidly in high permeability materials such as sand than in clay. When cracks are present in the soil, (such as appears to be the case with the upper brown ash layers), they not only provide channels through which water can easily enter and flow through the soil, they also enable the water pressure to act as an additional “external” force, increasing the tendency of the soil to slide downhill under gravity.

Very few of the slides inspected involved slip movement over the full height of the slope. Generally the actual slip failure (the block of material that initially moved) extended from the top to about half way down the slope. The slip material spread out over the lower slopes and in many cases travelled a considerable distance beyond the original toe of the slope. This form of failure is illustrated in Figure 1(a). The slip material generally disintegrated as it moved, and became mixed with water to form minor “mud flows”. The distance travelled depended on the shape of the slope and the quantity of water available to lubricate the slope and mix with soil as it slipped.

The fact that the initial failure generally occurred only in the upper part of the slope may be partly due to the buttressing effect of previous slip debris that covers the lower part of many slopes, and partly due to the rapid build up of seepage pressures in the upper part of the slope. The lower permeability of the lower layers may mean that the pore pressure rise here was not as pronounced as in the upper layers, so that the weakening effect of water ingress was not as significant as higher up.

There was, however, at least one slip that was rather different from most of the slips. This was the large slip in Vale St. which pushed the house below it a considerable distance towards the road. This slip extended over almost the full height of the slope and had the form of what is known as a “block” slide. In this case a large block of the slope moved semi-horizontally towards the front of the section. As with the other slips, it partly disintegrated as it moved, and became softened by any water that was available to it. This form of this slide is shown in Figure 1(b).

Figure 1(c) attempts to illustrate diagrammatically the way in which water induces slips in slopes. The mechanism is not one whereby previously dry sloped become wet. All soils, especially those in Tauranga consisting of fine-grained clayey materials, contain large quantities of water all year round. The influence of periods of intense rainfall is to “pressurise” this water, and consequently to weaken the soil. The longer the time over which the site is subjected to abundant supplies of surface water, the greater will be the increase in pressure and consequent weakening effect.

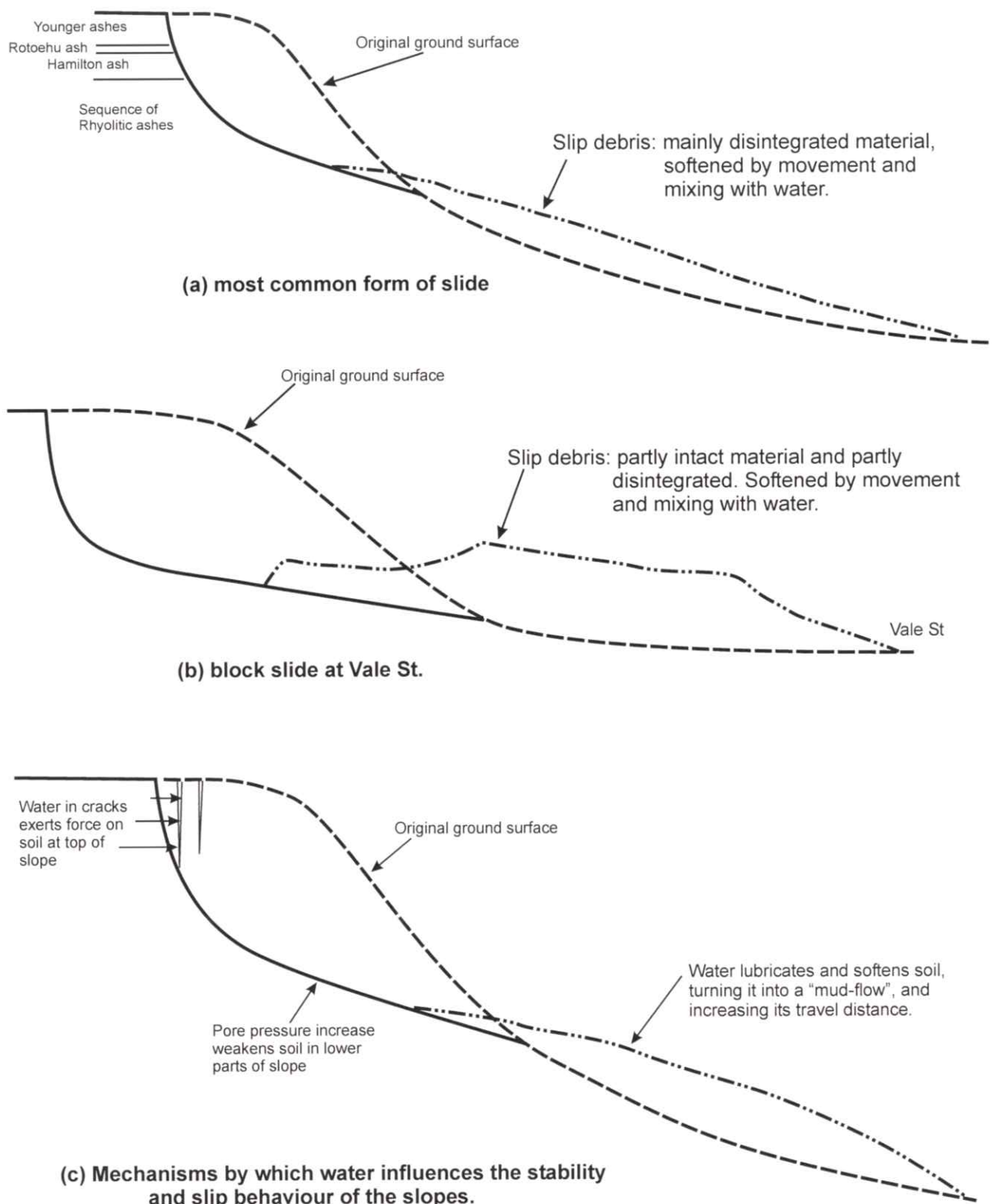


Figure 1 Diagramatic representation of slip cross sections

While the precise “mechanism” of movement initiation is of interest and significance to geologists and geotechnical engineers, it does not greatly influence the identification of the cause of the slips, which as already stated is the increase in seepage pressures induced by heavy rainfall. It is however of some importance in considering contributing causes of the slips and attempting to come up with measures that might be implemented to minimise the effect of possible future storms.

Other general observations concerning the nature of the slips are the following:

- Many of the slips have occurred in slopes that are the remains of cliffs that followed the old shore. In addition to these, there are a substantial number (possibly the majority) that have occurred in the slopes of valleys that run “inland” from the old cliff line. The precise explanation for these valleys is unclear, but the horse-shoe shaped head of such valleys tends to concentrate surface run-off as well as seepage flow through the ground, so that these areas are particularly susceptible to slope instability.
- It appears that slopes facing east have suffered more slips than those facing west. This suggests that there may be an influence on stability arising from dip of the ash layers in a west to east direction.
- The majority of houses that have suffered severe damage have been at the foot of slopes rather than at the top of them. The damage has been done by the impact of the slip debris material against these houses. A number of houses at the top of the slopes are in precarious positions, although they have not actually suffered material damage.
- The run-out distance of the landslide debris in general falls within a line projected at about 1V to 4H (14°) from the headscarp (the top edge) of the slip.

POSSIBLE CONTRIBUTING FACTORS FROM URBAN DEVELOPMENT.

Surface cover by houses, driveways, and other sealed areas:

The effect of surface cover is problematical. On the one hand it will tend to limit the amount of water entering the soil, and possibly reduce the likelihood of slipping. On the other hand it tends to concentrate discharges in certain places, and if these are the wrong place they will increase the probability of failure. We observed a number of streets ending in cul-de-sacs sloping down toward the top of steep slopes, followed by driveways ending almost at the edge of the slope. These would be expected to act as surface flow paths, and local residents spoke of torrents of water flowing down these driveways and then onto the slopes. In effect the streets formed streams and many driveways became spillways discharging the flow at the top of the slopes.

A number of slips had occurred in these situations and we noted that the upper limit of such slips was often precisely at the limit of the covered area created by house and driveway. We believe this indicates that the discharge of large volumes of water at the top of the slopes was a significant contributing factor to a considerable number of slips. This is likely to be the case in view of the presence of vertical cracks in the upper soil layers, as described earlier.

Stormwater discharge into soak holes:

In the light of what has been said above it is clearly not good practice to place soak holes close to the edge of steep slopes. We therefore examined the possible influence of soak holes as carefully as we could. We observed a number of slips that were sufficiently far from houses to be clear of major influence from soak holes. We also noted that in some slopes the ground closest to houses (and thus closest to soak holes) was intact, while that further away had slipped. We also inspected some slips on properties that were discharging all storm water into Council drains, so there was no soak hole influence on these properties. The form of the slips on these properties was similar to those that occurred at sites with soak holes. However we did inspect at least three properties where soak holes were sufficiently close to slips to be a substantial contributing cause of the failures.

Our conclusion was that there was no general relationship between the presence of soak holes and the occurrence of slope failures. This is probably not surprising. In a rainstorm of the intensity involved in this case, there was probably so much water entering the ground from many sources that the influence of that entering from soak holes was not great. At the same time removing soak holes will lower the risk of slip failure, at least on some particular sites. Regular discharge from soak holes tends to keep the ground saturated and increases the risk of failure in the event of a sudden storm. It should be understood however, that it would be quite wrong to believe that by doing away with all soak holes, there will be more than a small influence on the number of failures that will occur in some future event similar to the present one

Ground re-shaping

Ground re-shaping has been carried out to a lesser or greater extent on a number of sites. It is not easy to quantify the influence of re-shaping in any general way. It depends on what its aim is, and how it is carried out. Any re-shaping that results in flattening of slopes will generally make them less prone to slip, and vice versa. Any re-shaping that results in concentrations of run-off water will be harmful. The placing of substantial quantities of fill at the top of steep slopes, with or without retaining walls, is clearly undesirable, as it places an added load at the top of the slope, thus increasing the chances of failure. Fill retained by pole walls exerts a force on the poles that in turn exerts a horizontal thrust on the soil, which increases the chance of failure. On several sites visited, such walls had been built, and slips had occurred taking the walls and fill with them.

The influence of seepage flow along pipe trenches was observed on several sites, where internal erosion along the trench had taken place. This indicates the absence of seepage cut-offs which are normally placed in pipe trenches to prevent such erosion.

Conclusion re Cause of Slips

To summarise the above observations, the slips that have occurred are primarily a continuation of a natural process under which slips occur on steep slopes during periods of intense rainfall. Many of the recent slips have occurred where ancient or relic slips have occurred in the past. However some are first time slips initiated by a combination of the local geology and the local intensity of the storm rainfall. Human activities have to some extent contributed to the probability of such slips occurring, but in our opinion they are of secondary importance.

MEASURES TO REDUCE THE RISK OF SLIPS IN THE FUTURE

There are clearly a very large number of houses throughout the Tauranga area located on sites similar to those on which slips have occurred, and are thus vulnerable to similar slips in a future severe rainstorm event. This is the result of the way the city has developed and similar situations exist in many if not most New Zealand cities and towns. It is virtually impossible, for both technical and economic reasons to implement measures that will make these houses totally secure. However, there are some measures which can be taken to lessen the risk of slip failures, and which we believe should be implemented in the present situation as soon as practicable. These are outlined below.

Control of surface run-off and an end to the use of soak holes.

As indicated above, a very large amount of surface run-off tends to be concentrated and discharged towards the top of steep slopes at risk of slip failure. This comes about because of the natural shape of the land and the way streets are laid out. This is especially the case with cul-de-sacs and driveways near the edge of the slopes. This run-off needs to be intercepted and disposed of by properly designed systems. To do this, we believe that a thorough review needs to be undertaken of the complete storm-water disposal system throughout the Tauranga area. An integral part of this should be improved topographic cover of the city using a *Lidar* digital terrain model with

contouring at 1 metre accuracy, including built-up and vegetation covered areas. This would make possible the most accurate overland drainage modelling and identification of those situations where large surface flows concentrate at the top of vulnerable slopes.

As far as possible, all storm-water should be disposed of by piped systems. We are not experts in storm-water disposal, but it appears that improved pipe storm-water disposal should not be difficult in Tauranga, as no part of the city is far from the water's edge, either the open sea or harbours and estuaries. It is probable that the volume of water involved in major storm events (such that of 18th May) is probably too great to be handled entirely by piped systems, and surface systems (ie open drains) will also be needed to pick up water at the top of slopes and discharge it at the base. It may also be desirable to create "holding pond" areas to which surface flow can be directed and stored temporarily until it drains to discharge points at the water's edge.

In addition to the control of overland run-off, we recommend that all soak holes in "up-land" areas, such as those in Otumoetai where the current slips have occurred, be eliminated, and replaced with discharge into piped systems. This should include both private and TCC soak holes. It may be necessary to establish an accurate inventory of all soak hole storm water disposal. In the meantime, as a short term management guide, we suggest that soak hole drainage be discontinued within a zone extending 100m from west facing flanks of slopes and 200m from east facing flanks.

Control of earthworks

Many local authorities have quite stringent restrictions on the size of earthworks that can be carried out on urban properties without specific consents, and we believe this should be the case in Tauranga. Builders and house owners frequently carry out excavations or place fill on properties in a manner that clearly increases the risk of slope failures. Making excavations into the toe of relatively steep slopes, or building retaining walls and placing fill at the top of such slopes, to provide additional level ground, are clear examples of undesirable earthworks. In the Tauranga situation we believe that a fairly severe restriction should be placed on both fill depth and excavation depth. The limit should certainly be not more than one metre, although 0.6m may be more appropriate.

Specific stabilising measures for particular sites

To provide increased security to house sites that are clearly at high risk of slip damage in future storm events, there are some additional specific measures that can be taken, apart from the improvements to storm-water control recommended above. These are not measures that could be considered a Council responsibility, but some home owners, or groups of owners, may wish to implement them to make their own properties more secure. It must be recognised, however, that only extremely costly measures will provide complete security, and these may not be feasible for practical reasons.

One relatively simple measure that could be implemented at reasonable cost is the installation of bored horizontal drains. These are a relatively common method of trying to make vulnerable slopes more stable. The drains are essentially horizontal holes drilled into the slope and then lined with perforated pipes, the purpose of which is to provide outlets for water seeping into or through the slope. They thus prevent the build-up of seepage pressures that may trigger landslides. Such drains do not appear to have been used very much in Tauranga so their effectiveness has not been tested. We believe some trial work to investigate their effectiveness would be very useful, as outlined in the following section.

Various types of retaining walls can be constructed to help make the slopes more stable. These are generally expensive measures. Only careful investigation of particular sites can establish the possible effectiveness and cost of such measures.

Changes to Council Controls

Changes to storm water disposal and tighter controls on earthworks have already been mentioned above. There may be a need for other changes to existing “rule of thumb” guidelines such as the 2H:1V set back distance (measured from the base of the slope) for buildings at the top of slopes, and the 4H:1V run-out distance (measured from the top of the slope) at the base. These criteria are set out in the report of Bell, Richards, and Thomson of March, 2004 (Relic Slip Verification Study, Tauranga District Council Environs). As they stand at present, these guidelines determine whether or not specialist advice is needed for any particular site. They are thus not rigid “stand alone” criteria, and buildings can be located within the 2H:1V and 4H:1V lines provided specialist advice approves this.

Observations of the recent slips suggest that the above guidelines are well based, in the sense that buildings located outside these limits are unlikely to be affected by slips. However, the recent slips also suggest that only in rare circumstances would it be prudent to violate these criteria. Because of this we believe that the following changes to the criteria would be appropriate:

1. Buildings are not to be located within the 2H:1V line at the top of the slope, or 4H:1V line at the base. Only if special measures are taken, such as the construction of properly engineered structures (i.e. retaining walls, piled foundations and deflection bunds) can these criteria be exceeded.
2. Category 1 advice is required if the building is to be located at the top of a slope within a 2.5H:1V line, or at the base within a 5H:1V line.

The remaining guidelines in the Bell, Richards, and Thomson report (Table 2) should remain as they are.

These recommendations are based on observations to date. Some “fine tuning” may be desirable, depending on the results of the detailed survey of all recent slips, as described in the next section of this report.

RECOMMENDATIONS FOR FURTHER INVESTIGATION WORK

Detailed survey of all recent major slips.

It is essential that as much data as possible be gathered from the recent slips. To do this, careful surveys should be undertaken of the slips, covering the topography before and after each slip, identification of overland concentrations of surface run-off, information regarding soak holes, and a description of the soil profile over as much of the slope height as possible. A substantial amount of this information is probably already available from work being carried out for the EQC and possibly also by the City Council as part of their investigation into causes and possible remedial work etc. All the available information needs to be collated and the additional work to complete the study undertaken as soon as possible. The results of this study can then form the basis for review and possible changes to the Council’s planning criteria for sites involving slopes.

Geological cross-sections of the Otumoetai plateau.

It would be useful to establish geological cross-sections across the main ridges of Otumoetai (and elsewhere) by using the detailed landslide descriptions of the ash stratigraphy together with additional mapping of the exposed ash sequences and filling in the gaps with fully cored drill holes. In conjunction with this it would be very useful to obtain information on groundwater fluctuations by instrumenting the holes with vibrating wire piezometers that could be connected to automatically recording data loggers. A research institution, preferably a University, would possibly best do this.

While this study would be useful, it would not be as valuable as the study described in the next section, which relates directly to possible remedial and stabilising measures.

Investigations into groundwater seepage conditions and the effectiveness of bored horizontal drains in controlling seepage levels.

As far as we are aware, there is very little information on actual groundwater conditions in Tauranga, in particular on the extent to which they rise seasonally, or rise momentarily during periods of intense rainfall. This information in itself would be informative, but may not be directly helpful in designing measure to make slopes more stable. The information that would be most valuable would be the extent to which water levels could be lowered and controlled by drainage measures, in particular by the use of the horizontal bored drains described above. We consider that it would be very useful to carry out some field trials to investigate this issue. Such trials would involve the following steps:

1. The selection of a representative slope of reasonable length and uniform cross-section, and consistent soil properties.
2. The installation of stand-pipe piezometers at several cross sections (four or more) along the slope. These would need to be of a type that can be read and recorded automatically (such as the vibrating wire devices mentioned above), so that full coverage of all rainfall conditions is obtained.
3. The installation of bored horizontal drains on one section of the slope only, so that the piezometer readings from sections of the slope with and without horizontal drains can be compared. The bored drains should cover all of the slope, ie both the higher layers and those lower down the slope.

Such a trial should establish the effectiveness or otherwise of horizontal drains, and enable informed judgments to be made as to the benefit to be gained by their installation at sites clearly at risk of future slips.

CONCLUSION

The slips that have occurred are primarily a continuation of a natural process under which slips occur on steep slopes during periods of intense rainfall. Many of the slips occurred where ancient or relic slips have occurred in the past, although some are first time slips. Human activities have to some extent contributed to the probability of such slips occurring, but in our opinion they are of secondary importance. The majority of the slips appear to have occurred where natural storm water overland flow paths (accentuated in some cases by human activity) concentrate large discharges at the top of vulnerable slopes.

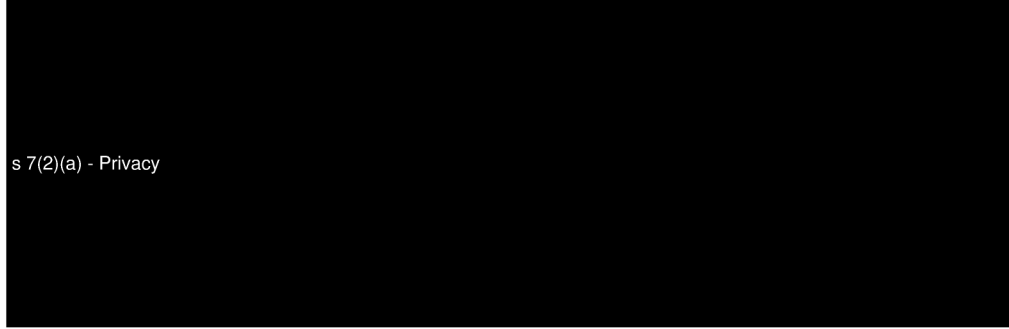
While it is not possible to eliminate the likelihood of future slips, it is possible to decrease the risk to some extent and we believe that measure to do this should be implemented as soon as practicable. These measures are aimed primarily at minimising both the amount of water flowing overland towards the top of vulnerable slopes, and the amount of water entering the ground and heading towards these slopes. It may also be feasible to lessen the risk of slips at specific sites by the installation of drainage measures such as horizontal bore drains. Measures to achieve these aims are described in the report above.

We are attaching to this report as Appendix 2 the report of Laurie Richards, which is a valuable addition to our own report, especially in view of Dr Richards earlier knowledge of the Tauranga situation.

ACKNOWLEDGEMENT

We are very grateful to Tauranga City Council officers for the assistance given to us in carrying out this study. We are equally grateful to the many home owners of affected properties who provided us with valuable information regarding the events affecting their properties.

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APPENDIX 1: A Note on the Properties of Volcanic Ash Soils.

The volcanic ash soils at Tauranga have been formed by the weathering of a sequence of airborne ashes that originated from a variety of sources in the Bay of Plenty, Rotorua and Waikato. These ashes can be broadly divided into two types, andesitic and rhyolitic. Andesitic ash has a relatively low quartz content, while rhyolitic ash has a high quartz content. Soils weathered from volcanic ash deposits tend to have rather distinctive properties, arising from the fact that they consist of unusual clay minerals. These minerals form because the ash particles of the parent material tend to be predominantly “glass”, that is they do not have the crystalline structure normally associated with rock minerals. The best known clay minerals found in volcanic ash soils are allophone/immogolite, and halloysite. It is a condition for the formation of allophone that the parent material be amorphous (ie “glass”), and this is likely to be the case with both andesitic and rhyolitic ashes.

Andesitic ashes are very common in the so called “ring of fire” countries around the Pacific “rim”, and soils derived from them are frequently referred to simply as brown ash soils. There is a great deal of information on these soils in the literature; this indicates that their engineering properties are generally good. They consist predominantly of the clay mineral allophone, which makes them stable, of low compressibility, and not subject to large shrinkage or swell as a result of water content changes. There appears to be very little information on rhyolitic ash soils, although some field records of their behaviour indicate they are little different from andesitic ash soils. This does not appear to be the case in Tauranga.

The engineering properties of the volcanic ash soils in Tauranga derived from these two ash types appear to be quite different, although the reason for this is not known. The brown Hamilton ash, which is andesitic, appears to conform to the behaviour of brown ashes in other parts of the country, and other parts of the world. It is not highly sensitive (meaning it does not lose strength when disturbed or remoulded), and appears to remain stable on steep slopes. It does have one undesirable property in the situation in which it exists in Tauranga, namely it appears to contain vertical cracks or discontinuities through which water can travel, and in which water pressure can build up. As mentioned earlier in this report, this is not desirable at the top of steep slopes.

The rhyolitic ash soils at Tauranga are quite different. They are light coloured, ranging from pale brown to pale yellow, and to almost white. Their most striking characteristic is that they are highly sensitive. In their undisturbed state they are firm to stiff, but when remoulded they become extremely soft, almost of liquid consistency. Samples of the rhyolitic ash clays were obtained from two sites and measurements made of their water content, Atterberg Limits, and mineralogical composition. The laboratory results are given in the following table.

Tauranga sites: Natural water content and Atterberg limit tests.

Site	198 Grange	20A Lemon	20A Lemon
Soil condition	Natural	Natural	Oven-dried
Natural water content (%)	59.9	55.6	0
Liquid Limit	48	58	43
Plastic Limit	38	40	29
Plasticity Index	10	18	14

These show surprisingly low values for volcanic ash soils. They also confirm the sensitive characteristics of the rhyolitic ashes, as the natural water content is close to the Liquid Limit in both samples. Oven drying reduces the plasticity somewhat but not dramatically. These properties all suggest that the allophone content of the soil is not high.

X-ray Diffraction analysis was carried out on the Grange sample. The interpretation of the “diffractogrammes” was that they “showed the “soil” material to be composed of a very fine grain-sized disordered mixture of kaolinite – halloysite. The kaolinite and halloysite both appear to have swelling properties”. The rhyolitic ash soil therefore does not appear to conform to most ash soils, which generally contain a substantial proportion of allophone.

The conclusion from this limited study confirms what the field behaviour demonstrates, namely that the rhyolitic ash soils do not have good engineering properties with respect to slope stability. The presence of swelling clay minerals in them suggests rather low shear strength, and their high sensitivity means they are likely to rapidly lose strength when disturbed. The reason these rhyolitic ashes are so different from the more common allophone rich ash soils is not known. Possible explanations are that the parent ash was low in “glass” content, and/or that the weathering environment in the relative flat Tauranga terrain was not conducive to the formation of allophone.

APPENDIX 2 Report of Dr Laurie Richards.

Laurie Richards

Rock Engineering Consultant

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**TAURANGA LANDSLIDES: 18 MAY 2005
SITE VISIT & REVIEW NOTES**

Report prepared for:

s 7(2)(f)(ii)

Tauranga District Council
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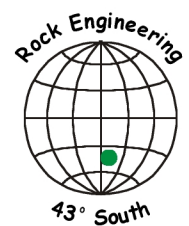


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INTRODUCTION

1. The writer visited Tauranga on 22 to 24 June 2005 to view the landslides that occurred during the 18 May 2005 storms. Discussions were held with s 7(2)(f)(ii) (TDC) and visits made with s 7(2)(a) - Privacy (Tonkin & Taylor) and s 7(2)(f)(ii) (University of Auckland) who had previously inspected the slides and made preliminary reports^{1,2} to TDC.

RAINFALL

2. The triggering event for the landslides was unprecedented rainfall leading to failure of the stormwater drainage system and uncontrolled overland flow. NIWA's Autumn 2005 climate summary indicates unprecedented rainfalls at Tauranga Airport on and prior to 18 May:
 - Total autumn rainfall of 751mm (highest since records began in 1898)
 - Torrential rainfall of 144mm in 24 hours on 3-4 May
 - Unprecedented maximum 24 hour rainfall of 347mm on 18 May
3. Local residents report considerable variation in rainfall and flooding over the city area during the 18 May event. The rainfall has been assessed as a 1 in 150 year event or greater. The effect of rainfall on the stability of slopes can be quantified by considering the total rainfall on the day of the event together with the cumulative rainfall over a previous number of days³. *Figure 1* shows the 18 May 2005 rainfall in comparison with the rainfall data at Chapel St from 1977 to 1998 (as used for the 1999 Mauao stability assessment⁴). The combination of daily and precedent rainfall exceeds any for the period from 1977 to 1998 and probably for the entire period of record in Tauranga.

SLIDE MECHANISMS

4. The slides inspected were notable for a number of features as follows (see *Figure 2*):
 - The heads of the slides are generally close to the slope crest and often controlled by changes in slope cover such as buildings or sealed areas
 - The back faces of the slides are often controlled by near vertical discontinuities or tension cracks
 - High water pressures in these tension cracks have the effect of causing slide "blowouts" which would have initiated regardless of the inherent soil or rock mass strength
 - The slide bases are controlled by less-permeable, low-strength ash horizons. The orientation of these layers (horizontal or dipping out of the slope) affects the size and geometry of the slide
 - Water pressures in the slopes would likely have been high because of the wet autumn but the high joint pressures developed from surface infiltration would have resulted in significant failures even with low groundwater pressures
 - Landslide runout was generally within a 4H:1V line projected from the headscarp. Most of the damage to houses was caused by runout rather than subsidence effects.

The presence of tension cracks is critically important to these slides. Such features have previously been identified by Oliver⁵ (*Figure 3*) who referred to these as *exfoliation defects* rather than the more appropriate terminology of *tension crack* or *stress-relief defect*. These features have a significant effect on slope failures since their orientation precludes any significant frictional resistance along the features, and the water pressure in the open joints can exert high horizontal pressures on the slide mass.

5. Without tension cracks or other structural controls present, the critical failure mode in these types of materials would be fairly deep-seated circular failures (see *Figures 4* and *5*) regardless of the level of the groundwater table. With water-filled tension cracks (*Figures 6* and *7*), the Factor of Safety (FOS) of the slope is significantly reduced and the critical failure surface moves closer to the slope crest for all groundwater conditions. Note that the above analyses are fairly simplistic since the toe of most failures is generally at the ash horizon.

¹ Hegan B, Wesley L. *Tauranga storm event 18 May 2005: Landslide issues. Preliminary report for TDC meeting 8 June 2005.* Report to TDC

² Hegan B, Wesley L. *Tauranga landslide event 18 May 2005: Observations and comments.* Report to TDC

³ Lumb P. *Slope failures in Hong Kong.* Q Jnl Engng Geol. Vol 8, pp31-65, 1975

⁴ Richards L. *Mauao stability assessment, Mt Maunganui, Tauranga.* Report to TDC, 31 May 1999

⁵ Oliver R. *A geotechnical characterization of volcanic soils in relation to coastal landsliding on the Maungatapu Peninsula, Tauranga, New Zealand.* MSc thesis in Engineering Geology, University of Canterbury, 1997

section properties and cascaded over the escarpment edges. The severity of the surface water flows is indicated by the failure of low garden retaining walls on some of the sections.

7. TDC's consultants have observed that the landslide runout for the May 2005 slides is about 4H:1V. This is consistent with the data collected for the 2001 relic slip review⁶.

COMMENTS AND OBSERVATIONS

8. The 18 May 2005 rainfall event was the highest 24 hour rainfall recorded in Tauranga. Because of the failure of the stormwater drainage system, slope failures would have been significant even if the previous few months had been drier than normal.
9. The subvertical features near the slope crests (*tension cracks*) have a critical effect on the stability of the slopes. Little is known about the extent of such features apart from some incidental descriptions in student theses. Detailed investigation and geological description of these features is required to investigate the extent to which these are located beyond slope crests and whether they are related to specific horizons only.
10. Very little is known about the response of these tension cracks to rainfall events (i.e. crack water pressure versus rainfall relationships). These features are most critical nearest the slope crests. Piezometers placed at some distance from the slope crest (measuring pore pressures within the slope) may give little indication of critical water pressures near the crest. Piezometric monitoring needs to take account of the tension cracks – this is likely to result in piezometers being placed in inclined drillholes to ensure interception of the tension cracks (*Figure 8*). Given the aerial variation of rainfall, automatic rainfall gauges should be located close to all automatic piezometer locations.
11. The slope failure mechanism is essentially a very rapid blowout of a volume of material close to the slope crest. Borehole inclinometers installed at some distance from the slope crest (measuring shear movements normal to the borehole axis) are not likely to provide adequate information for predicting future slope failures. Although horizontal borehole extensometers would be theoretically preferably, these have significant practical problems in this situation.
12. Laboratory testing of the slope materials is currently underway and this program is endorsed. However, the slope material properties are certain to be less critical than the tension crack properties (locations, extent and depth of water). Back analysis of the failed sections of slope will yield important information on slope behaviour.
13. The 2001 relic slip report recommended that specialist geotechnical advice would be required, *inter alia*, where buildings were located within the 4H:1V runout distance from an uphill slope. The May 2005 events and observations indicate that this criterion should be applied to all development in the TDC area. The council GIS database should be used to check for existing buildings with such a hazard zone.
14. TDC's consultants have made recommendations regarding further investigations of geology and groundwater – these are endorsed. Horizontal drains below the slope crest could theoretically provide some useful drainage but this would be dependent on a detailed geological investigation of the vertical fissuring within the ash. Stormwater and surface water control is clearly of paramount importance in the prevention of further slides.

RECOMMENDATIONS

15. Rainfall records should be reviewed to assess the severity of the daily and precedent rainfall for the 18 May 2005 event.
16. Geological cross sections should be established for all failure areas to identify failure mechanisms, allow back analyses and determine runout characteristics of the slides. If slide areas are assessed by different individuals, an overview report to bring all data together would be helpful.
17. Representative areas near the ridge crests should be investigated in detail to provide information on the characteristics of tension cracks near slope crest.

⁶ Bell D, Richards L, Thomson R. *Relic slip verification study*. Report to TDC, March 2001.

18. Piezometric monitoring should be established to identify critical water pressures near the slope crests. Automatic rainfall gauges will be required in the general area of the piezometers.
19. Any further proposals for slope monitoring should be reviewed in relation to the slope failure mechanisms and the instrument capabilities.
20. Conclusions arising from the review of these slides should be used to review TDC land development criteria and made available to all those concerned with development in this area.

s 7(2)(a) - Privacy

Laurie Richards

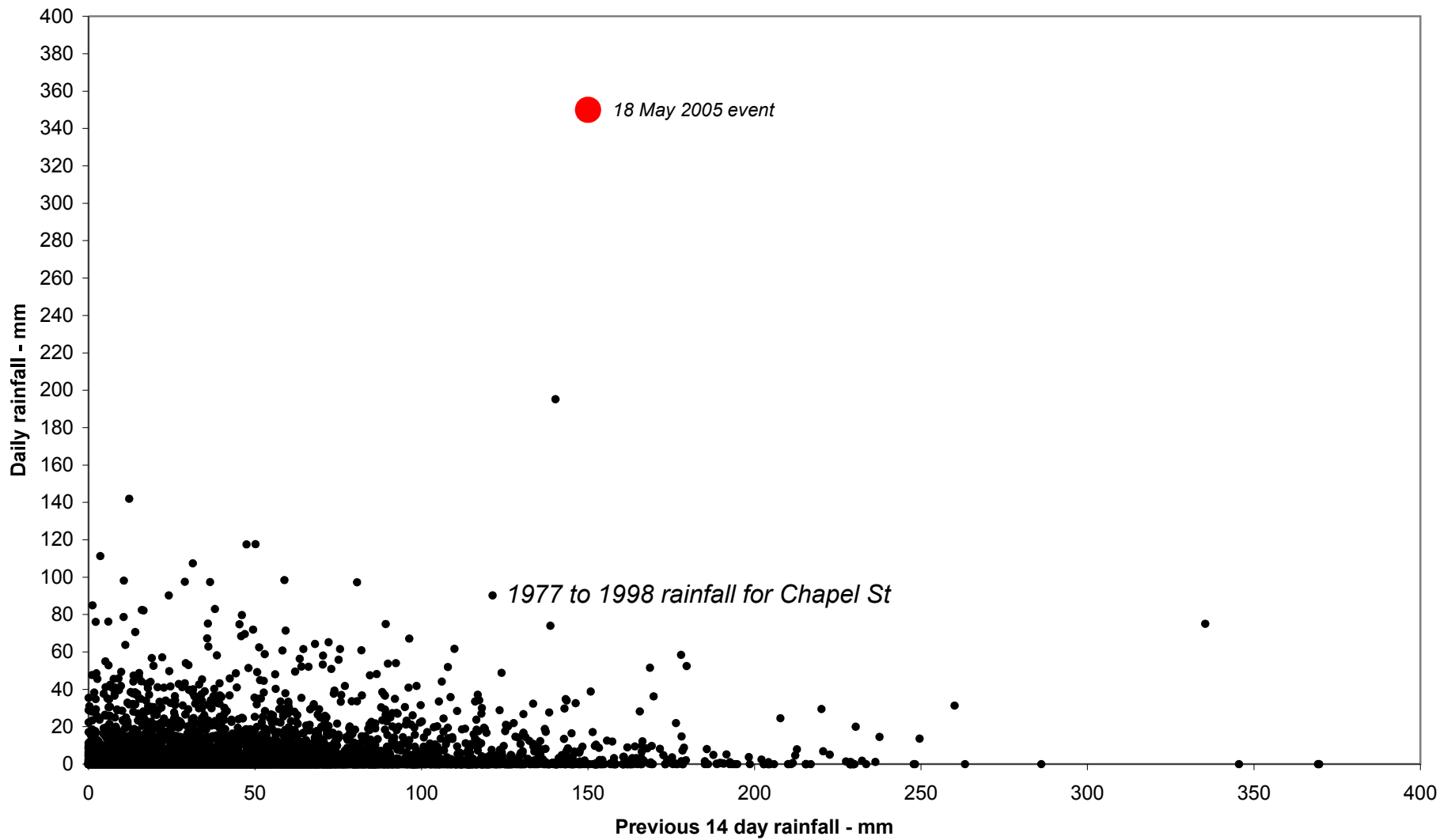


Figure 1: 18 May 2005 rainfall compared with 1977 to 1998 at Chapel St

TAURANGA MAY 2005 LANDSLIDES

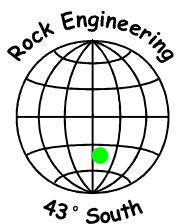
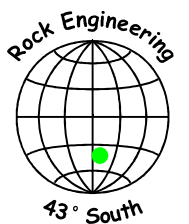
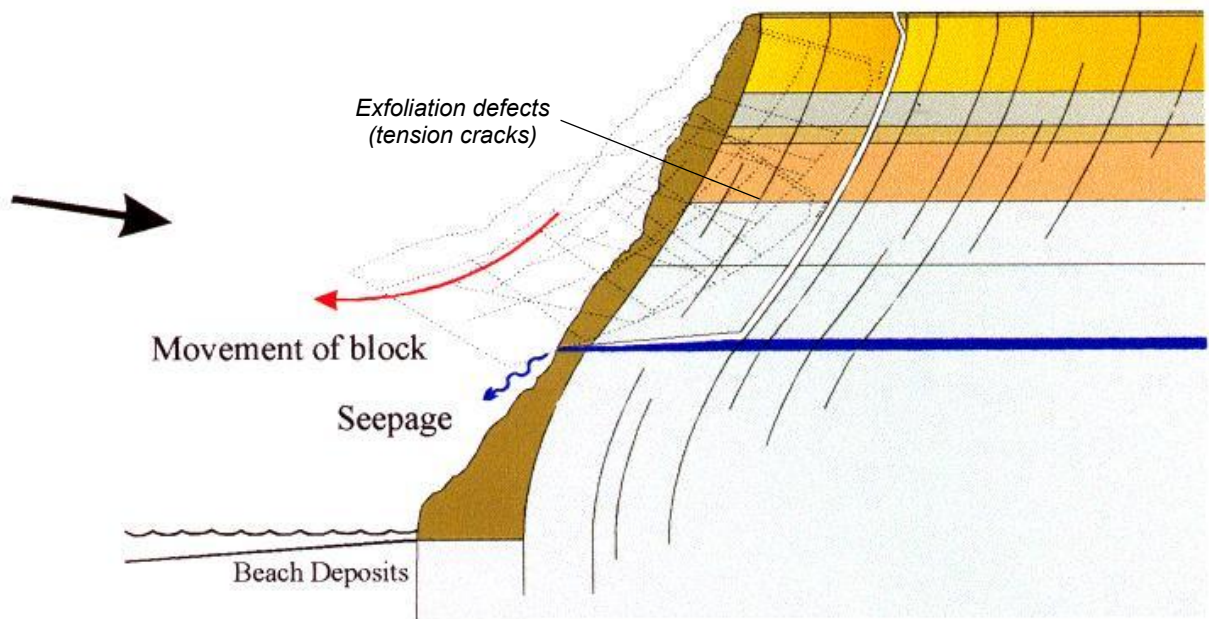


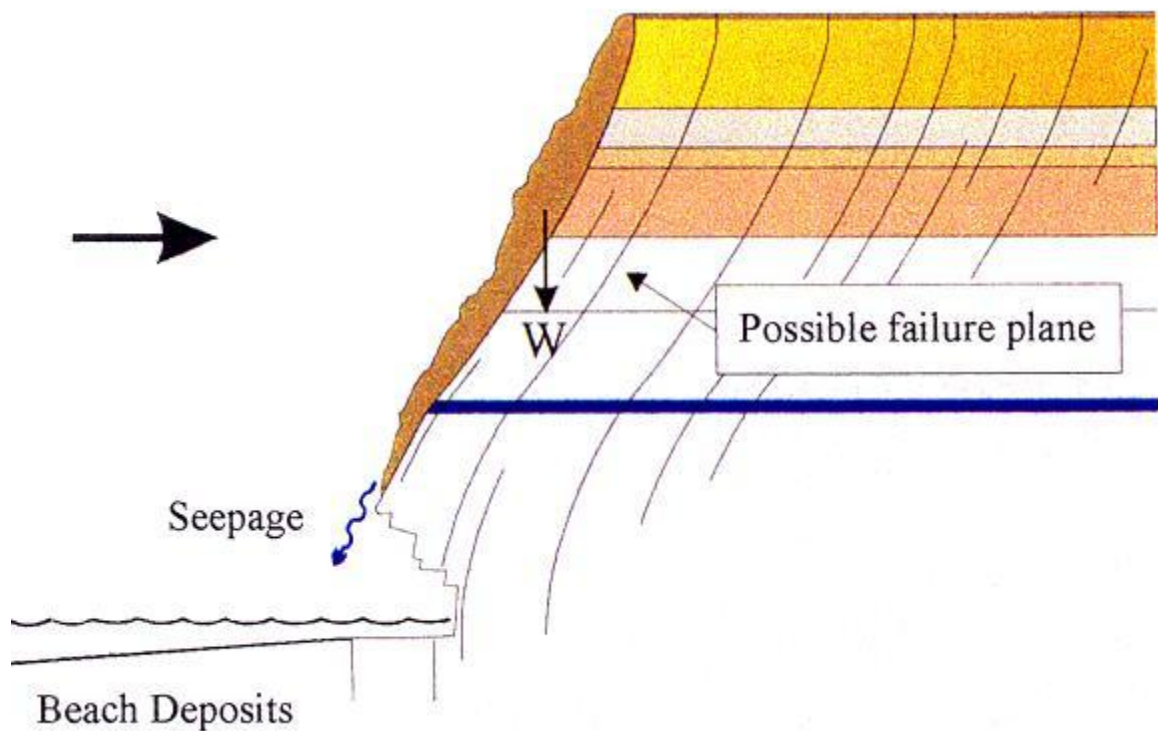


Figure 2: Example of landslide geometry at Vale Street
TAURANGA MAY 2005 LANDSLIDES





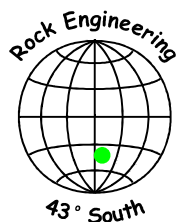
(a) Piping triggered block failure



(b) Wave erosion triggered block failure

Figure 3: Slide morphology described by Oliver 1997

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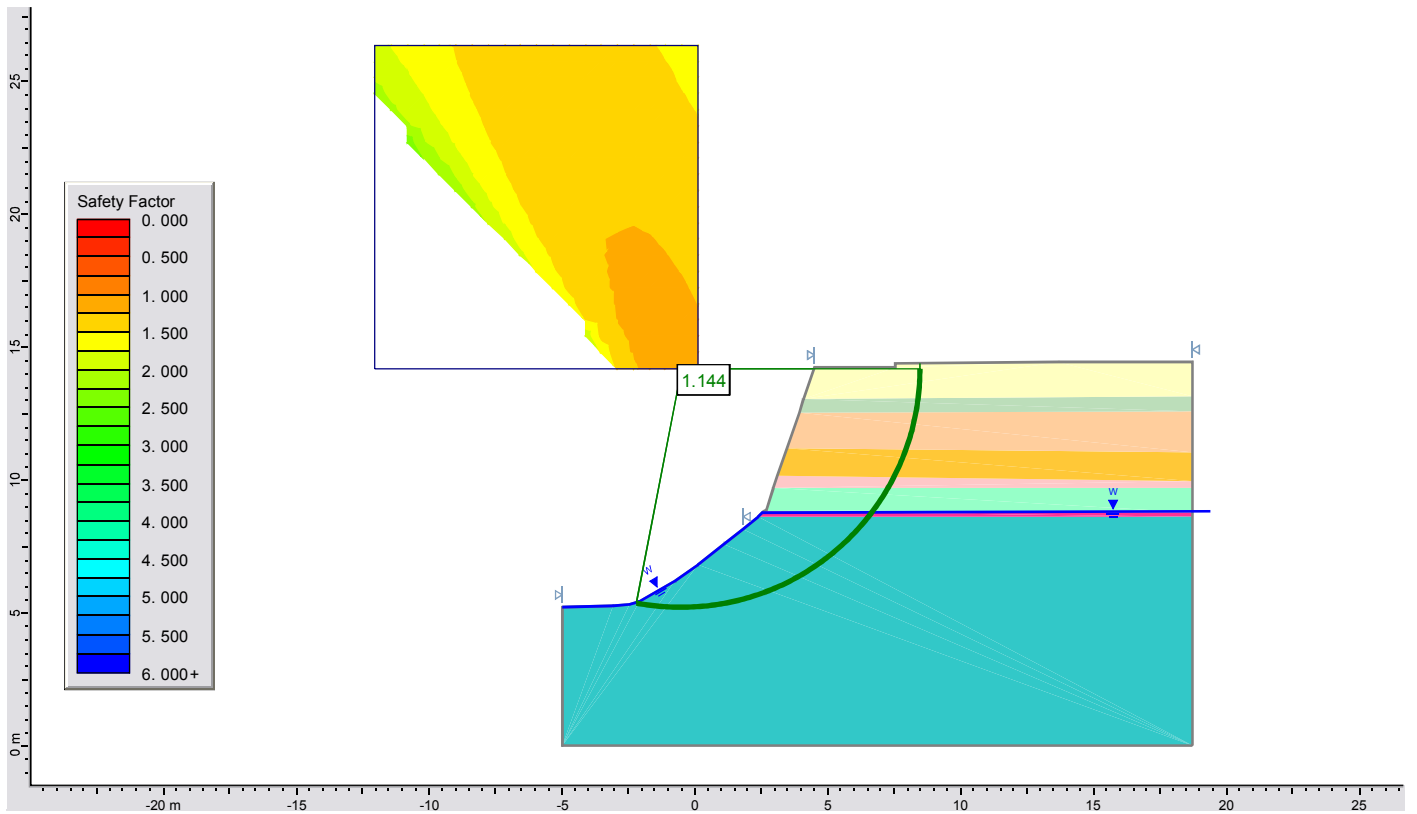


Figure 4: Slide with low groundwater level on ash layer

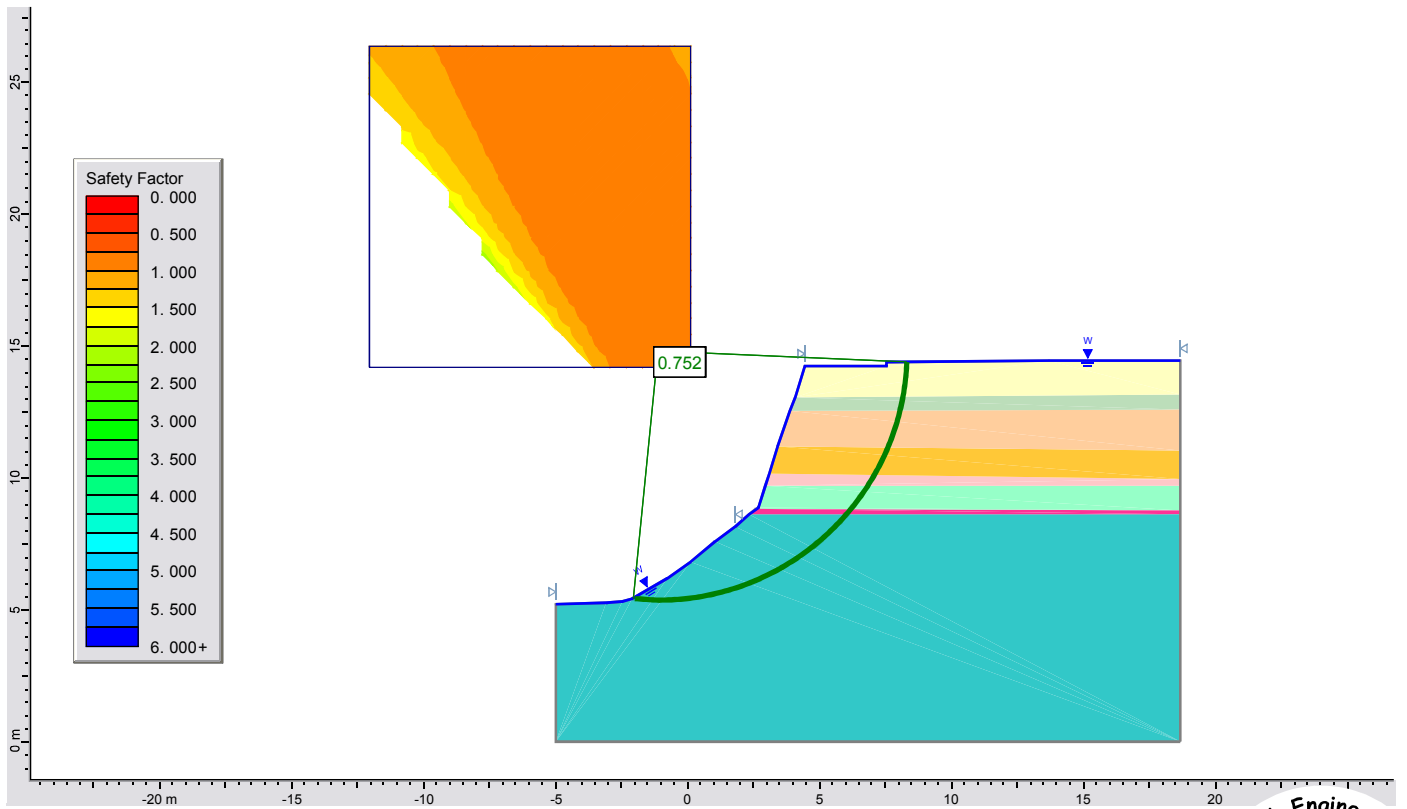
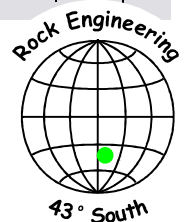


Figure 5: Slide with fully saturated groundwater levels

TAURANGA MAY 2005 LANDSLIDES



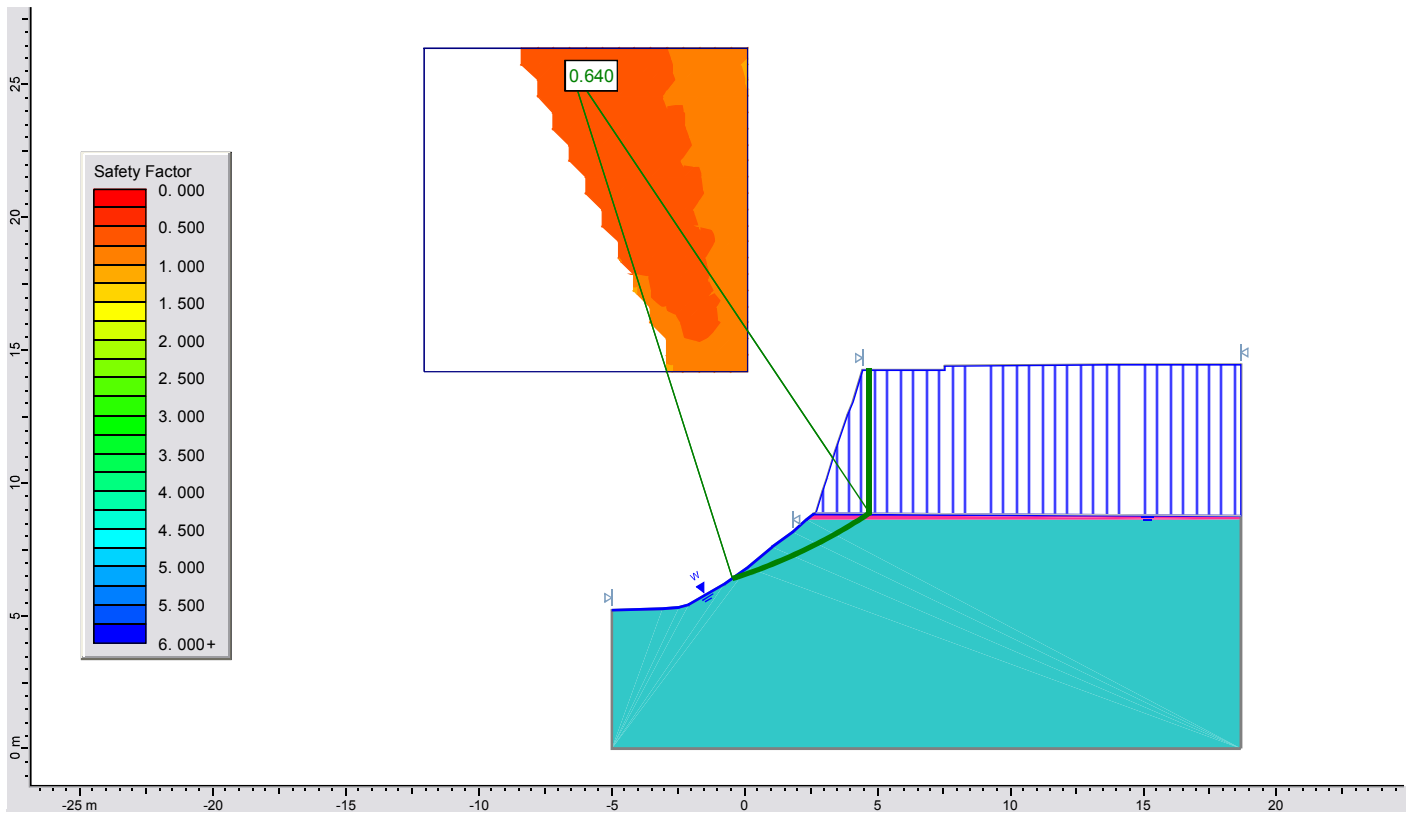


Figure 6: Slide with low groundwater level on ash layer plus tension cracks

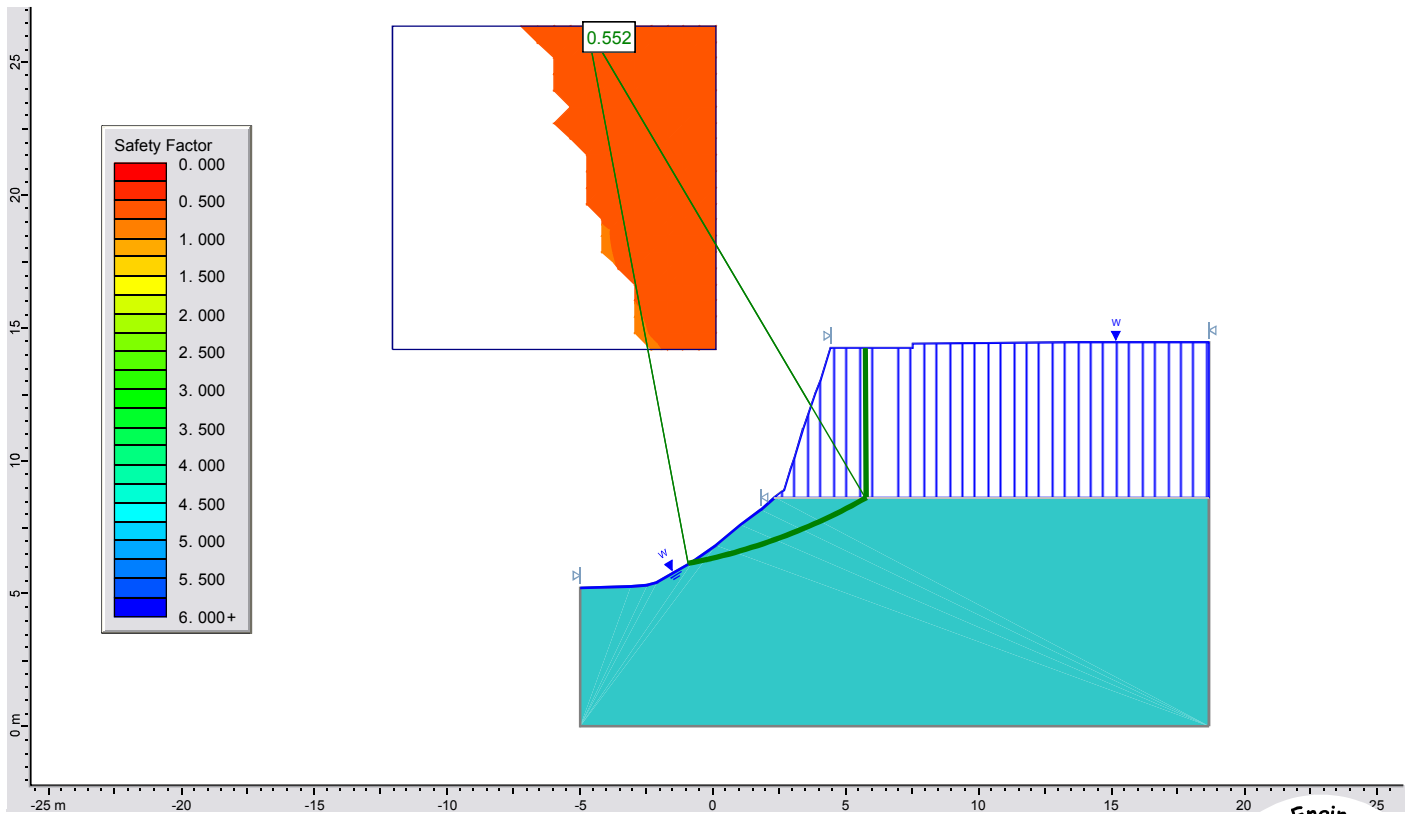
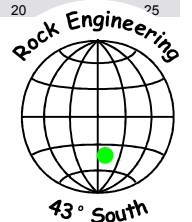


Figure 7: Slide with fully saturated groundwater levels plus tension crack

TAURANGA MAY 2005 LANDSLIDES



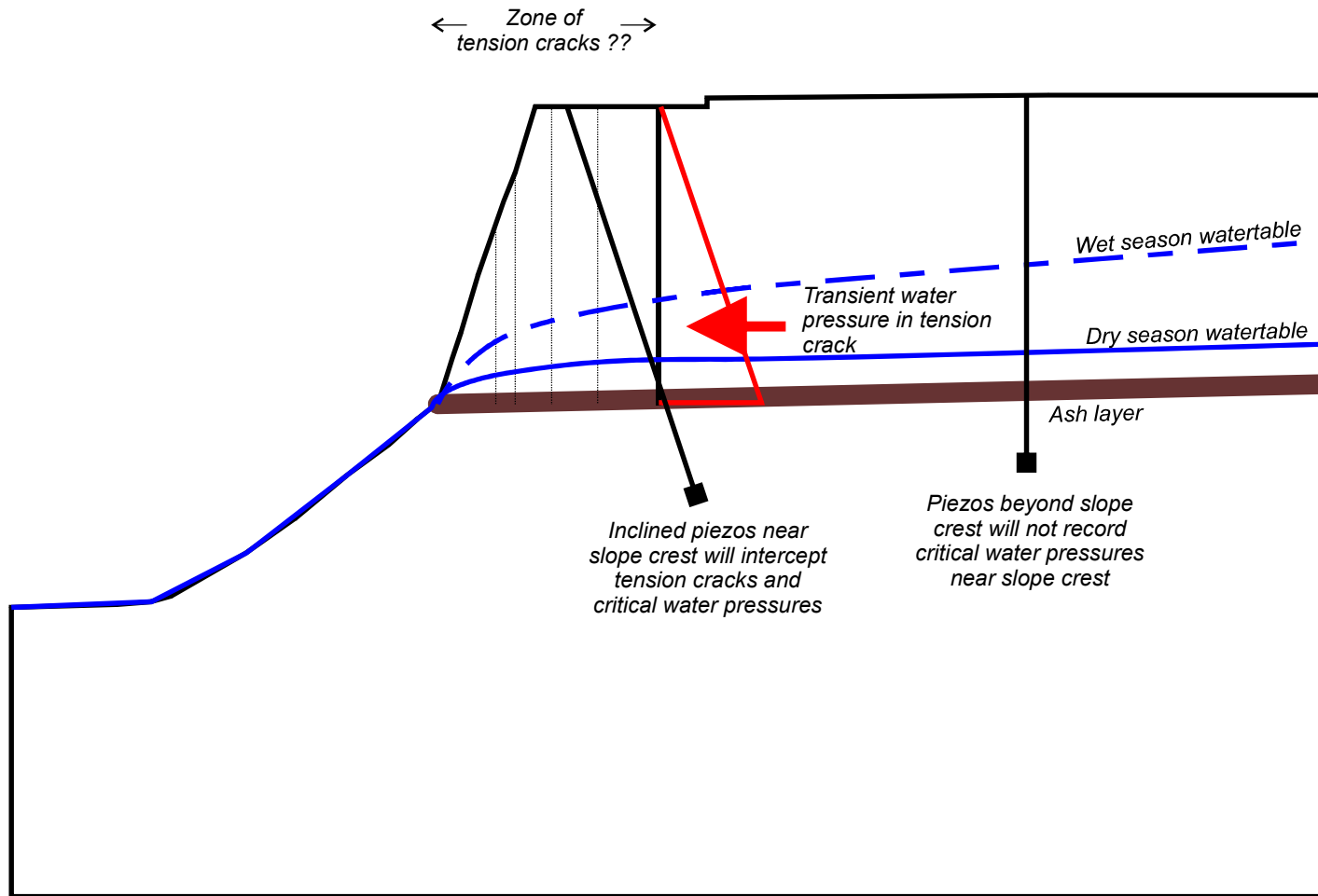


Figure 8: Piezo locations and slope water pressures
TAURANGA MAY 2005 LANDSLIDES

