GENERATING DESIRED FRAGMENTATION FROM DRILLING & BLASTING DESIGN

Case study of an underground hard rock mine

Contents

Introduction & Project Background

- Blast fragmentations depends on the following main factors;
  - Drilling & Blasting Design
  - Explosives quality
  - Rock Mass Property
  - Compliance to the drilling and blasting designs
- Predicting the fragmentation of the blasted rock mass is of great importance;
  - Makes the stakeholders aware of the % oversize rock expected
  - Provides a guidance on the ring burden and toe spacing required
  - Better fragmentation – decreases the cost of crushing & increases throughput
  - Better fragmentation - minimize the production loss time due oversize rocks
- Ring burden and toe spacing are the main drilling parameters influencing the fragmentation of the blasted rock
- The purpose of the study is to identify the optimal ring burden and toe spacing and to predict the expected fragmentation based the defined requirements

Objectives of study

The following are the objectives defined;

- Develop a Kuz-Ram fragmentation model based on the default rock property
- Use the site PSD result to calibrate fragmentation model
- Identify the calibrated rock factor for the predicted optimized fragmentation model
- Illustrate the explosives distribution theory around the production holes with respect to toe spacing and ring burden
- Determine the acceptable drill factor range based on the budget
- Run various scenarios by varying the toe spacing and ring burden
- Identify the best range of scenarios for the toe spacing and ring burden
- Make recommendations on the acceptable toe spacing and ring burden range and further recommendations to improve the fragmentation

Methodology of the study

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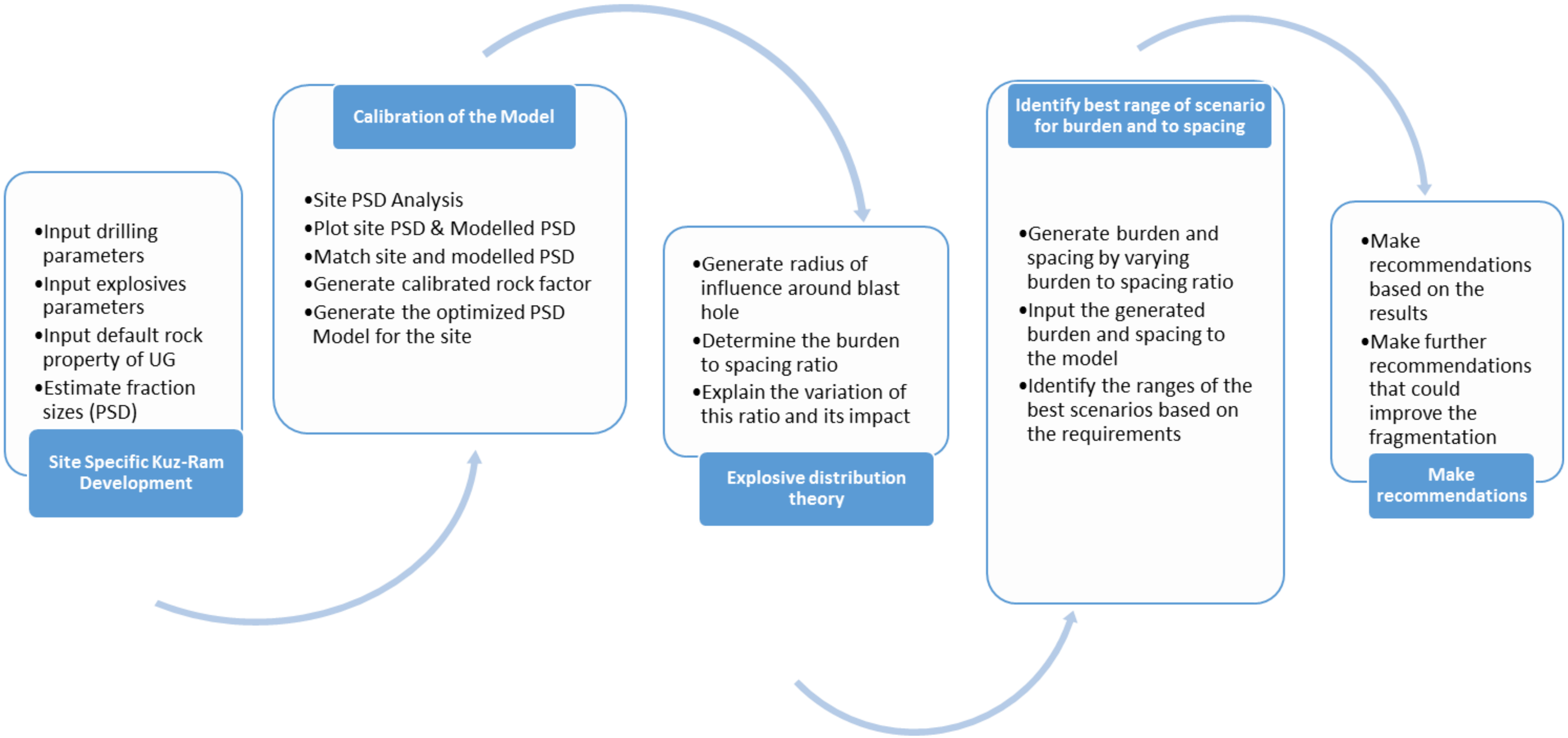

Limitation of the study (Scope)

Mining factors influencing fragmentation are excluded in the initial model;

- Timing design – effect of improving timing for better fragmentation is not included
- Active VOID – assumed that there will be enough active VOID
- Other rock mass property – only UCS, Young’s modulus, density, Joints are incorporated
- Non-compliance to drilling & charging – assumed that the execution will be done as planned
- Bridge collapsing – assumes there will not bridge collapse resulting in oversize
- Explosive quality – assumes the explosive will perform as expected within the required density
- Unexpected fall of ground (FOG) due to operational constraint – assumes there will not be FOG
- Oversize rocks falling off due to firing – assumes that there will not be oversize due to firing

Modelling Assumptions

Assumptions Description	Assumptions	Comments
Charge hole length	85 % of hole length	
Stemming (uncharged) length	15% of hole length	
Full coupling assumption	100 % coupling	
Q_{expl} correction factor	1.4 x Q_{expl}	Ring holes consideration
Drill factor correction factor	0.54 x original drill factor	Ring holes consideration
Correction factor for change of pattern to staggered	10% increase in the uniformity index	Improves explosive distribution when blasting
Note: Corrections factors have been applied to calibrate the Kuz-Ram model to suit underground ring designs. A stope with similar pattern was used for calibration.		

Results and Analysis: Kuz-Ram Initial Modeling

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KUZ RAM FRAGMENTATION MODEL - INITIAL DEVELOPMENT

PATTERN OF THE BLAST (INPUT): 2.8:3.3

Staggered (y/n):	n	
Ring Burden :	2.8	m
Hole Diametar	102	mm
Drill Deviation	1.46	m
Toe Spacing	3.3	m
Sub-drill	1	m
Hole Length	35	m
Tons Blasted	1071	T

TYPE OF ROCK / ACSA

Joint Plane Spacing	20	
Joint Plan Dip/Angle	40	
Firable/Fractured/Massive		
RDI	30.5	
HF	8.67	
Rock Density	3.22	t/m^3
Young Modulus:	26.00	GPa
USC:	192.00	MPa
Calculated Rock Factor	5.95	

EXPLOSIVES DETAILS

Explosive Property	Subtek Eclipse Emulsion	
Density:	1.20	t/m^3
Hole Diameter	102	mm
Explos.RWS:	97	
Charge Length	30.6	m

% Oversize at a specified input	6.1%	
Input > x	0.9	m
F80%	0.4	m

CALCULATED:

Uniformity Index,n:	0.78	
Average Size,X:	0.150	m
X_c:	0.241	m
Stemming:	5.250	m

Spacing:	3.3	m
Charge Length:	30.600	m
Explosive per hole:	420.07	kg
Powder Factor:	1.263	kg/m^3
	0.4	kg/t
Totale Blasted:	1071	tons
DF	14	T/m

FRACTION SIZES WITH % FEEDING

Size (m)	(%) Feeding Representation	Size (mm)
0.90	**94**	**900**
0.80	92	800
0.70	90	700
0.60	87	600
0.50	**83**	**500**
0.40	77	400
0.30	70	300
0.20	58	200
0.10	40	100
0.05	25	50
0.01	8	10

Results and Analysis: Kuz-Ram Modeling

- Kuz-Ram modelling is done based on the inputs below;
  - The drilling parameters
  - Blasting parameters
  - Default rock mass property
- The simulated Kuz-Ram model based on the inputs shows;
  - Simulated rock factor of 5.95
  - Mean size (F50%) of 150 mm and 900 mm representing F94%
  - Oversize (>900 mm) representing 6%
- The rock factor needs to be calibrated to optimise the modelling
- Optimizing the model will take into considerations certain aspects excluded while generating the model as stated in the scope of study
- This is done by gathering data from the actual PSD curve from site
- The actual PSD curve has similar drilling & blasting parameters with the simulated curve
- The calibration is conducted by trial and error method by varying the rock factor until there is a best fit between the modelled PSD curve & the actual PSD curve

Results and Analysis: Kuz-Ram Modeling

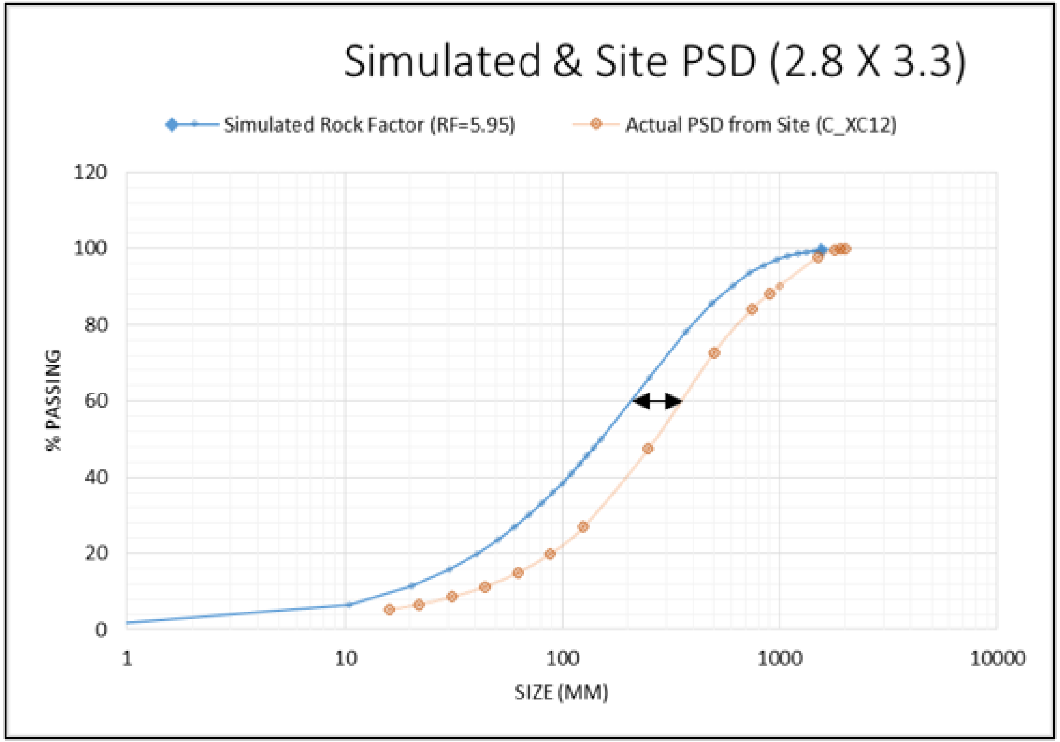

Figure 1: Simulated PSD (RF=5.95) and Actual PSD from site

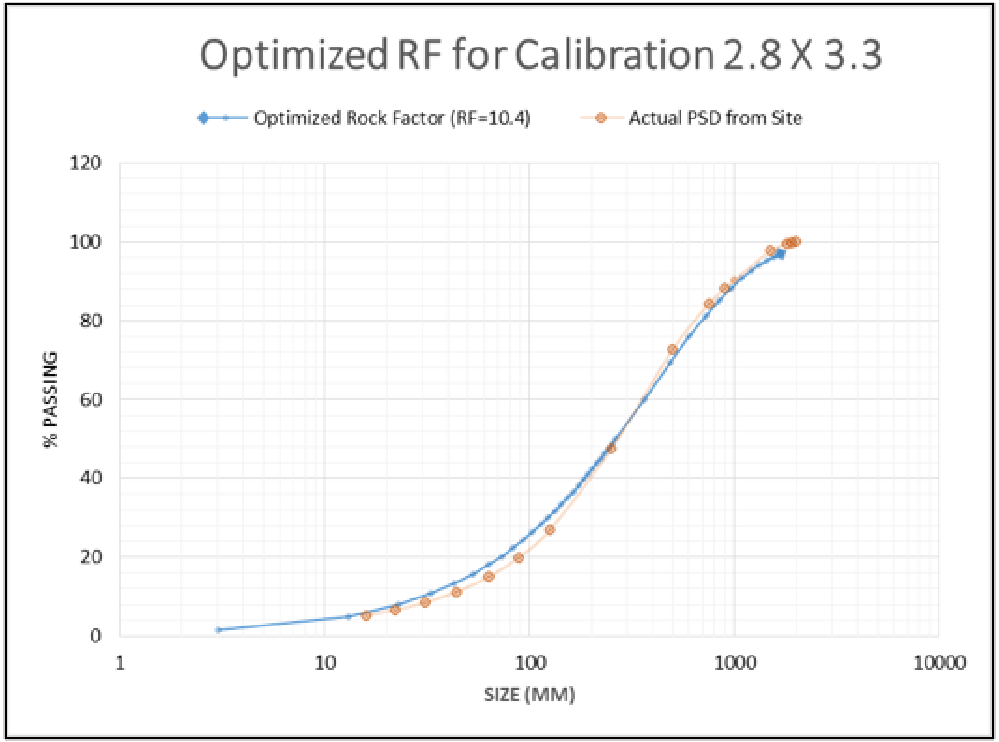

Figure 2: Calibrated PSD curve resulting in an optimized RF =10.4

- Distortion between the simulated PSD and actual site PSD – before calibration
- The best fit occurs when a rock factor of 10.4 was observed (Fig.2)
- The model is optimised based on the calibrated rock factor

Results and Analysis: Kuz-Ram Optimized Modeling

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KUZ RAM FRAGMENTATION MODEL - OPTIMIZED

PATTERN OF THE BLAST (INPUT):	2.8:3.3	
Staggered (y/n):	n	
Ring Burden :	2.8	m
Hole Diametar	102	mm
Drill Deviation	1.46	m
Toe Spacing	3.3	m
Sub-drill	1	m
Hole Length	35	m
Tons Blasted	1071	T

TYPE OF ROCK	ACSA	
Joint Plane Spacing	20	
Joint Plan Dip/Angle	40	
Firable/Fractured/Massive		
RDI	30.5	
HF	8.67	
Rock Density	3.22	t/m^3
Young Modulus:	26.00	GPa
USC:	192.00	MPa
Calibrated Rock Factor	10.4	
Calculated Rock Factor	5.95	

EXPLOSIVES DETAILS		
Explosive Property	Subtek Eclipse Emulsion	
Density:	1.20	t/m^3
Hole Diameter	102	mm
Explos.RWS:	97	
Charge Length	30.6	m
% Oversize at a specified input	16.4%	
Input > x	0.9	m
F80%	0.4	m

CALCULATED:

Uniformity Index,n:	0.78	
Average Size,X:	0.263	m
X_c:	0.421	m
Stemming:	5.250	m
Spacing:	3.3	m
Charge Length:	30.600	m
Explosive per hole:	420.07	kg
Powder Factor:	1.263	kg/m^3
	0.4	kg/t
Totale Blasted:	1071	tons
DF	14	T/m

FRACTION SIZES WITH % FEEDING

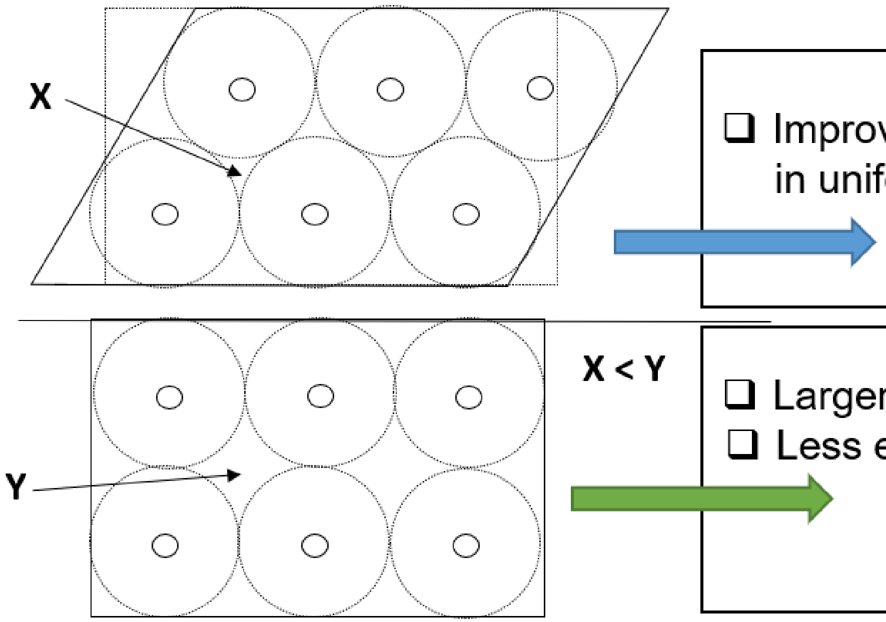
Size (m)	(%) Feeding Representation	Size (mm)
0.90	**84**	**900**
0.80	81	800
0.70	77	700
0.60	73	600
0.50	**68**	**500**
0.40	62	400
0.30	54	300
0.20	43	200
0.10	28	100
0.05	17	50
0.01	5	10

Results and Analysis: Kuz-Ram Optimized Modeling

- The simulated optimised Kuz-Ram model shows;
  - Calibrated optimised rock factor of 10.4
  - Mean size (F50%) of 263 mm and 900 mm representing F84%
  - Oversize (>900 mm) representing 16 %
- The optimised model can be used to generate different scenarios of toe spacing and ring burden to predict the expected fragmentation

Results and Analysis: Explosive distribution theory

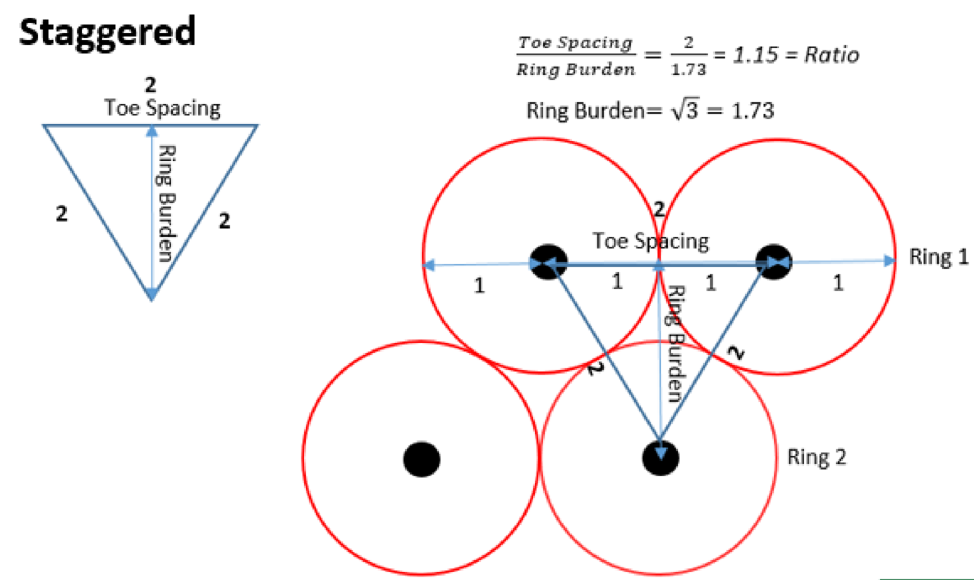
- Explosive distribution theory is the factor considered in the study to generate various scenarios for burden and spacing
- Two patterns will be considered;
  - Squared pattern
  - Staggered pattern

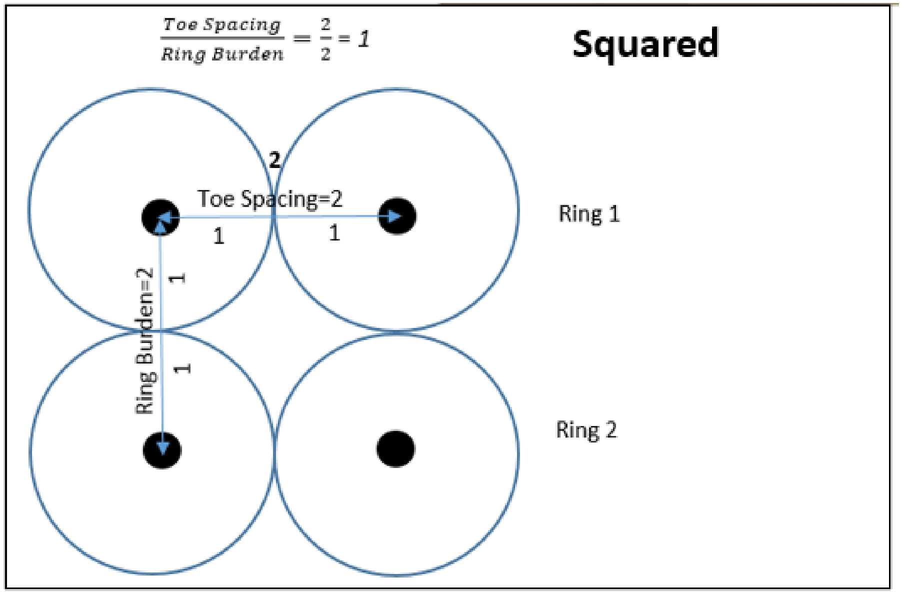


Staggered
- ❑ Improves explosive distribution resulting in uniform fragmentation – improves the uniformity index

Squared
- ❑ Larger fragments expected due to Y > X
- ❑ Less energy distributed evenly between the holes

Results and Analysis: Breakout geometry





- Increasing the S/B ratio – improves the fragmentation when the drilled ***holes are staggered***

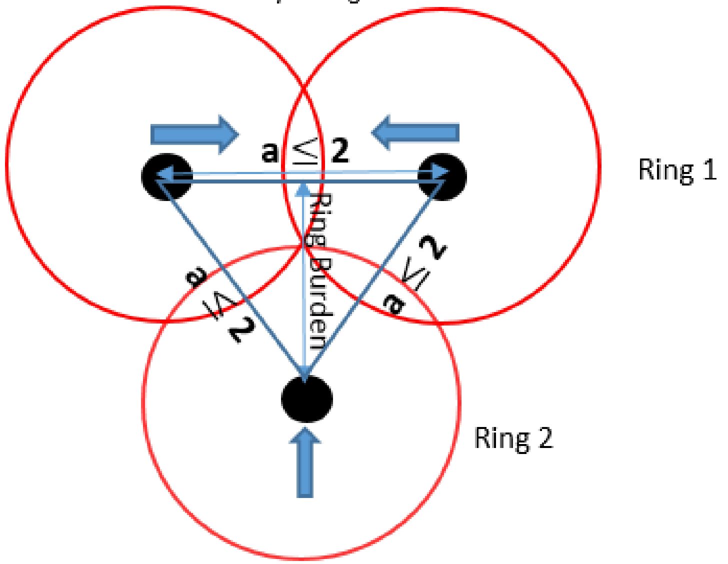
- Larger fragments expected due reduced S/B ratio in ***a squared pattern***

- Practically the holes are not drilled perfectly staggered as the equilateral triangle shown above but the goal is to have a staggered pattern from a design stage

Results and Analysis: Breakout geometry

$$\frac{Toe\ Spacing}{Ring\ Burden} = Ratio >=< 1.15$$

$$Ring\ Burden \leq 1.73$$
$$Toe\ Spacing \leq 2$$



- Staggering the production holes (with no equidistant ring burden and toe spacing will result in any of the following scenarios;
  - Reducing the toe spacing with fixed ring burden – reduces S/B ratio
  - Reducing the ring burden with fixed toe spacing – increase S/B ratio
  - Reducing the toe spacing and ring burden simultaneously – increase S/B ratio
- However the most efficient way to blast staggered holes is to have 1.15 S/B ratio for parallel rings
- Modelling is conducted based on the variation of the S/B ratio to generate various scenarios

Results and Analysis: Scenarios assumptions

Budget Assumptions 2018	Unit	Value
Budget Drill factor (DF)	T/m	12
Budget rate long hole drilling	m/day	230
Drilling Tons	T	4.1 M
Study Assumptions		
SOLO drilling capacity	m/day	250
CUBEX drilling capacity	m/day	150
Minimum DF required to achieve 2018 drill tons	T/m	9.8

Study assumptions discussion

- DF < 9.8 T/m – requires additional SOLO to achieve 2018 drill ton planned
- 9.8≤DF<12 will not require an additional SOLO but increases the drilling & explosives cost
- The first requirement for the simulation is to have a drilling pattern that will be more than 9.8 T/m

Results and Analysis: Simulation scenarios

Primary Objective of simulation scenarios;

- Identify the best top 10 scenarios for the toe spacing and ring burden based on the selection criteria

Scenarios selection criteria for toe spacing and ring burden

The following is the ranking of the selection criteria based on the underground requirement;

1. Achieving the drill tons for the year without an additional equipment
2. Achieving the higher percentage feeding through the grizzly
3. Achieving acceptable cost

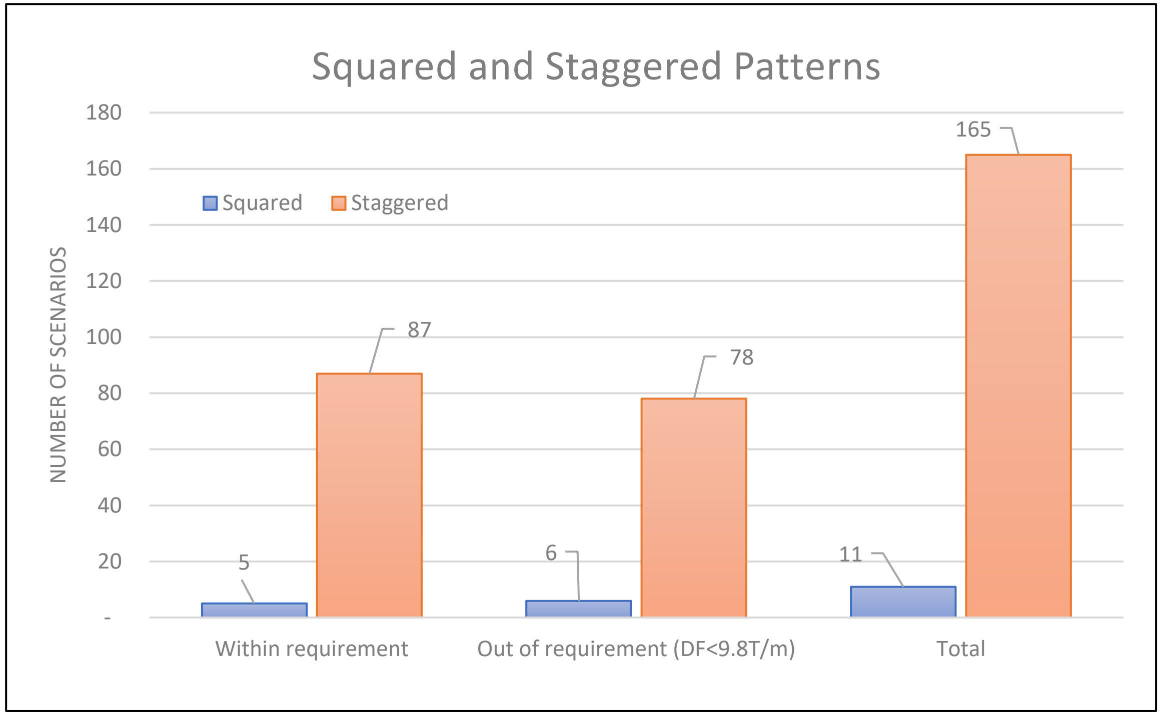
Relating the selection criteria with the simulation scenarios

Scenario selection criteria	Criteria in the simulation
1	Drill factor in the simulation should be ≥ 9.8 T/m
2	Maximum percentage passing at 900 mm
3	DF to be between 9.8 and 12 but DF closer to 12 will be preferred to minimise the drilling and explosives costs

Results and Analysis: Simulation scenarios

Simulation Details	
Simulation Model	Kuz-Ram Optimized Model
Ring burden range	2.0 to 3.0 (0.1 increment)
S/B ratio	1.00 to 1.15 (0.01 increment)
Pattern in simulation	Staggered and squared
Total simulation scenarios	176
Total staggered scenarios	165
Total squared scenarios	11

Scenarios results based on criteria 1



- Total of 84 scenarios were eliminated from the ranking based on criteria 1
- Some of these scenarios had high number of passing % but failed the requirements
- A typical case study of 2.3 burden with S/B ratio from 1.00 to 1.15 (16 scenarios) discarded due to failing of criterion 1

Scenarios summary results based on criteria 1,2 and 3

Scenarios Ranking	Burden, B (m)	Spacing, S (m)	Uniformity Index, n	Mean size (m)	S / B Ratio	DF T/m	P% @ 900 mm
1	2.6	2.63 ≈ 2.6	0.77	0.206	1.01	10.1	88.3
2	2.7	2.73 ≈ 2.7	0.80	0.219	1.01	10.9	88.2
3	2.8	2.83 ≈ 2.8	0.82	0.232	1.01	11.7	87.9
4	2.8	2.86 ≈ 2.9	0.83	0.234	1.02	11.8	87.9
5	2.7	2.81 ≈ 2.8	0.80	0.225	1.04	11.2	87.9
6	2.6	2.76 ≈ 2.8	0.78	0.215	1.06	10.6	87.9
7	2.6	2.73 ≈ 2.7	0.77	0.213	1.05	10.5	87.9
8	2.7	2.86 ≈ 2.9	0.81	0.228	1.06	11.4	87.7
9	2.5	2.70 ≈ 2.7	0.75	0.204	1.08	10.0	87.7
10	2.8	2.97≈ 3.0	0.83	0.242	1.06	12.3	87.5

- The ranking is based on the 3 selection criteria previously discussed
- The toe spacing has been rounded-off to 1 digit for practicality from the design perspective
- However the best scenarios close to the DF of 12T/m (2018) budget with a with high % passing are;
  - Ring burden 2.8 x 2.9 Toe spacing
  - Ring burden 2.8 x 2.8 Toe spacing
- The various scenarios from the simulation shows that reducing the ring burden and toe spacing too much does not necessarily increase the % passing (ref. to simulation database)

Conclusion

- Kuz-Ram model was developed and optimised based on the rock property;
  - Initial model resulted in a rock factor of 5.95
  - Calibrated model optimised the rock factor to 10.4
  - Calibrated rock factor was considered for the simulations
- Breakout geometry based on the toes spacing and ring burden;
  - Staggered pattern are preferred compared to squared pattern for better fragmentation
  - The most efficient way to blast staggered holes is to have 1.15 S/B
  - The variation of the S/B ratio was considered in the simulation for various scenarios
- A total of 176 scenarios were simulated of which 84 were eliminated;
  - The top 10 scenarios based on the defined criteria were generated from the simulation
- The top 3 scenarios based on the 3 selection criteria;
  - Ring burden 2.6 x 2.6 Toe spacing
  - Ring burden 2.7 x 2.7 Toe spacing
  - Ring burden 2.8 x 2.8 Toe spacing
- Although the ranking is based on the defined criteria;
  - It is possible to experience a good fragmentation from various burden and spacing irrespective of the ranking from the simulations
  - This is due to other factors influencing the fragmentation results such as drill design holes adjustments, charge lengths, timing and firing sequence
  - Therefore the simulation is a good indication to predict the fragmentation - the final decision on the toe spacing and ring burden is not solely dependent on the simulation

Recommendations

- Implement any of the following drilling pattern with DF>11 to 1 to 2 stopes and observe the results;
  - Ring burden 2.7 x 2.8 Toe spacing
  - Ring burden 2.7 x 2.9 Toe spacing
  - Ring burden 2.8 x 2.8 Toe spacing (previously implemented)
  - Ring burden 2.8 x 2.9 Toe spacing
- Consider other factors that could improve the fragmentation;
  - Staggered the holes in the ring design – improves explosive distribution
  - Reduce the burden timing for an effective timing – consistent fragmentation
  - When designing firing sequences – minimise the large unsupported span
  - Minimise the number of firing per stope to reduce the exposure of unsupported rock mass
  - Ensure QA/QC drilling and charging to prevent any failure in the execution
  - Ensure active VOID prior to firing
- Perform vibration monitoring consistently;
  - The actual timing vs. the design to observe the compliance of the execution
  - The effect of burden, toe spacing, holes deviation, charge lengths on the fragmentation results and compare this with the actual results from the fragmentation analysis
- Perform fragmentation analysis to observe the results and do the comparison with the simulation
- If the desired fragmentation is not achieved – implement pattern within10 ≤ DF< 11

Further work

- Calibrate the rock factor value after doing multiple analysis from various samples
- Determine the rock factor per mining zone based on fragmentation results from different lodes
- Take into account the total consumption cost (drilling, explosives, crushing) and conduct simulations for the best drilling pattern that will result in optimal cost (i.e. reducing the cost of crushing by reducing oversize)

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