Localised Failure of Cliff Top Waitemata Group Residual Soils, an Approach to Remediation

Andrew Gordon

WSP Opus, 100 Beaumont Street, Auckland, New Zealand

ABSTRACT

Cliff top soil failures are a common occurrence along the coastal margin of the Auckland Urban Area. With the continued development of this space for residential infill housing the impact of localised slope failures have increased. As the majority of development along the coastal margins are privately owned, any remediation measures proposed must be cost effective for individual landowners, constructible and provide a robust engineering solution to meet local authority requirements. WSP Opus and Earth Stability Limited have remediated numerous localised shallow slope failures along Auckland's coastal margin through the use of soil-nailing and the installation of drainage within the overlying residual soil mantle.

Due to access, budgetary and health and safety constraints, geotechnical investigations undertaken for cliff top properties are typically limited to the areas adjacent to the failure and terrain evaluations. The prominence of terrain evaluations in the development of geotechnical models has facilitated the use of WSP Opus's UAV capability to determine any underlying factors driving slope failure. Shallow slope failures are often the initial driver for the landowner to engage geotechnical specialists, however as geotechnical practitioners and stability contractors, the underlying cause of slope stability issues along the cliff line cannot be ignored.

The use of soil-nails to enhance the stability of a slope has long been established, but is typically constrained by site geometry to primarily provide support perpendicular to the slope. Therefore, it must be communicated to the client that soil nailed remediation of slope failures are not intended to prevent global cliff failure or lateral regression adjacent to the soil nailed section.

1 INTRODUCTION

Auckland's coastal cliffs have become highly desirable with dwellings constructed to exploit the expansive, unobstructed ocean views. In order to minimise the visual impacts from neighbouring structures, houses are often built as close to the top of the cliff as allowed by the regulatory authority, with ancillary structures such as decks and pools often constructed beyond this.

The Auckland urban area is concentrated on the Eastern Coastline and surrounds the Waitemata Harbour and extends from Beachlands in the south to Orewa in the North. The urban area generally overlaps with the spatial extent of the East Coast Bays Formation of the Waitemata Group (figure 1).

As the coastal margin continues to be developed, the impact of naturally occurring localised slope failures which occur within the over-steepened soils overlying the cliff have increased. The majority of development along the coastal margin in Auckland is privately owned, and as such any remediation measures developed must be cost effective for landowners and unobtrusive, while still providing a robust solution that meets the regulatory requirements.

This paper looks at one low-cost remediation technique, soil nailing. Soil nailing of numerous localised shallow slope failures across the Auckland Region has been undertaken by WSP Opus and Earth Stability Limited.

2 GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The majority of the Auckland Urban Area is underlain by Miocene-aged East Coast Bays Formation of the Waitemata Group. The formation is comprised of marine deposited fine-grained sandstones and mudstones, the overlying soil mantle is typically 3 -7m in thickness, derived from residually weathered Waitemata Group and can be overlain by younger sediments of the Tauranga Group (Edbrooke, 2001).

The Waitemata Group typically has contorted bedding and highly faulted. The contorted bedded is inferred to be the result of soft sediment deformation post deposition. The spatial variability of bedding and faulting is significant, due to its effect on the erosion processes and subsequent cliff line retreat (Moon and Healy, 1994) (Figure 2).

Regression of coastal cliffs is observed along much of Auckland's coast line. Although not the focus of this paper, the process of retreat is important to recognise, as any global cliff retreat will be reflected in the subsequent failure of the overlying soil mantle to regain an equilibrium. To propose a robust solution for slope stability issues in the soils at the top of the cliff, one must first identify the root cause of the cliff line regression. Other factors including natural processes, manmade features that contribute to the slope failure need to be consistent to develop a robust remediation measures.

Figure 1: Simplified geological map of the Auckland Region, showing the approximate extent of the East Coast Bays Formation. The formation, underlies the majority of the Auckland urban area

An understanding of groundwater is a key component of any slope stability investigation. Due to the complexity of the formation, groundwater is often found to be present in the form of locally perched aquifers confined by siltstone beds, and can be highly controlled by discontinuities. Following heavy or prolonged rainfall events, perched ground water is often encountered within the upper 1m of the soil mantle immediately following large or prolonged rainfall events, with saturated zones typically encountered along the soil-rock interface. Correlation between saturated zones and seepage provides a good indicator of the location of the soil-rock interface.

The interaction between groundwater and stormwater are a common contributor to slope instability, and as such, is particularly important to investigate areas of cliff line seepage and identify the correlation between seepage and saturated soils. Following heavy or prolonged rainfall, ground water is often encountered within the upper 1m of the soil mantle,. The ingress of water into the saturated soil mantle from damaged or overwhelmed stormwater systems and concentrated overland flows above the cliff face can contribute to further destabilising the slope.

3 INVESTIGATIONS

GEOTECHNICAL INVESTIGATIONS

Site investigations of cliff top slope failures are typically limited in extent; and usually only comprise hand augers with shear vane tests and accompanying Scala penetrometer tests. Investigations are typically focused on the area directly adjacent to the slope failure.

Some of the limiting factors include:

- Health and Safety: Cliffs in the Auckland area can exceed 45m in elevation, and can be overhanging. Due to the safety risks of manually handling equipment on often uneven ground at heights WSP Opus conservatively setback the closest investigation test localities a distance exceeding twice the thickness of the residual soil, or closest safe location behind the head scarp,

- Budget: The extent of investigations undertaken on small cliff top slope failures are typically limited by the owner's funds available, an expected constraint when operating within the residential environment, due to the lack of private funding or insurance to cover these types of works. As such, WSP Opus employs a small field team consisting of two experienced geotechnical professionals to undertake geotechnical investigations and UAV surveys.
- Access constraints: Access to coastal properties within Auckland is very often limited by lack of public spaces along most of the cliff tops in the Auckland area. In addition to with public reserves where they exist often lack vehicle access.

UNMANNED AERIAL VEHICLE (UAV) UTILISATION.

To overcome the constraints of the physical geotechnical investigation, detailed mapping and terrain evaluations become increasingly important. The use of 3D-models developed from UAV photogrammetry surveys combined with on the ground mapping methods have become extremely useful in the identification of the geotechnical issues driving cliff top failures (Figure 2). Traditional terrain evaluations of cliff top properties that are typically limited to visual observations from the top or bottom of the cliff and any rock exposures and blocks located at the base of the cliff and on shore platform.

3-D terrain models can be used to produce geological profiles and create accurate slope stability models to evaluate the stability of the slope. Survey control can be used, however even sites with not survey control can produce models with a spatial accuracy of 0.5m, which is an improvement over visual inspection methods.

4 DESIGN PHILOSOPHY

Due to the risk of soil failure to properties and the at times, limited investigation data available, a conservative approach to design is typically adopted.

The design of any remediation works is often constrained by a number of factors, including:

- The wishes of the landowner, if their budget allows, they may seek to reinstate a portion of the lost material in order to maintain the extent of useable land use area, or also to stabilise the soil mantle in front of a wall, or may just wish to stabilise the head scarp of the failure, while provide an aesthetically pleasing solution (Figure 3).
- Coastal environments are highly dynamic and the probability of similar failures occurring within the neighbouring properties is high, it can be attractive to continue the remediation scheme across adjacent properties. A compressive review of adjacent sites should be undertaken prior to extending remediation works, to ensure site conditions remain consistent and any design assumptions remain appropriate.
- Soil-nailed remediation measures are limited to providing support to the residual soil and are constrained by geometry to provide support perpendicular to the cliff, therefore the designer and contractor must be explicit with the design limitations, as these measures are not intended to prevent global cliff failure or prevent lateral regression from adjacent failures.

While the design life has long been important, safety in design and the whole life cost have been increasingly important in the New Zealand engineering sector in recent years. Two of the most important safety in design aspects that must be accounted for are the constructability of a design and maintenances requirements of a design, decisions made in the early design phases can greatly influence these two aspects:

Safety in design promotes collaboration between the designers and contractors, in order to identify and eliminate as many hazards as possible. Collaboration during the design phase can greatly reduce the risk to those onsite. As construction often requires the use of rope access, material weights and dimensions are limited, as materials must be moved and installed, with minimal access to plant. Remediation measures must therefore be designed with the goal of utilising the limited material size and quantise available effectively, while providing a robust solution.

As those responsible or the budgetary demands change over the 50-year design life of the system combined with the out of sight out of mind nature of cliff top remediation structures. It should be assumed that no maintenance will occur during the design life. If maintenance of the soil-nails and bored horizontal drains is required, the only safe methodology likely requires the use of rope access professionals, at a significant cost. If maintenance is required over the course of the design life of the remediation measures it must be clearly communicated with those parties responsible. It must be stated that if the specified maintenance is not undertaken as specified, the design cannot be guaranteed to provide resistance to failure.

To overcome maintenance concerns, any steel soil-nail components specified require adequate corrosion protection. In the past, a minimum corrosion protection consisting of hot dipped galvanizing in accordance with ASTM A-153 and epoxy coated in accordance with ASTM A-934 and ASTM A-775 has been used, to provide resistance to the coastal atmosphere and some resistance to the typically corrosively non-aggressive East Coast Bays Formation residual soils. Due to the conservative nature of the design philosophy employed, it is considered good practice to also increase the diameter of soil-nails specified to allow for the availability of some sacrificial steel.

Figure 2: Examples of terrain evaluations produced from UAV photography. A) Typical soil failure observed along cliff tops in the Auckland Area. B) The variability of the East Coast Bays Formation geologic structure, the influence of the underlying geological structure of soli failures is important.

Groundwater concentrates along the soil-rock interface along the majority of East Coast Bays Formation cliff lines, therefore bored horizontal drains should be targeted along the soil rock interface. To limit the requirement for maintenance, drains should be of adequate size and covered with a fine filter sock to limit sediment ingress and reduce blockages. Drains should be spaced close enough to allow some redundancy as drains become less effective over the design life.

Figure 3: Pre-and post-construction photos of the site in Figure 2a of a soil-nailed slope remediation. remediation was undertaken in two stages across a property boundary a few months apart, notice the rapid revegetation of the distal slope

5 CONCLUSIONS

A significant proportion of the Auckland urban area is founded upon East Coast Bays Formation residual soils overlying sandstones and siltstones. Stability issues within the coastal setting are variable and require a consistent and rigorous engineering geological assessment of each site in order to address any potential causes of instability. Although addressing the symptoms of failure is often the driver for engagement, as geotechnical practitioners and stability contractors the underlying cause of slope stability issues along the cliff line cannot be ignored, to ensure the long term stability of the slope.

As coastal environments are highly dynamic and the probability of similar failures occurring within the neighbouring properties is high. Soil-nailed remediation measures are limited to providing support to the residual soil and are constrained by geometry to provide support perpendicular to the cliff, therefore the designer and contractor must be explicit with the design limitations, as these measures are not intended to prevent global cliff failure or lateral regression behind the soil nails from adjacent failures.

6 ACKNOWLEDGEMENTS

The author would like to thank Glyn East, Aaron George and Harry Follas of WSP Opus for their assistance in the preparation of this paper. In addition to, Tim Allen of Earth Stability Ltd for permission to base this paper on recent projects.

7 REFERENCES

Edbrooke, S. W. (2001). Geology of the Auckland Area: Scale 1: 250 000. Institute of Geological & Nuclear Sciences.

Moon, V. G., & Healy, T. (1994). Mechanisms of coastal cliff retreat and hazard zone delineation in soft flysch deposits. Journal of Coastal Research, 663-680.