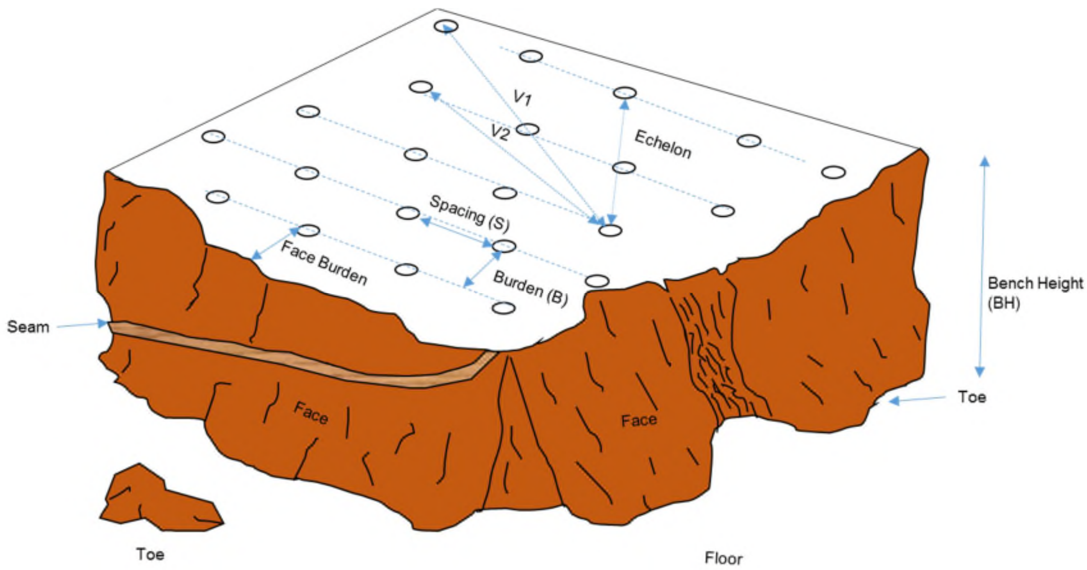
Coraki Quarry

Proposed Blast Parameters Evaluation



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Introduction

As part of an Environmental Impact Statement (EIS) to support the approval of the proposed Coraki Quarry, an assessment of the likely blasting impacts of the development on people, building, animals, infrastructure and significant natural features, must be undertaken. This will ensure that the proposed quarrying practices do not significantly impact on the surrounding neighbours and ensure that the quarry can comply with anticipated licence conditions.

This evaluation report assesses the ability of the proposed drill and blast practices to meet licence conditions. The report evaluates the proposed blast parameters to comply with blast vibration, airblast overpressure and flyrock requirements.

Recommendations are provided outlining best practice drill and blast solutions to meet licence conditions, in line with AS2187.2-2006 and ANZECC guidelines.

Blasting Assessment Process

The blasting assessment process is conducted using industry standards, industry rules and blasting experience to evaluate multiple blasting scenarios. Each scenario was evaluated to determine if the specific scenario complies with licence conditions and minimises disturbance to the neighbouring properties.

The closest properties were identified and the distance measured from the proposed extraction limit boundary to the closest residential property. A single set of site blast data was supplied and was used as a guide along with AS2187.2-2006 to determine the potential blast vibration, airblast overpressure and flyrock projection.

Vibration Assessment

The blast vibration assessment uses the ANZECC guidelines, which are in line with the requirements of AS2187.2-2006 Appendix J. The ANZECC guidelines require blast vibration of less than 5.0 mms^{-1} for 95% of all blasts and no greater than 10.0 mms^{-1} for 100 % of blasts at any sensitive receiver. This refers to measurements at any point within 30 metres of any residential boundary or in or on any other noise sensitive place or commercial property.

Where no suitable site data is available for analysis to determine the expected blast vibration equation, the AS2187.2-2006 Appendix J 50% probability exceedance equation J7.3(1) is widely accepted in the industry as the basis on which to estimate expected blast vibration levels. (Refer to Equation 1 overleaf)

$$V = K\,x\left(\frac{R}{Q^{1/2}}\right)^{-B}$$

Where:

V	= ground vibration as a vector peak particle velocity, in millimetres per second
R	= distance between charge and point of measurement, in metres
Q	= maximum instantaneous charge (effective charge mass per delay), in Kilograms
K_g, B	= constants related to site and rock properties for estimation purposes

Equation 1 Blast Vibration VPPV Prediction Equation

The AS2187.2-2006 50% probability exceedance equation uses a K value of 1140 and a B value of 1.6 when no suitable site data is available. K and B constants may be determined in the future following collation of site specific blast data.

Vibration and airblast results from a single blast were supplied and used as an indicator against the AS2187.2-2006 equation.

Airblast Assessment

The two closest residential properties were assessed for expected airblast overpressure using proposed blast parameters and distances to the closest residential dwellings. The ANZECC guidelines state that 100% of blasts must be less than 120 dBL and 95% of the blasts must be less than 115 dBL, which reflects the requirements of AS2187.2-2006.

Airblast estimation equations are generally very inaccurate as the actual airblast result is heavily dependent on factors such as blast confinement, atmospheric conditions and the topography between the blast and sensitive receiver. Equation 2 is an empirical equation developed by the United States Bureau of Mines when conducting blasting research, as documented in the RI 8507 report (Siskind).

$$Airblast\ (dBL) = 165 - 24\log_{10}(R/W^{1/3})$$

Where R = distance to point of concern (m)
W = charge mass per delay (kg)

Equation 2 Airblast Estimation Equation

In the author's experience, this equation delivers a better estimation of actual real world blasting results when compared to the equation documented in AS2187.2-2006 Appendix J section J7.2.

Flyrock Assessment

Australian Standard 2187.2-2006 Appendix E highlights considerations for blast design to minimise the generation of flyrock. AS2187.2-2006 Appendix E (E2.1) - Contributing Factors, outlines the key contributing factors that must be considered when addressing controls to minimise the effects of flyrock and developing a safe and productive Blast Exclusion Zone (BEZ).

Many industry experts have developed site prediction methodologies for determining a safe BEZ to protect quarry personnel, equipment, infrastructure and the general public. The causes of flyrock have been well studied and documented. The three main mechanisms are rifling, cratering and face bursting. The equations show in Figure 1 (Richards & Moore) address the three mechanisms of flyrock generation and will be used to determine the safe blast exclusion distances.

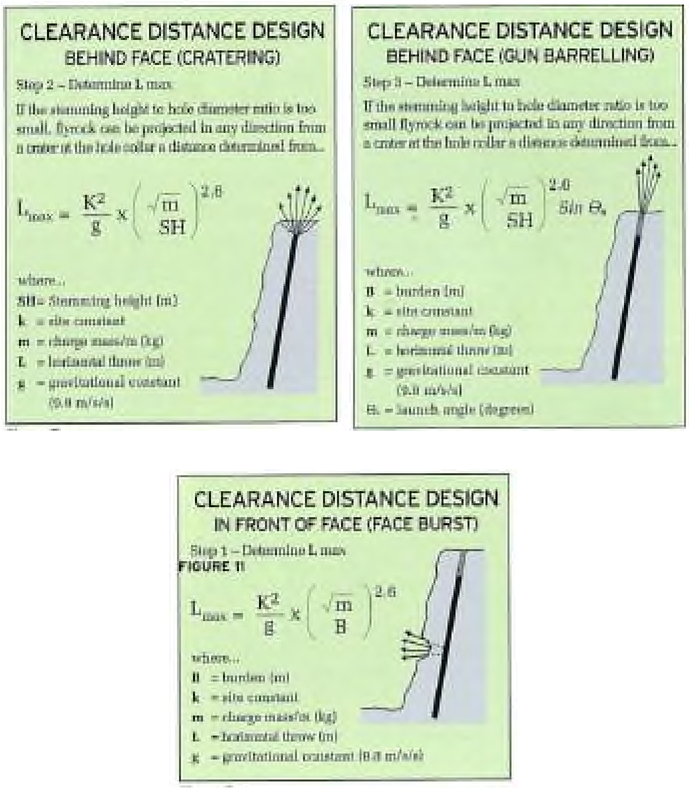

Figure 1 (Richards & Moore) Flyrock Equations

The above equations include a site constant “K”, which requires calibration to site conditions in order to improve the accuracy of the factor of safety calculation, and in some cases, improve productivity by ensuring good energy confinement. This can be achieved by measuring actual blast parameters and recording the maximum fly rock projection distance from each blast on site, thus ensuring specificity to the site’s drill and blast parameters and geology. In this case the absence of any site data dictates that a value of 27 should be used for “K” in order to maximise the factor of safety. Industry standard K values are from 13 in soft rock, to 27 in hard rocks such as granite.

The cratering mechanism can be eliminated by ensuring that the correct stemming length is used in relation to the blast hole diameter. Flyrock caused through a cratering scenario is typically associated with poor blast design. The empirical rule that determines the correct stemming length, as documented in Equation 3, and depicted in **Error! Reference source not found.**

$$SD = D/W^{0.333}$$

Where:

SD	= Scaled Depth (m/∛kg)
W	= Charge weight contained in 10 hole diameters (kg)
D	= Distance from point of interest (m)

Equation 3: Scaled Depth of Burial equation

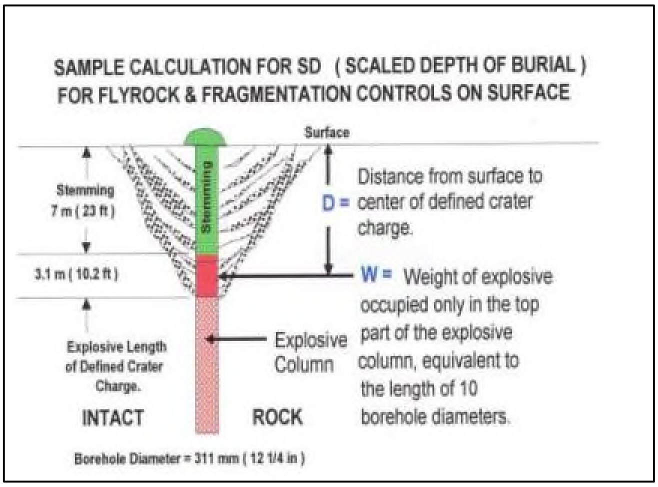

Figure 2 Scale Depth of Burial Dimensions Defined (Chiappetta)

To determine the trajectory of the flyrock, a launch velocity must be calculated using the following equation:

$$V_0 = \sqrt{\frac{L_{\max} g}{Sin 2\theta}}$$

Where:

θ	= Flyrock launch angle
L_{max}	= maximum flyrock range
V_0	= Launch velocity (ms^{-1})
g	= gravitational constant (9.81 ms^{-2})

Equation 4: Launch velocity

The above equations and techniques were used to determine safe blast exclusion zone and maximum theoretical flyrock throw distances.

Proposed Site Blast Parameters

The proposed Coraki Quarry blast parameters are based on typical blast parameters used in other quarries operating in similar rock masses. The blast parameters as listed in Table 1 were evaluated for compliance with airblast overpressure, blast vibration and flyrock requirements, in relation to the extraction boundaries and neighbouring properties. A typical powder factor of 0.7 kgm^{-3} for this type of quarry rock mass was used to determine burden, spacing and subdrill.

Blast Scenario	Hole Dia. (mm)	Bench Height (m)	Burden (m)	Spacing (m)	Stemming (m)	Subdrill (m)	Explosive Density (gcm-3)	MIC* (Kg)
12m_89mm	89	12.0	2.6	3.0	2.3	0.5	1.05	67
6m_89mm	89	6.0	2.3	2.6	2.3	0.5	1.05	28
12m_102mm	102	12.0	3.0	3.4	2.5	0.7	1.05	88
6m_102mm	102	6.0	2.8	3.0	2.5	0.7	1.05	36

*MIC refers to Maximum Instantaneous Charge weight. For the purpose of this evaluation it refers to the total charge weights firing in any 8ms time window from when the first charge fires to when the last charge fires.

Table 1 Site Blast Parameters

The parameters in Table 1, are typical for metropolitan quarrying operations which have nearby residential, commercial or industrial neighbours.

The following explosives systems are assumed:

Bulk explosives:	Emulsion or Watergel, water proof
Bulk explosive density (gcm-3):	1.05
Initiation system:	Non electric
Boosters (g):	150 (89mm) and 400 (102mm)
Down hole delays (ms):	400
Powder factor range (kg/m3):	0.7

Current Site Blast Results

A single set of blast data was supplied from the most recent blast fired at the adjacent council quarry. The blast parameters and results are documented in Table 2. The blast monitoring location was inside the council quarry location, not at a sensitive receiver compliance location. This set of data can be used to evaluate the attenuation of blast vibration and airblast overpressure, although the confidence is low, due to the data be a single data point.

Blast ID	Hole Dia, (mm)	Bench Height (m)	Burden (m)	Subdrill (m)	Stemming (m)	Explosive Density (gcm^{-3})	MIC (kg)	Distance to Monitor (m)	K Value (Constant)	Blast Vibration (mms^{-1})
01	89	16.6	2.9	0.5	2.0	1.2	288	318	743	6.75

Table 2 Actual Blast Results from Adjacent Petersons Quarry (Council Quarry)

For vibration prediction, using Equation 1 with an assumed value for the B constant of 1.6 (an industry average documented in AS2187.2-2006 Appendix J S7.3), the value of the attenuation constant K was back-calculated for the results displayed in Table 2. The resulting value of 734 is below the 50th percentile value of 1140, which is recommended for use in the absence of any other data. This suggests that using a K value of 1140 incorporates some conservatism, an important requirement when conducting an environmental blasting evaluation for a new site.

Proposed Site and Sensitive Receivers

The proposed site is included in Appendix 1, with the proposed extraction areas annotated. Based on the “Initial Extraction Area” there are three sensitive receivers:

- 140 Newmans Road, Coraki (Lot 4 DP6339), residential dwelling, 335 m from the closest extraction limit;

- 200 Lagoon Road, Coraki (Lot 12 DP6339), residential dwelling, 595m from the closest extraction limit;

- 95 Spring Hill Road, Coraki (Lot 12 DP714770), residential dwelling, 820m from the closest extraction limit;

Figure 3 displays the location of the two closest sensitive receivers in relation to the proposed quarry site. As the closest of the three sensitive receiver sites, only the distance to the sensitive receiver at 140 Newman Road, 335 m, will be used for the purpose of evaluating blast vibration and airblast overpressure levels. It is assumed that compliance at this location will result in compliance at all surrounding residential properties.

Figure 3 Coraki Quarry and Sensitive Receiver Locations

Blast Vibration Evaluation

As discussed in the “Current Site Blast Results” section, the blast vibration prediction equation AS2187-2006 Appendix J S7.3 (Equation 1) was applied to the site blast results listed in Table 3 to determine the attenuation constant K value of 743.

As this value is less than the 50th percentile generalised value of 1140, in order to increase the factor of safety based on the limited data available the K value was assumed as 1140 and the B value assumed as the industry average 1.6 for the purposes of determining expected blast vibration in the proposed blasting at the Coraki Quarry.

Blast vibration is calculated assuming a single blast hole firing scenario, which would require the blast to be limited to three rows in depth. If vibration predictions are less than 50% of the 5mms^{-1} value, then the number of blast holes firing in the 8ms time interval can be increased. The results of the vibration prediction equation are shown in Table 3.

Blast Scenario	Distance (m)	Hole Dia, (mm)	No Decks	Bench Height (m)	K	B	MIC (Kg)	PPV (mms-1)	Blast 1 K Value	PPV (mms-1) Using Blast 1 K
12m_89mm	335	89	1	12	1140	1.6	67	3.00	743	1.96
6m_89mm	335	89	1	6	1140	1.6	28	1.49	743	0.97
12m_102mm	335	102	1	12	1140	1.6	88	3.74	743	2.44
6m_102mm	335	102	1	6	1140	1.6	36	1.83	743	1.19

Table 3 Predicted Blast Vibration for Proposed Blast Parameters

Based on these results, the following guidelines are suggested for blasting within the proposed extraction limits to limit blast vibration to less than 5.00 mms^{-1}:

- Commence blasting using a maximum of a 12.0 m bench height;
- Commence blasting using a 102 mm blast hole diameter, with a maximum of 88 kg per delay;
- Commence blasting a minimum of 335 m away from the sensitive receiver, and collect actual measured data to compare against the predicted values. It would be recommended that blasting commences at the greatest distance initially to enable data collection and evaluation of the site blast vibration attenuation characteristics;
- Minimise the number of rows in any pattern - no more than 3 rows if using non electric initiation sequencing. Ensure that no more than a single blast hole MIC, (88 kg) is utilised, for initial blasts;
- Maintain a site vibration equation using actual vibration measured for each blast. This will allow for an accurate estimation of blast vibration prior to firing and blast parameter adjustment to ensure blast vibration compliance.

Using the current blast vibration limit of 5.0 mms^{-1}, blasting can be successfully implemented at the proposed Coraki Quarry initial extraction area using the prescribed blast parameters and initiation systems.

Airblast Overpressure Evaluation

Using Equation 2, the airblast overpressure was calculated for the proposed set of blast parameters, documented in Table 3. This equation does not take into account atmospheric conditions on the day, topography of the landscape between the blast and the sensitive receiver or specialised design techniques used to reduce airblast overpressure. Table 4 displays the results for the airblast overpressure modelling.

Blast Scenario	Distance (m)	Hole Dia, (mm)	No Decks	Bench Height (m)	MIC (Kg)	Airblast Overpressure (dBL)	Blast 1 Calibration Estimation
12m_89mm	335	89	1	12	67	119	116
6m_89mm	335	89	1	6	28	116	115
12m_102mm	335	102	1	12	88	120	119
6m_102mm	335	102	1	6	36	117	116

Table 4 Airblast Overpressure Predicted Value

The values displayed in Table 4, in the column labelled “Blast 1 Calibration Estimation”, were calculated using a modified version of Equation 2. The constant has been calibrated using the actual recorded results from Blast 1 at the Petersons Quarry (Council Quarry), the parameters of which are documented in Table 2. The modified equation is shown in Equation 5.

$$Airblast\ (dBL) = 163.8^{\#} - 24\log_{10}(R/W^{1/3})$$

Where R = distance to point of concern (m)
W = charge mass per delay (kg)
# = calibrated constant using site data

Equation 5 Calibrated Airblast Estimation Equation

To ensure airblast overpressure control at the proposed Coraki Quarry, a minimum face burden and stemming length must be adhered to. To ensure that the minimum face burdens are not compromised, the blasts should be surveyed and the blast holes bore tracked. Bench heights greater than 6.0 m must be face profiled and bore tracked. Surveying of blasts would also be required to determine accurate distances for developing a site airblast overpressure prediction equation, if required.

Table 5 has suggested minimum face burden dimensions for airblast overpressure control.

Hole Dia. (mm)	Minimum Face Burden (m) ANFO	Minimum Face Burden (m) HANFO (1.1)	Minimum Face Burden (m) Emulsion (1.1)
89	2.4	2.8	2.8
102	2.7	3.2	3.2

Table 5 Suggested Minimum Face Burdens

The suggested minimum face burden parameters are based on the Author's experience, however it is recommended to consider smaller minimum face burdens specific for site conditions and each blast. The blast bench must be surveyed/laser profiled, modelled and the actual blast holes bore tracked.

Airblast overpressure can also be significantly reduced by decking the face row holes (Martin). The lower the charge weight initiating along the face row, the lower the pressure exerted on the surrounding atmosphere, which reduces the airblast overpressure amplitude. Using non electric initiation, 200ms separation between the top deck and bottom deck has been demonstrated to reduce airblast overpressure by up to 50% or a 3 dBL reduction.

Airblast overpressure is also controlled by using suitable stemming material consisting of screened aggregate, approximately 1/10th of the blast hole diameter in size. The recommended minimum stemming lengths are 2.3m for the 89mm diameter blast holes and 2.5m, for the 102mm diameter blast holes. The suggested stemming lengths should be implemented for the initial blasts at the proposed site and subsequently refined if required.

To reduce the amplitude of the airblast overpressure, blast faces can be orientated in a direction that will reduce the affects. The airblast overpressure behind a well confined blast is much less than the airblast over pressure in front of the blast, measured at the same separation distance.

Using the proposed airblast overpressure limit of 115 dBL, blasting can be successfully implemented at the proposed Coraki Quarry using the prescribed blast parameters and initiation systems and decking the face row. It is suggested that the initial blast incorporates 89mm blast holes on a 12 m bench height scenario to enable evaluation of the actual airblast overpressure generated from blasting at the site.

The blast vibration analysis suggested the use of a 102 mm blast hole diameter on a 12 m bench height. The airblast analysis has determined that a maximum of an 89mm blast hole diameter should be utilised, and therefore the 89 mm blast hole diameter scenario should be used, as the analysis indicates that the quarry blasting activities will be more sensitive to airblast overpressure compliance than blast vibration compliance. A 12m face height, which utilises a decked front row will produce similar airblast overpressure to a 6m bench height.

Flyrock Blast Exclusion Zone

Table 6 lists the blast parameters that have been used to predict the expected blast vibration and airblast overpressure levels in the previous sections of this report, along with the maximum calculated flyrock distances and Scaled Depth of Burial (SDoB). The worst case scenarios were modelled using the equations documented in the "Flyrock Assessment" section of this report. A flyrock constant (K) of 27 was used in all calculations to maximise the factor of safety in the absence of any site data. Where the SDoB is greater than 1.3 the "Maximum Horizontal Distance Crater" value was not used.

Hole Diameter (mm)	89	102
Bench Height (m)	12	12
Face Burden (m)	2.8	3.2
Burden (m)	2.6	3.0
Spacing (m)	3.0	3.4
Stemming (m)	2.3	2.5
Subdrill (m)	0.5	0.7
Insert Deck Length (m)	0	0
Explosive Density (g/cm3)	1.05	1.05
Charge Weight (kg)	67	88
Max Horizontal Distance Face Burst (m)	76	89
Max Horizontal Distance Cratering (m)	104	119
Max Horizontal Distance Stem Ejection (m)	52	60
SDoB	1.5	1.44

Table 6: Calculated worse case flyrock projection distances

To determine the blast exclusion zone (BEZ), a factor of safety must be applied to the values in Table 6. A minimum factor of safety of 4.0 is recommended for the human clearance distance, which will form the BEZ distance. The BEZ distance is dependent on the blast parameters that are being used. If charge weights, face burdens, explosive types, ground conditions or stemming heights change significantly, the BEZ distance should be adjusted to suit. The factor of safety is only a recommended minimum. It is suggested that a risk assessment be conducted, using experienced blasting and quarrying personnel, prior to assigning a site specific factor of safety.

The author has observed that often when site management do not have a high level of confidence in adherence to blasting plans and procedures, the factor of safety is increased to compensate. An appropriate factor of safety should protect all personnel and property if all procedures and processes are implemented and adhered to.

Due to the large values for the SDoB, the cratering scenario for flyrock can be ignored, except where the stemming zone is broken and preconditioned greater than 500mm in depth. If stemming lengths are reduced, the flyrock model must be re-evaluated to determine the blast exclusion distances.

Figure 4 displays the theoretical blast exclusion zone, if using an 89mm blast hole with the blast parameters documented in Table 6.

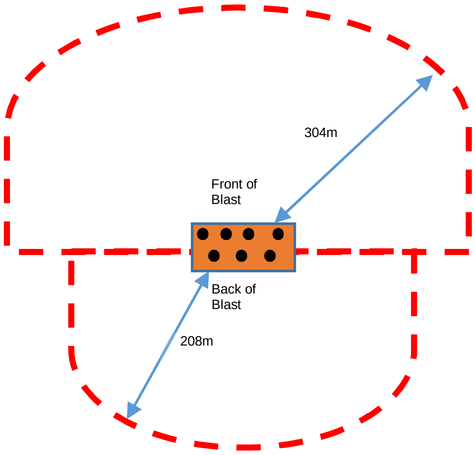

Figure 4 Example of Blast Exclusion Zone for 89mm Dia, On a 12m Bench Height (Free Faced)

Based on the results of the flyrock modelling using the proposed blast parameters, a BEZ with an appropriate factor of safety may be established without affecting neighbouring properties or infrastructure. With actual blast results and measured flyrock distances, the site specific K factor can be established and the BEZ may be able to be reduced.

To reduce the risk of flyrock, developing benches with faces orientated away from infrastructure, neighbouring properties, public infrastructure and open space can significantly reduce the risk associated with flyrock. Quarry Solutions have well establish systems and procedures to calculate, monitor and evaluate blasting plans and procedures to ensure no flyrock events occur.

Blast Volume Sizes and Frequency

The blast volumes for the proposed Coraki quarry will be limited by the maximum capacity of the vehicles transporting the bulk explosives to site. To maximise efficiencies, blasts should be designed to a 15 tonne total explosive load size. Most explosive suppliers can service this load size using a truck and trailer in a single load, or two truck loads of a single bulk explosives vehicle.

The proposed quarry production is 800,000 tonnes per annum, with a maximum of 1,000,000 tonnes. A specific gravity of 2.78 gcm^{-3} was assumed to determine the total volume.

Total Blast Volume (m3)	= 1,000,000/2.78	= 359,712 m^3
Total Explosives Required	= Volume x Powder factor	= 359,712 x 0.7
		= 251,799 Kg
Total Number of Blasts	= Annual Explosive T/ Explosive load per blast	
	= 251.80 / 15	= 17 blast per annum

Based on the above calculation and allowances for some smaller blasts due to planning implementation, there would be between 17and 24 blast per annum. This would result in a maximum of two blasts per month.

All blasts must be conducted during daylight hours, between the hours of 9am and 3pm, Monday to Friday.

Recommendations

Based on the evaluation of the proposed blast parameters it is suggested that the following recommendations be implemented to ensure that when quarrying commences in the proposed Coraki Quarry, blasting can be conducted with minimal risk or annoyance to neighbouring properties:

- Establish permanent blast monitoring locations at the two closest neighbouring properties;
- Start developing a blast vibration equation, specific to the Coraki Quarry. A suitably qualified person should be involved in this process, as using incorrect techniques can add additional cost to blast vibration control;
- Commence blasting using a maximum of a 12 m bench height and 89 mm blast holes to ensure compliance with airblast overpressure and blast vibration. After 3 blasts, the results can be reviewed and evaluated as to whether 102 mm blast holes should be implemented. The airblast overpressure and blast vibration compliance must be maintained;
- Establish the recommended Blast Exclusion Zones. If required measure the flyrock projection distances from the first 10 blasts and recalibrate the flyrock equations. This will enable optimisation of the BEZ distance. Due to the use of a conservative value for the constant K in the prediction equations it would be expected that the exclusion distance could be reduced, however this must not be taken for granted;
- All blasts must be face profiled, surveyed and bore tracked to ensure airblast overpressure compliance, combined with the ability to control face burst that can cause flyrock incidents;
- Blast volumes should be maximised to reduce the frequency of disturbances to the neighbouring properties. A target blast volume of 18,750 m^3 and 15 tonnes of bulk explosive load is recommended. Shot sizes should be limited to a maximum of 3 rows deep initially, to minimise vibration reinforcement if utilising a non-electric initiation system. Once actual blast vibration data has been collected and analysed shot sizes may be increased, if the data supports increasing the blast MIC and remaining under 5.00 mms^{-1};
- Orientate blasts with free faces not directly facing the sensitive receivers, to assist with airblast overpressure control;
- Initiation sequencing for initial blasts, should target a MIC of 1 blast hole maximum, until the vibration attenuation can be accurately assessed;
- All proposed parameters are for initial blasting at the site. Once actual blast data is available from blasting at the proposed site, then parameters may be optimised using the analysis techniques outlined in this document. K values will require calibration for flyrock, blast vibration and airblast overpressure.

Based on the assessment of the proposed blast parameters, blasting can be implemented at the proposed Coraki Quarry and comply with the standards outlined in the ANZECC guidelines. There is a very low probability that blast vibration, airblast overpressure or flyrock will affect or impact the neighbouring properties when blasts are designed, implemented and fired using controlled blasting techniques.

Conclusion

This report identified that the proposed blast parameters would enable blasting to occur within 335m of a neighbouring property, with minimal to no disturbance caused to neighbouring properties. According to this study the proposed blasting at the Coraki Quarry does not introduce any significant risk or impacts to the adjacent neighbouring properties. It would be expected that blasting can comply and be conducted safely in the proposed Coraki Quarry site, provided that:

a) The recommendations in this report are followed; and
b) Best practice blasting processes and procedures are implemented and adhered to.

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Appendix A Proposed Site Layout - Annotated