

Geotechnical Features of Tirohia Quarry Landfill

TONY DAVIES
Worley Consultants Ltd.
Auckland, New Zealand

Summary

At Tirohia Quarry, seven kilometers south of Paeroa, New Zealand, andesite rock is quarried for commercial aggregate use. The quarry owner proposes to construct a modern sanitary landfill at the site, filling the pit with 800,000 tonnes of municipal refuse while quarrying continues. The main issues considered while investigating the suitability of converting the quarry to a landfill included the effect of quarrying on the landfill liner (potential blasting/vibration effects), and the effect of leachate escape on the regional groundwater system.

1.0 INTRODUCTION

New Zealand, as with most developed countries, is experiencing rapid change in the business of municipal solid waste disposal. In a climate of considerable pressure to minimise waste and develop non-polluting disposal methods and facilities, waste management and disposal has become big business. Sites suitable for landfills, and acceptable to the public, are scarce, therefore any such sites are a valuable economic resource.

Disused quarries have a long history of use as landfills: combining solid waste disposal with an operating quarry is not so common but has obvious commercial benefits.

This paper presents some geological and geotechnical features of a proposed municipal landfill site at an operating quarry, 100km southeast of Auckland, New Zealand.

It is proposed to fill the existing quarry pit with non-hazardous municipal solid waste (approximately 800,000 tonnes of refuse) whilst quarrying continues.

The design of the landfill is based on best practice standards currently accepted in New Zealand and overseas as appropriate for municipal solid waste disposal.

2.0 SITE DESCRIPTION

Tirohia Quarry is situated on the north western end of a prominent spur protruding into the Hauraki Plains from the western side of the Coromandel-Kaimai Range (Figure 1). This spur has steep sides and a relief of approximately 300m.

The geological map of the area indicates that development of the spur most likely resulted from movement on faults that bound the spur along its northern and western margins.

Quarrying has resulted in the formation of a narrow valley, opening to the north, that is bounded by (i) the currently operating 70m high eastern highwall, (ii) a steep, benched slope at the head (southern end) of the valley, (iii) a remnant ridge to the west. The remnant ridge forms a barrier between the quarry and the terrace flats and Hauraki Plains to the west.

The western slope of the ridge is moderately steep and is covered by quarry waste (strippings) placed during the early stages of quarrying. The toe of the slope merges with the very gently sloping terrace flats, which in turn merge westward with the Hauraki Plains.

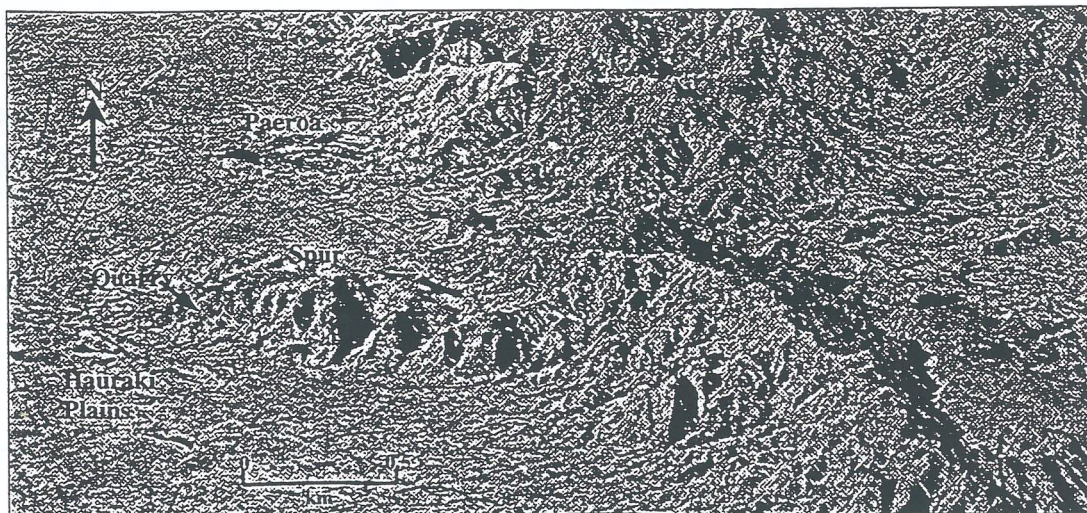


Figure 1. Geomorphology (reproduced from R.L. Brathwaite, A.B. Christie 1996)

2.1 Geology

The quarry is situated in complex volcanic terrain of Late Miocene and Pliocene age (i.e. 5 to 8 million years). The Hauraki Plains to the west of the ranges are underlain by Quaternary age, volcanic-derived fluvial sediments, peat, and primary volcanic deposits (pyroclastic flows and airfall ash) which infill the active Hauraki rift. The Waihi Basin to the east of the site contains deposits of Pliocene to early Pleistocene pyroclastics (e.g. ignimbrite) and fluvial (river) and lacustrine (lake) sediments.

Brathwaite and Christie (1996) map the andesite lava flows exposed at the quarry as Tirohia andesite, an informal member of the Kapukapu Andesite formation of mid-Miocene age (7 million years). Kapukapu Andesite consists predominantly of tuff breccias, tuff and andesite flows, estimated to be in the order of 800m in thickness.

The Tirohia andesite member is reported to be not generally hydrothermally altered and is interpreted as mostly intrusive, forming domes (Brathwaite and Christie 1996).

The Pleistocene age alluvial sediments underlying the western terrace consist mainly of undifferentiated, volcanic-derived sediments.

The western terrace and ridges surrounding the quarry have a variable cover of weathered andesitic and rhyolitic volcanic ash. The ash is thought to be an accumulation of many separate eruptive events originating in the Taupo Volcanic Zone.

2.2 Subsurface Conditions

The geology of the site is dominated by a considerable thickness of jointed, andesite lava flow underlain by a dome-shaped body of andesitic breccia that is also interpreted to be of considerable thickness (Figure 2). An upper breccia unit identified in drillholes overlies the andesite lava flow to the east of the quarry. The upper breccia is overlain by tuff breccia and, in places by thin andesite flows.

The andesite lava is fresh to slightly weathered, moderately strong, jointed rock. The andesite is the rock quarried for construction aggregates. The andesite forms a distinctive columnar jointing pattern as it cools from the molten lava state. Jointing is pervasive and is the rockmass property that to a large degree determines its bulk permeability.

The joints in the andesite form two prominent sets:

- Sub-vertical set that forms near vertical columns up to 20m long
- Sub-horizontal set forming flat plates between the sub-vertical joints.

At the southern end of the quarry, joint patterns are less regular, with convoluted and radiating columns indicating a possible sub aerial extrusion.

The breccia is a weak rock comprising andesite and rhyolite fragments to one metre diameter set in a poorly welded, coarse grained glassy matrix. Jointing is not common although closely spaced fractures were observed in zones up to 1m in thickness. The degree of welding in the matrix is variable, ranging from weakly welded to strongly welded.

Contact between the andesite lava and the underlying breccia dome is marked by a zone of alteration in the breccia between 1m and 4m in thickness. The zone is interpreted to result from heating of the breccia on contact with intruding lava. The zone is characterised by an increased degree of welding and a resulting decrease in permeability, compared to the unaltered breccia.

3.0 HYDROGEOLOGY

3.1 General Setting

Groundwater recharge and movement is controlled to a significant extent by the spur. Regional surface and groundwater flow is from the range westward to the plains, the latter being a major groundwater discharge zone characterised by swamps and peat growth. The regional westward flow pattern is affected locally by topographic features such as hills and valleys.

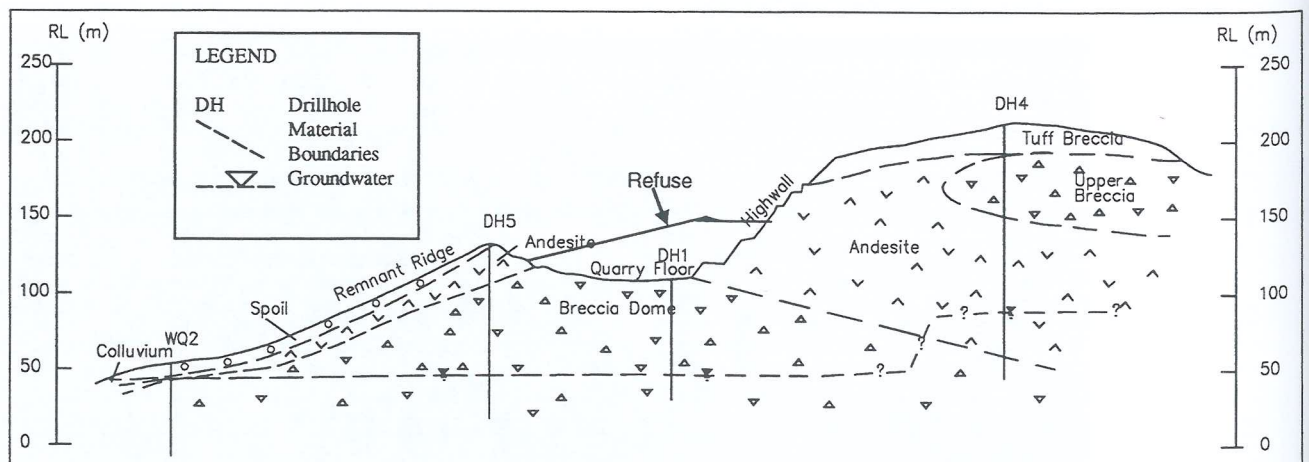


Figure 2. Section

In the vicinity of the landfill site shallow and moderately deep groundwater is likely to derive from rainfall on the spur while water at greater depth may include a small contribution from regional flow originating on the range.

Surface drainage off the spur is mainly via entrenched, steep-sided, ephemeral streams that flow to the north and south around the quarry. The streams have steep gradients and include waterfalls. Permanent flow in the Owihakatina Stream is recorded only near the western side of the quarry where it encounters the low land of the terrace flats west of the remnant ridge. The flow in the shallowly incised streams that rise on the terrace flats is likely to be dominated by discharging groundwater.

3.2 Water Level Measurements

Static water level data indicate that groundwater level is approximately 60m below the floor of the quarry and that groundwater flow direction is towards the northwest (Figure 3). The water table nears ground surface along the toe of the western flank of the remnant ridge, i.e. in the transition zone to the terrace flat. The shallowly incised, ephemeral streams on the terrace also rise in that area, suggesting groundwater close to the surface.

The data indicate that the streams that drain the high ground east of the quarry are ephemeral. The stream beds are essentially 'perched' above groundwater level for much of their length.

3.3 Hydraulic Conductivity of Main Lithological Units

The hydraulic conductivity of materials is an important parameter in landfill liner and cover design as it defines the rate at which fluid moves through the material.

The hydraulic conductivity (K) is dependent on the nature of both the material and the fluid passing through it. A high hydraulic conductivity (e.g. those of sand/gravel and fractured rock) implies high flow rates while low values (e.g. those of clay and solid rock) indicate low rates.

3.4 Breccia.

The landfill site is underlain in part by a dome-shaped breccia layer in excess of 80m in thickness. The breccia has a hydraulic conductivity that is assessed to be greater (i.e. allows water to flow through it more easily) than the surrounding andesite.

The breccia generally has few fractures (joints) but at depth contains narrow fractured zones and sections where the matrix is poorly welded. The measured laboratory permeability of a section of drill core is 1.1×10^{-6} m/s.

While drilling through the andesite (i.e. DH5) it was observed that as drillholes were advanced, relatively static drilling fluid levels were recorded.

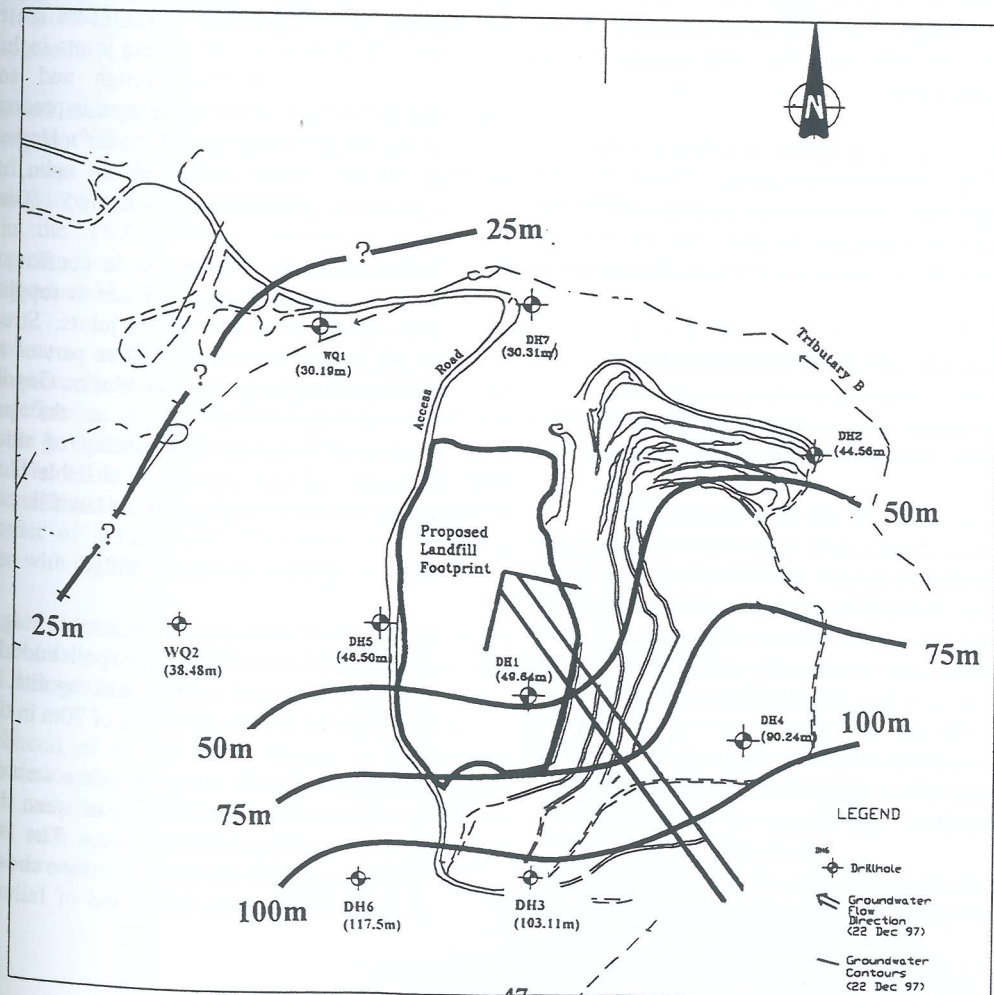


Figure 3. Hydrogeology

However, once the breccia was encountered, and the upper altered crust of the breccia penetrated, drilling fluids quickly drained and static levels did not occur again until deep groundwater was encountered. Shallow piezometers installed to intersect groundwater above the breccia remained dry after installation.

Falling head field tests in the unaltered breccia indicate a hydraulic conductivity of 1×10^{-6} m/s. Testing in the altered andesite/breccia contact zone indicates a much lower hydraulic conductivity of 8×10^{-9} m/s.

3.5 Andesite

The andesite is blocky with fractures (joints) both sub-vertically and sub-horizontally. The sub-horizontal fractures appear to be tight and therefore are considered to provide minimal permeability. Falling head field tests in the andesite range from 2×10^{-8} to 8×10^{-10} m/s.

3.6 Groundwater Flow

An understanding of groundwater flow direction assists in assessing potential effects that may arise in the event of seepage from the landfill site.

There are no groundwater users within 2km of the quarry at present, although groundwater may be utilised at some future time. Any leachate which seeps through the landfill liner system will move with groundwater in a north/north-westerly direction towards the installed monitoring wells (Figure 3). The assessed seepage rate of leachate is minimal and its effect on groundwater is expected to be negligible.

Groundwater levels indicate a steep gradient between the southern ridge and the base of the quarry (Figure 4). The steepening of gradients appears to be associated with the transition from the andesite to the breccia and in particular, to the zone of alteration at the andesite/breccia contact.

4.0 LINER AND COVER MATERIALS

The suitability of the near surface deposits of volcanic ash and colluvium for liner and daily cover material was investigated.

Testing indicated the colluvium was the most suitable liner material. The measured laboratory permeability of the colluvium is 10^{-10} m/s using deionised water, and 10^{-8} m/s using leachate from a municipal landfill. This compares to liner and final cover design permeability requirements of not less than 10^{-9} m/s and 10^{-7} m/s respectively. The permeability of the colluvium tested using leachate, and the ash using water, do not meet 10^{-9} m/s requirement and a supplementary synthetic HDPE liner will be required.

Soil liner permeability is dependent on a number of factors including leachate chemical composition, liner

soil fabric and liner protection during landfill construction and operation.

Leachate chemicals can affect permeability by solutioning and precipitating soil minerals and by clay particle flocculation, dispersion and swelling. Testing completed for this assessment classified the colluvium as non-dispersive. The chemical composition of the leachate was not determined, however a published study (Qasim and Chaing 1994) indicates that acids can cause dissolution of kaolinite which is abundant in the colluvium (IGNS, 1997).

5.0 SLOPE STABILITY

The long-term security of the landfill requires that the landfill site and surrounding slopes are stable. The assessment of landfill slopes is based on an analytical approach, which considers both static and seismic load conditions.

5.1 Quarry Highwall

Between 20m and 40m of tuff breccia overlies andesite in the quarry highwall. Existing vertical cut slopes up to 10m high show minor spall type failures. Spall debris is contained on benches at the base of slopes and does not present a significant hazard. The ongoing use of benches is proposed to mitigate this type of instability.

The lower half of the quarry highwall comprises very strong, jointed andesite rock. There are two main joint sets. A vertical set of cooling joints includes joints that are continuous (20m+), rough and some are iron stained/infilled. Joint orientation is predominantly to the south and west dipping at $70^\circ - 80^\circ$. Horizontal joints dip at $5^\circ - 10^\circ$ to the north and are open, tight, irregular, continuous (5-10m), and spacing is 5 - 50 mm.

Assessment of the lower slope confirms that the most likely instability in the andesite is toppling-type failure with release along the vertical joints. Structural mapping of the quarry face completed as part of this assessment has identified some unstable blocks. Ongoing observation will identify unstable blocks as the quarry operation progresses. Potential instability of this type will be mitigated by the removal of unstable blocks during the initial construction phase of the landfill.

5.2 Quarry Remnant Ridge

Drilling in the quarry remnant ridge (west side) encountered 5m of andesite spoil underlain by 35m of very hard fractured andesite and rhyolite. The andesite is underlain by breccia in excess of 70m in thickness.

Quarry overburden dumping on the west side of the ridge has formed a wedge of debris between the ridge and the base of the slope to the west. The debris comprises boulders and gravel. The west slope showed no evidence of instability and the likelihood of failure is considered

very low. In the unlikely event that instability did occur it would have no effect on the stability of the landfill.

The remainder of the ridge, including the east side, comprises competent andesitic rock which will contain the landfill. Instability in this material is not expected.

5.3 Quarry Floor

The quarry floor steps down from south to north in floors approximately 10m (vertical) apart and is underlain by very strong andesitic lava and welded breccia. These materials represent competent bedrock. No existing or potential instability has been identified in the quarry floor.

6.0 Earthquake Effects

The site is distinct from the main seismic region of New Zealand in an area of relatively low seismicity. It is situated on the western side of the Coromandel Volcanic Zone (CVZ). There is no evidence of active faulting in the CVZ that would have a significant effect on the site. Immediately to the west is the Hauraki Rift, which extends from Whangarei, through the Hauraki Gulf and the Hauraki depression into the Taupo Volcanic Zone (TVZ). The rift consists of a set of fault-angle depressions.

The most significant known fault associated with the rift is the Kerepehi Fault, which is known to be active. The fault is located some 5.5 km west of the site and has several segments.

The assessed average recurrence interval for movement on the segment closest to the site is 2,500 years. It is estimated that such a movement could generate magnitude Mw 6.9 earthquakes (Figure 7).

Faults in the TVZ are not considered capable of producing the level of ground shaking at the site that could be produced by the Kerepehi Fault.

The maximum credible earthquake (MCE) level of shaking has been based on a deterministic approach. The MCE is defined as the earthquake that would cause the most severe ground shaking capable of being produced at the site. The MCE is associated with a magnitude Mw 6.9 earthquake on the Kerepehi Fault with a return period of the order of 2,500 years. The duration of shaking associated with the MCE is in the order of 20 seconds.

The assessed factors of safety against slope failure of the landfill front face for the 450 year and MCE events are 1.2 and 1.0 respectively.

The likelihood of landfill liner damage by differential liner foundation displacement as a result of earthquake faulting is very low. The liner will be constructed on competent rock and is therefore unlikely to sustain any damage as a result of earthquake shaking.

6.1 Blasting Effects

It is proposed to continue quarry activities while operating the proposed Tirohia landfill. Quarry blasting activities will be within 150m to 200m of the landfill operation and will induce ground vibrations.

Vibrations induced by blasting are different to those associated with earthquakes. The most significant difference is the duration of shaking. The duration of strong shaking associated with blasting vibrations is about 1 second and compares to the duration of strong shaking associated with the site MCE of 20 to 30 seconds. Consequently, the potential effects of blasting are considerably less than those associated with earthquakes.

The assessment indicates critical peak particle velocities of 83mm/s and 44mm/s for the quarry east and south faces respectively and 55mm/s for the landfill front face. All but one of the peak particle velocities actually measured while blasting at the site were less than the assessed critical peak velocity values. The exception was for a blast measured at a distance of 50m. Future quarry blasting is estimated to occur at a distance of 150m to 200m from the landfill and at this distance the peak particle velocities are likely to be less than 20mm/s (i.e. much less than the critical values).

The effect of blasting on the landfill liner is not expected to be significant. The only mechanism by which the liner could be damaged is if differential movements were induced in the underlying rock mass. This is not expected to occur since the liner will be constructed on competent rock and is confined by the overlying landfill mass.

7.0 CONCLUSIONS

The existing quarry site is underlain by a sequence of andesitic volcanic materials comprising breccia, tuff and lava flows.

Groundwater flow is from the high ground of the spur to the Hauraki Plains. In the vicinity of the quarry the groundwater gradient increases from the low permeability andesite lava to the higher permeability materials of the lower part of the breccia dome.

Site colluvium and ash materials as tested do not satisfy the maximum allowable permeability design requirement for the landfill liner and a supplementary synthetic HDPE liner will be required. Colluvium and ash materials tested are of suitable quality and present in sufficient quantity to satisfy the requirement for final cover and daily cover for the proposed landfill.

Quarry and landfill slope stability under static and seismic (earthquake and blasting) conditions is acceptable. The integrity of the landfill liner is expected to be maintained during seismic events.

The geological, hydrogeological, geotechnical and seismic investigations indicate that the Tirohia Quarry site is suitable for the development and operation of the proposed sanitary landfill.

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