Stornoway Quarrying

Raeburn Quarry

Development Proposal and Environmental Management Plan

APPENDIX H

Terrock Blasting Report

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STORNOWAY QUARRY

RAEBURN QUARRY – EFFECTS OF BLASTING

‘DRAFT 1’

Adrian J. Moore
3rd July 2009

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'<u>DRAFT 1</u>'

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RAEBURN QUARRY – EFFECTS OF BLASTING

'<u>DRAFT 1</u>'

1 INTRODUCTION

This report gives an assessment of the effects of blasting in the Raeburn Quarry located near Breadalbane, South of Launceston. The relative locations of the existing quarry and surrounds and the proposed extraction area are shown in **Appendix 1.** It is proposed to undertake the extraction within the quarry in five stages over the next 70 years. The stages are labelled **A-E** in **Appendix 1**.

The quarry is operated by Stornoway Quarries and is a medium-scale operation producing approximately 100,000 tonnes of crushed rock products per year. Until now, the rock in the quarry has been broken by mechanical means. The time will come in the near future when the rock will require to be broken by blasting. The broken rock is loaded into trucks and carted to a stockpile area or dumped directly into the mobile crusher. Secondary breaking of oversize will be conducted by hydraulic impactor. The depth of the rock to be broken by blasting will be a maximum of 12 metres on each bench.

For the benefit of those unfamiliar with blasting and vibration, a basic description of '*Quarry Blasting Practice*' has been included as **Appendix 4**, together with a section covering the '*Nature and Measurement of Blast Vibration*'.

This report gives details of estimated blast vibration levels in the surrounding area from the main extraction stages. It also recommends applicable control procedures to limit vibration to the regulatory limits, during the life of the quarry at the nearby houses, as the extraction area moves within the quarry.

2 BLAST VIBRATION LIMITS

2.1 GROUND VIBRATION

Ground vibration from blasting is barely noticed below 0.5 mm/s. The ground vibration limits applied at the quarry are based on the Australian and New Zealand Environment Consultative Council (ANZECC) guidelines to minimise annoyance due to ground vibration from blasting and are set as a planning permit condition.

The ground vibration is limited to a peak vector particle velocity (PPV) of 5 mm/s at residences not owned or occupied by quarry personnel or at other sites with sensitive use. This limit may be exceeded on 5% of blasts in a 12 month period up to an absolute limit of 10 mm/s.

This is an environmental limit intended to minimise annoyance due to ground vibration at sensitive sites such as houses. The prevention of damage to structures by blast vibration is a separate issue. 'Safe' levels for ground vibration limits to control damage to structures are recommended in Table J4.5(B) of Australian Standard 2187.2-2006, reproduced as **Table 1**.

Table 1 - Australian Standard 2187.2-2006 - Table J4.5(B) – Recommended Ground Vibration Limits for Control of Damage to Structures (see Note)

2.1.1.1.1 Category	Type of blasting operations	Peak component particle velocity (mm/s)
Other structures or architectural elements that include masonry, plaster and plasterboard in their construction	All blasting	Frequency-dependent damage limit criteria Tables J4.4.2.1 and J4.4.4.1
Unoccupied structures of reinforced concrete or steel construction	All blasting	100 mm/s maximum unless agreement is reached with the owner that a higher limit may apply
Service structures, such as pipelines, powerlines and cables	All blasting	Limit to be determined by structural design methodology

NOTE: Tables J4.5(A) and J4.5(B) do not cover high-rise buildings, buildings with long-span floors, specialist structures such as reservoirs, dams and hospitals, or buildings housing scientific equipment sensitive to vibration. These require special considerations, which may necessitate taking additional measurements on the structure itself, to detect any magnification of ground vibrations that might occur within the structure. Particular attention should be given to the response of suspended floors.

Limiting ground vibration to 5mm/s at any house will be a basis of blast design at this quarry.

2.2 AIR VIBRATION

Air vibration from blasting is barely noticed below 100 dBL. Air vibration limits applied at the quarry are based on guideline levels of the ANZECC guidelines to minimise annoyance due to blasting overpressure and are set as a planning permit condition. The air vibration limit at a residence or sensitive use site is a maximum of 115 dBL (peak), which may be exceeded on up to 5% of the total number of blasts over a twelve-month period, but should not exceed 120 dBL at any time.

This airblast limit is a human response limit intended to minimise the effect of airblast on people at sensitive sites, such as residences or schools and is not a limit to prevent possible damage.

Australian Standard 2187.2-2006 states:

> *'From Australian and overseas research, damage (even of a cosmetic nature) has not been found to occur at airblast levels below 133 dBL….. A limit of 133 dBL is recommended as a safe level that will prevent structural/architectural damage from airblast.'*

Limiting airblast to 115dBL at any house will be another basis of blast design at this quarry.

3 DETERMINATION OF GROUND VIBRATION LEVELS

3.1 BASIS FOR BLAST VIBRATION LEVEL EVALUATIONS

The vibration from a blast in the quarry was monitored on the 11th June 2009, with the results being used in this assessment. The results of this monitoring were in conformance with previous monitoring of blasts at the adjoining BIS quarry in October 2008.

The blasting specifications used in the blast vibration analysis are shown in **Table 2**. It is proposed to use ANFO explosive whenever possible as its characteristics better suit the rock encountered. In the quarry a reduced scale of blasting is proposed during years 0-6 because of the close proximity of House 1. Further adjustment of the specifications is required for blasts closer than 300m to this house to control air and ground vibration to the regulatory limits. In Stage B there is a further need to adjust the front row burden for north facing blasts to achieve regulatory compliance.

Table 2 – Blast specifications used in analysis

	Stage A 0-6 years	**Stages B-E 7-70 years**
Bench height (m):	12	12
Hole depth (m):	12.6	12.6
Hole angle (^{o}):	10°	10°
Blasthole diameter (mm):	89	89
Blasthole spacing (m)	2.75	2.8
Blasthole burden (m):	2.75	2.8
Front Row Burden (m)	3.5	3.0
Stemming height (m):	3.5	3.0
Explosive	ANFO	ANFO
Charge mass per m (kg)	5	5
Charge mass per delay (kg):	*from environmental design	48kg
Powder factor (mg/m^3):	0.5	0.5

3.2 EVALUATION OF MAXIMUM GROUND VIBRATION LEVELS

Ground vibration varies with distance from the blast, charge mass per delay, type of explosive, geological conditions and blasting specifications. For similar geological conditions and blasting specifications, ground vibration varies with distance and charge mass per delay, according to the Site Law formula:

$$V = k_g \left(\frac{D}{\sqrt{W}} \right)^b \qquad [1]$$

where:
- V = ground vibration as peak particle velocity (PPV) (mm/s)
- D = distance from blast (m)
- W = charge mass per delay (kg)
- b = site exponent or drop off (attenuation) rate
- k_g = site constant

The regression analysis of the previous ground vibration measurements showed that conservative (worst case) site parameters are as follows:

- Site exponent:- -1.6
- Site constant: 2400

Hence, the formula used for ground vibration prediction at the site is:

$$V = 2400 \left(\frac{D}{\sqrt{W}}\right)^{-1.6} \quad [2]$$

In similar quarries vibration levels less than half the maximum predicted by this model is commonly experienced. The attenuation rate varies because of the characteristics of the rock through which the vibration travels. Characteristics, such as faults and jointing planes, degree and depth of weathering and the soil profile, contribute to the wide variation of vibration levels.

Ground vibration contours for a blast based on the above Site Law and a maximum charge mass per delay of 48 kg are shown in **Figure 2** and **Appendix 2b.** During Stage A, the maximum charge mass is 45.5kg and the contours are shown in **Appendix 2a.** When these are superimposed on the site photo as an overlay and moved around the proposed extraction area for each stage, the effect of a blast anywhere in the planned extraction area can be readily seen.

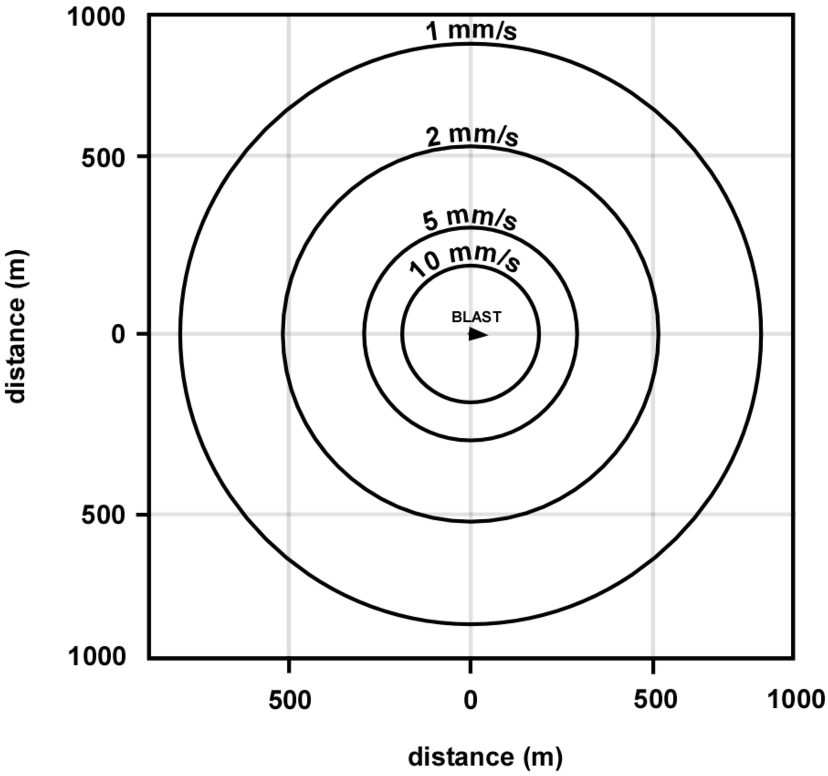


Figure 1 - Worst-case ground vibration contours – charge mass 48kg

Assuming worse-case vibration transmission, the milestone vibration levels occur at the predicted distances from a blast, as shown in **Table 3.**

Table 3 – Estimated ground vibration levels

PPV (mm/s)	Stage A (45.5kg)	Stages B- E (48kg)
	Distance(m)	Distance(m)
10	210	212
5	320	330
2	570	582
1	880	900

The maximum extent of the 10, 5, 2 and 1mm/s contours for blasting using 45.5kg of explosives is shown in **Appendix 2a** for Stage A and 48kg (**Appendix 2b)** for the remaining stages. These represent the highest ground vibration levels in the area surrounding the quarry for any blast over the life of the quarry. The single blast contours are also shown.

An area has been identified in the Stage A extraction (years 0-6) where a modification to blasting practice may be required to limit the ground vibration to 5mm/s at an existing house (House 1). Blasts closer than 320m to the house will require a charge mass reduction. This area is shown in **Appendix 2a.** The relationship between the maximum charge per delay, the hole loading required to limit the PPV to 5mm/s and distance are shown in **Table 4** and **Figures 2a - 2b.** Blasts closer than 300m will require 2 decks of explosive, and closer than about 190m will require 3 decks of explosive. Loading holes with 3 decks of explosives is considered to be impractical in the quarry situation so the practical limit of 89mm diameter holes is about 190m from the house. Reducing the hole size to 76mm would permit the loading of 2 decks to approach within about 160m of the house before a further charge mass reduction by additional decks is required. The effect on the proposed extraction area is shown in **Figure 3.**

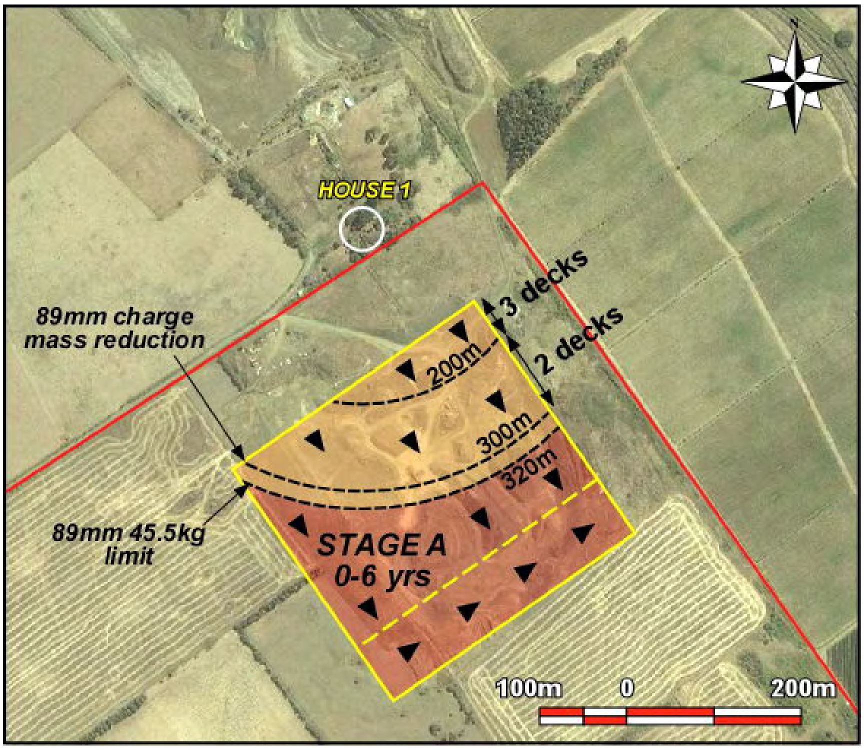


Figure 3 - Charge mass adjustments near House 1

Table 4 – Hole loading with distances to limit PPV to 5mm/s at House 1.

Distance to house (m)	5mm/s Limiting Charge mass (kg)	Maximum column length φ 89mm (m)	Loading	Maximum column length φ 76mm(m)	Loading
140	8.7			2.4	3 decks
150	10	2.0		2.8	3 decks
160	11.4	2.3		3.1	3 decks
170	12.9	2.6	3 decks	3.6	2 decks
180	14.4	2.9	3 decks	4.0	2 decks
190	16.1	3.2	3 decks	4.4	2 decks
200	17.8	3.6	2 decks	4.9	2 decks
210	19.6	3.9	2 decks	5.4	2 decks
220	21.5	4.3	2 decks	8.2	2 decks
230	23.5	4.7	2 decks	6.5	2 decks
240	25.6	5.1	2 decks	7.0	2 decks
250	27.8	5.6	2 decks	7.6	2 decks
260	30.1	6.0	2 decks	8.3	Single column
270	32.4	6.5	2 decks	8.9	Single column
280	35	7	2 decks	9.6	Single column
290	37.4	7.5	2 decks	10.3	Single column
300	40.1	8	Single column		
310	42.8	8.5	Single column		
320	46	9.2	Single column		

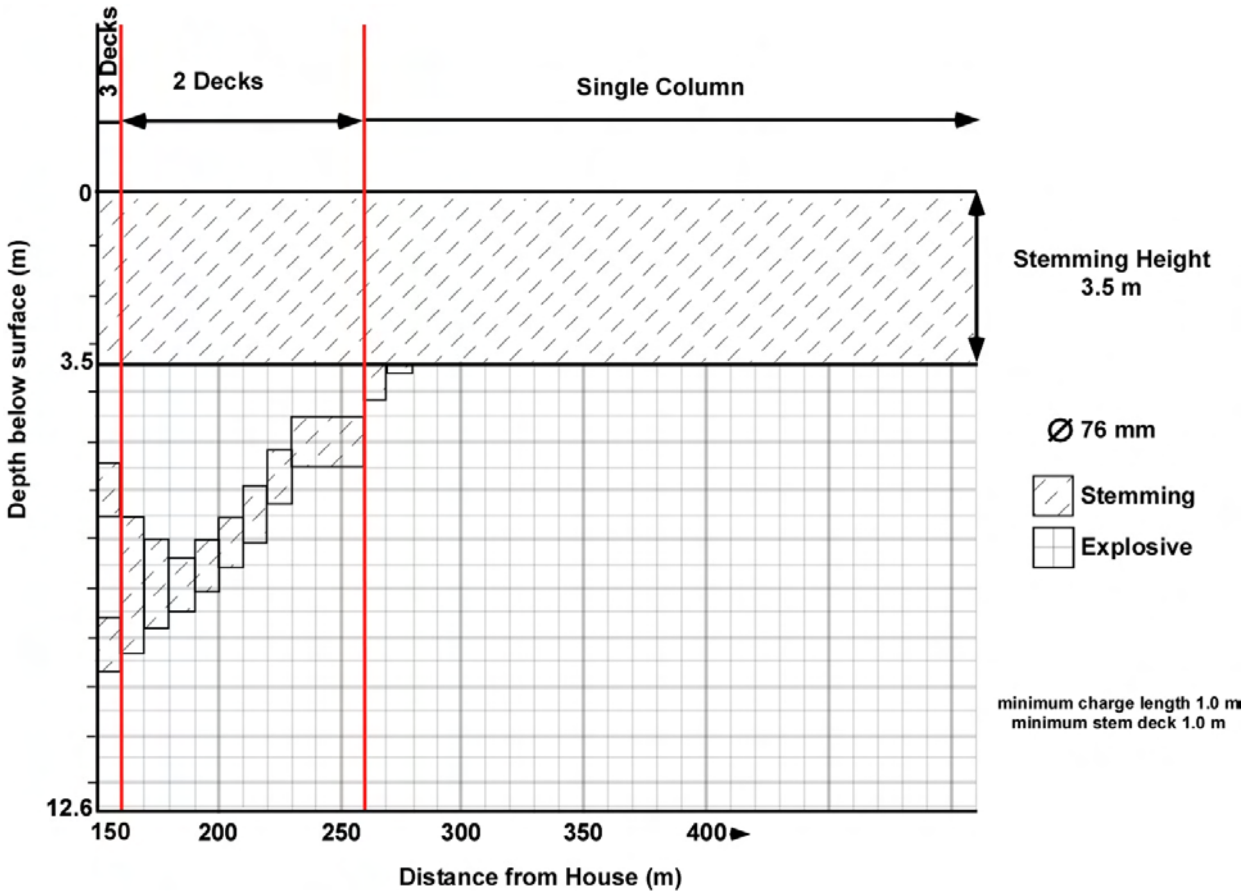


Figure 2a- Charge limit hole loadings with distances from House 1 (76mm diameter)

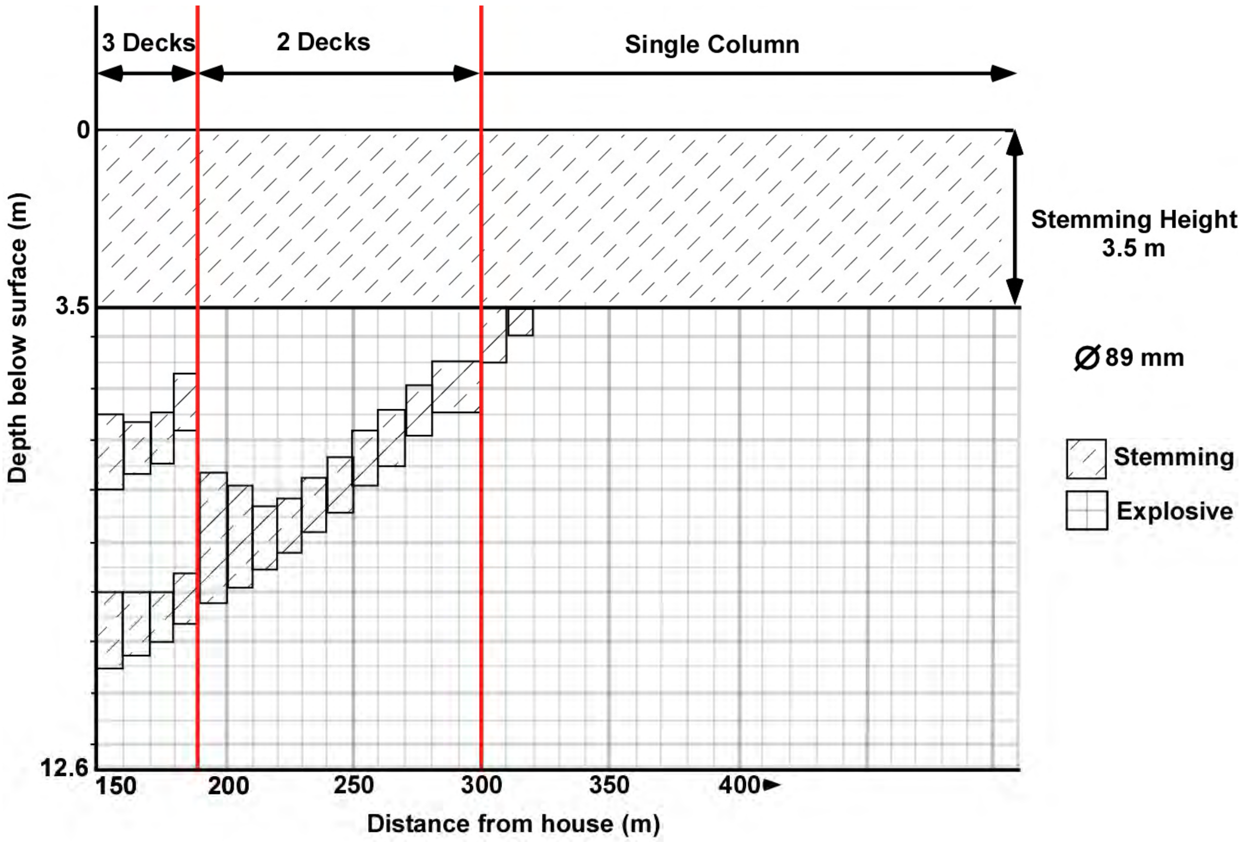


Figure 2b- Charge limit hole loadings with distances from House 1 (89mm diameter)

While technically possible to blast even closer to the house than 160m, it becomes a commercial decision as to whether the additional cost of drilling and loading the holes is economically justifiable compared to the volume of rock that can be extracted.

The peak ground vibration at any house will be 5mm/s at any house during the period the quarry operates.

4 DETERMINATION OF AIR VIBRATION LEVELS

4.1 PREDICTION OF MAXIMUM AIR BLAST LEVELS

The magnitude of airblast levels arriving at a point remote from the blast is a function of many parameters, including charge mass, confinement, burden, attenuation rate, shielding direction relative to the blast and meteorological conditions at the time of the blast. The attenuation rate for low frequency blast vibration has been found from experience to be a 9 dBL reduction with doubling of distance.

Analysis of blasting data from this and other quarries has permitted the relationship between maximum 120 dBL distance (the distance in front of the blast that the 120 dBL contours occurs), charge mass per delay and burden to be established.

The predictive model is:

$$D_{120} = \left(\frac{k_a \times d}{B}\right)^{2.5} \cdot \sqrt[3]{m} \qquad [3]$$

where:

D_{120} = Distance to the 120 dBL air blast level (m)
d = hole diameter (mm)
B = burden (mm)
m = charge mass (kg)
k_a = an empirical constant = 250 (is usual for quarry blasting)

For Stage A, from the analytical method, the 120 dBL distance for a 45.5 kg charge mass and front row burden of 3.5 metres is a maximum of 365 metres in front of the blast. This equates to 115 dBL at 540m. The airblast levels in front of a blast are 8-10 dBL higher than those behind a blast. The worst-case airblast contours from Stage A blasts are shown in **Figure 4.**

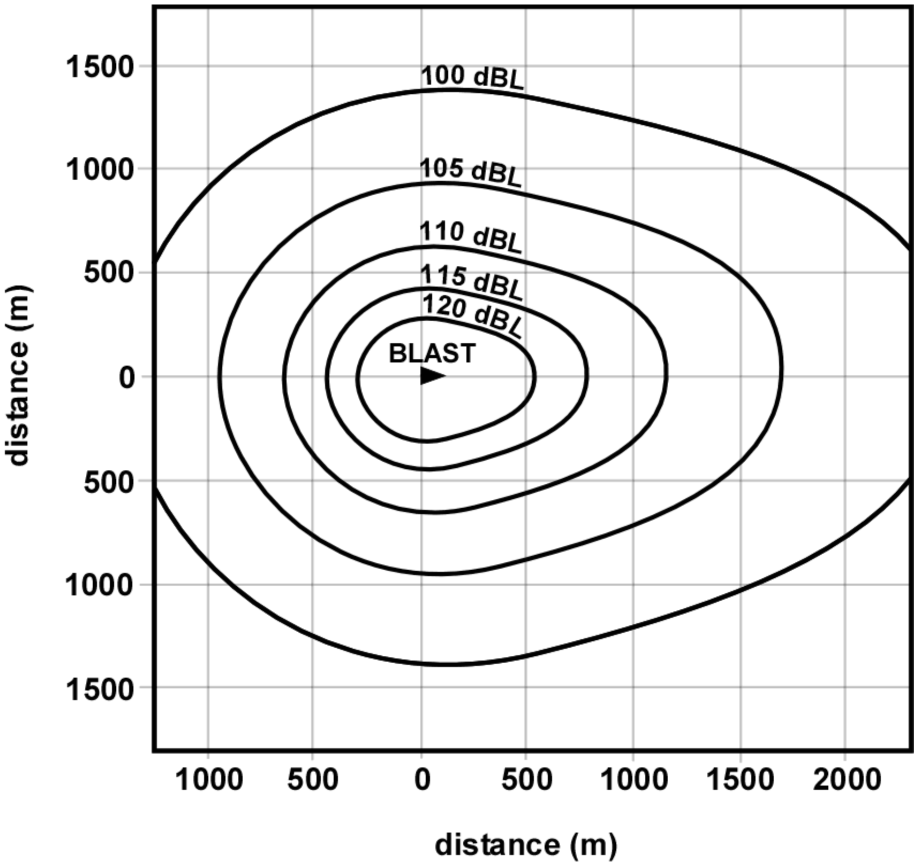


Figure 4- Worst –case airblast contours from a standard specification blast

For the other stages, the 120 dBL distance for 48kg and front row burden of 3.0m is a maximum of 544m, which equates to 115 dBL at 800m.

4.2 EXTENT OF AIRBLAST LEVELS

An assessment was made based on blast specifications for 89 mm diameter blastholes, a face height of 12 metres, a charge mass of 45.5 kg for Stage A and 48kg for the other stages with the face direction assumed to be as shown in **Appendices 3a** and **3b.** North facing blasts will have to retain a 3.5m front row burden until south of the line indicated in **Appendix 3b.** The front row burden may then be progressively reduced to a minimum of 3.0m until the line indicated on **Appendix 3b**. By the extraction sequence proposed all blasts may be planned to face away from other neighbours thereby reducing airblast. The extent of the air vibration levels was determined and is shown in **Appendices 3a** and **3b**. The distances to milestone airblast levels for current blasting practice and different orientations are shown in **Table 5**.

Table 5 - Distances to milestone airblast levels for standard specification blasts

Air Vibration Level (dBL)	Stage A 45.5kg		Stages B-E 48kg	
	Distance in front (m)	Distance at side/behind (-10dBL)(m)	Distance in front (m)	Distance at side/behind (-10dBL)(m)
120	365	200	544	300
115	540	290	800	430
110	800	420	1200	640
105	1160	640	1700	940

During Stage A, the reduction of charge mass necessary to limit ground vibration at House A will be generally effective in reducing air blast to the 115 dBL limit. However, for blasts closer than 220m the stemming height may need to be increased from 3.5m to 3.6m. The distances to the 115 dBL contour behind blasts designed to limit the ground vibration to 5mm/s are listed in **Table 6.**

Table 6- The distances to the 115dBL contour behind blasts

Distance (m)	Charge mass (kg)	D_{115}
200*	17.8	200
220*	21.5	214
240	25.6	240
260	30.1	257
280	35	270
300	40.1	283
320	46	296

* *stemming height increased to 3.6m*

The planned extraction sequence and resulting blast directions will enable air blast levels to be kept below the 115 dBL at any house for the remainder of the quarry's operation.

5 EFFECTIVE CONTROL OF BLASTS

5.1 GENERAL

Blasting in Tasmanian quarries is regulated by the Department of Primary Industries, Water and Environment through the Quarry Inspectorate. All quarries in Tasmania are required by law to record details of every blast in an official report book and these reports are available for official inspection. The report book includes a stocktaking section, which can be checked against official records which explosives suppliers are required to keep. Quarry Managers and shotfirers are also required to hold statutory certificates and permits and are liable to have these suspended or cancelled if they do not obey the regulations.

5.2 FLYROCK

Efficient blasting practice results in broken rock being left in a pile next to the blasting face, as shown in **Appendix 4**, **Figure A4.4**, but the possibility of flyrock and its effective control must always be considered.

Flyrock is controlled by having the explosive charge confined by sufficient stemming and burden. Care and attention to detail, as outlined in **Appendix 5**, *'General Recommended Blasting Practice'*, during all stages of face survey, blast design and loading will ensure that in the unlikely event of flyrock occurring, it will be contained within the Work Authority boundaries and will present no danger to the public.

Terrock has developed a predictive model for the estimation of flyrock distances. The basic model for quarrying operations is:

$$L_{max} = \frac{27^2}{9.8} \cdot \left(\frac{\sqrt{m}}{B}\right)^{2.6} \qquad [4]$$

where: L_{max} = maximum flyrock throw (m)
m = charge mass per metre (kg) = 5.0
B = burden or stemming height (m) = 3.5

The maximum predicted throw for the proposed specifications during Stage A is therefore, 24 metres. To this we recommend the application of a factor of safety of '4', ie. the minimum clearance distance in front of blasts is to be 96 metres and applied in a 90^o arc at 45^o to the face. The maximum throw during Stages B-E is predicted to be 35m and the minimum clearance in front of face is 140m.

In directions parallel to the face and behind the face, the possible flyrock mechanisms are cratering and rifling of the stemming (or gun barrelling). Providing the stemming height is greater than about 15 hole diameters (1.3 metres), cratering is practically eliminated. Rifling produces high trajectory flyrock with little horizontal projection.

The throw distance can be determined by substituting burden in the above equation and multiplying by Sin 2θ, where θ is the launch angle. For vertical holes, nominally 10^o, an allowance is made for a possible angular trajectory spread beyond the hole collar – say 10^o. For Stage A, the maximum throw in other directions becomes 24 Sin 140^o = 15.0 metres. For Stages B-E, the throw is 23m. The recommended minimum clearance zone for a '4' factor of safety to be applied for each blast is shown in **Figures 6a** and **6b.**

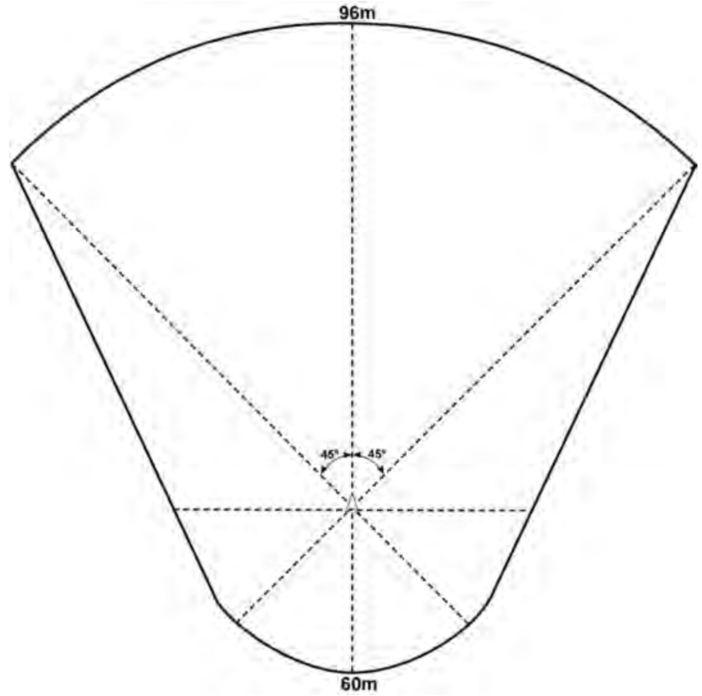


Figure 6a – Minimum exclusion zone for personnel, Stage A

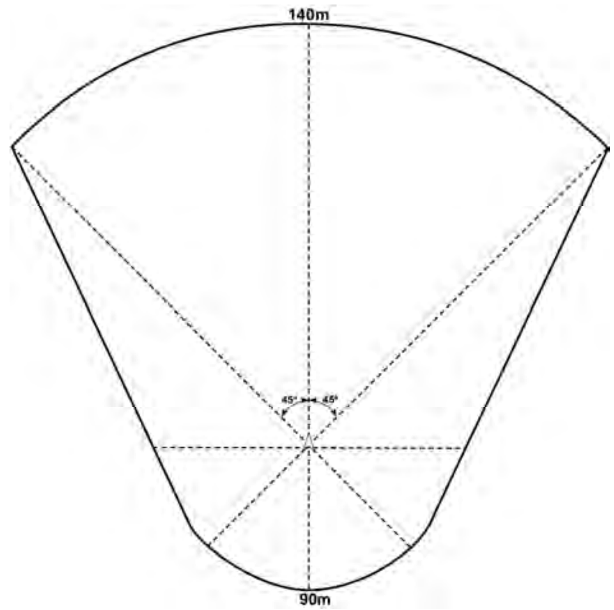


Figure 6b – Minimum exclusion zone for personnel, Stages B-E

The adoption of the minimum exclusion zones in **Figures 6a** and **6b** will prove conservative for most blasting. However, the determination of the exclusion zone is the responsibility of the quarry manager and shot firer for each blast.

5.3 BLAST VIBRATION MANAGEMENT PROGRAM

Blasting must be carried out in accordance with the proposed blasting specifications applicable Explosives Use Regulations and the recommended blasting practice specified in **Appendix 5**. Compliance with vibration limits can be demonstrated by the adoption of a monitoring regime conducted at House 1. Regular review of the monitored levels and modifications to blasting practice at an appropriate time will ensure continuing compliance.

6 CONCLUSIONS

Blasting can be carried out in the proposed quarry extension safely and in conformance with the applicable Explosives Use Regulations and planning permit vibration limits, subject to compliance with the specifications and recommendations given in this report.

People within the range of perceptible ground vibration will experience both air and ground vibration from blasting for less than four seconds on about 12 occasions per year, depending on the blast size. Beyond the range of perceptible ground vibration, the air vibration may be perceptible for less than two seconds for each blast.

It is predicted that peak ground vibration will remain below the 5mm/s limit at the nearest house and thereby all neighbouring houses for the life of the quarry.

Airblast can generally be controlled to the 115 dBL limit at the nearest house using current blasting practice for the life of the quarry and observance of the blast directions shown in **Appendices 3a** and **3b.**

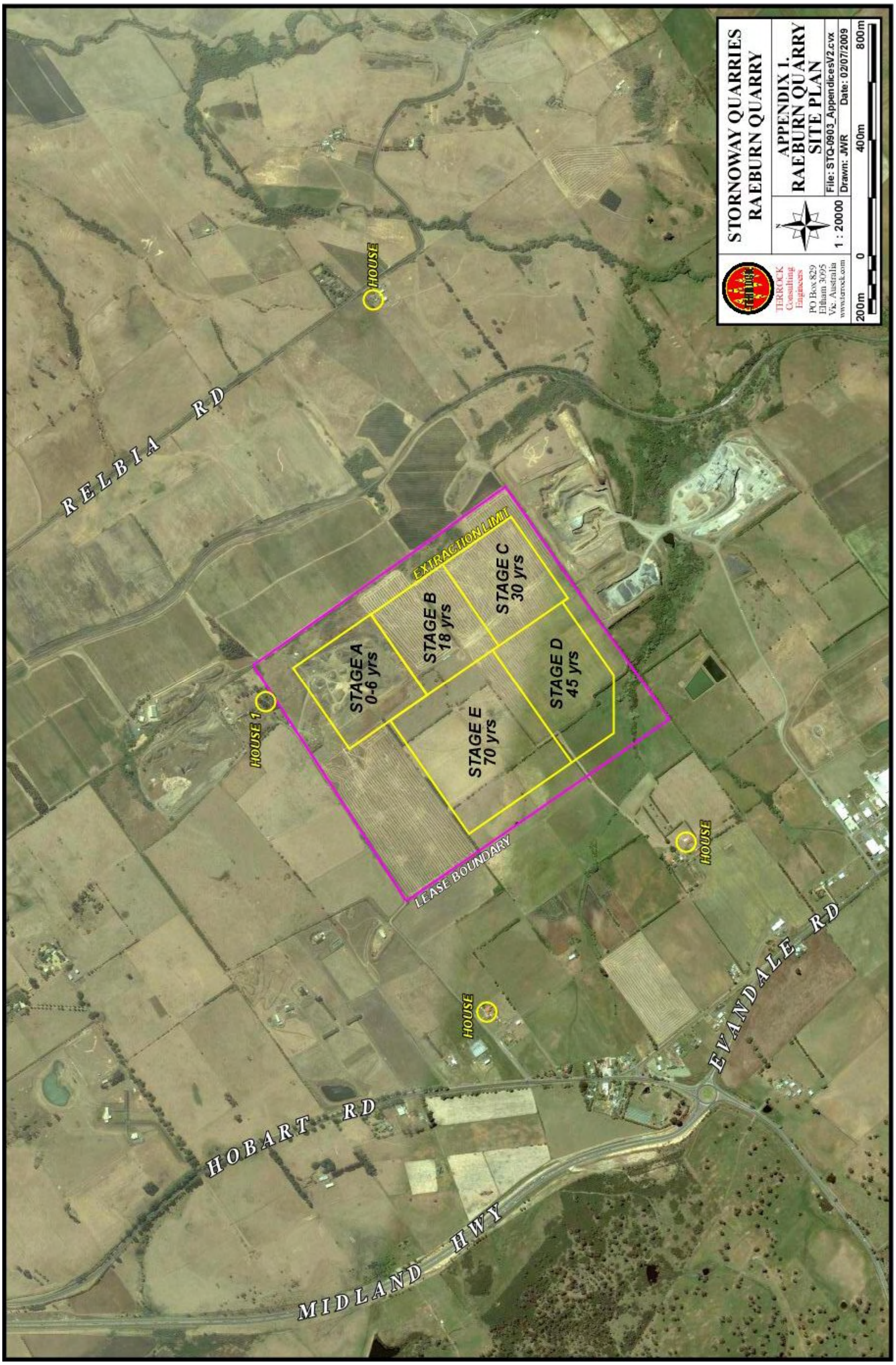
Compliance with vibration limits can be readily demonstrated by the adoption of a monitoring program to record the vibration levels from each blast.

If recorded vibration levels are approaching 5 mm/s and/or 115 dBL at the nearest house, a ground vibration reduction can be achieved simply by decking the holes to reduce the charge mass. An air vibration reduction can also be readily achieved by additional confinement of the explosion with greater front row burden and/or increased stemming height.

Adrian J. Moore
3rd July 2009

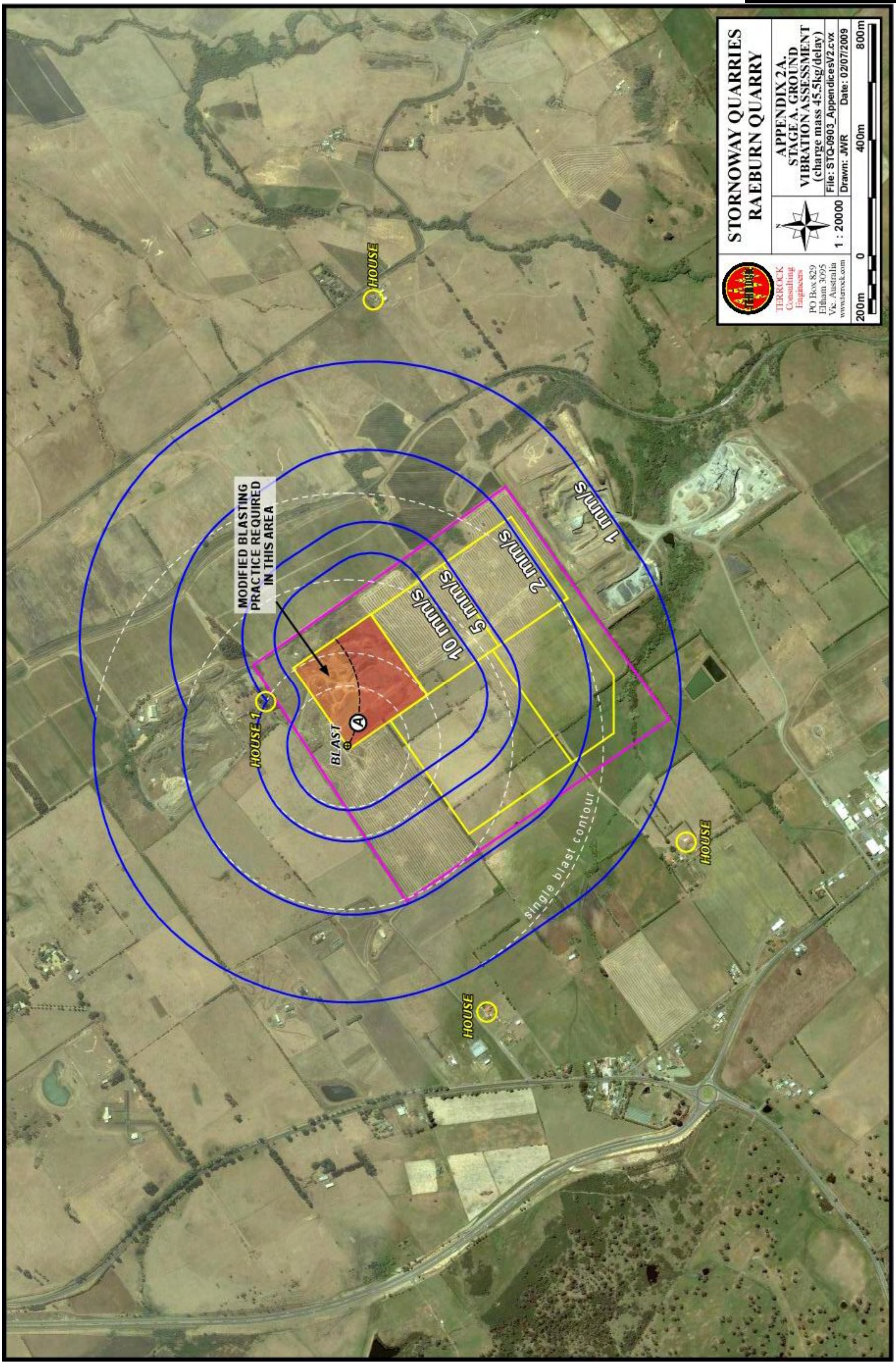
APPENDICES

APPENDIX 1



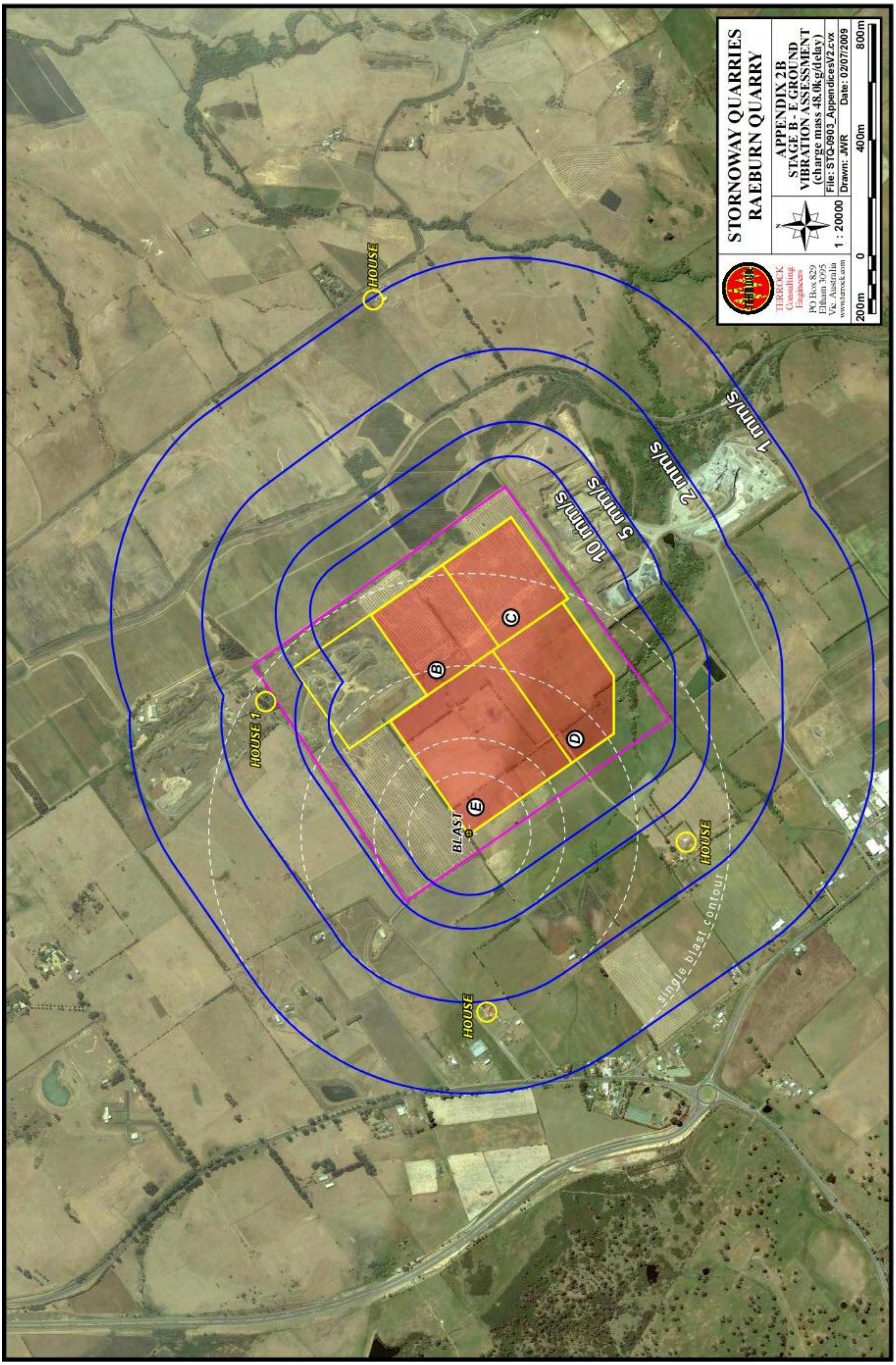
Appendix 1- Existing quarry and proposed extraction areas

APPENDIX 2a



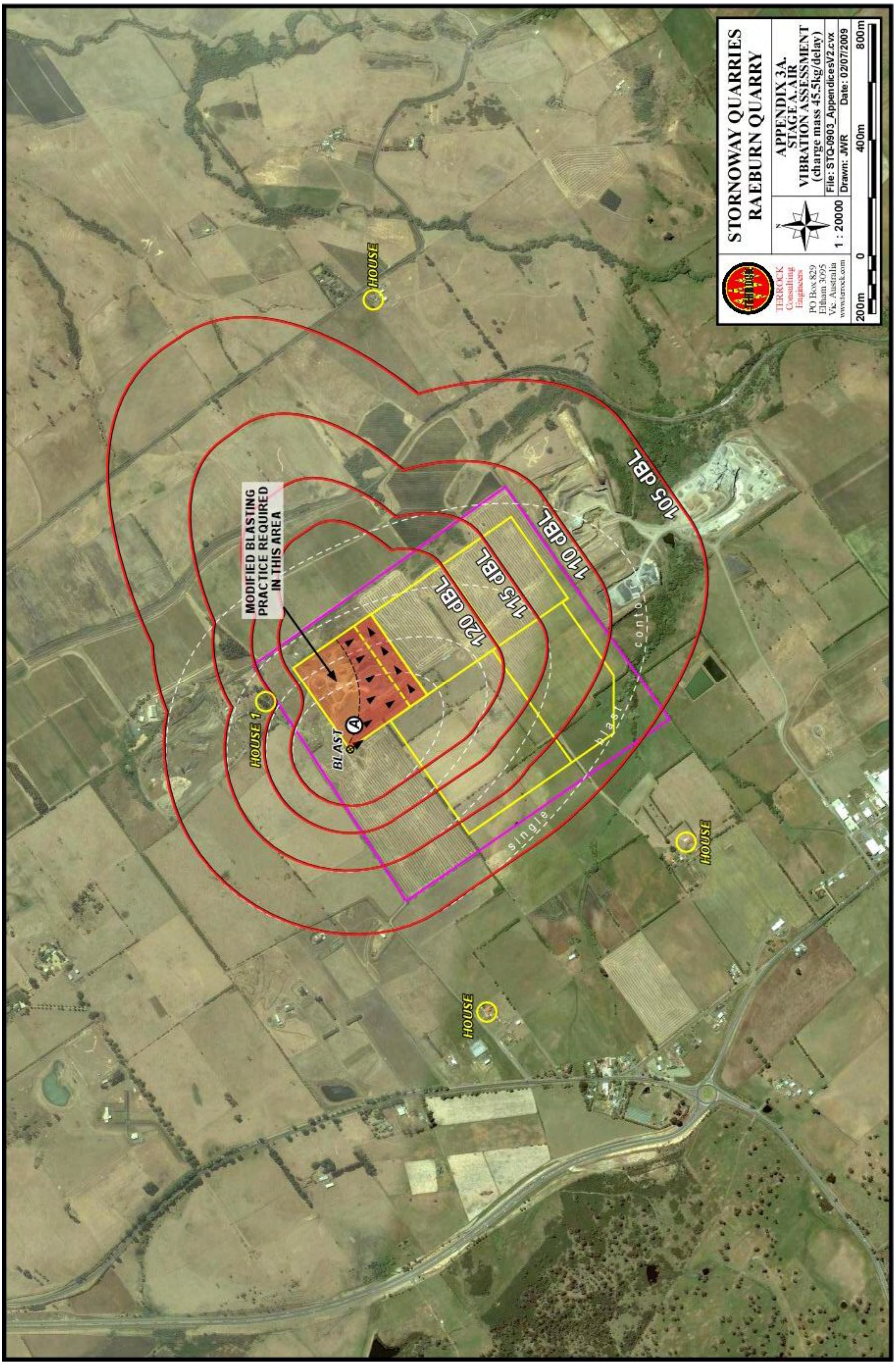
Appendix 2a- Stornoway Quarry ground vibration - years 0-6

APPENDIX 2b



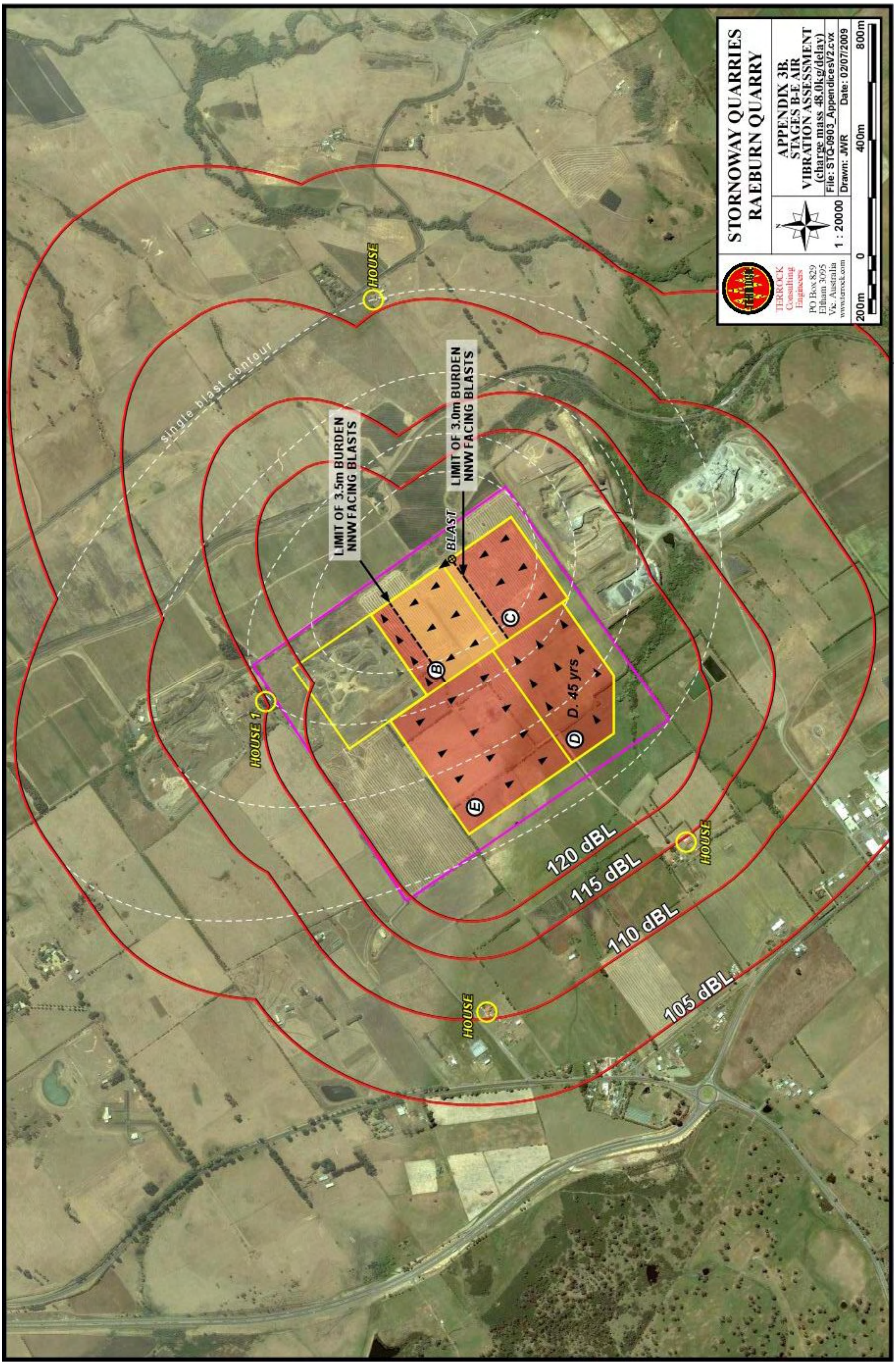
Appendix 2b Stornoway Quarry ground vibration- years 7-70

APPENDIX 3a



Appendix 3a – Air blast years 0-6

APPENDIX 3b



Appendix 3b – Air blast years 7-70

APPENDIX 4 – EXPLANATORY NOTES

A4.1 QUARRY BLASTING PRACTICE

This section has been included to provide a basic explanation of quarry blasting practice for those who are unfamiliar with the subject.

Blasting is an important process in hard rock quarrying because it fragments and separates rock pieces from the rock mass, which enables it to be loaded and carted to the crusher for size reduction and screening to a range of commercial products.

Blastholes are drilled downwards into the rock. A quantity of explosives is then placed in each blasthole, which is then topped up with crushed aggregate to effectively confine the explosives charge. Blasting practice at the quarry for a 12 metre face is described below:

89 mm diameter blastholes, 12.6 metres deep, are drilled metres distance from the edge of the quarry bench. Blastholes are spaced 2.7 metres apart, as shown in **Figure A4.1**. Holes are drilled vertically with 0.5 metre of sub-drill to assist in maintaining the floor level.

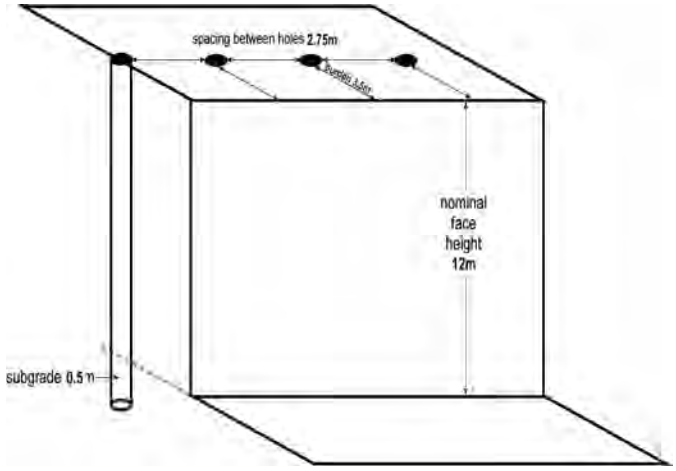


Figure A4.1 – Blasthole design for Raeburn Quarry

The burden and spacing are varied to match the characteristics of the rock being blasted. The actual face height may also vary to suit the depth of the rock to be excavated in the sloping terrain to establish and maintain level benches. The burden of the front row of holes may need to be increased to control airblast.

Explosives are then loaded into the blasthole until the top of the explosive charge is no closer than 2.7 metres from the top of the blasthole. The weight of explosives in the blasthole depends on the density of the explosive used. ANFO explosive will generally be used with a density of 0.8 g/cc or 5.0 kg/m. The charge mass in a 12.6 metre deep hole is approximately 46 kg. The hole is then topped up with at least 3.5 metres of aggregate to effectively confine the explosives charge, as shown in **Figure A4.2**.

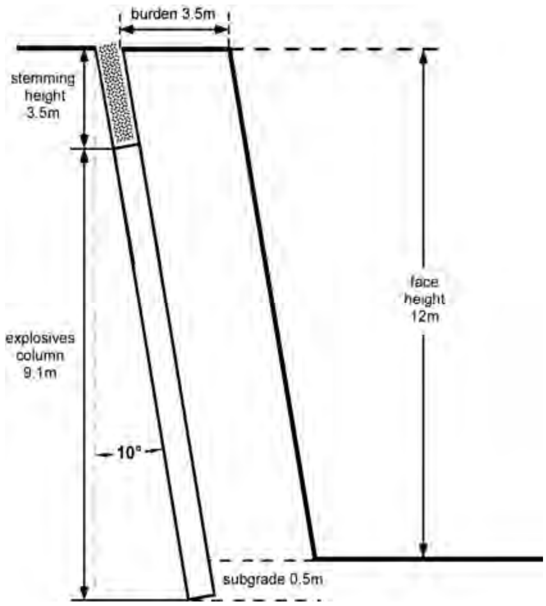


Figure A4.2 – Blasthole design for ANFO explosive

ANFO explosive will generally be used because it is cheaper and its characteristics suit the rock being quarried. Emulsion explosive may be used because it can be used in blastholes containing water where a water resistant explosive must be used. In this case the hole pattern can be expanded to utilize the additional charge mass.

It is common practice for the number of blastholes loaded and fired in any one blast to vary up to 80 or more holes. The explosives in each blasthole are initiated by signal tube delay detonators.

The signal tube leads from each blasthole are joined together by surface signal tube delay detonators to form a blasting circuit. At the approved firing time, after warning signals have been given, the blasting circuit is connected to an exploder and fired.

All blastholes do not, however, explode at the same instant of time. Reduced blast vibration and improved fragmentation result because the blastholes detonate in sequence, with a small time delay of several milliseconds between each explosion. This small time delay is provided by the surface signal tube delay detonators and an unlimited number of delay intervals are possible. It is usual for only one blasthole to be exploded at any instant of time. In the case of 20 blastholes being fired in the one blast, a possible delay sequence is shown in **Figure A4.3**.

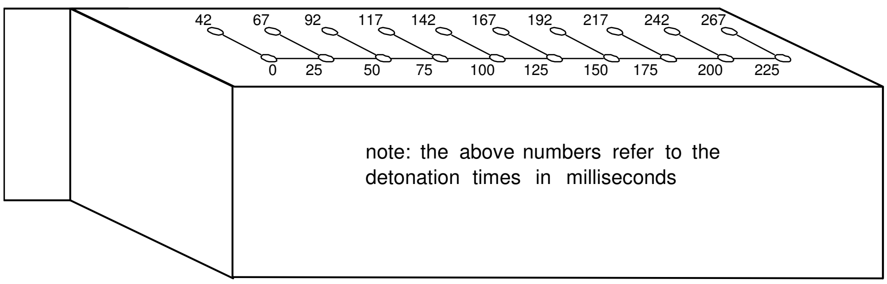


Figure A4.3 - Typical delay sequence

The blastholes at one end of the blast explode first, and are followed by the succeeding blastholes in the sequence shown. The total time for the 20 blastholes to be exploded would be approximately a quarter of a second. The total time for 80 blastholes in this delay pattern would be a second.

After the blast, the broken rock is left lying against the wall of the quarry excavation, as shown in **Figure A4.4**. The broken rock is then loaded into trucks and taken to the crusher.

Figure A4.4 – Rock left after a blast

A blast of 80 holes would break approximately 8,000 cubic metres of rock. To maintain a production rate, blasts will be fired at approximately monthly intervals.

A4.2 THE NATURE AND MEASUREMENT OF BLAST VIBRATION

Explosive energy produces the following effects:

- Rock shattering and displacement.
- Ground vibration.
- Air vibration.

The energy contained in explosives used in quarry blastholes is designed to break and displace rock, and the more the energy available that can be utilised for that purpose, the more efficient the blast. However, even in efficient blasts, some of the energy is not utilised in breaking rock and creates vibration in the surrounding rock and air. Vibration from blasting in Tasmanian quarries is regulated by limits specified in the planning permit.

A4.2.1 Ground Vibration

Ground vibration radiates outwards from the blast site and gradually reduces in magnitude, in the same manner as ripples behave when a stone is thrown into a pool of water, schematically shown in **Figure A4.5**. The motion of the wave can be defined by taking measurements of a float on the surface of the water. With suitable instruments we can measure the displacement or amplitude, the velocity, the acceleration of the float and the wave length of the waves.

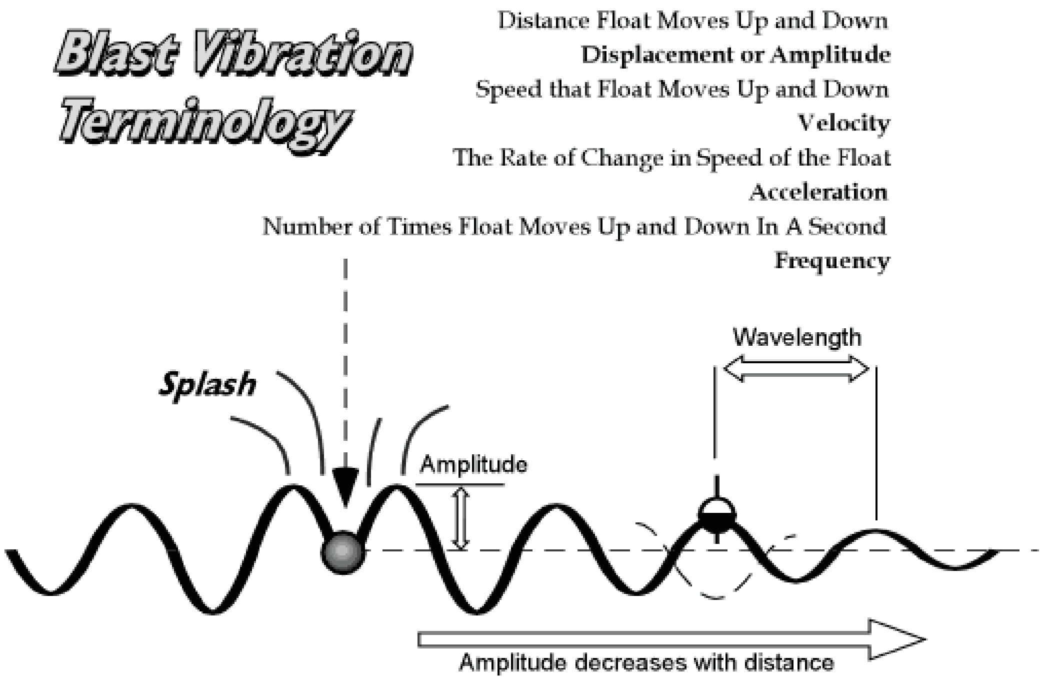


Figure A4.5 – Schematic diagram of vibration terminology

With ground vibration, the motion of the surface of the ground can be measured by coupling a suitable instrument directly to the surface.

Early researchers into ground vibration discovered a closer relationship between velocity of the ground surface and the response of structures than either displacement or acceleration. Measurement of velocity of the motion of the surface of the ground near where it enters a building has become the standard by which ground vibration is measured and regulated.

Ground vibration is measured with a blasting seismograph and is commonly expressed in terms of Peak Particle Velocity (PPV) and measured in terms of millimetres per second (mm/s). To define the motion in three dimensions, it is necessary to use three transducers to measure the vibration in three mutually perpendicular directions and then determine a Peak Particle Velocity or Peak Vector Sum (PVS), which is the instantaneous maximum vector of the three individual measurements:

ie. $PPV\ (PVS) = \sqrt{v_t^2 + v_l^2 + v_v^2}$

The ground vibration arriving at a location remote from a blast is a function of many factors, including:

- Charge mass of explosive fired in each hole.
- Distance from the blast.
- Explosives properties and coupling to the rock.
- Ground transmission characteristics.
- Origin of the rock, ie. igneous or sedimentary.
- Presence of structures within the rock, such as bedding, faults and joints.
- Degree and depth of weathering at the surface.
- Soil profile.
- Initiation sequence and direction of firing.

Generally, all other factors being equal, the ground vibration increases with increasing charge mass and reduces with distance.

The manner in which ground vibration reduces with distance is demonstrated in **Figure A4.6**. This shows typical maximum vibration levels that result from a large blast (many holes) with a maximum charge mass of 45.5 kg/hole and an attenuation rate determined for the Raeburn Quarry.

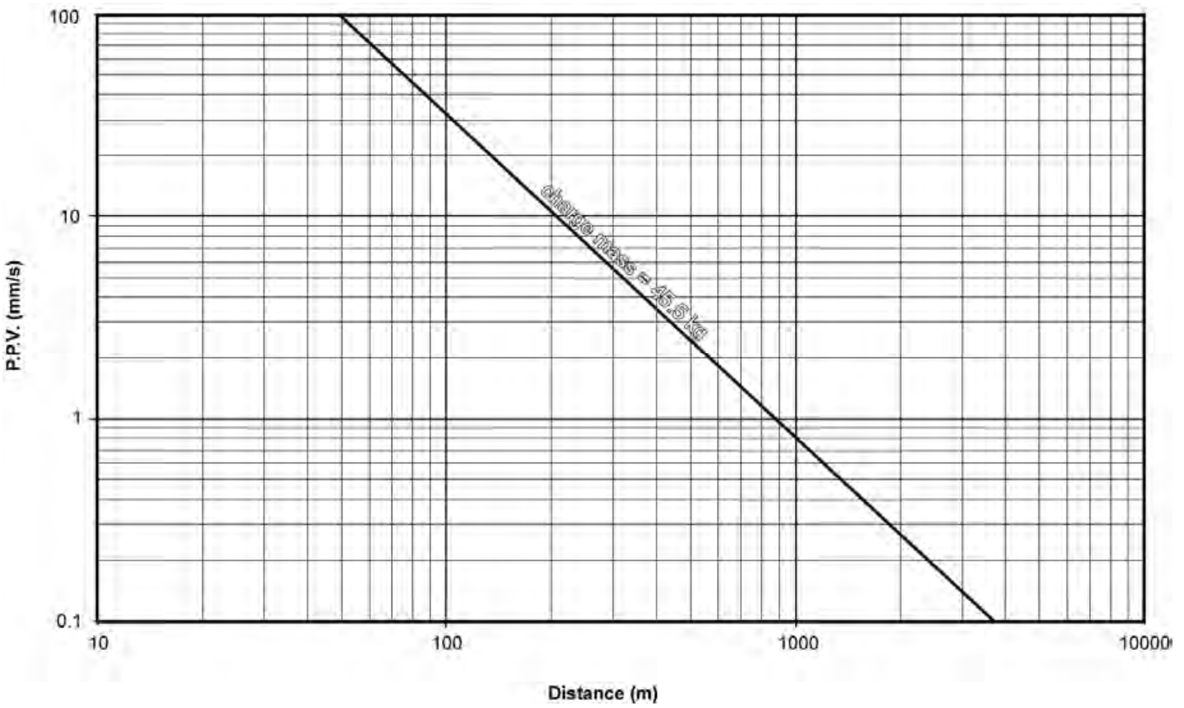


Figure A4.6 - Relationships between charge mass, distance and vibration levels

The relationships between charge mass, distance and vibration levels can be analysed and then used in a predictive formula to limit the ground vibration. The information in **Figure A4.6** can be produced in contour form and, if moved around an extraction outline, can be used to determine the maximum extent of each contour interval for each stage, as shown in **Appendices 2a-b**.

A4.2.2 Air Vibration Assessment

The air vibration levels resulting at a location remote from a blast are a function of many factors, including:

- Charge mass of explosives fired.
- Distance from the blast.
- Direction of the receptor relative to the free face.
- Confinement of the explosion by burden and stemming (height and stemming material).
- Topographic shielding.
- Burden, spacing and initiation timing sequence,
- The performance of the shotfiring crew during loading.
- Meteorological conditions at the time of the blast.

Generally, all other factors being equal, air vibration increases with increasing charge mass and reduces with distance.

From our research into air vibration, we have developed our own assessment model, which permits confinement conditions and face direction to be considered (Moore et al 1993 and Richards et al 2002). The model is incorporated in our ENVIB software, which has been accepted by the regulatory authorities in Victoria, New South Wales and Queensland.

The ENVIB model is that the basic emission from a quarry blast can be determined from the formula:

$$D_{120} = \left(\frac{250 \times d}{B}\right)^{2.5} \cdot \sqrt[3]{m} \qquad [A4.1]$$

where:
- D = distance in front of the blast to the 120 dBL vibration level
- d = hole diameter (mm)
- B = burden (mm)
- m = charge mass per hole (kg)

The model can be used to control airblast because it allows the front row burden to be designed to achieve vibration levels at sensitive sites.

The basic emission must then be modified for face conditions and topographical shielding. Wind has not been found to significantly effect the basic air vibration emission and its effects are not considered in the model.

For single bench quarry in flat topography, higher levels of blast vibration are recorded in front of the face than at the same distance behind the face. For the blast specifications used in this evaluation, measurements of 6-8 dBL higher are common in front of the face due to a 'face shielding' effect. This is illustrated in **Figure A4.7**.

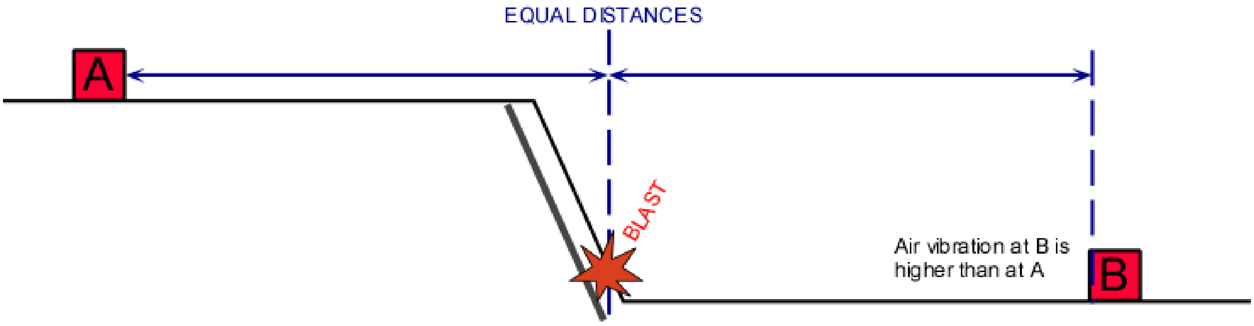


Figure A4.7 – The effect of the face on air vibration levels

Basic airblast emission contours for a worst-case Raeburn Quarry blast, with no topographical shielding, are shown in **Figure A4.8**.

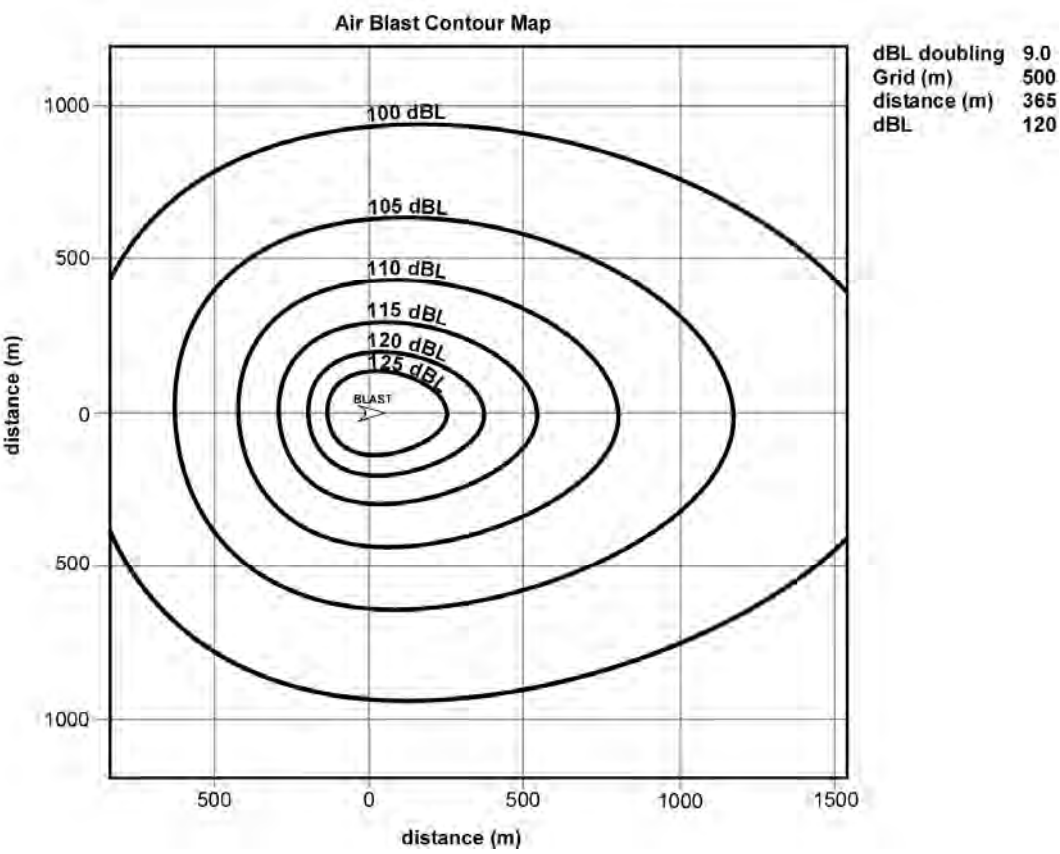


Figure A4.8 - Basic airblast emission contours for a worst-case Raeburn Quarry blast, with no topographical shielding (8 dBL increase in front of blast)

In hilly topography and deep quarries, the contours are modified by shielding. The amount of shielding depends on the factors illustrated below in **Figure A4.9**.

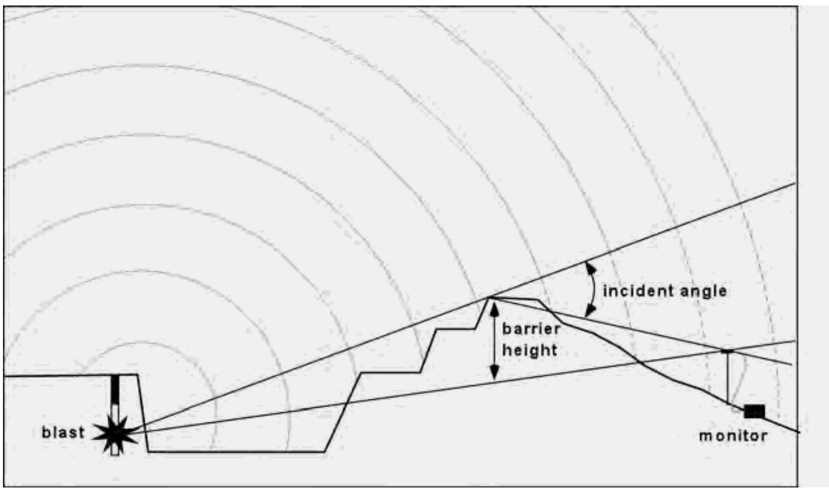


Figure A4.9 – The topographic effects on air vibration levels in more complex situations

Shielding is a function of the effective barrier height and the incident angle to the measuring point. The terms are illustrated in **Figure A4.9**. Our research has shown the amount of shielding afforded by the topography can be estimated from **Figure A4.10**.

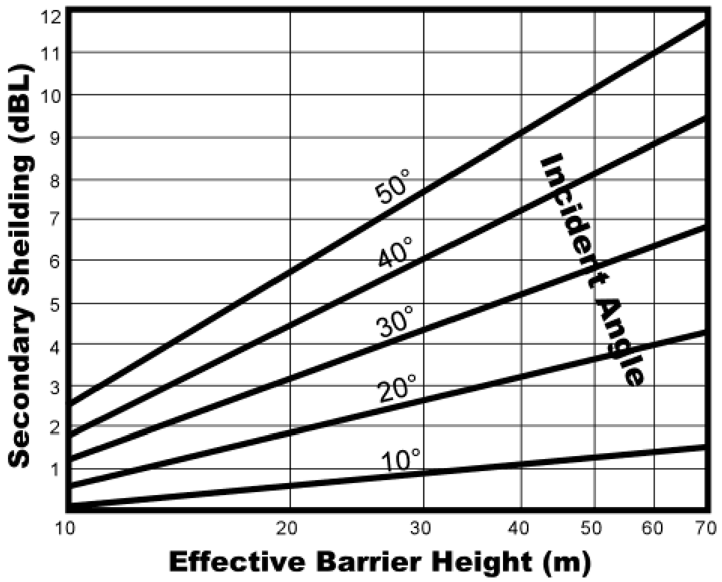


Figure A4.10 – Air vibration contours for current specification blasts, no shielding

It should be noted that the effects of shielding are only experienced beyond the perimeter of the quarry. Within the excavation, the air vibration levels are unaffected. The amount of shielding that will be experienced around the Raeburn quarry is considered to be negligible.

An air vibration assessment is made by moving the basic emission contours around the limit of extraction and, while observing blast orientation, record the maximum extent of each contour interval. This has been conducted for each stage and is shown in **Appendices 3a-b**.

A4.2.3 Effects of Meteorology on Airblast

Under 'normal' atmospheric conditions the airblast attenuates with distance and eventually reduces to levels that are below those of human perception. Under certain atmospheric conditions, the airblast levels at a distance from a blast may be increased by a mechanism known as 'meteorological reinforcement'. This is demonstrated in Figure **A4.11**.

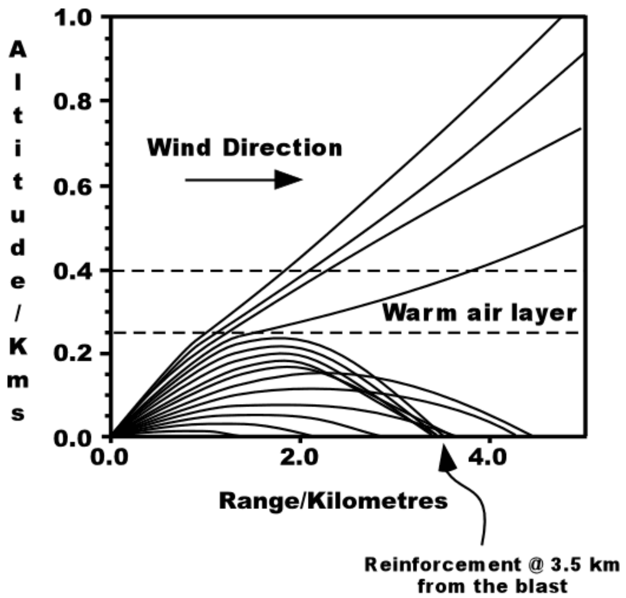


Figure A4.11 – Combined effect of wind and temperature inversion on sound rays causing surface reinforcement

When an 'inversion' or layer of warm air between cold air layers occurs above a blast site, or wind velocity increases with altitude, the conditions may concentrate or focus the air vibration in certain directions and distances from a blast.

An inversion layer 60-200 metres from a blast can cause an increase of up to 10 or more decibels from 2-5 dBL from the blast. Wind velocity itself has little effect on airblast levels, although the change of pressure across the microphone due to wind velocity may influence the recorded signal and a spurious reading may result. Specialist techniques are available to separate airblast and wind on a recorded signal.

The practical effect of meteorology is that, on some occasions, people 2-5 km from the quarry who are usually unaware of airblast due to normal attenuation, may experience airblast at perceptible levels. The possibility of airblast increase, due to meteorological conditions, can be reduced by firing mid-afternoon during late autumn/early winter, when any inversion is at its highest and delaying firing if Raeburn quarry is just below the cloud level.

APPENDIX 5 – GENERAL RECOMMENDED BLASTING PRACTICE

- Before drilling, the shotfirer or person responsible should examine the face and the area of blasting and lay out the drilling pattern, ie. burden and spacing, to indicate to the driller the position of the collar of the hole. The hole inclination and direction and depth of holes must also be given to the driller by some means. The driller should drill all holes as laid out.

- Before commencing to load the blastholes, the shotfirer or person responsible should:
  - Examine the face, blasting site and area within 200 metes of the blast location.
  - Measure the face, position and depth of all blastholes using applicable survey techniques. Make sure all holes have correct minimum burden and depth. Drill new holes or deepen shot holes if necessary.
  - Plan the blast loading in detail, estimate the explosive and detonator quantities to be brought to site.
  - Before bringing the explosives to the blasting site, check that all persons in the area are aware that blasting will take place and that warning signals and signs are in place as required.

- Applicable survey techniques are used to measure the following to the accuracy specified:
  - Face Height: (± 150 mm)
  - Blasthole angle from vertical: (± 1 degree if not vertical)
  - Toe and brow burden of blastholes: (± 150 mm)
  - Blasthole depth: (± 150 mm)
  - Blasthole spacing: (± 150 mm)

- When loading blastholes, all personnel should be careful and methodical. Monitor the position of the explosive charge rising in the hole with a tape or loading pole.

- Light-load any blast hole as necessary to achieve safe blasting, by such means as decking with stemming, using packaged explosives or artificially burdening under-burdened blastholes.

- Use sufficient stemming length of appropriate material. A general guideline is for stemming height to equal burden, but greater stemming heights may be necessary in some cases. Drill cuttings are generally not appropriate for containing explosives gases in the blasthole. Crushed aggregate approximately $1/10^{th}$ of the blasthole diameter (ie. – 10 mm aggregate) is the most suitable stemming material.

- Treatment of voids: if the shotfirer has been notified of a void by the driller or if the presence of a void is detected during loading, the shotfirer shall either:
  - Backfill the hole with stemming to rise above the void. Prime, load to explosives column height, stem and fire as normal.
  - Prime and load explosive column inside a lay-flat plastic tube liner to correct the column height, stem and fire.

  - Abandon the hole.

  - **DO NOT CONTINUE TO POUR EXPLOSIVES INTO A HOLE AFTER IT FAILS TO RISE IN THE HOLE.** Take action to seal the void before continuing to add more explosives. Reprime above stemming if necessary.

- When all holes are loaded, complete the surface firing circuit connections and connect the firing cable.

- Clear the area, give warning signals and fire the shot from a safe location when safe to do so.

- Inspect the blast site and sound the **'ALL CLEAR'**.