ASSESSMENT AND MITIGATION: SLOPE STABILITY RISKS FOR TSF CLOSURE

Presented by:

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SAIMM CONFERENCE, 04 MARCH 2026

PRESENTATION OVERVIEW

- Introduction
- Site Description
- Material Parameters & Material Zoning
- Stability Review
- Bench Drop Review
- FoS vs Remining Stages
- Conclusions & Recommendations

Introduction

- TSFs closure complex geotechnical, environmental, and operational requirements.
- Detailed understanding of current and long-term conditions.
- Growing emphasis on sustainable resource recovery.
- Introduces additional uncertainty in geotechnical parameters and pore pressure.

Objective: Assess closure stability and evaluate remining feasibility

Site Description

- Location: South Africa
- Status: Active
- Raising Method: Upstream with a buttress
- Current Height: 27m (Maximum height)
- Area: 6.4 ha
- GISTM Consequence Classification: Extreme
- Closure Concept: Remining

Extreme consequence classification
(near communities & Mine Infrastructure)

Background

- **2018:**
  - CPTu campaign – 6 test positions
- **2019:**
  - 12 test pits
  - 5 rotary core boreholes
  - Basin tailings sampled and laboratory tested
- **2022**:
  - CPTu campaign – 2 test positions per flank

Data gaps (2024):

- Shear strength parameters
- Pore pressure regime
- Stratigraphy

Recommendation:
Conduct updated site investigation

Investigation Program

2024/2025 CPTu Campaign

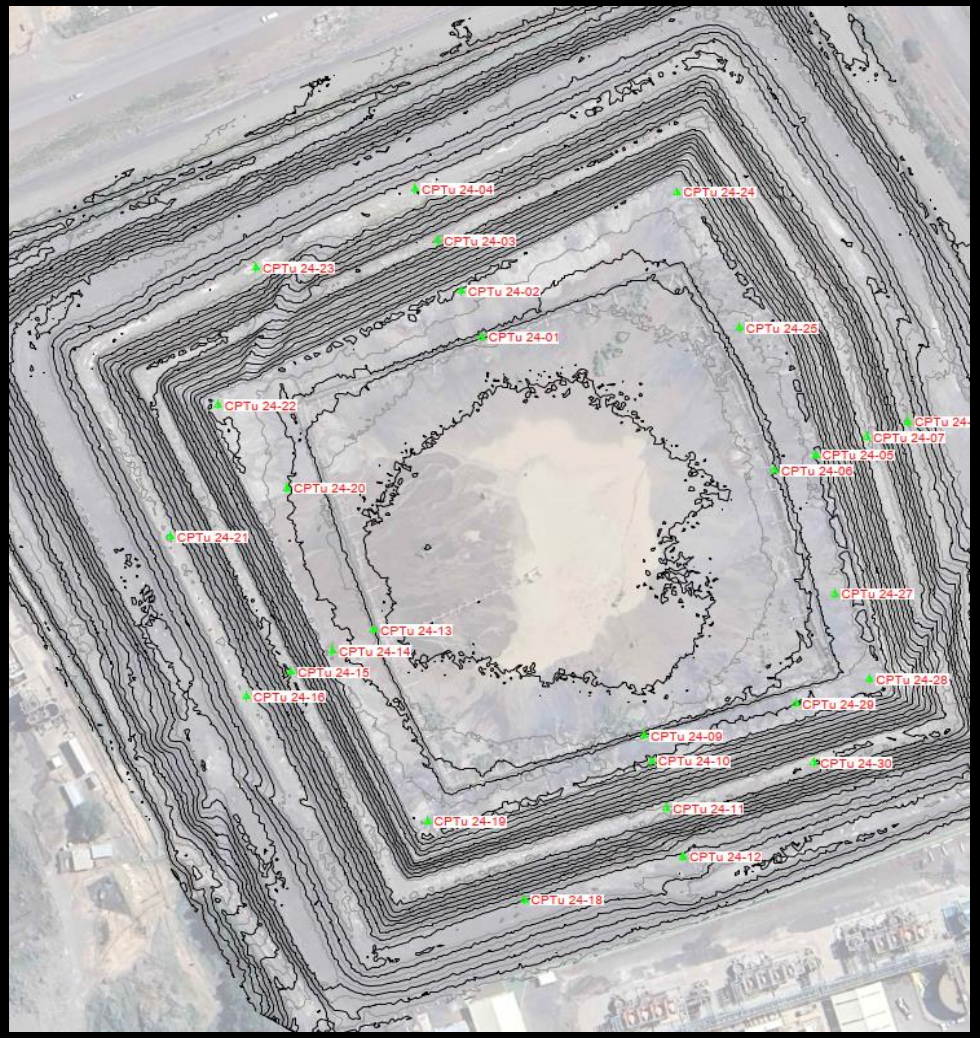
- 28 CPTu tests
- Laboratory testing
- VWP & standpipe piezometer review

Outcome: Refined stratigraphy & phreatic surface

Material Characteristics

Tailings:
Non-plastic silty fine sand
Moisture content ~13%
Loose to medium dense
Dense at base
Local soft clay zones

Foundation:
Highly weathered soft norite
Slightly weathered hard norite



Interpreted Information: FHP Test

	Depth	Elaspsed Time	Cumulative Head Loss (cm)	Average Permeability (m/s)
BH02	6m	5 min	4	8.48E-07
		10 min	11	
		15 min	18	
		20 min	25	
	9m	5 min	17	1.33E-06
		10 min	32	
		15 min	46	
		20 min	58	
	12m	5 min	66	2.54E-06
		10 min	106	
		15 min	125	
		20 min	143	
	15m	5 min	21.5	8.16E-07
		10 min	35.5	
		15 min	48	
		20 min	60	

	Depth	Elaspsed Time	Cumulative Head Loss (cm)	Average Permeability (m/s)
BH03	3m	5 min	51	7.28E-06
		10 min	72	
		15 min	82	
		20 min	95	
	6m	5 min	120	1.07E-05
		10 min	176	
		15 min	214	
		20 min	243	
	9m	5 min	138	9.06E-06
		10 min	215	
		15 min	274	
		20 min	328	
	12m	5 min	57	3.00E-06
		10 min	96	
		15 min	134	
		20 min	167	
	15m	5 min	110	4.18E-06
		10 min	181	
		15 min	236	
		20 min	283	

	Depth	Elaspsed Time	Cumulative Head Loss (cm)	Average Permeability (m/s)
BH06	3 m	5min	0.05	1.33E-08
		10min	0.1	
		15min	0.15	
		20 min	0.2	
	6 m	5min	24	2.65E-06
		10min	41	
		15min	58	
		20min	70	
	9 m	5min	54	3.02E-06
		10min	82	
		15min	105	
		20min	126	
	12 m	5min	83	3.21E-06
		10min	120	
		15min	148	
		20min	178	
	15 m	5min	75	3.50E-06
		10min	133	
		15min	190	
		20min	241	

	Depth	Elaspsed Time	Cumulative Head Loss (cm)	Average Permeability (m/s)
BH05	3 m	5min	94	1.24E-05
		10min	108	
		15min	124	
		20min	130	
	6m	5min	25	1.84E-06
		10min	37	
		15min	45	
		20 min	53	

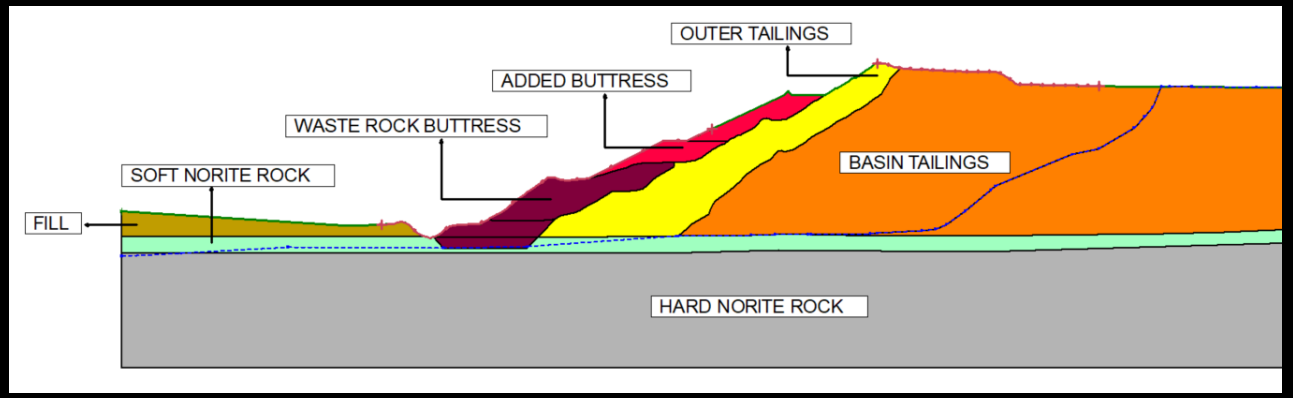
	Depth	Elaspsed Time	Cumulative Head Loss (cm)	Average Permeability (m/s)
BH04	3m	5 min	30	4.77E-06
		10 min	46	
		15 min	55	
		20 min	61	
	6m	5 min	28	2.62E-06
		10 min	46	
		15 min	60	
		20 min	71	
	9m	5 min	12	1.07E-06
		10 min	24	
		15 min	36	
		20 min	47	
	12m	5 min	144	6.47E-06
		10 min	215	
		15 min	280	
		20 min	332	

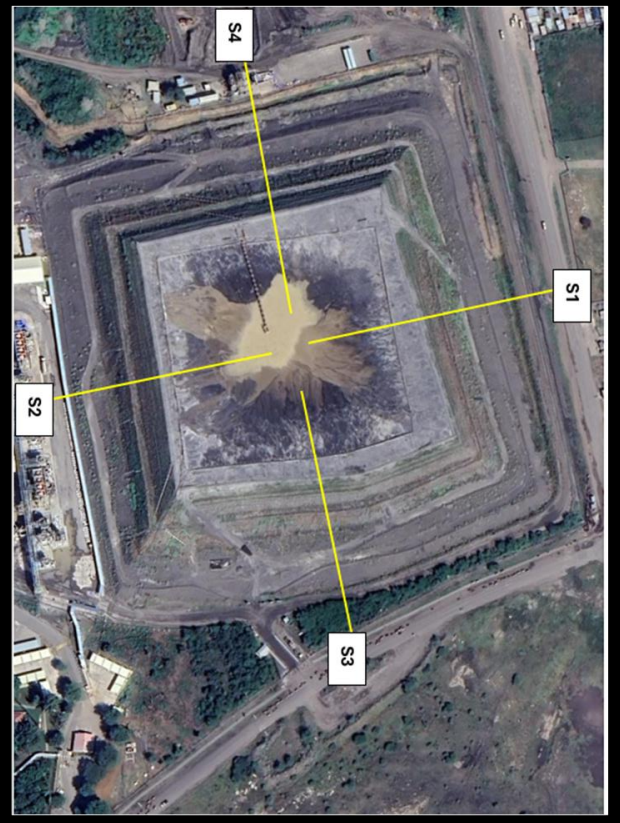
	Depth	Elaspsed Time	Cumulative Head Loss (cm)	Average Permeability (m/s)
BH07	8.05 m	5min	26	2.20E-06
		10min	46	
		15min	65	
		20 min	84	
	11 m	5min	31	1.33E-06
		10min	47	
		15min	60	
		20min	71	
	14 m	5min	112	4.27E-06
		10min	174	
		15min	225	
		20min	269	

	Depth	Elaspsed Time	Cumulative Head Loss (cm)	Average Permeability (m/s)
BH08	6 m	5min	26	4.03E-07
		10min	46	
		15min	65	
	9 m	5min	31	1.58E-07
		10min	47	
		15min	60	
		20min	71	
	12 m	5min	112	1.14E-06
		10min	174	
		15min	225	
		20min	269	

Material Parameters & Material Zoning

Geotechnical Characteristics				Section	Shear Strength Ratio (su/σ'v)			
					Peak Undrained		Residual Analysis	
Material	ϒ (kN/m³)	c (kPa)	ϕ (degrees)		Tailings above WT	Tailings below WT	Tailings above WT	Tailings below WT
Fill	18	5	32					
Waste Rock Buttress	23	0.1	35					
Added Buttress	23	0.1	35					
Hard Norite Rock	24	100	50	S1	0.4	0.24	0.2	0.06
Soft Norite Rock	23	15	35	S2		0.25		0.08
Basin Tailings	19.6	0.1	33	S3				
Outer Tailings	19.6	0.1	33	S4		0.24		0.06





Stability Assessment Methodology

Software: SLOPE/W
Method: Morgenstern-Price method (GLE)
Loading cases:

- Drained
- Undrained
- Post-seismic

FoS Summary: Current Stability Assessment

	S1		S2		S3		S4	
Analysis	FoS							
Min. slip surface depth (m)	8	20	8	20	8	20	8	20
Drained Analysis	1.5	2.5	1.5	2.7	1.5	2.7	1.5	2.0
Undrained Analysis	1.4	2.1	1.4	2.0	1.5	2.0	1.4	1.8
Post Seismic Analysis	0.9	1.2	1.0	1.0	0.9	1.0	1.0	1.0

Conclusions:

- All sections below required FoS
- Extreme classification → higher reliability required
- Mitigation required prior to closure

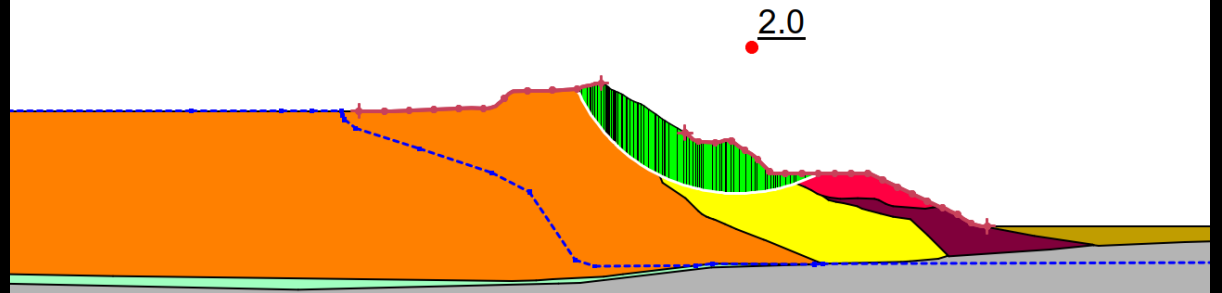
Mitigation: Raise Buttress

- Raise rock buttress by 3 m
- Improve resisting forces
- Reduce global slip potential

STABILITY POST 3 m BUTTRESS RAISE

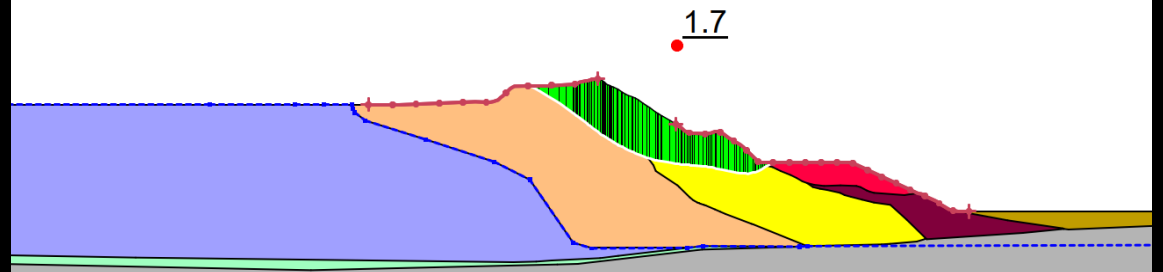
Critical Section (S2) - Raised Buttress

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23	0.1	35
	Basin Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Fill Material	Mohr-Coulomb	18	5	32
	Hard Rock Norite	Mohr-Coulomb	24	100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Soft Rock Norite	Mohr-Coulomb	23	15	35
	Waste Rock Buttress	Mohr-Coulomb	23	0.1	35



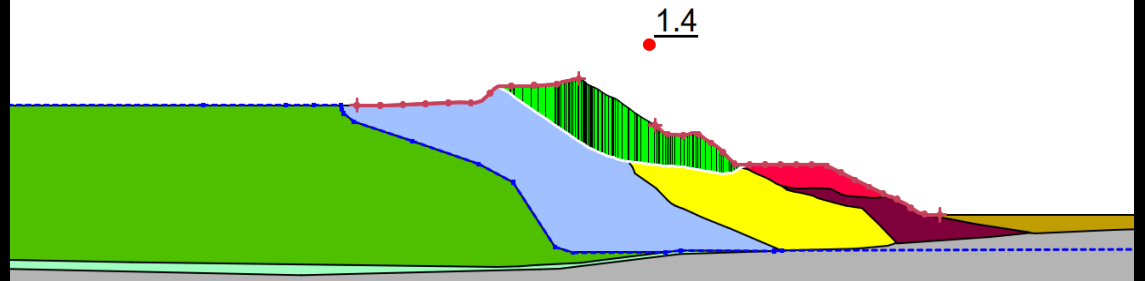
Drained Analysis

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23		0.1	35
	Basin Tailings - Undrained (above WT)	SHANSEP	19.6	0.4		
	Basin Tailings - Undrained (below WT)	SHANSEP	19.6	0.26		
	Fill Material	Mohr-Coulomb	18		5	32
	Hard Rock Norite	Mohr-Coulomb	24		100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6		0.1	33
	Soft Rock Norite	Mohr-Coulomb	23		15	35
	Waste Rock Buttress	Mohr-Coulomb	23		0.1	35



Undrained Analysis

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23		0.1	35
	Basin Tailings - Post Liq (above WT)	SHANSEP	19.6	0.2		
	Basin Tailings - Post Liq (below WT)	SHANSEP	19.6	0.08		
	Fill Material	Mohr-Coulomb	18		5	32
	Hard Rock Norite	Mohr-Coulomb	24		100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6		0.1	33
	Soft Rock Norite	Mohr-Coulomb	23		15	35
	Waste Rock Buttress	Mohr-Coulomb	23		0.1	35



Residual Analysis

REMINING: BENCH DROP ANALYSIS

Overview

S1 Section Flank

- Basin and embankment lowered in 6 m benches.
- Remining slope of 1V:8H.

S2 Section Flank

- Basin and embankment lowered in 6 m benches.
- Remining slope of 1V:8H.

S3 Section Flank

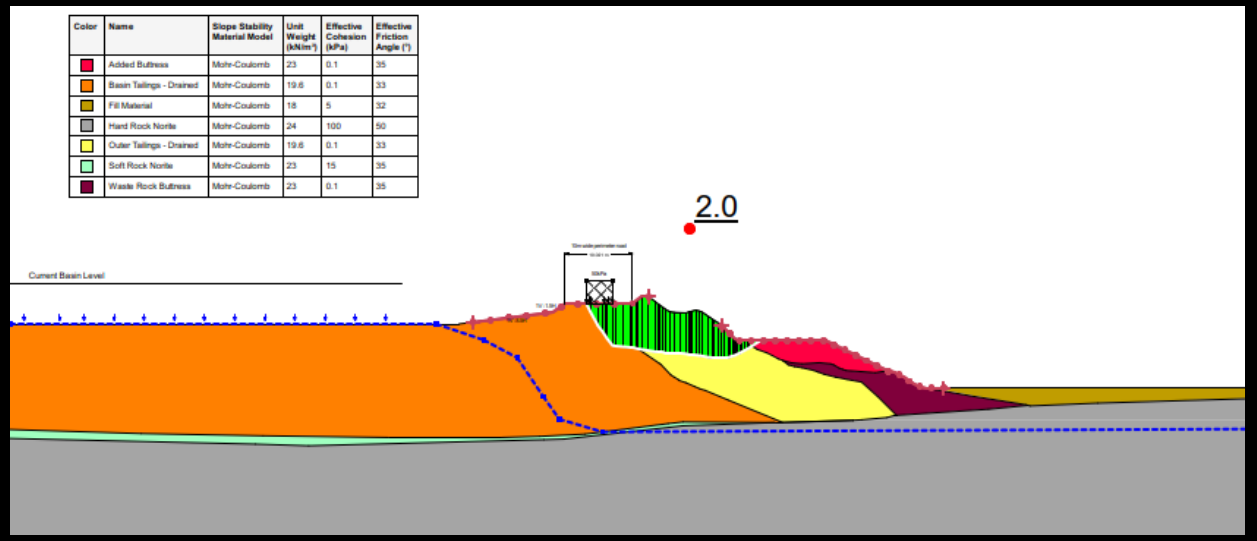
- Basin and embankment lowered in 6 m benches.
- Remining slopes of 1V:1.5H.

S4 Section Flank

- Basin and embankment lowered in 6 m benches.
- Embankment progressively lowered with each bench, maintaining consistent freeboard of 3 m plus above mining bench.

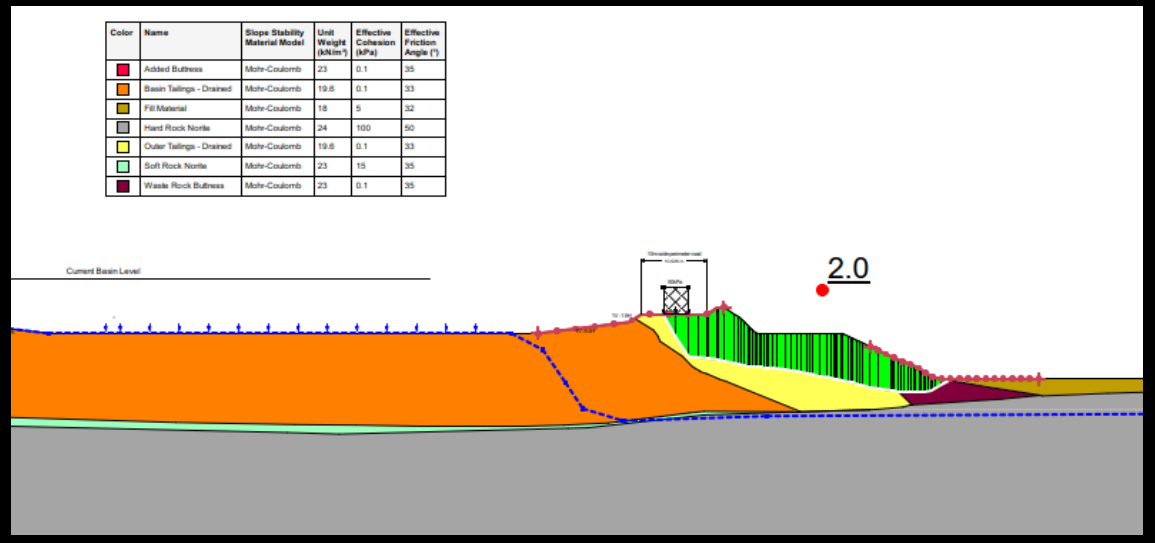
S2(Drained) - Bench Drops

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23	0.1	35
	Basin Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Fill Material	Mohr-Coulomb	18	5	32
	Hard Rock Norite	Mohr-Coulomb	24	100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Soft Rock Norite	Mohr-Coulomb	23	15	35
	Waste Rock Buttress	Mohr-Coulomb	23	0.1	35



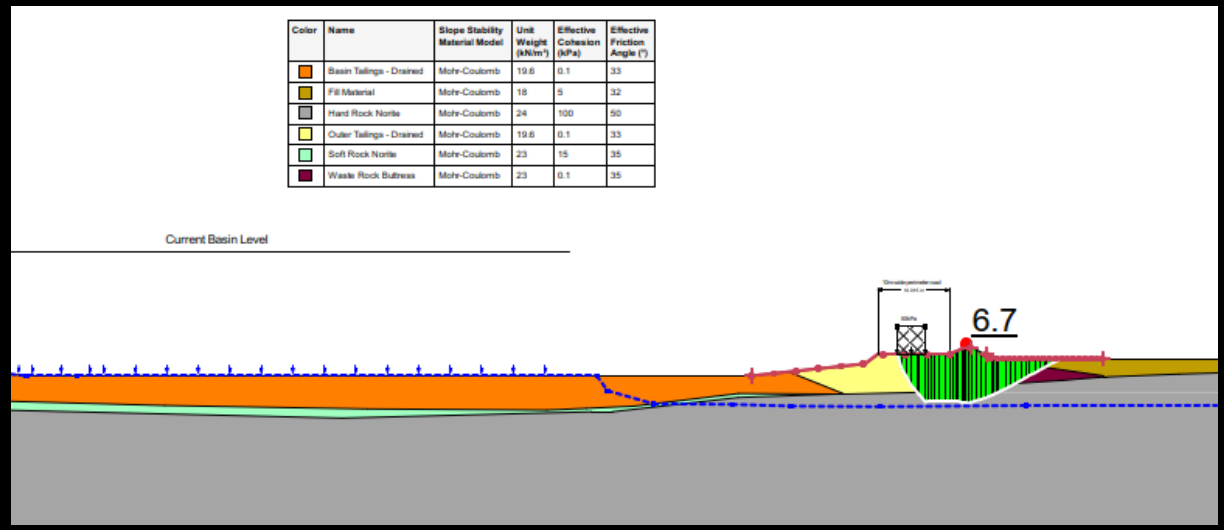
6 m

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23	0.1	35
	Basin Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Fill Material	Mohr-Coulomb	18	5	32
	Hard Rock Norite	Mohr-Coulomb	24	100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Soft Rock Norite	Mohr-Coulomb	23	15	35
	Waste Rock Buttress	Mohr-Coulomb	23	0.1	35



12 m

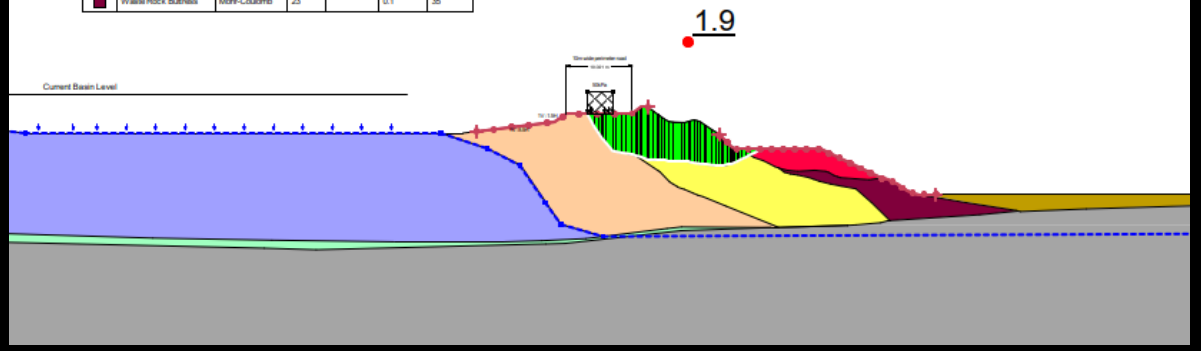
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Basin Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Fill Material	Mohr-Coulomb	18	5	32
	Hard Rock Norite	Mohr-Coulomb	24	100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6	0.1	33
	Soft Rock Norite	Mohr-Coulomb	23	15	35
	Waste Rock Buttress	Mohr-Coulomb	23	0.1	35



18 m

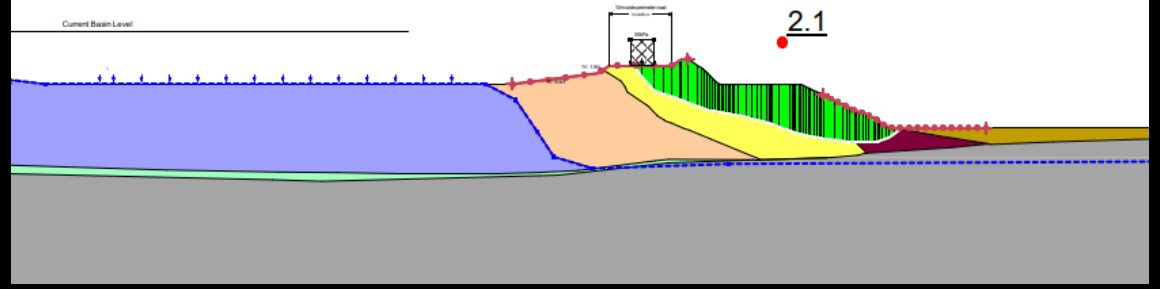
S2 (Undrained) - Bench Drops

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23		0.1	35
	Basin Tailings - Undrained (above WT)	SHANSEP	19.6	0.4		
	Basin Tailings - Undrained (below WT)	SHANSEP	19.6	0.26		
	Fill Material	Mohr-Coulomb	18		5	32
	Hard Rock Norite	Mohr-Coulomb	24		100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6		0.1	33
	Soft Rock Norite	Mohr-Coulomb	23		15	35
	Waste Rock Buttress	Mohr-Coulomb	23		0.1	35



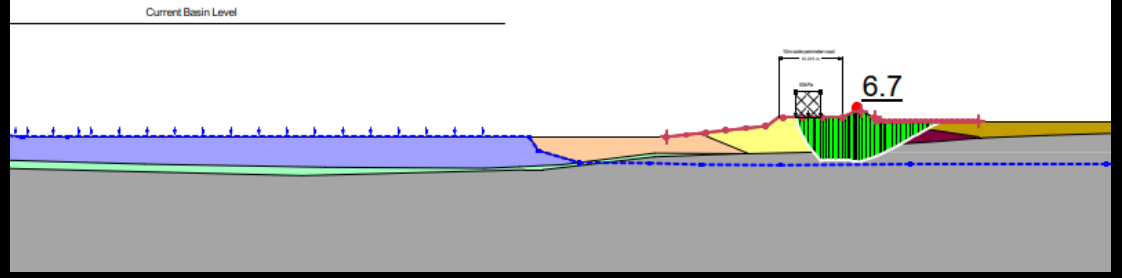
6 m

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23		0.1	35
	Basin Tailings - Undrained (above WT)	SHANSEP	19.6	0.4		
	Basin Tailings - Undrained (below WT)	SHANSEP	19.6	0.26		
	Fill Material	Mohr-Coulomb	18		5	32
	Hard Rock Norite	Mohr-Coulomb	24		100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6		0.1	33
	Soft Rock Norite	Mohr-Coulomb	23		15	35
	Waste Rock Buttress	Mohr-Coulomb	23		0.1	35



12 m

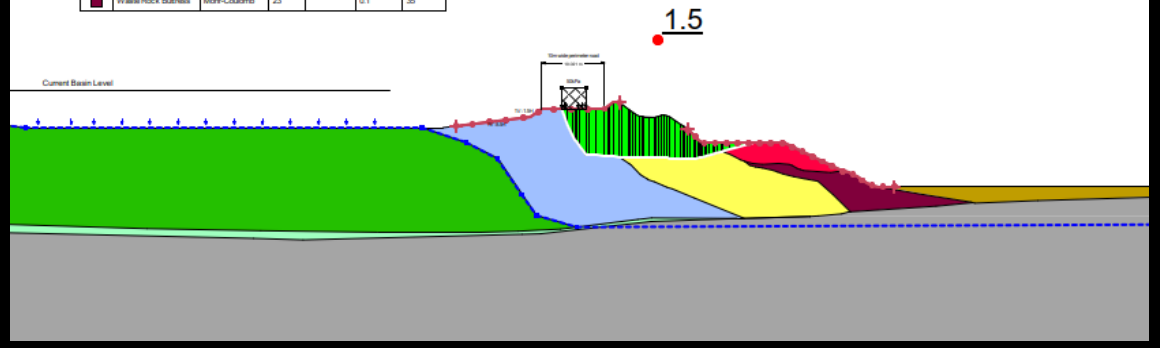
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Tau/Sigma Ratio
	Basin Tailings - Undrained (above WT)	SHANSEP	19.6			0.4
	Basin Tailings - Undrained (below WT)	SHANSEP	19.6			0.26
	Fill Material	Mohr-Coulomb	18	5	32	
	Hard Rock Norite	Mohr-Coulomb	24	100	50	
	Outer Tailings - Drained	Mohr-Coulomb	19.6	0.1	33	
	Soft Rock Norite	Mohr-Coulomb	23	15	35	
	Waste Rock Buttress	Mohr-Coulomb	23	0.1	35	



18 m

S2 (Residual) - Bench Drops

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23		0.1	35
	Basin Tailings - Post Liq (above WT)	SHANSEP	19.6	0.2		
	Basin Tailings - Post Liq (below WT)	SHANSEP	19.6	0.08		
	Fill Material	Mohr-Coulomb	18		5	32
	Hard Rock Norite	Mohr-Coulomb	24		100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6		0.1	33
	Soft Rock Norite	Mohr-Coulomb	23		15	35
	Waste Rock Buttress	Mohr-Coulomb	23		0.1	35

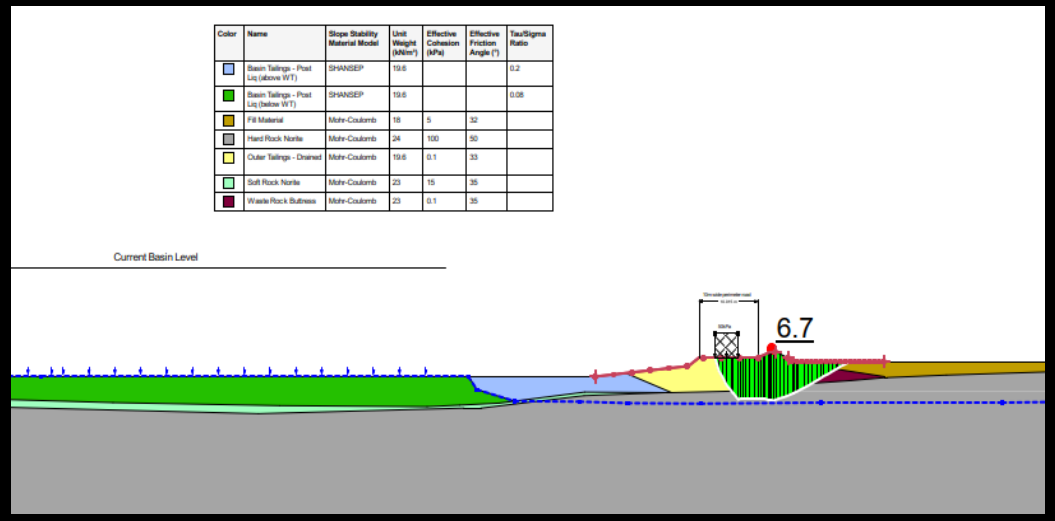


6 m

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Tau/Sigma Ratio	Effective Cohesion (kPa)	Effective Friction Angle (°)
	Added Buttress	Mohr-Coulomb	23		0.1	35
	Basin Tailings - Post Liq (above WT)	SHANSEP	19.6	0.2		
	Basin Tailings - Post Liq (below WT)	SHANSEP	19.6	0.08		
	Fill Material	Mohr-Coulomb	18		5	32
	Hard Rock Norite	Mohr-Coulomb	24		100	50
	Outer Tailings - Drained	Mohr-Coulomb	19.6		0.1	33
	Soft Rock Norite	Mohr-Coulomb	23		15	35
	Waste Rock Buttress	Mohr-Coulomb	23		0.1	35

12 m

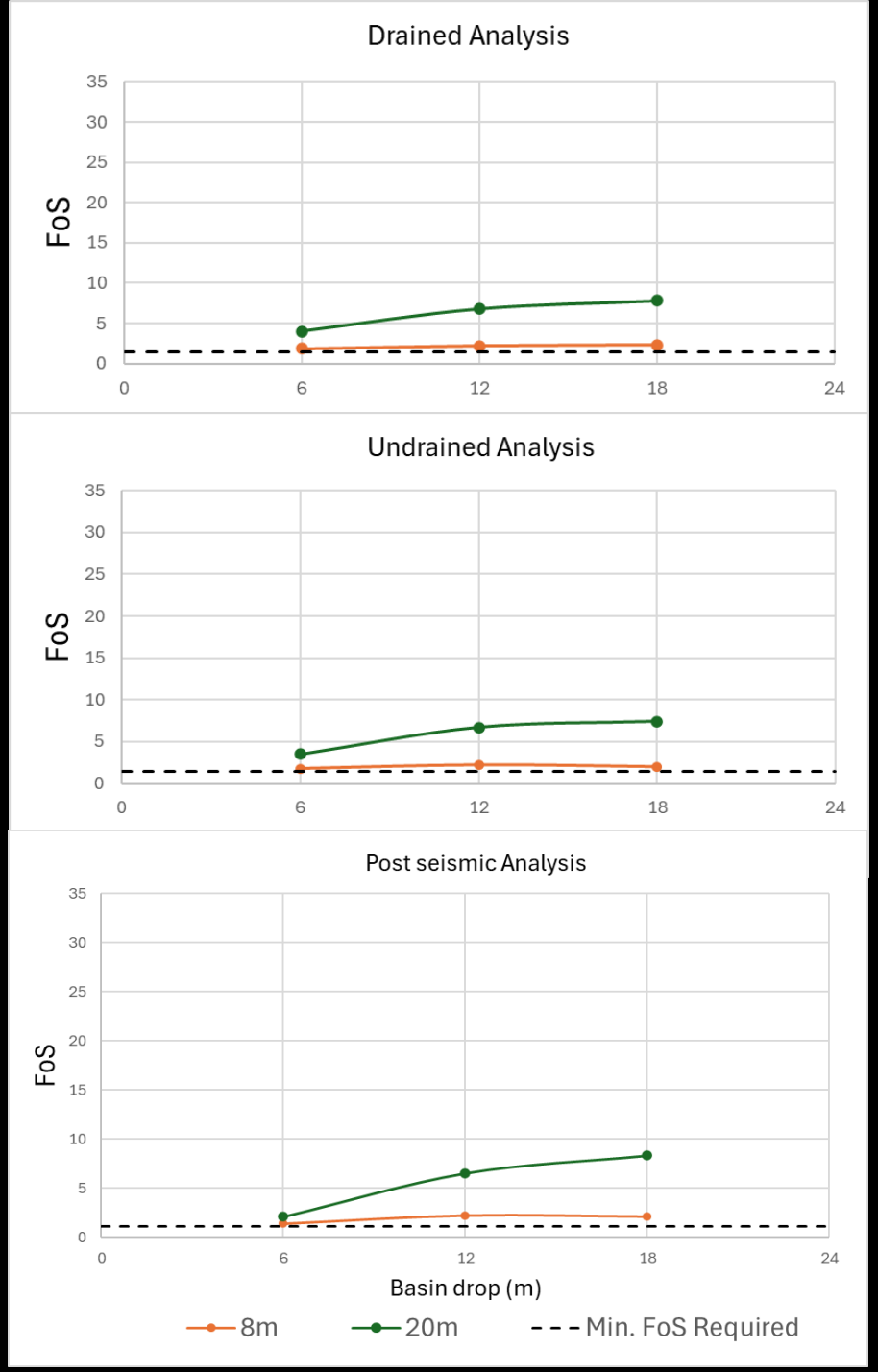
Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Tau/Sigma Ratio
	Basin Tailings - Post Liq (above WT)	SHANSEP	19.6			0.2
	Basin Tailings - Post Liq (below WT)	SHANSEP	19.6			0.08
	Fill Material	Mohr-Coulomb	18	5	32	
	Hard Rock Norite	Mohr-Coulomb	24	100	50	
	Outer Tailings - Drained	Mohr-Coulomb	19.6	0.1	33	
	Soft Rock Norite	Mohr-Coulomb	23	15	35	
	Waste Rock Buttress	Mohr-Coulomb	23	0.1	35	



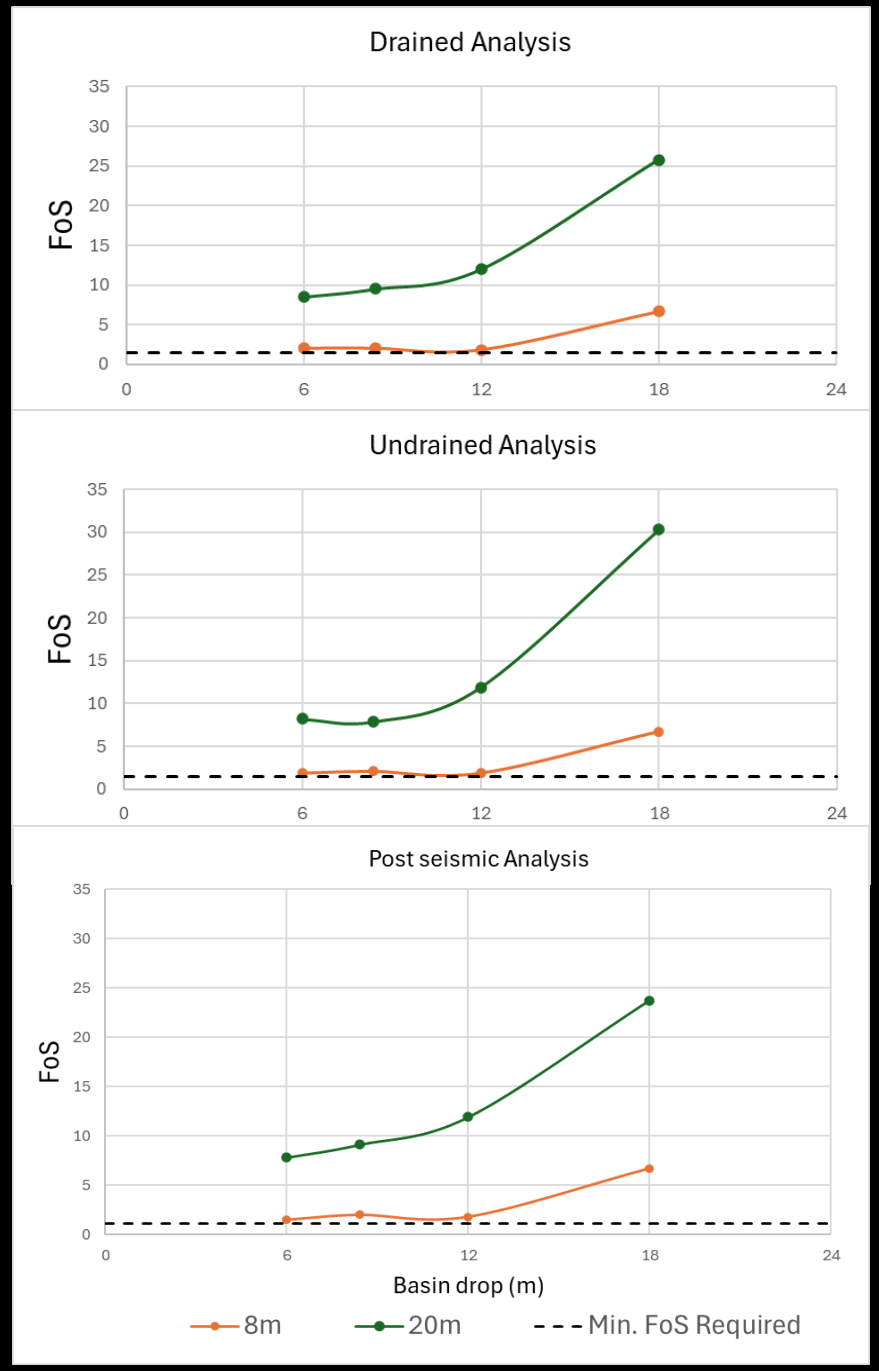
18 m

FoS vs BENCH DROPS

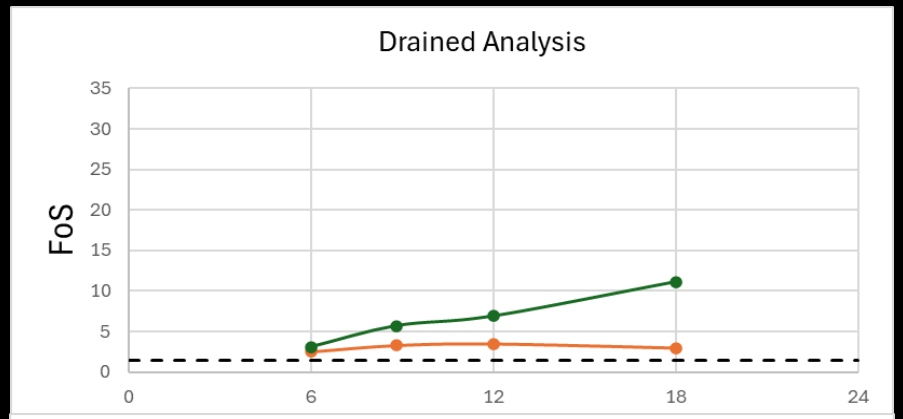
S1 - Bench Drops

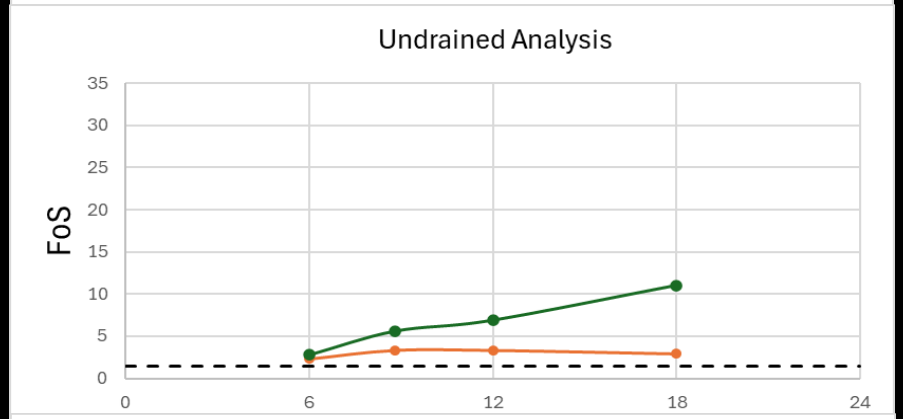


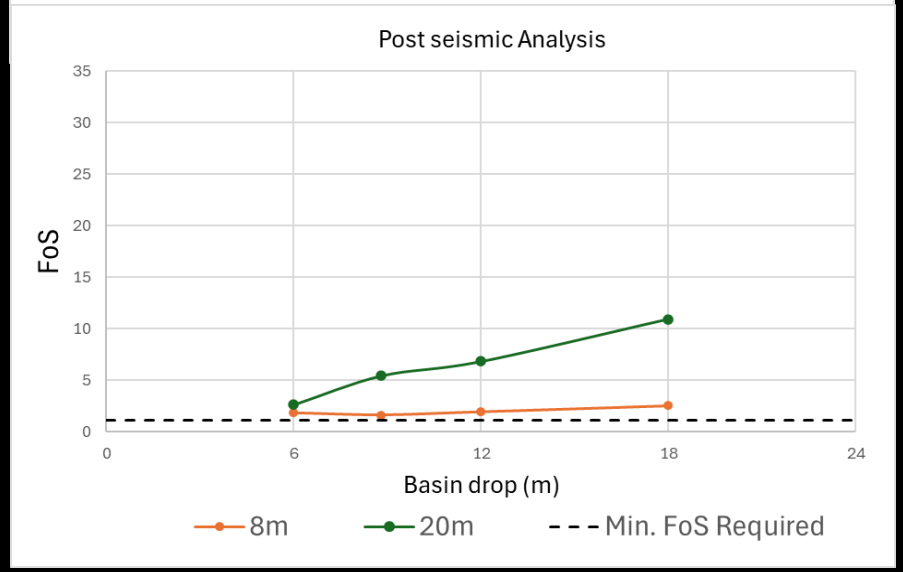
S2 - Bench Drops



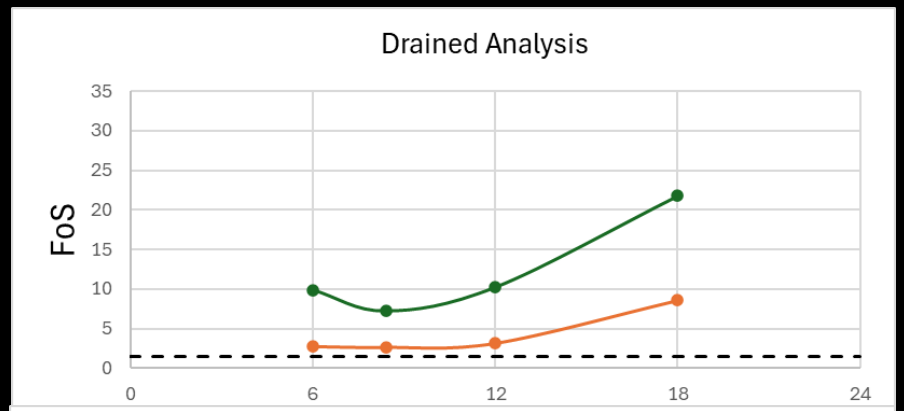
S4 - Bench Drops

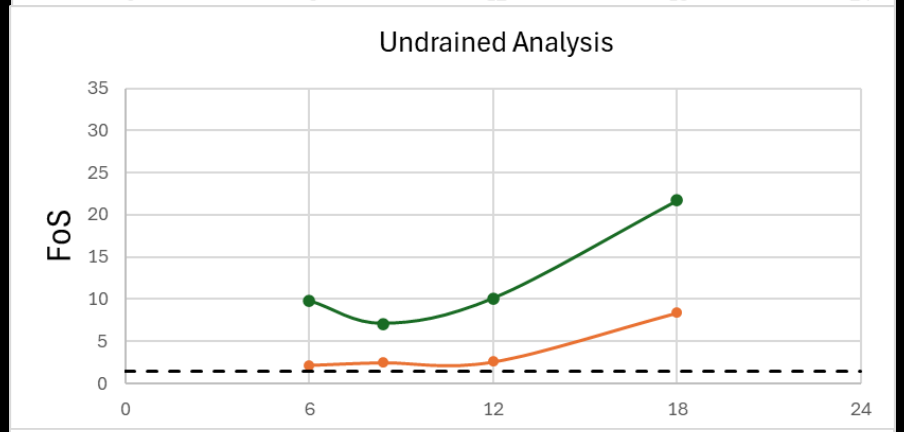


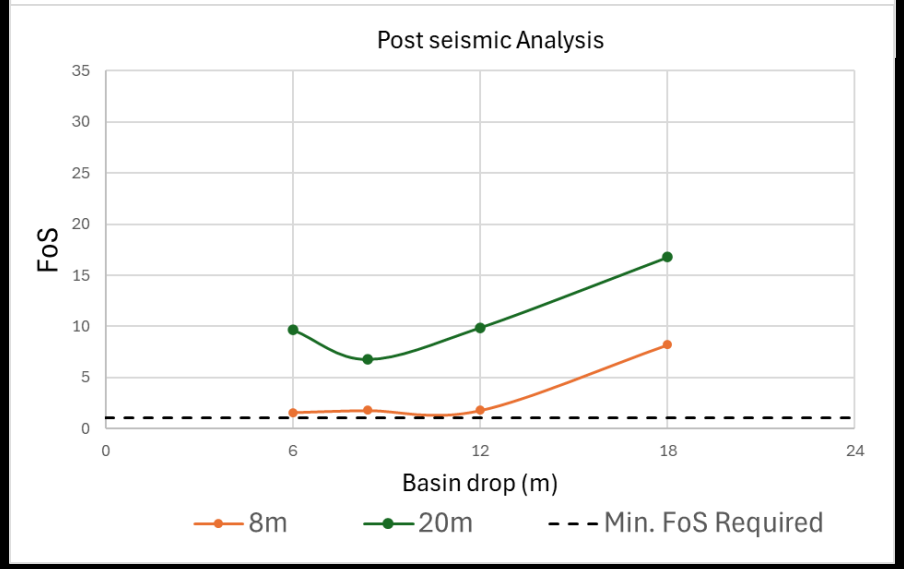




S3 - Bench Drops







Conclusions

- Current case FoS improvement.
- Static (drained & undrained) and Post-seismic FoS acceptable for all cases.
- FoS increases as basin and embankment are lowered.

Recommendations

- Stability should be reviewed periodically as tailings mining progresses.
- Instrumentation care.
- Routine inspection, Surveillance & Monitoring.

Thank you