The paper was published in the proceedings of the 12th Australia New Zealand Conference on Geomechanics and was edited by Graham Ramsey. The conference was held in Wellington, New Zealand, 22-25 February 2015.

Population explosion onto unstable ground in the Auckland region

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ABSTRACT
As a result of the dramatic increase in the population of the Auckland region over the last 15 years, the Metropolitan Urban Limits have extended into areas of unstable ground including development on land containing both shallow and deep seated instability. This recent and historic landsliding is largely controlled by thin defects at multiple levels with extremely low effective stress parameters, (e.g. C'=0kPa and ϕ'=8 degrees). As a result since the year 2000, several areas of sloping land have required land stability improvement, such as large size bulk earthworks, shear keys and land drainage. This combined with the development mentality of the early 2000's to flatten contours as opposed to the more recent philosophy of working with the natural land contours, and clustering development has driven, the requirement for bulk earthworks on a scale that may never again be seen in Auckland.
This paper captures the recommendations and constructed remedial works across the following four example case study developments:

1. Pacific Palms Residential Development, Arkles Bay, Whangaparaoa (50+ lots);
2. Point Ridge Residential Development, Gills Road, Albany (medium density 100+ lots);
3. Crestview Residential Development, Redhills, Papakura (300+ lots); and,
4. Ponga Road, Hunua / Papakura (rural and residential 50+ lots).

Recent subdivision development with large scale bulk earthworks and implemented remedial measures has led to an increased level of geotechnical understanding. It is essential that we capture and record these findings and remedial solutions for consideration and possible implementation in future projects.

Keywords: Auckland, Land Development and Geotechnical Engineering Solutions.

1. INTRODUCTION

Over the past 15 years the population of the wider Auckland region has significantly increased, mainly as a result of immigration and domestic migration. This increased population base, combined with the areas of natural geographic constraints i.e. to the east flanked by the Hauraki Gulf and west by the Manukau Harbour has provided a catalyst for rapid geographic expansion in a northerly and southerly direction pursuing the traditional ideal of a quarter acre dream (see Figure 1).

Case Study Development Location Key:

1. Pacific Palms Residential Development, Arkles Bay, Whangaparaoa
2. Point Ridge Residential Development, Gills Road, Albany
3. Crestview Residential Development, Redhills, Papakura
4. Ponga Road Subdivisions, Hunua / Papakura

Figure 1. Auckland Area, Geographic Constraints / Case Study Locations - Map Google 2014

The purpose of this paper is to capture the development process and specific remedial measures or engineering solutions constructed to mitigate the geotechnical hazards identified (mainly landslides) within four residential developments completed over the last 15 years within the wider Auckland area. Identification of geotechnical hazards the remedial solutions recommended and ultimately constructed to mitigate the identified hazards form an important body of information for reference for future development.

2. AUCKLAND'S GEOLOGICAL SETTING

The geological setting of the wider Auckland region is complex and varied containing multiple geological formations, each of which generate with their own geotechnical hazards which require a variety of specific geotechnical solutions to facilitate residential and commercial land development. The Southern Landslide Zone (SLZ) broadly skirts the southern portion of the metropolitan urban limit's combined with the land instability driven by the Northland Allochthon to the north of the wider Auckland area provides several examples of development of unstable challenging land.

Within the wider Auckland area, the following geological formations dominate the landscape:

- East Coast Bays Formation (Waitemata Group);
- Puketoka Foundation Tauranga Group); and,
- Northland Allochthon.

3. THE GROUND MODEL

Within land development, it is essential that a robust ground model is put together for any development. The primary aim of a ground investigation is to form a ground model. This three dimensional representation (model) of the subsoil strata includes but is not limited to; groundwater, soil, transition zone (interface between soil and rock) and bedrock. The information (and lab test data/background information) is then compiled and correlated to produce a 3D model of subsurface conditions.

At the start of a specific project, any background information should be researched and summarised. This would include but not be limited to, a review of the following items:

- Aerial photographs and historical maps available;
- Geological and geomorphological mapping and groundwater information;
- Existing infrastructure records such as service location plans and as-builts; and,
- Relevant information and existing investigations that may be on territorial authority records.

Following the assembly of a ground model via desktop assessment and intrusive ground investigations the sites specific geotechnical hazards can be overlaid onto the model along with the failure mechanisms and drivers which may facilitate any instability or settlement that may have an adverse effect on future infrastructure. Geotechnical remedial measures or solutions can then be specifically tailored to mitigate the geotechnical hazards. If each of these geotechnical hazards such as deep seated planar failure are not specifically identified and mitigated, post development failures or ground settlement could result in significant infrastructure damage.

Superimposed onto the ground model are the mechanisms that have occurred (or may possibly occur) and where they are situated (or may be situated). These may include:

- Circular slope failure – within the subsoil profile;
- Scour / Piping – due to water movement within sensitive and/or soluble subsoils;
- Debris flows and other mass movement types;
- Translational movement – generally situated within the transitional zone;
- Liquefaction and Settlement - within soft and/or saturated subsoils etc;
- Wedge failure - on unfavourably orientated sets within the rock mass;
- Topple failure - on a combination of joint sets and/or bedding plains; and,
- Planar failure – within the rock mass on bedding planes or joint/joint sets.

Drivers of movement or instability are also identified i.e. what has caused (or may cause) the above mechanisms to activate and generate movement:

- Surface erosion – such as fluvial (river) and surface runoff;
- Ground water – elevated ground water levels and/or confined ground water;
- Soft natural subsoils and colluvial subsoils;
- Soft or very soft shear zones;
- Change of the natural water balance/water cycle – vegetation removal;
- Seismic loads generated by earthquakes;
- Flood events generated by extreme rainfall events etc;
- Loading of slopes i.e. development;
- Uncontrolled stormwater discharge;
- Soft / Uncompacted filling / filling Surcharge; and,
- Undercutting oversteepening of slopes.

4. CASE STUDIES

The following are four residential greenfield land developments captured in case study format. Each of these land parcels contained existing land instability features pre development that required geotechnical remedial measures / solution during sub dividual construction.

1. Pacific Palms Residential Development, Arkles Bay, Whangaparaoa (residential, 50+ lots);
2. Point Ridge Residential Development, Gills Road, Albany (residential medium density, 100+ lots);
3. Crestview Residential Development, Redhills, Papakura (residential, 300+ lots); and,
4. Ponga Road, Hunua / Papakura (rural and residential, 50+ lots).

PACIFIC PALMS SUBDIVISION, STAGES 4W and 4E, ARKLES BAY

Address: Ferry Rd, Arkles Bay, Whangaparaoa **Development Period:** 2002 to 2007

Site Description

The Pacific Palms Residential Development comprises an irregular shaped block of land located off the north-western side of Ferry Road, Arkles Bay (Stages 4E & 4W). It is bound to the north by rural residential lots and south by residential properties. The block is contained on the western flank of a south-west trending valley.

In a greenfield setting, (pre-development), the site was undulating to moderately steep, with slope gradients ranging from approximately 5 to 35°.

Vegetation cover pre development comprised of pasture, native bush and scrub. Stands of large trees and bush occupy the central western and northern corner of the block. As minor south-east trending gully and associated small ephemeral stream with a pond are located within the central portion of the site.

Summary Ground Conditions

The site is located on an area of Waitemata Group sedimentary lithology (Miocene Epoch 20 million years ago) (Edbrooke, 2001; Kermode, 1991). Areas of flood plain and coastal alluvium are present along the base of the gully through which Ferry Road runs although this is outside the immediate area of the site.

Site features included both shallow seated rotational slumps in the overburden soils and remnants of historic transitional zone land movement in the form of head scarps, debris mounds, mid-slope benches and soil creep. Investigation encountered / defined two main failure types:

1. Deep Seated Failures (Transitional / Planar); and,
2. Residual Soil Failures shallow seated (circular).

Following the deep seated slope movement, recent residual shallow seated circular failures in the form of soil slumping / creep have occurred along the southern and eastern slopes of the site.

The machine boreholes and the trial pits revealed that these features are probably controlled by fine sand or silty fine sand layers (rock soil interface). Above this zone the overburden consists of predominantly clayey silts and silty clays.

Geotechnical Recommendations

Considering the ground investigation phase of several machine and hand anger boreholes along with trial pits the following remedial measures were recommended and constructed:

- Eastern and Western Shear Key's with underfill drainage (see Figures 2 and 3);
- 20+ Counterfort Drains (6m deep); and,
- In ground Timber Retaining Walls.

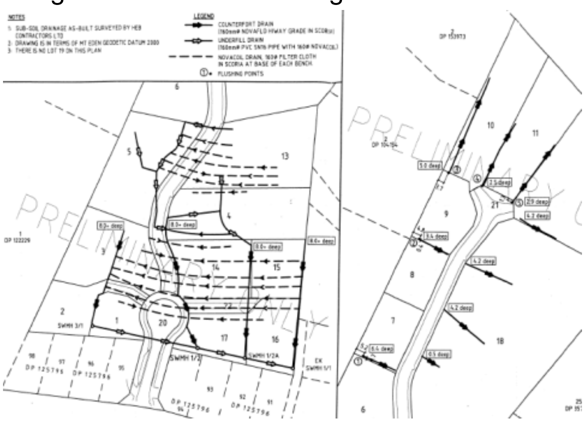


Figure 2. Shear Key / Subsoil Drainage (4E)

Figure 3. Aerial Photograph and Shear Plane 4W

MEDIUM DENSITY DEVELOPMENT - POINT RIDGE SUBDIVISION, GILLS ROAD

Address: Point Ridge Subdivision, Gills Road, Albany **Development Period:** 2000 to 2008

Site Description

The subject site is an elevated portion of land accessed off Gills Road which overlooks the Albany town centre (see Figure 5).
The site pre development was predominantly in long grass, however, the south western sidling slope and ridge contained a dense cover of gorse and large pine trees.

Summary Ground Conditions

The site is located on an area of Waitemata Group sedimentary lithology (Miocene Epoch 20 million years ago) (Edbrooke, 2001).
Site features included both shallow seated rotational slumps in the overburden soils and remnants of historic transitional zone land movement in the form of head scarps, debris mounds, mid-slope benches and soil creep. Investigation encountered / defined two main failure types:

1. Deep Seated Failures (Transitional / Planar Failures movement in line with bedding dip direction); and,
2. Residual Soil Failures shallow seated (circular).

Following the deep seated slope movement, recent residual shallow seated circular failures in the form of soil slumping / creep have occurred along the southern ridge.

The machine boreholes and the trial pits have revealed that these features are controlled by fine sand or silty fine sand layers (rock soil interface) and bedding failures. Above this zone the overburden consists of predominantly clayey silts and silty clays.

Shear key excavations confirmed that these features are controlled by fine sand or silty fine sand layers (rock soil interface) and on bedding plane.

Geotechnical Recommendations

Considering the ground investigation phase of several machine and hand anger boreholes along with trial pits the following remedial measures were recommended and constructed:

- Upper and Lower Shear Key's (10 and 14m deep, both 150+m long and 10 to 20m wide at base) with underfill drainage;
- Maximum Filling Depths of 21m (below finished ground level, see Figures 4 and 5);
- 10+ Counterfort Drains (6m deep) and 32mmϕ slotted bored drains;
- Concrete Block Retaining Walls, earth reinforced Embankment; and,
- In-ground Timber and Steel Tied-Back Retaining Walls.

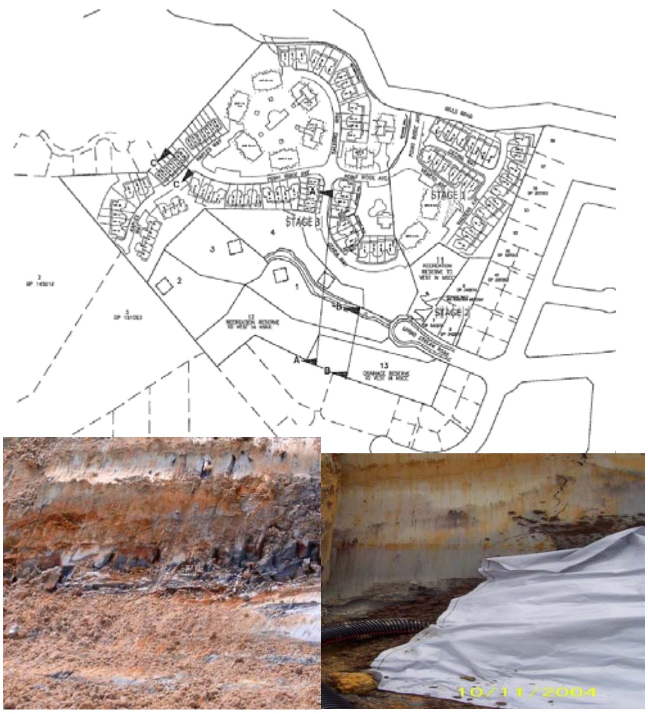


Figure 4. Subdivision Scheme and Shear Zones

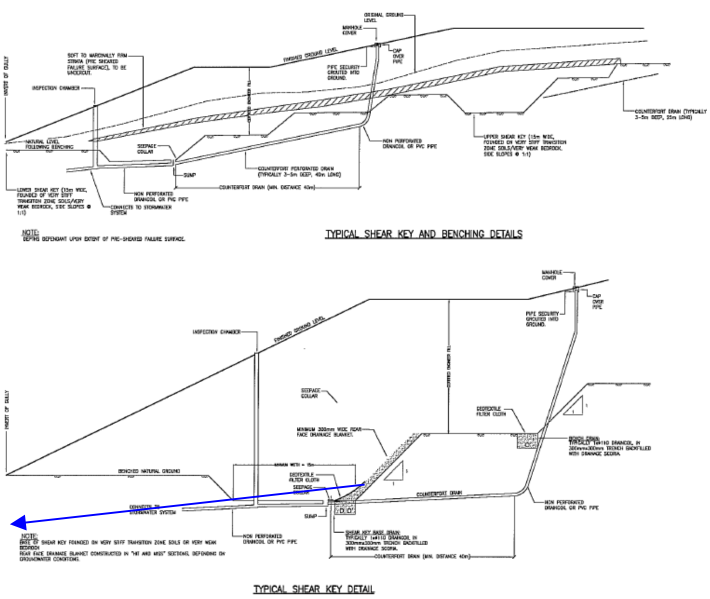


Figure 5. Typical Shear Key Details A-A'

CRESTVIEW HEIGHTS SUBDIVISION, REDHILLS, PAPAKURA

Address: Crestview Development, Redhills, Papakura **Development Period:** 2003 to 2010

Site Description

The subject site is an irregular shaped block of land located at the western edge of the Papakura Hills and accessed by Kerry Vista Rise from the south and by Kale Place to the south-west which are both within Stage 2 of the Papakura (Dominion Road) residential subdivision. The block is bound to the north by farmland, to the east by rural residential lots accessed from Kaipara Road, and to the north-west by older developed residential properties.

The block is divided by a central predominant ridge which trends in a north to north-west direction. On the western side of the ridge are two tributary spurs. The eastern margin of the Manukau Lowlands forms low-lying land on the western margin of the block. The eastern portion of the block is marked by a deep valley that drains northward and runs parallel to the ridge. The site is predominantly in long grass, however, the northern portion of the western sidling slope and large areas of the eastern gully contained a cover of gorse.

Summary Ground Conditions

Published geological records indicate that the block is underlain by two main lithologies, namely Pleistocene alluvial terrace deposits to the west on the lowlands and by Waitemata Group sedimentary siltstones and sandstones to the east (i.e. ridge and adjoining slopes) (Edbrooke, 2001).

The north-trending Drury Fault marks the boundary between the two units and is the principal reason for the topographical boundary between the lowlands and the Papakura Hills. The fault is not considered active although it is linked too much of the instability observed on the western slope.

Further, exposures of Waipapa Group (Jurassic Epoch) may also be present within the lower (north-western) corner of the site. The Waipapa Group sedimentary lithology (Greywacke) comprises of massive to thinly bedded, lithic volcaniclastic sandstone and argillite which form an overburden of clays and silts when exposed to weathering.

A significant landslide was identified within the western side of the subdivision (within area labelled Upper/Lower Key on Figure 6). Dual shear keys (upper and lower) were required to be constructed to provide code compliant land for development. Investigation encountered / defined two main failure types:

- Deep Seated Failures (transitional / planar – slope movement oblique to bedding dip); and,
- Residual Soil Failures (shallow seated circular).

Following the deep seated slope movement, recent residual shallow seated circular failures in the form of soil slumping / creep have occurred along the southern and eastern slopes of the site.

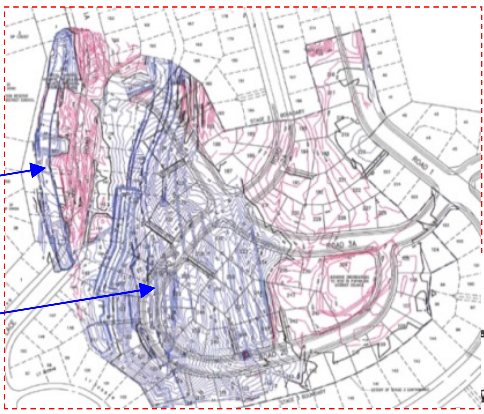
Shear key excavations revealed that these features are controlled by fine sand or silty fine sand layers (rock soil interface) and to bedding plane.

Geotechnical Recommendations

Considering the ground investigation phase of several machine and hand anger boreholes along with trial pits the following remedial measures were recommended and constructed (see Figures 6 and 7):

- Upper and Lower Shear Key's (6-10m deep,
- 150+m long and 10 to 20m wide at base);
- 30+ Counterfort Drains (6m deep); and,
- In ground Timber and Steel Tied-Back Retaining Walls.

Figure 7. Aerial Photograph



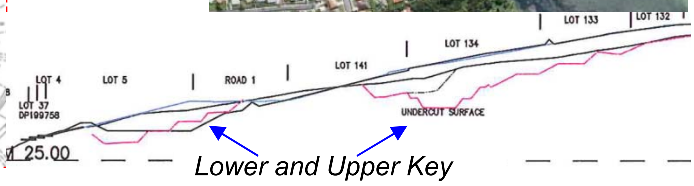


Figure 6. Shear Key As-built and Section

RURAL / RESIDENTIAL DEVELOPMENT, PONGA ROAD SUBDIVISION

Address: 586 Ponga Road, Hunua **Development Period:** 2004 to 2008

Site Description

The subject site is an irregular shaped block of rural land located off the eastern side of Ponga Road, Papakura. The site, formally named "Ponga Farms", is bounded to the north and east by Symonds Creek and to the south and north-west by recently developed rural residential properties.

The western portion of the block is characterised by a large amphitheatre shaped gully feature (landslide), while the eastern portion is dominated by three ridges which run in a northerly direction. The eastern portion of the block is also marked by two deep valleys which contain small streams that drain northward.

Pre development the majority of the block is in pasture and used for stock grazing. There are also hedge rows of large trees around the old farmhouse, and there are large stands of native bush in the eastern, northern, and north-western of the block.

Summary Ground Conditions

Published geological information (as referenced below) indicates that the block is underlain by three main geological groups. Most geological maps depict several complex faults within the vicinity of the site. Specifically, the "Ponga Lodge" fault has been mapped running north to south within the central to eastern portion of the site (Edbrooke, 2001; Kermode, 1992).

Site features included both shallow seated rotational slumps in the overburden soils and historic transitional zone land movement in the form of head scarps, debris mounds, mid-slope benches and soil creep. Based on our work to date, we have defined two main failure types.

1. Deep Seated Failures (Transitional / Planar 20+m bgl); and,
2. Residual Soil Failures shallow seated (circular).

Geotechnical Recommendations

Considering the ground investigation phase of several machine and hand anger boreholes along with trial pits the following remedial measures were recommended and constructed. Investigations were used to target and confirm shear zones within the complex profile. This was crucial to confirm the founding depth of the shear keys and drainage:

- Significant Shear Key (200+m long, 12+m wide 12+m deep) with underfill drainage;
- Horizontal Bored Drainage (100mmϕ, 200+m long, 15+ deep);
- 25+ Counterfort Drains (6m deep); and,
- In ground Timber Retaining Wall.

5. SUMMARY OF GEOTECHNICAL REMEDIAL RECOMMENDATIONS

Each of the enclosed case studies have several differences however many of the geotechnical recommendations were comparable. Considering this, the following provides a more detailed summary of the key remedial solutions implemented during the development of the case studies:

Shear Key Construction

The four case studies stability analyses have demonstrated that construction of the shear keys, extensive benching and the installation of underfill and counterfort drainage was required to stabilise the existing instability features and to make sure that the long term minimum factor of safety does not drop below 1.5.

Shear keys constructed range between 10 and 20 metre's wide (base of excavation) and extend at least 2 metres into rock. The base of the shear keys should extend well below any pre-existing failure surfaces with side slopes formed no steeper than 1(v):1(h).

Full height drainage blankets comprising SAP 50 (i.e. self-filtering) drainage material and 160mm diameter Hiway grade Novaflo draincoils were placed against the rear face of each shear key to intercept and collect all groundwater. This material was also wrapped in suitable filter cloth (eg Bidim A14 or Terram 1000). Depending upon ground conditions exposed in the shear key excavations, rear face drainage may be constructed in "hit and miss" sections.

Upslope of the shear keys, additional drainage was required at the toe of all cut benches prior to filling. Backfilling of the shear keys should comprise compacted Engineer certified filling placed in accordance with the earthworks specification outlined in the sites Geotechnical Investigation Report.

With all such excavation work (see Figure 8) there is a risk of batter collapse or instability. Careful consideration was given to the stability of all temporary batters during shear key construction and benching and drainage works.

Figure 8. Photographs 1, 2 and 3: Shear Key Excavation and Compaction of Engineer Certified Filling

Land Drainage Installation

Land drainage is fundamental within land development in all of the case studies. Specifically the following measures were recommended. Lowering groundwater levels reduces the driving force towards instability and limits pore-water pressure buildup within the subsoil profile.

Underfill and Subsoil Drains

Perforated underfill drains were installed in narrow trenches cut into bedrock or other competent strata along the toes of all cut benches. Localised seepages were tapped and drained using Novaflo pipes and adequate amounts of SAP20 drainage material. These drains were covered in a suitable geotextile to prevent migration of fines and to help maintain long term control of groundwater conditions.

Counterfort Drainage

Counterfort drains were required in all sites of sloping ground where it is necessary to provide control over groundwater levels to maintain a minimum factor of safety of 1.5 against instability.

The counterfort drains were 450mm to 600mm wide and installed to depths of up to approximately 6 metres. The draincoil in the base of counterfort drains were extended up to ground level at the top end and a flushing point installed.

The positions of the counterfort drains are shown on the engineering plans and approved by the engineer prior to commencement of the works (see counterfort drainage detail).

Bored Subsoil Drainage System

A series of bored drains in a fan configuration were installed under the shear key within the Ponga Road development to intercept artesian groundwater at approximately 11m bgl to reduce pore water pressure and to help maintain adequate factors of safety.

The 100mm diameter drains were slightly inclined above the horizontal and were up to approximately 200 metres long. They extended beneath the shear key and daylight at upslope with a flushing point.

Pressure Relief Wells

In addition to the above, pressure relief wells were required to further relieve pore water pressures within the Waikato Coal Measures (Ponga Rd development – see Figure 9). The locations of the wells were surveyed and recorded within the as-built plans and Geotechnical Completion Reports.

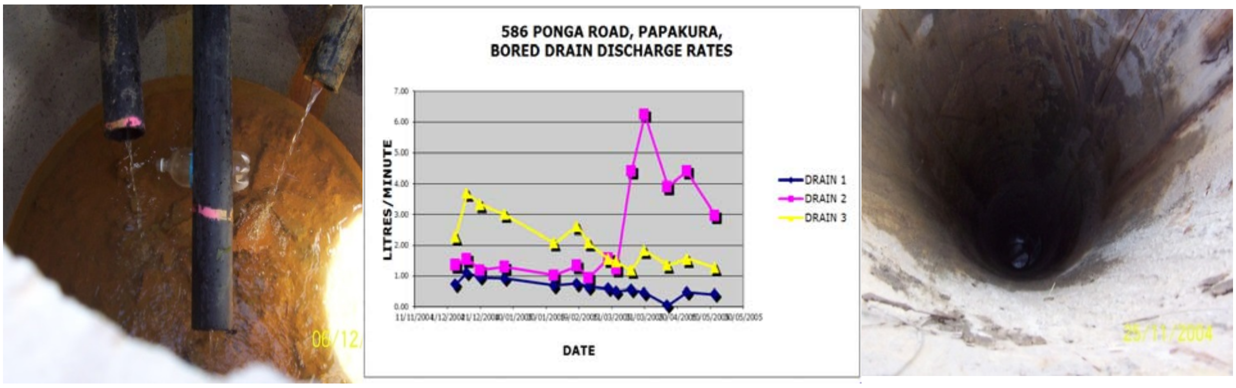


Figure 9: *Bored Subsoil Drainage Discharge Manhole, Discharge Data and Example Drainage Well.*

These wells were 600mm diameter bored chambers backfilled with approved scoria, eg. SAP50. Collected groundwater seepage will be discharged via one of the proposed bored drains recommended above.

Timber In ground Retaining Wall

Due to steep land gradients, combined with the propensity for soil creep and shallow seated land movement, in-ground cantilever pole retaining walls were installed on the downslope side of several residential lots / building platforms.

Inclinometers and Piezometers

Inclinometers and piezometers were installed and monitored on a regular basis throughout and beyond the earthworks period and the results will be presented in the Geotechnical Completion Report.

6. CONCLUSIONS

Population explosion within the Auckland region has driven the need for development of land within complex and sometimes unstable settings. This has provided an opportunity for exposing and learning about the region's geology and accompanying engineering remedial measures.

The above case studies are finished developments that were all constructed within a complex geological setting involving site specific remedial earthwork's and land drainage measures.

These case studies and specific remedial measures should provide relevant information when considering future developments. It is essential that we as a collective continue to capture and record specific geotechnical projects as it is crucial we learn from our projects as a community for the benefit of society.

With the onset of a clustered approach to development it has also become possible to lessen the effects of bulk earthworks and land drainage within residential land development and isolate unstable areas which can be returned to useable green space with clusters of building on more stable areas.

ACKNOWLEDGEMENTS

GHD Limited, Coffey Geotechnics, Thornton Estates Limited, Ponga Farms Developments Limited, Urban Developments Limited and Redhills Developments Limited.

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