Ingeniería de Minas
FACULTAD DE CIENCIAS FÍSICAS Y MATEMÁTICAS UNIVERSIDAD DE CHILE
Educación continua

Diploma en Geomecánica Aplicada al Diseño Minero

9ª. Versión

2024-2025

Módulo 4: Geomecánica en Minería a Cielo Abierto

BHP

Geotecnia de botaderos de lastre y ripios

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Introduction

Waste dumps are associated with large open pit mines

East Dump at the Antamina Mine, Peru, 2010 (Guidelines for Waster dump and Stockpile design, 2017)

Introduction

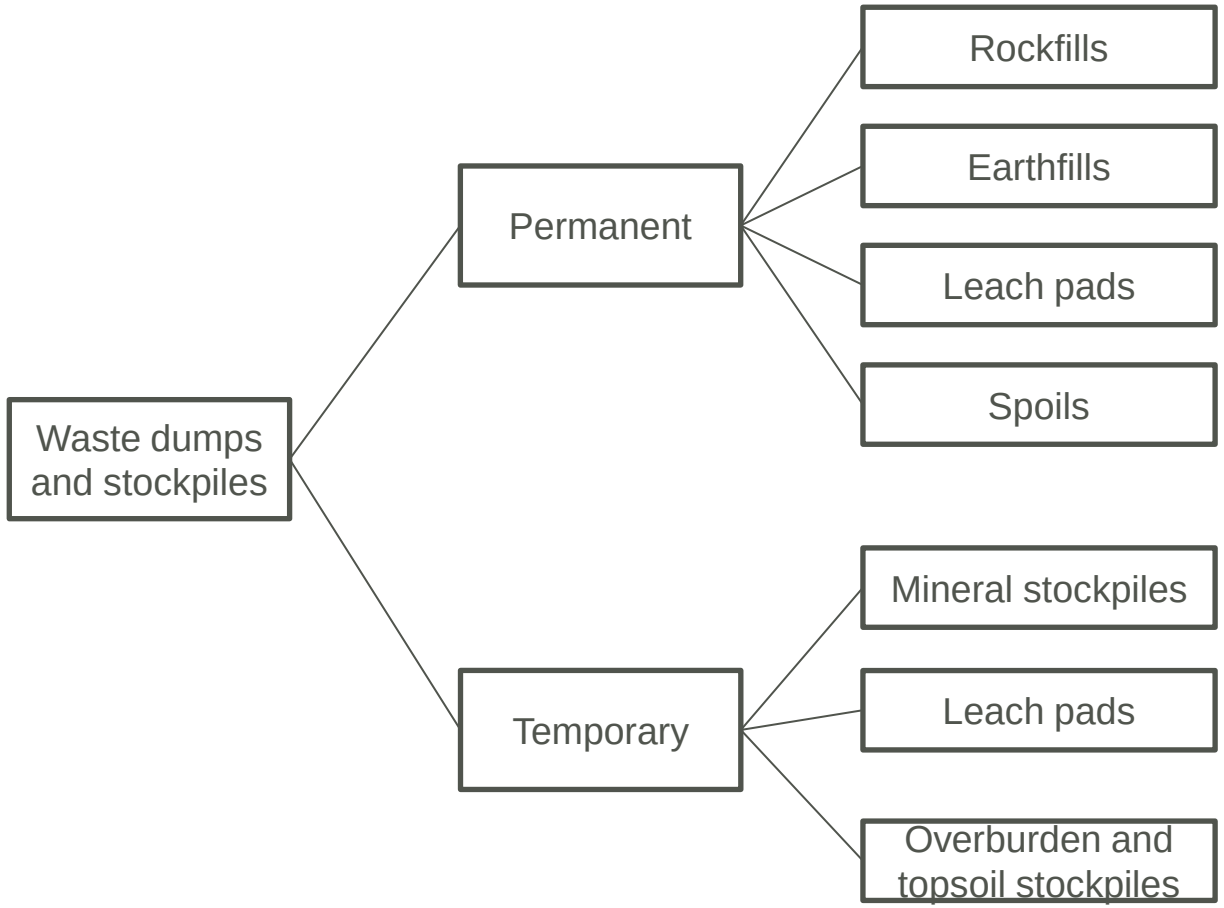
Waste dumps and stockpiles may cover extensive footprints

BHP - Copper Cities Mine Layout, Arizona, US

BHP – Cerro Colorado, Iquique, Chile

Waste dump and stockpile types

Adapted from Hawley & Cunning (2017)



Mined rock (waste)

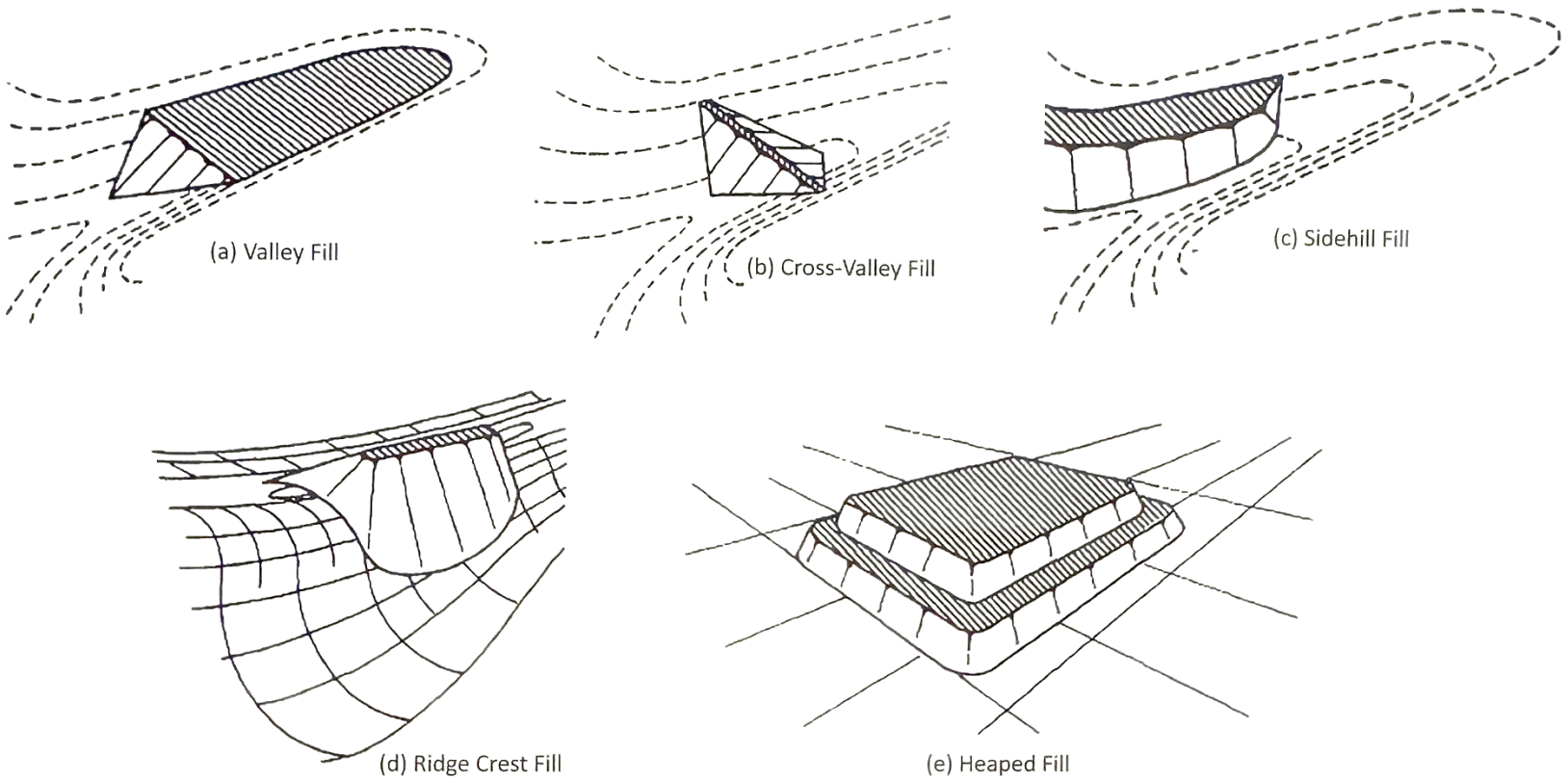
Surficial soils, Residual soils, very weak rocks, etc.

Tailings, ripios

Mined rock (ore)

Waste dump and stockpile types

From Hawley & Cunning (2017)



Basic design considerations

Site selection factors

Regulatory/Social	Mining	Terrain & Geology	Environmental	Geotechnical	Fill material quality	Closure
• Permitting requirements	• Proximity	• Topography	• Climate	• Foundation slopes	• Gradation	• Containment
• Regulated standards	• Access	• Geomorphology	• Vegetation	• Foundation shape	• Intact strength	• Reshaping
• Land ownership	• Mining method	• Natural hazards	• Hydrology	• Overburden type	• Durability	• Reclamation
• Inhabitant relocation	• Haulroad grades	• Bedrock geology	• Hydrogeology	• Overburden thickness	• Chemical stability	• Water quality
• Land & water use	• Equipment	• Surficial geology	• Water quality	• Bedrock competency		
• Visual quality	• Capacity	• Glaciology	• Dust	• Groundwater		
• Archaeology	• Alternative users		• Habitat			
• Artisanal mining	• Mineral potential					

Site selection criteria

Identify potential sites

Prioritise sites for further studies

Conceptual design

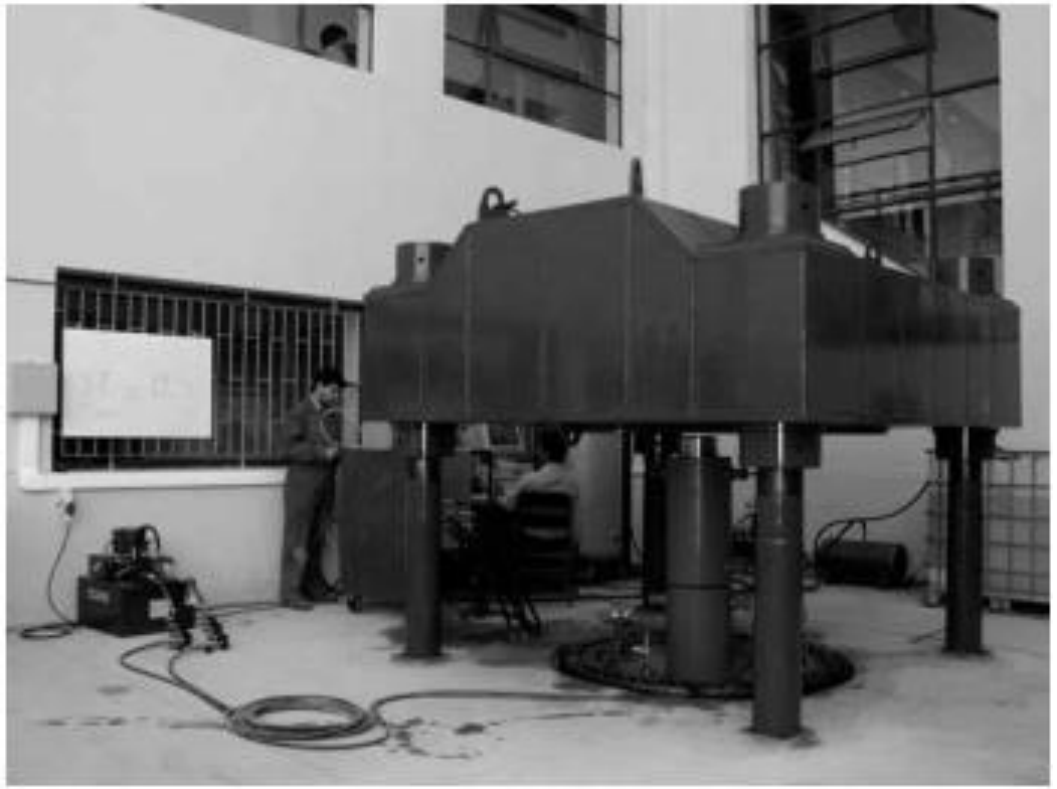
Site and material characterisation

Geotechnical characterisation of waste material (Lineros et al, 2007)

Waste dump characterisation

- Waste dump material is composed mainly of mined rock (coarse material) and challenging to be tested.

- Special equipment allow to test specimens of 2 m high and 1 m in diameter, under controlled stress conditions, and confining pressures up to 2.5 MPa.



Triaxial equipment at IDIEM laboratory

Site and material characterisation

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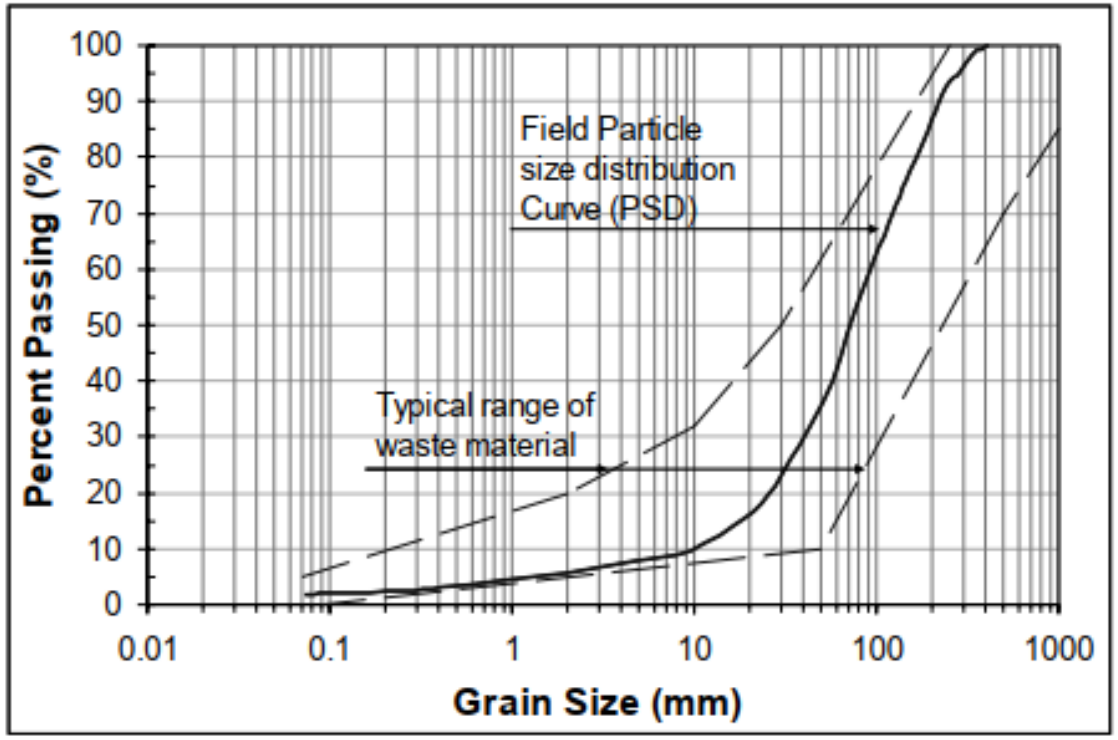
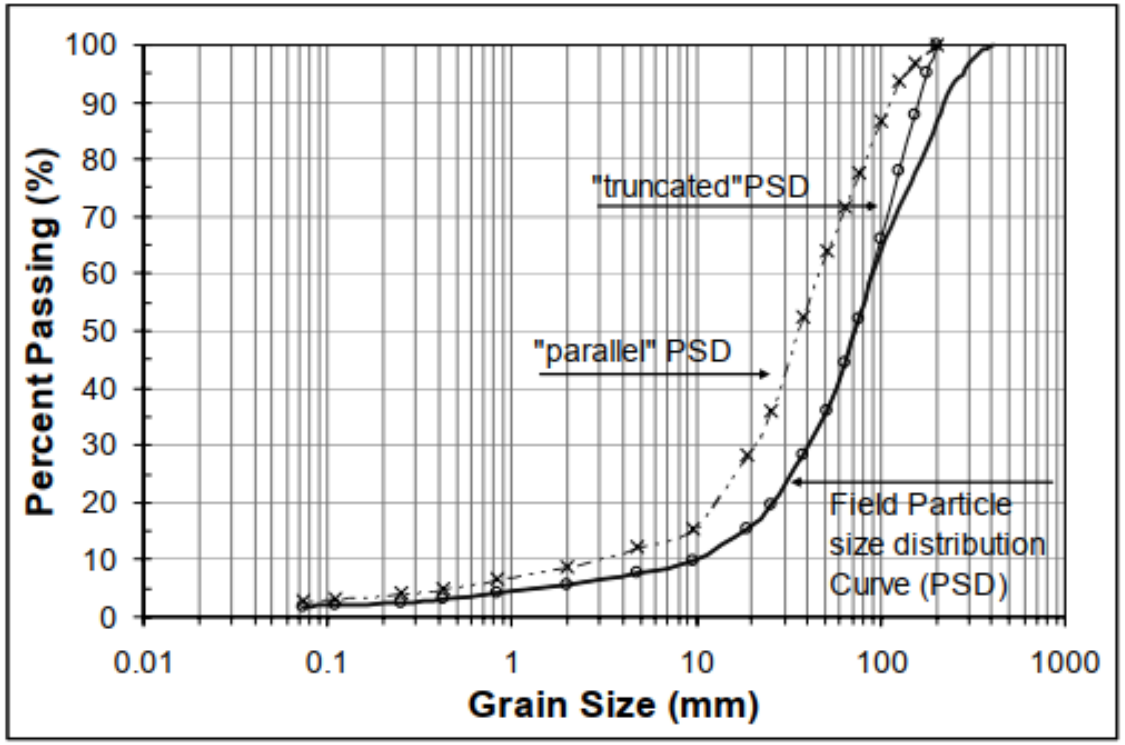
Geotechnical characterisation of waste material (Lineros et al, 2007)

Waste dump characterisation



Particle size distributions of the field sample and typical range of waste materials



Particle size distribution: field sample curve, “parallel” curve and “truncated” curve

Site and material characterisation

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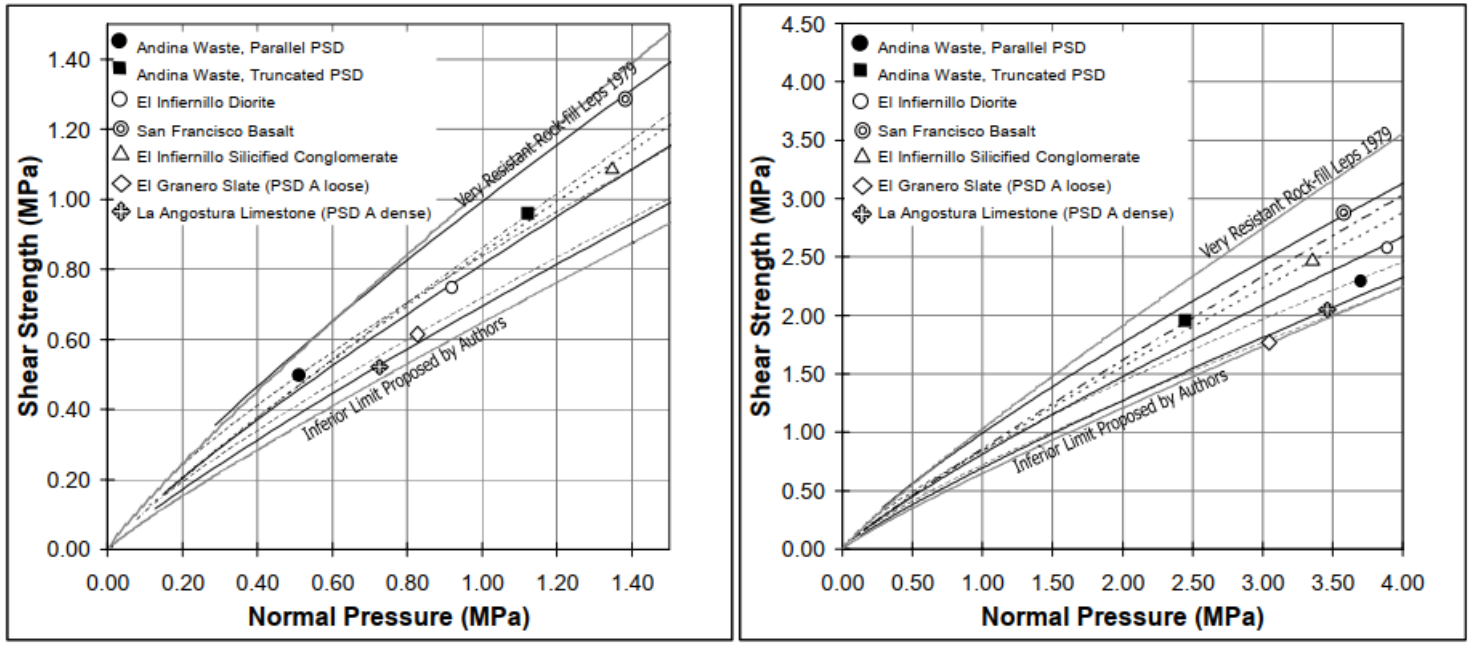
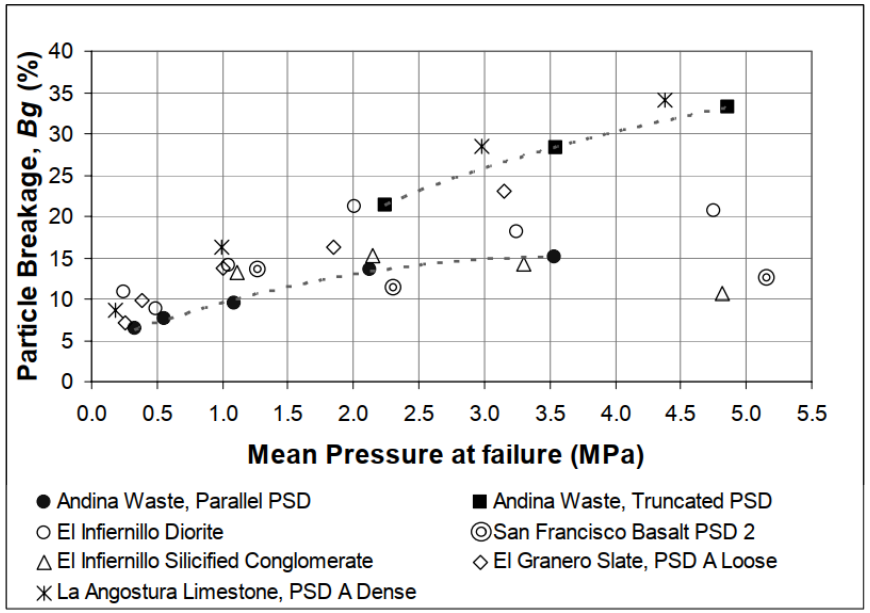
Geotechnical characterisation of waste material (Lineros et al, 2007)

Waste dump material strength



Failure envelopes at different levels of confinement



Grain breakage (Bg) parameter variation

Site and material characterisation

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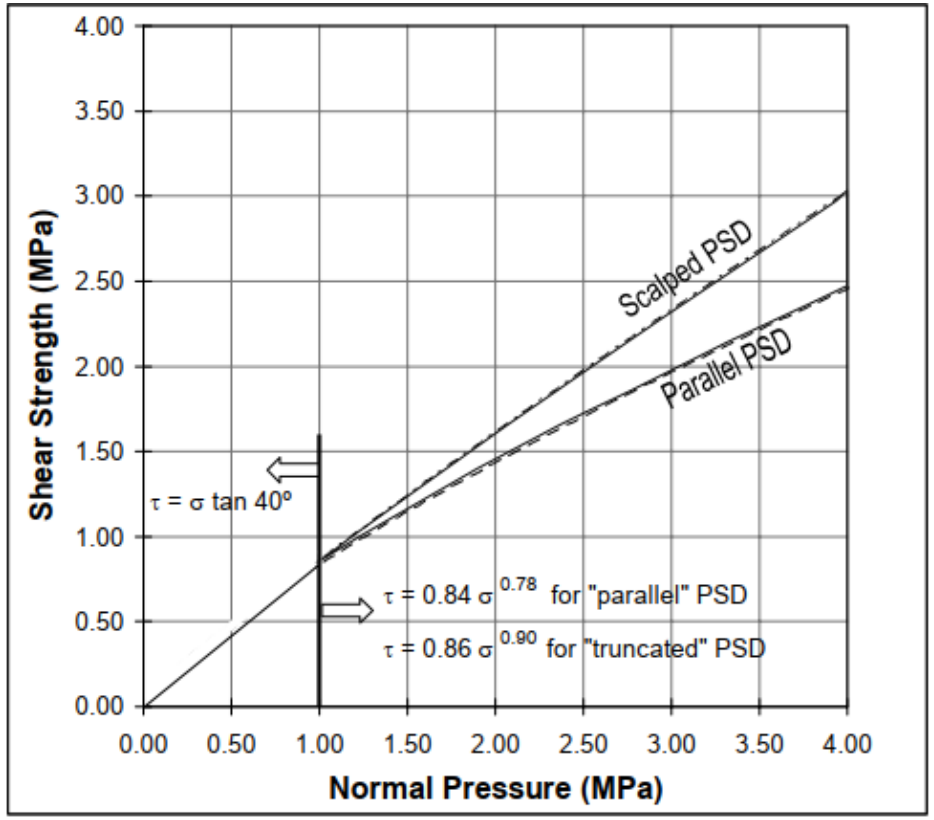
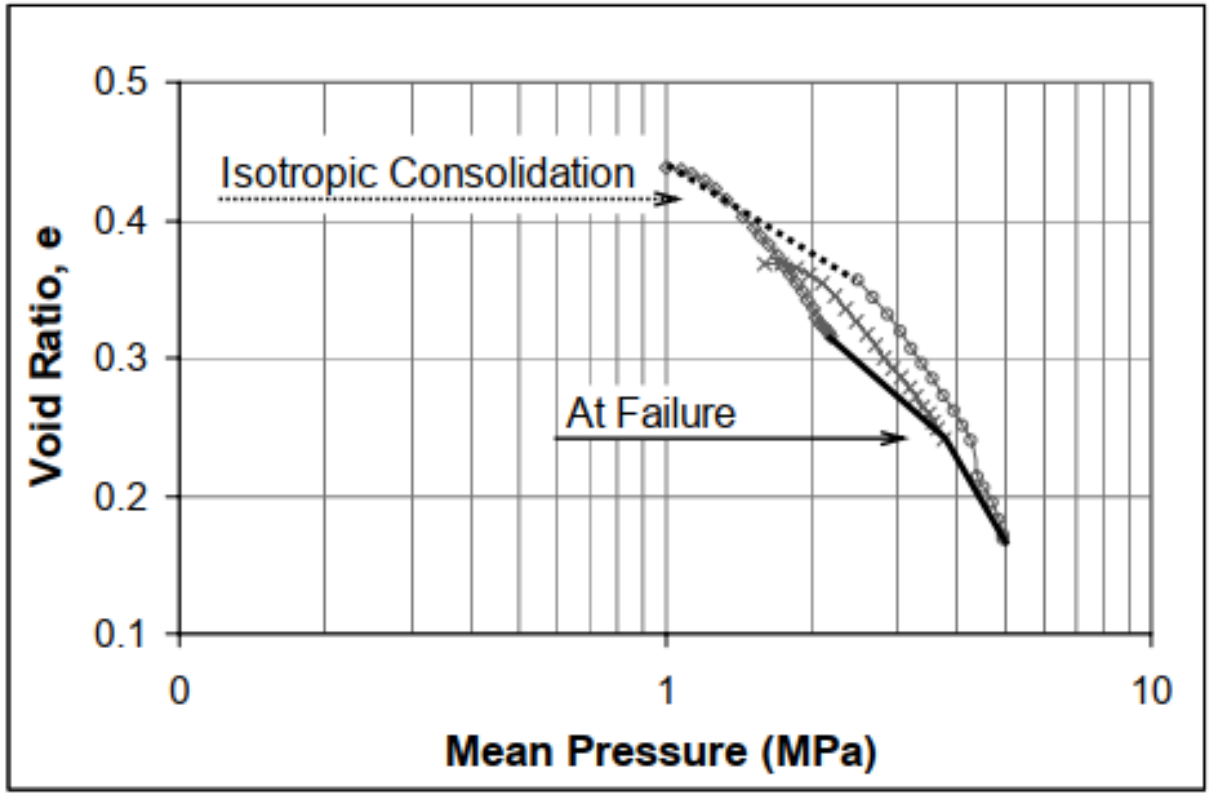
Geotechnical characterisation of waste material (Lineros et al, 2007)

Waste dump material strength



Failure envelopes for “truncated” and “parallel” PSD curves



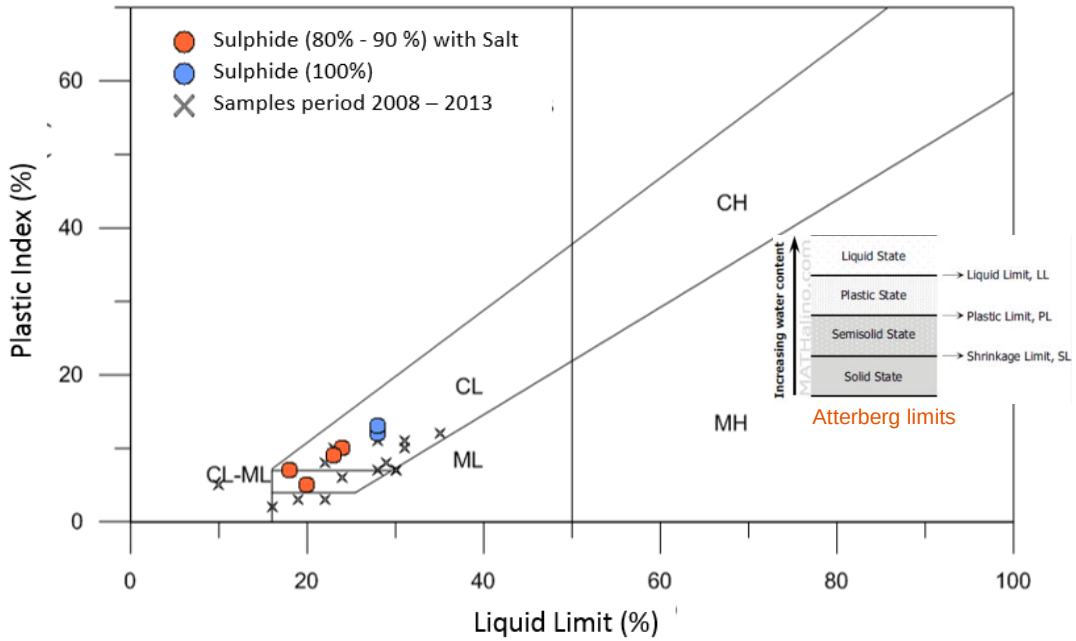
Voids ratio versus Mean pressure, “truncated” PSD

Site and material characterisation

Geotechnical characterisation of ripios (Rimmelin & Vergara, 2018)

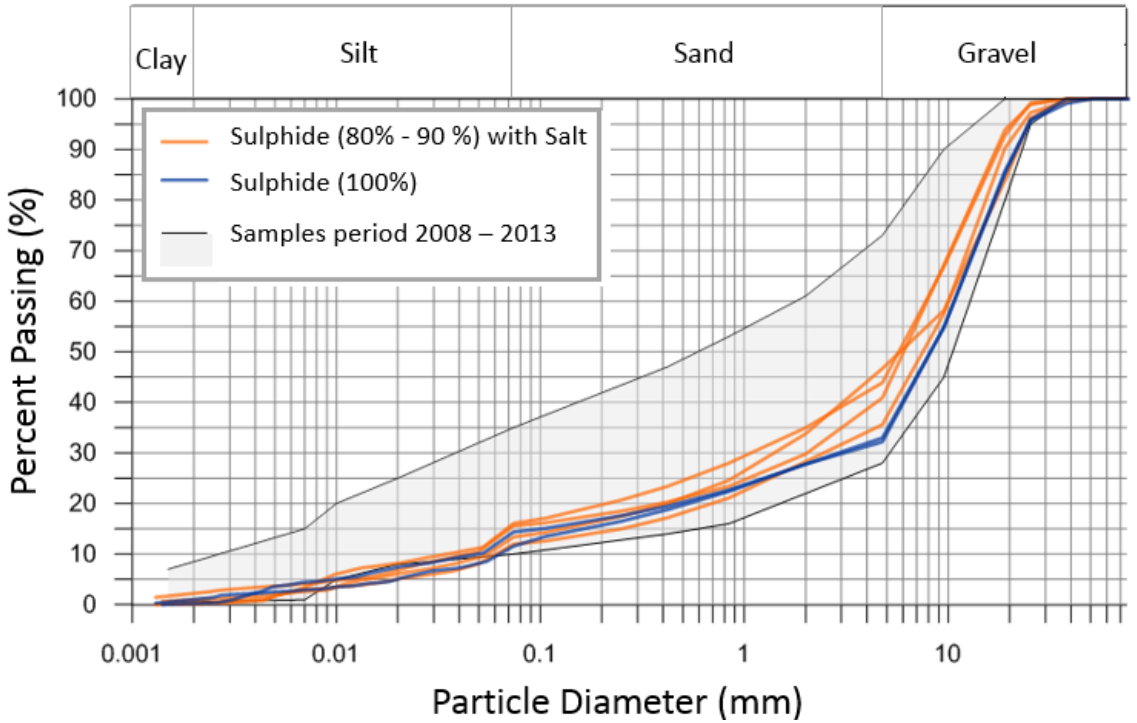
Ripios material strength

LL - PL



Plasticity chart for classification of fine-grained soils

CL = Clay of low plasticity; OL/OH = Organic silt or organic clay; CH = Clay of high plasticity; CL-ML = Silt-Clay; ML = Silt of low plasticity; MH = Silt of high plasticity



Site and material characterisation

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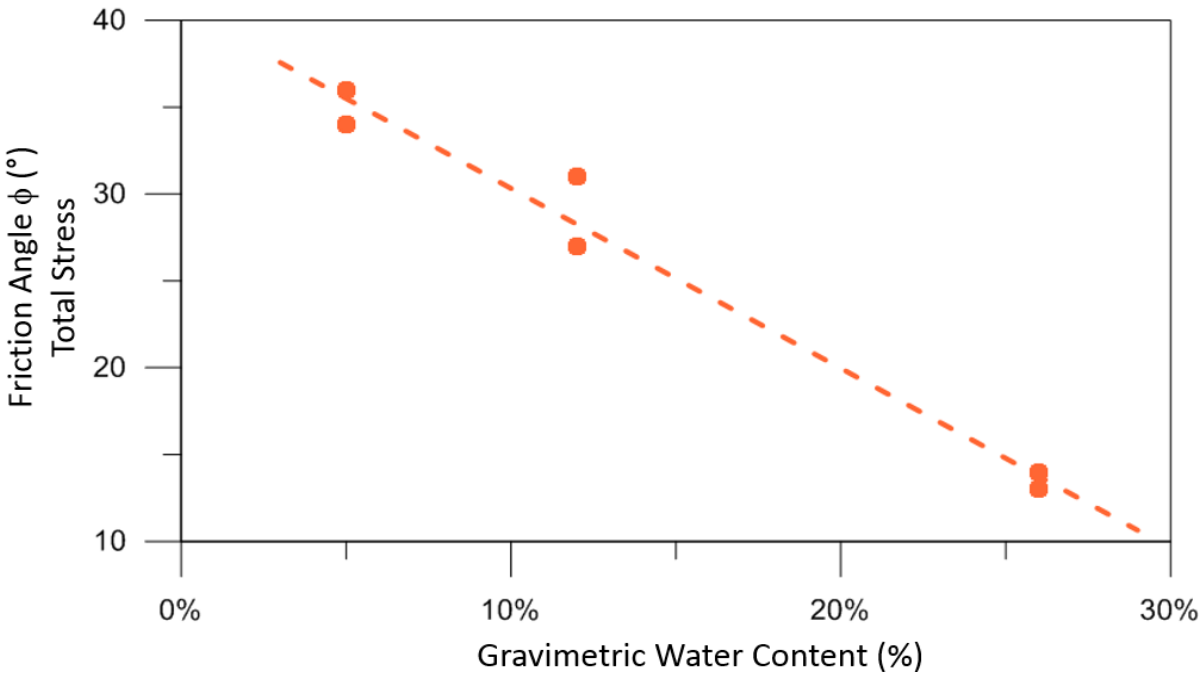
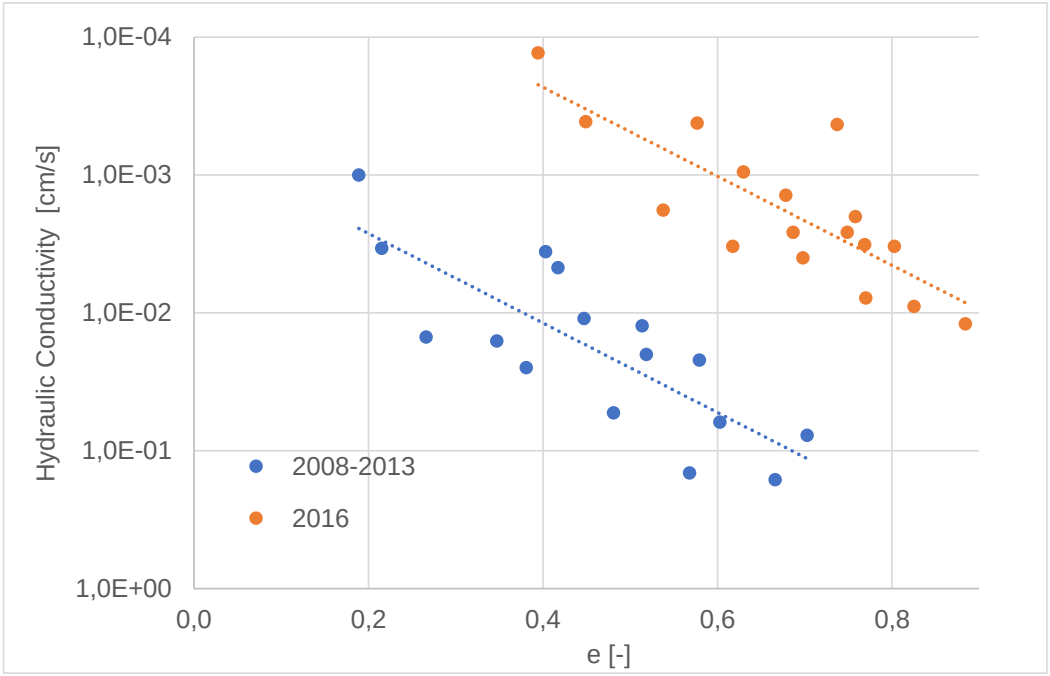
Geotechnical characterisation of ripios (Rimmelin & Vergara, 2018)

Ripios material strength



Friction angle (total stress) for CIU Unsaturated triaxial test

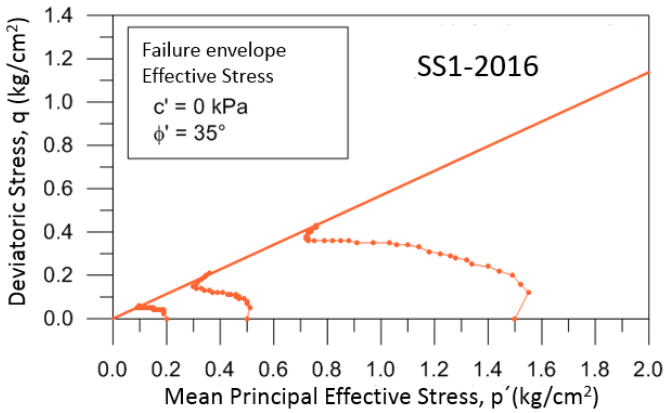


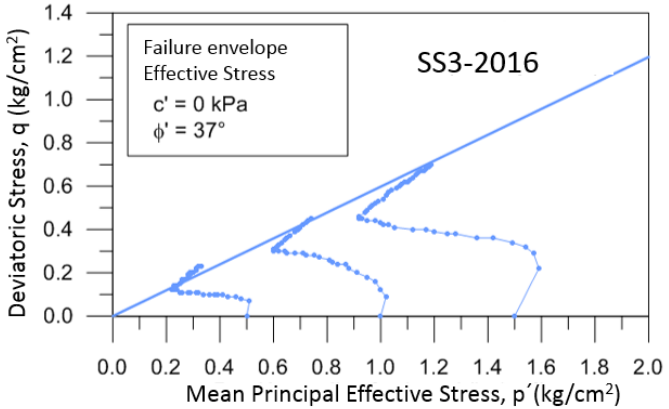
Hydraulic conductivity vs void ratio

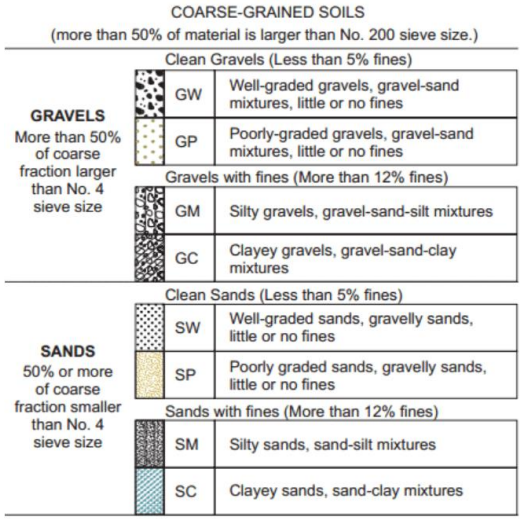
Site and material characterisation

Geotechnical characterisation of ripios (Rimmelin & Vergara, 2018)

Ripios material strength







Oxides

Sulphides

Sample	USCS Classification	%Gravel	%Fine	ϕ' (°)
OS1-2008	SC	34	27	29
OS2-2008	GM	55	14	36
OS1-2012	SC-SM	32	22	31
OS1-2013	GM	62	15	37
SS1-2013	GM	72	15	39
SS1-2016	GC	56	16	35
SS2-2016	GP-GC	64	12	36
SS3-2016	GP-GC	67	13	37

Note: OS: Oxide Sample / SS: Sulphide Sample (>80% Sulphide)

Surface water and groundwater characterisation

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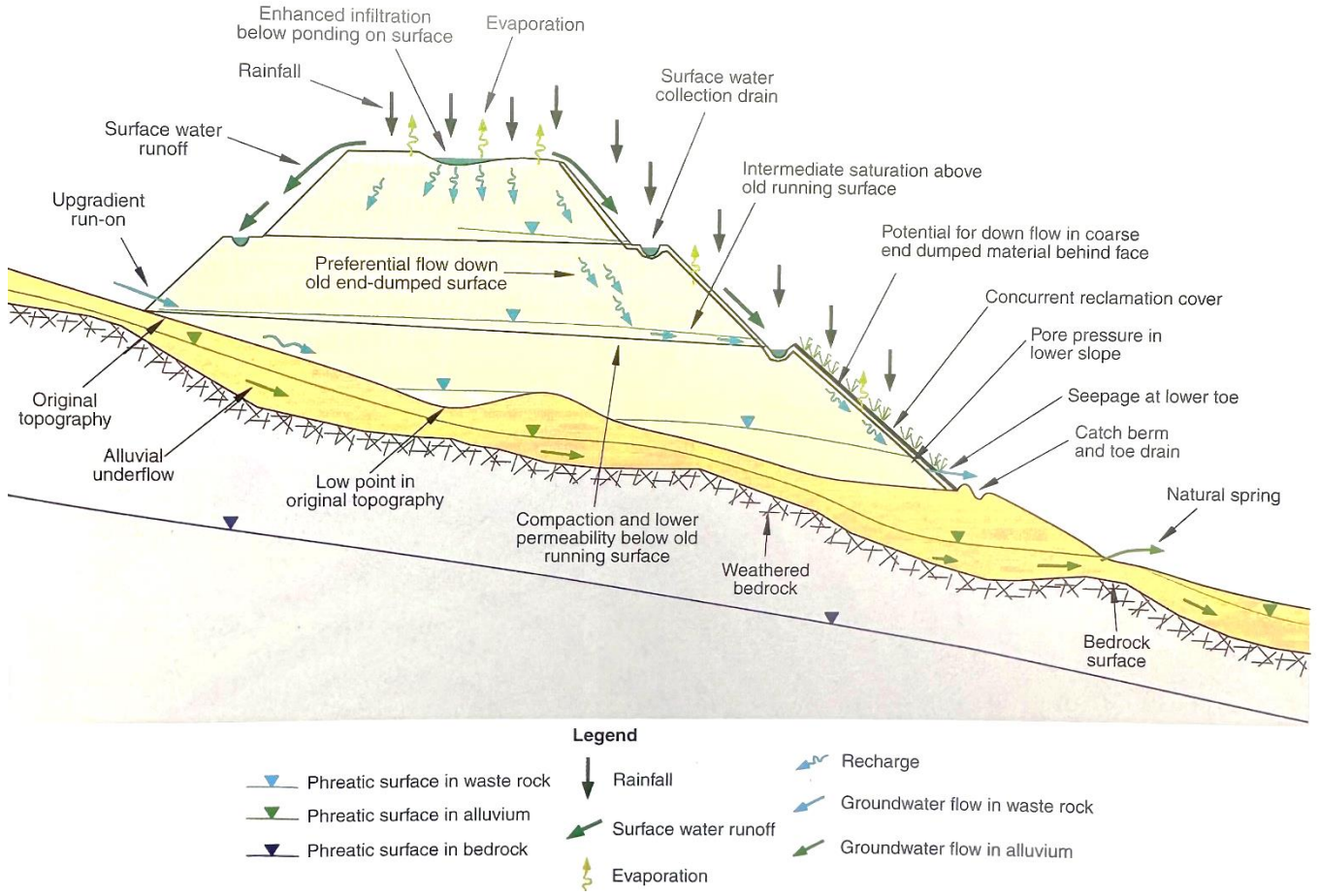
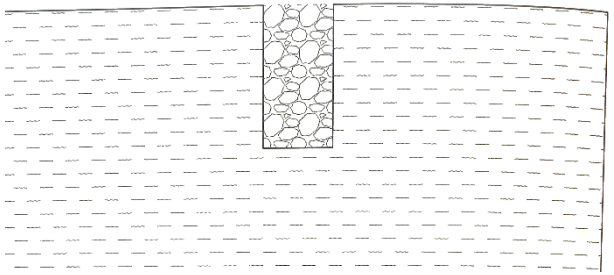
Conceptual hydrogeological model of a mine waste dump or stockpile (Hawley & Cunning, 2017)

Illustration of piping along internal preferential flow pathways

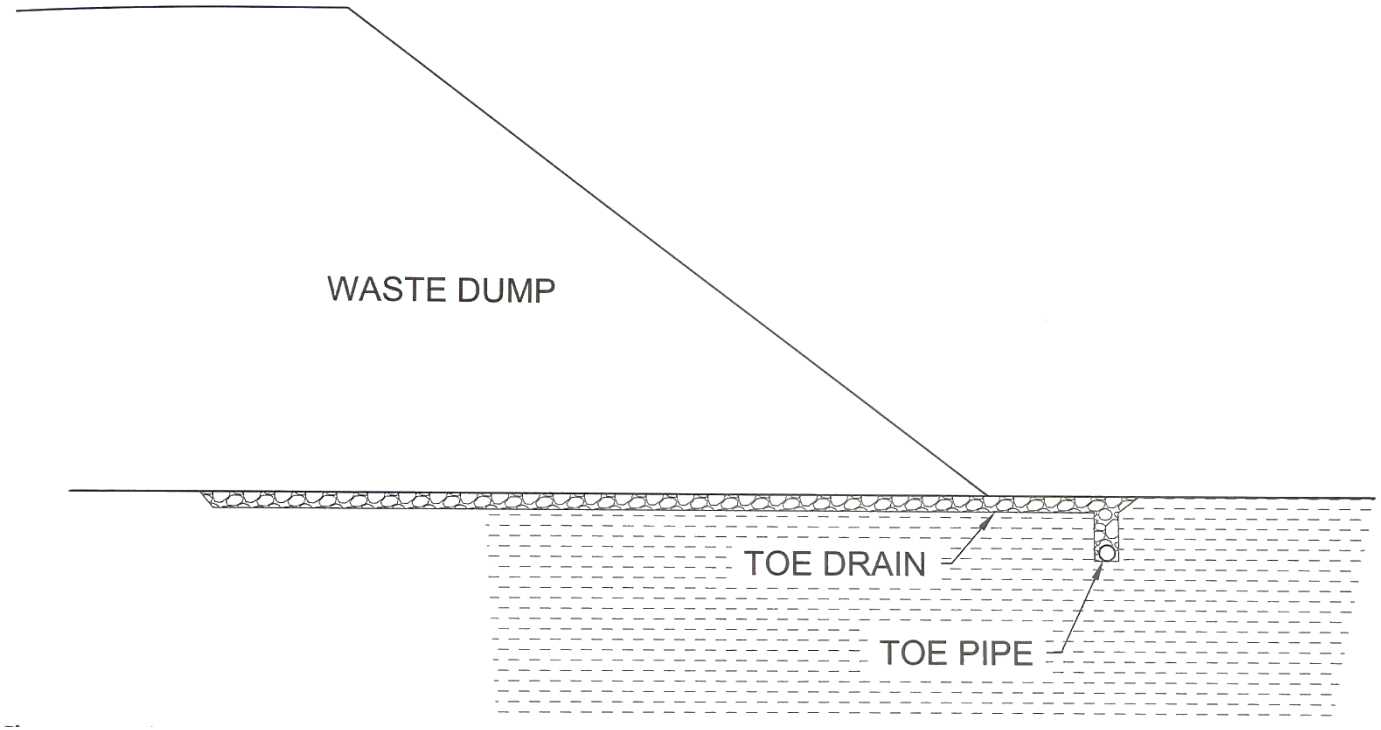


Diversion and rock drains



French drain composed of a ditch filled with drain rock

Rock drain under construction showing drain rock and granular filters



Schematic illustration of a toe drain with an integral drain pipe

Stability analysis

Acceptance criteria charts

(a) STATIC ANALYSIS[1,2,3]

CONSEQUENCE[2] \ CONFIDENCE[2]	LOW	MODERATE	HIGH
HIGH	FoS ≥ 1.5 PoF ≤ 1%	FoS 1.4-1.5 PoF 1-2.5%	FoS 1.3-1.4 PoF 2.5-5%
MODERATE	FoS 1.4-1.5 PoF 2.5-5%	FoS 1.3-1.4 PoF 5-10%	FoS 1.2-1.3 PoF 10-15%
LOW	FoS 1.3-1.4 PoF 10-15%	FoS 1.2-1.3 PoF 15-25%	FoS 1.1-1.2 PoF 25-40%

(b) PSEUDO-STATIC ANALYSIS[1]

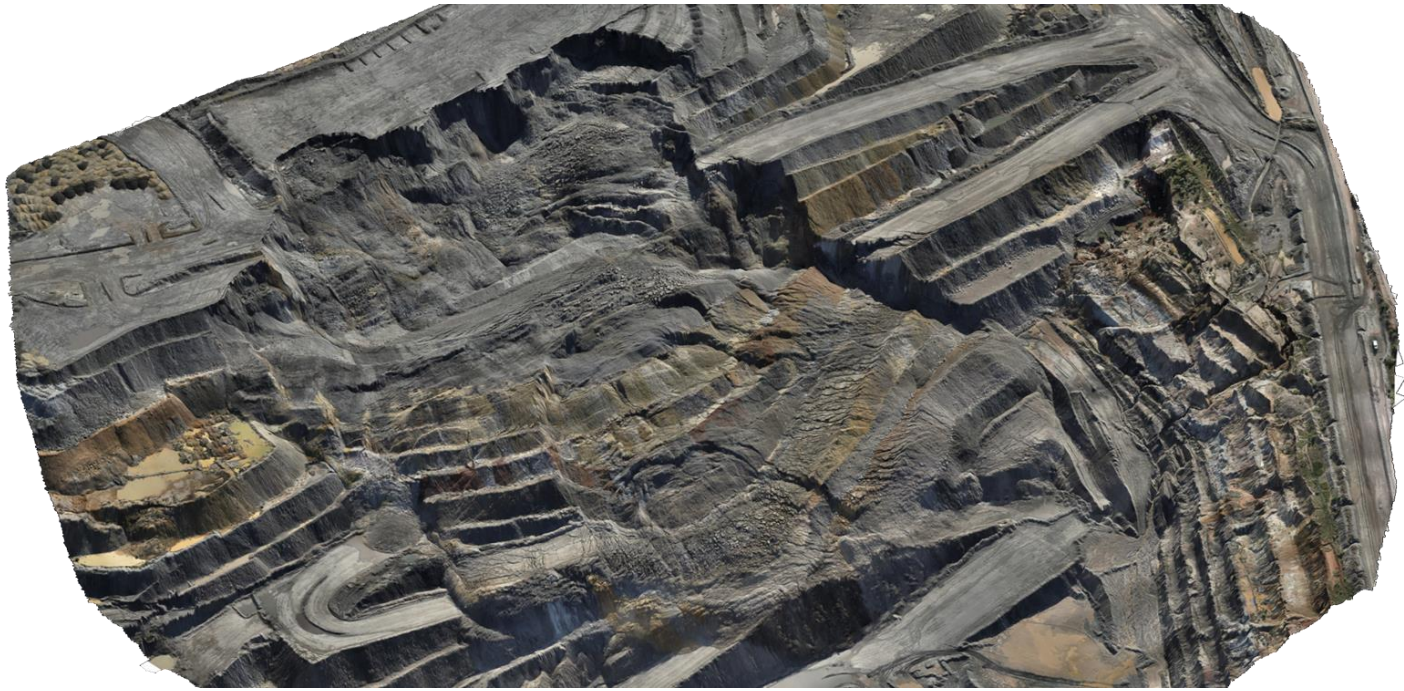
CONSEQUENCE[2] \ CONFIDENCE[2]	LOW	MODERATE	HIGH
HIGH	FoS ≥ 1.15	FoS 1.1-1.15	FoS 1.05-1.1
MODERATE	FoS 1.1 -1.15	FoS 1.05-1.1	FoS 1.0-1.05
LOW	FoS 1.05-1.1	FoS 1.0-1.05	FoS ≥ 1.0

(c) DEFORMATION ANALYSIS[4]

CONSEQUENCE[2] \ CONFIDENCE[2]	LOW	MODERATE	HIGH
HIGH	≤ 0.5% Strain	≤ 0.75% Strain	≤ 1% Strain
MODERATE	≤ 0.75% Strain	≤ 1% Strain	≤ 1.5% Strain
LOW	≤ 1% Strain	≤ 1.5% Strain	≤ 2% Strain

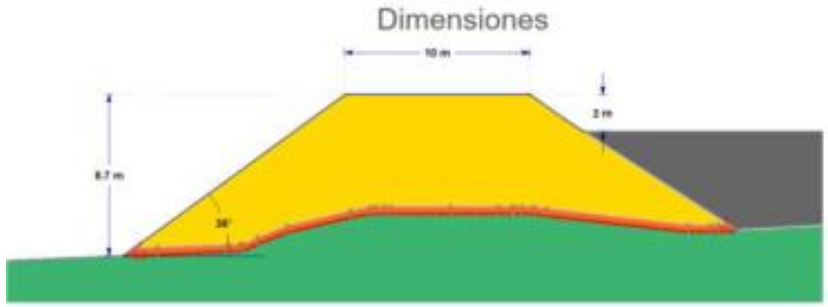
Stability analysis

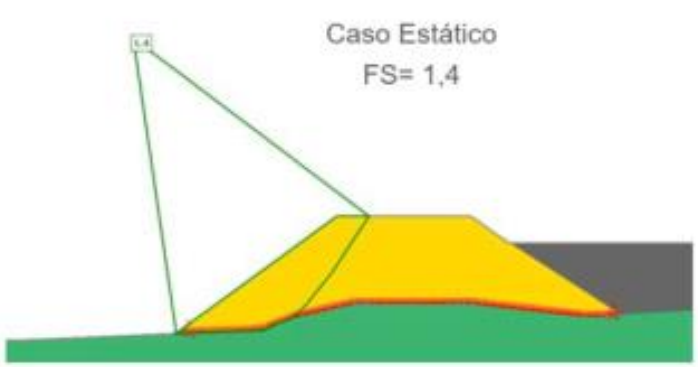
Failure modes

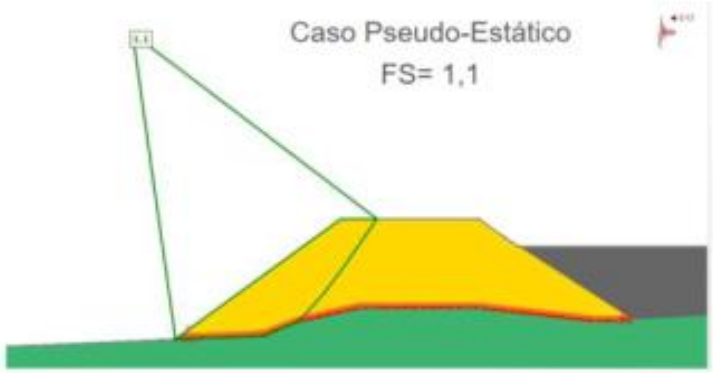


Spoil dump failure

Stability analysis

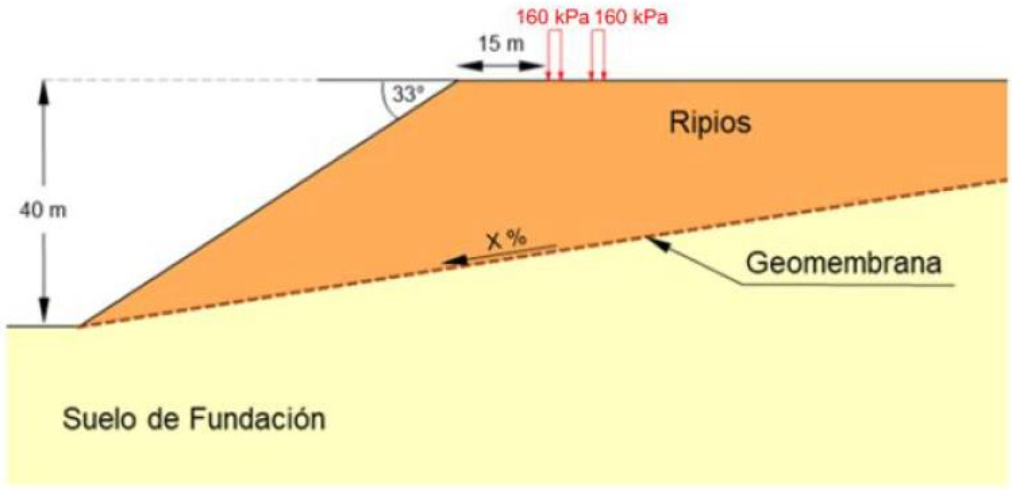


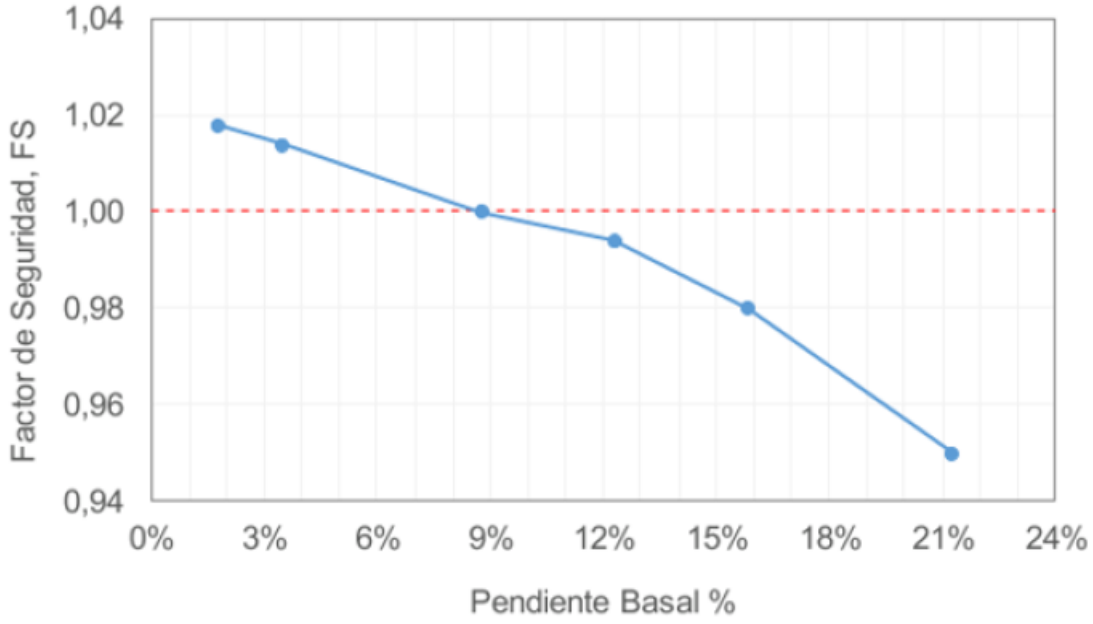




Stability analysis

Effect of foundations on stability conditions

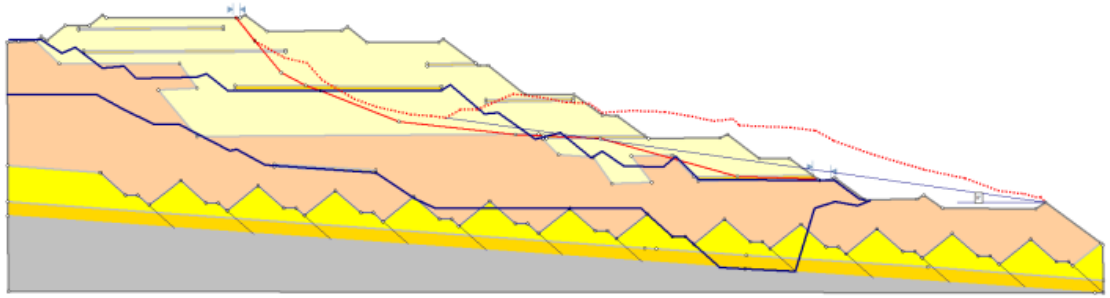




Stability analysis

Waste dump

Material	Phi	C
Category 1 Unsaturated	23	25
Category 1 Saturated	18	0
Category 2 Unsaturated	28	30



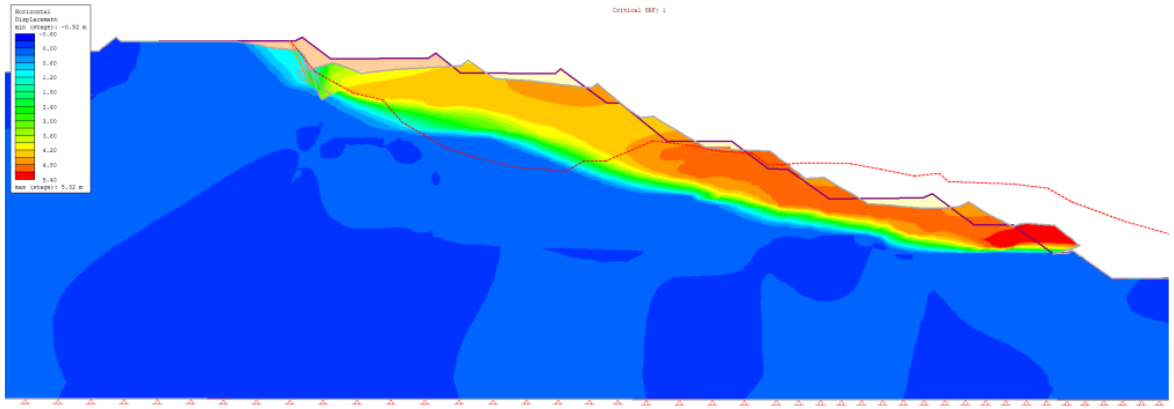


Figure 12. Horizontal Displacement at failure initiation

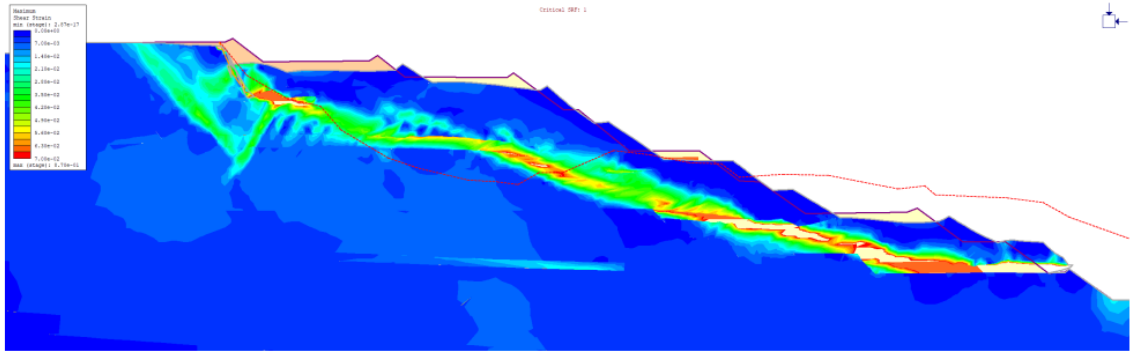


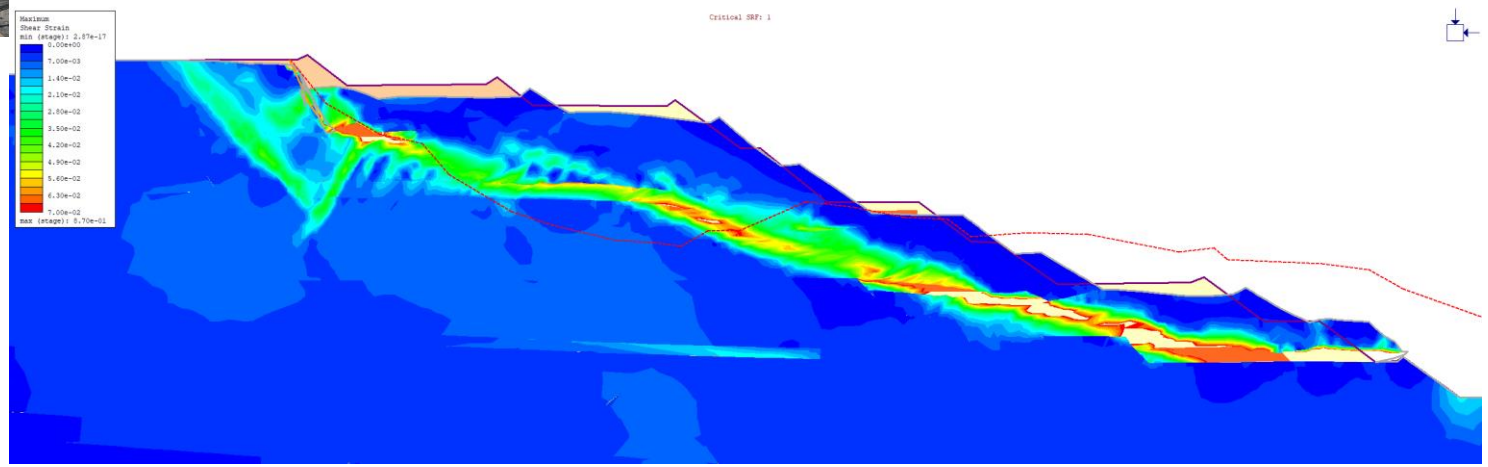
Figure 13. Shear strain at failure initiation

Stability analysis

Back analysis

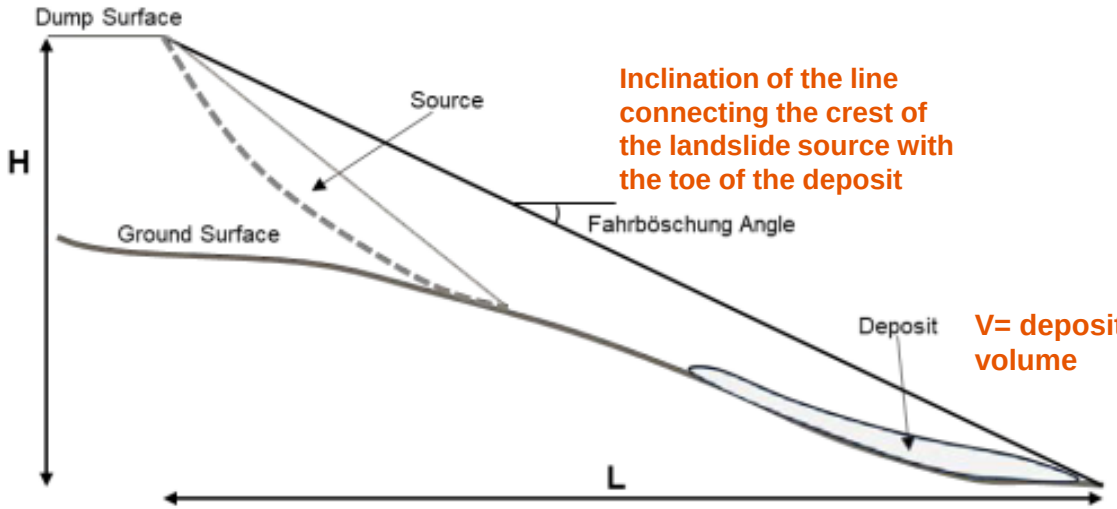
Calibration of properties using a spoil dump failure

Material Back-analysis	Phi	C
Category 1 Unsaturated Peak	23	25
Category 1 Unsaturated Residual	~~18~~ 15	~~0~~ 15
Category 1 Saturated Peak	~~18~~ 10	0
Category 1 Saturated Residual	~~18~~ 9	0
Category 2 Unsaturated	28	30



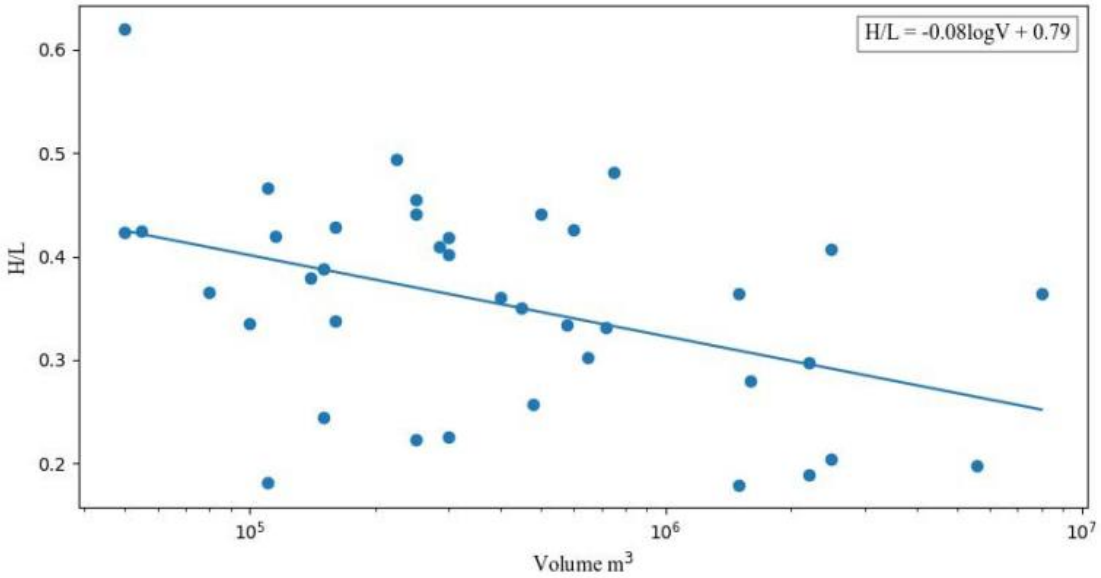
Runout analysis

Waste dump failure runout (White et al, 2023)



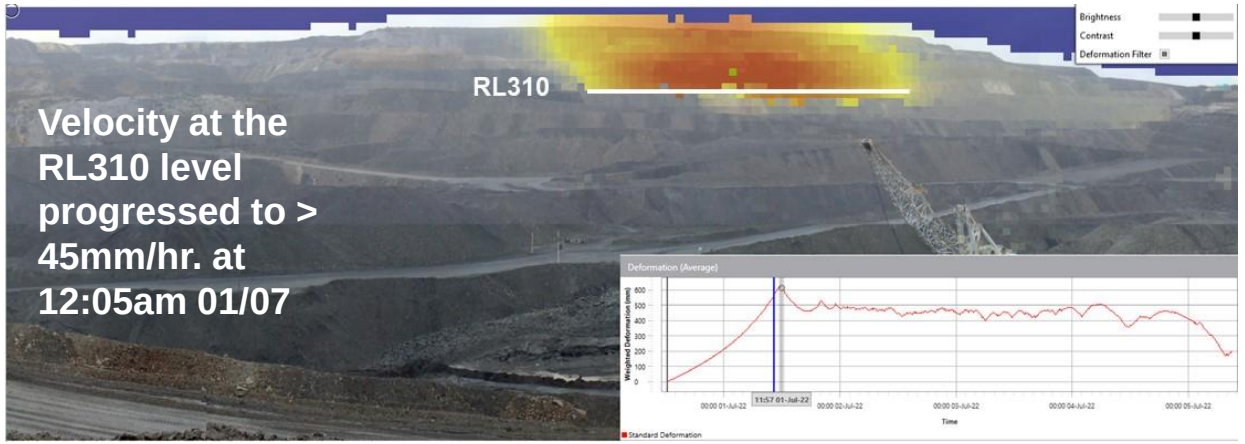
Inclination of the line connecting the crest of the landslide source with the toe of the deposit

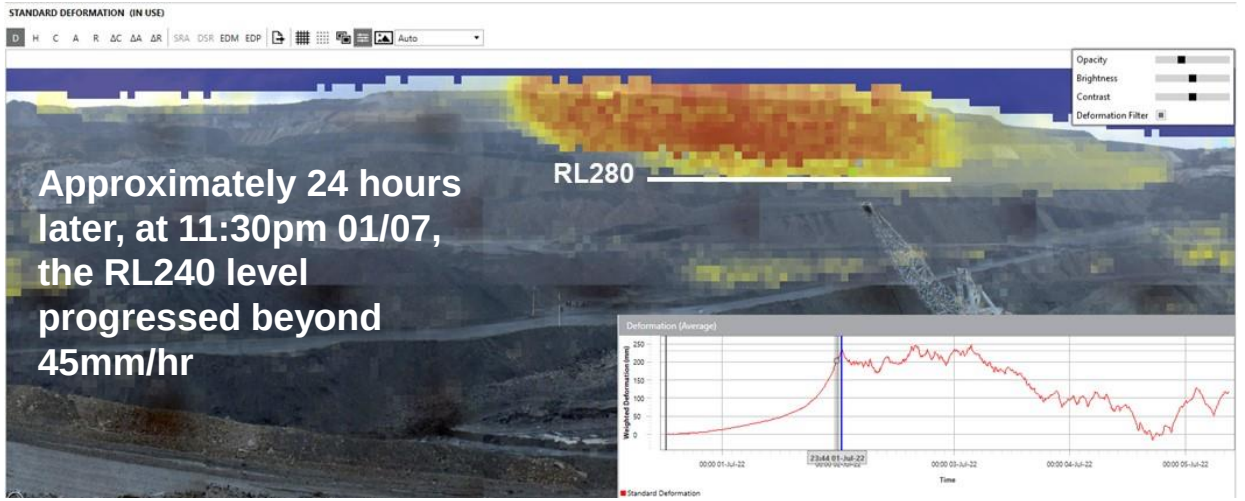
V= deposit volume



Fahrböschung angle (H/L) versus volume (V) for 39 waste dump failure cases

Instrumentation and monitoring





Waste dump failure

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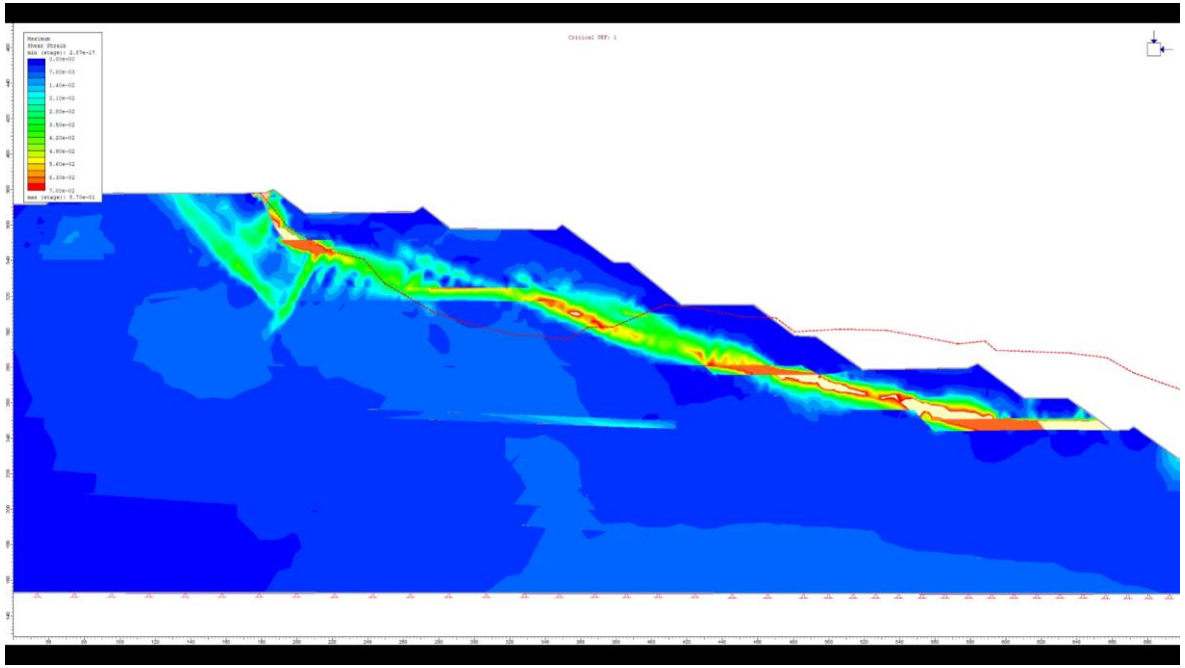
Fast motion video

Numerical animation



BHP