



Boffa Miskell Limited  
Mauao Base Track Remediation  
Geotechnical Assessment

July 2018

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# 1. Introduction

## 1.1 Purpose and Scope

Boffa Miskell Ltd has been engaged by Tauranga City Council to design a southern section of the Mauao (Mount Maunganui) Base Walking Track. GHD Ltd has been engaged by Boffa Miskell, as a subcontractor, to assess the geotechnical risks associated with re-aligning the track. This geotechnical assessment is limited to the area of the proposed track re-alignment as denoted on Figure 1.

The re-alignment is required following a landslide that damaged the existing walking track in April 2017. Following the damage to the original walking track, a temporary route was established above the landslide head. This temporary track includes flights of steps in both directions. The base track provides significant value for both the local community and tourism. For this reason, Tauranga City Council wishes to reinstate the track without steps to ensure it is accessible for all persons.

The assessment included a visual reconnaissance of the site as well as intrusive investigations on the beach and slopes along the alignment of the proposed walking track.

This report is a preliminary assessment to accompany the resource consent application. Detailed geotechnical analysis should be undertaken prior to the final design and construction of the track.

## 1.2 Proposed Development

The site is located on the southern (harbour) side of Mauao, beyond the wharf at the end of Pilot Quay. The proposed track re-alignment is approximately 370 m long as shown on Figure 1. The proposed re-alignment will allow the track to descend to and ascend from the beach and follow a revetment structure on the beach for approximately 190 m. The realigned track will have a gradient that will require no steps on the track.

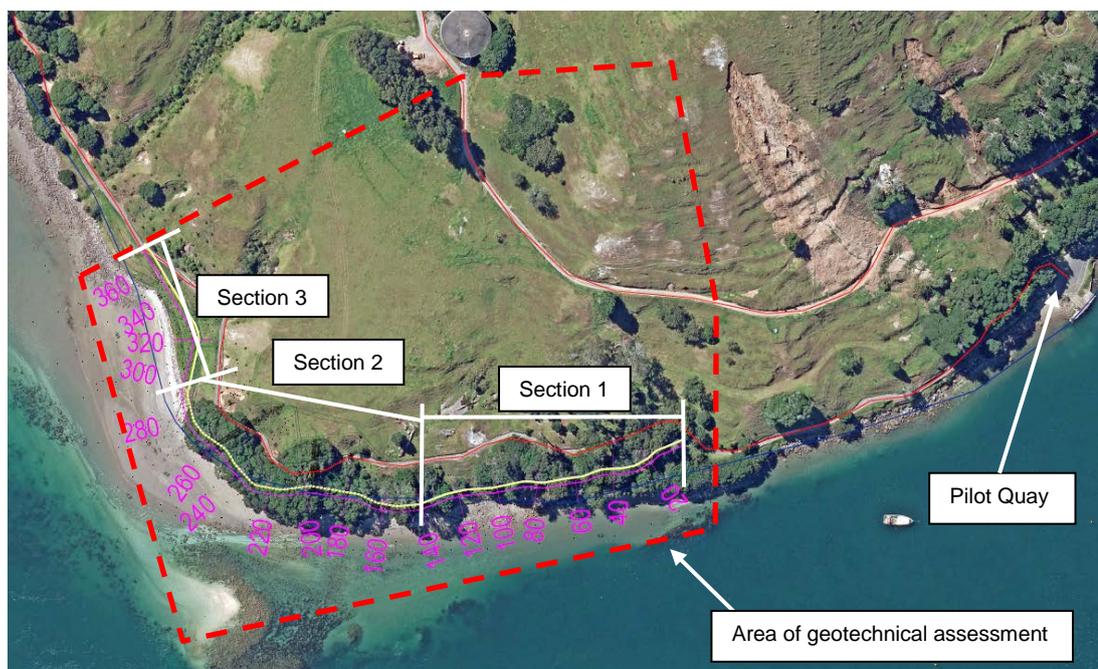


Figure 1: Aerial photo of the southern edge of Mauao.

The yellow line denotes the proposed walking track.

The track re-alignment can generally be broken up into three sections as shown in Figure 1:

- Section 1 – Approximate chainage 0 m – 140 m: this section of track will reduce elevation from the existing base track down the vegetated slope to the proposed revetment structure on the beach. The track will stay on the slope until a practical location can be determined for the construction and tie-in to the revetment structure. The revetment structure should avoid covering the boulder field as much as practical in order to avoid removal of those boulders for construction, however this might not be achievable throughout the whole length of the boulder field. The slope along this section of the track is generally between 15° and 40° (Drawing 18-37691-G002 – Appendix A).
- Section 2 – Approximate chainage 140 m – 290 m: this section includes the proposed revetment structure along the beach. The slope above the proposed revetment structure in this area is generally 50° - 70° and includes the landslip that closed the previous walking track (Drawing 18-37691-G003 – Appendix A).
- Section 3 – Approximate chainage 290 m – 370 m: this section is on-grade along an area of flat fill at the base of an approximately 45° natural slope. Towards the end of this section, the track climbs back to the elevation of the existing walking track (Drawing 18-37691-G004 – Appendix A).

### 1.3 Site Description and Geology

The 1:250K New Zealand Geology Web Map (available on the GNS website), indicates the site is underlain by Minden Rhyolite Subgroup rocks. These rocks are described as ‘flow-banded rhyolite to rhyodacite lava; often as domes or dome complexes’. The rhyolite lava flows encountered in the site area are derived from the volcanic eruption of Mount Maunganui (Mauao).

Mauao is a steep sided, flat topped rhyolite dome. The upper slopes of Mauao are very steep bluffs of rhyolite lava flows. The middle slopes are steep and are obscured by vegetation and rhyolite talus (Hall, 1994). The lower slopes exhibit a much shallower gradient and represent a terrace deposit of Matua Subgroup fluvial and air fall deposits (Hall, 1994). These fluvial deposits outcrop in the coastal cliffs around the base of Mauao. Matua Subgroup sediments therefore underlie the proposed walking track. On the southern side of Mauao a ‘peninsula’ of shallow water can be seen on the aerial photos followed by a sudden drop into deep water (Figure 1). It is interpreted that this is a shelf of either rhyolite lava or rhyolite boulders.

The Matua Subgroup soils are described as terrestrial and estuarine sedimentary deposits with intercalated ignimbrites and tephtras. The subgroup contains a wide variety of lithologies which change rapidly both laterally and vertically. A large proportion of the sediments are derived from reworked ignimbrites, lava domes and tephtras both from the Tauranga region and the Taupo Volcanic Zone.

Lithologies include pumiceous silts, sands and gravel of rhyolitic to andesitic composition, lignite and peat, lacustrine and estuarine muds, with intercalated air fall tephtras and possibly distal ignimbrite (Hall, 1994).

Large boulders of Minden Rhyolite (up to 1.5m diameter) are encountered towards the base of the Matua Subgroup fluvial deposits. These are interpreted as being transported in an active fluvial channel. The size of the rhyolite boulders fine upwards through the profile (Hall, 1994).

Rock fall from the rhyolite bluffs on Mauao is a stability issue on the northern and eastern flanks of the volcano. On the upper southern side of Mauao above the site area, there are few visible outcrops of rock.

A seismic survey of entrance channel (adjacent to Mt Maunganui) was completed for the Port of Tauranga in 2014. This survey indicated that Rhyolite lava flows from the Mt Maunganui Rhyolite dome do not extend into entrance channel (de Lange, Moon & Fox, 2014).

## 2. Geotechnical Investigations

### 2.1 General

An initial geotechnical investigation was undertaken on 31 January 2018. This investigation consisted of five hand auger holes and ten Dynamic Cone Penetrometer (DCP) tests. Further works were then required with the potential need of significant excavation on the track through Section 1 to achieve grade. A second investigation was therefore completed on the 23<sup>rd</sup> of April 2018 to aid in this design. This investigation consisted of another five hand auger holes and 5 Dynamic Cone Penetrometer (DCP) tests. The locations of the hand auger holes and DCP tests are shown on the geomorphological map, drawing 18-37691-G001 in Appendix B.

### 2.2 Auger Holes

Eleven hand auger holes were bored to a depth between 1.35 m and 3.00 m Below Ground Level (bgl). The ten holes were all terminated due to target depth, refusal or hole collapse. In-situ testing comprised hand held Shear Vane tests undertaken where possible given the material encountered. Shear Vane testing within borehole and hand auger holes was performed in accordance with NZ Geotechnical Society 'Guideline for Hand Held Shear Vane Test, August 2001'.

Soils and rocks were logged generally in accordance with NZGS Guidelines (NZ Geotechnical Society Inc, December 2005).

Groundwater was not encountered in any of the auger holes.

The hand auger hole logs are attached in Appendix C.

### 2.3 Dynamic Cone Penetrometer Testing

Ten DCP tests were undertaken along the beach, the tests were spaced along the area of the proposed revetment structure. The purpose of the DCP testing was to determine depth to competent material (refusal). SC5a was undertaken due to refusal of SC5 on an assumed shallow boulder. DCP tests were also carried out at the base of majority of auger holes.

Refusal of DCP testing was taken as 20 or greater blows for a 50 mm increment or >10 blows for five 50 mm increments in a row.

Table 1 summarises the depth to competent material (refusal) in each of the DCP tests. There are a number of large rhyolite boulders on the beach and entrained in the surrounding slopes. It cannot be determined if refusal of testing is due to competent rock or rhyolite boulders.

Table 1: DCP test refusal depths.

DCP test	Depth to Refusal (m)
SC1	0.35
SC2	0.5
SC3	0.95
SC4	0.55
SC5	0.2
SC5a	0.8
SC6	0.55
SC7	1.1

SC8	0.9
SC9	0.5

The DCP results are attached in Appendix D.

## 3. Ground Conditions

### 3.1 General

The geological units encountered within the hand auger holes and the refusal depth of each hole are summarised in Table 2.

Table 2: Depth range of units within the auger holes.

	Depth Range of Unit (m)					
	Topsoil	Fill	Fill (Midden Material)	Matua Subgroup	Auger Termination Depth	DCP Refusal
HA01	0.0 – 0.1	0.1 – 1.35	NE	NE	1.35*	NT
HA02	0.0 – 0.1	0.1 – 1.95	NE	NE	1.95*	NT
HA03	0.0 – 0.2	NE	NE	0.2 – 2.3	2.30*	2.65*
HA04	0.0 – 0.2	NE	0.2 – 1.7	NE	1.70+	NT
HA04a	NE	NE	0.0 – 1.4	NE	1.40+	2.00*
HA05	NE	0.0 – 2.8	NE	2.8 – 3.0	3.00-	3.75-
HA06	NE	0.0 – 0.6	NE	0.6 – 2.0	2.00*	4.00-
HA07	0.0 – 0.2	NE	NE	0.2 – 1.8	1.80*	1.80*
HA08	0.0 – 0.2	NE	NE	0.2 – 3.0	3.00-	4.00-
HA09	NE	NE	0.0 – 1.0	NE	1.00+	3.90-
HA10	NE	0.0 – 1.8	NE	1.8 – 3.0	3.00-	3.85-

NE = Not Encountered NT = Not Tested \*Obstruction +Hole Collapse -Target Depth

### 3.2 Fill

Fill was encountered in HA01, HA02 from the base of the topsoil to the termination of the auger holes. Personal communication with Tauranga City Council staff indicates that the fill was placed on the beach using material from a landslip elsewhere on Mauao. The soil encountered was generally loose to medium dense sand and stiff silt. It is unknown if refusal at the base of these holes was on rock or boulders. Besides that, fill was also encountered in HA05, HA06 and HA10 on top of the Matua Subgroup sediments.

### 3.3 Fill – Midden Material

Midden material from early Maori settlement was encountered in HA04, HA04a and Ha09. This material was generally unconsolidated, very soft to soft, dark brown organic silt with some white shell fragments. The midden material was on the slopes where Section 1 of the track is proposed to be constructed. HA04, HA04a and HA09 were terminated due to hole collapse at 1.70m, 1.40m and 1.0m below ground level respectively. DCP testing at the base of HA04a and HA09 indicated loose midden material to a depth of 2 m bgl and 3.6m bgl respectively.

### 3.4 Matua Subgroup

Matua Subgroup sediments were encountered in HA03, HA05, HA06, HA07, HA08 and HA10, and seen in the cliffs/slopes above the beach. Matua Subgroup sediments are generally stiff to very stiff silt and medium dense to dense sand. The material is volcanic in origin with pumice content.

## 4. Geological Mapping

A geological field assessment was made of the general site area along the proposed walkway alignment and the surrounding area. The field assessment was complemented by a desktop study.

The findings of the geological assessment are as follows:

- A distinct break in slope on the volcano's flanks indicates the Matua Subgroup fluvial terrace discussed by Hall (1994).
- A number of shallow soil slips on the hillside are generally concentrated where cuts have been made for the existing walking track and on steep slopes.
- Although there are some minor soil slips in existing Matua Subgroup cut faces, the sediments generally stand un-retained at angles greater than  $60^\circ$  as shown on Figure 2.
- The April 2017 slip surface generally comprises weathered silts and sands of the Matua Subgroup. The slip surface is generally  $60^\circ$  to  $70^\circ$ , in places there is localised overhang.
- Rock fall is occurring on the northern and eastern sides of Mauao. However, there is no visible evidence for rock fall from the volcano's upper slopes within the assessment area.
- Boulders were encountered on the beach and entrained in the coastal cliffs. These boulders are inferred to be derived from fluvial processes rather than rock fall.
- A section of hummocky ground was encountered to the east of the assessment area. This hummocky ground is steep and likely indicates a change from the fluvial terrace into rhyolite lava flows.



Figure 2: Angle of existing cut batters in the project area.

The findings of the geological assessment are summarised by the geomorphic map - drawing 51-37691-G001, attached in Appendix B and the three annotated photos illustrating key areas

along the track alignment; drawing numbers 51-37691-G002, 51-37691-G003 and 51-37691-G004 attached in Appendix A.

# 5. Discussion and Recommendations

## 5.1 Stability

### 5.1.1 Quantitative Slope Stability Analysis

The Australian Geomechanics Society (AGS) “Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning” has been used to determine the estimated risk of loss of life due to landslide effects on the proposed track development (AGS 2007a).

In order to derive the individual risk loss of life calculation, the AGS guidelines recommend the following formula be used (Figure 3).

For loss of life, the individual risk can be calculated from:

$$R_{(LoL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad (2)$$

Where

$R_{(LoL)}$  is the risk (annual probability of loss of life (death) of an individual).

$P_{(H)}$  is the annual probability of the landslide.

$P_{(S:H)}$  is the probability of spatial impact of the landslide impacting a building (location) taking into account the travel distance and travel direction given the event.

$P_{(T:S)}$  is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.

$V_{(D:T)}$  is the vulnerability of the individual (probability of loss of life of the individual given the impact).

A full risk analysis involves consideration of all landslide hazards for the site (e.g. large, deep seated landsliding, smaller slides, boulder falls, debris flows) and all the elements at risk.

Figure 3: Loss of life risk calculation (AGS guidelines)

The calculated annual probability of death of the person most at risk in the zone beneath the proposed track was calculated to be  $7.4 \times 10^{-5}$ , which corresponds to a low risk zone descriptor. Appendix E shows the full extent of the assumptions, calculations and results used in defining the loss of life calculation. Based off the Australian Geomechanics Society suggested tolerable risk criteria, ‘New Developments should achieve an annual probability of death of the person most at risk in the zone of  $10^{-5}$  which this assessment currently achieves. Tolerable Risk is defined as “risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable”.

Although based off this risk assessment the track development sits within Tolerable limits, visual reconnaissance of the site taking into account the results of the investigation and engineering judgement have allowed us to provide the following risk mitigation options to further reduce the potential risk. This risk assessment should be reviewed during and post construction to re-assess any unforeseen risks to the development.

### 5.1.2 Existing Slip Face

- The April 2017 slip has left an exposed unvegetated very steep slope (Appendix A).
- Where it exists, soil/rock overhang on the face should be locally battered back until a consistent gradient is achieved.
- The slope as a whole should not be battered back any further. Although it will decrease the overall angle of the exposed face, further cutting will result in the removal of the old track. The old track is currently acting as a bench between the very steep slip face and the steep un-mobilised slope above.

- Following re-grading of localised overhangs we recommend that the exposed slip face is covered in MacMat, DuraMAT or other suitable approved product. The matting should be secured in place with suitably designed anchors.
- Once installed the MacMat, DuraMAT or other suitable approved product can be hydroseeded. Vegetation growth on this surface will further improve stability of the slip face.

#### 5.1.3 Track Section 1

- The gradients along Section 1 are generally 25° - 40° with a 15° - 30° shallower 'bench' in the middle of the slope.
- These slopes are currently vegetated – we recommend that during and following construction as much vegetation as possible is retained on the slopes to maintain stability.
- There may be extensive midden deposits on these slopes, based on HA04, HA04a, HA09 and observations of existing middens on the surrounding ground surface. The midden deposits are generally unconsolidated, very soft to soft, and will likely result in stability issues if excavated. We recommend that midden material underlying the proposed track/foundations be removed/avoided as required. Midden material will be required to be removed if it is on the downhill side of the track, if it underlies any retaining or boardwalk structures or if it is present in any cut surfaces.
- No boulders inferred to be derived from rock fall were visible, indicating that the risk of rock fall from the upper slopes of Mauao is low.

#### 5.1.4 Track Section 2

- The slopes/cliffs above Section 2 (revetment structure on the beach) generally grade at 50° - 70°.
- The April slip that damaged the previous walking track is located in this section.
- There is a risk of further instability of the slip scarp due to steep gradients, weathering of pumice rich volcanic deposits and large trees on the slopes.
- We recommend that during construction, large trees are either pruned or removed (after specific assessment by an arborist). We recommend that as much vegetation as possible is retained to maintain stability of the slopes.
- We recommend that the natural slope profile is maintained as battering back of these slopes will cause damage to the existing vegetation on the slopes.
- If, during construction inspections, small scale rock fall is identified after excavation of new and existing slopes, localised rock fall prevention methods such as matting or netting should be installed to reduce the chance of rock fall onto the track from ravelling of the slopes/cliffs.
- No boulders inferred to be derived from rock fall were visible, indicating that the risk of rock fall from the upper slopes of Mauao is low.

#### 5.1.5 Track Section 3

- The slopes above Section 3 generally grade at 40° to 50°.
- The slopes in this section are grassed and show no evidence of failure above the proposed track. There are failures of the cut slope in this section above the existing walking track.

- If the existing slopes are not excavated, additional work is unlikely to be required to stabilise the slopes in section 3.
- No boulders inferred to be derived from rock fall were visible, indicating that the risk of rock fall from the upper slopes of Mauao is low.
- Material in the flat low lying areas of this section of track was fill won from site from existing slope failures and placed in an uncontrolled manner. Therefore, track construction in these areas may be prone to settlement. If a track on grade through this section is proposed either the non-engineered fill will need to be removed and replaced or an allowance should be made for track maintenance due to settlement.

## 5.2 Stormwater

- Uncontrolled stormwater is a major contributing factor to slope instability.
- We recommend that stormwater be controlled for the entire length of the proposed walking track.
- We recommend that stormwater above the existing slopes, proposed cut batters and cliffs is intercepted and diverted to minimise stormwater flows over the faces of the slopes, cuts and cliffs.
- We recommend that temporary stormwater control is implemented during track construction.

## 5.3 Track Formation

A number of different options for track formation can be pursued each having its own geotechnical merits and constraints. Achieving an acceptable grade down to the proposed revetment structure through section 1 will likely provide the most challenging construction issues for track formation due to the steep terrain and large elevation difference.

- Option 1 could be to create a fill batter slope to achieve the grade down to the revetment structure. This option however would create a significant slope potentially toeing out into the water requiring large quantities of fill and would likely require an extensive cut into the existing slope to enable compaction of fill into the slope. This option would likely result in a large area of disturbance in terms of heritage sites as well as reducing the aesthetic values of the site.
- Option 2 would be to construct the track on cut ground rather than filled ground. This could potentially require retaining on the downhill side of the track in places. The recommend cut styles are illustrated in Figure 4. The constraints of this option is that in order to achieve a safe batter angle upside of the track, and due to the proposed gradient of the track down to the revetment, large amounts of excavations would be required along this length of track. This would result in disturbing heritage sites and removing significant amounts of vegetation leaving large exposed cut faces and retaining structures.

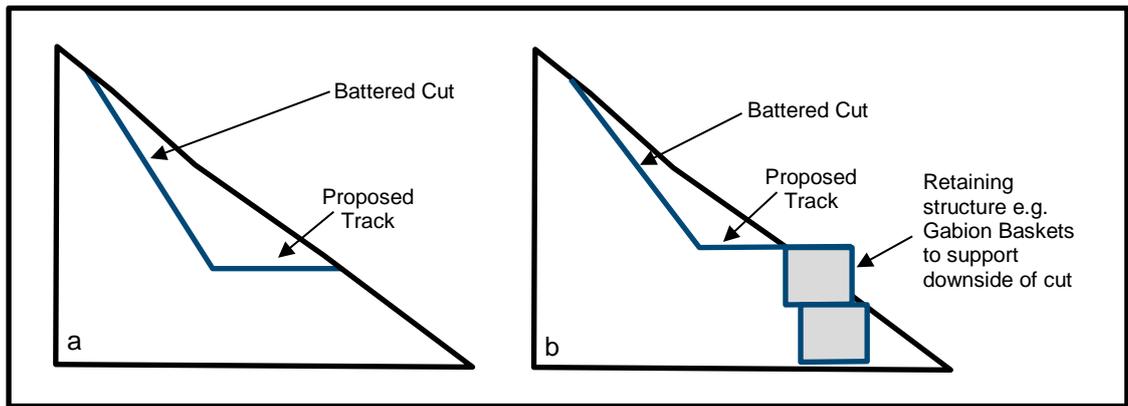


Figure 4: Track Formation recommendations.

[a) Cut track entirely constructed on cut ground. b) Cut track half on cut and half on fill, supported by a Gabion Basket retaining wall].

- Option 3 could be to create a full height retaining structure to reduce the amount of cut batters to form the track. The constraints of this option would be that due to the gradient of the slope the retained heights would be large resulting in significant retaining structures, likely to require tie-back anchors. In order to form this retaining structure excavation would be required to create a working platform for construction as well as the excavation for tie-back anchors. This retaining structure would likely become extensive and not in keeping with the current aesthetics on Mauao.
- Option 4 would be to construct a raised boardwalk on piles. This option is by far the least intrusive option with minimal disturbance to the local heritage sites and ecology. The constraints would be the potential requirement for very minor superficial localised excavation to achieve grade, however would be the least amount of disturbance of the four options.

Where required, we recommend that midden material is removed from below the proposed track and placed in stable mounds in approved areas elsewhere on Mauao. Cuts on the upper side of the tracks where required should be battered at a cut angle specific to the material they are cut into. Preliminary batter angles are summarised in Table 3.

Table 3: Batter angle of track cuts for different material types.

Material Type	Batter Cut Angle
Matua Subgroup Rock	2 V in 1 H
Matua Subgroup Soil	1 V in 1 H
Midden Material	Retaining Required

The cut faces along the track can have MacMat, DuraMAT or other similar approved product installed onto them and held in place with suitably designed anchors. These can then be hydroseeded to provide further stability and an aesthetic finish.

#### 5.4 Revetment Foundations

- The DCP tests encountered refusal between 0.2m and 1.1m, with an average depth to refusal of 0.65m. Rhyolite boulders are encountered on the beach and based on the geomorphology of the site and the variable refusal depth of DCP testing it is concluded that refusal is more likely to be occurring on boulders.

- Foundation conditions for the revetment structure are likely to comprise sands and marine sediments to an unknown depth with rhyolite boulders in the sand.
- Excavation of the revetment foundation may be difficult if the loose sand extends below the water table and trench walls will likely collapse. Temporary support will be required for the trench excavation in sand.
- Revetment and foundation designs should be further assessed by the coastal and geotechnical engineers.

## 5.5 Further Investigations

Further investigations for the revetment foundation are not feasible without a machine drilling rig. The need for these investigations should be assessed during revetment design.

## 6. Summary

It is proposed to construct an alternative route to the existing Mauao Base Walking Track. Geological mapping and geotechnical investigations conclude that Matua Subgroup sediments generally underlie the area of interest around the proposed walking track. These sediments are generally of fluvial and air fall origin, consisting of reworked volcanic materials. There are also extensive deposits of unconsolidated soft midden material.

As described in Figure 1 the proposed track can be broken into three sections. Section 1 negotiates a 15° - 40° slope of Matua Subgroup sediments. Potentially extensive midden fill deposits overlie this slope. Track formation will likely require either significant earthworks in conjunction with retaining structures or a raised boardwalk. The raised boardwalk option is the least intrusive form of track formation, which retains the existing vegetation cover with the least disturbance to heritage sites. Midden material under the track footprint can be avoided with a raised boardwalk, however if an earthworks option is preferred then this material should be carefully relocated to another approved location on Mauao.

Section 2 of the track is proposed to follow the beach on a revetment structure at the base of the existing coastal cliffs and slopes. The ground conditions are anticipated to be rhyolite boulders entrained in loose sand to an unknown depth. The Matua Subgroup cliffs and slopes above the proposed track are 50° to 70°, these cliffs may need to be battered during construction to maintain and increase stability. There are also several large trees on these slopes/cliffs, for stability of the cliffs these trees should be pruned or removed (subject to arborist assessments).

Section 3 of the track is predominately on a flat fill platform slightly elevated above the beach. The fill is generally firm to stiff. The proposed track will follow the base of a visibly stable 45° natural slope. Based on this preliminary assessment, it is considered that with no major excavation, the slopes along section 3 are relatively stable, however localised settlement could occur due to the uncontrolled nature of the fill in this area.

Further investigations for the revetment foundation should be assessed during revetment design.

## 7. Limitations

This report has been prepared by GHD for Boffa Miskell Limited and may only be used and relied on by Boffa Miskell Limited for the purpose agreed between GHD and Boffa Miskell Limited as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Boffa Miskell Limited arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Boffa Miskell Limited and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

## 8. References

Australian Geomechanics Society, 2007a. 'Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning' Journal and News of the Australian Geomechanics Society Volume 42 No 1 March 2007.

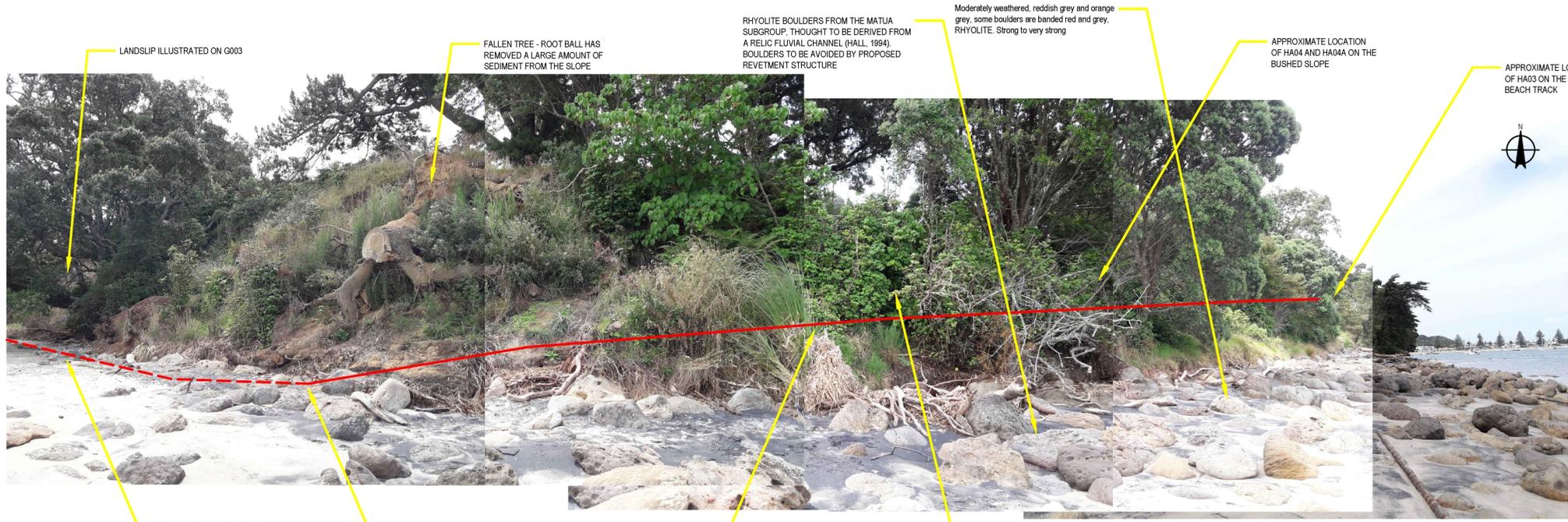
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# Appendices

# Appendix A - Annotated Photos of Proposed Track Location



LANDSLIP ILLUSTRATED ON G003

FALLEN TREE - ROOT BALL HAS REMOVED A LARGE AMOUNT OF SEDIMENT FROM THE SLOPE

RHYOLITE BOULDERS FROM THE MATUA SUBGROUP, THOUGHT TO BE DERIVED FROM A RELIC FLUVIAL CHANNEL (HALL, 1994). BOULDERS TO BE AVOIDED BY PROPOSED REVETMENT STRUCTURE

Moderately weathered, reddish grey and orange grey, some boulders are banded red and grey, RHYOLITE. Strong to very strong

APPROXIMATE LOCATION OF HA04 AND HA04A ON THE BUSHED SLOPE

APPROXIMATE LOCATION OF HA03 ON THE EXISTING BEACH TRACK

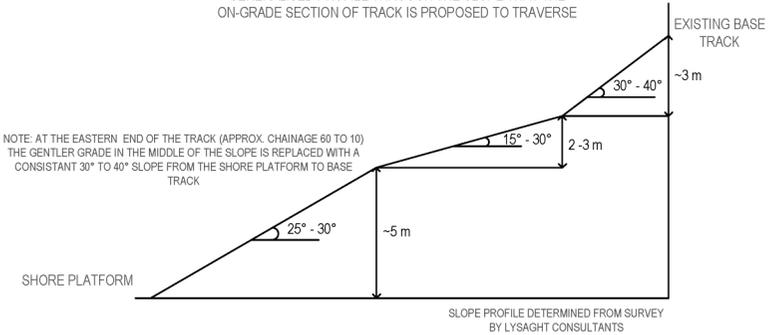
APPROXIMATE LOCATION OF PROPOSED BASE TRACK REVETMENT STRUCTURE

APPROXIMATE LOCATION THAT PROPOSED BASE TRACK TRANSITIONS FROM BEING ON A REVETMENT STRUCTURE TO ON-GRADE

APPROXIMATE LOCATION OF PROPOSED BASE TRACK GRADING UP THE EXISTING SLOPE

SLOPE IS APPROXIMATELY 10 - 15 m HIGH. SEE GENERALISED SLOPE PROFILE IN SECTION BELOW

GENERALISED PROFILE THROUGH THE SLOPE THAT THE ON-GRADE SECTION OF TRACK IS PROPOSED TO TRAVERSE



**PRELIMINARY**

No	Revision	Note	Drawn	Job Manager	Project Director	Date
A		Geotechnical				

**GHD**

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Drafting Check	Design Check
Approved (Project Director)	Date
	13/02/2018

Scale AS SHOWN

This Drawing must not be used for Construct on unless signed as Approved

Client **Boffa Miskell Limited**  
Project **Mauao Base Track Remediation**  
Title **Proposed Track up Slope to Merge with Existing Track**

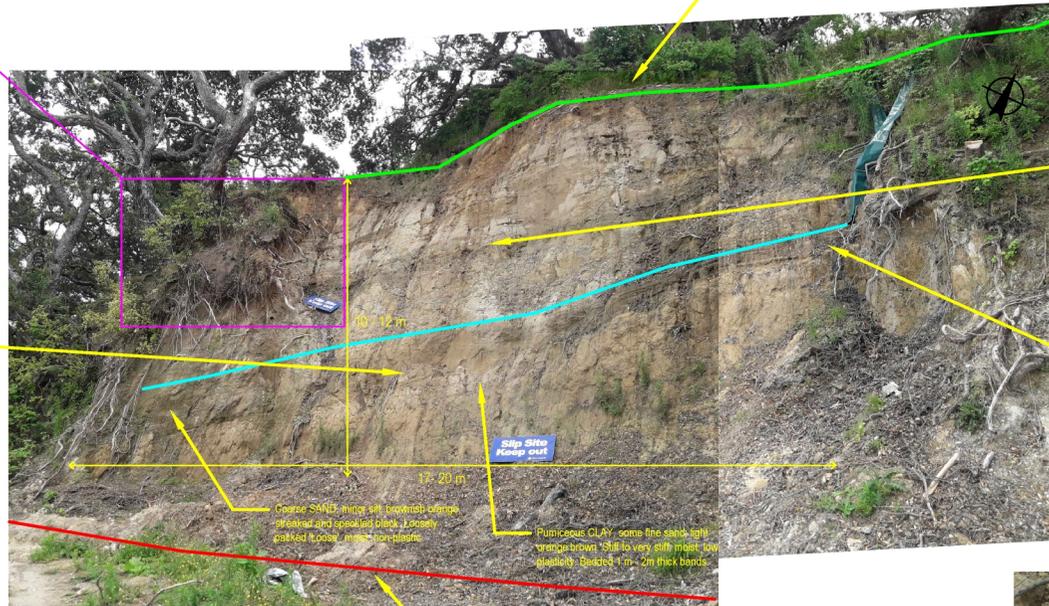
Original Size **A3** Drawing No: **51-37691-G002** Rev: **A**



EROSION OF SOIL AROUND TREE ROOT SYSTEM. COLLAPSE OF TREES MAY RESULT IN FURTHER CLIFF FAILURE



PREVIOUS BASE TRACK ALIGNMENT IN SLIP LOCATION



PREVIOUS MAUAO BASE TRACK, HALF REMOVED BY LANDSLIP

TOP OF SLIP HAS REMOVED APPROXIMATELY HALF THE WIDTH OF THE PREVIOUS BASE TRACK

CLIFF ANGLE IS GENERALLY 55° TO 65° BASED ON THE SURVEY BY LYSAGHT CONSULTANTS

BEDDING DIP (10° - 15°) OF UNIT CONTACT WITHIN THE MATUA SUBGROUP

MATUA SUBGROUP SEDIMENTS DERIVED FROM BOTH FLUVIAL PROCESS AND AIR FALL DEPOSITS (ASH & IGNIMBRITE) (HALL, 1994). SEDIMENTS VARY BOTH Laterally and vertically as demonstrated by the different materials encountered in the slip face

Orange Siltstone with low strength, friable and granular, loosely grained & poorly indurated

Pumiceous CLAY - some fine sand, light orange/brown. Silt is very stiff, moist, low plasticity. Bedded 1 m - 2m thick bands

SLIP SCARP AND COLLUVIUM PILE



COLLUVIUM FROM LANDSLIP, SILT & SAND IS BEING REMOVED BY TIDAL EROSION. TREE STUMPS AND ROOT SYSTEMS LIKELY CONTRIBUTED TO FAILURE

APPROXIMATE POSITION OF PROPOSED BASE TRACK

PUMICEOUS SILT ENCOUNTERED IN COLLUVIUM PILE

ORANGE BANDING LIKELY INDICATING THIN AIR FALL DEPOSITS



Pumiceous SILT, some fine sand, pale orange brown, banded orange. Silt to very stiff, moist, low plasticity

**PRELIMINARY**

No.	Revision	Note: * Indicates signatures on original issue of drawing or last revision of drawing	Drawn	Job Manager	Project Director	Date
A.	Geotechnical		S 7 (2)(a)			

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Approved (Project Director): [ ]	Date: 13/02/2018	Scale: AS SHOWN	Title: <b>Slip Face</b>
		This Drawing must not be used for Construction unless signed as Approved.	Original Size: <b>A3</b>
			Drawing No: <b>51-37691-G003</b>
			Rev: <b>A</b>

NATURAL SLOPE OF ASSUMED MATUA SUBGROUP MATERIALS. OCCASIONAL RHYOLITE BOULDERS SEEN ENTRAINED AT THE BASE OF THE SLOPE. THE SLOPE IS 7m HIGH AT AN ANGLE OF APPROXIMATELY 45° - AS PER THE SURVEY COMPLETED BY LYSAGHT CONSULTANTS.

APPROXIMATE POSITION OF PROPOSED BASE TRACK ON A REVETMENT STRUCTURE

COLLUVIUM MATERIAL TAKEN FROM A PREVIOUS LANDSLIDE ON MAUAO AND COMPACTED IN PLACE

APPROXIMATE POSITION OF PROPOSED BASE TRACK ON-GRADE



EROSION FROM DECEMBER 2017, MORE RIP RAP MAY BE REQUIRED TO PROTECT THIS PLACED FILL

APPROXIMATE POSITION OF HA02

RHYOLITE BOULDERS PLACED AS RIP RAP TO PROTECT THE PLACED FILL

**PRELIMINARY**

A		Geotechnical		S 7(2)(a)		Drawn		S 7(2)(a)		Designer		S 7(2)(a)		Client		Boffa Miskell Limited					
No		Revision		Note		Drawn		Job Manager		Project Director		Date		Project		Mauao Base Track Remediation					
Title		Western End of Proposed Track																			
Scale		AS SHOWN														Original Size		A3			
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# Appendix B – Geomorphological Map



### Geomorphology Key

Hummocky Ground	
Landslide Scarp	
Concave Break in Slope	
Convex Break in Slope	
Overland Flow Paths	
Hand Auger Location	
Scala Location	
20m Contours	
1m Contours	

### Route Key

Current Walking Track	
Proposed Track on Grade	
Proposed Track on Retevment Structure	



**PRELIMINARY**

FOR GEOTECHNICAL REPORT		s 7(2)(a)		12/02/2018	
No.	Revision	Drawn	Job Manager	Project Director	Date



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Drawn	s 7(2)(a) ... Privacy
Drafting Check	
Approved (Project Director)	
Date	16/02/2018
Scale	AS SHOWN

Client	Tauranga City Council
Project	Mauao Base Track Remediation
Title	GEOMORPHOLOGICAL MAP: MAUAO BASE TRACK, MT. MAUNGANUI
Original Size	A3
Drawing No:	51-37691-G001
Rev:	A

Plot Date: Plotted by: Cadd File No:

# Appendix C – Hand Auger Logs





Project : Mauao Base Track Remediation  
 Client : Boffa Miskell Ltd  
 Site : Mount Maunganui  
 Job Number: 513769100

Hole No. : HA02  
 Sheet : 1 of 1  
 Hole Length : 1.95  
 Scale @ A4 : 1:21

Commenced: 31/01/2018 Completed: 31/01/2018

Logged : XXXXXXXXXX  
 Processed : s 7(2)(a)  
 Checked :

Easting: 5829920.647 Northing: 1879577.029 System: NZTM2000  
 RL: Datum:

RL (m)	Depth (m)	Graphic	Material Description	Geological Unit	Moisture condition	Consistency / Relative density	Sample		Shear Vane	Water level (m)	Dynamic Cone Penetrometer Type: Scala Ppenetrometer Blows per 50mm intervals
							Number / Type	Depth			
	0.00 - 0.10		Topsoil.								
	0.10 - 0.75		Medium to coarse SAND, minor shell fragments; brown steaked orange and white. 'Loose', dry, non-plastic. (FILL)		D	'L'					
	0.50		some fine sand.								
	0.70		some silt.								
	0.75 - 0.90		Fine to medium SAND, trace pumice; light grey, beige. Dense, dry, non-plastic. (FILL)		D	D					
	0.90 - 1.45		Sandy SILT, trace clay; dark brown streaked black. Firm, moist, non-plastic. (FILL)	FILL	M	F					
	1.45 - 1.95		Fine to medium SAND; sark brown. Medium dense, moist, non-plastic. (FILL)		M	MD					
	1.55		greyish brown.								
	1.80		light brown.								
	2.00		End of Hole at 1.95m, Refusal.								

**Notes and Comments:**  
 End of Hole @ 1.95m, R  
 No Groundwater Encountered

This is the default disclaimer for output on reports. It is selectable in the POINT table.

Ground Water Level		
Date	Time	Reading (mbgl)

Shear Vane Id: Geo 1826



Project : Mauao Base Track Remediation  
 Client : Boffa Miskell Ltd  
 Site : Mount Maunganui  
 Job Number: 513769100

Hole No. : HA03  
 Sheet : 1 of 1  
 Hole Length : 2.3  
 Scale @ A4 : 1:21

Commenced: 31/01/2018 Completed: 31/01/2018

Logged : [Redacted]  
 Processed : 7(2)(a)  
 Checked :

Easting: 5829863.442 Northing: 1879808.281 System: NZTM2000  
 RL: Datum:

RL (m)	Depth (m)	Graphic	Material Description	Geological Unit	Moisture condition		Sample		Shear Vane	Water level (m)	Dynamic Cone Penetrometer Type: Scala Ppenetrometer Blows per 50mm intervals
					Consistency / Relative density	Number / Type	Depth				
	0.00 - 0.20		Topsoil.								
	0.20 - 0.40		Fine to medium SAND, trace silt, trace rootlets and plant remains; dark brown streaked light brown. 'Loose to medium dense', moist, non-plastic. (MATUA SUBGROUP)	M		'L-MD'					
	0.40 - 1.20		SILT, trace sand; brown. Very stiff, moist, non-plastic. (MATUA SUBGROUP) 0.60 trace clay.	M		VSt		163/33kPa			
	1.20 - 2.00		Clayey SILT, trace rootlets and plant remains; brown. Very stiff, moist, low plasticity. (MATUA SUBGROUP) 1.80 trace fine sand.	M		VSt		207+/kPa			
	2.00 - 2.30		Sandy SILT, trace clay; dull brown. Very stiff, moist, low plasticity. (MATUA SUBGROUP)	M		VSt		163/77kPa			
	End of Hole at 2.30m, Refusal.										

**Notes and Comments:**  
 End of Hole @ 2.3m, R  
 No Groundwater Encountered

This is the default disclaimer for output on reports. It is selectable in the POINT table.

Ground Water Level		
Date	Time	Reading (mbgl)

Shear Vane Id: Geo 1826

Report ID: HAND\_AUGER || Project: 37691\_HA\_GP || Library: GHD - NZGD\_01\_005.GLB || Date: 25 June 2018





Project : Mauao Base Track Remediation  
 Client : Boffa Miskell Ltd  
 Site : Mount Maunganui  
 Job Number: 513769100

Hole No. : HA04A  
 Sheet : 1 of 1  
 Hole Length : 1.4  
 Scale @ A4 : 1:21

Commenced: 31/01/2018 Completed: 31/01/2018

Logged : [REDACTED]  
 Processed : S 7(2)(a)  
 Checked :

Easting: 5829853.349 Northing: 1879741.666 System: NZTM2000  
 RL: Datum:

RL (m)	Depth (m)	Graphic	Material Description	Geological Unit	Moisture condition	Consistency / Relative density	Sample		Shear Vane	Water level (m)	Dynamic Cone Penetrometer Type: Scala Ppenetrometer Blows per 50mm intervals
							Number / Type	Depth			
	0		0.00 - 0.60 Organic SILT, fossiliferous, white broken shells; streaks of brown silt. Soft to firm, dry to moist, non-plastic. (FILL - MIDDEN MATERIAL)	FILL	D-M	S-F					0 2 4 6 8 10 12 14 16 18 20
	0.6		0.60 - 0.90 CORE LOSS.	LOSS							
	0.9		0.90 - 1.40 Organic SILT, fossiliferous, white broken shells; streaks of brown silt. Soft to firm, moist, non-plastic. (FILL - MIDDEN MATERIAL)	FILL	M	S-F					0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	1.4		End of Hole at 1.40m, Hole Collapsing.								1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 30

**Notes and Comments:**  
 End of Hole @ 1.4m, C  
 No Groundwater Encountered

This is the default disclaimer for output on reports. It is selectable in the POINT table.

Ground Water Level		
Date	Time	Reading (mbgl)



Project : Mauao Base Track Remediation  
 Client : Boffa Miskell Ltd  
 Site : Mount Maunganui  
 Job Number: 513769100

Hole No. : HA05

Sheet : 1 of 1  
 Hole Length : 3  
 Scale @ A4 : 1:23

Commenced: 23/04/2018

Completed: 23/04/2018

Logged : [REDACTED]

Processed : 7(2)(a)

Checked :

Easting: 5829858.996

Northing: 1879688.822

System: NZTM2000

RL:

Datum:

RL (m)	Depth (m)	Graphic	Material Description	Geological Unit	Moisture condition	Consistency / Relative density	Sample		Shear Vane	Water level (m)	Dynamic Cone Penetrometer Type: Scala Ppenetrometer Blows per 50mm intervals	
							Number / Type	Depth				
0	0	x x x	0.00 - 0.40 SILT, some fine to medium sand, trace rootlets, trace shells; dark brown. Soft to firm, moist, non-plastic. (FILL).	FILL	M	S-F			186+/kPa	1	0.2 4 6 8 10 12 14 16 180 0	
0.4	0.4	x x x	0.40 - 1.10 Sandy SILT, trace rootlets, trace fine gravels; dark brown. Stiff to very stiff, moist, non-plastic. (FILL).		M	St-VSt					3	2
1.1	1.1	x x x	1.10 - 1.90 SILT, trace clay, minor fine sand, trace rootlets, trace shells; brown. Very stiff, moist, non-plastic. (FILL).		M	VSt					3	3
1.9	1.9	x x x	1.40 minor clay, low plasticity.								3	2
2.2	2.2	x x x	1.90 - 2.20 SILT, some pumiceous fine to medium sand, trace shells, trace rootlets; greyish brown streaked reddish brown. Very stiff, moist, non-plastic. (FILL).		M	VSt					3	6
2.8	2.8	x x x	2.20 - 2.80 Sandy SILT, trace shells, trace pumiceous sand; brown streaked light grey. Very stiff, moist, non-plastic. Sand: fine to medium. (FILL).		M	VSt					3	3
3.0	3.0	x x x	2.80 - 3.00 Sandy SILT, trace clay; light brown. Stiff, moist, non-plastic. Sand: fine to coarse. (MATUA SUBGROUP).	MATUA SUBGROUP	M	St			186+/kPa	2	6	
3.0	3.0		End of Hole at 3.00m, Target Depth.								2	3
4.0	4.0									3	5	
										5	3	
										2	2	

Notes and Comments:  
 End of Hole @ 3m, TD  
 No Groundwater Encountered

Ground Water Level		
Date	Time	Reading (mbgl)

This is the default disclaimer for output on reports. It is selectable in the POINT table.

Shear Vane Id: Geovane 2335





Project : Mauao Base Track Remediation  
 Client : Boffa Miskell Ltd  
 Site : Mount Maunganui  
 Job Number: 513769100

Hole No. : HA07  
 Sheet : 1 of 1  
 Hole Length : 1.8  
 Scale @ A4 : 1:23

Commenced: 23/04/2018 Completed: 23/04/2018

Logged : [REDACTED]  
 Processed : s 7(2)(a)  
 Checked :

Easting: 5829852.259 Northing: 1879724.091 System: NZTM2000  
 RL: Datum:

RL (m)	Depth (m)	Graphic	Material Description	Geological Unit	Moisture condition	Consistency / Relative density	Sample		Shear Vane	Water level (m)	Dynamic Cone Penetrometer Type: Scala Ppenetrometer Blows per 50mm intervals
							Number / Type	Depth			
	0		0.00 - 0.20 SILT, trace rootlets, trace fine sand; dark brown. Soft to firm, moist, low plasticity. (TOPSOIL).	MATUA SUBGROUP	M	S-F					0 2 4 6 8 10 12 14 16 180
	0.2		0.20 - 1.80 SILT, minor clay, trace fine to coarse sand; light brown. Stiff to very stiff, moist, moderate plasticity. (MATUA SUBGROUP).		M	St-VSt					
			0.50 very stiff.			VSt			146/43kPa		
	1		1.00 some clay.						109/45kPa		
			1.70 moist to wet.		M-W			UTP/kPa			
	2		End of Hole at 1.80m, Refusal.							30	
	3										
	4										

**Notes and Comments:**

End of Hole @ 1.8m, R  
 No Groundwater Encountered

This is the default disclaimer for output on reports. It is selectable in the POINT table.

**Ground Water Level**

Date	Time	Reading (mbgl)

Shear Vane Id: Geovane 2335





Project : Mauao Base Track Remediation  
 Client : Boffa Miskell Ltd  
 Site : Mount Maunganui  
 Job Number: 513769100

Hole No. : HA09  
 Sheet : 1 of 1  
 Hole Length : 1  
 Scale @ A4 : 1:23

Commenced: 23/04/2018 Completed: 23/04/2018

Logged : [Redacted]  
 Processed : 7(2)(a)  
 Checked :

Easting: 5829869.846 Northing: 1879771.794 System: NZTM2000  
 RL: Datum:

RL (m)	Depth (m)	Graphic	Material Description	Geological Unit	Moisture condition	Consistency / Relative density	Sample		Shear Vane	Water level (m)	Dynamic Cone Penetrometer Type: Scala Ppenetrometer Blows per 50mm intervals			
							Number / Type	Depth						
0	0	x x	0.00 - 1.00 SILT, trace fine sand, trace fine gravel, trace shells; dark brown. Soft, dry to moist, non-plastic, hole collapsing. (FILL-MIDDEN MATERIAL).	FILL	D-M	S					0 2 4 6 8 10 12 14 16 180			
		x x												
		x x												
		x x												
		x x												
		x x												
		x x												
		x x												
		x x												
		x x												
1	1		End of Hole at 1.00m, Hole Collapsing.											
										0 0 0 0				
										0 0 0 0				
										0 0 1 0				
										1 0 1 0				
										0 0 0 0				
										1 0 0 0				
										1 1 1 1				
										1 2 2 1				
										1 1 1 1				
										0 1 1 0				
										1 1 1 1				
										2 3 2 4				
										4 4 2 2				

**Notes and Comments:**  
 End of Hole @ 1m, C  
 No Groundwater Encountered  
 scala to 4.0 m indicating loose material

This is the default disclaimer for output on reports. It is selectable in the POINT table.

Ground Water Level		
Date	Time	Reading (mbgl)



Project : Mauao Base Track Remediation  
 Client : Boffa Miskell Ltd  
 Site : Mount Maunganui  
 Job Number: 513769100

Hole No. : HA10

Sheet : 1 of 1  
 Hole Length : 3  
 Scale @ A4 : 1:23

Commenced: 23/04/2018

Completed: 23/04/2018

Logged

Processed

Checked

Easting: 5829862.586

Northing: 1879752.523

System: NZTM2000

RL:

Datum:

s 7(2)(a)

RL (m)	Depth (m)	Graphic	Material Description	Geological Unit	Moisture condition	Consistency / Relative density	Sample		Shear Vane	Water level (m)	Dynamic Cone Penetrometer Type: Scala Ppenetrometer Blows per 50mm intervals
							Number / Type	Depth			
	0	x x x	0.00 - 0.50 SILT, trace to minor shells, trace fine sand; dark brown speckled white. Soft, dry to moist, non-plastic. (FILL).	FILL	D-M	S					0.2 4 6 8 10 12 14 16 180
	0.5	x x x	0.50 - 1.80 SILT, trace fine to medium sand, trace clay, trace shells: brown. Very stiff, moist, non-plastic. (FILL).		M	VSt			170/53kPa		
	1	x x x	1.00 low to moderate plasticity						186+/kPa		
	1.8	x x x	1.70 minor fine to medium sand. Stiff to very stiff, moist to wet, trace yellowish orange speckles.		M-W	VSt					
	2	x x x	1.80 - 2.10 Sandy SILT, trace clay; greyish brown speckled orange. Very stiff, moist to wet, low plasticity. (MATUA SUBGROUP).		M-W	VSt			186+/kPa		
	2.1	x x x	2.10 - 2.65 Silty SAND, trace clay; light grey streaked orange. 'Medium dense to dense', moist to wet. (MATUA SUBGROUP).		M-W	MMD-D			UTP/kPa		
	2.65	x x x	2.65 - 3.00 SAND, some silt; light grey speckled light orange. Dense, moist, non-plastic. (MATUA SUBGROUP).		M	D					10 5 3 2 2 3 3 4 4 4 7 16 8 8 7 8 7
	3		End of Hole at 3.00m, Target Depth.								

Notes and Comments:  
 End of Hole @ 3m, TD  
 No Groundwater Encountered

Ground Water Level		
Date	Time	Reading (mbgl)

This is the default disclaimer for output on reports. It is selectable in the POINT table.

Shear Vane Id: Geovane 2335

# Appendix D – Dynamic Cone Penetrometer Test Results



SCALA PENETROMETER

Contract No.: 5137691

Site: Mauao Base Track Remediation

Location : Mauao Southern Shore Beach

Notes : All Tests were started from beach level. In most tests the equipment sunk under its own weight for some initial depth. This is denoted by 'HW' on the following test sheets.

Station SC01 Position Centre Initial Depth 0

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data rows from 50 to 350 depth.

Station SC02 Position Centre Initial Depth 0

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data rows from 50 to 500 depth.

Station SC03 Position Centre Initial Depth 0

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data rows from 50 to 950 depth.

Station SC04 Position Centre Initial Depth 0

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data rows from 50 to 550 depth.



SCALA PENETROMETER

Contract No.: 5137691

Site: Mauao Base Track Remediation

Location : Mauao Southern Shore Beach

Notes : All Tests were started from beach level. In most tests the equipment sunk under its own weight for some initial depth. This is denoted by 'HW' on the following test sheets.

Station SC05 Position Centre Initial Depth 0

Station SC05A Position Centre Initial Depth 0

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data points for depths 50 to 200.

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data points for depths 50 to 800.

Station SC06 Position Centre Initial Depth 0

Station SC07 Position Centre Initial Depth 0

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data points for depths 50 to 550.

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Data points for depths 50 to 1100.



SCALA PENETROMETER

Contract No.: 5137691 Site: Mauao Base Track Remediation

Location : Mauao Southern Shore Beach

Notes : All Tests were started from beach level. In most tests the equipment sunk under its own weight for some initial depth. This is denoted by 'HW' on the following test sheets.

Station SC08 Position Centre Initial Depth 0

Station SC09 Position Centre Initial Depth 0

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Rows include data from 50 to 900 depth.

Table with 5 columns: Depth, No. Blows, Penetration, mm per blow, CBR. Rows include data from 50 to 500 depth.

# Appendix E – Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning

## Landslide Susceptibility, Hazard and Risk Zoning

### Scope Definition:

Calculate the risk to persons Figure 1 walking along the new section of the proposed Mauao base track which passes beneath sections of costal cliffs which have shown signs of instability in the past. Assess the tolerability of this risk against the tolerable risk criteria shown in Table 1.

For loss of life, the individual risk can be calculated from:

$$R_{(LoL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad (2)$$

Where

$R_{(LoL)}$  is the risk (annual probability of loss of life (death) of an individual).

$P_{(H)}$  is the annual probability of the landslide.

$P_{(S:H)}$  is the probability of spatial impact of the landslide impacting a building (location) taking into account the travel distance and travel direction given the event.

$P_{(T:S)}$  is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.

$V_{(D:T)}$  is the vulnerability of the individual (probability of loss of life of the individual given the impact).

A full risk analysis involves consideration of all landslide hazards for the site (e.g. large, deep seated landsliding, smaller slides, boulder falls, debris flows) and all the elements at risk.

Figure 1: Loss of life individual risk calculation

Table 1: AGS Suggested Tolerable Loss of Life Individual risk.

Table 1: AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	$10^{-4}$ / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	$10^{-5}$ / annum

### **1. Danger (Landslide) Characterisation $P_{(S:H)}$**

The revetment structure proposed will likely abut to the 3m contour and will therefore be located at the toe of the costal cliffs and slopes in the southern section of the track. This area of the track has seen slope instability in the past which would have rille dout onto a track if it were located below. Based on the preceding information from the recent slip in 2017 and the geometry of the slope in this ocation, it is estimated that the probability of the landslide reaching the element at risk (the track) is quite high;

**$P_{(S:H)}=0.8$**

### **2. Frequency Analysis**

Using the historical information collected from “Martin\_Brideau\_2014” Figure 2 the following events occurred in the location of our study area;

1943- 2 events

1959- 3 events

- 1977- 2 events
- 1992- 3 events
- 1997 – 1 event
- 2011- 6 events
- 2017-1 event

Using an average over this 74 year period approximately 0.2 events occurred per annum which correlates to a “moderate hazard” description for small landslides on natural slopes therefore;

$P_{(H)}=0.2$

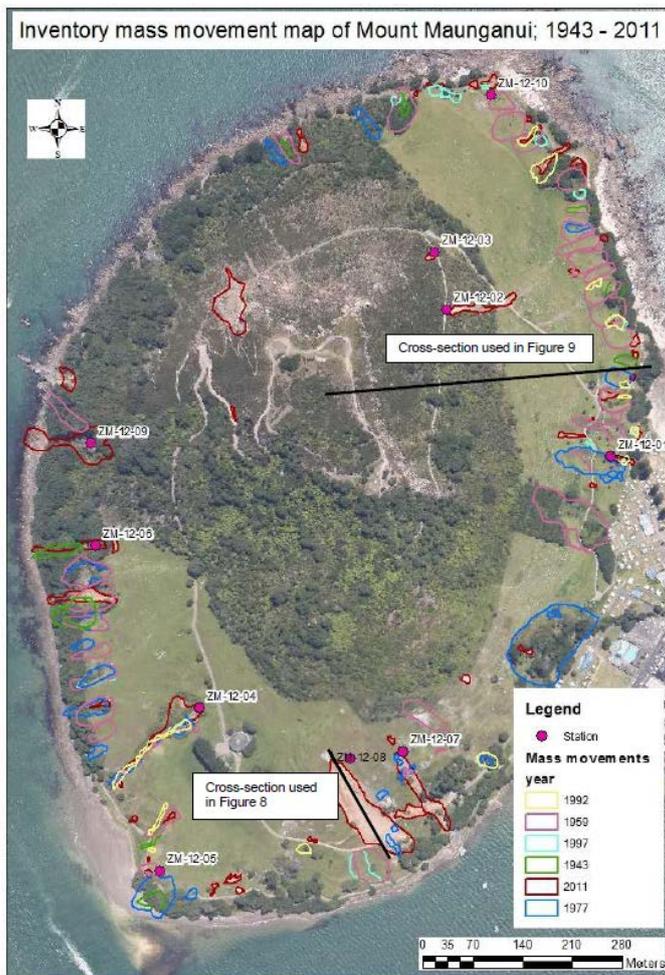


Figure 4: Spatial distribution of the landslide on Mount Maunganui between 1943 and 2011. Stations represent landslides that were described in details during the 2012 field season.

Figure 2: Spatial distribution of landslides on Mount Manganui.

### 3. Consequence Analysis

Temporal spatial probability  $P(S:T)$  of the persons was determined based on the method used for roads and railways in which transient populations are at risk. This uses an approximate assessment of temporal spatial probability from the traffic volumes and velocities.

The following information and assumptions were used to determine this value;

- Based off the Dec 1st 2016 to Jan 8th 2017 statistics for people walking around Mauao 39461 people walked the track in the year with the busiest day over summer being approximately 2406 people and quietest day in summer being around 90 people. Therefore conservatively assuming 100 people are walking around the track in a potentially rainy day in winter (most likely time to induce slope failure)
- 360m length of track where people exposed
- Average walking speed of 5km/hr
- One person exposed at a time

**$P_{st} = (100/24) * (1/360) * (1/5) = 0.00231$  For the person most at risk over the track width**

**4. Vulnerability (of the persons  $V_{(D:T)}$ )**

This is a best estimate based on majority of the historical events being small scale with only one large event in which engulfment could have occurred down to the location of the proposed track with potential for loss of life over the 74 year recorded period. Therefore likely to be small scale localised slumping, result in unravelling of the face in which the vulnerability risk of the individual would be assumed to be low.

**$V_{(D:T)} = 0.2$**

**5. Risk Estimation**

The annual probability of the person most at risk losing his/her life is

**$R_{(LOI)} = 0.8 * 0.2 * 0.00231 * 0.2 = 7.4 \times 10^{-5}$**

**6. Risk Assessment**

**Individual risk,**

Based off the AGS suggested tolerable risk criteria Table 2 this New Development should achieve  $10^{-5}$  per annum which this assessment currently achieves.

*Table 2: AGS Suggested Tolerable loss of life individual risk*

Table 1: AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	$10^{-4}$ / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	$10^{-5}$ / annum

The Tolerable Risk criteria is described in the excerpt from the practice notes below in Figure 3;

Acceptable risks are usually considered to be one order of magnitude lower than the Tolerable Risks.

It is important to distinguish between “acceptable risks” and “tolerable risks”.

*Tolerable Risks* are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable.

*Acceptable Risks* are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

*Figure 3: Tolerable Risk Definition*

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