FLYROCK EXCLUSION ZONE ANALYSIS

HANSON SANCROX QUARRY

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INTRODUCTION

Hanson has requested a review of the risk of flyrock to the property on the northern boundary of the Sancrox Quarry (see Figure 1) and provide recommendations to mitigate these risks.

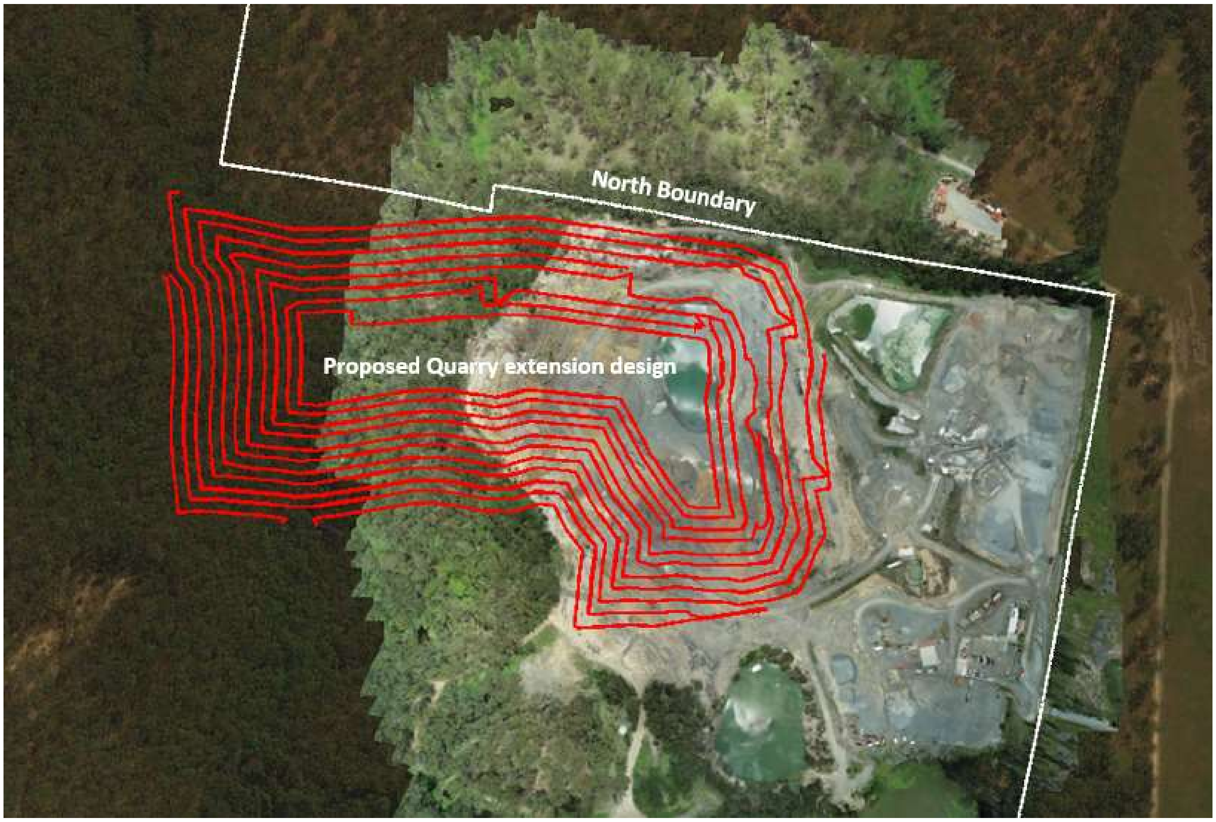

Figure 1 Sancrox quarry pit shell design

This report includes:

- a review of previously completed flyrock assessment
- a review of existing flyrock controls at Sancrox Quarry
- results of flyrock calculations using Terrock model
- conclusions and recommendations

FLYROCK

Flyrock can be defined as per this extract from 'Flyrock Control – By Chance or Design (2004)'

> *Flyrock occurs when the explosive in the blasthole is excessive or poorly confined, and energy in the form of high-pressure gas is available to throw broken rock fragments into the air, accompanied by excessive airblast. If there is insufficient stemming height, or poor quality stemming material is used (eg. drill cuttings in wet blastholes), material may be projected from the collar region of the blasthole at a high trajectory into the air around the blast site. If the blasthole has insufficient burden in front of the blasthole, flyrock may be projected at a somewhat flatter trajectory in front of the face.*

Figure 2 shows three categories of flyrock including:

1. Face burst: rock ejecting from the free face due to **insufficient burden** most likely projected perpendicular to the face
2. Cratering: rock ejecting from bench top in any direction indicating **weak surrounding rock**, **overcharging** and/or **insufficient stemming length**

3. Rifling: rock ejecting from bench top, indicating **ineffective, poor-quality or bridged stemming**.

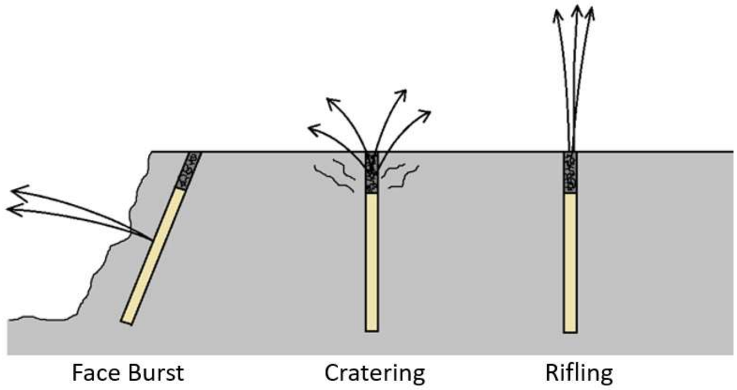

Figure 2 – Causes of Flyrock

MAXIMUM INSTANTANEOUS CHARGE (MIC)

MIC is the charge mass of often more than one blasthole as the combined mass can produce a higher level of vibration or air overpressure measured at a point of interest. This does not necessarily have an influence on flyrock, therefore MIC is not an input into flyrock calculations.

SCALED DEPTH OF BURIAL

The scaled depth of burial (SDOB) concept was defined by Chiappetta and Treleaven (1997). After conducting cratering experiments, they found that flyrock is affected by the depth of burial or stemming length, 'St' and the length of explosives directly below the stemming as dictated by the charge length factor, 'm'. Figure 3 is a diagram of components that influence flyrock.

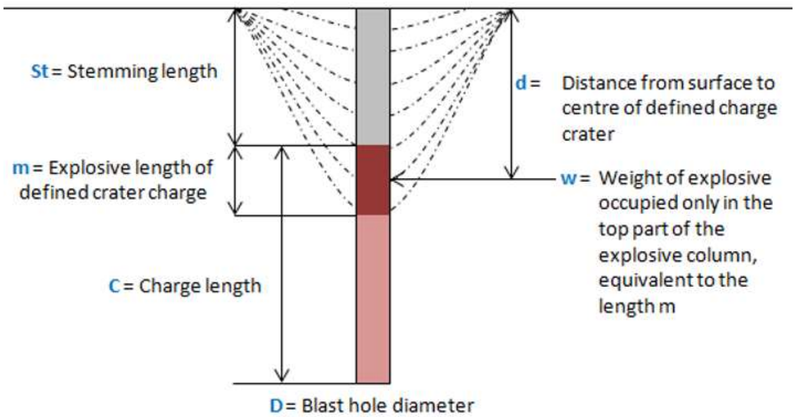

Figure 3 - Scaled depth of burial

Figure 4 shows the expected surface expression for a range of scaled depth of burial. SDOB of 0.92 – 1.4 is typically targeted for blast fragmentation.

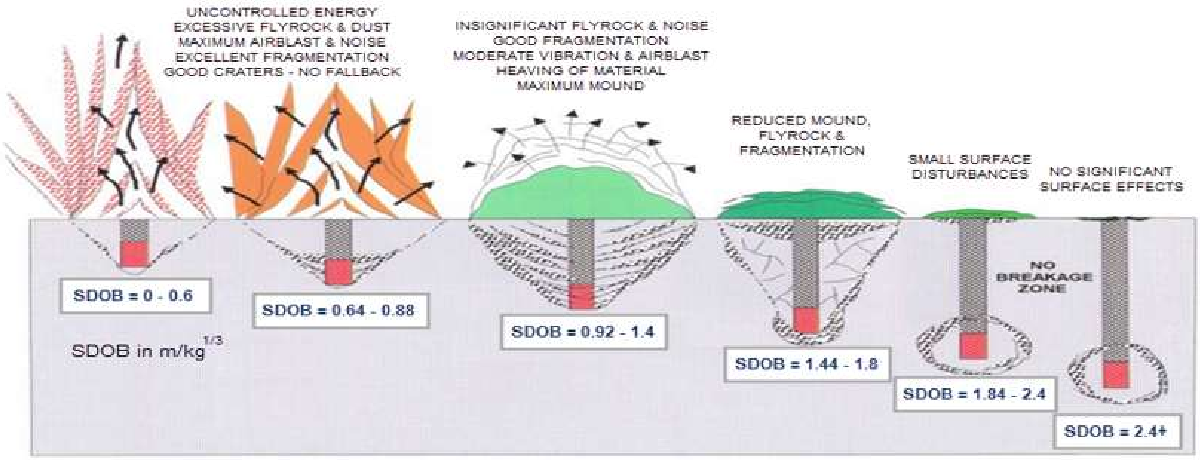

Figure 4 - Effects of scaled depth of burial on the bench surface

FLYROCK RISK REVIEW

SANCROX EMPLOYMENT PRECINCT BUFFER ZONE ASSESSMENT (SKM 2009)

A report titled Buffer Zone Assessment (SKM, 2009) was prepared in support of the development application for the Sancrox Employment precinct (Industrial estate).

MIC FOR VIBRATION AND OVERPRESSURE (SKM 2009)

The SKM 2009 report recommended a 90m "buffer zone" to mitigate risks of excessive vibration and overpressure on proposed Industrial buildings.

Table 1 and Table 2 show overpressure and vibration calculations respectively for MIC of 87kg and 37kg.

- 87kg represents a typical an 11.6m charge length using 1.2g/cc density bulk explosives in an 89mm blasthole
- 37kg represents a DA1995/193 Condition 25 that is no longer applies to the quarry

It is important to note that MIC for the purposes of vibration and overpressure management is not relevant to flyrock.

Table 1. Predicted Overpressure Levels (Table 5.3, SKM 2009)

Distance (m)	Calculated Overpressure Level – dB(L) MIC 87kg	Calculated Overpressure Level – dB(L) MIC 37kg
10	148	146
17	143	**140**
21	**140**	138
34	135	**133**
42	**133**	131
50	131	129
73	127	**125**
90	**125**	123
100	124	122
118	122	**120**
146	**120**	118
200	117	115
500	107	105
1000	100	98

Table 2. Predicted Vibration Level (Table 5.5, SKM 2009)

Distance (m)	Calculated PPV - mm/sec (MIC 87kg)	Calculated PPV - mm/sec (MIC 37kg)
10	1019.8	514.6
50	77.7	39.2
66	49.8	**25.1**
100	25.6	12.9
101	**25.2**	12.7
180	10.0	**5.0**
200	8.5	4.3
277	**5.0**	2.5
500	2.0	1.0
1000	0.6	0.3

FLYROCK (SKM 2009)

The report for the development identified:

> *"…with adjoining landowners permission, adjoining land may become part of the safety exclusion zone Noting that a minimum 90 m buffer zone between quarry activity and any future industrial /commercial receivers has been determined from theoretical assessment of quarry noise, air quality as well as blast vibration and overpressure"*

Flyrock calculations from the report are shown in Figure 5 for drill and blast parameters used in 2008.

Table 2 - Flyrock Throw and Clearance Distances for Current Practice

	Level 1: B = 3.0m, S.H. = 2.5m			Levels 4 and 5: B = 2.5m, S.H. = 2.0m		
	Max. Throw (m)	F.O.S. = 2 Plant/Equip (m)	F.O.S. = 4 Personnel (m)	Max. Throw (m)	F.O.S. = 2 Plant/Equip (m)	F.O.S. = 4 Personnel (m)
Front of face	51.6	103	206	83	166	332
Behind face (Angle = 5°)	41.5	83	166	74.1	148	296
Behind face (Angle = 10°)	53.3	107	214	95.3	190	380
Behind face (Angle = 14°)	61.6	23	246	110	220	440

** F.O.S = Factor of Safety*

Figure 5 - Flyrock calculations SKM 2009

Figure 5 and Figure 6 show the report's recommended face burden, stemming height and hole angle controls for flyrock based on throw calculations to ensure infrequent flyrock would not leave the 90 m zone.

Stemming height	5 deg hole angle	10 deg hole angle
2.5 m	164	212
3.0 m	104	132
3.5 m	68	88
4.0 m	48	64

- Suggested Mitigation Options:
  - Consideration of stemming height and hole angle during blast design

Figure 6 - SKM flyrock mitigation measures

The report also recommended:

"The procedures and checks must ensure that the following tolerances are met:

Designed Front row burden e.g. 3.0m – zero mm

Designed Stemming height e.g. 3.5m – zero mm

To achieve these burden tolerances, the faces must be profiled using laser theodolite survey and bore tracking systems, the surveyor and shotfirer being mindful that:

- *The minimum front row burden required is 3.0 m of solid rock - whoever does the survey must carefully examine the face to ensure that loose slabs or blocks, hanging lumps, weak ground etc. are not interpreted as solid rock.*
- *The face profiling system is only accurate to ±0.5m*
- *The face profiling system set to auto mode may not pick up the extremes of the humps and hollows of the face and some extreme face points may require manual sighting, especially on an irregular face.*
- *Minimum side burden is a particular issue on irregular faces and the surveyor and shotfirer to pay particular attention to loss of burden towards the boundary.*

The person designing the loading should be mindful that:

- *The minimum burden shown on the face profile to guarantee the minimum cover over a fully loaded explosive column is in the order of an additional 0.5m or more. Anything less must be decked through or the holes redrilled and the original holes backfilled with stemming."*

CURRENT SANCROX FLYROCK CONTROLS

CURRENT BLAST DESIGN PARAMETERS

Figure 7 shows the drill and blast parameters and tolerances used at Sancrox quarry.

Pattern Data			
Hole Diameter	89	REFER TO TS IF VALUES OUTSIDE RANGE	
Pattern	Staggered Throw		
Item	Target	Max.	Min.
Drill Angle	10 °	20 °	0 °
Front burden	3.4m	3.7m	3.1m
Burden	2.5m	2.8m	2.3m
Spacing	2.8m	3.1m	2.5m
Bench Height	9m	13.0m	5.0m
Subdrill	0.5m	0.6m	0.3m
Front Row Sub-Drill	0.8m	1.0m	0.6m
Powder Factor kg/m³	0.89	0.94	0.84
Stemming Length	2.2m	2.7m	2.0m
Side Angle	0 °	3 °	0 °
Air Deck	1.5m	2.0m	0.0m
Inert Deck	2.5m	3.0m	2.0m

Loading Data				
Orica Bulk Explosive Product Name	Centra Gold 1.2	Centra Gold 1.2	Centra Gold ES 1.1	
Loading Options/Use	Front Row	Body	As Required	
In-Hole Density	1.2	1.2	1.1	g/cc
RWS	115	115	103	
RBS	172	172	142	
Charge per metre	7.47	7.47	6.84	kg/m
Min charge burden	3.1	3.1	2.8	m
Orica Packaged Explosive Product	Buster 55	Buster 65	PowerSplit 32mm	
Weight	0.89	1.25	0.36	kg
Length per package	0.33	0.33	0.40	mm
RBS	183	183	147	
Charge per metre	2.74	3.85	0.89	kg/m
Min charge burden	2.0	2.3	1.0	m

Figure 7- Typical blast pattern parameters used by Orica at Sancrox

FACE BURST CONTROLS

- The blast face surface is profiled using an MDL™ laser scanner and holes are designed with a face burden between 3.1 m - 3.7 m.
- Post drilling, the blast hole deviation is measured to determine actual burden.
- A charging plan is developed based on actual burden for each face hole to maintain sufficient confinement of the explosive (see Figure 8). Should the burden be insufficient a lower density (energy) explosive product or stemming deck is used to mitigate the risk of face burst.
- Opposing high-walls can attenuate flyrock from a potential face burst incident.

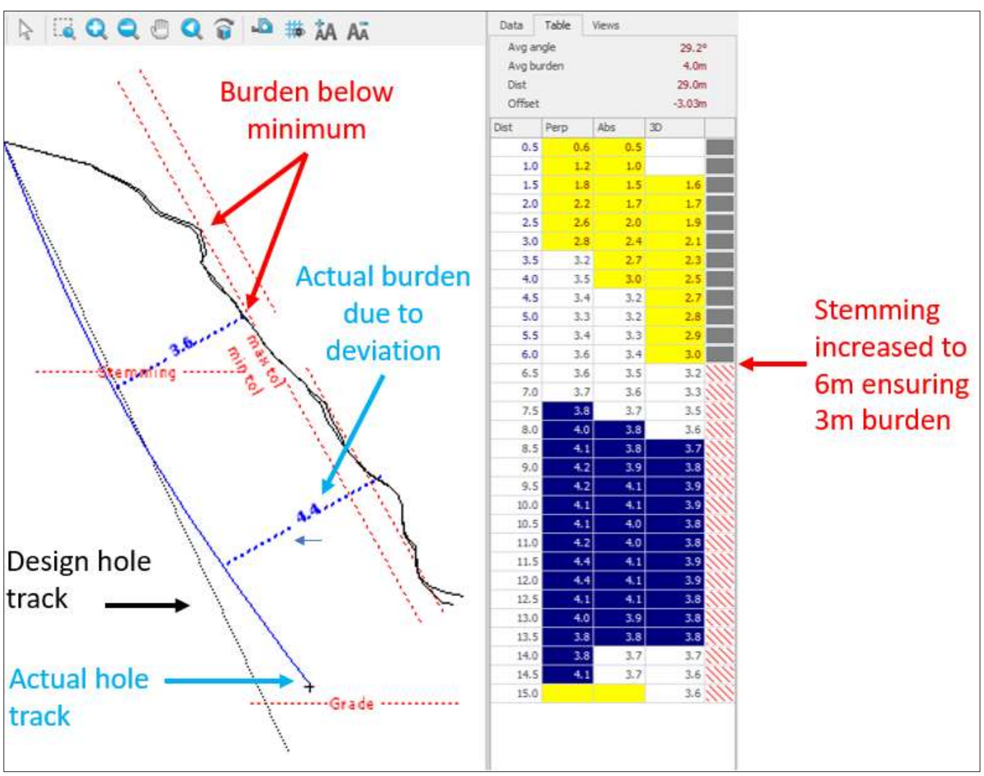

Figure 8 - Burden distance measurement Sancrox blast SXQ21-07

CRATERING CONTROLS

- The 2.2 m stemming length and 1.2 g/cc bulk emulsion used results in SDOB of 1.40 (see Figure 3).
- Drill information is logged for fractured or broken ground. Where broken ground is encountered close to the bench surface, stemming length is increased on the loading plan.
- Every stemming deck is measured prior to stemming. Any stemming deck that is below 2.2 m a ‘sucker’ tool is used to ensure the correct height.

RIFLING CONTROLS

- Stemming is manually poured into blastholes and any anomalies indicating bridging are reported to the shotfirer
- Stemming specification is screened angular rock sized at 10% of hole diameter

UPDATED FLYROCK CALCULATIONS (TERROCK MODEL)

Flyrock clearance distances were calculated using Richard and Moore’s (2004) model, known as the Terrock model. Figure 9 shows the formulae for calculating the clearance distance designs for face burst, rifling (gun barrelling) and cratering.

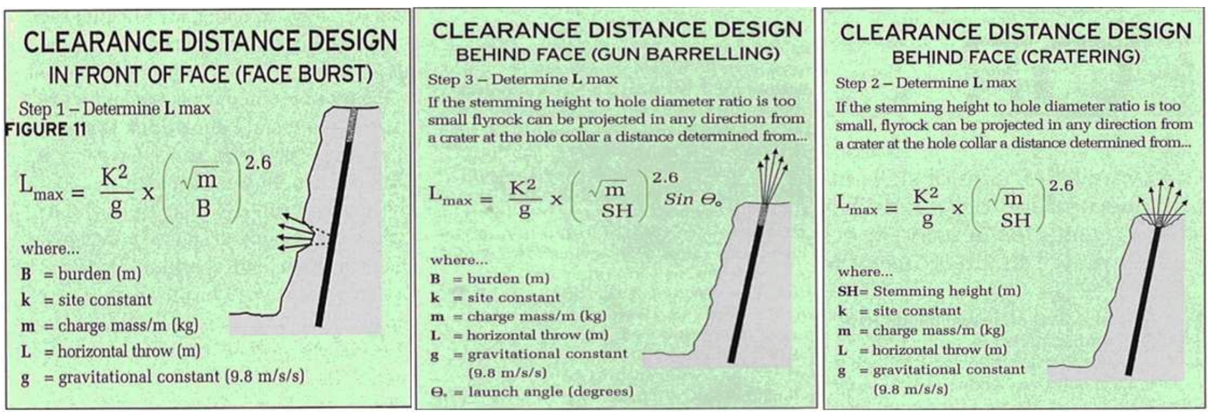

Figure 9, Terrock Model Calculation Methods

The equations in Figure 9 have been incorporated into a tool used to predict the maximum flyrock distance likely to result from a blast (see Figure 10).

Flyrock Assumptions		
Rock density	g/cc	2.7
Hole diameter	mm	89
Stemming length	m	2.2
Charge length	m	10.3
Burden	m	3.1
Explosive density	g/cc	1.2
Flyrock constant		20.3
Factor of safety	FoS	1
Trajectory angle (Stemming ejection)	deg	10
Charge mass/m	kg/m	7.5
Gravity	m/s/s	9.81
Scaled Depth of Burial		
Contributing charge length factor		10
Scaled depth of burial	m/kg^1/3	1.40
Maximum Flyrock Projection Range		
Distance	m	598
Clearance Distance and Projectile Size		
Projectile size	mm	26
Projectile weight	kg	0.02
Clearance Distance	m	106
Maximum Horizontal Distance		
Face burst	m	30
Cratering	m	74
Stemming ejection	m	25
Maximum Vertical Distance		
Launch velocity (FB)	m/s	17
Launch velocity (C)	m/s	27
Launch velocity (SE)	m/s	16
Face burst	m	15
Cratering	m	37
Stemming ejection	m	13

	Maximum Horizontal Distance			Maximum Vertical Distance		
Factor of Safety	1	2 (Equip)	4 (Human)	1	2 (Equip)	4 (Human)
Face burst	30	61	121	15	30	61
Cratering	74	148	295	37	74	148
Stemming Ejection	25	50	101	13	25	50

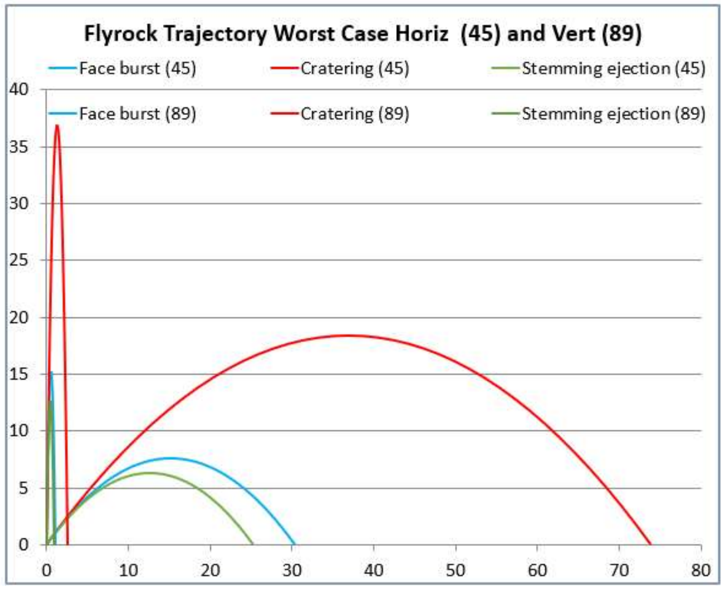

Figure 10 - Terrock model results for Sancrox

The site constant (k) considers the measured blasting response of the rock mass at a specific site and takes values between 13 and 28. Figure 10 shows a k factor of 20.3 which was the k factor used in the Sancrox Employment Precinct Buffer Zone Assessment (SKM 2009) shown in Figure 5.

Figure 10 shows that cratering has the longest range for flyrock of 74 m. A safety factor of 4 is typically considered for humans which is 295 m (for current blasting parameters). Figure 11 shows a 295 m zone where additional flyrock controls should be considered if there are people in the property. If people can be excluded from the property by blast sentries, then normal blasting parameters can continue to be used.

Figure 11 - 295m area inclusive of SKM 90m buffer zone

CONCLUSION

- The current drill and blast practices to manage the risks of flyrock at Sancrox are consistent with mitigating measures identified in the SKM 2009 report.
- The risk of face burst events occurring can be reduced by accurate measurement of face burden distances, and blasthole deviation measurement.
- The risk of cratering and rifling events occurring and throw distance can be reduced by Increasing the scaled depth of burial through increasing stemming lengths and/or decreasing bulk explosive density.
- The direction that a face burst occurs can be controlled by the orientation of the free face.

Comparisons of SKM and Orica recommendations and modelling (Table 3,Table 4,Table 5)

Table 3 - design parameter comparison

	Design parameters		
	2008 (level1)	2008 (level 4&5)	Current
Face burden	3.0m	2.5m	3.1-3.7m
Stemming length	2.5-3.0m	2.0-2.7m	2.2m
Bench height	18m	12m	12m
Front hole angle	5 °	5 °	10 -20 °
Hole angle	10-14 °	10-14 °	10 °

Table 4 - Modelling result comparison

	Modelling results		
	SKM 2008 (level 1)	2008 (level 4&5)	Orica 2022
Face burst	51.6m	83m	30m
cratering	53.3m	95.3m	74m
Rifling	Not provided		25m

Table 5 - Recommendations comparison, burden and stemming length

	Recommended (for 90m)		Recommended (for 50m)	
	SKM 2008	Orica 2022	SKM 2008	Orica 2022
Face burden	3.5m	direct away or opposing wall	Not recommended	
Stemming length	3.5m	3.5m	4.4	4.4

RECOMMENDATIONS

- As recommended in 2009, agreement should be reached to extend the exclusion zone as far as practicable into the neighbouring land as poor blast results are likely due to increased scaled depth of burial required.

FACE BURST

- Mitigate the risk of face burst by orientation of free faces away from the north boundary (Figure 13)
- Extraction plans for the quarry can utilise opposing walls to attenuate face burst.

CRATERING

- Stemming lengths increased if the exclusion zone distance decreases due to the presence of equipment/infrastructure or humans. (Table 6, Figure 12,Figure 13)

Table 6 - Recommendations for 89mm diameter blasthole

Stemming length 89mm	Scaled depth of burial	Factor of safety 1	Factor of safety 2	Factor of safety 4
2.2m (current)	1.40	74m	148m	295m
2.5m	1.6	53m	106m	212m
3.5m	2.16	22m	44m	**88m**
4.0m	2.44	16m	31m	62m
4.4m	2.66	12m	24m	**49m**

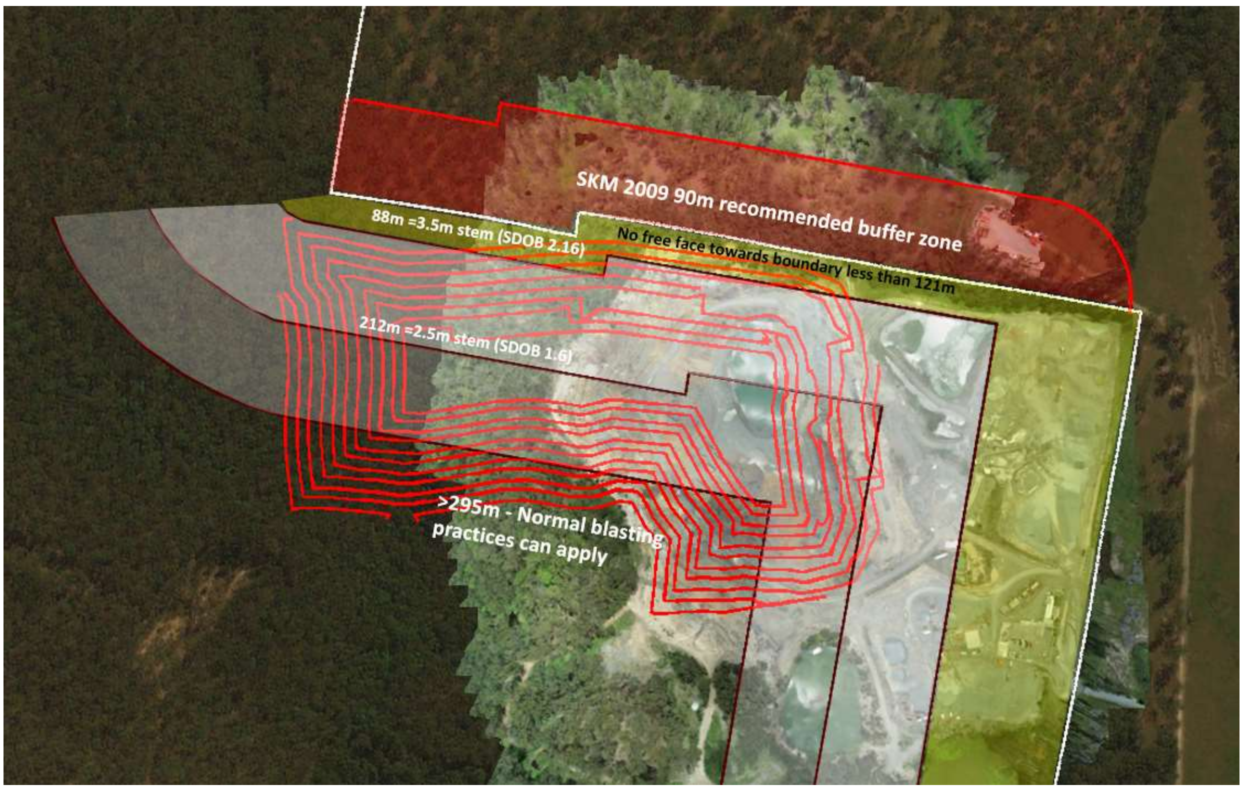

Figure 12 - illustration of recommended controls for 89mm blastholes

Figure 13 - Exclusion zone distance illustration for recommended controls (89mm blastholes)

- Explosive distribution can be improved as the distance decreases by reducing the hole diameter to 76mm and bulk explosive density to 1.15 g/cc, resulting in an equivalent scaled depth of burial and exclusion distance. (Table 7)

Table 7 - Recommendations for 76mm diameter blasthole and 1.15 density bulk explosive

Stemming length 76mm @ 1.15 density	Scaled depth of burial	Factor of safety 1	Factor of safety 2	Factor of safety 4
1.9m	1.43	68m	136m	271m
2.4m	1.75	37m	74m	148m
2.9m	2.09	22m	44m	**90m**
3.3m	2.37	16m	32m	65m
3.7m	2.66	12m	24m	**48m**