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OPTIMISING SAFETY IN BLASTING: FLYROCK HAZARD MITIGATION, MODELLING, AND EXCLUSION ZONES

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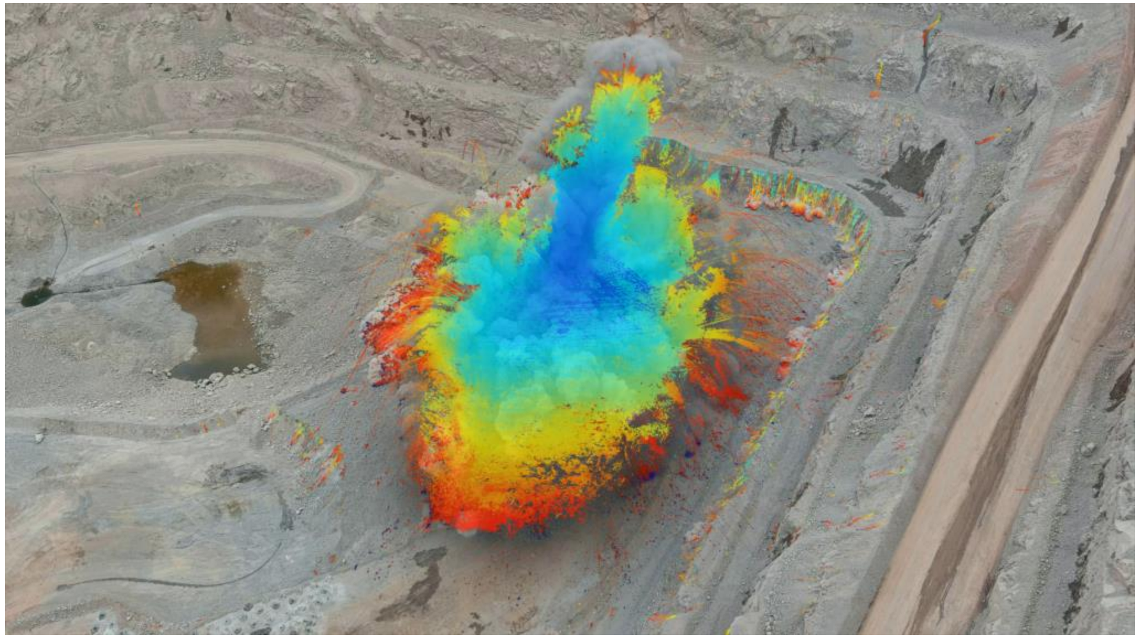
FLYROCK HAZARD MITIGATION

What is Flyrock

Flyrock is a rock that is ejected from a blast site by explosive energy. It results when the energy applied is greater than what's needed to fragment and displace the muckpile, in a controlled manner. It can be classified into three mechanisms:

1. **Face burst:** Occurs near geological structures or weak zones, where explosive gases follow paths of least resistance, generating flyrock.
2. **Cratering:** Results from insufficient stemming height or weak collar rock, causing flyrock to be launched.
3. **Rifling:** Happens when there is inadequate stemming material, leading blast gases to eject stemming and collar rock as flyrock.



Face Burst Flyrock

Rifling Flyrock

Cratering Flyrock

Causes and Consequences of Flyrock

Improper Blast Design: Inadequate blast parameters like improper burden, spacing, or stemming.

Inadequate Blast Control: Insufficient stemming material or inadequate confinement of the explosive charge.

Rock Characteristics: Weak zones, jointed rock masses, or excessive overburden present.

Detonation Issues: Problems with timing, misfires, or premature detonations occur.

Safety Hazards: Pose severe risks to personnel, equipment, and nearby communities.

Legal and Financial Ramifications: Potential lawsuits, regulatory fines, damage to equipment and operational shutdowns

Recent Flyrock Incidents

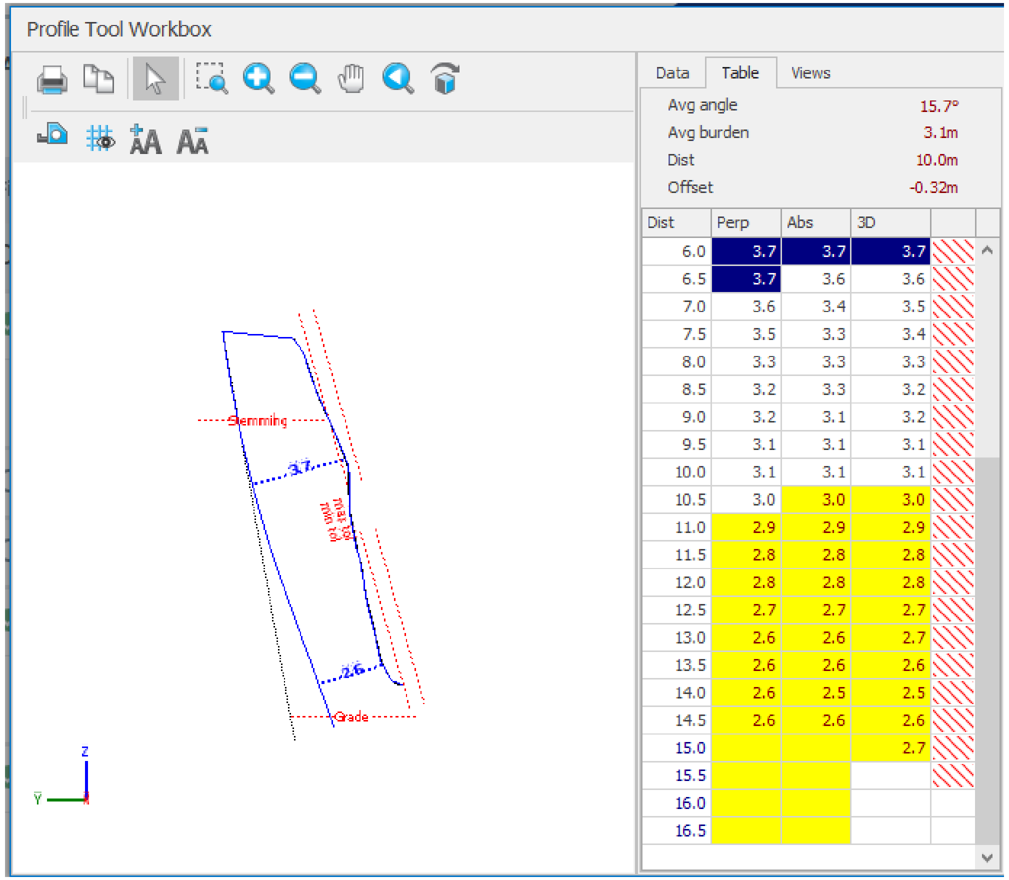
- Unfortunately, Flyrock incidents are not uncommon and occur more often than we want to see.
- Orica has recorded **54 Flyrock** related incidents, Globally, since 2016. This includes an incident that occurred in Russia in 2023, that resulted in a fatality of an Orica employee.
- Database with the regulators shows **18 Flyrock** incidents in quarries across east-coast Australia and New Zealand since 2005.
- NSW regulator has released an investigation report with videos from an event that occurred in 2018 and details some good recommendations for consideration.

Figure 8 - Early stages of main blast (note large flyrock)

Figure 9 - Flyrock landing in dam in front of firing location

Flyrock Prevention in Quarries

- Flyrock is a particular challenge for quarries given the smaller operating footprint and proximity to the public.
- Survey blast faces and Boretrak holes to measure face burdens
- Drill logs to identify broken or overburden material, cavities, voids or cracks
- Removing buffered material is a risk, ensure your blasting contractor is notified if the face is altered after being designs
- Be mindful of increased flyrock risks with secondary breakage



Dist	Perp	Abs	3D
6.0	3.7	3.7	3.7
6.5	3.7	3.6	3.6
7.0	3.6	3.4	3.5
7.5	3.5	3.3	3.4
8.0	3.3	3.3	3.3
8.5	3.2	3.3	3.2
9.0	3.2	3.1	3.2
9.5	3.1	3.1	3.1
10.0	3.1	3.1	3.1
10.5	3.0	3.0	3.0
11.0	2.9	2.9	2.9
11.5	2.8	2.8	2.8
12.0	2.8	2.8	2.8
12.5	2.7	2.7	2.7
13.0	2.6	2.6	2.7
13.5	2.6	2.6	2.6
14.0	2.6	2.5	2.5
14.5	2.6	2.6	2.6
15.0			2.7
15.5			
16.0			
16.5			

FLYROCK MODELLING

Flyrock Modelling

Literature available to provide estimates of flyrock velocities that can be used determine trajectory of flyrock particles.

Lundborg (1975)

$$V_0 = K_V . \left(\frac{\emptyset}{x_f}\right)\left(\frac{2.6}{\rho_r}\right)$$

where;
$\emptyset$ = Hole Diameter (inches)
x_f = Particle Size (m)
ρ_r = Rock Density (g/cc)
K_V =Factor

St George and Gibson (2001)

$$V_0 = \frac{3\rho_e D^2 \Delta t}{32\emptyset\rho}$$

where;
ρ_e = Density of explosives
D = VOD of explosives
Δt = Impulse time (s)
$\emptyset$ =Equivalent diameter particle (mm)
ρ =Rock Density (g/cc)

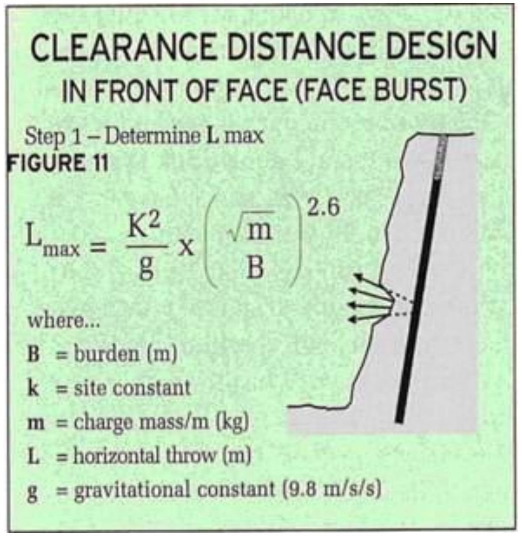
Richards and Moore (2005)

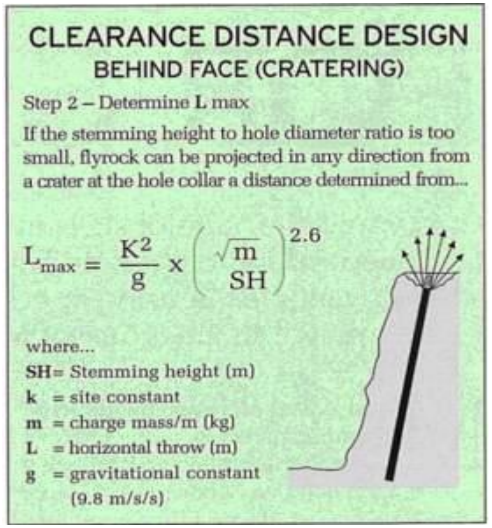
$$L = \frac{k^2}{9.81} . \left(\frac{\sqrt{m}}{S.H}\right)^{2.6} . sin2\theta$$

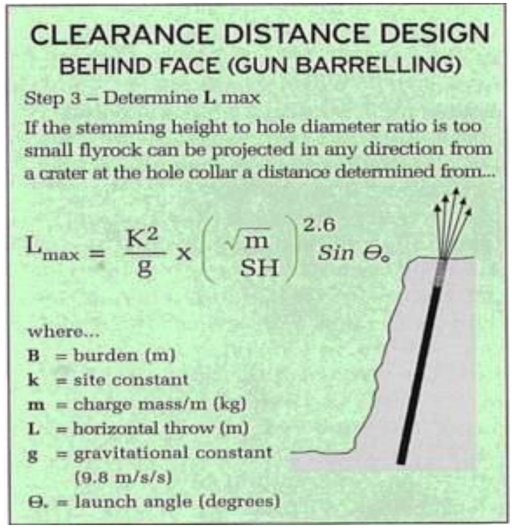
where;
L = maximum throw (m)
m = charge mass per delay (kg)
S.H. = Stemming height (m)
θ = Launch angle from horizontal
k = constant

Flyrock Modellings Commonly Adopted

Formula developed by Richards & Moore applied to 3 potential sources of Flyrock:







Formula requires a site constant (k) to determine maximum distance

Calibrating Flyrock Constants (k)

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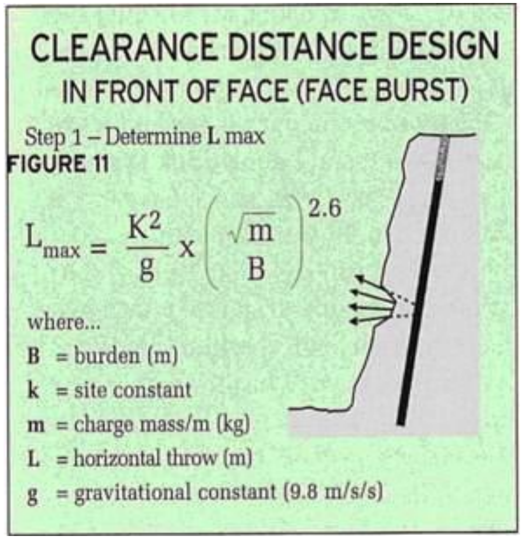
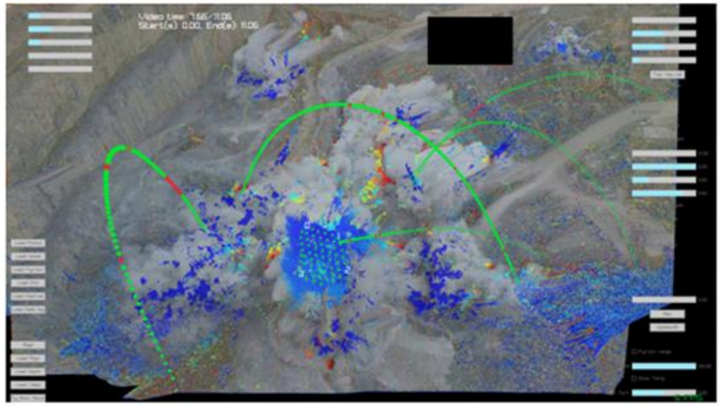
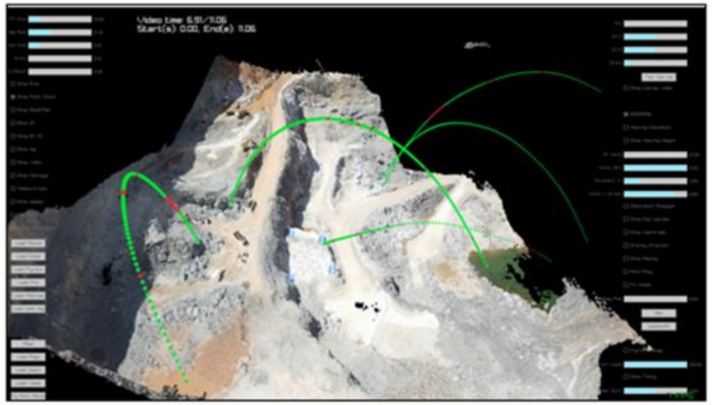
- Review of blast videos and measurements of particle ranges used to determine site constant (k)
- Complete for different blast types, and geological zones



BlastVision Video Analysis Software

There are five fly rocks trajectories observed clearly surrounding the blast area in varying directions with the detail parameter as shown below. The fly rock appeared produced from the rock boulder blasting and primary blasting holes that might be experiencing an ejection process.

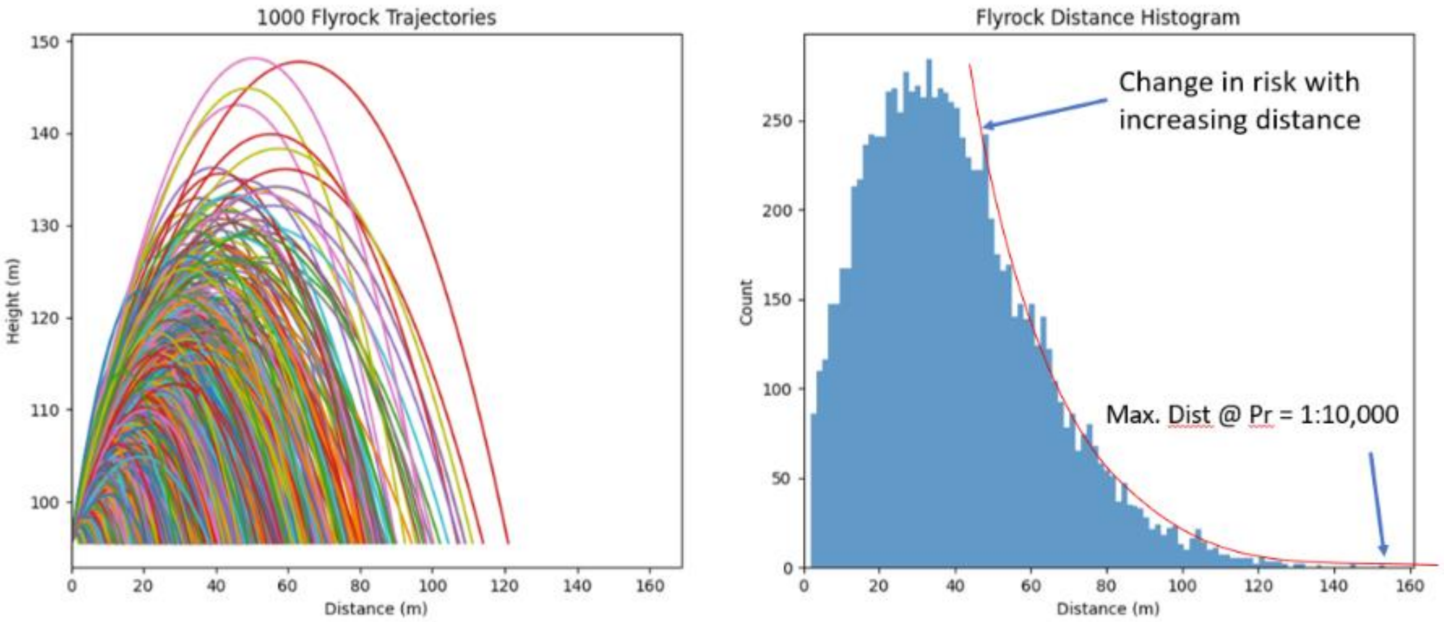




Trajectories Number	Travel Distance (m)	Direct Distance (m)	Average Velocity Vox (m/s)	Initial Velocity Vo (m/s)	Final Velocity (m/s)	Min. Velocity (m/s)	Max. Height (m)	Gravity (m/s2)
1	396	331	32	47	143	22	96	9.8
2	204	72	22	50	92	12	27.1	9.8
3	246	162	45	37	53	23	78.2	9.8
4	362	333	253	44	209	38	87.8	9.8
5	383	377	104	6.7	203	6.7	63.7	9.8

wildFire Modelling for a Statistical Approach

- Orica's WildFire modelling takes the initial velocity and standard deviation of results to offer a statistical model considering thousands of potential Flyrock outcomes.



EXCLUSION ZONES

Implementing Blast Exclusion Zones

- Modelling flyrock distances can help us make better decisions around required exclusion zones distance
- This does little to protect against flyrock if exclusion zone distances and not adequately implemented and managed

Blast Exclusion Zone Maps

- High resolution and update aerial photo of the quarry.
- Include exclusion zone distances for reference
- Exclusion Zones with different Safety Factors adopted, typically:
  – 2 for Equipment
  – 4 for Personnel

Site		
Shot Number	SQ22-24	
Radio Channel		
Hole diameter	mm	102
Stemming lengt	m	3
Charge length	m	12
Front Burden	m	3.3

Maximum Horizontal Distance				Maximum Vertical Distance			
Factor of Safety	1	2 (Equip)	4 (Human	Factor of Safety	1	2 (Equip)	4 (Human)
Face burst	65	130	259	Face burst	32	65	130
Cratering	Not Valid*	Not Valid*	Not Valid*	Cratering	Not Valid*	Not Valid*	Not Valid*
Stemming Ejectio	28	57	114	Stemming Ejectio	14	28	57

N.B. "Face burst will eject material in front of the blast and not behind. Face burst is only applicable for shots with a free face (i.e. not valid for drop cuts etc.)."

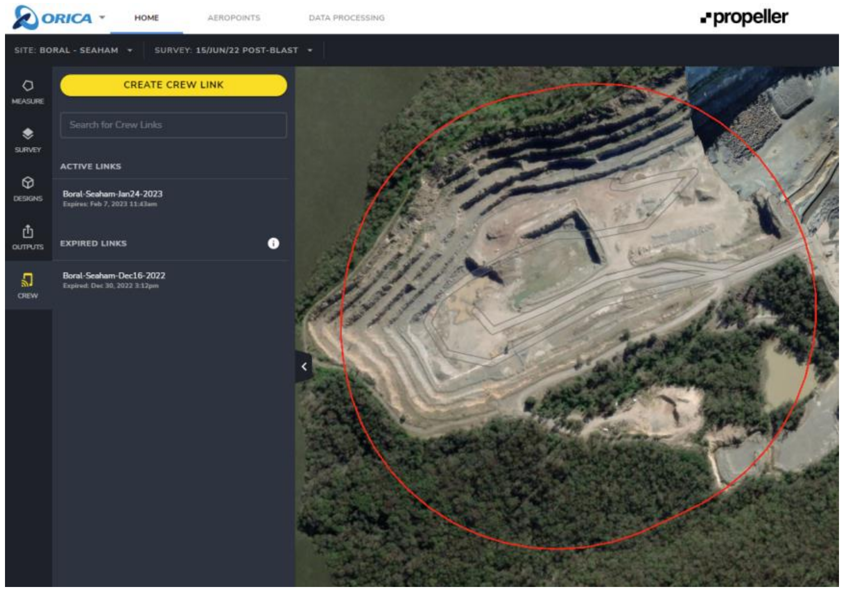
Stemming ejection will eject material behind the blast and not in front (assuming hole angle is >0 degrees)

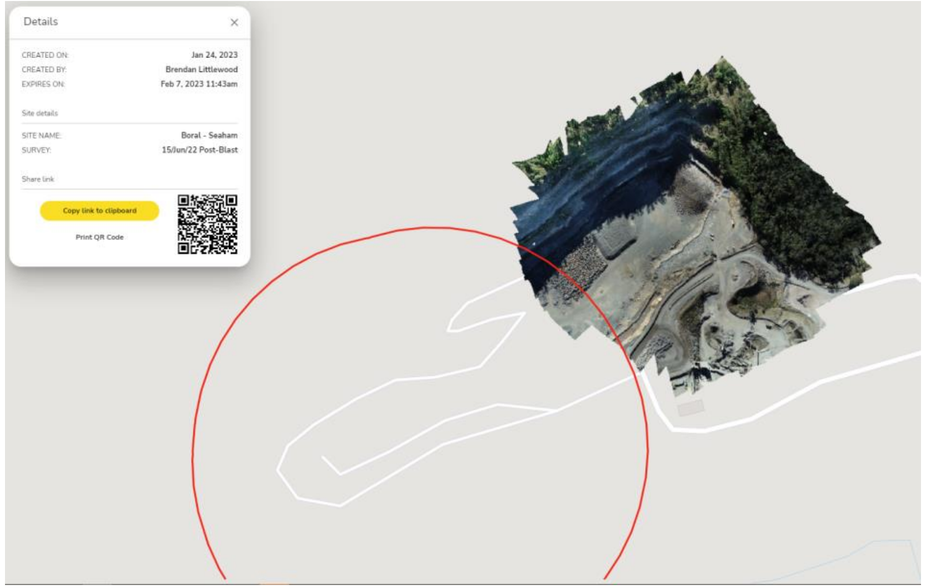
Notes:

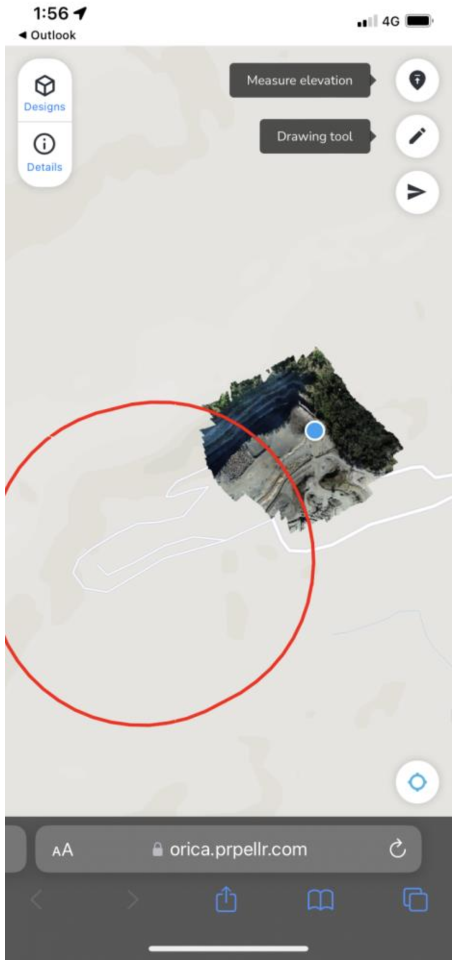
Refer to SIS for site specific exclusion zone distances that supersede Maximum Horizontal Distance

Blast Guards	Name	Phone Number
Blast Contro		
Shotfirer		
Guard 1		
Guard 2		
Guard 3		
Guard 4		

GPS Functionality for Exclusion Zones







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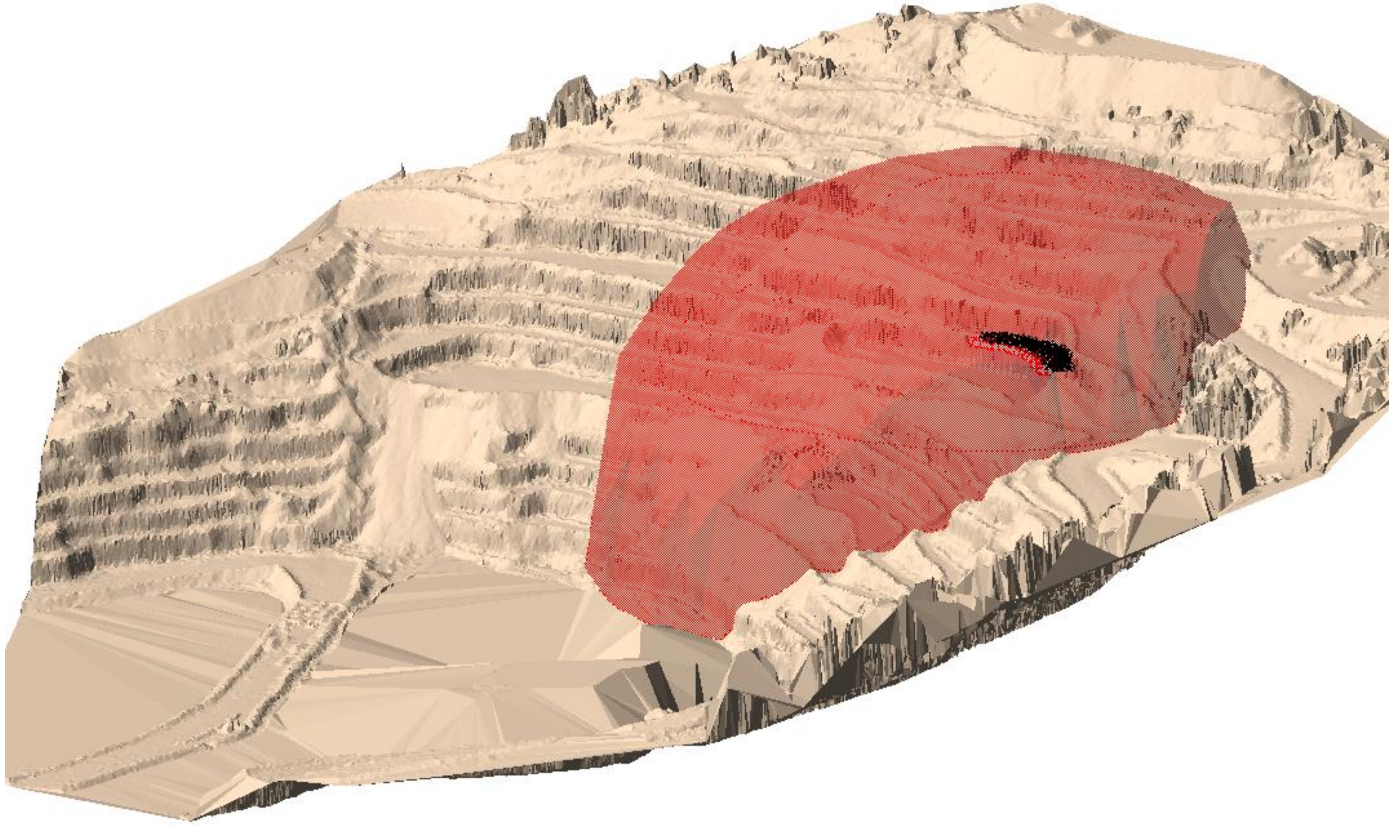
Influence of Surrounding Topography

- Surrounding topography will influence the potential trajectory, rarely is this considered.
- Blasting from lower horizons on steep terrain will limit horizontal distances to upper horizons.
- Inversely, rocks may travel further than expected to lower horizons.



Managing Exclusion Zones

- Pre-blast meeting to discuss exclusion zone
- Blast guarding – trained and competent
- Understand where each guard positioned
- Ensure the exclusion zone is clear
- Scripted blast process with standard words to avoid radio confusion and delays
- Ensure firing equipment allows the Shotfirer to position themselves far enough away from the blast, Electronic Blasting Systems (EBS) as a starter detonator

Flyrock Summary

- Flyrock is a series risk and people have been fatally injured, we should remain diligent at every step of the blasting process.
- We aim to control as many variables that we can, but some variables such as geology are hard to measure and predict – A Statistical approach can help predict rare events.
- Modelling helps to establish suitable exclusion distances but be aware when aspects of the blast change and are no longer accurately reflected by the model.
- Exclusion zones are required to be clearly communicated to all personnel associated with the blast, these should be documented and implemented by trained and competent people.

QUESTIONS