From Ground to Air: Advancing Rock Slope Characterization with TLS and ULS

Case Study of the PR-52 Rockslide, Salinas, Puerto Rico

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Agenda

- Introduction
- Objectives
- LiDAR Basics
- Methodology
- Case Study – PR-52 Rockslide, Puerto Rico
- TLS vs ULS Comparison
- Conclusions
- Recommendations for Future Work

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Introduction

- Traditional methods for measuring rock discontinuity orientations are effective for small areas but inefficient and unsafe for large or inaccessible slopes.
- LiDAR technology enables rapid acquisition of millions of 3D points, creating detailed slope models.
- In this study, Terrestrial Laser Scanning (TLS) is used as the benchmark and compared with Unmanned Laser Scanning (ULS) mounted on drones.
- Combining TLS and ULS provides both high-precision detail and rapid wide-area coverage for geotechnical engineering applications.

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Objectives

- Acquire high-resolution TLS data along the rockslide.
- Capture ULS data to complement TLS in inaccessible areas.
- Combine TLS/ULS data into a seamless 3D dataset.
- Compare the discontinuity orientation measured with TLS and ULS

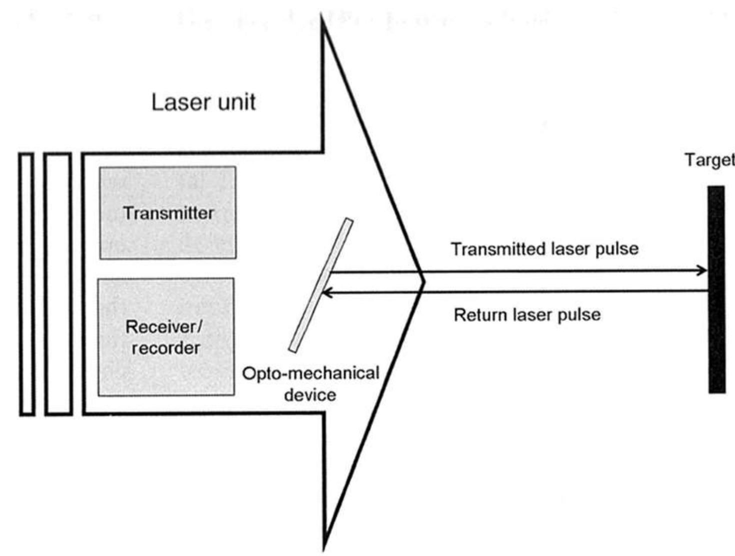
LiDAR Background

- Laser – "Light Amplification by the Stimulated Emission of Radiation".
  - First built in 1960 by Theodore H. Maiman.
- LiDAR – "Light Detection and Ranging"
  - Developed shortly after the laser as a surveying tool.
- TLS (Terrestrial Laser Scanning): Ground-based LiDAR, tripod-mounted
- ULS (Unmanned Laser Scanning): LiDAR integrated with drones (UAS)

LiDAR Background (cont.)

LiDAR components

- Transmitter – generates laser pulses
- Optomechanical system – directs and scans the beam
- Receiver/Recorder – detects returns and records data
- Together, these components produce a 3D point cloud of the surface



Basic components of a TLS instrument (Heritage and Large, 2009).

LiDAR Background (cont.)

How LiDAR Creates a Point Cloud

- A laser pulse is transmitted toward a target surface
- Energy is reflected to the receiver
- Process repeats millions of times per second
- Result: a dense 3D point cloud resembling a detailed image

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LiDAR Background (cont.)

From Points to 3D Space

- Each laser return is stored as X, Y, Z coordinates relative to the scanner.
- Points also include reflectivity (intensity) information
- By tying scans to field control points, local data can be transformed into a geographic coordinate system
- Result: every point can be accurately located in real 3D space

LiDAR Background (cont.)

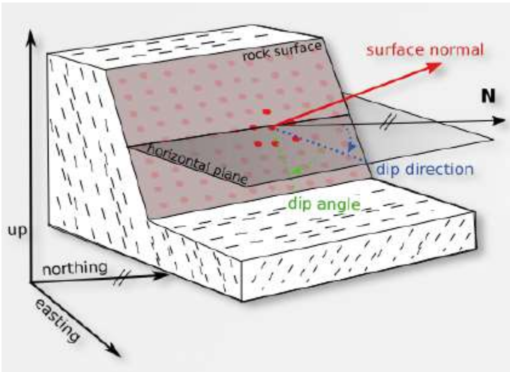
LiDAR Data Processing

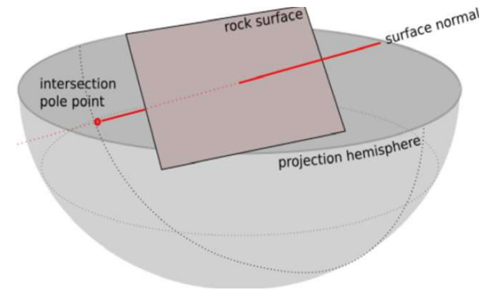
- Field scans produce a raw point cloud
- Data must be processed to extract measurements
- Software used in this study:
  - Riegl RiScan Pro and RiProcess
  - Trimble UAV PosPac
  - LIS GeoTec Plugin – dip/dip direction, pole plots

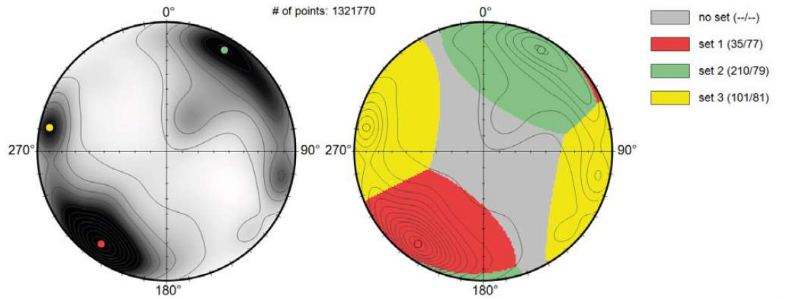
LiDAR Background (cont.)

Geotechnical Outputs

- Surface Normals – orientation of slope faces
- Dip & Dip Direction – discontinuity measurements
- Density Plots – identify clusters and dominant sets

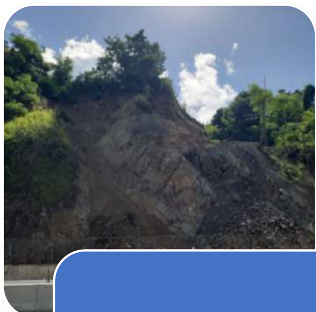




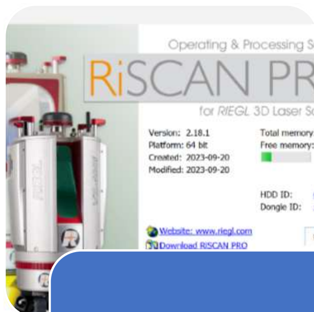


From Riegl (2025)

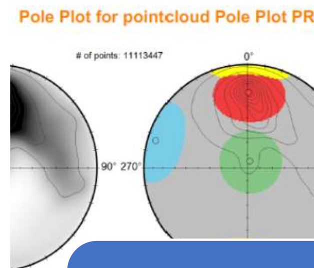
Methodology



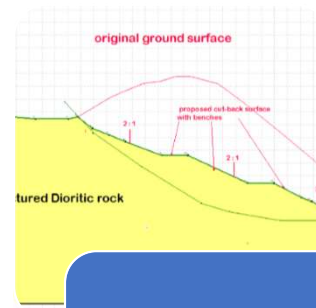
Field Data



Data Processing



Discontinuity Orientation



Mitigation

Methodology (cont.)

TLS Riegl VZ-2000i

- Pulse rate: up to 1.2 MHz
- Data capture: 500,000 measurements/sec
- Field of view: 100° vertical × 360° horizontal
- Range: up to 2,500 m with 5 mm accuracy
- Integrated GNSS RTK for positioning

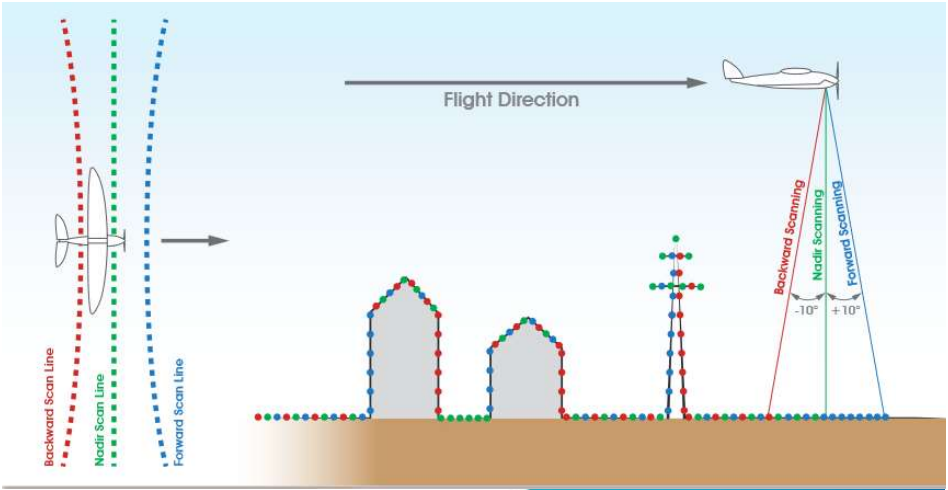
From Riegl (2025)

Methodology (cont.)

Riegl VUX-120 (Drone-mounted)

- Pulse rate: up to 2.4 MHz
- Measurement rate: 2,000,000 points/sec
- Scan speed: 400 lines/sec
- Flight altitude: up to 720 m (2,350 ft)
- Field of view: 100°
- Weight: 2.3 kg
- Nadir, forward, and backward scanning capability

From Riegl (2025)



Methodology (cont.)

Drone Platform - Harris Aerial Carrier H6 Electric

- Max payload: 17.6 lbs (8 kg)
- Wheelbase: 5.3 ft
- Propeller size: 29 in
- Empty weight: 21.5 lbs (9.8 kg)
- Max take-off weight: 55 lbs (25 kg)
- Max flight time: 48 minutes

From Harris Aerial (2025)

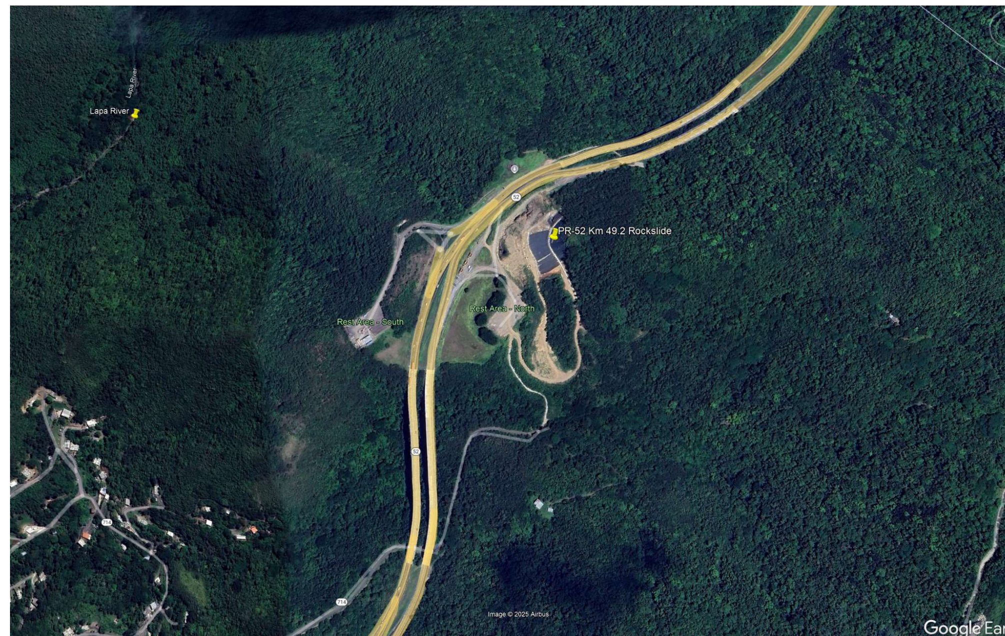
Case Study – PR-52 Rockslide

- Date: November 5, 2022 (following Hurricane Nicole, which reached Puerto Rico as a tropical storm)
- Event: Rockslide blocked the main north-south highway of the Island
- Location: PR-52, Km 49.2, Municipality of Salinas

From Montalvo (2022)

Case Study (cont.)

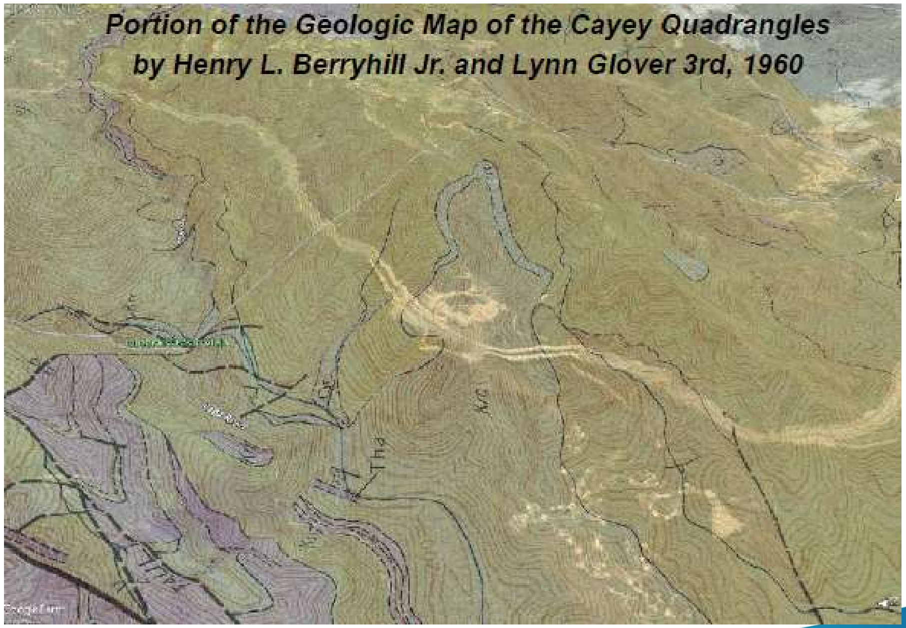
Rockslide Location



Case Study (cont.)

Geology of the Rockslide Site

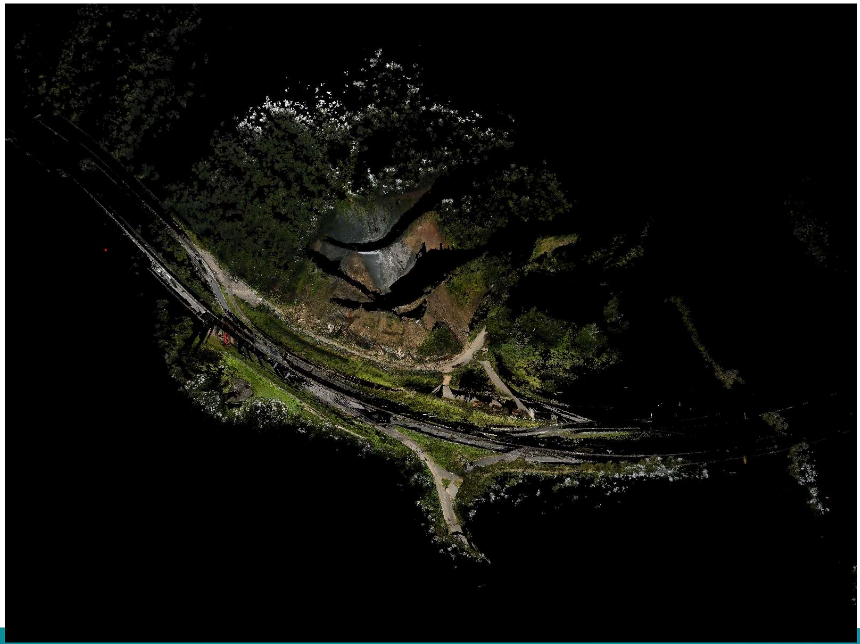
- Slope orientation: NW-facing, above the Lapa River
- Geologic unit: Cayey Siltstone Member, Cretaceous Robles Formation
- Lithology: Predominantly siltstone with interbedded sandstone
- Engineering relevance: Bedding planes and lithology strongly influence slope instability during heavy rainfall events



From Joyce, 2025

Case Study (cont.)

TLS Point Cloud – 24 Scan Positions full day of data collection



ULS Point Cloud – 15-minute north-south/east-west grid

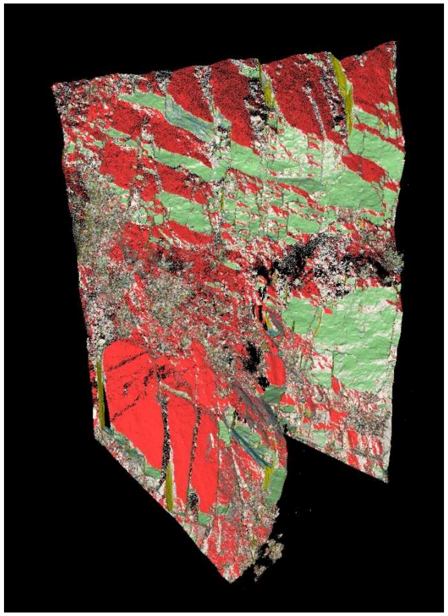
Case Study (cont.)

TLS Point Cloud showing the Area of Interest (AOI)

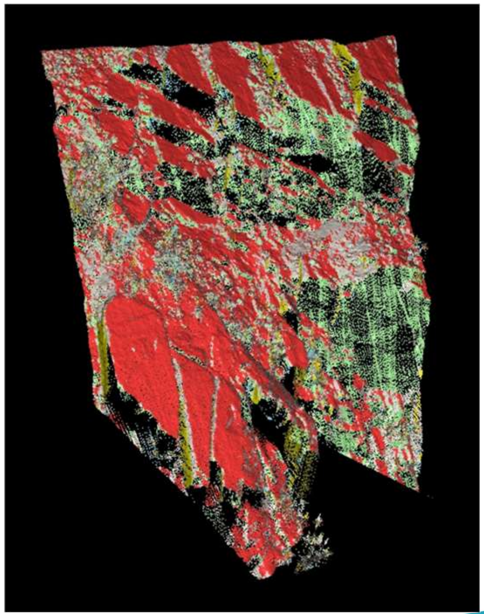
Picture showing the Area of Interest (AOI)

Case Study (cont.)

TLS Data – Discontinuities highlighted in color (note shadows on horizontal surfaces)



ULS Data – Discontinuities highlighted in color (dense horizontal coverage; limited vertical detail

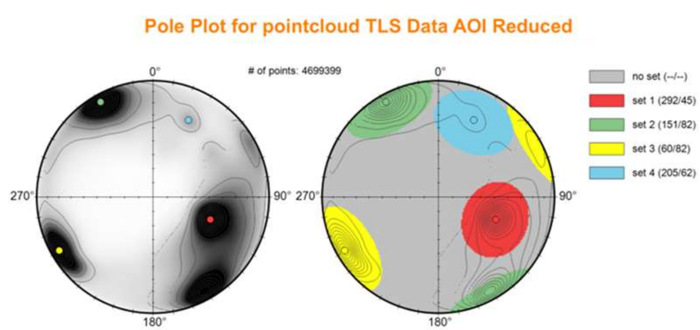


Case Study (cont.)

Pole Plot Comparison

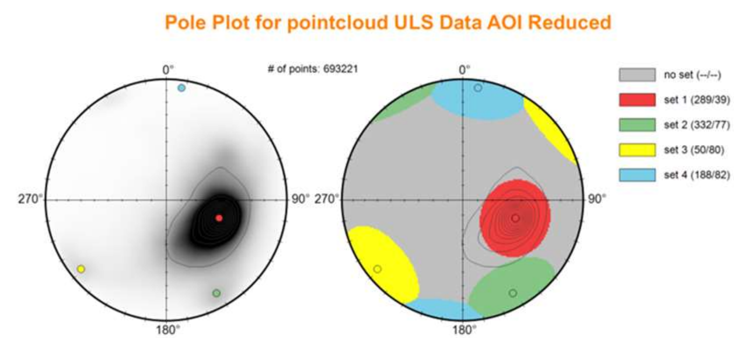
TLS Pole Plot

- Data Density: ~4.7 million points, very detailed dataset.
- Discontinuity Sets: Four main sets are clearly identified



ULS Pole Plot

- Data Density: ~693k points, less dense than TLS.
- Discontinuity Sets: Equivalent to TLS

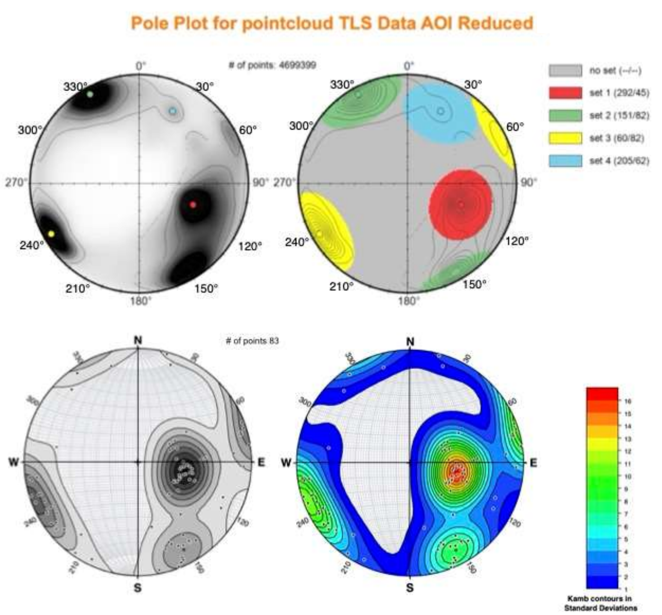


Case Study (cont.)

Comparison TLS joint pole data with in-situ measured joint pole data

From Romero (2025)

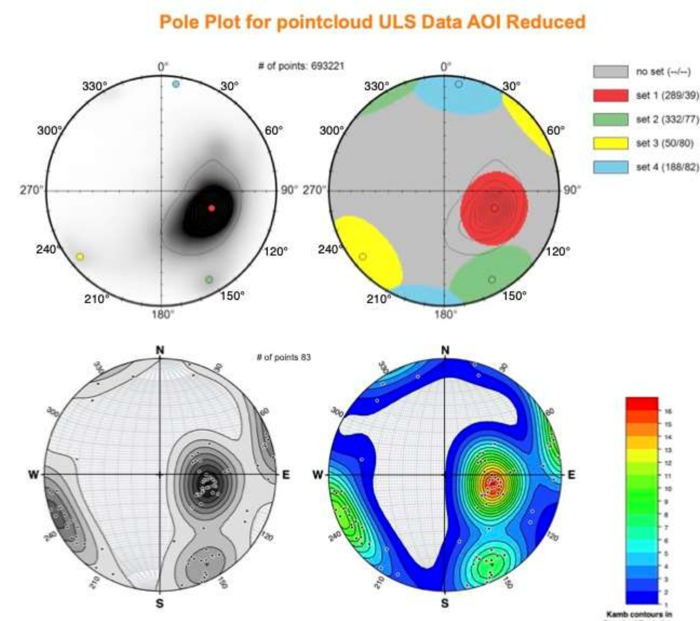
From Joyce (2025)



Comparison ULS joint pole data with in-situ measured joint pole data

From Romero (2025)

From Joyce (2025)



Case Study (cont.)

- James Joyce, PhD, PG, Professor of Geology, University of Puerto Rico
  - "The TLS and ULS joint pole maximum planes proved equally proficient in extracting the same rockslide kinematics as the in-situ directly measured joint planes. In fact the TLS and ULS were more accurate than the equivalent in-situ measured joint pole maximum plane. Therefore, both systems are capable of generating the critical data required for both reliable rock slope stability analysis and efficacious rockslide remedial design."

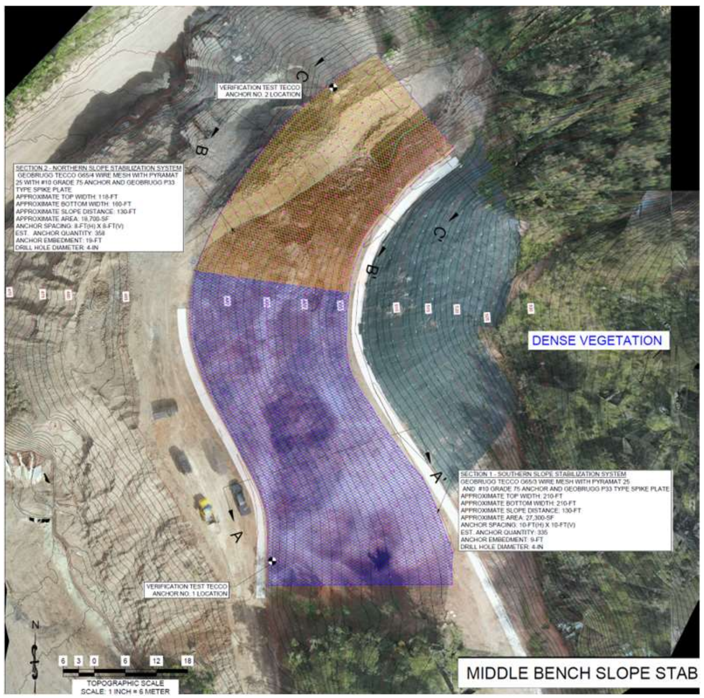
Case Studies (cont.)

From Kane (2023)

Remediation for Upper Bench Slope

- Remediation Method: Geobrugg Tecco® High-Strength Steel Wire Mesh System
- Design Team:
  - KANE GeoTech
  - Suelos, PSC
  - JM Caribbean Distributors, Inc.

Case Studies (cont.)



From Kane (2025)

Middle Bench Remediation

- Remediation Method: Geobrugg Tecco® G65/3 and G65/4 Steel Wire Mesh System
- Anchorage: #10 Grade 75 steel anchors
- Design Team: KANE GeoTech, Inc.

TLS vs. ULS Comparison

TLS (Terrestrial Laser Scanner)

- Data Acquisition: 24 scan positions, full day of fieldwork
- Resolution: High-resolution vertical detail
- Strengths:
  - Captures vertical discontinuities with millimeter accuracy
- Limitations:
  - Line-of-sight shadows (especially horizontal surfaces)
  - Time- and labor-intensive

ULS (Unmanned Laser Scanner)

- Data Acquisition: 15-minute drone grid (N–S / E–W)
- Resolution: Dense horizontal coverage, less detail on steep vertical faces
- Strengths:
  - Rapid wide-area coverage
  - Safer in inaccessible slopes
- Limitations:
  - Fewer details on steep walls

Conclusions

- Both TLS and ULS provide high-resolution 3D data crucial for geotechnical and structural geology studies.
- TLS delivers millimeter accuracy from fixed positions, ideal for detailed monitoring of localized features and measuring dip direction and dip of discontinuities.
- ULS, deployed via drones, excels in covering large or inaccessible areas quickly and safely.
- Integration of TLS and ULS offers complementary strengths:
  - TLS = precision and structural detail
  - ULS = broad spatial coverage and rapid deployment

Recommendations for Future Work

- Time-Series Monitoring: Use repeat surveys to detect slope movements and deformation trends.
- Sensor Fusion: Combine LiDAR with complementary technologies (e.g., photogrammetry, InSAR, GBIR) for multi-source validation.
- Geotechnical Applications: Apply 3D data to advanced slope stability modeling and hazard assessment.
- Standards & Guidelines: Develop protocols for DOTs and consultants to adopt TLS/ULS workflows.

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- Mr. José Muñoz, President, JM Caribbean

References

- Heritage, George, and Andy Large. 2009. Laser scanning for the environmental sciences. US: Wiley-Blackwell.
- Joyce, James (2025). TLS vs ULS Geologic Evaluation, PR-52 Km 49.2, Barrio Vazquez, Salinas
- Rodriguez, Carlos (2023). Preliminary Landslide Geologic Report at PR-52 Km 49.2, Barrio Vazquez, Salinas, Puerto Rico

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From Montalvo (2024)

Thank you!

"Expect the best. Prepare for the worst. Capitalize on what comes."

by Zig Ziglar