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

Diploma en Geomecánica Aplicada al Diseño Minero

9ª. Versión

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Módulo 4: Geomecánica en Minería a Cielo Abierto

BHP

Analisis banco-berma

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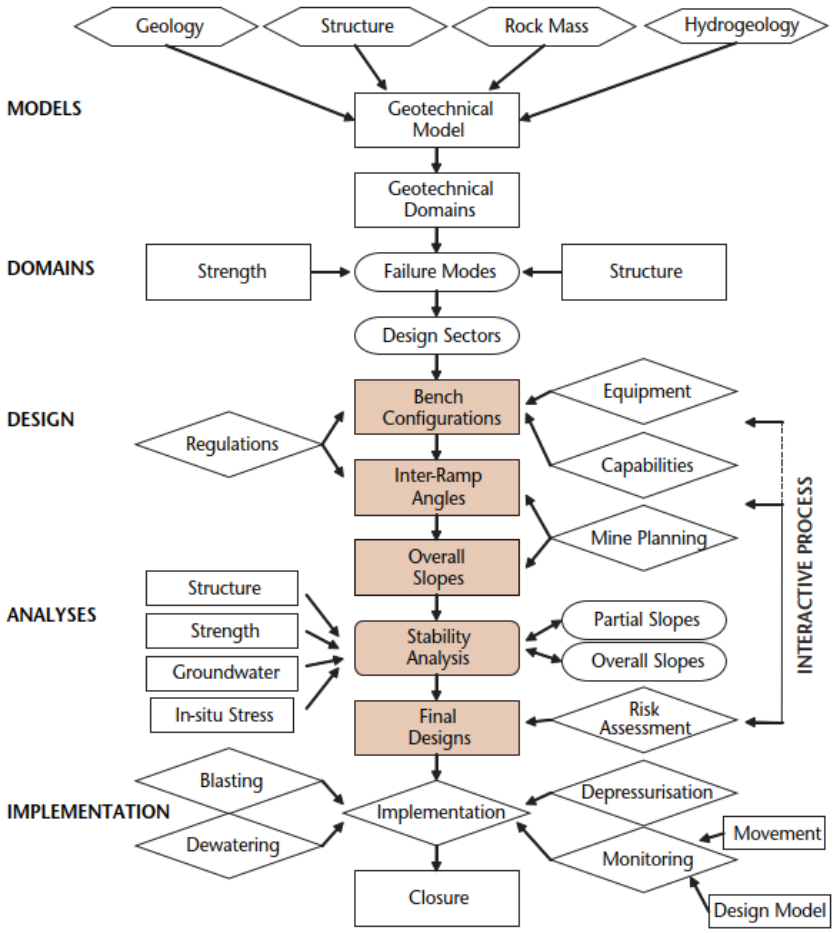
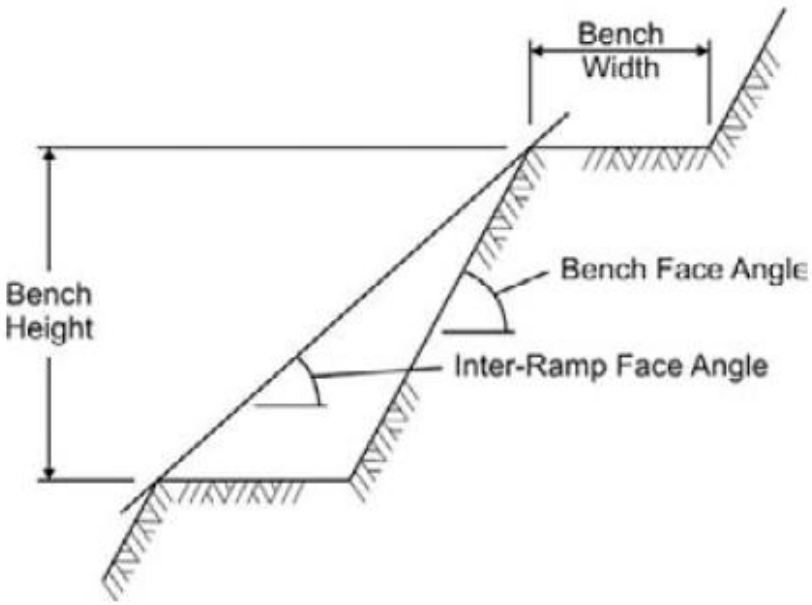


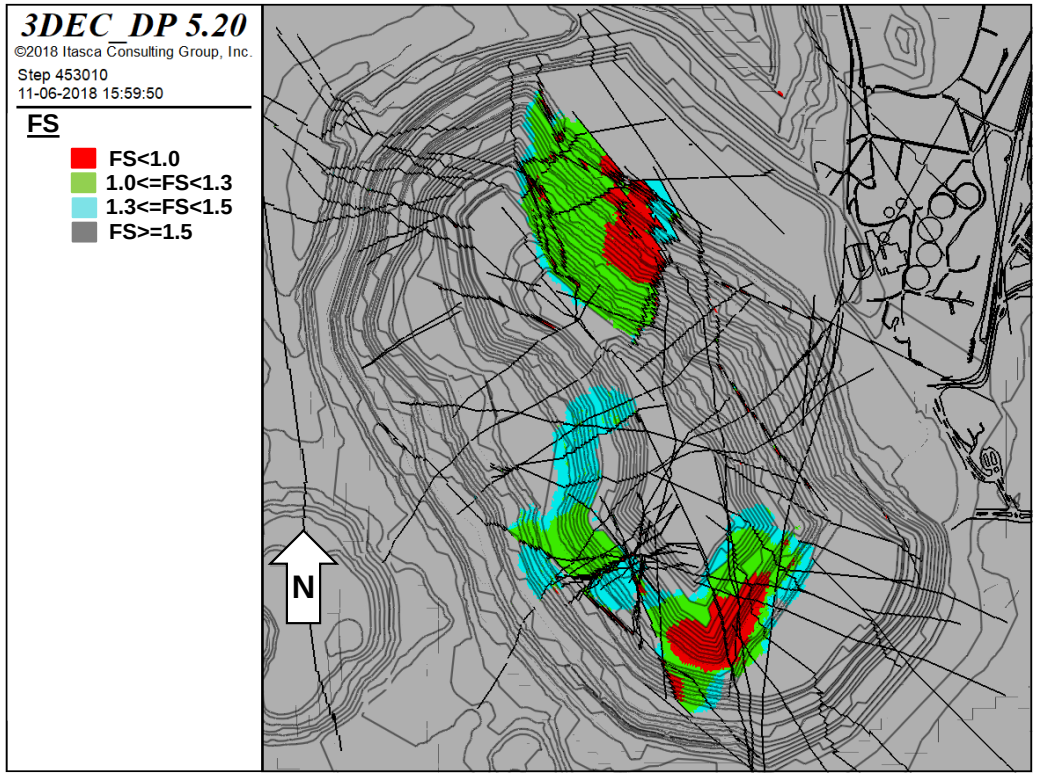
Introduction

Bench, interramp and global analysis

Bench-berm analysis



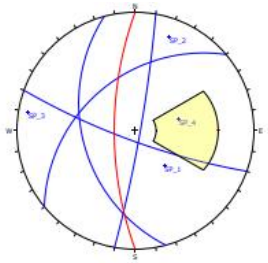
Stability analysis



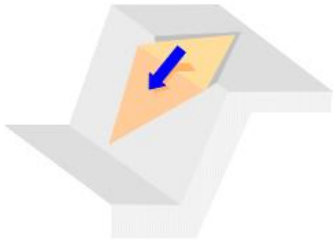
Introduction

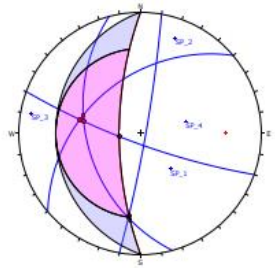
Simple and complex modes of failure

Planar failure

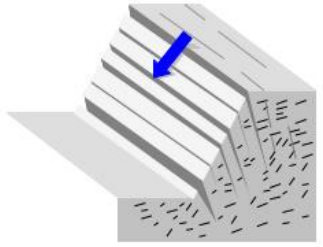


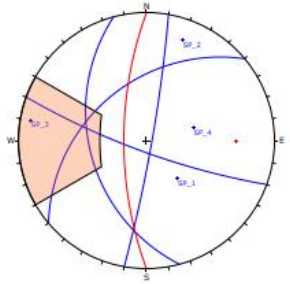
Wedge failure





Toppling failure





Complex modes of failure

Introduction

Design acceptance criteria

Reliability	Descriptor	Consequence					Comments
		Very low	Low	Moderate	High	Very high	
1	Very low reliability	1.35	1.4	1.5	X	X	Limited knowledge
2	Low reliability	1.3	1.3	1.4	1.45	1.5	Reasonable knowledge: bottom of Large Open Pit (LOP) range
3	Moderate reliability	1.25	1.25	1.3	1.35	1.4	LOP approach: central case
4	High reliability	1.2	1.2	1.25	1.3	1.3	Top of LOP range
5	Very high reliability	1.15	1.2	1.2	1.25	1.25	Detailed knowledge

RTKC reliability-based design acceptance criteria table of Factory of Safety for overall slope (ME Robotham, 2021)

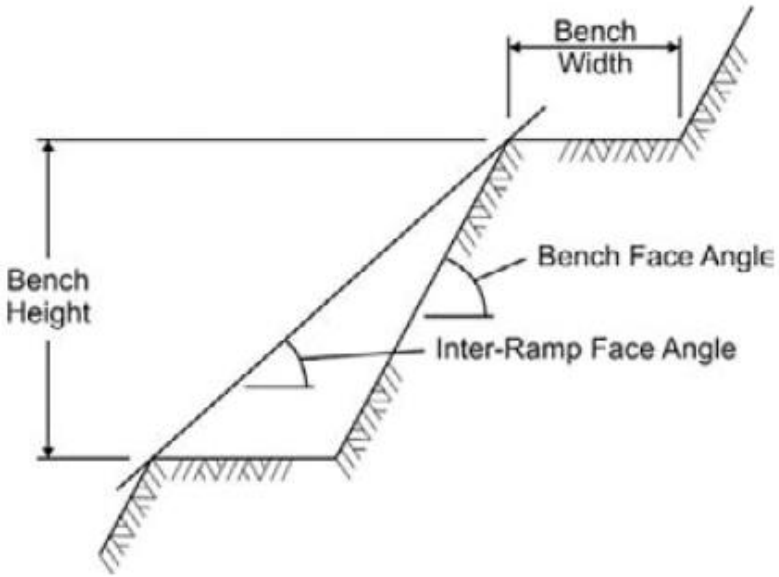
Bench-berm analysis

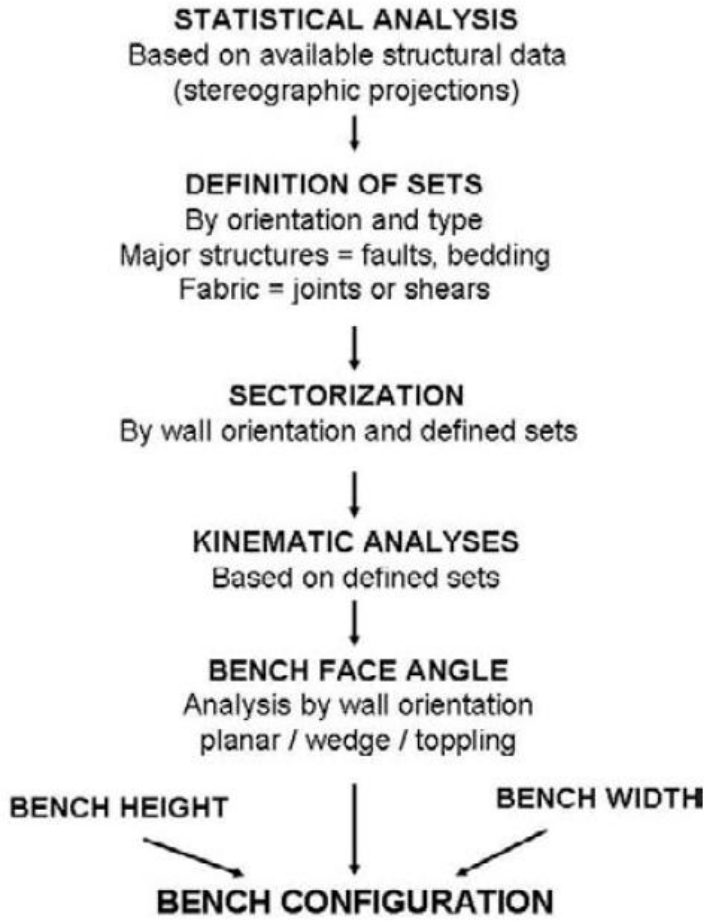
Geotechnical design process

The principal function of the benches is to provide a safe environment for personnel and equipment that must work near the slope face. Accordingly, they must satisfy needs for:

- Reliability, which requires stable bench faces and bench crests
- Safety, which requires bench widths sufficient to arrest and mitigate the danger of rockfalls and contain any spillage from the benches above.

(LOP guidelines, 2009)

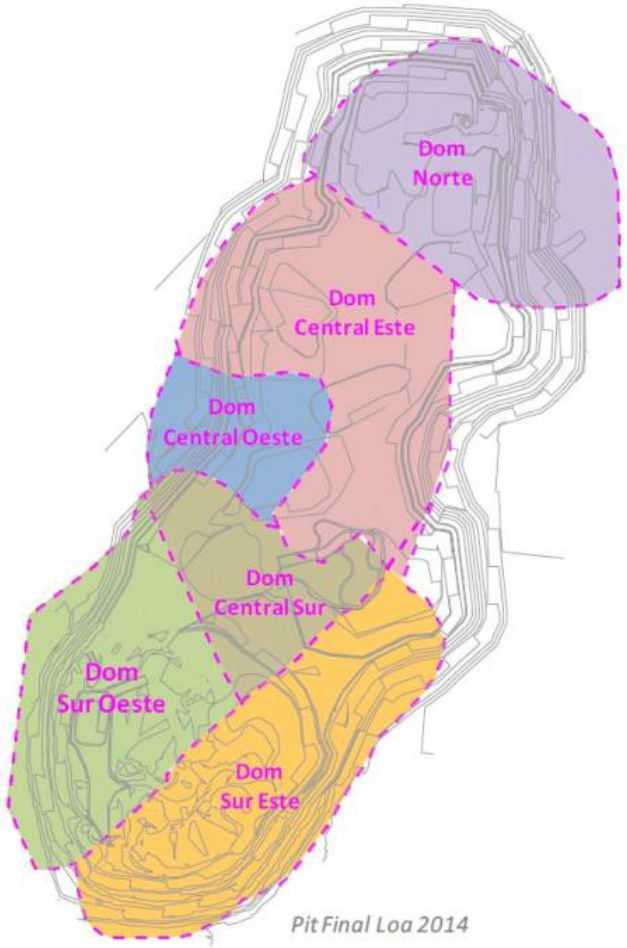




Bench-berm analysis

Example of structural domains and joint sets

Domain		Dip			Dip Dir		
Name	Set	(°)			(°)		
Central Este	1a	74	±	3	274	±	6
	2ac	71	±	3	251	±	6
	3bc	75	±	2	200	±	4
	4bc	82	±	3	18	±	6
	5ac	76	±	2	76	±	4
Central Sur	1a	72	±	3	5	±	6
	2ac	82	±	3	27	±	6
	3ac	77	±	2	203	±	4
	4br	77	±	2	70	±	5
	5bc	82	±	2	94	±	5
	6bc	81	±	2	278	±	4
Central Oeste	1a	59	±	2	29	±	4
	2ar	58	±	2	6	±	4
	3b	59	±	2	195	±	4
	4a	35	±	2	35	±	4
	5br	60	±	3	231	±	7
Norte	1	85	±	4	17	±	8
	2	85	±	4	201	±	7
	3	37	±	3	17	±	6
	4	85	±	2	138	±	3
	5	85	±	2	241	±	5
	6	50	±	2	113	±	4
Sur Este	1	43	±	3	320	±	6
	2	73	±	4	356	±	8
	3	83	±	3	152	±	6
	4	52	±	1	171	±	3
	5	69	±	3	303	±	7
Sur Oeste	1	76	±	4	290	±	8
	2	83	±	2	166	±	5
	3	69	±	2	249	±	4
	4bc	75	±	2	201	±	4
	5a	29	±	4	300	±	9
	6bc	54	±	4	32	±	9
	7ac	33	±	3	96	±	5



Bench-berm analysis

Backbreak anaylsis

Assumption

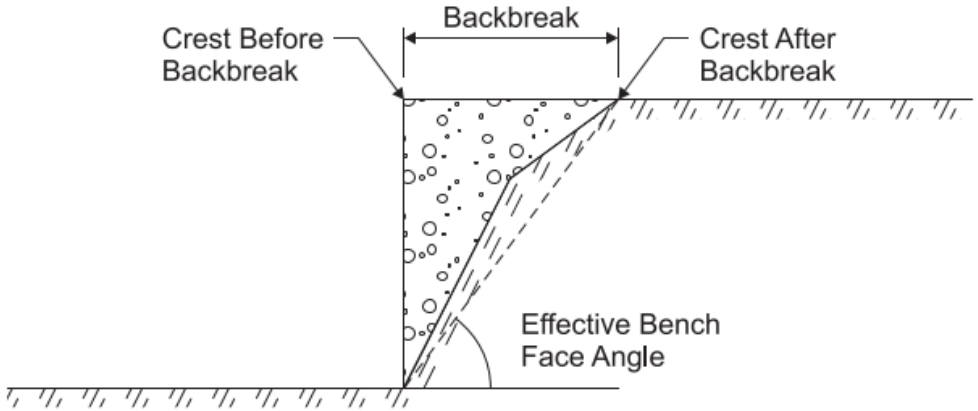
- Catch bench width (by design) is input and determined to provide enough retention to contain spillage from every potential failure from above benches.
- Bench height is also input based on ore selectivity.
- Bench width (m) = 0.2 x bench height +4.5 m (Ryan & Pryor, 2000)

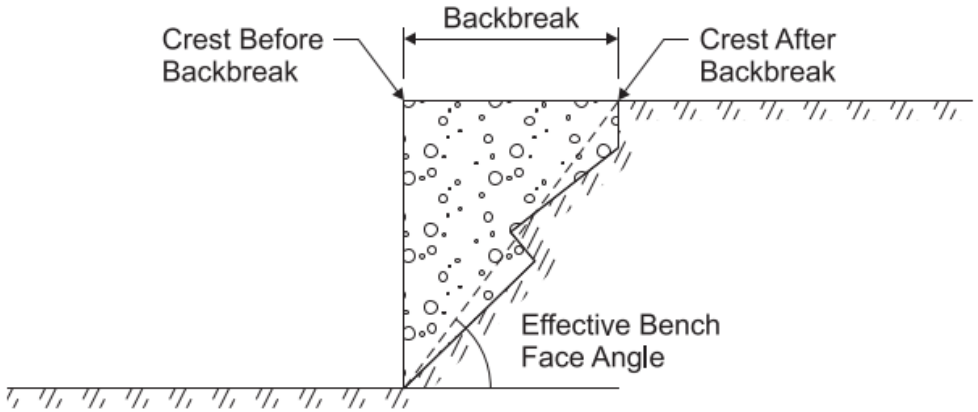
Acceptance criteria

- Establish a bench reliability that usually is 80%

Bench geometry

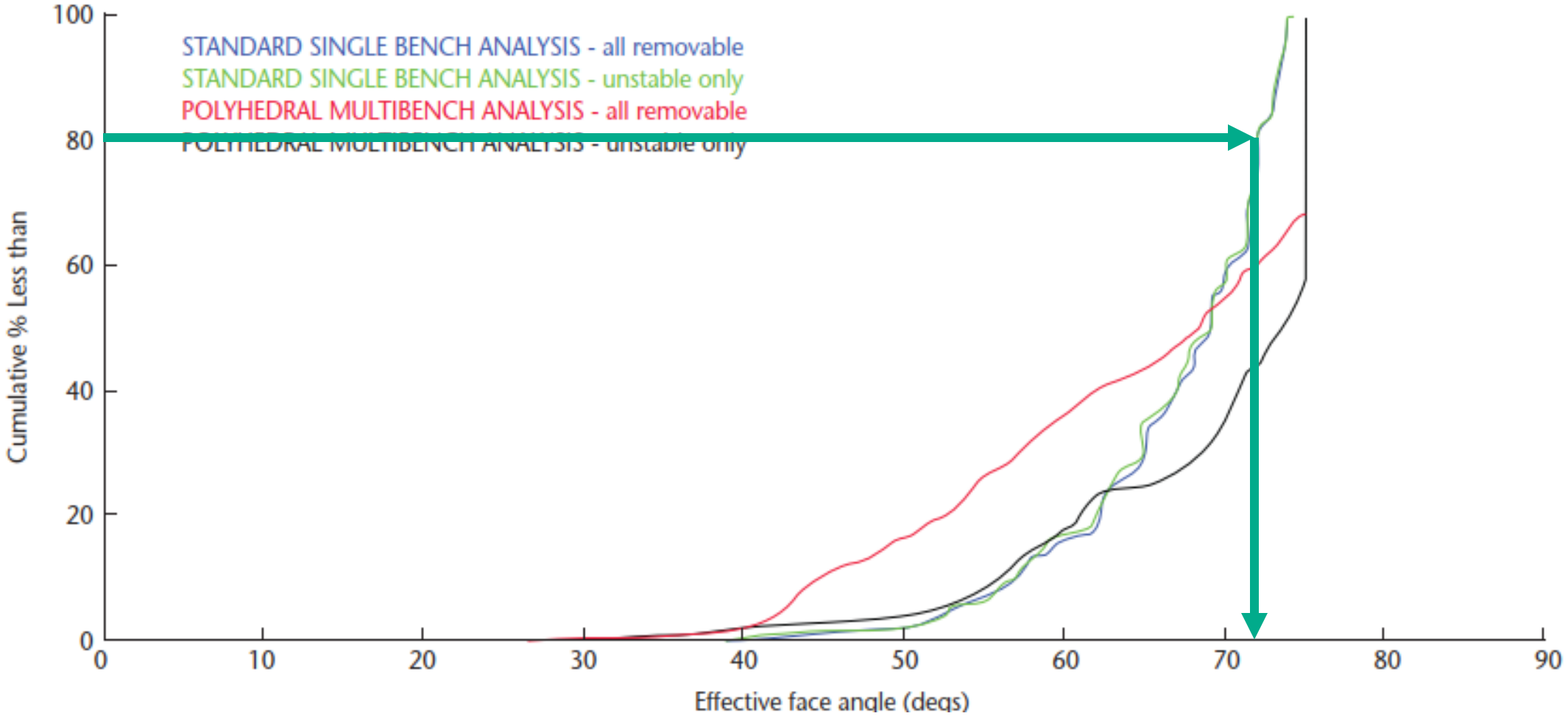
- Bench face is an output to determine bench geometry and interramp angle constrained by bench retention.





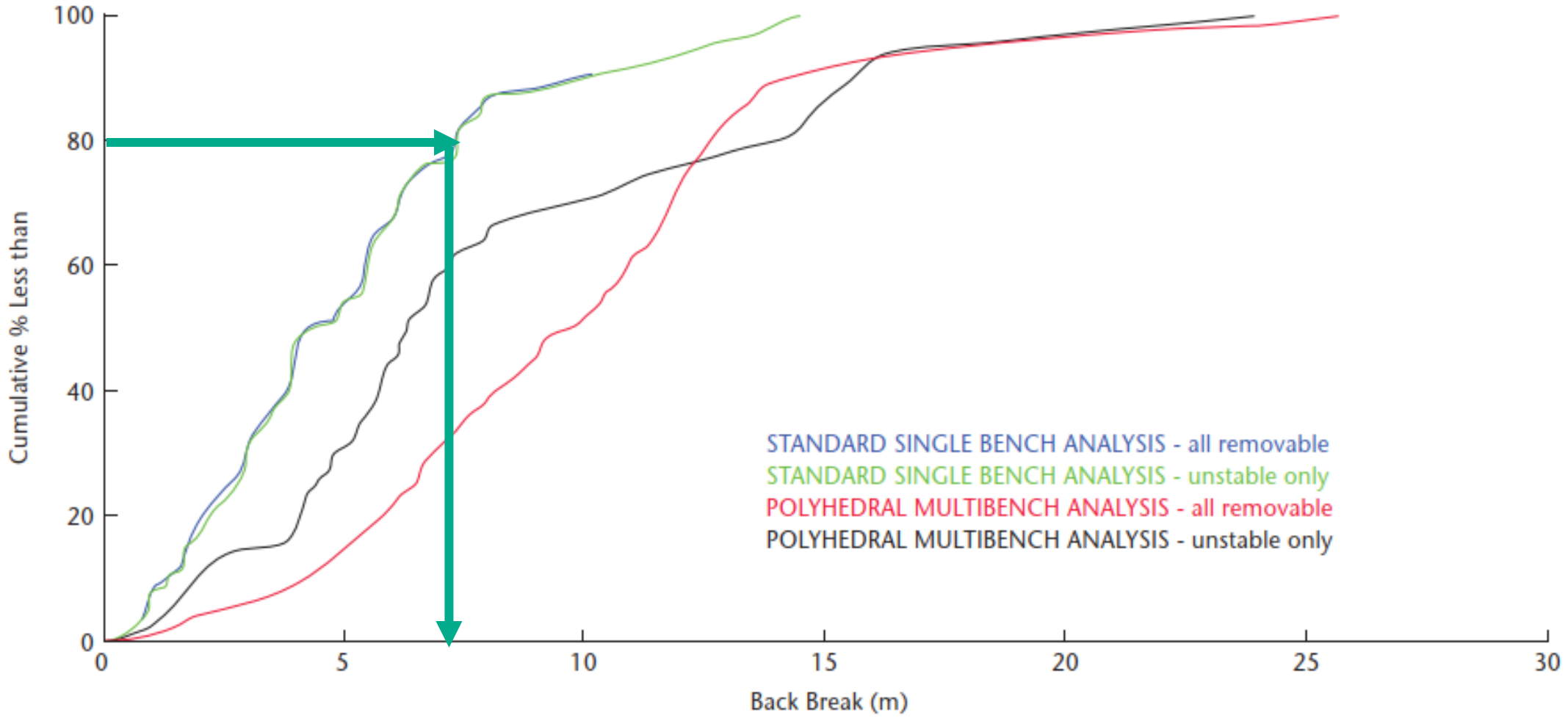
Bench-berm analysis

Backbreak analysis



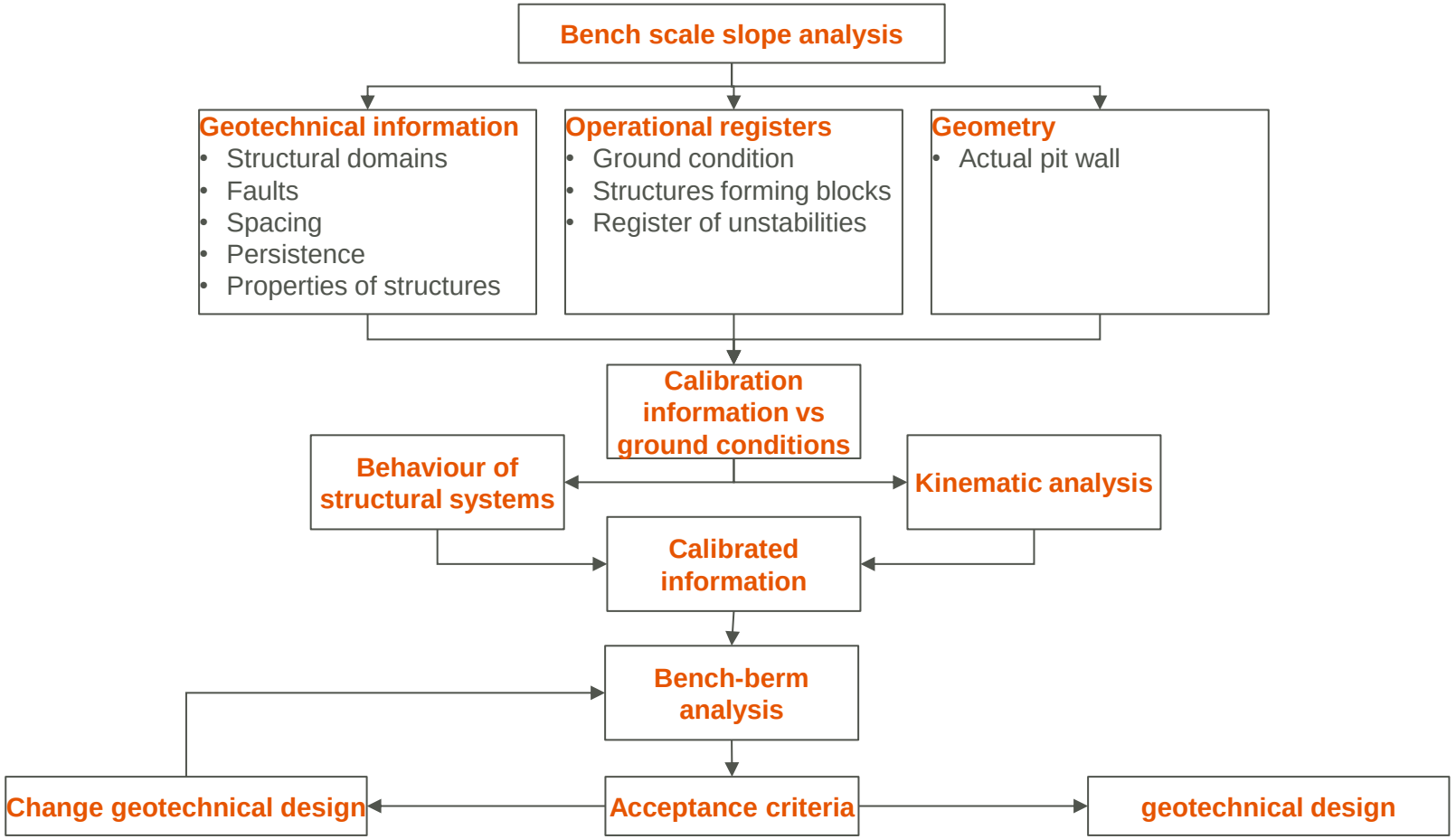
Bench-berm analysis

Backbreak analysis



Bench-berm analysis

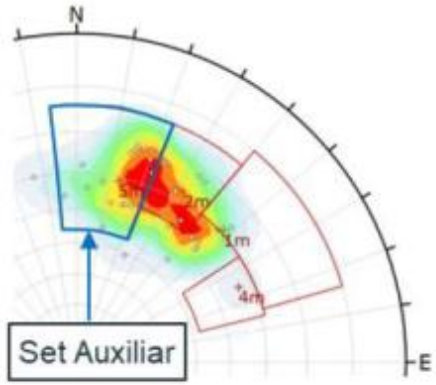
Example of application

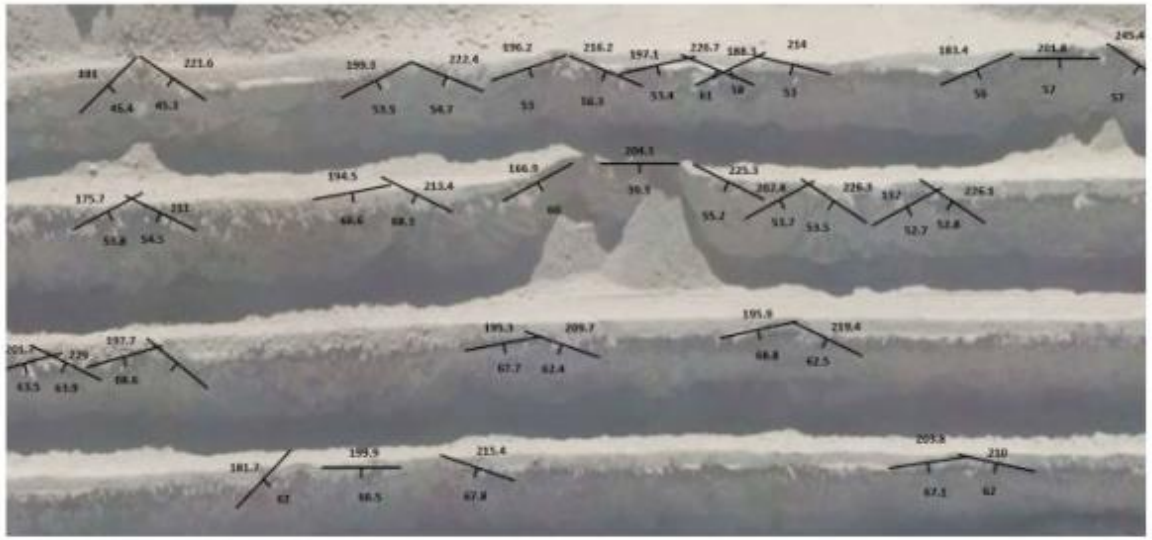


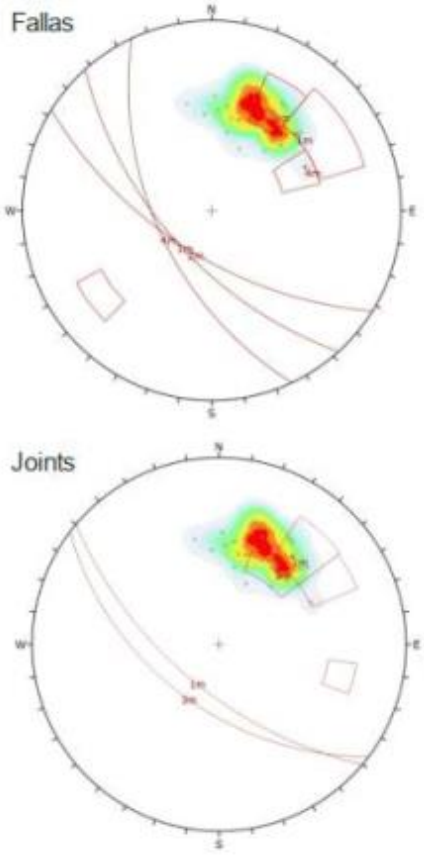
Adapted from Hormazabal et al, 2015

Bench-berm analysis

Structural condition impacting bench performance

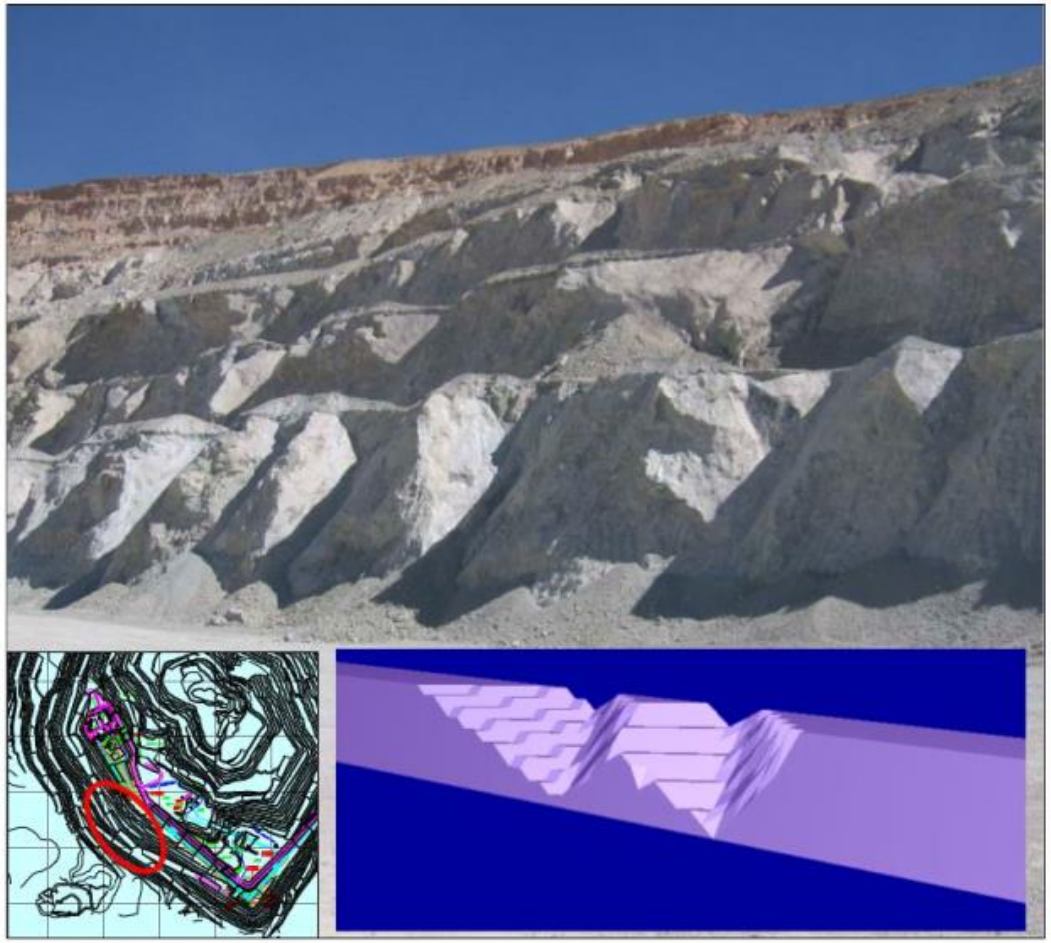


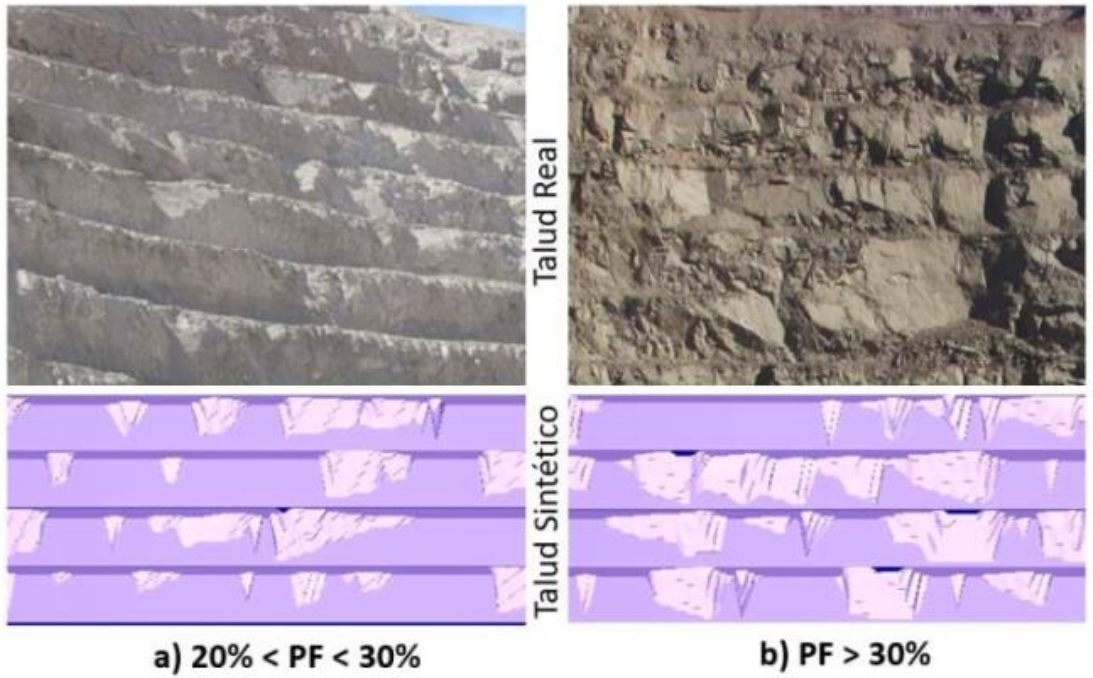




Bench-berm analysis

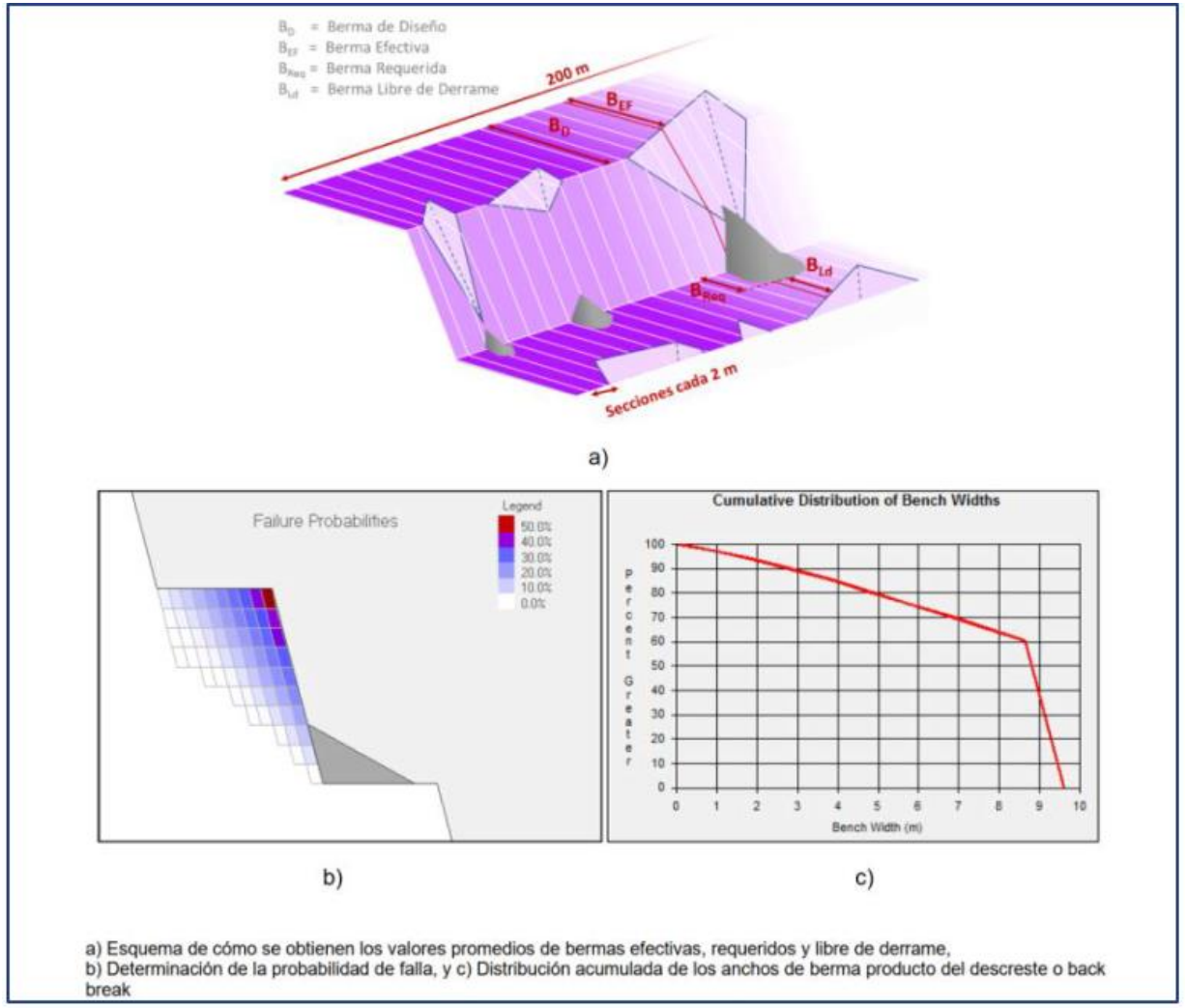
Calibration of results





Bench-berm analysis

Compliance with acceptance criteria



a) Esquema de cómo se obtienen los valores promedios de bermas efectivas, requeridos y libre de derrame,
b) Determinación de la probabilidad de falla, y c) Distribución acumulada de los anchos de berma producto del descreste o back break

Hormazabal et al, 2015

Bench-berm analysis

Runout analysis

Assumption

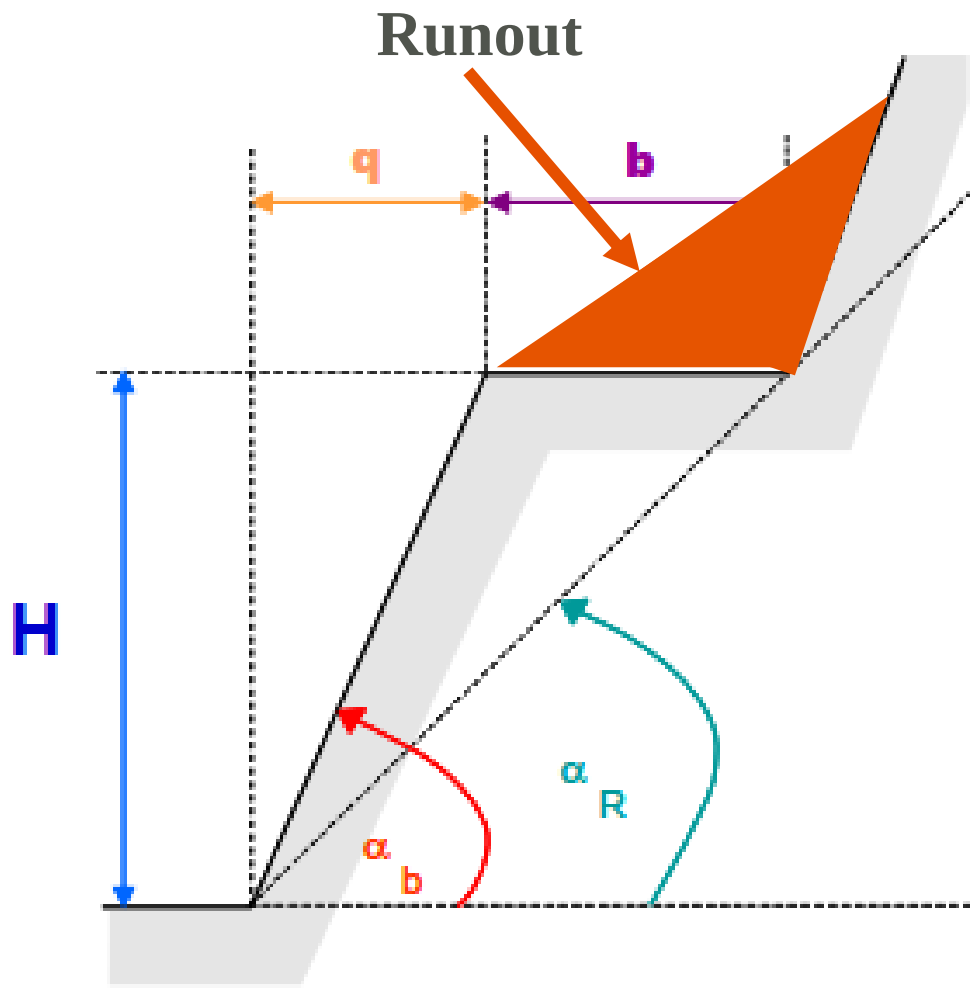
- Bench face is an input determined by equipment capacity to dig a certain angle.
- Bench height is also input based on ore selectivity.

Acceptance criteria

- Establish a catch bench runout retention usually 80%, to contain a failure of the above bench.

Bench geometry

- Bench width is an output to determine bench geometry and interramp angle constrained by bench retention.

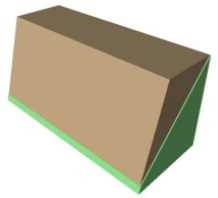
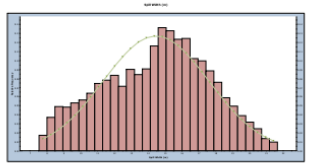
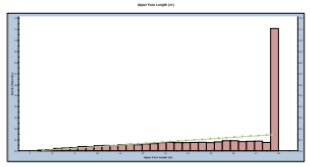


Bench-berm analysis

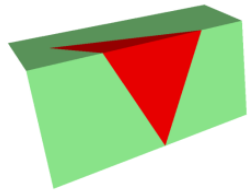
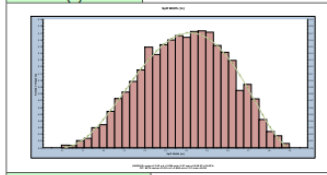
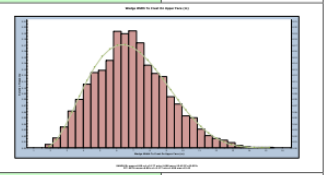
Runout length estimation

- For each structural domain
- For each Bench failure mechanism
- Number of stable and unstable cases (probability of failure)
- Each failed volume determine a spillage length and backbreak

Ficha B.4: Inestabilidad a nivel de banco – Deslizamiento plano – Rajo Spence

Set 1	DIP (°)	DIPDIR (°)	
	43±3	320±6	
Tipo	Principal		
Dominio	Sureste		
Probabilidad de Ocurrencia	24.9		
DIPDIR Talud (°)	320		
Sector	Fase 09		
Altura de Banco (m)	30	Volumen (m³/m)	249.4
Ángulo de Cara de Banco (°)	75	Tonelaje (ton/m)	623.5
Berma de Diseño (m)	18.0	Probabilidad de Falla (%)	100.0
Ángulo Interrampa (°)	49	Factor de Seguridad	0.28
			
Largo de Derrame (m)	14.5±3.1	Pérdida de Berma (m)	15.4±2.9

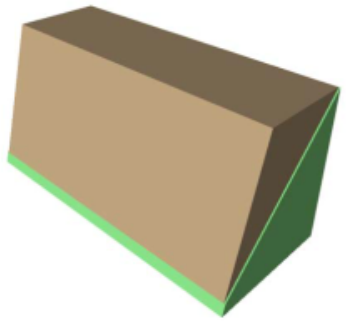
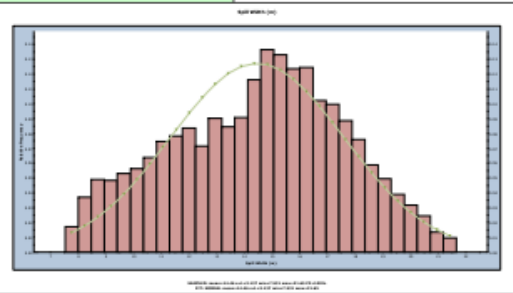
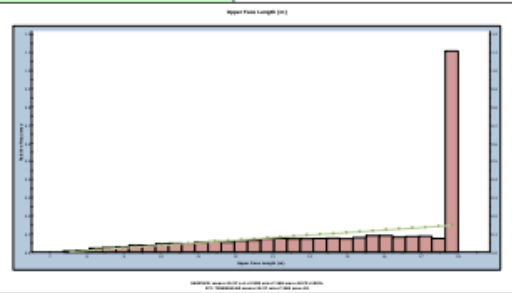
Ficha A.12: Inestabilidad a nivel de banco – Cuñas – Rajo Spence

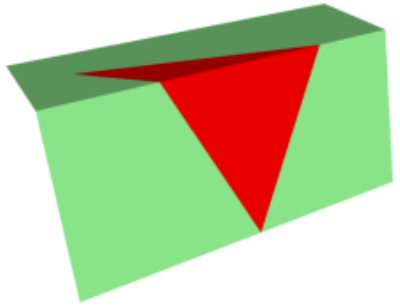
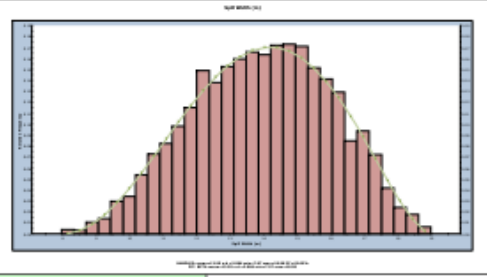
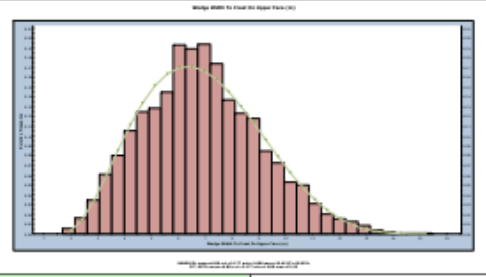
	Set 3	Set 5	
DIP (°)	83±3	69±3	
DIPDIR (°)	152±6	303±7	
Tipo	Principal	Principal	
Dominio	Sureste		
Probabilidad de Ocurrencia (%)	13.8	20.1	
DIPDIR Talud (°)	290		
Sector	Fase 09	Volumen (m³)	1473.3
Altura de Banco (m)	30	Tonelaje (ton)	3683.3
Ángulo de Cara de Banco (°)	75	Probabilidad de Ocurrencia (%)	2.8
Berma de Diseño (m)	18.0	Probabilidad de Falla (%)	43.05
Ángulo Interrampa (°)	49	Factor de Seguridad	1.07
			
Largo de Derrame (m)	14.0±2.1	Pérdida de Berma (m)	6.9±2.2

From DERK, 2014. Internal study for BHP Spence.

Bench-berm analysis

Runout length estimation for each bench failure mechanism

FICHA B.4: INESTABILIDAD A NIVEL DE BANCO – DESLIZAMIENTO PLANO – RAJO SPENCE				
SET 1	DIP (°)	DIPDIR (°)		
	43±3	320±6		
TIPO	PRINCIPAL			
DOMINIO	SURESTE			
PROBABILIDAD DE OCURRENCIA	24.9			
DIPDIR TALUD (°)	320			
SECTOR	FASE 09			
ALTURA DE BANCO (M)	30		VOLUMEN (M^3/M)	249.4
ÁNGULO DE CARA DE BANCO (°)	75		TONELAJE (TON/M)	623.5
BERMA DE DISEÑO (M)	18.0		PROBABILIDAD DE FALLA (%)	100.0
ÁNGULO INTERRAMPA (°)	49		FACTOR DE SEGURIDAD	0.28
				
LARGO DE DERRAME (M)	14.5±3.1		PÉRDIDA DE BERMA (M)	15.4±2.9

FICHA A.12: INESTABILIDAD A NIVEL DE BANCO – CUÑAS – RAJO SPENCE				
	SET 3	SET 5		
DIP (°)	83±3	69±3		
DIPDIR (°)	152±6	303±7		
TIPO	PRINCIPAL	PRINCIPAL		
DOMINIO	SURESTE			
PROBABILIDAD DE OCURRENCIA (%)	13.8	20.1		
DIPDIR TALUD (°)	290			
SECTOR	FASE 09		VOLUMEN (M^3)	1473.3
ALTURA DE BANCO (M)	30		TONELAJE (TON)	3683.3
ÁNGULO DE CARA DE BANCO (°)	75		PROBABILIDAD DE OCURRENCIA (%)	2.8
BERMA DE DISEÑO (M)	18.0		PROBABILIDAD DE FALLA (%)	43.05
ÁNGULO INTERRAMPA (°)	49		FACTOR DE SEGURIDAD	1.07
				
LARGO DE DERRAME (M)	14.0±2.1		PÉRDIDA DE BERMA (M)	6.9±2.2

From DERK, 2014. Internal study for BHP Spence.

Bench-berm analysis

Results of bench geometry for a structural domain

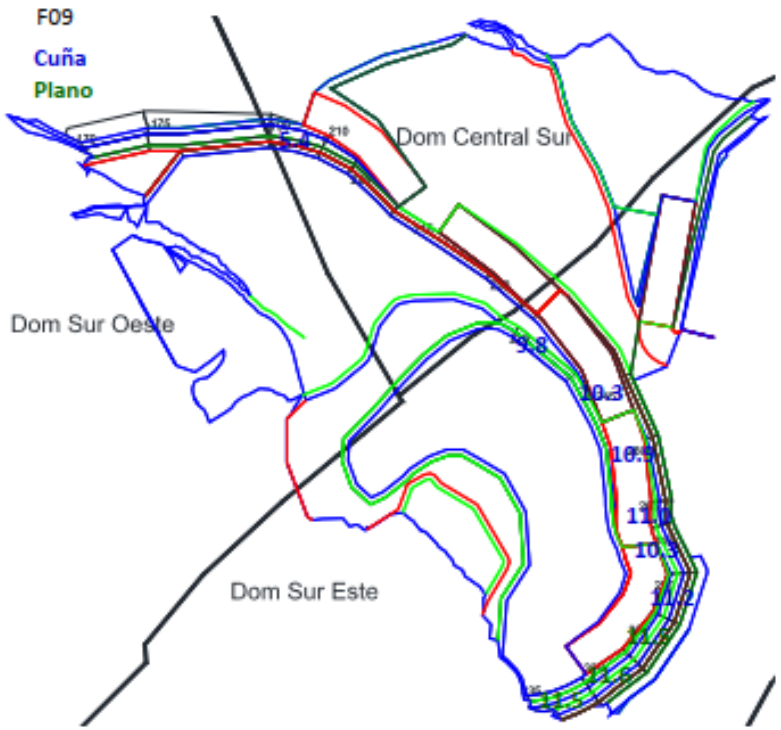
Fase	Dominio Estructural	Pared	Diseño de Bancos					Sistemas Estructurales Desfavorables		PO (%)	P_b (m)	L_D (80%) (m)	FS	PF (%)
			α (°)	DIP DIR (°)	H (m)	Berma (m)	IRA (°)	Set 1	Set 2					
9	Sureste	Noreste	75	220	30	18,0	49	1	2	8,8	5,0 ± 2,8	4,2 ± 2,0	0,49	39,19
9	Sureste	Noreste	75	220	30	18,0	49	3	5	2,8	15,5 ± 2,6	9,8 ± 0,9	1,07	43,05
9	Sureste	Noreste	75	245	30	18,0	49	1	2	8,8	13,1 ± 3,5	8,1 ± 1,9	0,45	40,64
9	Sureste	Noreste	75	245	30	18,0	49	3	5	2,8	16,0 ± 2,3	10,3 ± 0,8	1,07	43,05
9	Sureste	Noreste	75	260	30	18,0	49	1	2	8,8	15,3 ± 2,9	9,0 ± 1,6	0,45	40,64
9	Sureste	Noreste	75	260	30	18,0	49	3	5	2,8	14,8 ± 2,6	10,9 ± 1,1	1,07	43,05
9	Sureste	Noreste	75	265	30	18,0	49	1	2	8,8	15,6 ± 2,8	9,1 ± 1,6	0,45	40,64
9	Sureste	Noreste	75	265	30	18,0	49	3	5	2,8	14,0 ± 2,7	11,0 ± 1,2	1,07	43,05
9	Sureste	Este	75	290	30	18,0	49	1	2	8,8	13,3 ± 3,3	9,3 ± 2,2	0,45	40,64
9	Sureste	Este	75	290	30	18,0	49	2	5	7,1	2,9 ± 1,5	5,9 ± 2,4	0,14	92,43
9	Sureste	Este	75	290	30	18,0	49	3	5	2,8	6,9 ± 2,2	11,2 ± 1,7	1,07	43,05
9	Sureste	Este	75	305	30	18,0	49	1	2	8,8	6,6 ± 2,6	5,7 ± 2,1	0,45	40,64
9	Sureste	Este	75	305	30	18,0	49	1	5	5,0	1,9 ± 1,3	3,1 ± 1,8	0,10	71,30
9	Sureste	Este	75	305	30	18,0	49	2	5	7,1	1,7 ± 1,0	4,2 ± 2,1	0,09	97,37
9	Sureste	Este	75	305	30	18,0	49	3	5	2,8	0,7 ± 0,4	1,8 ± 1,0	0,09	47,22
9	Sureste	Sureste	75	320	30	18,0	49	1	2	8,8	1,8 ± 1,1	2,0 ± 1,2	0,29	55,66
9	Sureste	Sureste	75	320	30	18,0	49	1	3	3,4	1,1 ± 0,6	1,4 ± 0,7	0,29	45,04
9	Sureste	Sureste	75	320	30	18,0	49	2	5	7,1	3,8 ± 1,2	7,7 ± 1,7	0,16	100,00
9	Sureste	Sureste	75	335	30	18,0	49	1	2	8,8	1,8 ± 1,1	2,0 ± 1,2	0,29	55,66
9	Sureste	Sureste	75	335	30	18,0	49	2	5	7,1	3,3 ± 1,4	6,5 ± 1,9	0,16	99,23
9	Central Sur	Noreste	75	190	30	15,4	52	3ac	4br	3,2	3,0 ± 1,8	5,4 ± 2,2	0,47	86,07

α : Inclinación de la cara del banco.
DIP DIR : Dirección de manteo del talud.
h : Altura del banco.
IRA : Ángulo Interrampa.
PO : Probabilidad de Ocurrencia.
P_b : Pérdida de Berma.
L_D : Largo de Derrame.
FS : Factor de Seguridad
PF : Probabilidad de Falla.

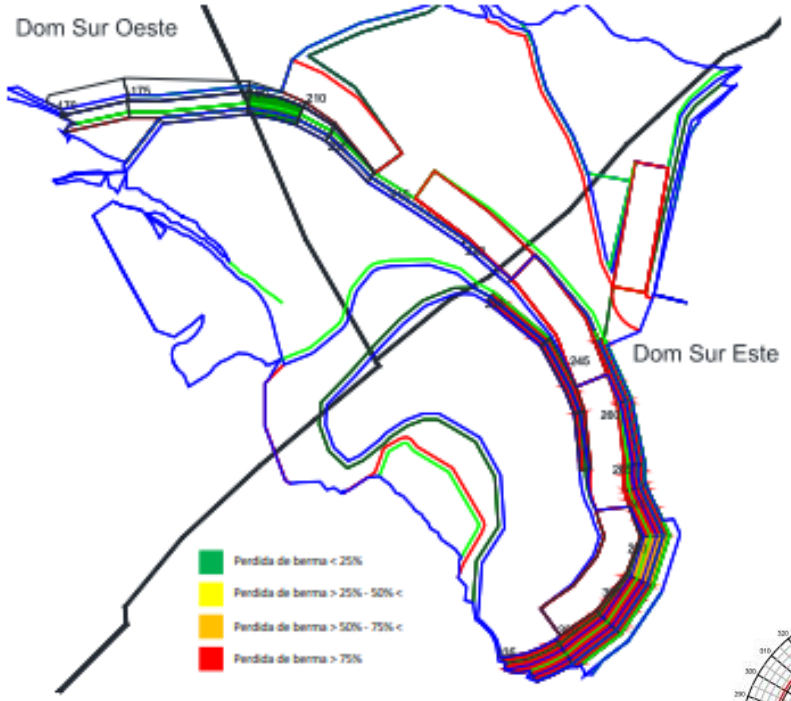
From DERK, 2014. Internal study for BHP Spence.

Bench-berm analysis

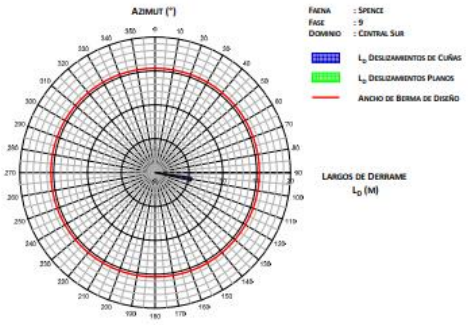
Results of bench geometry for a structural domain

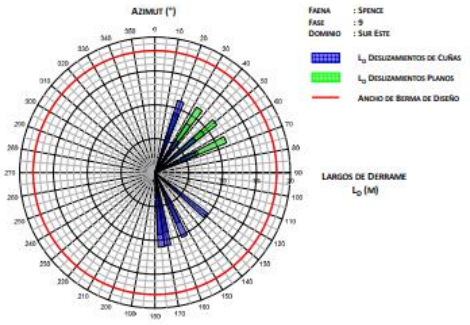


LARGOS DE DERRAME (M)



PÉRDIDAS DE BERMA (%)






BHP