Stabilisation of Highwall Instability Using Numerical Modelling and Statistical Analysis for Open Pit Mining

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Rock Engineering Geotechnics Geology

Background

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The project's open pit is located in the Bushveld Complex, where mining activities target chromitite seams dipping northward at angles between 12° and 15°.

Rising concerns after highwall failure led to an urgent detailed assessment as increasing fractures and block movement developed at the failed highwalls crest and is close to a public road, approximately 100m.

Problem statement:

A highwall failure is more than just a geotechnical issue, it's a question of safety and operational efficiency. With fracture areas propagating and structural stability compromised, urgent action is needed to prevent any further failure.

Immediate objectives are to:

- Determine the factors contributing to the instability.
- Derive the extent of progressive propagation, specifically how far fractures may propagate toward the public road.
- Determine the height, thickness and width of the slope wall buttressing.

Pit Layout

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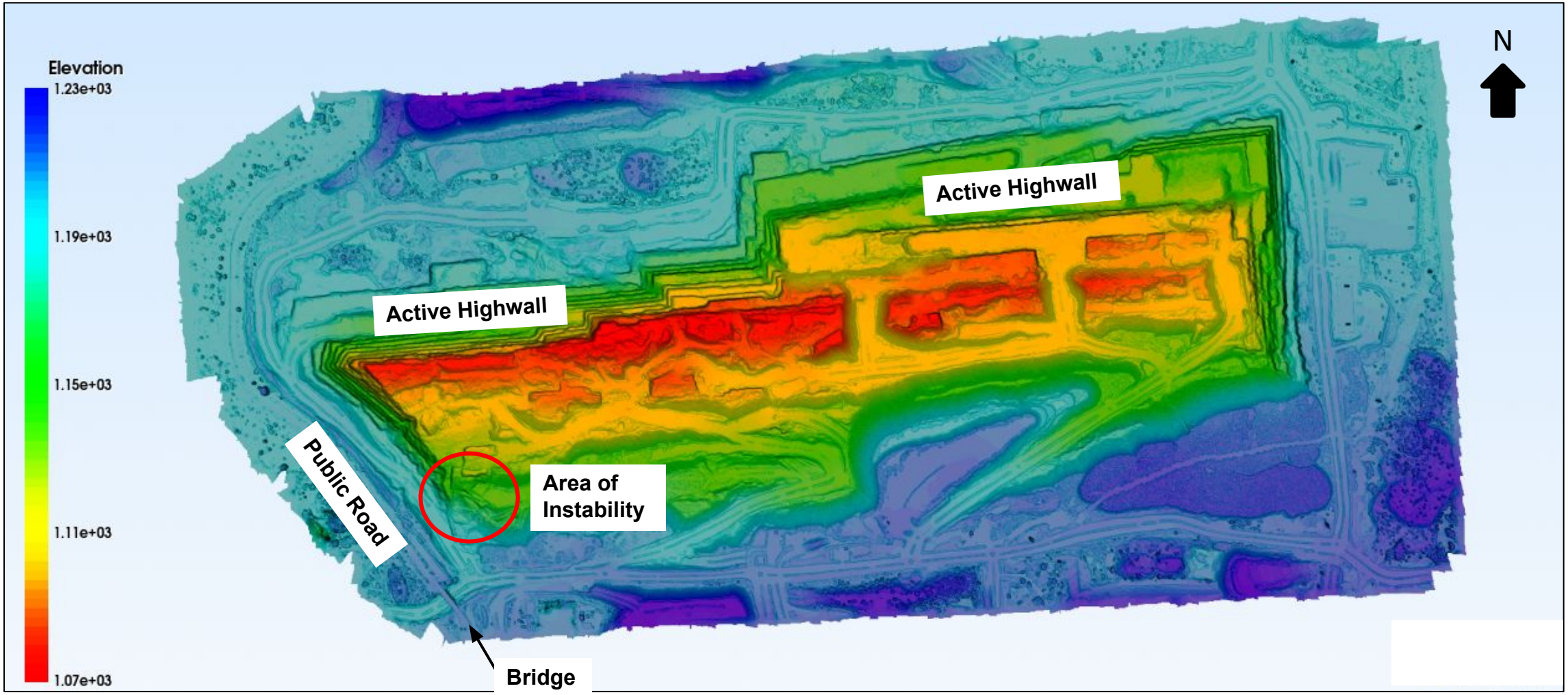

Site Inspection & Initial Observations

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- A site inspection was conducted to assess reported tensile cracks and ground displacement along the south-western crest of the East Pit.
- Prominent open cracks (tension cracks) in ground surface.
- Cracks follow a stepped path in multiple directions.
- Significant block separation and vertical displacement.
- Block toppling/sliding evident.
- Ground displacement visible along crest and surface.

Process Followed

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The process followed to forensically investigate and formulate mitigating measures were:

- Analysis of fracture footprints based on aerial imaging
  - Fracture length propagation
  - Fracture counts
  - Aperture
- Consolidation of rock properties
  - Mine database
  - Data reduction using RSData
- Analysis of stability in RS2/RS3 of various sections of the wall
  - Cross sections derived from as-built files
  - Simulation of North-South and East-West sections
  - Derivation of SRF (SF) and deformations
- Propagation potential of failure
- Sizing of buttress

Fracture Analysis

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To better understand the progression of the fractures:

- Fracture propagation analysis using aerial photographs captured over a six month period.
- A total of 10 Dip fractures, 15 strike fractures, and 28 radial fractures were observed and analysed using QGIS.

Progression: 1 January 2023 to 1 May 2023

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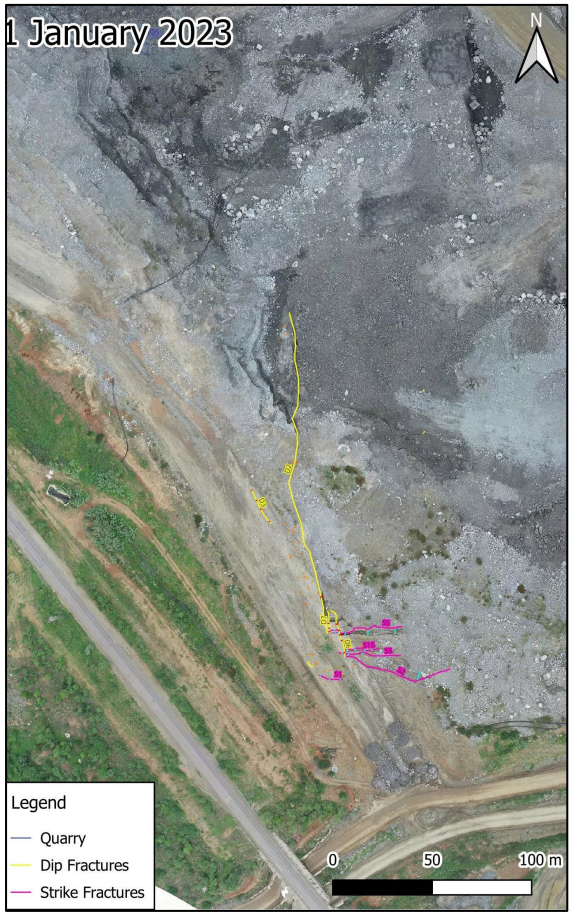

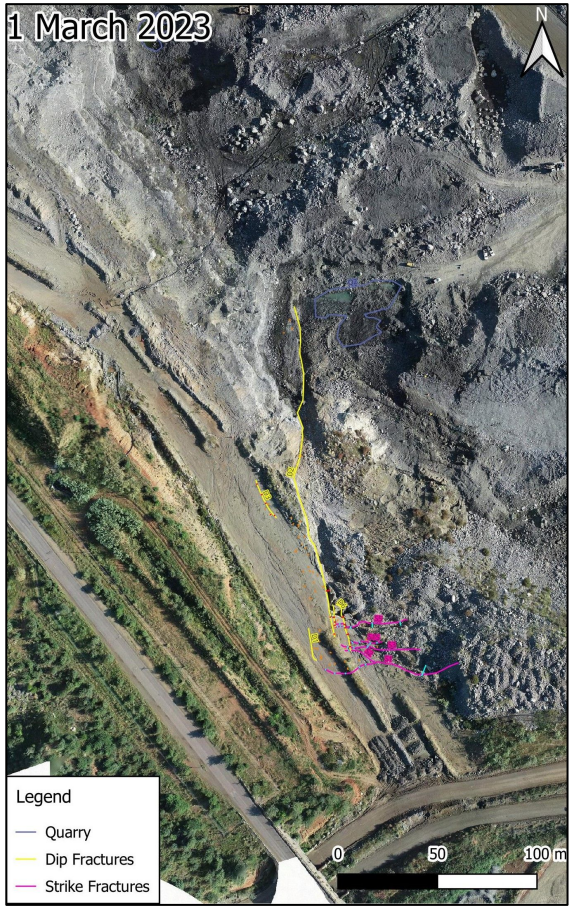

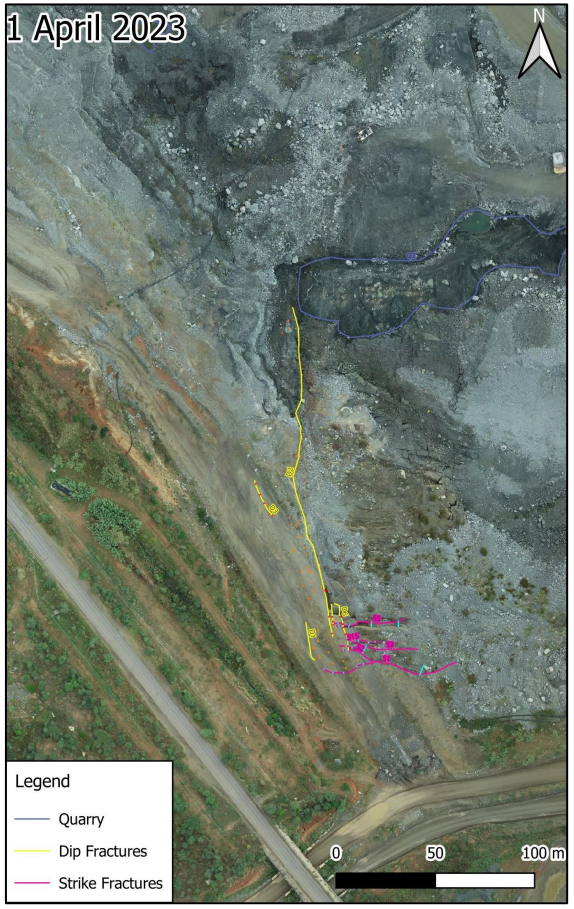

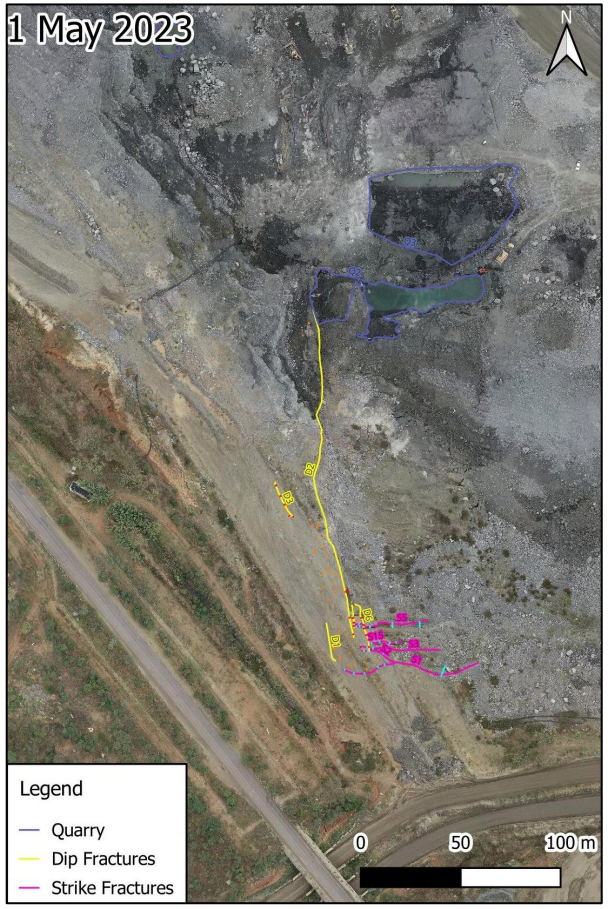

Progression: 1 May 2023 to 28 June 2023

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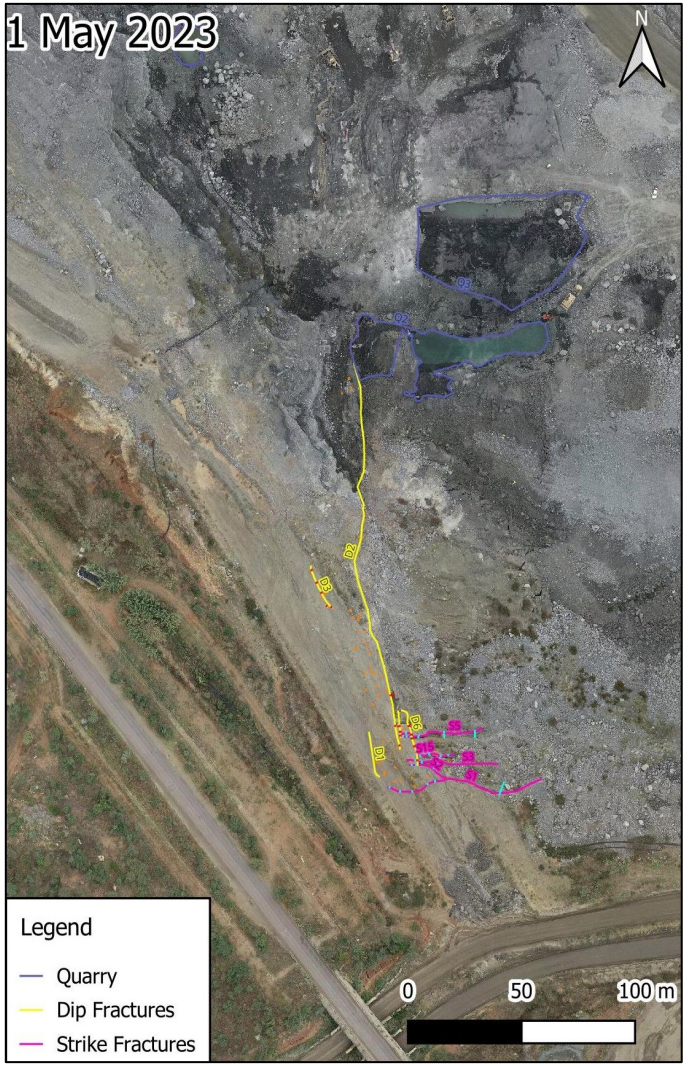

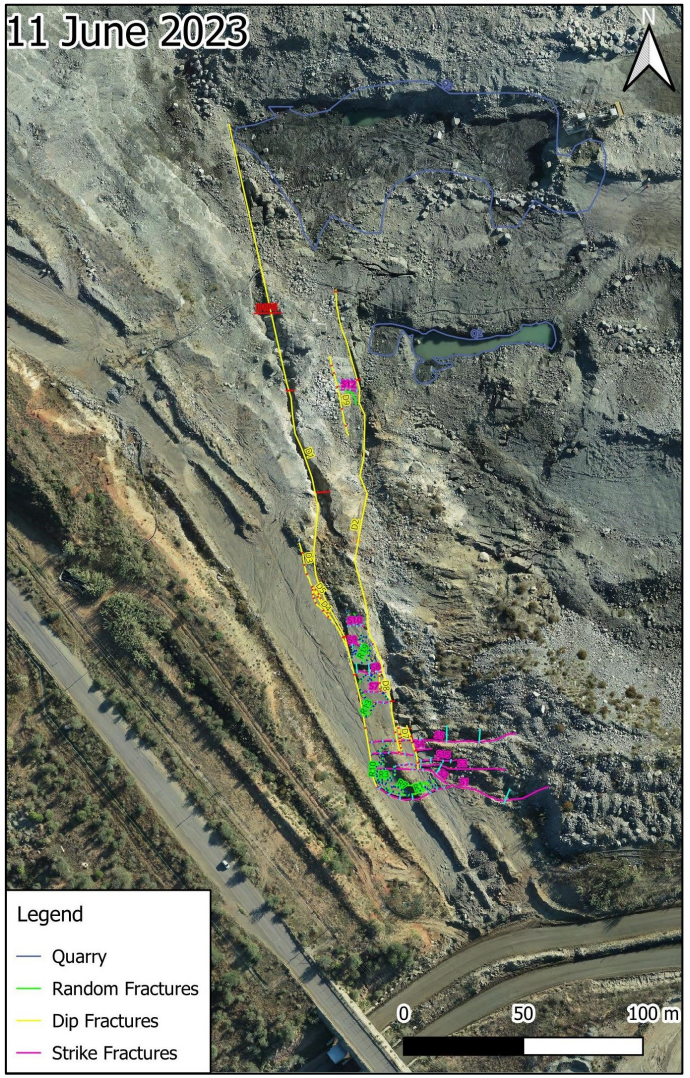

Fracture Data & Trends: Dip Fractures

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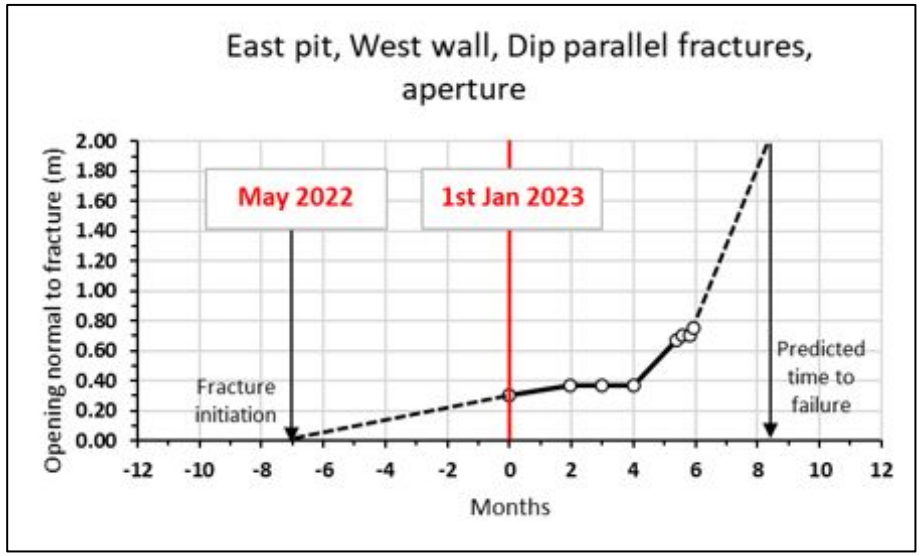

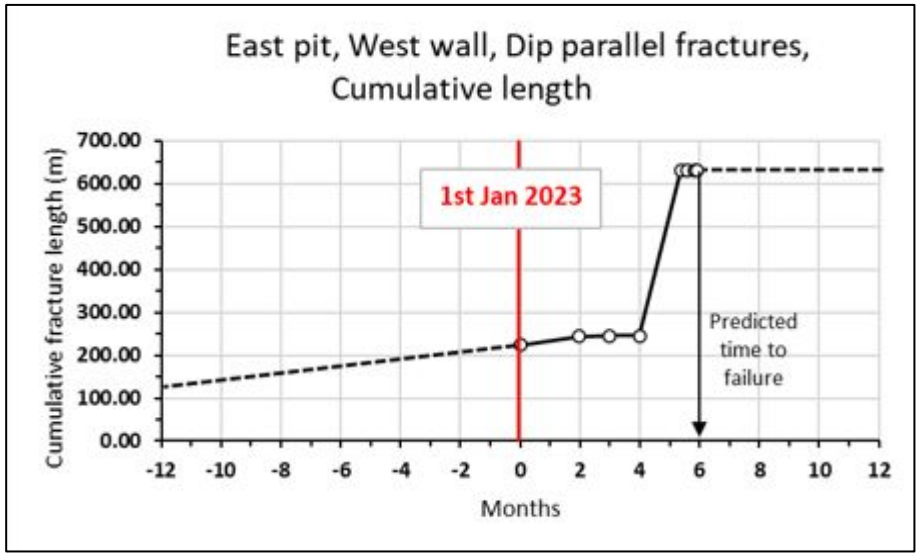

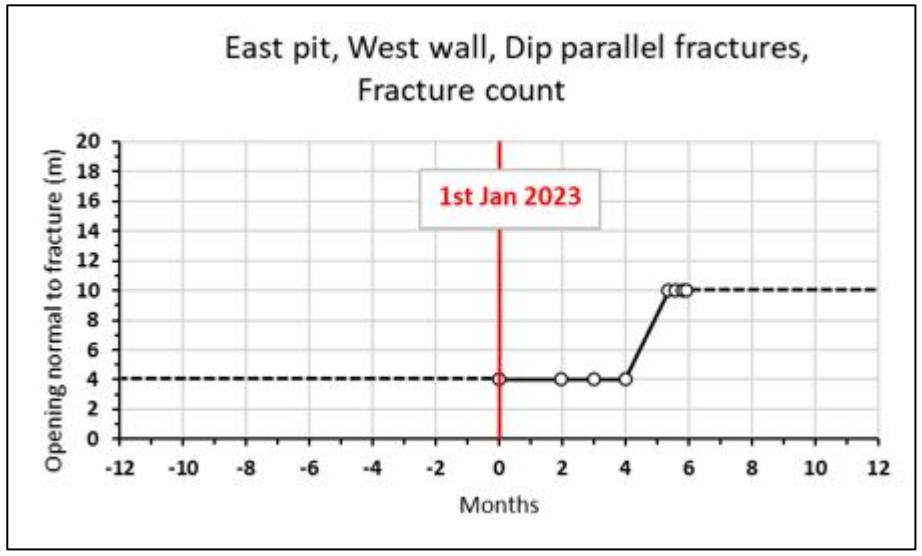

Fracture Data & Trends: Strike Fractures

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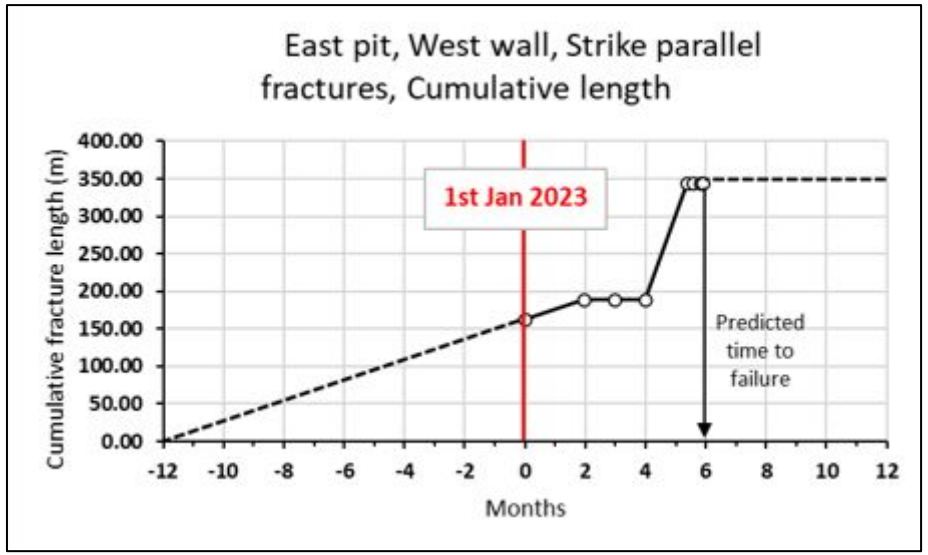

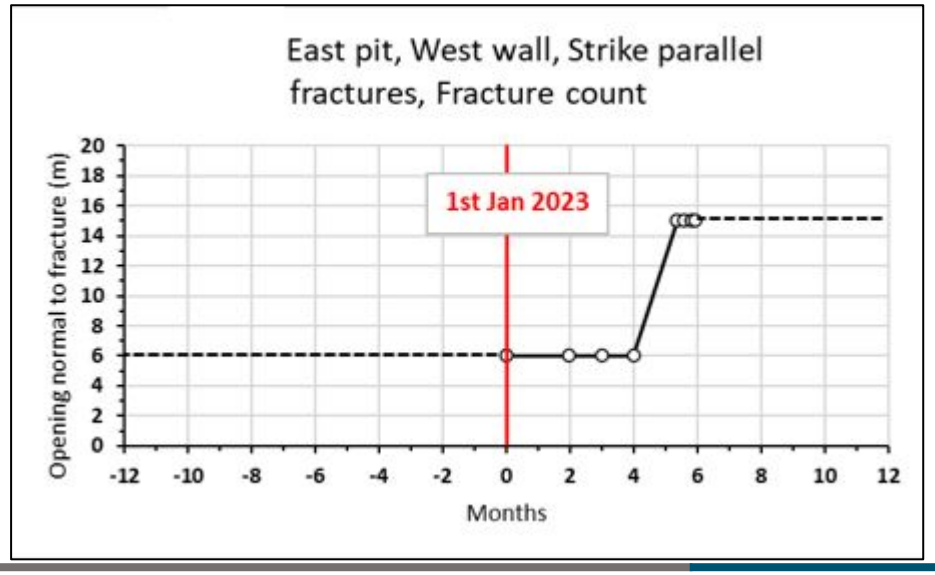

Fracture Data & Trends: Radial Fractures

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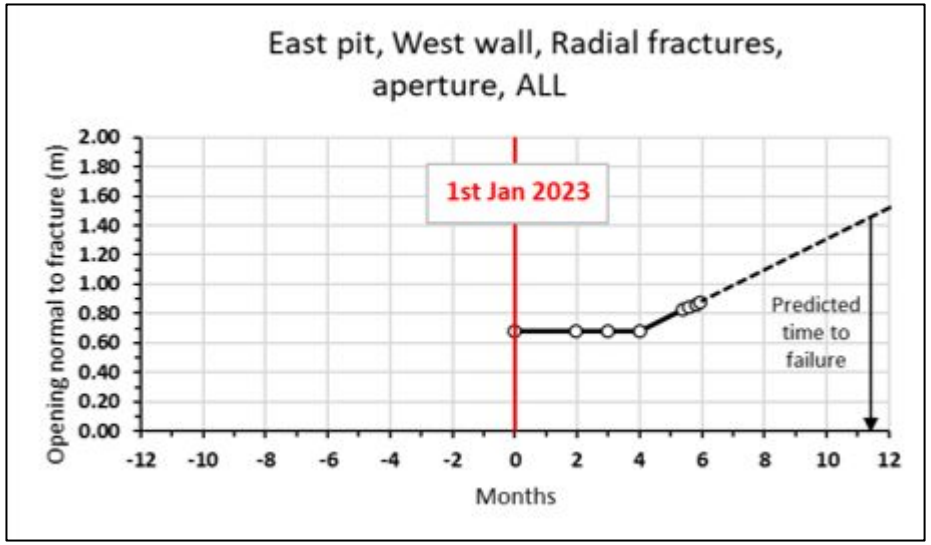

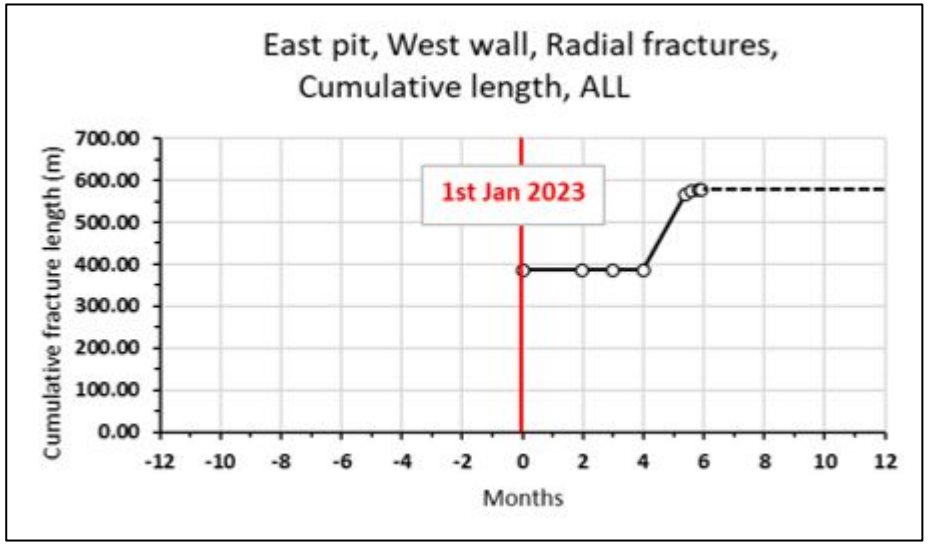

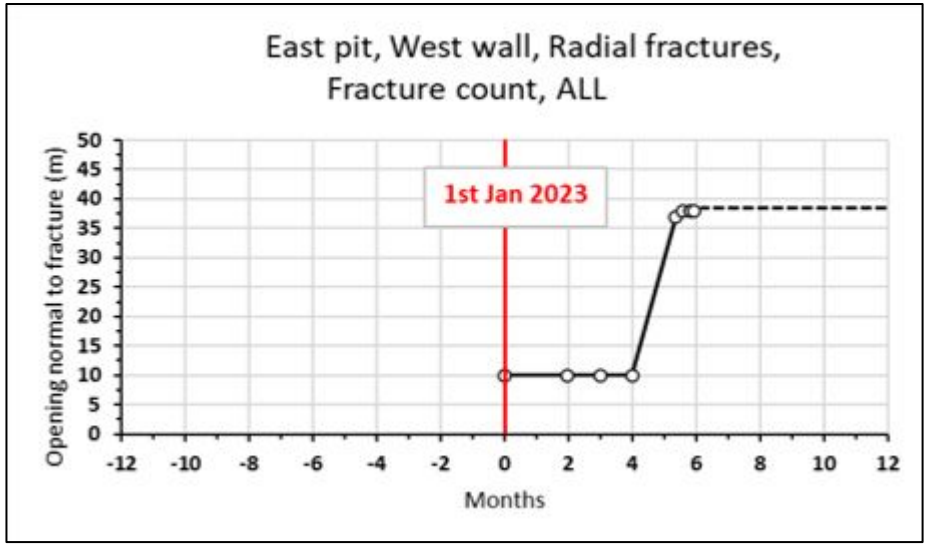

Numerical Modelling

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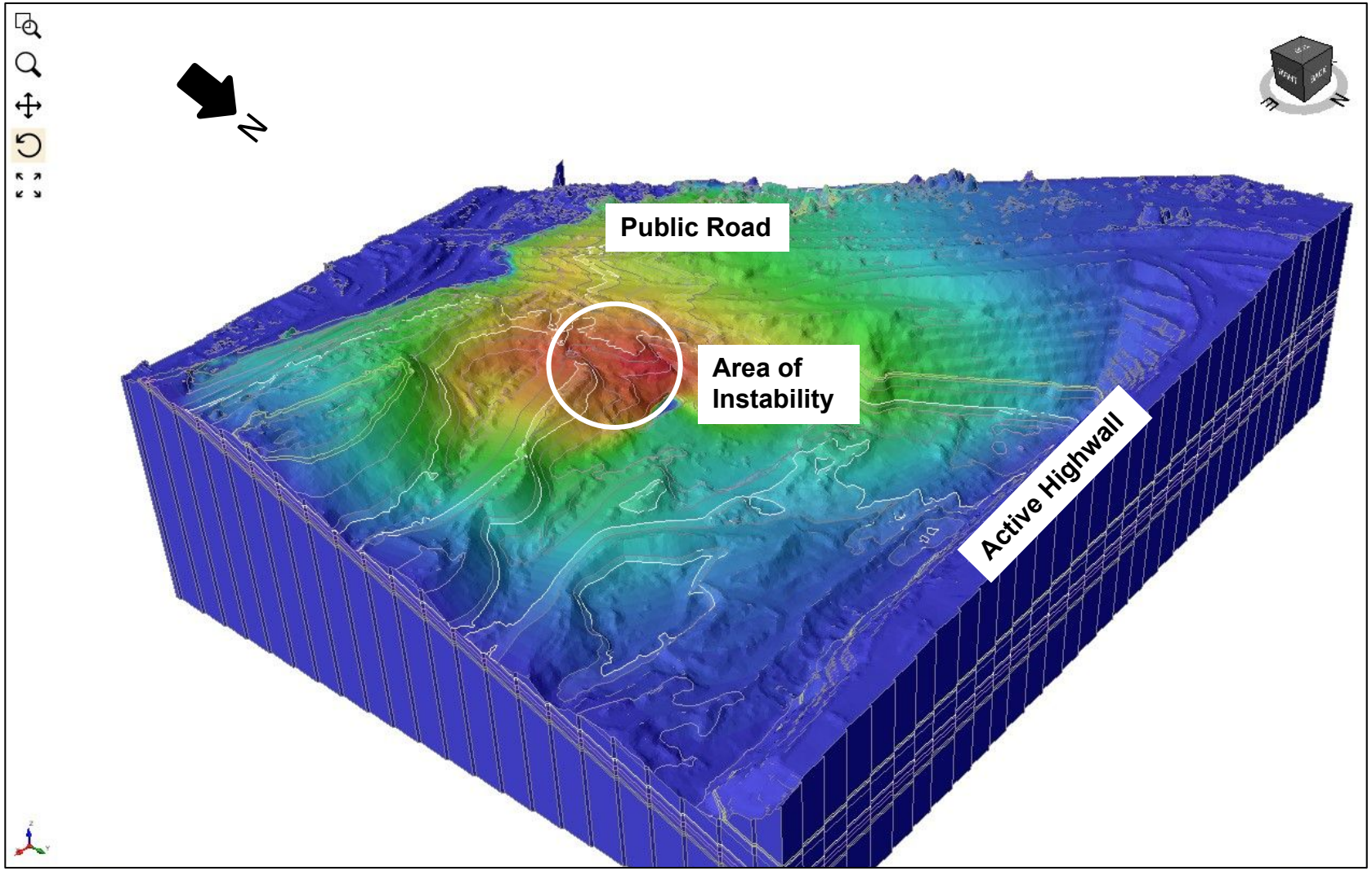

Risk to public road (NS Section 1)

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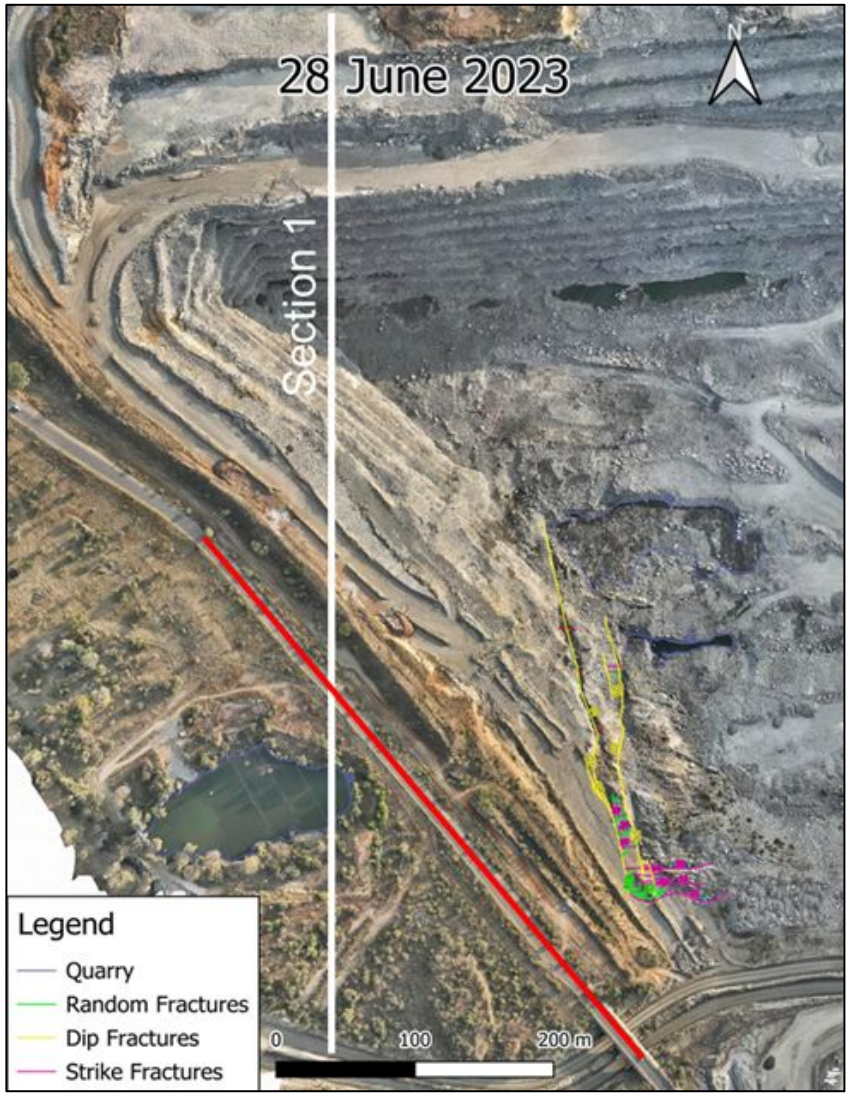

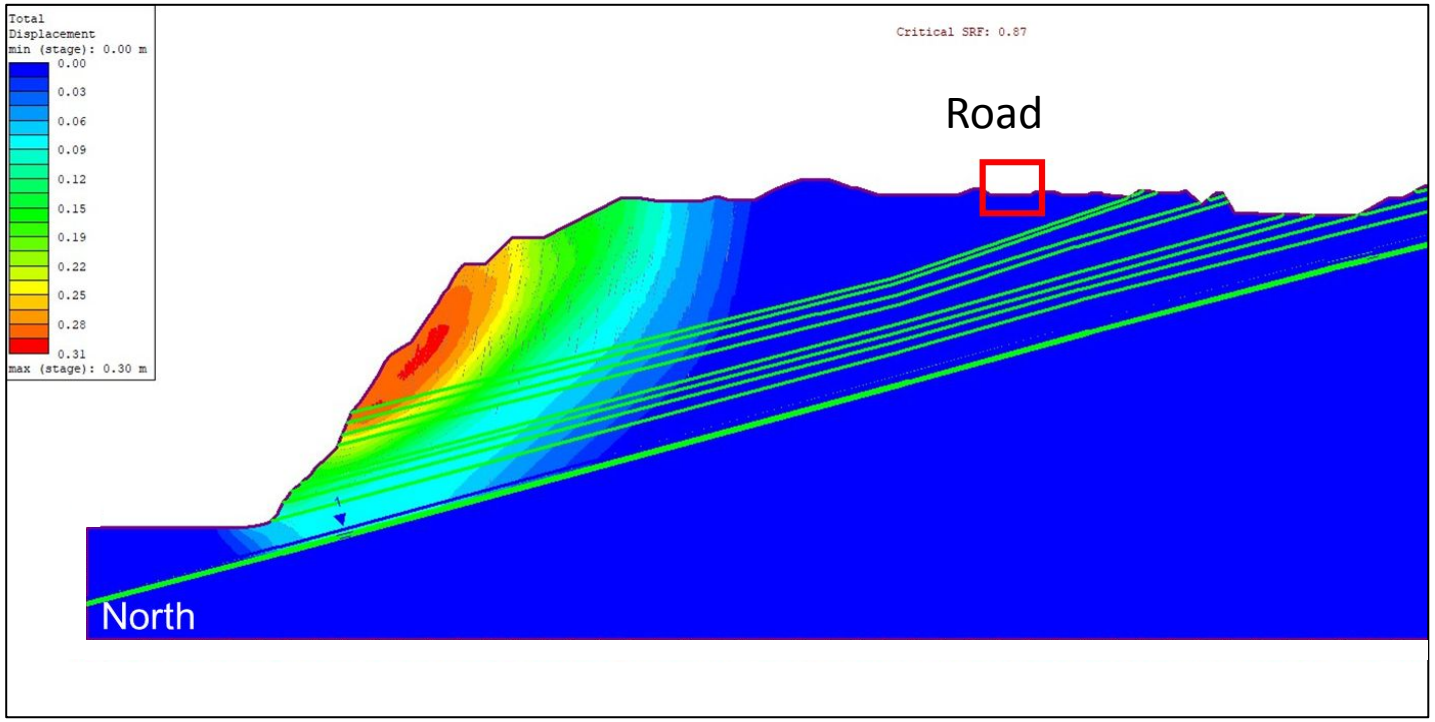

SRF	0.87
Total Displacement	0.31m

Risk to public road (NS Section 2)

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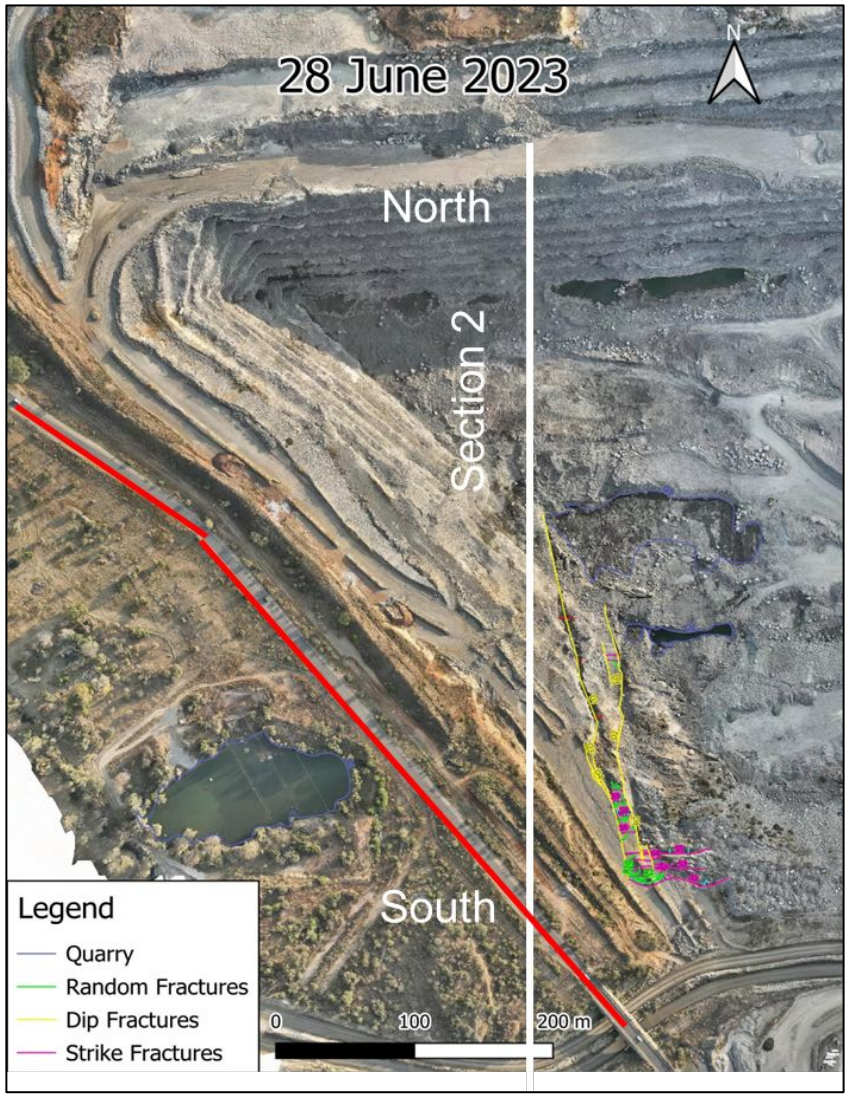

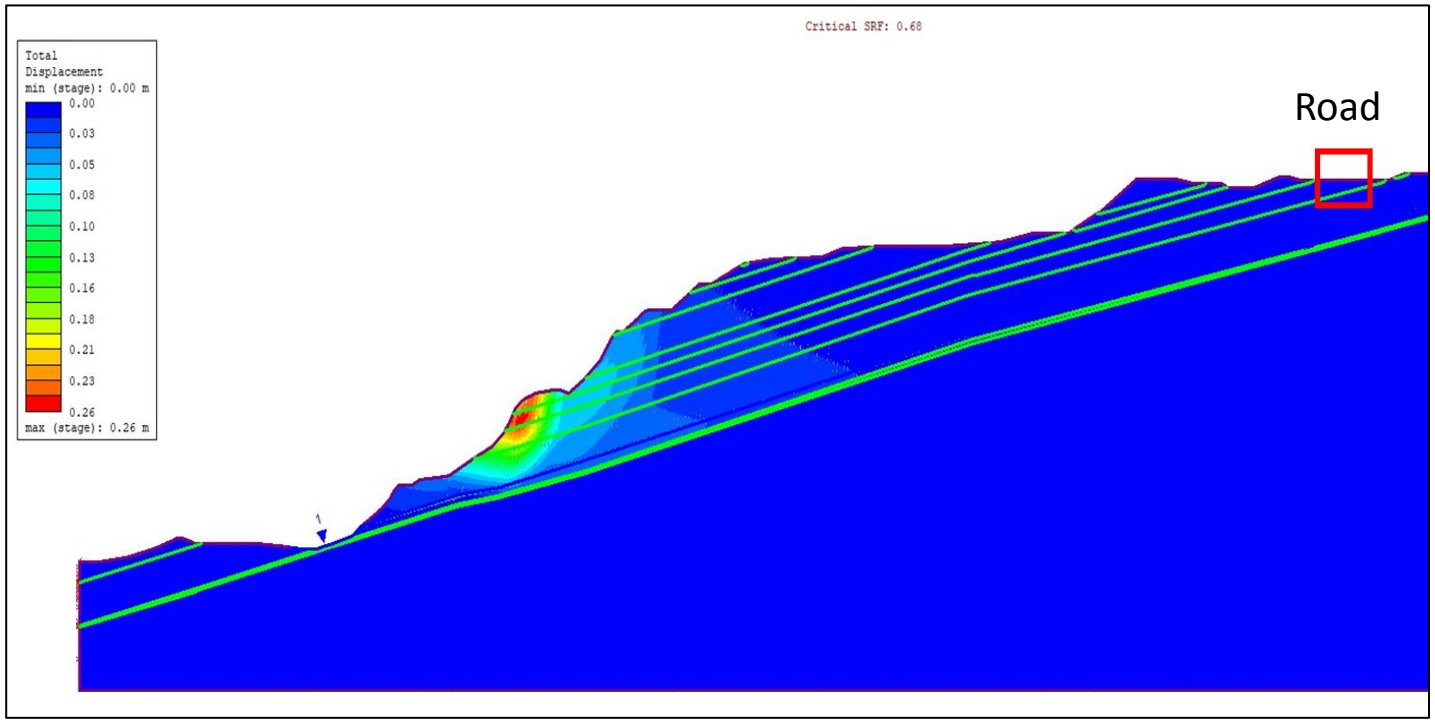

SRF	0.68
Total Displacement	0.26m

Risk to public road (NS Section 3)

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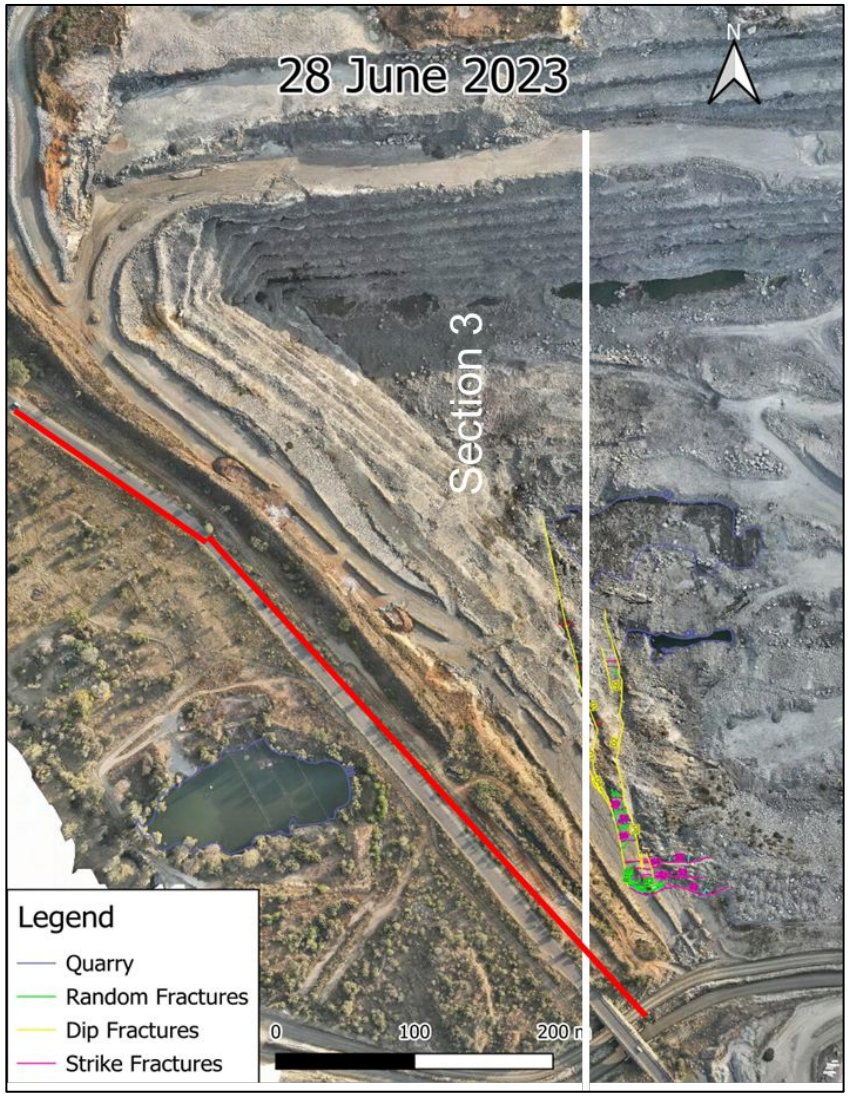

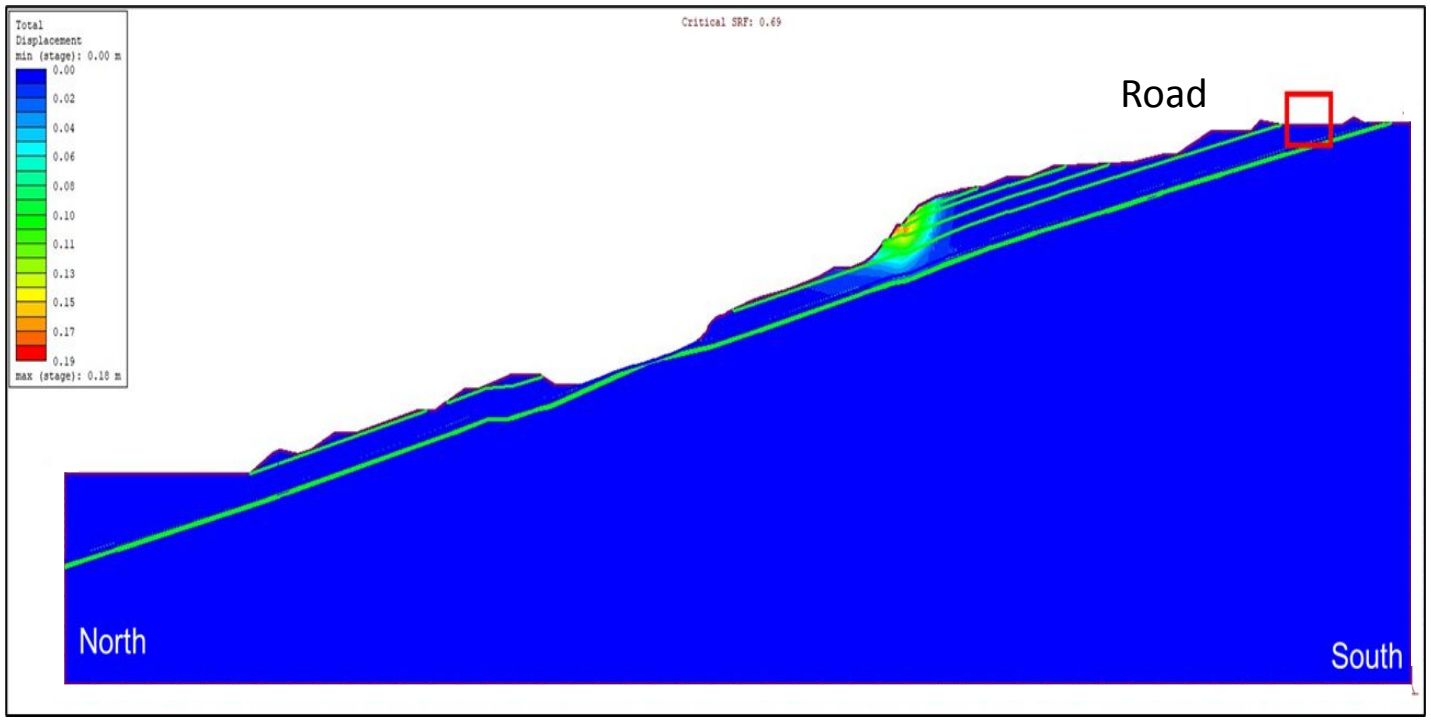

SRF	0.69
Total Displacement	0.19m

Risk to public road (EW Section 1)

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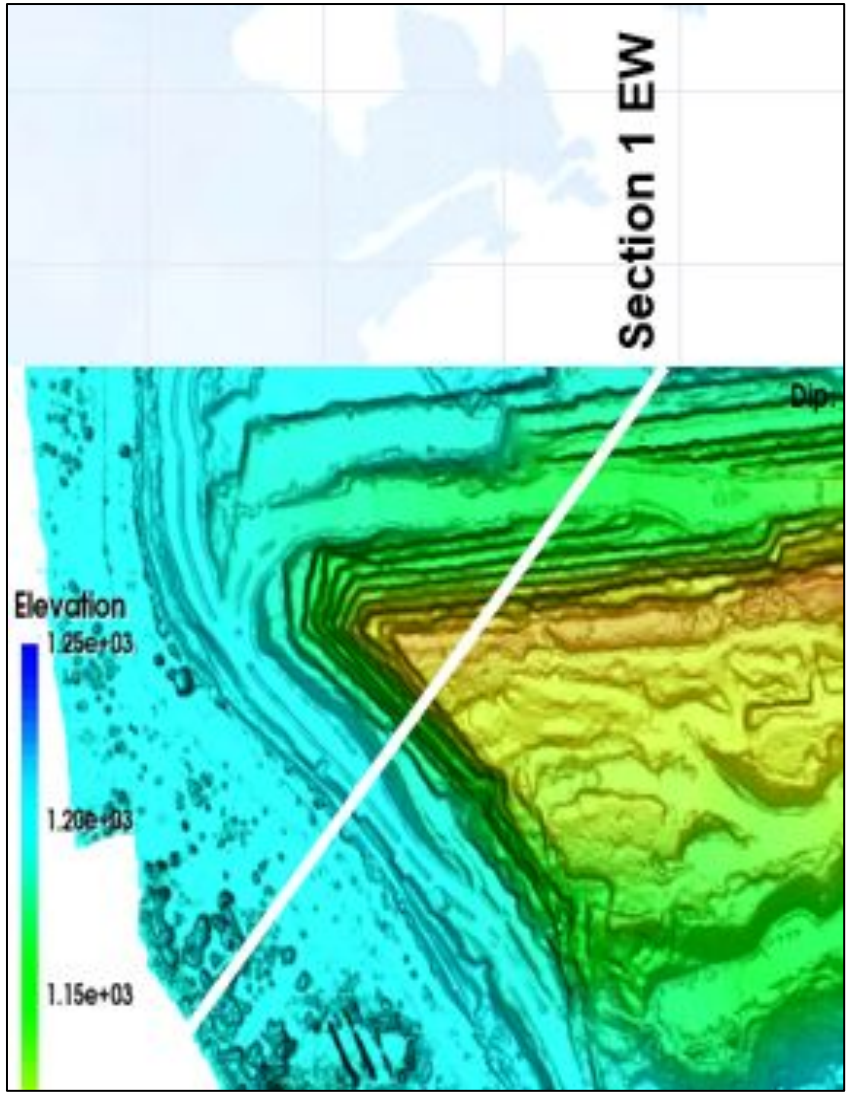

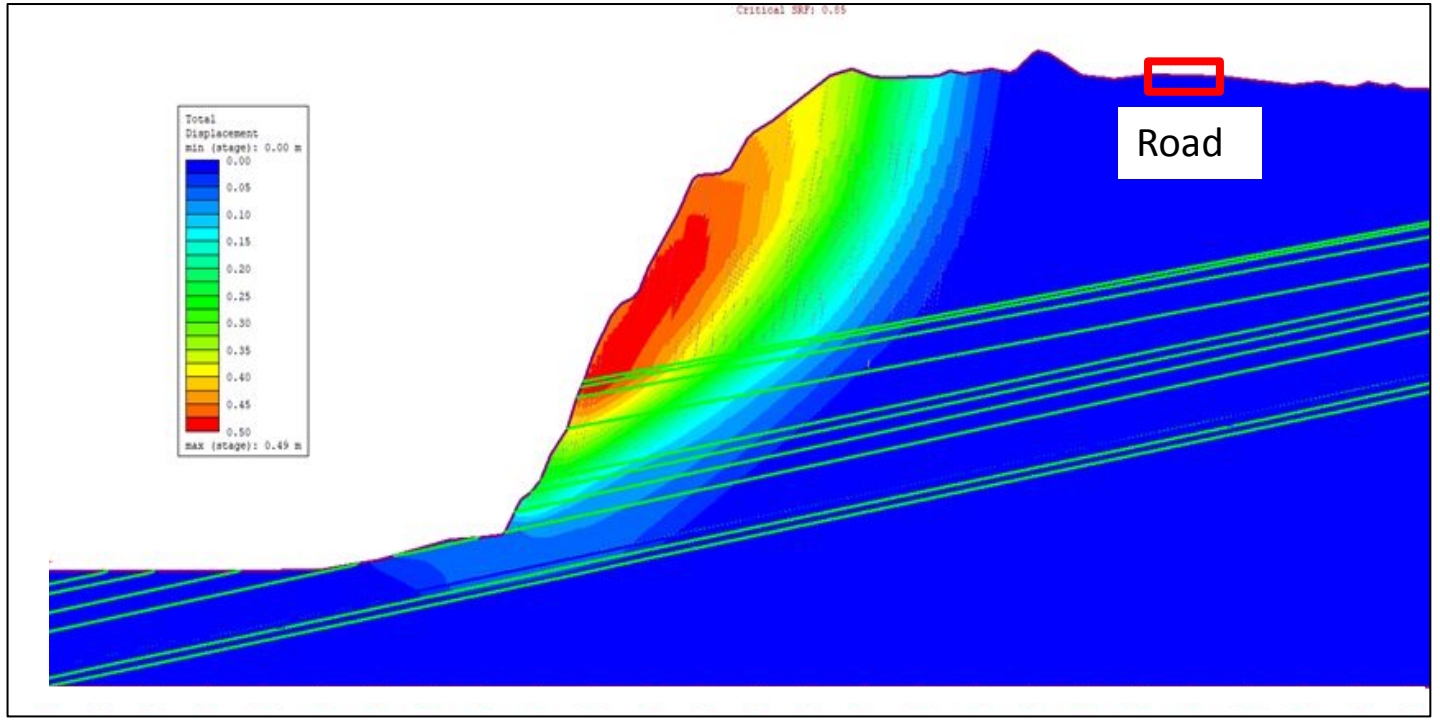

SRF	0.85
Total Displacement	0.49m

Height of Buttress Across Highwall

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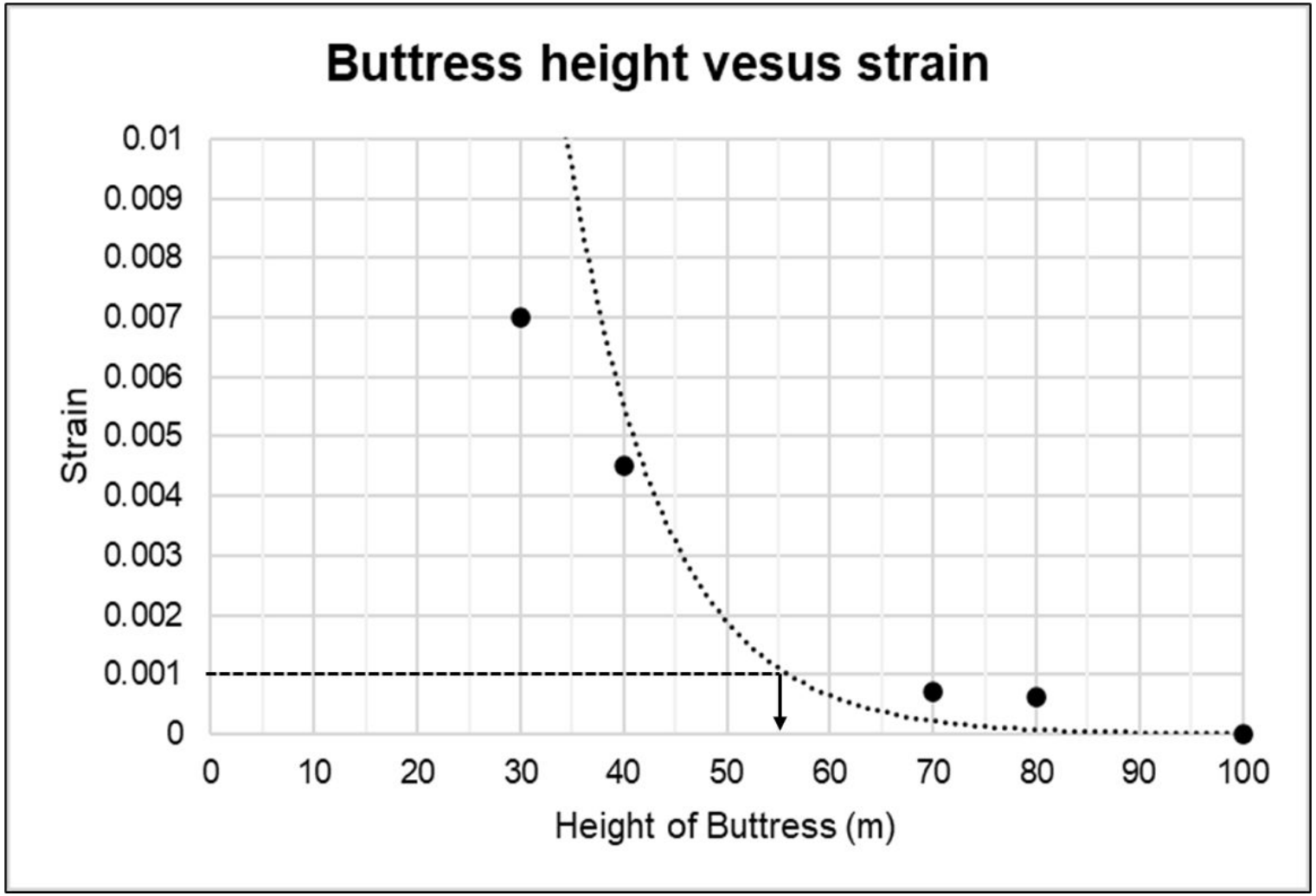

- The West Highwall spans approximately 579 m in width.
- A strain cut-off of 0.001 was used, as this represents the industry standard for allowable strain limits.

Length of Buttress Across Failed Highwall

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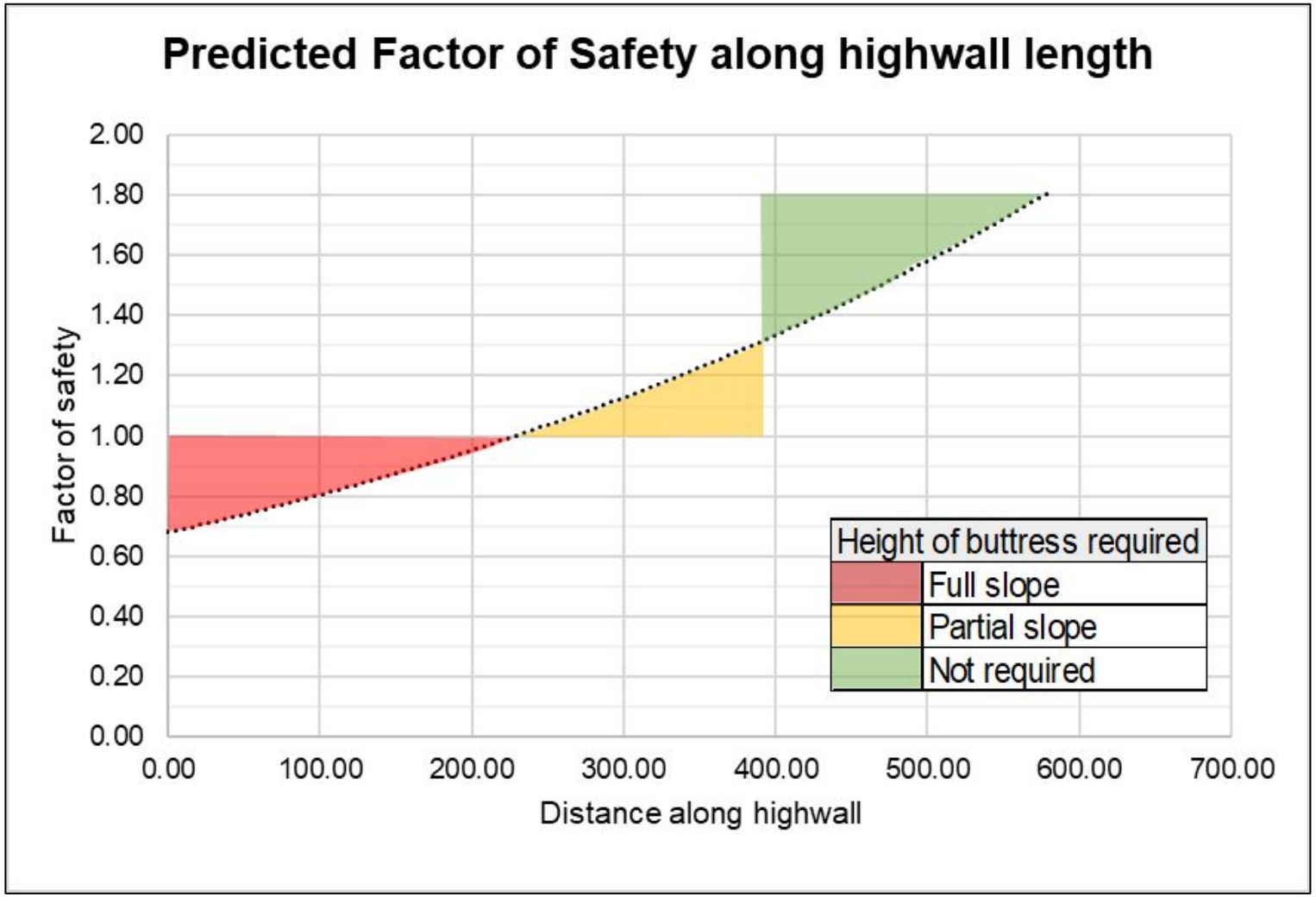

- Our analysis showed that for the first 227m, the West Highwall shows a SF below 1 (red).
- Between 227m and 395m, there is a zone of potential weakness (yellow) .
- Beyond 395 m, no buttressing is needed, allowing for a gradual slope decline.

Spill Width

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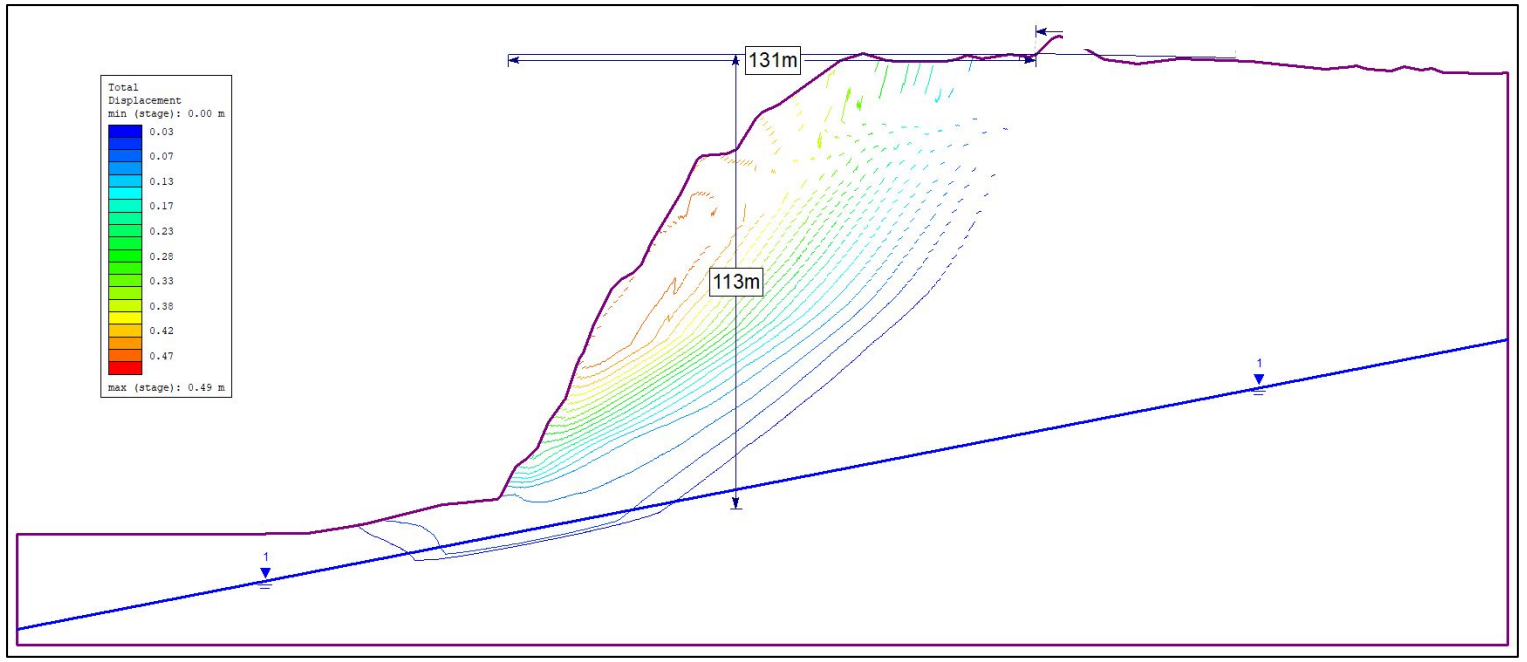
$$\text{Spill width} = \sqrt[3]{BulkingFactor \times FailureVolume}$$

Section	Base (m)	Height (m)	Area (m²)	Bulking Factor	Spill Width (m)
NS Section 1	169	118	9971	1.5	24.64
NS Section 2	92	55	2530	1.5	15.60
NS Section 3	71	38	1349	1.5	12.65
EW Section 1	131	113	7401.5	1.5	22.31



Conclusions and Recommendations

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- Highwall stability was effectively assessed using integrated fracture mapping and numerical modelling.
- Buttress design was successfully validated through simulation, supporting both safety and continuous operations.
- The buttress has been fully constructed and movement has been confined.
- Long term slope stability relies on ongoing monitoring and proactive management strategies.

Recommendations:

- Install wire extensometers along the crest, spaced every 100m.
- Weekly inspections by a certified Strata Control Officer.
- Immediate notification of a Rock Engineer if further movement is detected.

Acknowledgements

This work was conducted by Middindi Consulting (Pty) Ltd project team, with contributions from our Directors Trevor and Brendan.

Thank You!

Questions?