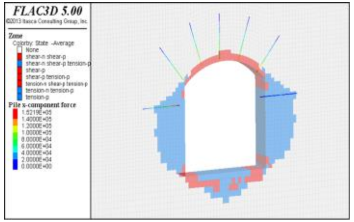
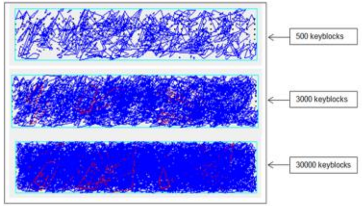
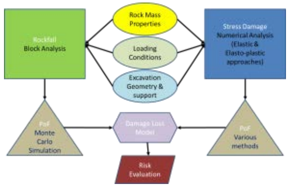
Risk based design of ground support

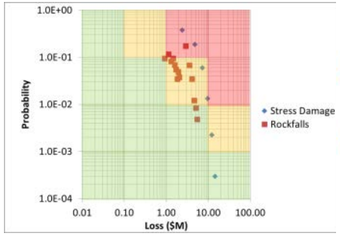
William Joughin

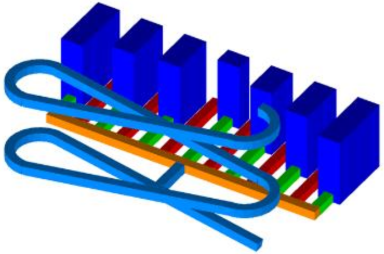
Joseph Muaka, Philani Mpunzi, Denisha Sewnun, Johan Wesseloo

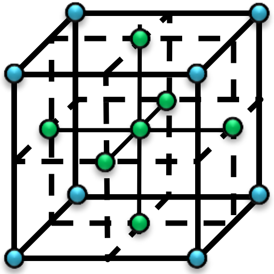












ACG AUSTRALIAN CENTRE FOR GEOMECHANICS

srk consulting

Risk based design of ground support

Sub project of "Ground Support Systems Optimization" research project lead by the Australian Centre for Geomechanics (ACG).

Participants

- William Joughin (SRK SA)
- Johan Wesseloo (ACG)
- Joseph Muaka (SRK SA)
- Philani Mpunzi (SRK SA)
- Denisha Sewnun (SRK SA)

Advisors

- Luis-Fernando Contreras (SRK SA)
- Michael Dunn (SRK Australia)
- Dick Stacey (University of the Witwatersrand)
- Shaun Murphy (SRK SA)
- Jeanne Walls (SRK SA)

Data

- IvanPlats Pty Ltd

Major sponsors

Glencore Mount Isa Mines, Independence Group NL, Codelco Chile, MMG Limited, Minerals Research Institute of Western Australian, and the Australian Centre for Geomechanics.

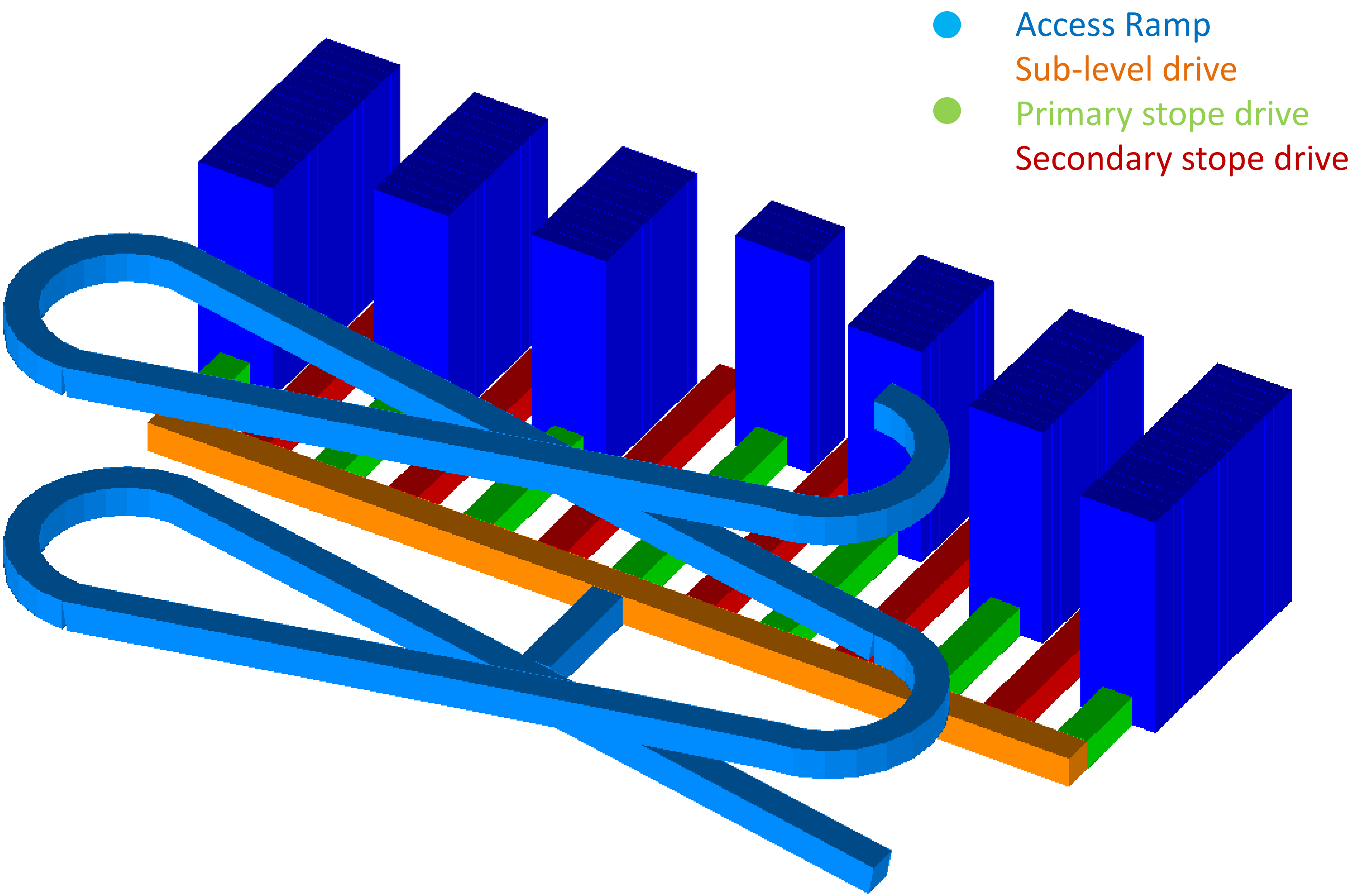
Minor Sponsors

Jennmar Australia, Dywidag-Systems International Pty Ltd, Fero Strata Australia, Golder Associates Pth Ltd, Geobrugg Australia Pty Ltd, Atlas Copco Australia Pty Limited.

Introduction

- Purpose of Risk Based Design
  - Cater for the inherent variability in rock mass conditions
  - To address uncertainty
  - To apply engineering judgement
  - To enable decisions to made based on the level of risk to the operation
  - Risk = probability x consequence
- Probabilistic vs Deterministic
  - Advantages of probabilistic analysis well known
  - Powerful methods of probabilistic analysis developed
- Not widely applied in underground mining geotechnical applications
  - Additional effort
  - Acceptable probabilities of failure?

Example Mining Layout



Hazards

Tunnel supported with bolts and mesh

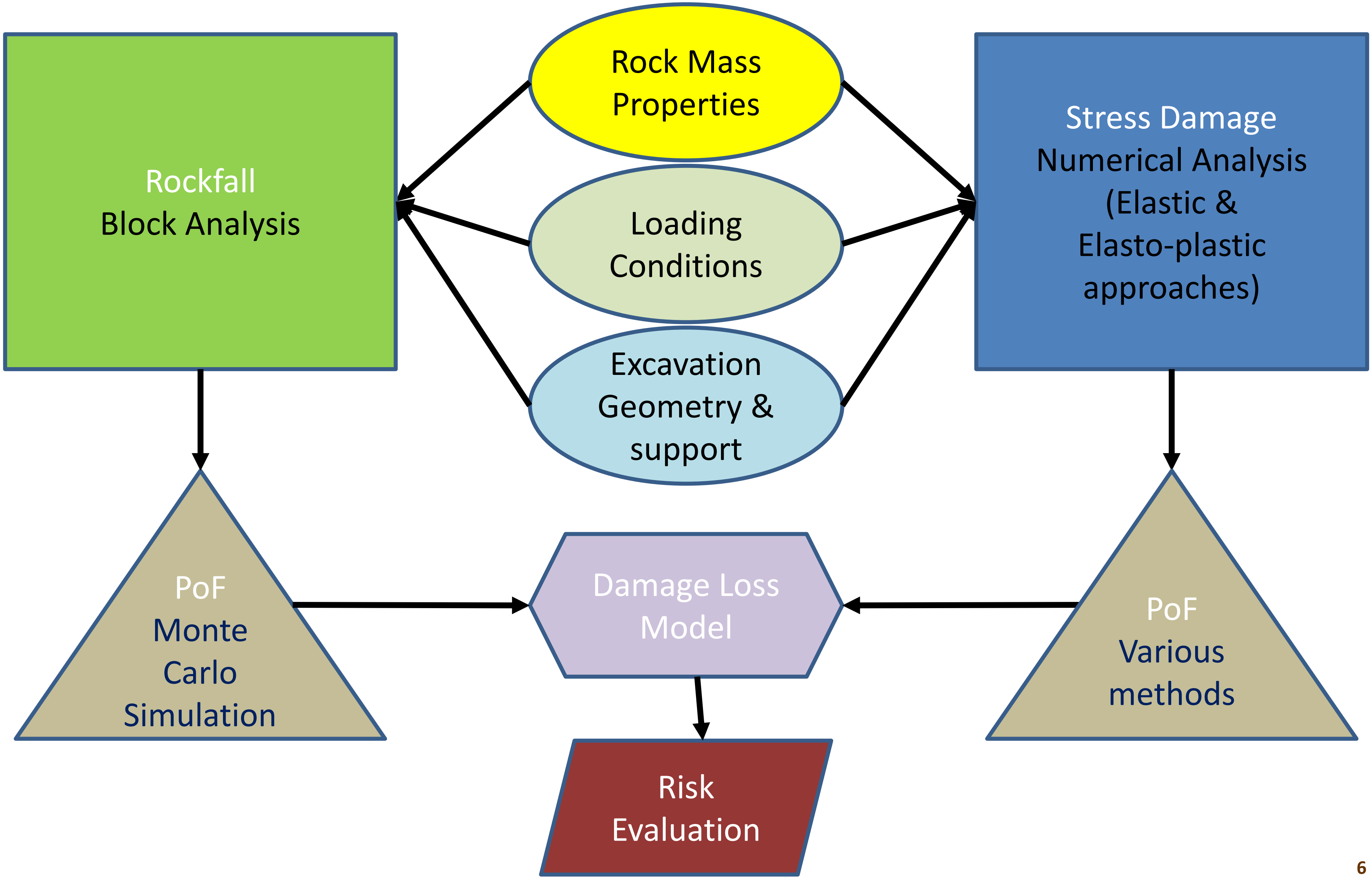
Rockfall (joint bounded)

Stress Damage (depth of failure)

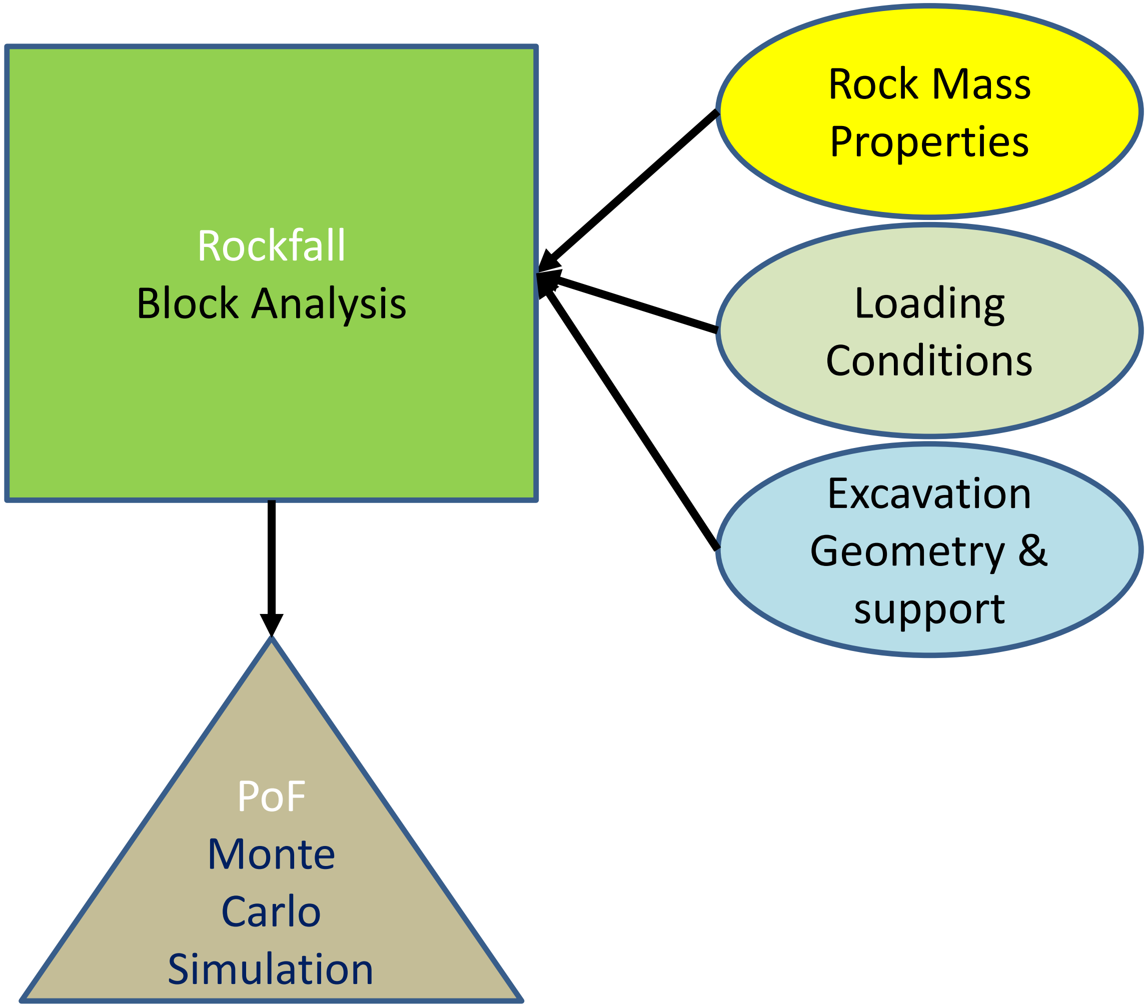
Consequences

- Production delays – loss of income
- Rehabilitation costs
- Injuries
- Cost of damage to mobile equipment

Risk Analysis Process



Rockfall


Rock Mass Properties
Loading Conditions
Excavation Geometry & support
Rockfall Block Analysis
PoF Monte Carlo Simulation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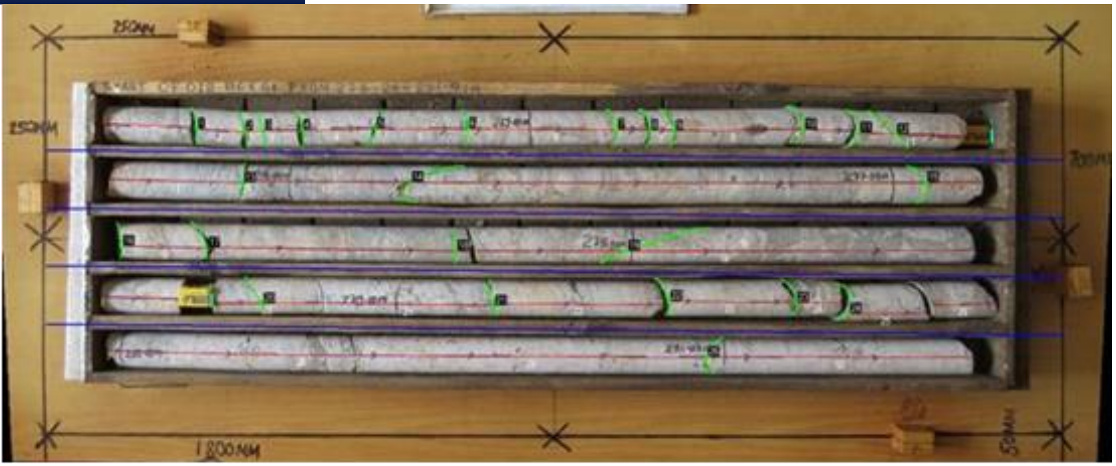
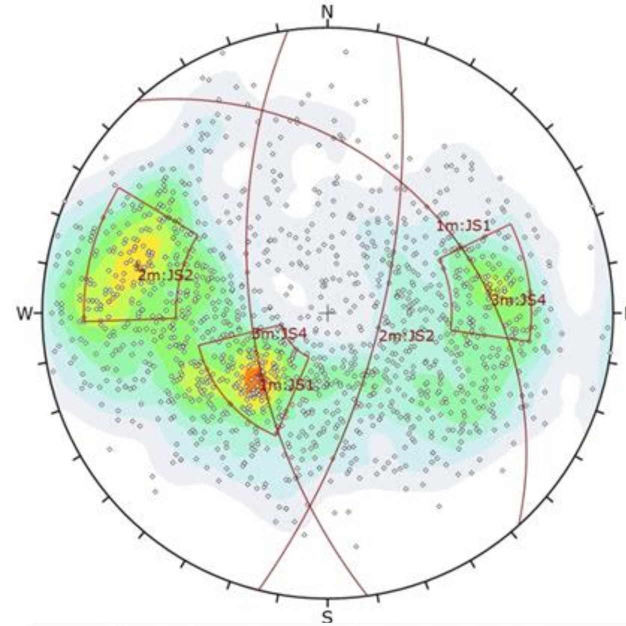
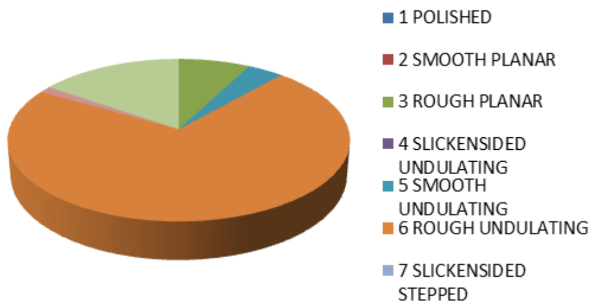




Joint Roughness

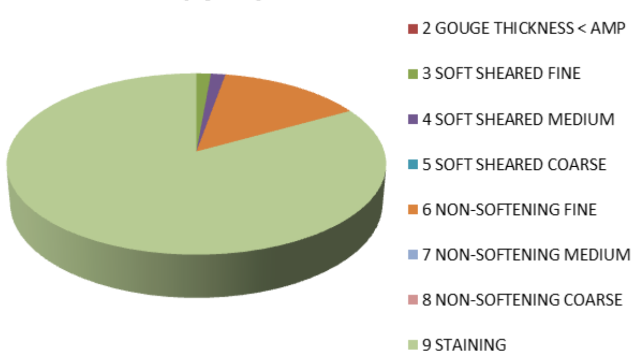


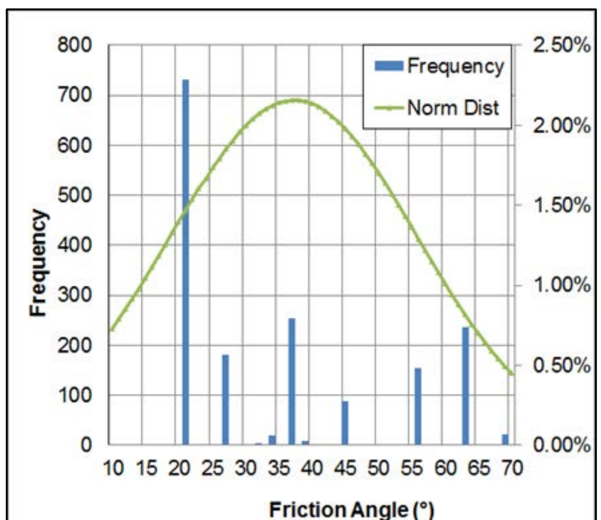
Barton

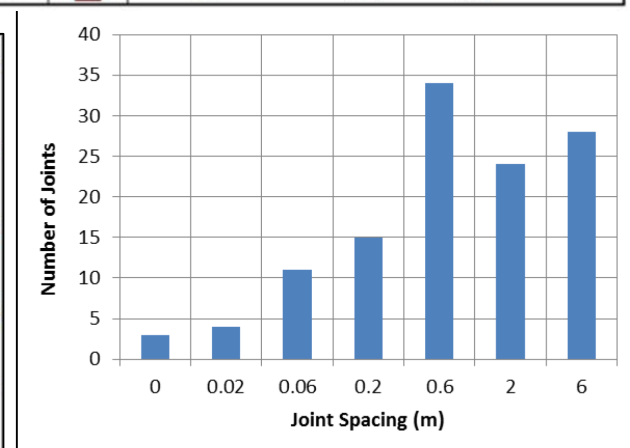
$$\varphi = \arctan\left(\frac{Jr}{Ja}\right)$$

	Color	Dip	Dip Direction	Label
		Mean Set Planes		
1m		36	48	JS1
2m		69	104	JS2
3m		60	262	JS4

Joint Fill



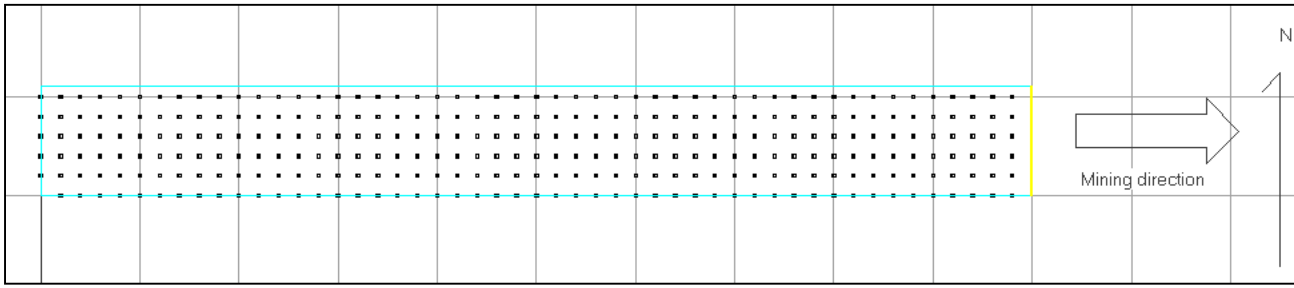


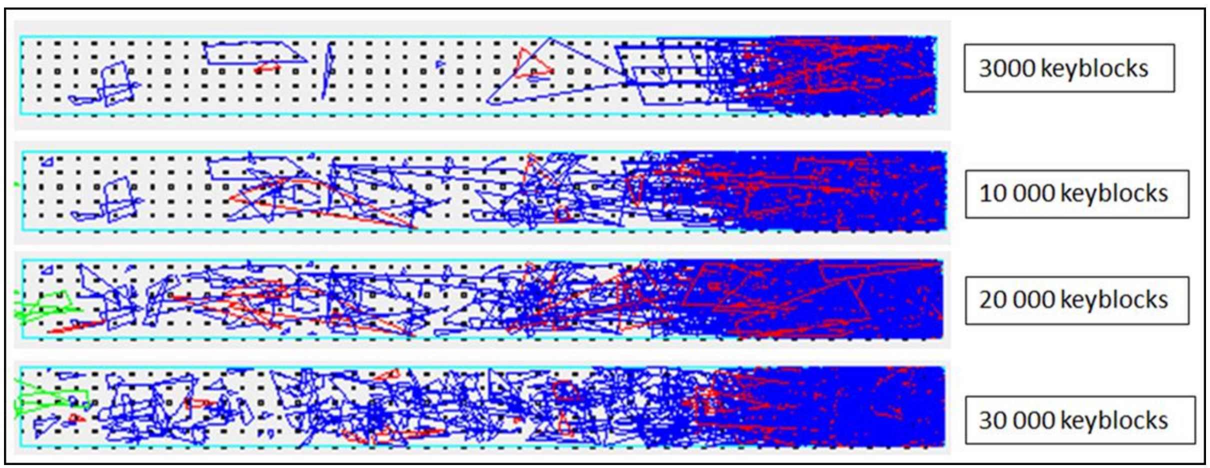


Rockfall

Block Analysis & Monte Carlo Simulation

JBLOCK GS Esterhuizen





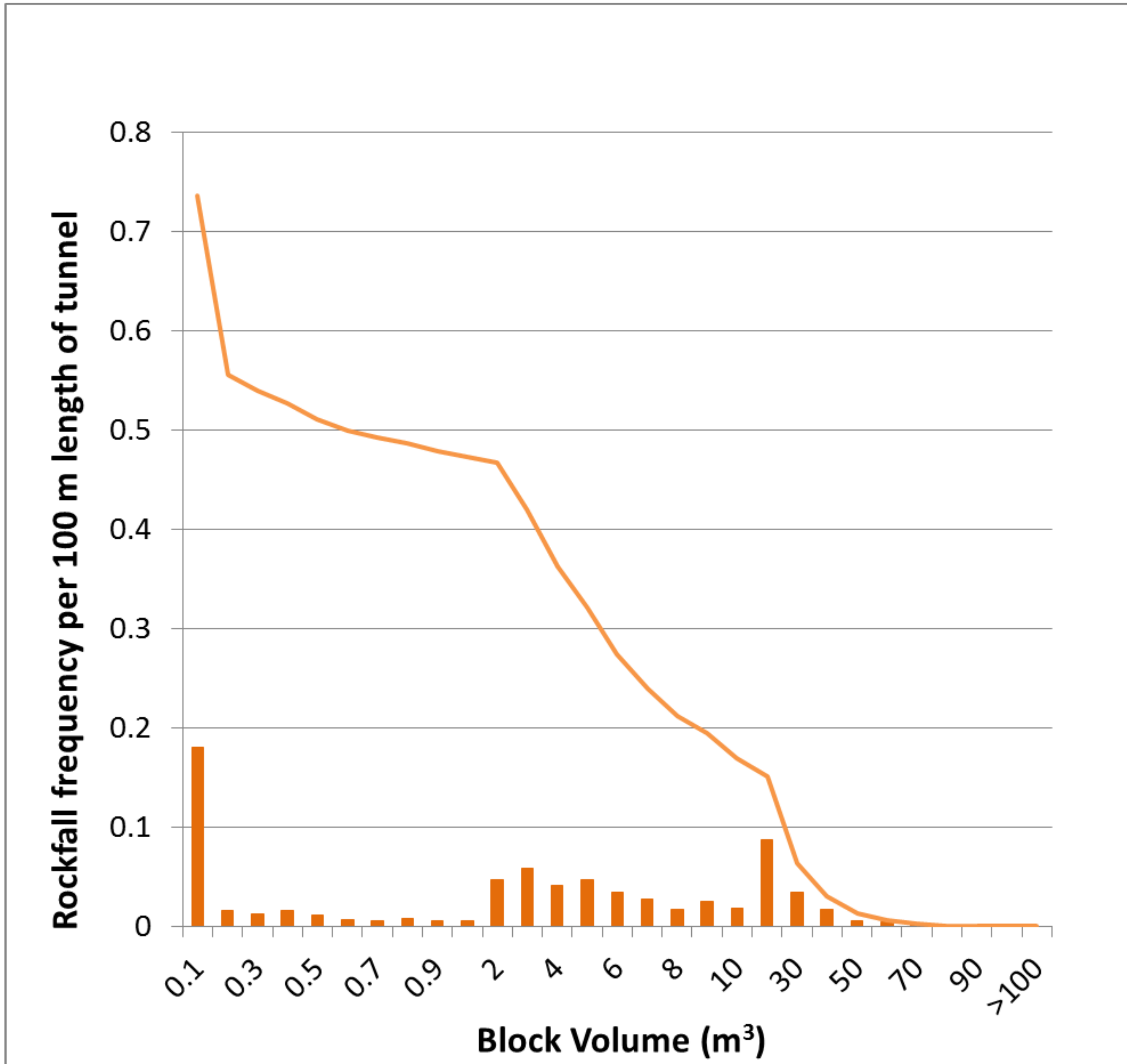
Simple DFN process to generate blocks using joint data. >100 000 Blocks

Unwedge image

Limit equilibrium analysis – Monte-Carlo > 100 000 blocks
Gravity fall, sliding, rotation – effect of support
Keeps track of the surface area exposed for normalisation

Rockfall

Results
Rockfall
Frequency



Stress Damage

Rock Mass Properties

Loading Conditions

Excavation Geometry & support

→

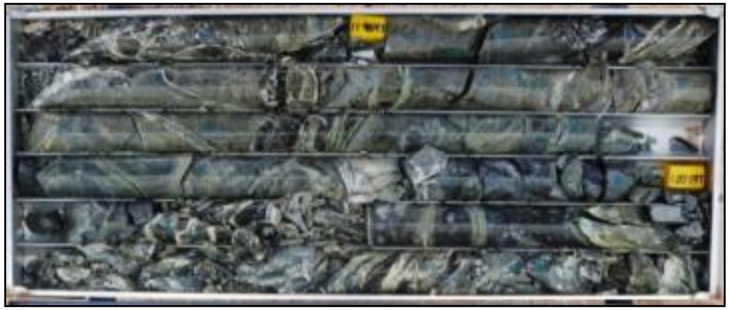
Stress Damage Numerical Analysis (Elastic & Elasto-plastic approaches)

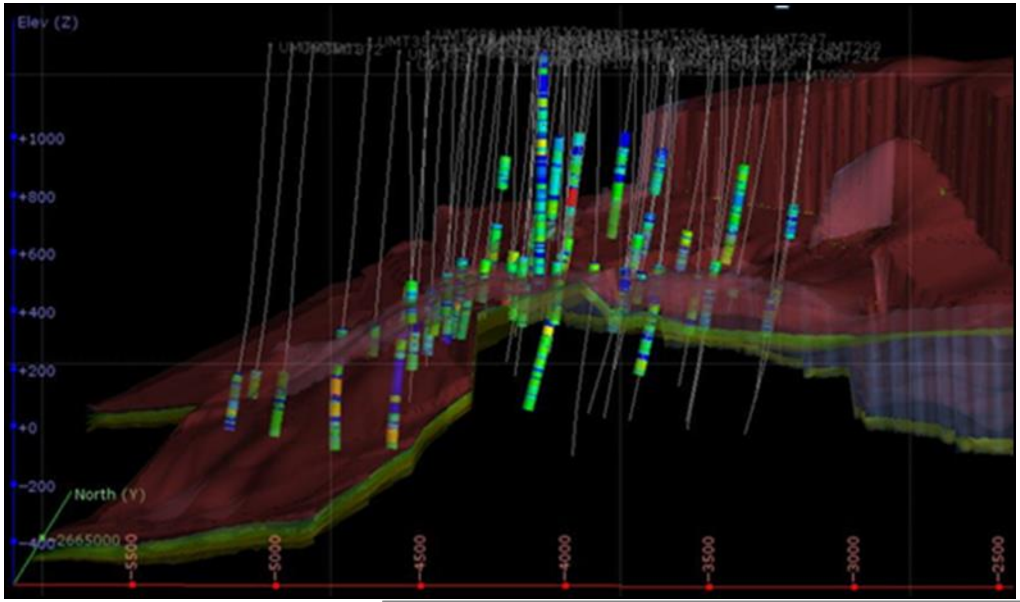
↓

PoF Various methods

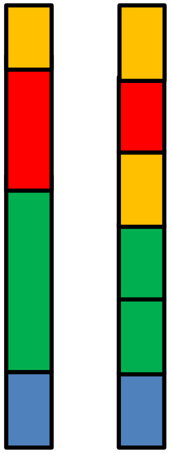
Stress Damage

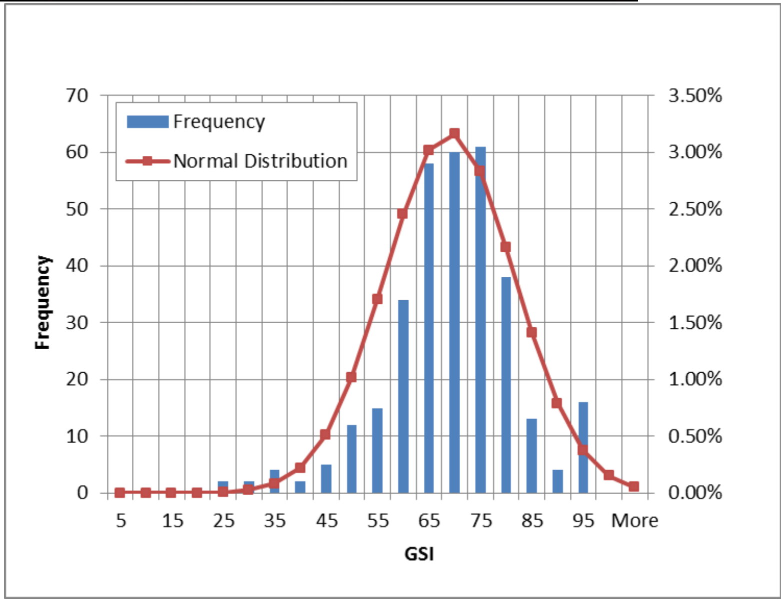
Data - GSI





Composite
10m intervals





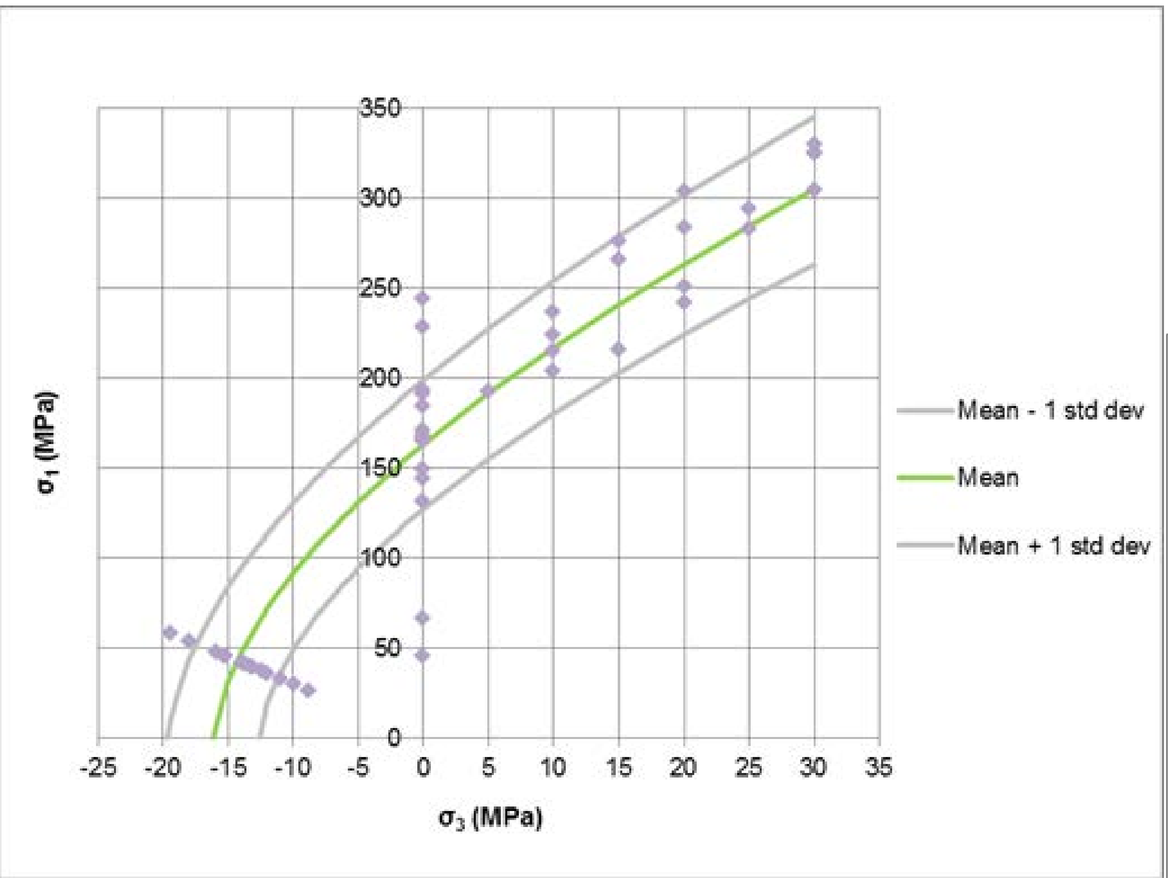
Stress Damage

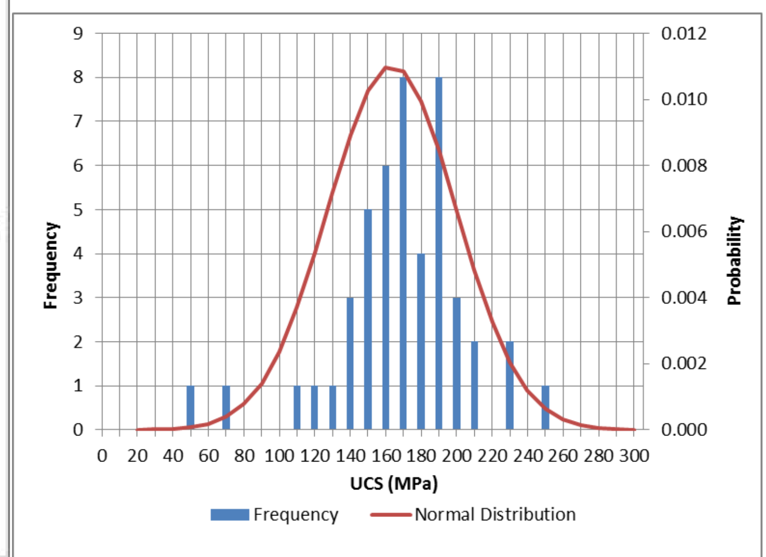
Data – Rock Strength

Hoek-Brown failure criterion

Laboratory tests

Fixed m_i
Variable UCS



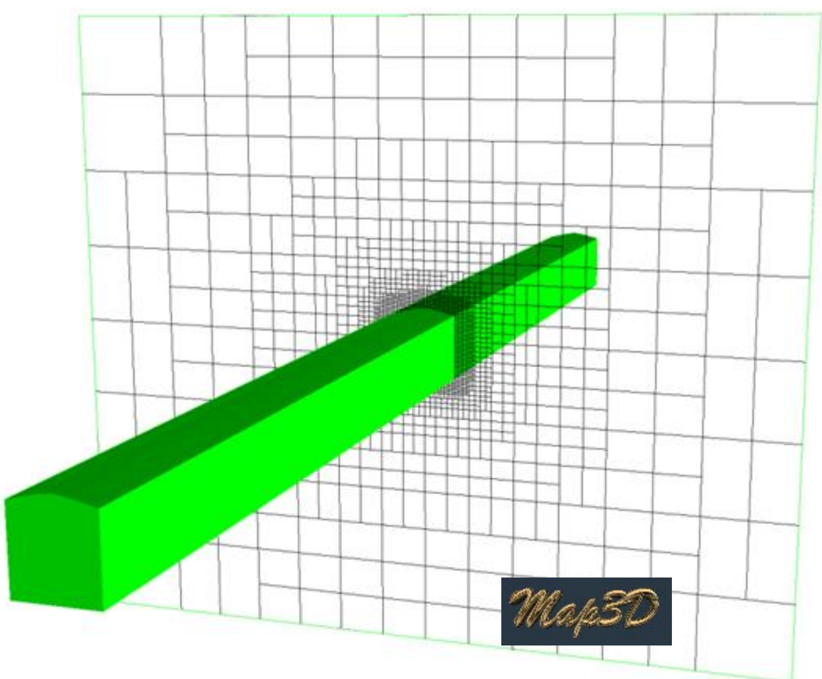


Stress Damage

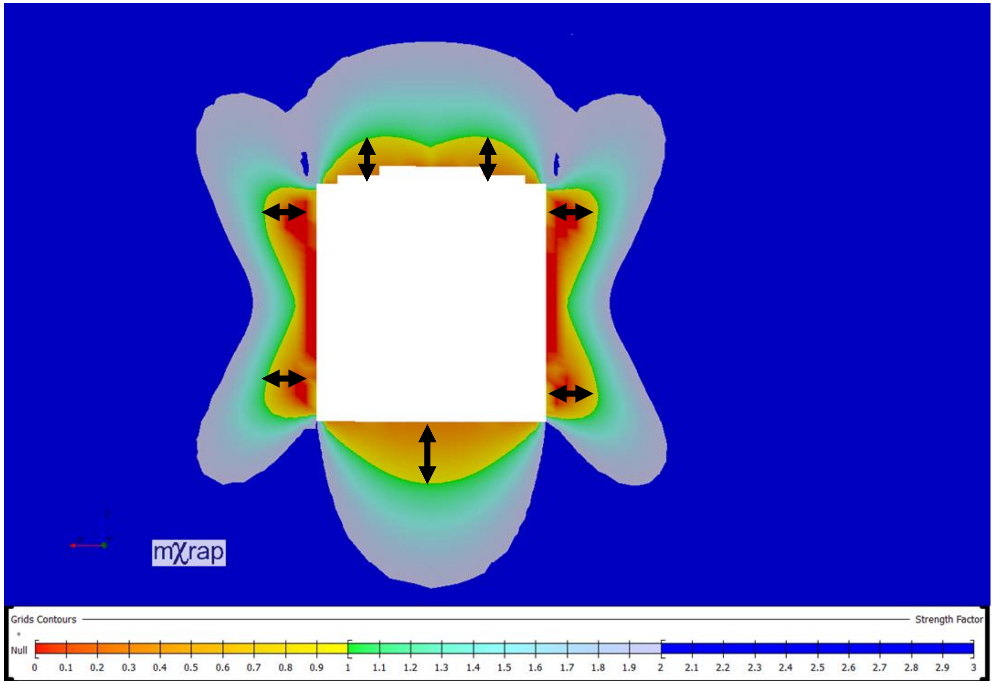
Numerical Analysis

Elastic (Johan Wesseloo)

- **Unit stress elastic boundary element analyses (Map3D)**
- **Stress super-position (mXrap)**
- **Strength Factor (mXrap)**
- **Monte-Carlo (mXrap)**



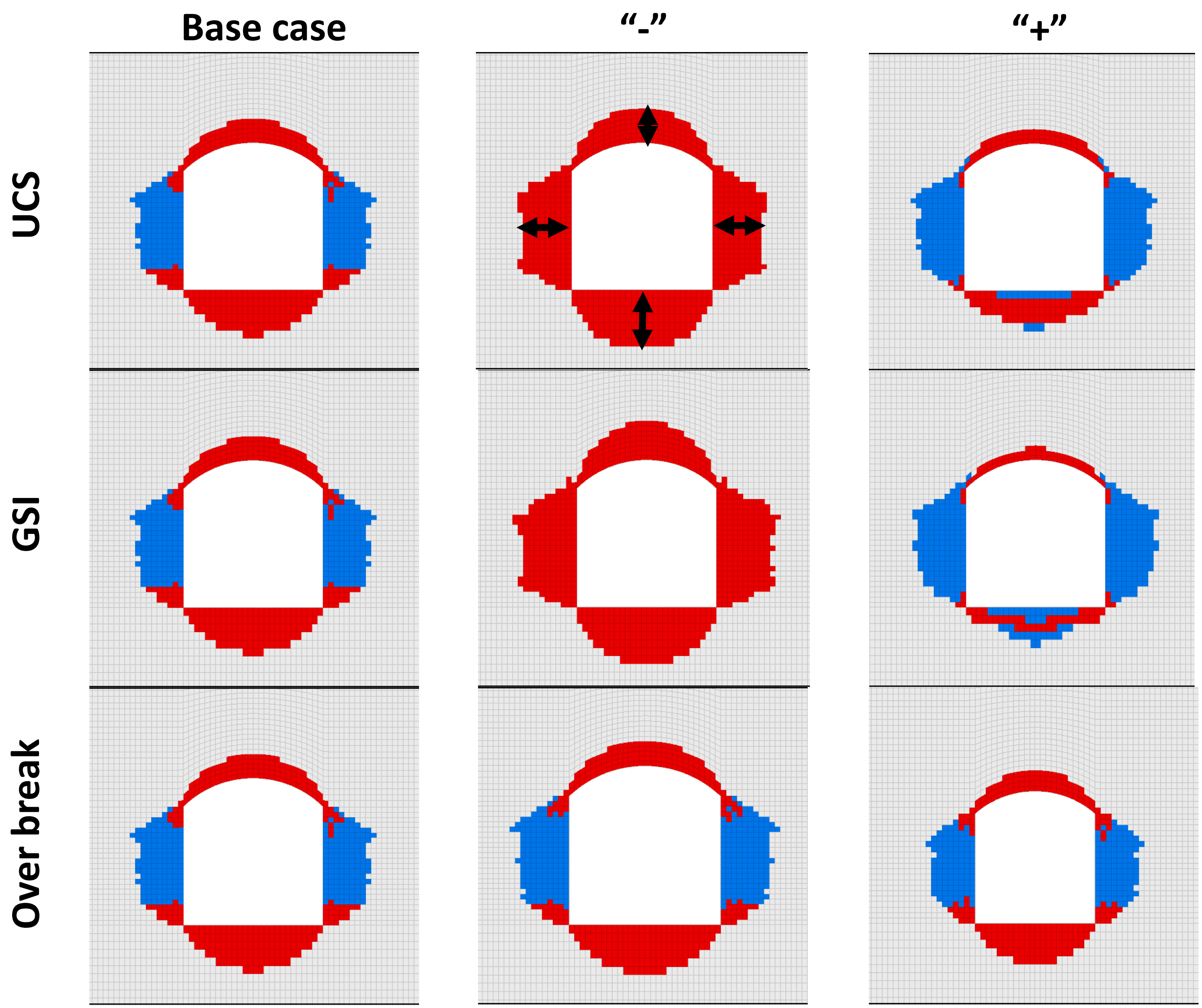
Depth of failure



Numerical Analysis

Stress Damage

Elasto-plastic



Depth of failure

Monte-Carlo Simulation not practical

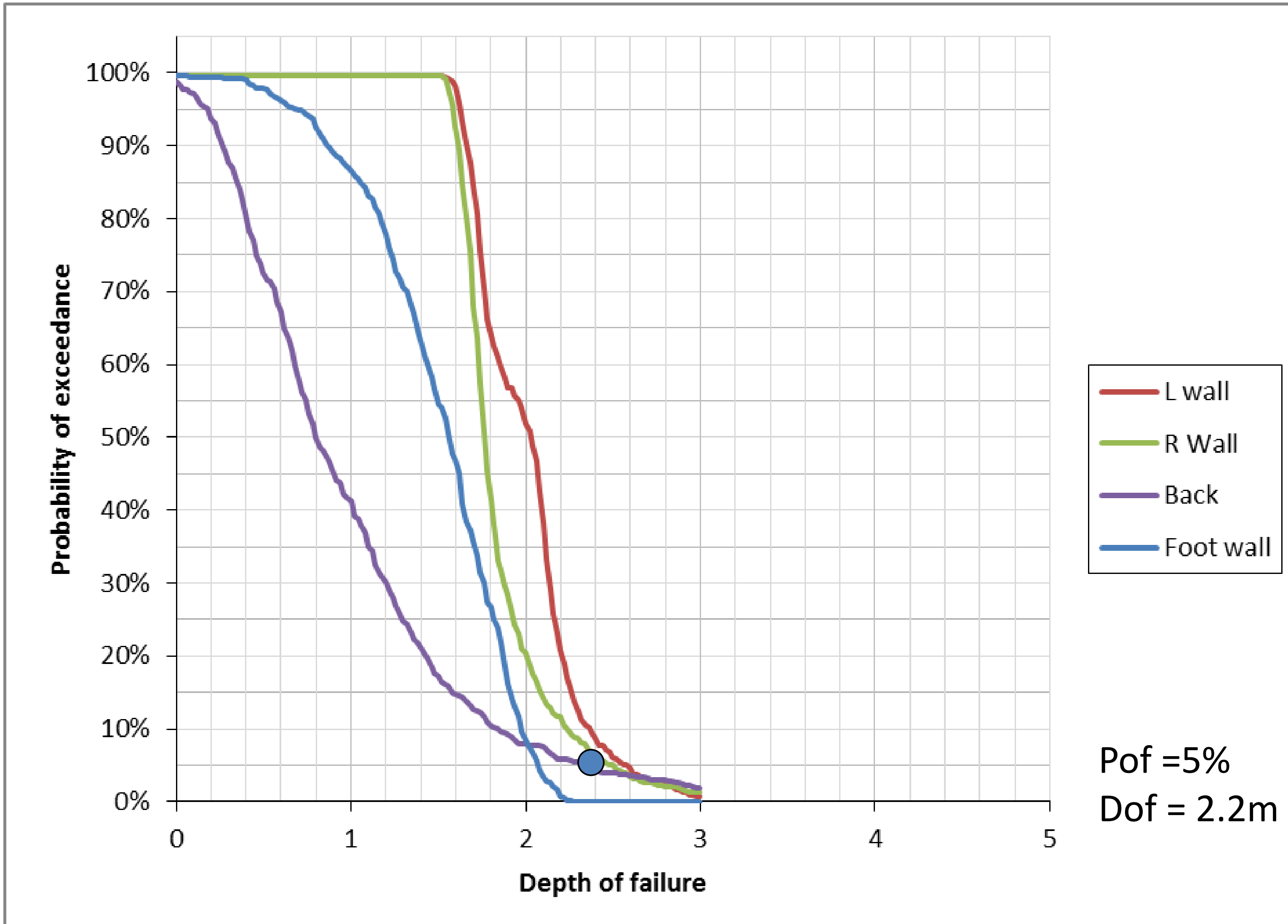
Other probabilistic methods required

- Point Estimate method (PEM)
- Response Surface Method (RSM)
- Response Influence Factor (RIF)

Itasca
FLAC/UDEC (Fish/Python)
or
RocScience
Phase2 / RS2 (built in functions only - PEM)

Stress Damage

PoF

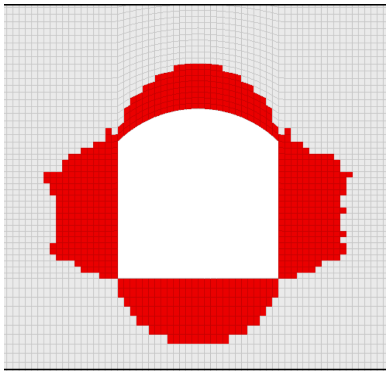


Pof =5%
Dof = 2.2m

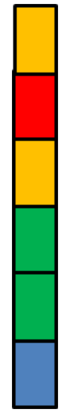
Stress Damage

Pof Interpretation

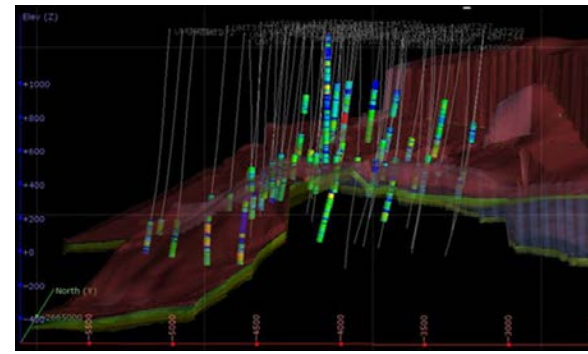
PoF = 5%

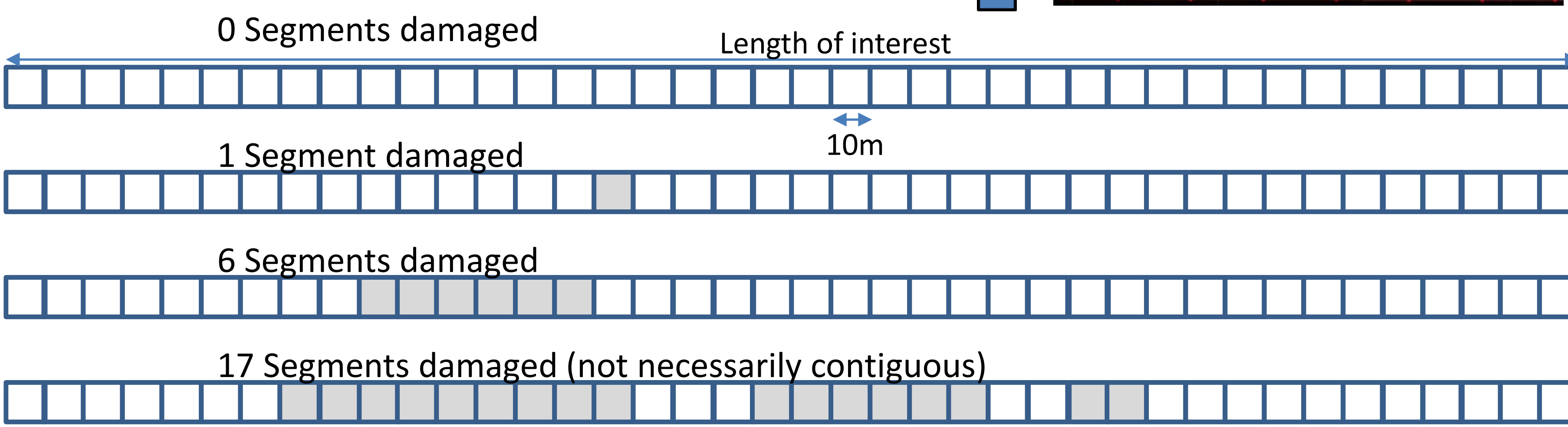


10m intervals



Rock mass characteristics



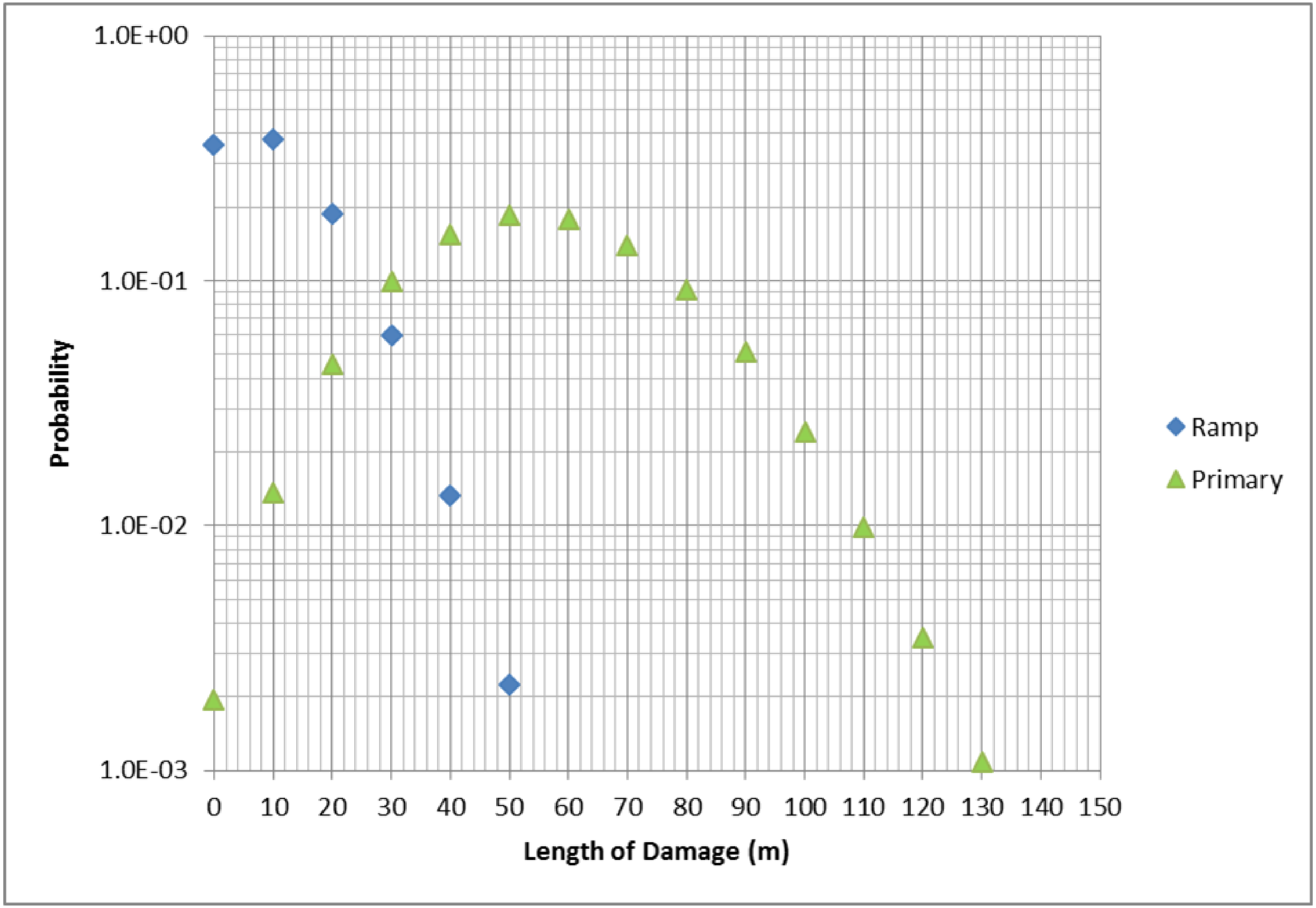


Use Binomial distribution to determine the probability of various lengths of tunnel damage

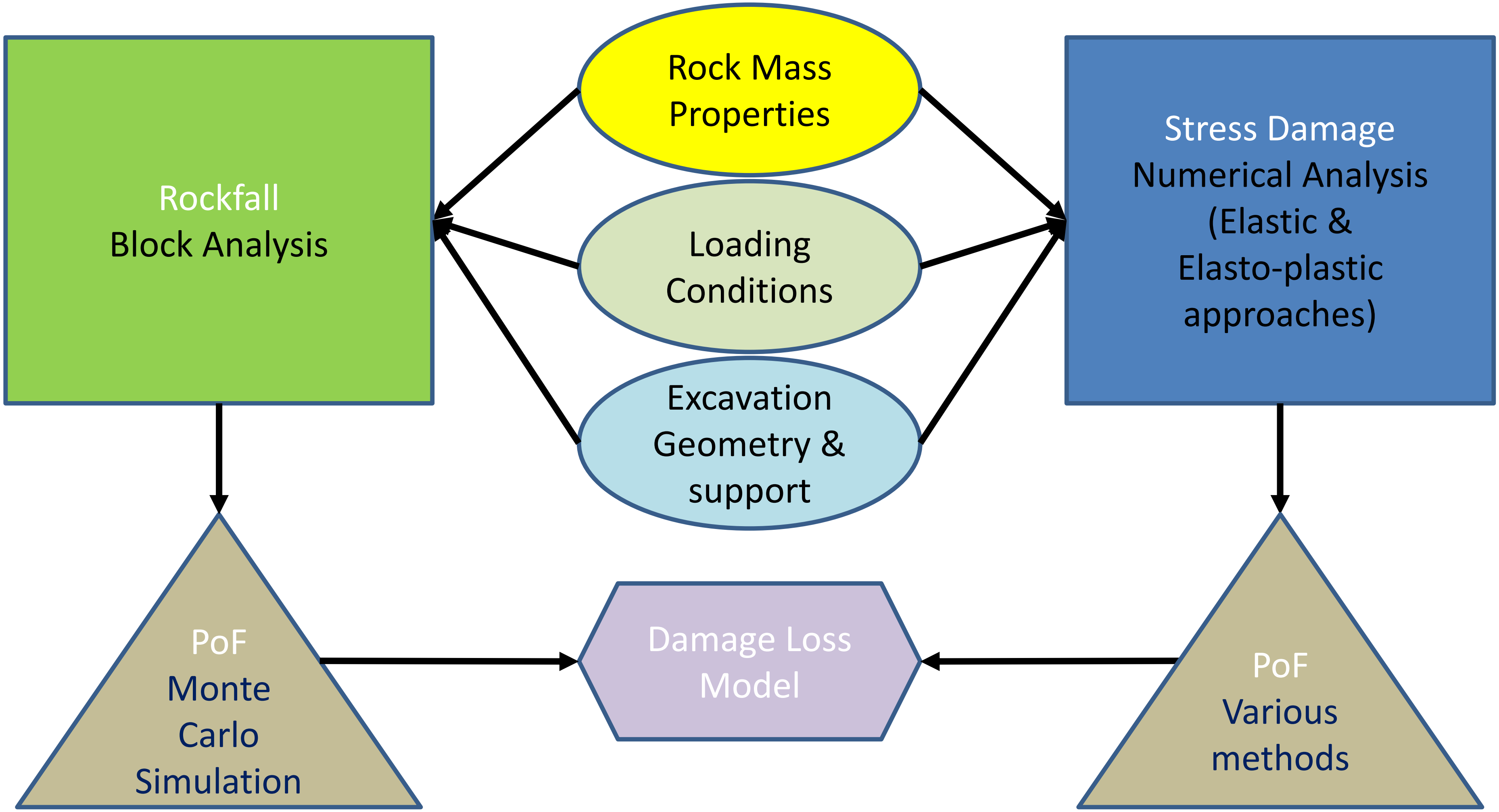
$$\Pr = \frac{n!}{k!\,(n-k)!}\,p^k\,(1-p)^{n-k}$$

Stress Damage

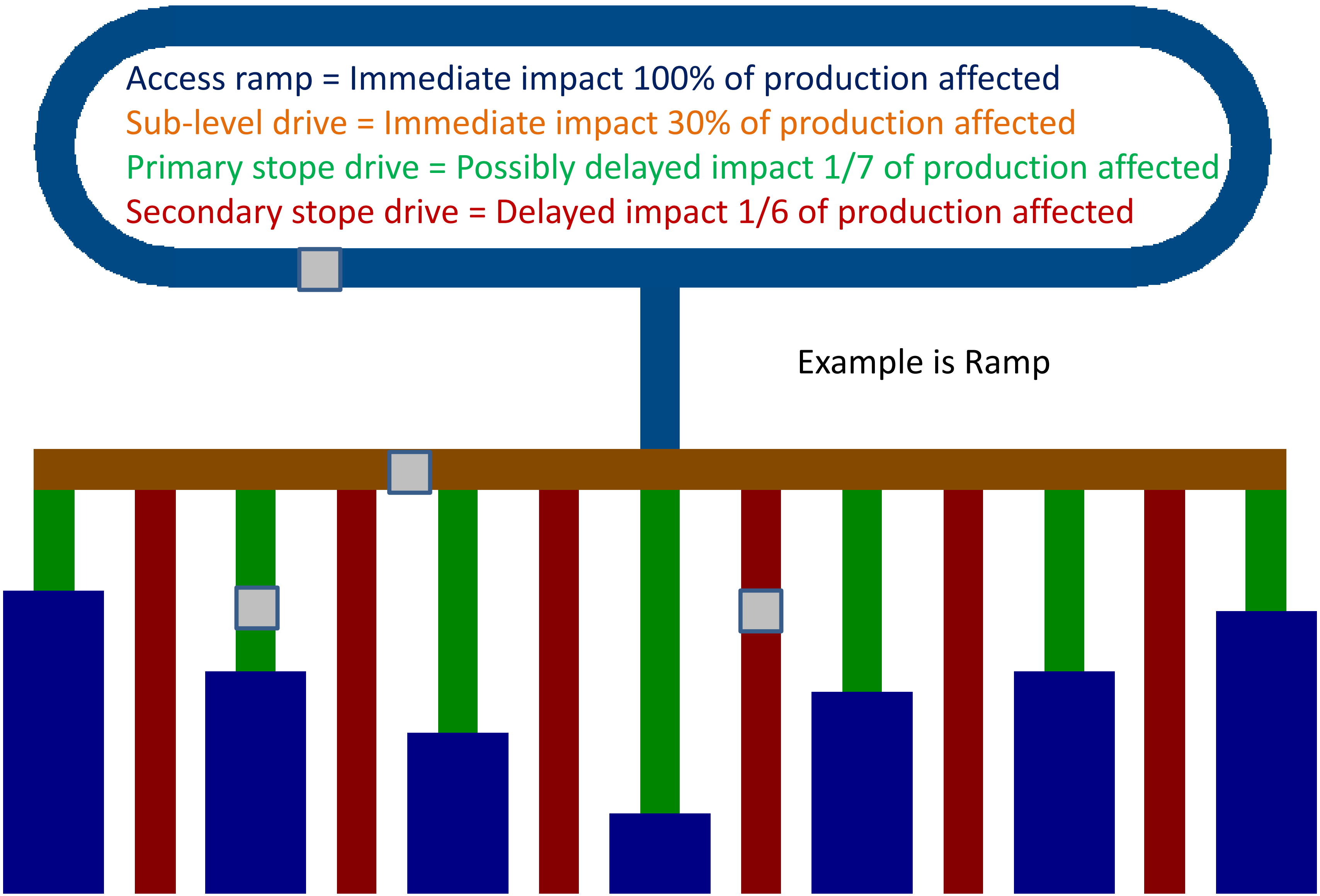
Probability Distribution



Damage Loss Model



Damage location



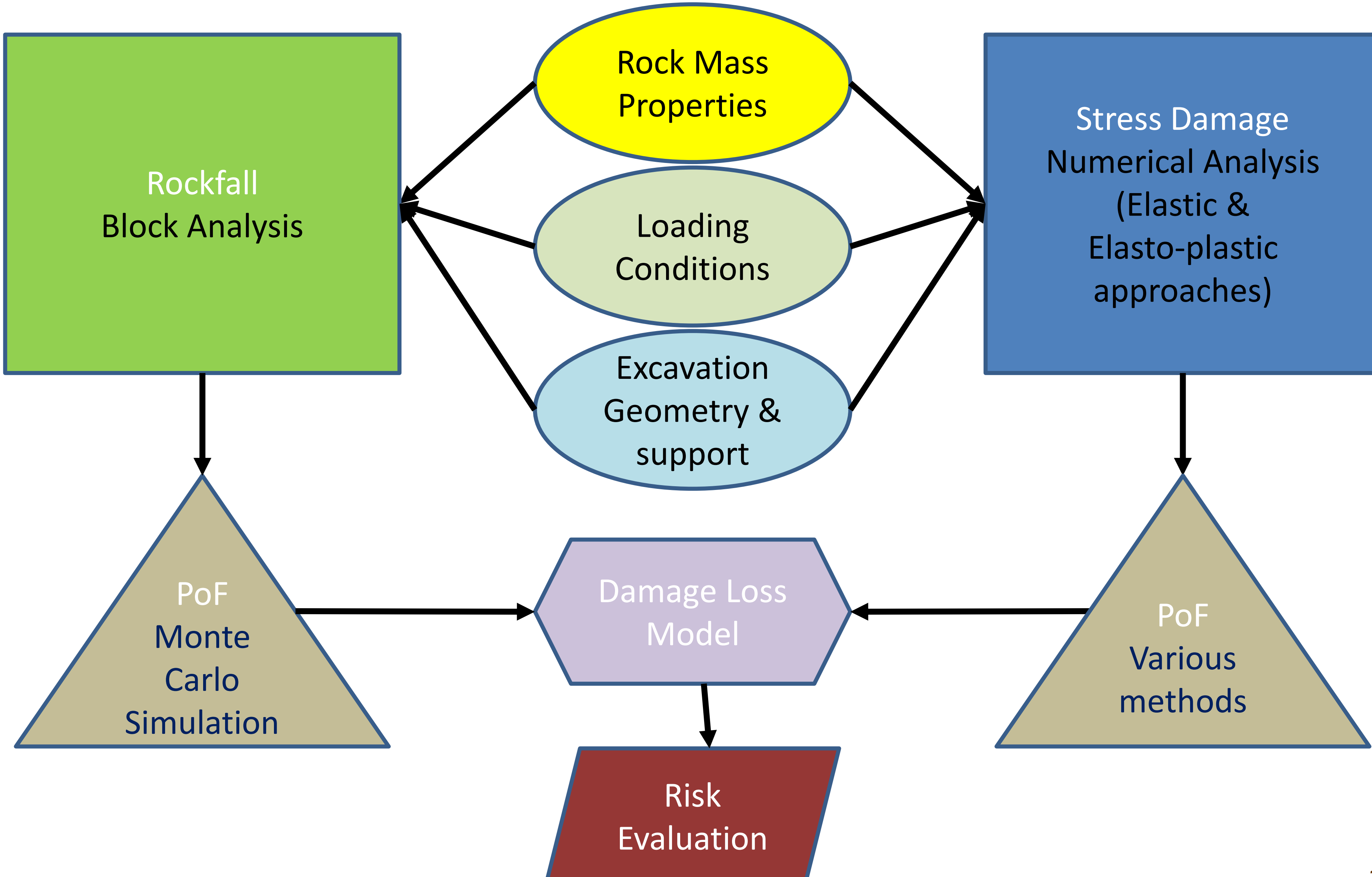
Damage Loss Model

1. Cost of repair ($/m x length affected)
2. Production loss (duration of rehabilitation where access is prevented = rate of rehabilitation x length of damage) x daily tonnage x $/ton

Stope Production		
Stope Height	30	m
Stope Width	10	m
Ring spacing	2	m
Ring volume	600	m^3
Rings	1	Rings/day
Density	2.7	tonnes/m^3
Daily production	**1620**	**tonnes**
Financial		
Grade	6	g/t
Conversion	31	g/ounce
Gold Price	1278	$/ounce
Revenue	247	$/tonne
Direct Cost	40%	
Loss	**148**	**$/tonne**
Daily Loss	0.240	$M
30 Day loss	7.2	$M
365 Day loss	87.6	$M

Evaluation of damage costs	
Tunnel length considered (m)	200
Segment length (m)	10
Segments	20
Probability of segment failure (%)	5.0%
Impact on Daily production (%)	100%
Time until impact (days)	0
Rehabilitation Rate (m/day)	1
Rehabilitation cost ($/m)	1000

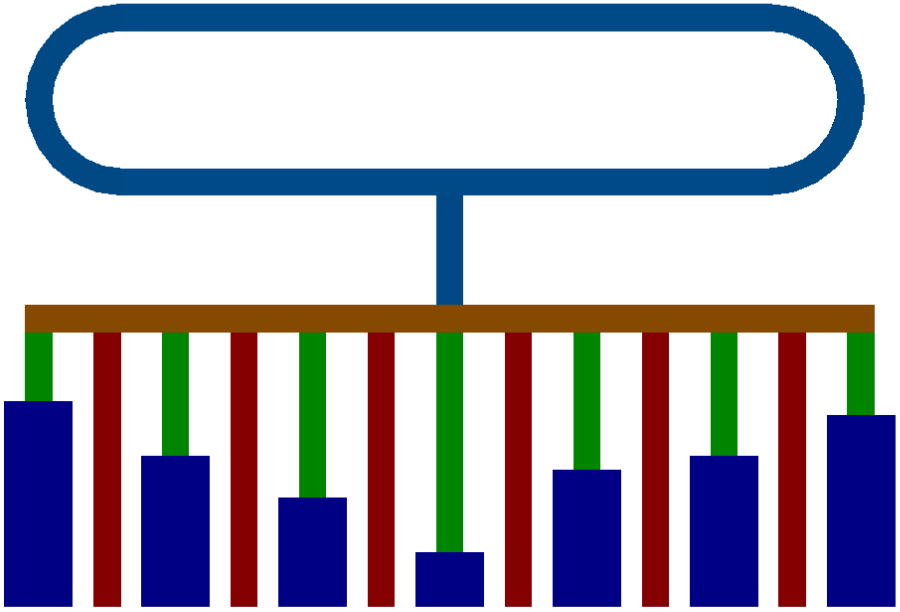
Risk Evaluation



Risk Evaluation

Expected losses ($M)

	Tunnel	Rockfalls	Stress Damage	Total
● (blue)	Access ramp	$1.92M	$2.41M	$4.33M
● (green)	Primary stope drive	$0.02M	$1.78M	$1.80M



Risk Evaluation

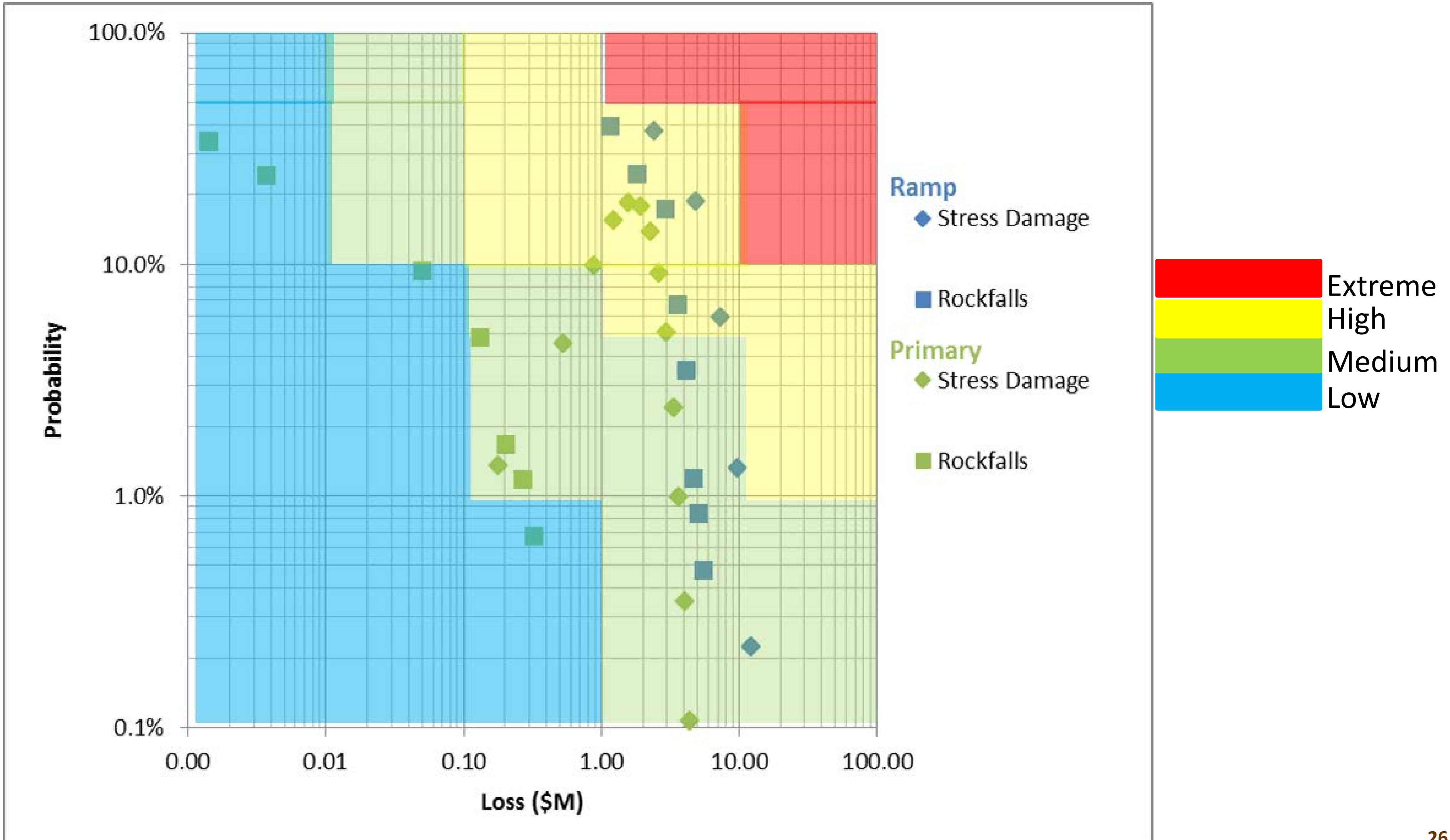
Risk Matrix

Probability of Occurrence	Damage Loss				
	Insignificant <$0.01M	Minor $0.01M-$0.10M	Moderate $0.10M-$1.0M	Major $1M-$10M	Catastrophic >$10M
Certain	Low	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Low	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

Probability Description	Criteria	Probability
Certain	The event will occur. The event occurs daily	>50%
Likely	The event is likely to occur. The event occurs monthly	10% to 50%
Possible	The event will occur under some circumstances. The event occurs annually	5% to 10%
Unlikely	The event has happened elsewhere. The event occurs every 10 years	1% to 5%
Rare	The event may occur in exceptional circumstances. The event has rarely occurred in the industry.	< 1%

Risk Evaluation

Risk Matrix



Factors to Consider

- Types of Uncertainty
  - Aleatoric variability
    - The natural randomness in a system (Data required)
  - Epistemic uncertainty
    - The scientific uncertainty due to limited data and knowledge Sources of Uncertainty (Engineering Judgement)
- Factors to consider
  - Incomplete rock mass data (estimates of confidence)
  - Scale variability
  - Uncertain stress field
  - Influence of major geological structures
  - Time dependant deterioration
  - Model bias (simplification and assumptions)
  - Human error during implementation

Occam's Razor - increasing complexity does not necessarily increase understanding of the risk

Conclusions

- A preliminary risk based approach to ground support design has been developed
  - Rockfall and stress damage analyses
  - Probabilistic solution techniques
  - Damage Loss Model
  - Risk Evaluation
  - Process could be adapted to other analytical methods

Conclusions

- Probability Interpretation (Vick S.G., 2002)
  - Relative frequency approach:
    - The probability of an uncertain event is its relative frequency of occurrence in repeated trials or experimental sampling of the outcome.
  - Subjective, degree of belief approach:
    - The probability of an uncertain event is the quantified measure of one's belief or confidence in the outcome, according to their state of knowledge at the time it is assessed.