

ISSUES WITH GEOTECHNICAL INVESTIGATIONS, DESIGN AND CONSTRUCTION IN REMOTE LOCATIONS

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ABSTRACT

This paper discusses the complexities of providing geotechnical design parameters for rock anchors and shallow foundations for an access stairwell at the 20 m high, vertical walled, To Sua Ocean Trench in Samoa.

Restricted by an absence of relevant published geotechnical information, local resources and equipment, as well as on-site testing limited to shallow subsurface investigations and visual site observations, the geotechnical design parameters are constrained to conservative estimates.

Hand auger borehole testing with associated in situ strength testing (Scala penetrometer and shear vane testing) was completed in the surficial soils at the top of the trench, rock samples were collected for UCS testing (where accessible) from the vertical walls, and Scala penetrometer testing was completed through the water at the base of the trench. Additionally, geological mapping and detailed evaluation of the rock face was undertaken.

Without cored borehole investigations, rock strength data and evaluation of the presence and prevalence of defects within the rock mass, recommended geotechnical design parameters are conservative assumptions, analogous with published values for weathered, relatively porous, basalt rock from internationally recognized standards. Consequently, geotechnical designs are less cost-effective and assumptions require verification during construction.

1 INTRODUCTION

Scoping geotechnical investigations in remote locations requires more diligence and vigilance than a typical assessment in an area dense with publically available geological, geotechnical and high quality digital information. This paper discusses the challenges and complexities of undertaking a geotechnical investigation for the To Sua Trench in Samoa.

The To Sua trench is a popular tourist attraction located adjacent to the south-eastern coast of the island of Upolu in Samoa. The trench is up to 30 m wide, and approximately 20 m in height (from ground level at the top to water level at the base). Current access to the base of the trench is via an 18 m high, narrow timber ladder, fixed precariously to the top and bottom of the trench, and standing at approximately 70° (shown in Figure 1). The site is just over an hours' drive from Apia, where the majority of the country's major development projects exist. Aside from it being an international location, the site is also considered to be in a remote area within Samoa as the surrounding area is largely undeveloped and densely vegetated.

It is proposed to replace the current access ladder with a more user-friendly, safety-conscious stairwell (including a hand-rail). The new stairwell has been designed to be anchored into rock near the crest of the slope, and at the base of the stairwell. The purpose of our assessment was to undertake a geotechnical investigation and slope stability assessment in order to provide geotechnical design input for the proposed stairwell foundations. In keeping with the current conditions of contract, no figures depicting the new structure are included in this paper and descriptions of the foundation details have been kept relatively broad.

The objective was not significantly different to an investigation for a project in a well-documented urban area, where the intention of the geotechnical scope is to obtain useful geological and geotechnical data such that a workable ground model can be developed and appropriate geotechnical advice provided to inform foundation design.

New Zealand's available geotechnical, geographical, geological, topographical, geomorphological, geomechanical, seismological and hydrological data collection is extensive, recent, of high quality, and somewhat standardised across the country. Its utilisation in scoping a project significantly reduces the risk of encountering unforeseen ground conditions, and allows for relatively cost effective investigations (either by undertaking fewer tests or utilising less intrusive and time sensitive testing methods).

Further, most consultants in New Zealand's main centres will have completed a number of in-house projects within the general vicinity of their location and have an understanding of the local ground conditions to assist with scoping and design.

In this case, little credible geological and geotechnical data is made publically available in Samoa and clear and relevant aerial photography is lacking, making a preliminary desktop scoping study a challenge. Further, data collection techniques on the island are limited by an absence of available, conventional geotechnical *in situ* testing resources. One publication that was particularly useful, and referenced within this paper is Schaefer et al (2015).

The shortcomings of undertaking a geotechnical investigation for the proposed development at the To Sua Trench in Samoa are discussed herein, with comparison to completing a similar scope in well-documented and accessible locations.



Figure 1: Aerial view and location of the To Sua Trench. Image (left) sourced from www.samoa-travel/ and map (right) sourced from Google Maps.

2 GEOLOGICAL SETTING AND SITE DESCRIPTION

Based on our review of the available literature, the islands of Samoa were formed through Quaternary hot spot volcanism comprising Oceanic Island Basalts (Kear & Wood, 1959). The To Sua and To Le Sua trenches at the site are interpreted to have developed from an adjoining lava tube associated with the Salani Volcanics. The Salani Volcanics are described as typically homogenous and porous basalts, overlain by a thin soil layer derived from both windblown (Aeolian) deposits and weathering of the bedrock. Prior to scoping the project we determined, through correspondence with a local construction consultant, that the site is underlain by volcanic deposits of basaltic composition with varying vesicularity.

Google Earth aerial imagery of the site was of low resolution and so was unhelpful in assessing the landform of the general area. In contrast, given that the site is Samoa's "must-see" tourist attraction, a number of useful photos of the site were able to be viewed through a Google Image search.

Based on our review of the Google Images, combined with our subsequent site observations, the structure of the trench can be described as having three geotechnically distinct layers. These have been defined as the lower portion, central portion, and upper slope. This is further illustrated in Figure 2 below.

2.1.1 Lower Portion

The lower portion of the trench is between approximately 3 m and 10 m height, from the base of the trench. The walls of the trench in this area stand (approximately) vertically, and overhang by approximately 1 m to 2 m at the water line. The exposed rock comprises a slightly weathered, oxidised, reddish-brown basalt.

2.1.2 Central Portion

The trench walls are also vertical in the central portion, however this section is more vegetated than the lower portion which is attributed to its more weathered state (allowing gaps for root growth), and sun exposure.

2.1.3 Upper Portion

The upper portion of the slope reclines between 30° and 70° and is densely vegetated with mature trees and shrubs. With the exception of the access path cut into the slope, this slope does not appear to have been modified.

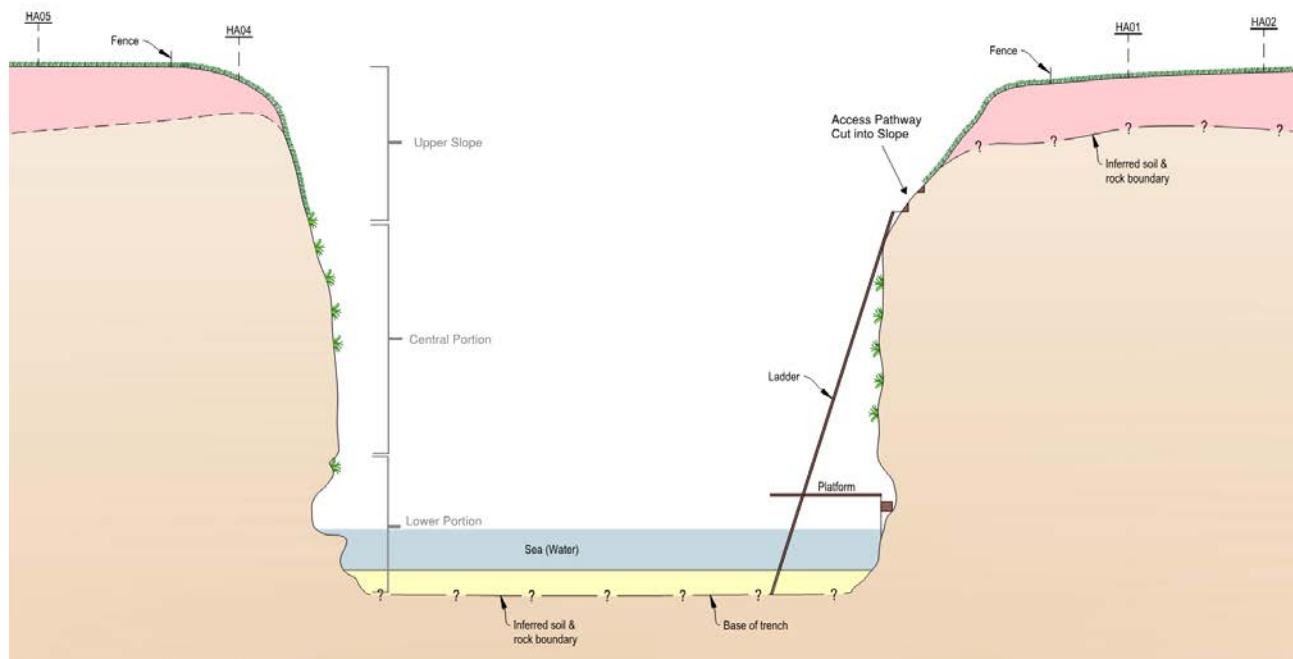


Figure 2: Cross-Section through the To Sua Trench

3 GEOTECHNICAL INVESTIGATION AND ASSESSMENT SCOPE

A preliminary understanding of the geometry and likely geology at the trench assisted with the development of our testing and investigation scope. The purpose of the investigation scope was to collect appropriate data to provide geotechnical advice that is sufficient to inform the design, while keeping with the economical and practical limitations of the project, and limiting the risk to the client and to us as the consultant.

For this project, clear communication with the wider project team was critical as there was no provision to return to site and collect further data once back in New Zealand. The key geotechnical information required to support the proposed stairwell construction included the following:

- Characterisation of the site geology, in particular the depth to competent rock.
- Understanding of the stability of the slope within the proposed stairwell location.
- Details of the geomechanical properties of the rock, as well as the rock mass properties, for the application of value engineering in anchor and foundation design.

For retrieval of representative and specific data through the basalt, drilling of a machine borehole from the existing ground surface through to the base of trench was considered to be the most appropriate method. This would allow us to assess the nature of the *in situ* rock mass, the presence and prevalence of defects and voids, and the *in situ* rock strength. Further, representative samples could be collected for laboratory testing to determine specific geotechnical parameters for foundation design.

A machine borehole is generally more expensive than most other techniques, and becomes significantly more so when the drill rig has to be shipped from New Zealand to Samoa. The cost of a machine borehole (including mobilisation and drilling to approximately 25 m) was on the order of \$50,000. Transportation to the site was expected to take six to eight weeks, according to fee estimates obtained from New Zealand-based drilling sub-contractors. The client had pre-arranged site access with the land owners for two days' work exactly one month from the date of scoping discussions and formal engagement, so time constraints meant we could not engage a New Zealand-based driller. We were advised

that there are no available, operational machine borehole drilling rigs in Samoa, ultimately ruling this method out of the scope.

Geophysical testing methods, including Ground Penetrating Radar (GPR) and Multichannel Analysis of Surface Waves (MASW) are appropriate techniques for this site. Although this method is suitable, it is typical to supplement the geophysical data with a machine borehole for increased certainty. Geophysical methods were not included in the scope as a testing technique as there were no known available resources to undertake the surveys in the country, and shipping of the equipment would exceed the clients' budget.

Cone Penetrometer Testing (CPT) was considered unsuitable, given the likely presence of impenetrable rock, further ruled out by the lack of CPT testing capabilities in Samoa. Testing through test pitting techniques was also explored, however this option was denied by the land owner due to the likely disturbance and impact it would have on the site's landscaping and overall aesthetic.

To achieve a less cost-prohibitive scope without significantly reducing the quality of collected data, and to meet pre-arranged testing schedules, a scope with a more "hands-on" approach was designed on the basis that geotechnical recommendations would be conservative and require verification during construction.

The investigation scope for the project allowed for one representative to visit the site and complete the following:

- Hand auger borehole and associated shear vane and Scala penetrometer testing at several locations (where accessible) through the surficial soils on the upper slopes leading down into the trench, and where the construction crane foundations were proposed on the nearby level ground.
- Evaluation of the base of the trench through swimming / diving, and Scala penetrometers (undertaken from the ladder platform) to understand the material at the base of the trench and assess the depth to competent rock for foundation support.
- Detailed engineering geological mapping of the cliff face, assessing the structural condition and stability of the rock (i.e. weathering, fractures, joints and discontinuities), and extent of the overhanging rock. Dimensions of joints, fractures and voids were measured by swimming up to the face and exposures accessible from the ladder.
- Collection of representative rock samples for point load testing (to be completed at a lab back in New Zealand).
- Assessment of the slope stability of the trench using computer modelling software SLIDE.

Due to the compromises in the investigation scope, it was made known to the client that conservative design assumptions would be provided that may proportionally increase construction costs. Following discussion, the project team decided that this was an acceptable risk for the project. With the intention of verifying the design assumptions during construction, an allowance was made for the potential for variations to the design, likely through the addition of anchors or increase of dimensions and reinforcing.



Figure 3: Undertaking Scala penetrometer testing from the platform at the base of the ladder and evaluating the base of the trench through swimming.

4 EQUIPMENT MOBILISATION AND OPERATIONAL COMPLEXITIES

4.1 TESTING EQUIPMENT

Fieldwork for a straightforward, shallow geotechnical investigation in urban Auckland is somewhat uncomplicated for local consultants. Typically, field testing equipment suitable for the project site and anticipated subsurface conditions is loaded into a work vehicle and driven to site by the field representative. If equipment is damaged onsite, or additional parts are required, it is not too difficult to return to the office or visit a supplier and collect the equipment on the same day.

Conversely, travelling with field testing equipment to Samoa required significantly more vigilance in preparation and had the potential to limit the ability to collect geotechnical data. There is a maximum baggage allowance of 23 kg before having to purchase additional checked luggage and / or pay for exceeding the weight limit. A Scala penetrometer drop weight is 9 kg, independent of a full set. Accordingly, several additional pieces of checked baggage was required.

In preparation for clearing customs coming back into New Zealand, thorough and vigilant cleaning of the equipment was essential. Further, there was a risk that the rock samples (contaminated with soil) collected for point load testing may be seized by customs officials, or quarantined and decontaminated at cost.

4.2 ACCESSIBILITY, VARIABLES AND REGULATIONS

Further challenges arose during execution of the fieldwork scope associated with accessibility restrictions, weather conditions, and compliance with Health & Safety policies. These considerations are necessary when undertaking geotechnical investigations in almost all locations, however the remoteness and unfamiliarity of the To Sua Trench made their application unique.

The approved budget allowed for one representative from ENGEO to visit the site and complete the fieldwork scope. Adherence to the company Health & Safety policy (in accordance with the New Zealand Health and Safety at Work Act 2015) required collaboration and reliance on the client, and other consultants at the site. Throughout the assessment of the base of the trench and Scala penetrometer testing from the base platform, active spotting from a non-participating person was required.

Due to the dramatic geometry of the trench, and the available access via a ladder greater than 2 m in height, Work Safe NZ regulations determined that investigations at the site are classed as 'Working at Height' and specific height safety equipment (including a harness, fall-arrest device and anchor point) and certification was required to be compliant with the Act (NZQA Unit Standards S17600, 23229 and 25045). In addition to providing the safety equipment, staff were appropriately trained and demonstrated competency through assessment of the practical standards listed above.

Swimming to undertake an evaluation of the base of the trench is unique to the To Sua Trench assessment and added further challenges to the project. The depth of the water at the base of the trench is approximately 2 m, greater than the average height of a person. Active spotting by a non-participating person and proven competency for the task of swimming was essential. Swimming specific equipment, such as a snorkel and mask, a life jacket, and flippers were also necessary to carry out the assessment. All site assessments were completed by appropriately trained staff in compliance with the aforementioned regulations, utilising the necessary equipment, as per the task requirements.

Weather conditions are difficult to define, particularly one month out from the scheduled testing date, but can be suitably managed in the majority of circumstances. Cyclone season in Samoa is experienced from November through to April and typically involves increased rainfall and daily thunderstorms. The site visit was arranged in the month of January. Throughout field testing, heavy rainfall prevailed and thunderstorms with lightning strikes were intermittent. On two occasions Scala penetrometer testing was abandoned to avoid the risk of lightning strike. Further, owing to the obvious wet environment, documentation and data collection records at the base of the trench were largely undertaken through dictated videos and photos, using a GoPro.

Collection of representative rock samples for laboratory testing was included within the scope of work. Weathering conditions of the exposed rock varied throughout the three portions of the trench, and was expected to differ within the rock mass throughout the remainder of the site. However, as there was no allowance for evaluation of the rock through abseil access, obtaining a sample was limited to areas that were within "arms reach" of the ladder and able to be removed with a rock hammer, as well as from the base of the trench by swimming to an outcrop.

The point load testing was undertaken at an ISO accredited laboratory using a Shimadzu REH100TV Universal Testing Machine, in accordance with ASTM : D 5731 – 016 methods. The estimated Qu (MPa) was calculated from values presented in Table 1 of the ASTM : D 5731 – 16.

Given that the rock samples (of acceptable sizes for point load testing) were collected from the weathered face, nearby to and at the intertidal level, we anticipate they are likely to be weaker samples.

4.3 RESULTS AND RECOMMENDATIONS

The fieldwork and collection of data was successful, and development of a workable ground model was possible. Although only a brief desktop study was undertaken using Google Image photographs, the site conditions were generally as expected and the properties of the exposed rock was in keeping with our preliminary assumptions.

Schaefer et al (2015) published index Unconfined Compressive Strength (UCS) rock values associated with basalts from Samoa that have typical porosity values. Generally, highly vesicular basalts (>25% vesicles) had notably lower UCS strength results than basalts with less than 10% vesicles. The two samples of basalt rock analysed for point load testing from To Sua comprised a highly vesicular sample (30% vesicles) and a low vesicularity sample (5% vesicles).

Table 1 below presents a comparison of the To Sua UCS representative strengths, and the index strengths provided by Schaefer et al (2015).

Table 1: Unconfined Compressive Strength Tests of Samoan Basalts of Various Porosity

Basalt Porosity	To Sua Trench Sample Results	Schaefer et al (2015) Index Values
<10 %	56 MPa	138 MPa
>25 %	32 MPa	21 MPa

The estimated UCS values calculated from the point load tests broadly align with the >25% index UCS values published by Schaefer et al (2015). It is recognised that two samples is not an ideal data set for utilisation in design and value engineering. Furthermore as point load testing does not directly determine a compressive strength, the estimated UCS determined in this way may have associated uncertainties.

Based on the limited investigation scope, our design parameters and construction recommendations were provided with conservatism, factored in accordance with New Zealand design standards, and subject to verification testing during construction.

All assessments and analyses for this geotechnical investigation were completed in accordance with New Zealand standards and codes, and geotechnical advice provided met the requirements of the following British and New Zealand Standards:

- BS1377
- BS8081 : 1989
- NZS1170.5:2004

5 DISCUSSION AND CONCLUSION

Within a comprehensively studied project area, a typical geotechnical investigation would be completed using conventional subsurface testing methods (i.e. machine borehole drilling), thus reducing the unknowns and allowing provision of practical and cost effective geotechnical recommendations. Table 2 presents a summary of the comparisons when undertaking geotechnical investigations in remote locations versus central locations.

Table 2: Comparisons of Geotechnical Investigations between Central and Remote Locations

Task	Central Location	Remote Location
Desktop Study and Scoping <ul style="list-style-type: none">• Aerial Photographs• GIS Database• NZGD• Local Experience	Available	Limited
Intrusive / Deep Data Collection Techniques (i.e. machine operated equipment) <ul style="list-style-type: none">• Machine Borehole Drilling• Percussion Drilling• Test Pits• Geophysical Survey• CPT	Available	Limited or Not Available
Low-Impact / Shallow Drilling Techniques (i.e. handheld equipment) <ul style="list-style-type: none">• Hand Auger Testing• Scala Penetrometer Testing	Available	Available

However, the approach of a combined high-level assessment, shallow investigation and limited analysis for this project was achievable and useful (albeit conservative) geotechnical advice was able to be provided for the foundation design. All of the challenges and testing limitations imposed on the project were able to be controlled and mitigated through adequate scoping, vigilant preparation and clear communication.

It was intended to include results from construction, however at the time of preparing this paper construction has not begun due to a significant weather event damaging main arterial routes in Samoa, consequently restricting access for delivery of the construction equipment and structures to the site for the development. Another challenge to overcome when undertaking construction projects in remote locations.

6 ACKNOWLEDGMENTS

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The experience of undertaking this assessment has expanded my investigation and assessment methodologies and techniques, and been an extremely valuable opportunity to improve personal technical growth and to be involved in a unique project.

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