Use of the variable energy DCP Panda for landslide risk assessment and slope analysis

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ABSTRACT

Landslides are a significant hazard to infrastructure, public safety, and environmental stability, particularly in regions affected by intense rainfall, steep terrain, and weak or saturated soils. Rapid in-situ assessment of near-surface conditions is essential for effective risk evaluation and emergency response. This paper explores the application of the Variable Energy Dynamic Penetrometer (VEDP) / Panda probe as a versatile, portable, and efficient in-situ testing tool for use across the landslide risk lifecycle — from preliminary risk screening and emergency triage to detailed geotechnical assessment, repair design and construction support.

The Panda VEDP is a lightweight, portable, and fully instrumented tool capable of providing continuous strength versus stiffness profiles in difficult-to-access environments. The variable-energy driving principle, automated measurement of impact energy and penetration, and real-time digital acquisition enable high-resolution characterisation of soil behaviour. Correlations between Panda VEDP measurements and key geotechnical parameters, such as undrained shear strength, relative density, friction angle, and void ratio, highlight the method's relevance for slope stability assessment. Case studies demonstrate its effectiveness through-out the landslide risk lifecycle. The Panda VEDP offers a fast, robust, and cost-effective complement to conventional site investigation and compaction control methods.

Keywords: landslide, slope stability risk assessment, design, disaster recovery, infrastructure, Variable Energy Dynamic Penetrometer (VEDP)

1 INTRODUCTION

Landslides are among the most widespread natural hazards globally, often triggered by rainfall, earthquakes, or anthropogenic disturbance. In the Pacific, Australian, and New Zealand contexts, intense precipitation events, cyclones, and long-duration wet seasons regularly lead to slope failures that threaten roads, railways, pipelines, and utilities. The ability to rapidly characterise near-surface ground conditions prior to and following such events is fundamental to assessing residual risk, prioritising interventions, and planning safe access for emergency and reconstruction teams.

Traditional geotechnical investigation methods - such as boreholes, standard penetration tests (SPT), or laboratory triaxial tests - are invaluable but often impractical immediately after a landslide. Access constraints, equipment weight, cost, and the time required to mobilise drilling rigs can delay data acquisition by days or weeks. Lightweight in-situ tools such as the Panda VEDP bridge this gap by enabling continuous strength–stiffness profiling within hours of failure, even on unstable or remote terrain.

This paper presents the principles, methodology, and field application of the Panda VEDP system across the landslide risk management cycle—from reconnaissance and triage to design verification and long-term monitoring. The objective is to demonstrate how this modern DCP approach complements, rather than replaces, traditional testing to deliver rapid, quantitative insight into slope behaviour.

2 LANDSLIDE RISK AND GEOTECHNICAL INVESTIGATION

2.1 Landslide Processes and Investigation Needs

Landslides typically involve complex interactions between geological structure, hydrology, and mechanical soil behaviour. Weak layers, perched water tables, or abrupt changes in material stiffness can all influence slope performance. Key parameters for assessment include shear strength, stiffness (or small-strain modulus), and spatial variability.

During emergency or reconnaissance phases, practitioners need tools that can:

- Identify weak or softened horizons related to shear surfaces;
- Quantify relative stiffness variation along a slope;
- Provide data rapidly enough to inform access, stabilisation, or reinstatement decisions.

2.2 Limitations of Conventional Methods

Common in-situ tests such as SPT, CPT, or vane shear tests provide valuable data. These are difficult to mobilise in landslide terrain or during emergency response. Even portable hand augers or shear vanes are limited to shallow depth and provide discrete, not continuous, results.

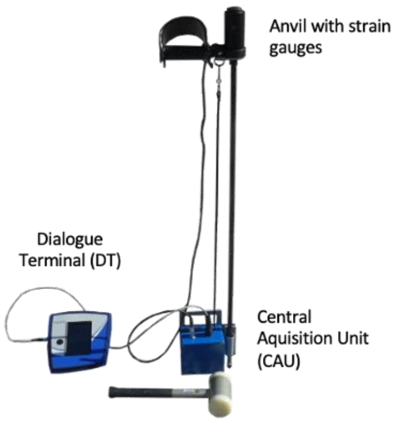
Laboratory testing requires sampling, transport, and curing - steps that can take days and alter in-situ conditions. Consequently, there is a need for rapid, continuous, and low-disturbance in-situ methods to characterise strength and stiffness profiles.

3 THE PANDA VARIABLE-ENERGY DYNAMIC PENETROMETER (VEDP)

3.1 System Overview

The PANDA VEDP is a modular, hand-operated dynamic cone penetration device developed in France (1989) and used worldwide for rapid assessment of soil strength and stiffness to a depth of a few metres (typically 2m to 6 m depth, depending on material composition and strength). It consists of:

- A drive rod with interchangeable cones (2cm^2, 4cm^2 or 10cm^2);
- An anvil with strain gauges built in that measures the energy applied for every applied blow;
- An electronic data acquisition unit that records impact energy per blow, depth of penetration per blow and displays data in graphical and numeric format;
- Integrated GPS connectivity for test location



Cone resistance Qd is calculated using the Dutch Formula as follows:

$$q_d = \frac{1}{A} \times \frac{E}{e} \times \frac{1}{1+\frac{P}{M}}$$

A = the cone area (2, 4 or 10cm²)

E = the variable energy given to the system each blow

e = the depth measured each blow

P = the weight of the driven system into the soil (anvil + rods + cone)

M = the weight of the hammer (manual, automatic, hammering column)

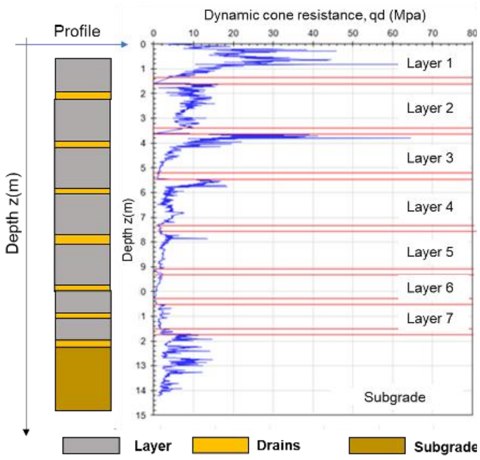


Figure 1a - Panda VEDP Components

Figure 1b - General measurement principle of the Panda

Figure 1c - Penetrogram curve log of qd as a function of depth (z) obtained during a characterization test

A defining feature of the Panda VEDP is its variable impact energy, enabling adjustment to suit the cone resistance encountered and target depth. Lower energies improve resolution within soft, sensitive, or saturated soils typical of landslide failure planes or mobilised soil materials, while higher energies allow penetration into denser layers or residual weathered rock. The flexibility of the energy applied during each impact minimises the risk of excessive disturbance and allows continuous testing through contrasting strata.

Because the Panda probe does not rely on gravity to undertake the test, it means that tests can be carried out anywhere from vertical to horizontal, making it ideal for landslide work where you are often looking to test at right angles to the slope.

The fundamental aim of any Dynamic Cone Penetrometer is to measure resistance at the cone tip, not along the rod. If the rod and cone had the same diameter, friction along the rod ("shaft friction") would contribute significantly to the measured resistance, making results inconsistent and depth-dependent.

Figure 2 - Sacrificial Cone

To minimise shaft friction and isolate tip resistance, especially in weak soils, the Panda utilises cones of a diameter significantly larger than the trailing rod stem. The soil displaced by the cone leaves a slightly over-sized cavity, which results in :

1. The rod travelling in a "relieved" zone behind the cone, with minimal contact friction, and
2. The measured energy loss per blow is dominated by tip resistance to the cone, rather than side friction.

This arrangement improves the accuracy and consistency of qd (dynamic cone resistance). The level of friction on the rod string can also be assessed when each rod is added using a torque wrench. Be adjusting for skin friction, a corrected Qd value can then be reported.

The Panda VEDP technology is primarily employed for shallow-depth soil investigations and compaction control in earthworks such as road embankments, dikes, and earth dams. It is widely used to assess the bearing capacity of disturbed grounds or engineered fills, as well as to evaluate the liquefaction potential of earth dams and tailings dams. The device is also well suited for slope characterization, providing valuable input parameters for stability assessments. A less common application concerns the characterization of snow thickness in the Alps (Switzerland and France) for avalanche prevention.

3.2 Data Processing, Analysis and Integration in Digital Workflows

The recorded data make it possible to generate penetrograms with exceptionally high spatial resolution, as illustrated in Figure . Controlled trials indicate that the coefficient of variation (CoV) for repeated Panda VEDP tests typically ranges between 10 % and 30 % ((Sastre Jurado et al., 2021). Consequently, repeat testing at a single location can provide meaningful confidence bounds for the interpreted geotechnical parameters.

As described by (Benz et al., 2024), signal processing is required on the raw penetrometer data in order to filter noise and improve the overall quality of the measurements. Standard procedures typically include clipping (removal of outliers), followed by smoothing and regularization to obtain a consistent and interpretable signal. All these processing steps can be performed rapidly using the Websprint interpretation software provided with the device.

Seamless data transfer enables direct integration into geodata management platforms, supporting real-time visualization, 3D subsurface modelling, and multidisciplinary slope-risk dashboards. Combining Panda VEDP datasets with UAV photogrammetry and piezometric monitoring enhances situational awareness and accelerates reporting, representing a significant step toward data-driven and resilient infrastructure management.

3.3 Applications Across the Landslide Risk Lifecycle

Phase	Objective	Panda VEDP Contribution
Screening & Mapping	Identify potentially unstable zones in broad reconnaissance	Rapid profiling of near-surface stiffness variability
Emergency Response	Determine safe access, assess residual strength	Triage - quick tests guiding road closures or machinery movement
Design Investigation	Characterise soil parameters for modelling	Quantitative E and c inputs for limit-equilibrium or FEM
Construction Support	Verify compaction or drainage efficiency	Compare pre- and post-works Qd profiles
Long-Term Monitoring	Assess progressive changes or softening	Repeat testing for trend analysis

3.4 Advantages for Landslide and Slope Stability Applications

The Panda VEDP offers several practical benefits that make it unusually well suited to landslide investigations, especially in terrain where transporting heavier equipment is impractical or unsafe. Advantages include:

- Lightweight (≈20 kg total) - transportable by foot or rope descent.
- Safe deployment - no reaction frame or high-energy drop weight.
- Continuous profiling - detects subtle stiffness variations indicative of slip planes.
- Material variability - ability to perform highly detailed layer-by-layer exploration over a wide range of soil resistances - from very soft to very dense materials (by controlling the hammering energy and adjusting the hammering intensity).
- Testing at angles - tests can be carried out anywhere from vertical to horizontal, making it ideal for landslide work where you are often looking to test at right angles to the slope.
- Real-time data - supports rapid decision-making during emergency or routine investigations.

- Correlation capability - links with undrained shear strength, void ratio, friction angle, and bulk or relative density for stability analysis.

3.5 Practical Correlations for Landslide Applications and Slope Stability

Terzaghi (1950) postulated that the overall stability of a slope depends on the balance between driving forces and resisting forces, the latter being controlled primarily by the shear strength of the soil. Shear resistance is commonly described through the Mohr–Coulomb parameters (cohesion *c* and internal friction angle *φ*) which together define the soil's ability to withstand shear stresses along potential failure surfaces. Numerous authors have confirmed the central role of these parameters in slope stability assessment (e.g., Skempton 1964; Duncan & Wright 2005; Abramson et al. 2002). Because shear strength depends not only on *c* and *φ* but also on the in-situ density or relative density (especially in granular soils), reliable field measurements are essential. For this reason, in-situ tools such as the Panda VEDP are particularly valuable: they allow indirect yet robust estimation of key geotechnical parameters including friction angle, cohesion, and bulk or relative density. These measurements, when interpreted through appropriate empirical or analytical correlations, provide critical input for stability analyses and enable more accurate identification of weak layers, potential slip surfaces, and overall slope behaviour.

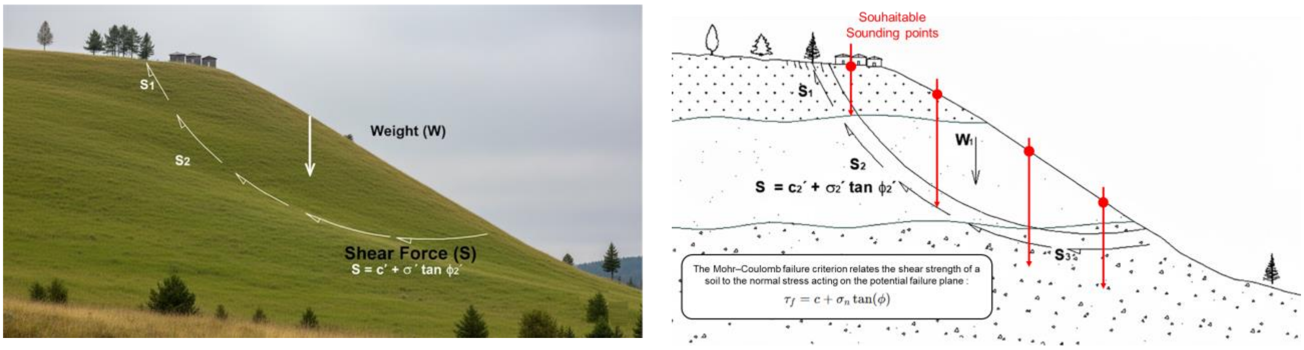


Figure 3a (left) – General Schema, Figure 3b (right)– Cross Sectional Schema for main principle of slope stability - The resistance to sliding and the overall stability of a slope are primarily governed by the Mohr–Coulomb failure criterion, which depends on soil cohesion, the vertical stress (and therefore the soil density), and the friction angle. These parameters can be expressed in terms of either effective or total stresses (elaborated with AI Gemini).

Several studies have sought to establish correlations between Panda dynamic cone penetrometer measurements and the shear strength parameters that govern slope stability. In particular, research has focused on relating cone penetration resistance to undrained cohesion in fine-grained soils, as well as to the friction angle in granular soils. For sands and other cohesionless soils, Panda VEDP are widely used to assess state parameters such as relative density (DR), dry density, or void index, as well as mechanical parameters including the friction angle. Villavicencio et al. (2016, 2021, 2022) proposed, for silty sands, an empirical model obtained through simple regression using pairs of experimental data *(qd_1, DR) cf.* (Benz et al., 2024).

$$DR = 28.5 \ln(qd_1) - 65.4 \quad ; \quad 20 \leq qd_1 \leq 326 \qquad (1)$$

In his works, concerning the landslide and slope analysis, Athapaththu et al. (2015) and Tsuchida et al. (2011) proposed a relationship linking void index (e), degree of saturation (Sr), and cone resistance qd5, where qd5 represents the cone resistance normalized to an overburden pressure of 5 kPa and is calculated as

$$e = 1.19 - 0.084 \ln(qd_5) - 0.007\, S_r \qquad (2)$$

Concerning the evaluation of the friction angle ϕ′, (Villavicencio et al., 2011) proposes the expression :

$$\emptyset' = 14.79 + 5.54\ln(qd_1) \quad ; \quad 10 \leq qd_1 \leq 280 \qquad (3)$$

(Athapaththu et al., 2015; Tsuchida et al., 2011) proposes a relationship between friction angle *φ′*, apparent cohesion (c_d in kPa), cone resistance *qd* and degree of saturation (*Sr*) of the Masado soils (equation 5)

$$\emptyset' = 29.9 + 1.61\ln(qd_5) + 0.142S_r$$
$$c_d = 10.6 + 1.19\ln(qd_5) + 0.041S_r \qquad (4)$$

Moreover, for fine cohesive soils, such as clays and silts, the most important parameter in the field is undrained shear strength, notes s_u. Dynamic penetration tests have long been used to estimate the value of s_u. There is a very good relationship between *qd* and s_u.

$$s_u = \frac{qd - \sigma_{vo}}{N_{kt}} \qquad (5)$$

With σ_{vo} the vertical effective stress and N_{kt} the cone factor, which depends on the plasticity of the soil. For Panda VEDP data, the undrained shear strength *su* is often approximated using the simplified range s_u = qd / (15 to 20). A more precise estimation of N_{kt} can be obtained from the soil's plasticity index (IP) using the empirical relationship: $N_{kt} \approx 0.285*IP + 7.64$.

Finally, one of the most useful correlations established for the Panda VEDP concerns its relationship with Cone Penetration Test (CPT) measurements, particularly the cone tip resistance *qc* (Benz Navarrete et al., 2021; Oliveira et al., 2024). Several studies have demonstrated that the dynamic cone resistance *qd*, once corrected for friction along the rods and for hydrostatic effects below the water table, exhibits a strong and consistent correlation with CPT tip resistance (*qc* or *qt*). The ability to relate Panda *qd* values to CPT-based interpretations significantly enhances the reliability of Panda-derived geotechnical parameters and allows the method to be integrated into classical CPT-based frameworks for evaluating shear strength, state parameters, and stratigraphic variability.

$$qc = 1.06qd - 0.21$$
$$0.87 \leq \frac{qc}{qd} \leq 1.11 \qquad (6)$$

Benz Navarrete et al. 2024 provides a summary of useful correlations for interpreting the dynamic cone resistance (qd) measured with the Panda VEDP.

4 CASE STUDIES

4.1 Stability Assessment of Natural Slopes at Risk of Failure - Japan

Slope failures induced by rainfall on weathered granite are common worldwide, and are particularly severe in Japan, where many slopes are susceptible to failure. In this context and based on geotechnical investigations, including Panda VEDP testing and analysis, (Athapaththu et al., 2007, 2015, 2016; Hanaoka et al., 2011; Tsuchida et al., 2011, 2014, 2015) proposes a series of applications for individual landslide hazard assessment of natural valleys and slopes. The authors present a new geotechnical method for natural slope investigation and analysis. These studies and analyses rely not only on direct measurements of the dynamic cone resistance (q_e) but also on established correlations with the internal friction angle, apparent cohesion, and void ratio. Another significant and interesting result is that their analyses include evaluation of the penetrometer response patterns, which are used to define characteristic "patterns" necessary for detailed slope assessment.

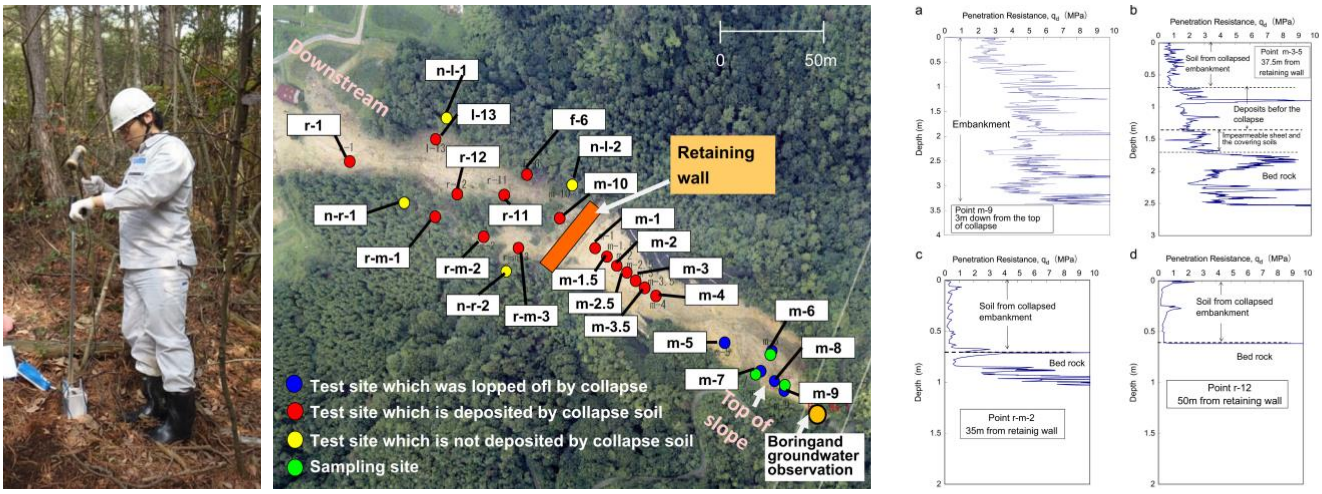


Figure 4a (left) – operator performing a VEDP test, Figure 4b (middle) – Plan to testing locations, Figure 4c (right) – Example VEDP profiles: Stability Assessment of Natural Slopes at Risk of Failure assessment by means of geotechnical test and its analysis (Athapaththu et al., 2007, 2015, 2016; Hanaoka et al., 2011; Tsuchida et al., 2011, 2015)

The works conducted by Tsuchida et al. and Athapathu et al. currently represent one of the most widely cited references regarding the use of the Panda VEDP for the characterization of landslides and natural slopes. They have applied this method and testing technique for more than ten years, relying on the models and correlations they themselves developed, which now serve as a basis of inspiration for similar studies worldwide.

4.2 Site Characterisation and Mapping of Extents of Landslide Footprint – Australia

A portion of Naughton's Gap Road, which is a critical road link between the regional NSW centres of Casino and Lismore, was closed to traffic after it experienced a significant slope instability event due to an extreme rainfall event in March 2021 and regional flooding event in 2022. The onsite conditions encountered in December 2023 included the presence of multiple, discrete landslides that encroached either partially or fully across the road footprint over a 400 m longitudinal section, resulting in slope instability occurring both above and below the road's trafficable surface. However, the exact extent of each landslide feature, and depth of the slip plane, remained unclear and was required to be appropriately characterised to enable the remedial design of the site to proceed.

The Panda VEDP was utilised as a component of the site investigation completed at the site due to its comparatively high resolution and flexibility of the equipment – that the equipment could be used to access locations of the slope beyond the road reserve, including areas of recently mobilised materials, without the need of installing access tracks and the test, and the impact load of the test could be tailored onsite (and progressively during the completion of the test) to identify and characterise any comparatively weaker / thin plane (that was anticipated may be present between colluvial and residual soils).

Geotechnical engineers completed 13 Panda VEDP profiles over a 2 day period, with each Panda VEDP extended up to 4.2 m depth. From the qd profiles recovered from the onsite testing, the following was able to be achieved:

1. Clear identification of material unit change – interpreted to represent a profile of colluvial soil overlying residual soil and rock material.

2. Characterisation of strength parameters associated with each material unit / test location, and the typical strength range / variability associated with each material unit.

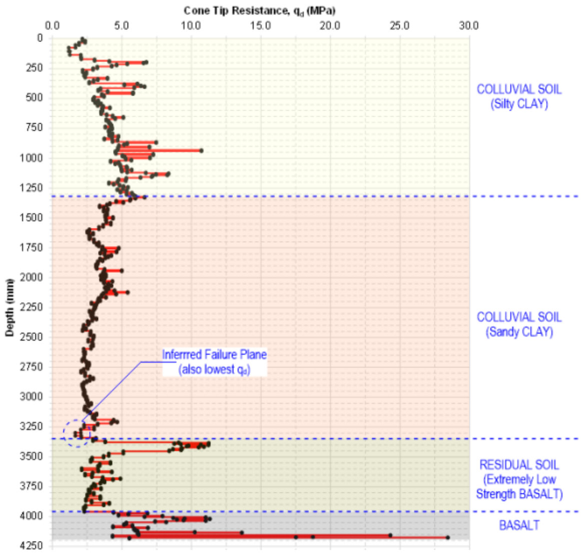


Figure 5 - Annotated Panda DCPT profile as interpreted for Naughton's Gap Road site

Figure presents an annotated PANDA VEDP profile for the site, showing the obvious changes in qd parameter between (and variation within) each material unit, as well as the comparative lower qd value associated with the inferred slip plane at the interface between colluvium and residual soil materials.

Via compilation of the Panda VEDP test profiles and comparison to surface geological mapping of the site, a realistic geological model of the site was developed and the identification of the varying depth of the colluvial materials and depth of the slip plane (at base of the colluvial materials) was characterised across the site. Estimates of insitu shear strength were also achieved using the relationship between Panda DCPT and CPT as detailed in Benz Navarrete et al. (2021) Both the geological and material strength parameter interpretations derived from the Panda DCPT profiling were subsequently verified for the site during additional site investigations and during the construction phase of the project.

4.3 Design Inputs for Landslide Detailed Remedial Designs - UK

This case study relates to a landslide that occurred near Cardiff, Wales. Prior to commissioning a slope-stabilisation study, the slopes in question had experienced small to medium landslides over several decades. The event that triggered a more formal response was a large failure that exposed an approximately 30m wide section of the underlying slope, creating a significant risk to site users at the base—namely car-parking areas and boat-servicing yards.

Remediation was deemed necessary to prevent damage to vessels stored in the yard and to mitigate the risk of injury or fatalities to site users.

Figure 6 – Section of visible rock beneath recent mantle failure

Figure 7a (left) - Visible mantle profile on crest, Figure 7b (right) - Visible mantle profile on slope

At the outset, it was initially thought that the mechanism involved a traditional rock or wedge failure triggered following periods of significant rainfall.

However, it was quickly established that the failure was confined to a “mantle” of residual soil and weathered rock that draped the slope face and was partially stabilised by vegetation. This mantle extended from the crest across the entire slope face, meaning further failures could occur across the remaining slope where this material was present.

The proposed investigation comprised drilling boreholes behind the crest, undertaking structural mapping of the newly exposed rock face, and completing four to five evenly spaced transects down the slope to determine mantle thickness, profile, and material classification.

The Panda VEDP, being extremely portable, lightweight, and capable of operating on steep inclines or horizontally - was ideally suited to determining the approximate mantle thickness. Conventional techniques such as borehole drilling or traditional dynamic cone penetrometers would have been either disproportionately expensive or impractical on near-vertical slopes.

Rope-access technicians and geotechnical engineers collected data at three points along each transect, including material classification samples and Panda VEDP testing. This enabled the mantle thickness and profile to be mapped, and design parameters to be assigned based on probing and laboratory test results. These data sets ultimately supported the development of detailed remedial designs that were both technically appropriate and cost-effective.

The Panda results for Figure 8 (locations A, B, and C) show the variation in penetration resistance down the slope. Location A, positioned near the crest, records approximately 1.0–1.5 m of comparatively weaker material before the probe encounters a marked increase in resistance, interpreted as refusal on weathered to fresh rock. A similar profile is observed at Locations B and C, although the thickness of the weaker mantle reduces progressively downslope. This indicates that the surficial mantle thins toward the base of the slope, with rockhead becoming shallower along the transect. The consistent refusal depth across the three positions supports the interpretation of a well-defined underlying rock mass with a variable but generally diminishing overlying mantle thickness.

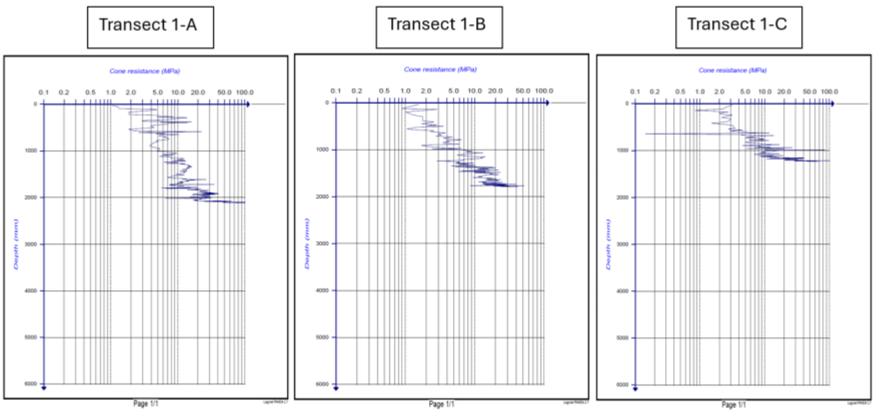


Figure 8a (left) - Location 1-A, - Figure 8b (middle) - Location 1-B, Figure 8c (right) - Location 1-C: Transect 1 - Panda Probe Profiles

The Panda results for Figure 9 (locations A, B, and C) show a distinct change in subsurface conditions down the slope. At Location A, the probe records alternating zones of low to moderate resistance before refusing at depth, indicating a mantle of fractured or blocky material overlying more

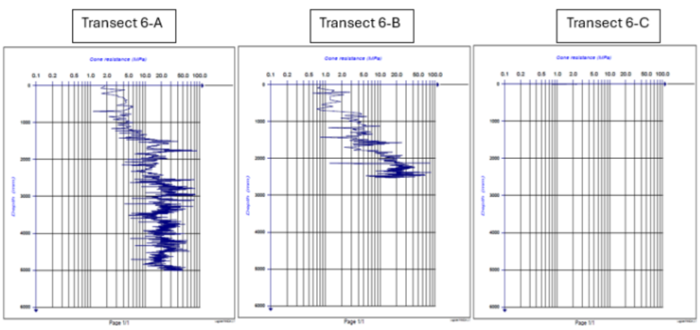


Figure 9a (left) - Location 6-A, - Figure 9b (middle) - Location 6-B, Figure 9c (right) - Location 6-C: Transect 6 - Panda Probe competent rock. This mantle reduces in thickness at Location B, where a clearer transition to competent material is observed at a shallower depth.

At Location C, situated near the base of the slope, the probe refuses at a shallower depth, confirming that rock is present close to the ground surface in this area. The results across the transect demonstrate a consistent geomorphological trend, with the weathered mantle thinning downslope and the rockhead rising towards the toe.

Collectively, the data shows how Panda data can define the geometry of the weathered mantle and rockhead with high resolution along a slope profile. This level of detail enables rapid identification of zones of loosened or disturbed material, supports targeted remediation such as rock-bolted mesh. This demonstrates the effectiveness of the Panda system as a lightweight, repeatable, and highly responsive tool for characterising shallow ground conditions on complex slopes.

Without the ability to deploy the Panda VEDP, the investigation costs would likely have been an order of magnitude higher than the local authority had forecast—potentially rendering the project unfeasible. The probe therefore proved to be an ideal solution for mapping mantle thickness and deriving in-situ parameters required for the remedial design.

4.4 Tailing Storage Facility - Slope Compaction and Soil Variability Characterisation - Chile

One of the major risks in Tailings Storage Facilities (TSF's) is liquefaction and slope instability. Most of these structures are built using embankments and earthworks with varying fills. Regardless of the construction method, it is essential to ensure overall slope stability and proper compaction of the embankments to prevent landslides. In this context, the Panda VEDP is widely used in Chile and other parts of the world, not only for compaction control but also for soil characterization, particularly in slopes. In their 2022 study, (Villavicencio et al., 2022) address the challenge of monitoring and controlling compaction in classified sand tailings dams.

This study highlights the critical importance of spatially distributed compaction monitoring in classified sand tailings dams. By combining the lightweight Panda penetrometer with geostatistical mapping, Villavicencio et al. demonstrated that conventional point-based methods may fail to capture significant variability in compaction and density across the embankment. Their approach enables the identification of both under-compacted and over-compacted zones, improving safety assessment and optimizing resource use.

Overall, this work provides a practical, cost-effective, and reliable framework for quality control in tailings dam construction, offering clear insights for both engineering practice and further research on dam stability and compaction efficiency. An example of the obtained results is presented in Figure 10b.

Figure 10a - Slope compaction control

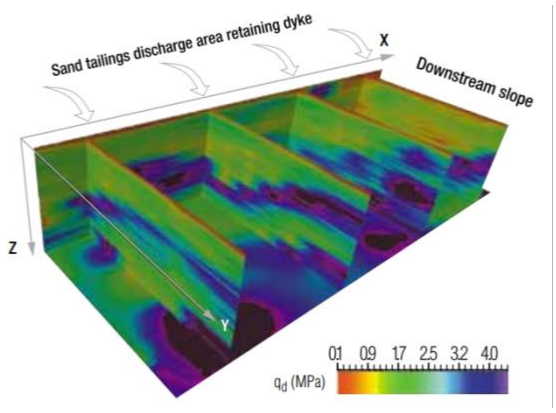


Figure 10b - Soil variability characterisation (cf. Villavicencio et al. 2022)

Furthermore , Benz et al. (2024) present a similar application for compaction control of the slopes in a tailings storage facility in Canada. The primary objective of their study was to assess the compaction state of the slopes in an existing facility, with the aim of optimizing and improving its construction processes. An example of the results is shown in Figure 11.

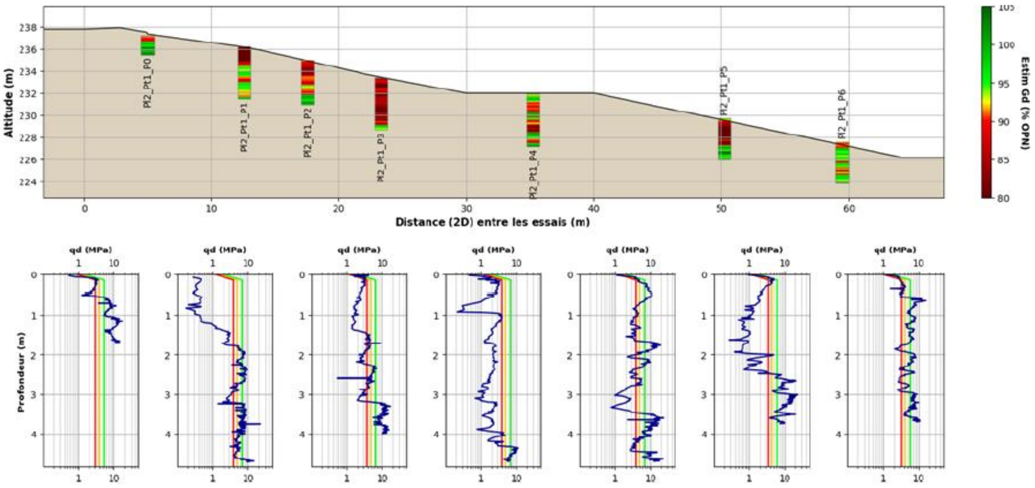
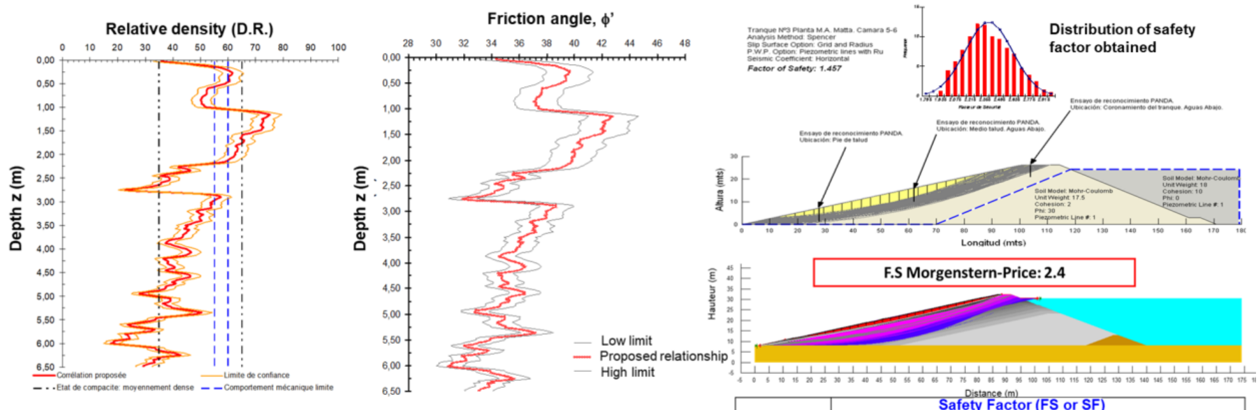


Figure 11 – Tailing storage Facilities Slope compaction control through Panda test (cf. Benz et al. 2024)

Villavicencio et al. developed specific methodologies for assessing the liquefaction risk of these structures, as well as methods for evaluating the overall stability of TSF slopes using Panda VEDP measurements and established correlations between the dynamic cone resistance *qd* and the relative density and internal friction angle of the stored sandy silts. Their procedure incorporates the concepts of variability and probability, enabled by the large amount of data provided by the Panda VEDP. Furthermore, to accurately evaluate the most probable failure surface, the authors propose conducting Panda VEDP tests at multiple locations along the slope (namely at the crest, mid-height, and toe) as illustrated in Figure 12.



$DR = 28{,}5\ln(qd_{N1}) - 65{,}4\ ; 20 \le qd_{N1} \le 326$ $\phi' = 14{,}79 + 5{,}54\ln(qd_{N1})\ ; 20 \le qd_{N1} \le 280$

Condition	Safety Factor (FS or SF) Values Min. y Max	Median	C.V (%)	Failure probability
static	1,95 et 3,02	2,4	9,5 %	$<10^{-6}$

Figure 12a (left) – Relative Density Plot, Figure 12b (middle) – Friction Angle Plot, Figure 12c (right) – Slope Stability Model: Slope stability analysis of tailings storage facilities conducted using state and strength parameters derived from Panda VEDP measurements (cf. Villavicencio et al. 2018; 2021; 2022)

5 CONCLUSIONS

The Panda Variable Energy DCP has proven to be a practical and reliable in-situ tool throughout the landslide risk lifecycle:

- Rapid Reconnaissance: Provides immediate strength–stiffness profiles to delineate weak layers.
- Emergency Response: Supports safe access and prioritisation decisions within hours of failure.
- Design and Remediation: Supplies quantitative inputs for modelling and verifies improvement works.
- Monitoring: Tracks stiffness change over time, complementing displacement or pore-pressure sensors.

Its portability, repeatability, and integration potential make it ideally suited to modern slope-risk frameworks in Australia, New Zealand, and the wider Pacific region. By embedding Panda VEDP testing into standard landslide workflows, practitioners can reduce uncertainty, enhance safety, and accelerate recovery—contributing to the development of smarter, more resilient ground-engineering practices.

6 CONFLICT OF INTEREST

Robin Power / Insitutek support the Panda VEDP in the Pacific region. Miguel Benz-Navarrete / Sol Solution research, develop and manufacture the PANDA VEDP.

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