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BANORA POINT UPGRADE ALLIANCE

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INDEPENDENT REVIEW OF BLASTING PROPOSAL

Adrian J. Moore
16th December, 2010

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PRELIMINARY

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BANORA POINT UPGRADE

INDEPENDENT REVIEW OF BLASTING OPERATIONS

EXECUTIVE SUMMARY

The Banora Point Upgrade project requires the excavation of approximately 35,000 cub.m of rock which includes about 25,000 cub.m of extremely hard (200 MPa) basalt which requires blasting. The ground vibration from blasting operations during the Banora Point Upgrade project are currently limited by the Ministers Conditions of Approval (CoA), which are as follows:

Peak Particle Velocity (mm/s) — *$\leq$5 mm/s which may be exceeded for 5% of blasts in a 12 month period*

< 10 mm/s for all blasts

To conduct blasting operations to comply with these limits will require closely spaced drilling and small charge masses that will result in poor fragmentation from inefficient blasting.

It is proposed by the BPUA that the ground vibration limits of the CoA be modified to the following:

	Peak Particle Velocity (mms^{-1})	Allowable Exceedance
Criterion 1 *If no agreement with effected receiver*	10	Never. Similar to existing conditions
Criterion 2 *If a written agreement from the affected receiver is obtained.*	10	5% of the total blasts over a 12 month period. [1]

[1] Note: 95% of blasts below 10mm/s ensures 99% of blasts are below 12mm/s and 100% are below 15mm/s. This is indicated in the figure below.

Provision is made in Australian Standard AS2187.2 – 2006 that for construction projects, agreement may be reached with the occupiers of affected houses that a higher limit may apply.

The vibration limits imposed by the CoA are to '*minimise annoyance due to blasting over pressure and ground vibration*' and are therefore human response limits. The vibration levels at which the lowest level of damage (cosmetic damage) has been proven to occur is well above the modified limits proposed.

The vibration from a construction blast is 'felt' at nearby houses for 2-3 seconds for each blast.

Modifying the ground vibration limits, as requested, will result in expanded drill patterns, fewer drill holes, larger charge masses and fewer, more efficient blasts with better rock fragmentation.

The net benefit to the community in the reduction of annoying activities resulting from modified ground vibration limits can be quantified as follows:

- 24% reduction in drilling – 1.5 months with an airtrack;
- 28% reduction in the number of blasts – 25 blasts instead of 35 blasts;
- 50% reduction in rock breaking – 2.3 months of continuous rock breaking by hydraulic hammer;
- 28% reduction in the number of traffic stoppages.

The increased vibration from blasting will be felt for 2-3 seconds per blast, an exposure of 50-70 seconds for many months. The real offset is the considerable reduction in the audible noise from drilling and rock breaking; the impulsive nature of which many people find particularly annoying.

Civil Contractors for construction projects in Victoria have an immediate advantage over those in NSW because the vibration limits applied are from AS2187.2 – 2006. This virtually doubles the allowable levels to 10mm/s and provides a basis for the negotiation of higher vibration limits with affected owners and occupiers.

1. INTRODUCTION

Terrock Consulting Engineers were engaged by the Banora Point Upgrade Alliance (BPUA) to conduct a review of various documents and methodologies outlined in a request to modify the blasting limits specified in Ministers Conditions of Approval 2.14, Application No: 07_0059.

The scope of the review is summarised as follows:

- Brief assessment of BPUA proposal (submission document and Blast Management Plan)
- Review BPUA proposal and determine if the assessment of a NET benefit to the greater community is correct i.e. increased Quality of Life and Human Comfort
- Review BPUA proposal and Blast management plan and determine if the increased limits pose a risk to property damage.
- Review BPUA dilapidation, and community consultation / complaints / close out procedures for adequacy.
- Review BPUA proposal and comment on any improvements that can be made to better engage the community and respond to community issues throughout the process to reduce tail end issues and complaints
- Review BPUA proposal and determine if the approach is consistent with other high profile projects.

The documents reviewed are as follows:

1. BPUA Modification Request for Blasting Limits Rev. 2 26/11/2010 (with 3 Annexures);
2. BPU Community Consultation Report – Blasting Proposal 5mm/s-10mm/s Rev. 1 27/10/2010 (with 2 Appendices);
3. BPUA Blasting for the BPUA Review of Trial Blasting – Heilig & Partners, August 2010;
4. BPUA Blast Management Plan.

2. SCOPE ITEM 1 – ASSESSMENT OF BPUA PROPOSAL (SUBMISSION DOCUMENT AND BLAST MANAGEMENT PLAN)

2.1 BPUA SUBMISSION DOCUMENT

The blast vibration limits specified in the Ministers Conditions of Approval (CoA) listed in Cl. 2.13 and 2.14 Annexure A are summarised as follows in **Table 1**:

Table 1 – Blast Vibration Limits (CoA)

Peak Particle Velocity (mm/s)	Allowable Exceedance
5	5% of total number of blasts in a 12 month period
10	Never

Blasting is permitted during the following hours: 9.00am to 5.00pm Monday–Friday, 9.00am to 1.00pm Sunday

Blasting is not permitted on Sundays or public holidays.

The source reference for the specified limits is the Australian and New Zealand Environment Consultative Committee (ANZECC) "*Technical basis for guidelines to minimise annoyance due to blasting overpressure and ground vibration*".

It should also be noted that the vibration from construction blasting has a duration of only 2-3 seconds for each blast and is perceptible only for this time.

The specified limits are to "*minimise annoyance and discomfort*" and as such are based on human comfort criteria and not on structural integrity or the effects on houses and other infrastructure. Houses are damaged at much higher vibration levels than specified in the CoA.

The recommended criteria apply to mining, quarrying, construction which involve the use of explosives for fragmenting rock. The recommended criteria apply only to the minimisation of annoyance and discomfort arising from blasting.

In addition, Cl. 2.3.2 of the ANZECC guidelines states, "*Blasting should generally take place no more than once per day*".

Cl. 2.3.4 of the guidelines state, "*It is recognised that under some circumstances, or at certain mines blasting that cannot comply with the criteria.....will have to be carried out. Environmental authorities should apply controls for such blasting with appropriate consideration for the circumstances applying*".

The proposed modification to CoA 2.14 is outlined as follows: *"The proponent shall ensure that the ground vibration generated by blasting associated with the project does not exceed the criteria specified in Table 2 when measured at the most affected residence or other sensitive receiver"*.

Table 2 – Peak Particle Velocity Criteria (BPUA Modification Request)

	Peak Particle Velocity (mms^{-1})	*Allowable Exceedance*
Criterion 1 *If no agreement with effected receiver*	*10*	*Never. Similar to existing conditions*
Criterion 2 *If a written agreement from the affected receiver is obtained.*	*10*	*5% of the total blasts over a 12 month period.* [1]

[1] Note: 95% of blasts below 10mm/s ensures 99% of blasts are below 12mm/s and 100% are below 15mm/s. This is indicated in the figure below.

The effect of the increase of PPV from 5mm/s (95%) to 10mm/s (95%) can be shown graphically. The logarithmic distance/vibration relationship is shown in **Figure 1**.

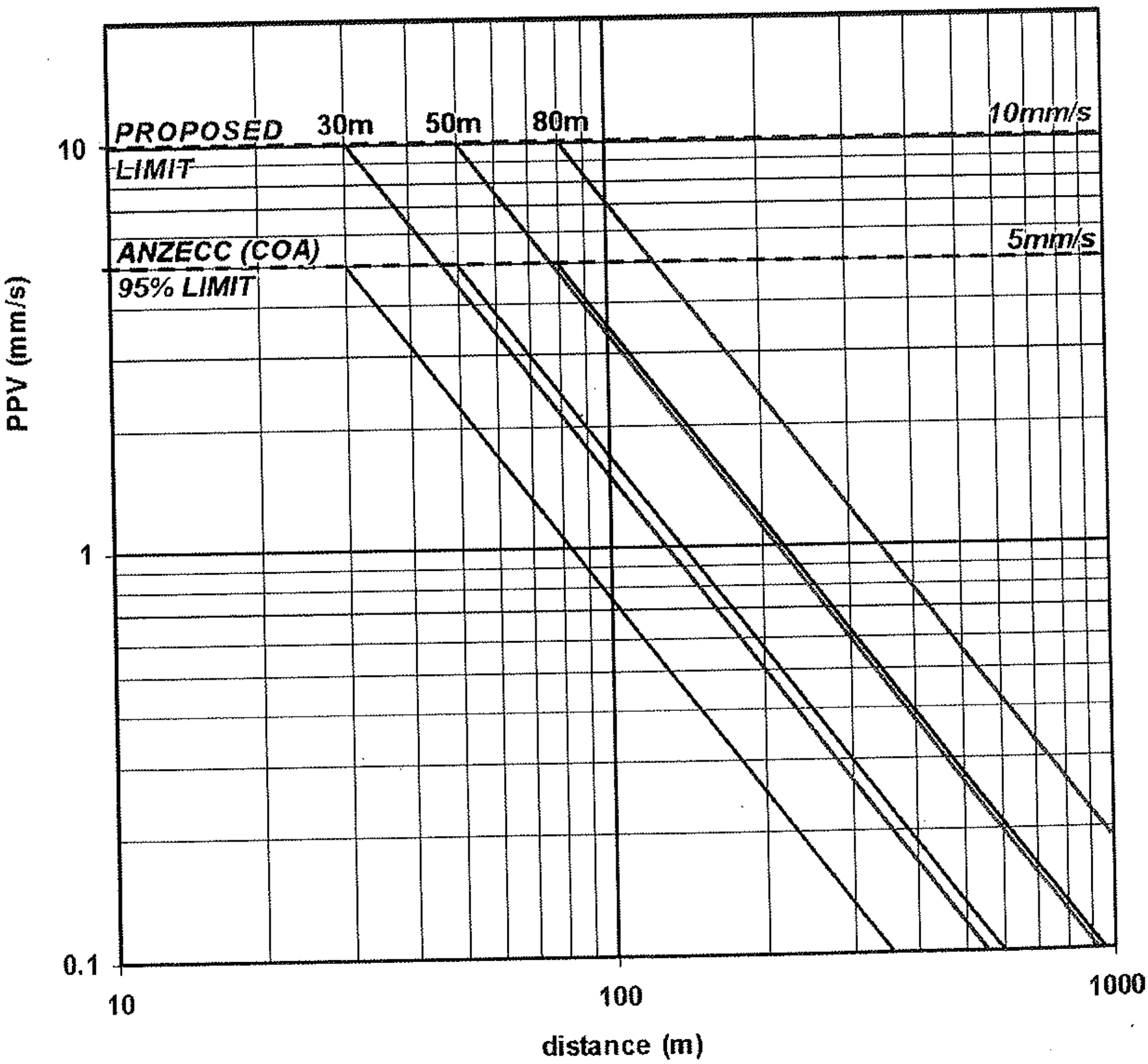


Figure 1 – Logarithmic distance/vibration relationship

If the CoA limit of 5mm/s at 50m is lifted to 10mm/s at 50m, the net affect is to extend the 5mm/s intercept to about 76m. If the 5mm/s limit at 30m is raised to 10mm/s, the 5 mm/s intercept extends to 45m.

The main content of the submission is that the vibration limits from blasting specified in the CoA should be lifted to what is still a human annoyance minimisation level and the justification is that there will be a Net Benefit gain to the community as 'improved quality of life' by:

- Reduced noise and vibration from fewer drilling hours;
- Less blasts;
- Less impulsive noise and vibration from fewer rock breaking hours resulting from more efficient blast fragmentation;
- Less traffic stoppages and disruption;
- Less complaints from known complaint sensitive activities;
- Faster project completion time;
- Marginal increase in the potential risk of cosmetic damage to houses.

The Net Benefit gain to achieve an improvement in the quality of life will be achieved by:

- Consultation and negotiation with the owners of the 14 most affected houses to seek an agreement that higher vibration limits will be acceptable to them;
- Higher vibration levels will permit expanded drill patterns which reduces the number of blasts;
- The more efficient blasting will result in improved fragmentation and less rock breaking;
- The trade-off is an increased blast vibration level lasting 2-3 seconds per blast against reduced impulsive noise and vibration from hydraulic or airtrack drills and rock breakers operating for up to10 hours per day for days at a time.

The concept of negotiations with occupiers that higher blast vibration levels may become acceptable is raised in AS2187.2 – 2006. The negotiated limits become the new project vibration limits at the houses concerned.

The concept of Net Benefit by reduced vibration dose values is a feature of both Environmental Noise Management and Vibration Assessment in the NSW Department of Environment and Climate Change publications, "*Interim Construction Noise Guidelines*" and "*Assessing Vibrations – a Technical Guideline*".

Also, if houses are evacuated at the time of a blast, either by agreement or as part of the blast evacuation, then it can be argued that human annoyance criteria is not appropriate and vibration limits to prevent damage to the houses should apply.

The authoritative references on the potential for damage to structures are the frequency dependant criteria of either British Standard BS7385-1:1900 or United States Bureau of Mines (USBM) Damage Criteria. Both are reproduced in AS2187.2 – 2006. Both are based on analysis of the same data, and give similar criteria. The USBM criteria may be mathematically purer in that the limit curve is based on either constant displacement or constant velocity lines. The *Transient Vibration Guide Values for Cosmetic Damage* (BS7385-2) is reproduced below in **Figure 2**. The PPV limits listed are peak component particle velocity [PCPV] (either of the two horizontal components or the vertical component) and not the Peak Vector Particle Velocity [PVPC]. If the PVPC is applied as a limit, there is an inbuilt element of conservatism, e.g. three equal components near 20mm/s would equate to a PVPC of 34.6mm/s.

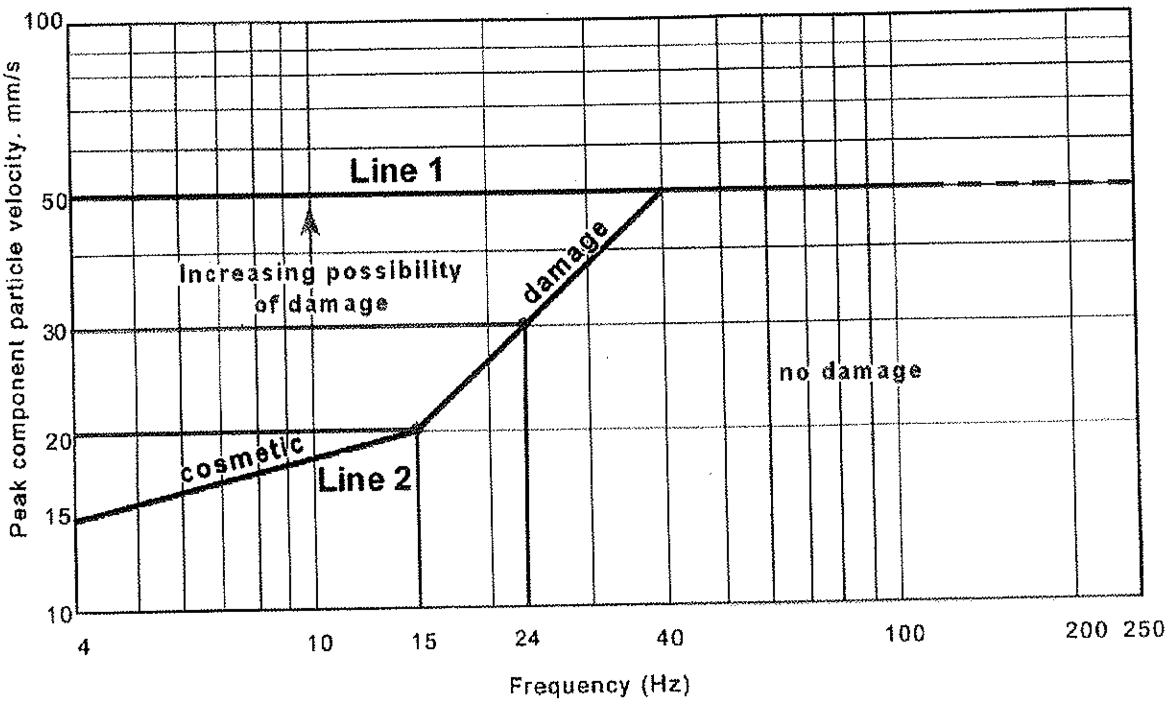


Figure 2 – Transient Guide Values for Cosmetic Damage (BS7385-2)

From damage observations, cosmetic damage to houses begins to occur when the PPV levels exceed Line 2. The Damage classification is shown in **Table 1.**

Table 3 - BS 7385 1:1990 – DAMAGE CLASSIFICATION

Classification	Description
Cosmetic	The formation of hairline cracks[2)] [21] on drywall surfaces, or the growth of existing cracks in plaster or drywall surfaces: in addition, the formation of hairline cracks in mortar joints of brick/concrete block construction.
Minor	The formation of large cracks or loosening and falling of plaster or drywall surfaces, or cracks through bricks/concrete blocks.
Major	Damage to structural elements of the building, cracks in support columns, loosening of joints, splaying of masonry cracks, etc.

The close order frequency component of the vibration from construction blasts is largely determined by the surface delays used in the initiation. For example, a 17ms x 42ms initiation sequence will result in frequencies of about 58hz ($\frac{1000}{17} = 58.8$) and 24hz ($\frac{1000}{42} = 23.8$) in the vibration (with slight adjustment for the Doppler effect because of the moving vibration source). The lower frequency component has the greater potential to damage houses. From **Figure 2**, the vibration levels at which cosmetic damage would be expected to begin to occur is about 30mm/s.

The BPUA modification request limit of 10mm/s is well below damage classification criteria limits.

2.2 BLAST MANAGEMENT PLAN

The Blast Management Plan prepared for the project are model documents and cover the requirements of Appendix A (AS2187.2-2006) at this stage of the Project. Specific details can be added as required as the project proceeds, including blast design for blasts at specific locations.

2.3 FLYROCK ASSESSMENT

A simple flyrock prediction model developed by Terrock for vertical blast holes with adequate stemming to prevent cratering is:

$$\text{Lmax} = \frac{k^2}{9.8}\left(\frac{\sqrt{m}}{S.H.}\right)^{2.6} \text{Sin } 160°$$

Where:
Lmax = Maximum Throw (m)
m = Charge Mass per metre or total charge if < 1m(kg)
$S.H.$ = Stemming Height (m)

For 5mm limit design, $m = 0.5$kg (from Section 3).

$$\text{Lmax} = 74.4\left(\frac{\sqrt{.5}}{2.5}\right)^{2.6} \text{Sin } 160° \quad =0.95\text{m}$$

For 10mm limit design, m=– 1.0kg (from Section 3).

$$\text{Lmax} = 74.1\left(\frac{\sqrt{1}}{2.5}\right)^{2.6} \text{Sin } 160° \quad =2.34\text{m}$$

The 15.0m minimum clearance radius shown in the Blast Clearance Plan of the BMP affords adequate factors of safety around the blast site. The 50m exclusion zone proposed around the blast site will provide adequate protection of the public.

3. SCOPE ITEM 2 - REVIEW BPUA PROPOSAL AND DETERMINE IF THE ASSESSMENT OF NET BENEFIT TO THE GREATER COMMUNITY IS CORRECT I.E. INCREASED QUALITY OF LIFE AND HUMAN COMFORT

The significant benefits to the community listed in the BPUA proposal are:

- 24% reduction in drilling = 1.5 months with an airtrack drill rig
- 20% less blasts – 35 blasts reduces to 25 blasts, a reduction of 10 blasts
- 50% reduction in rock breaking = 2.3 months of continuous excavators rock breaking
- 20% less traffic stoppages affecting approximately 10,700 commuters
- Less complaints generated from the above known complaint sensitive activities.

3.1 REDUCTION IN DRILLING

1st Approach – Simple Area Approach

A simple check on the reduction in drilling claimed in the BPUA Request is conducted as follows:

Total area of blasting	190m x 30m = 5700m^2	
5mm/s limit design	No. holes assuming 1m x 1.1m pattern	= 5700 holes
10mm/s limit design	No. holes assuming 1.1m x 1.2m pattern	= 4318 holes
Hole Reduction =	1382 holes	
% Hole Reduction =	1382 ÷ 5700 = 24%	

2nd Approach – Loading Considerations

The planned blasting area for the BPUA is shown in **Figure 4** together with the positions together with the positions of the adjoining houses. 35m and 50m radii are drawn from the five closest houses that will limit and control the blast design to achieve PPV limits.

If the 95% Site Law determined from the test blasts results (Heilig and Partners, August 2010) is adopted as being sufficiently accurate for estimation purposes, over the whole site, a number of estimates can be made.

Site Law $$PPV = 4420\left(\frac{d}{\sqrt{w}}\right)^{-1.6}$$

Where: PPV = Peak Particle Velocity (mm/s)
d = distance
w = charge mass per delay (kg)

The relationship between charge mass, distance and PPV is listed in **Table 4**.

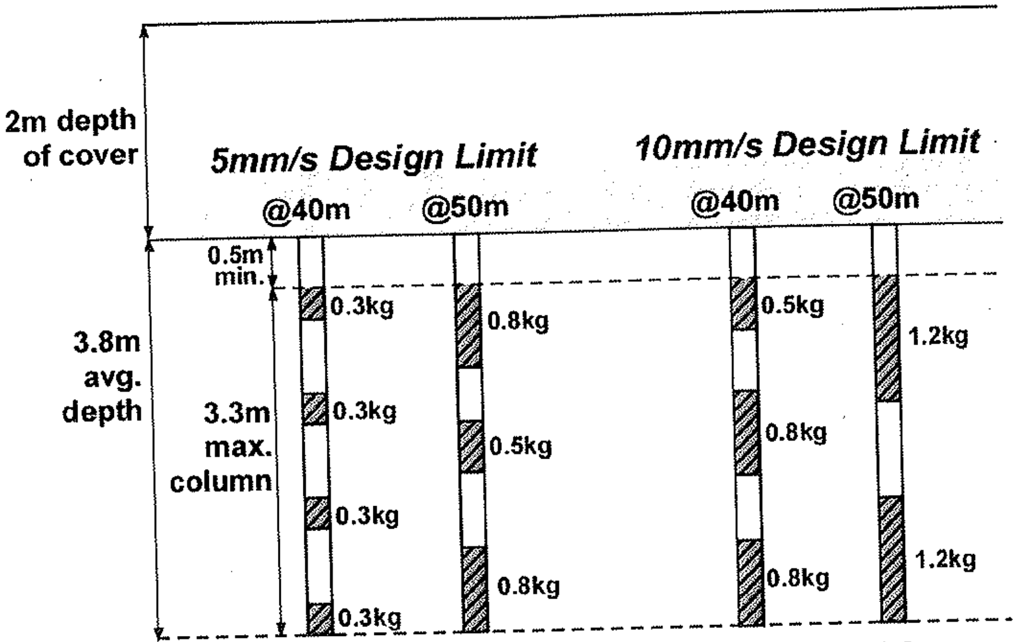
Table 4 –Relationship between Charge Mass, Distance and PPV

Distance (m)	PPV 5mm/s Limiting Charge (kg)	PPV 10mm/s Limiting Charge
35	0.25	0.60
40	0.33	0.80
45	0.42	1.00
50	0.50	1.20
55	0.63	1.50
60	0.75	1.80

To determine the number of holes required to blast the 5700m^2, a number of assumptions are made regarding loading as illustrated in **Figure 5** below.

Figure 4 shows the 30m and 50m radii drawn from the 5 houses that will determine the limiting blasting design. The blue coloured area is 50m plus, the purple area 30-50m and the green area less than 30m from the houses. The number of holes required to be drilled can be determined from the limiting blast design for each area to achieve 5mm/s and 10mm/s limits. If it assumed that the loading at 50m applies over the blue area, and a loading at 40m applies over the purple and green areas the drilling pattern to achieve a Powder Factor of 0.5 kg/m^3 and thereby the number of holes can be calculated, as shown in **Figure 5.**

Figure 4 – Location Plan



	5mm/s @40m	5mm/s @50m	10mm/s @40m	10mm/s @50m
Max. Charge per deck (kg):	0.3	0.5	0.8	1.2
No. decks:	4	3	3	2
Max. Charge/Hole (kg):	1.2	1.5	2.1	2.4
Assume Powder Factor:		$0.5kg/m^3$	Spacing = 1.1 x Burden	
Burden (m):	0.8	0.85	1.0	1.1
Spacing (m):	0.9	0.95	1.1	1.2
Area/Hole (m^2):	0.72	0.8	1.1	1.3
% Total Area:	45%	55%	45%	55%
Avg. Area/Hole:	$0.76m^2$		$1.21m^2$	

Figure 5 – Schematic Loading

Avg. depth	3.8m
Avg. area to be blasted	$5700m^2$
@ 5 mm/s, No. holes @ $0.8m^2$/hole	7125 holes
@ 10 mm/s, No. holes @ $1.2m^2$/hole	4750 holes
Hole reduction =	2375 holes
% hole reduction =	$\frac{2375}{7125} = 33\%$

The number of holes by this approach (4750) is within 10% of the number of holes calculated by the BPUA approach (4320) which is considered to be close enough for the type of calculations made.

Based on the assumptions made, the 33% reduction indicated in the approach outlined is much greater than the 24% reduction listed in the BPUA Request.

The difference between the figures is that the 1m x 1m pattern used in the BPUA calculations would only achieve a Powder Factor of 0.36kg/m^3. Whereas the closer spacing to achieve a 0.5kg/m^3 Powder Factor requires many extra holes to be drilled and an increase in the number of blasts. The lower Powder Factor is considered to be too low to efficiently fracture hard basalt which will require extended rock breaking hours. The trade-off is that with the 5mm/s design limit, either more drilling hours are required to improve fragmentation, or that more rock breaking is required.

It can be confidently stated that there will be at least a 24% reduction in drilling time.

To express this reduction in terms of drilling time requires an assumption to be made as to drilling performance. The assumption made in the BUAP request is that the 1380 (or so) holes would be drilled in 325 hours or about 4.2 holes per hour, which is a hole every 14 minutes including relocating and centring. The average hole depth is 5.8m, so the time allows drilling penetration at 1.5m/minute and 5.3 minutes for relocating and centring. This assumption seems reasonable.

3.2 REDUCTION IN BLAST NUMBERS

The BPUA request states that the number of blasts reduces from 35 to 25, i.e. 10 blasts.

Such a reduction is actually a $\frac{10}{35} = 28.5\%$ reduction (say 28%).

This calculation assumes that a blast consists of a certain number of holes. From the BPUA figures above, 5700 holes fired in 35 blasts would equate to 170 holes per blast. Assuming the same blast size, 4320 holes would require 25 blasts. These calculations are in agreement with the BPUA Request.

3.3 REDUCTION IN ROCK BREAKING HOURS

The BPUA request lists a 50% reduction in rock breaking hours, equivalent to 2.3 months of continuous rock breaking activity.

It is beyond question that loading more explosives into each blast hole, without decking results in more efficient blasting and improved fragmentation and heave. In my experience with granite, the charge mass to comply with vibration limits and drilling pattern based on Powder Factor design resulted in no rock breakage at all. The holes were blown out and reloaded with a large charge that did break the rock, but exceeded PPV limits with the house owners' permission.

The BPUA assumption that a 1m x 1m pattern would be required to achieve a 5mm/s target will result in a Powder Factor of 0.35 kg/m^3 which is not adequate for hard basalt and especially in this deep cover situation. Underloading hard basalt may give a similar result to the granite example above. The fragmentation will certainly be poorer and will require additional rock breaking. With a 5mm/s target limit the 2nd Approach calculations for the number of holes required highlights the problem. More efficient blasting will require more drilling and an increased number of blasts but rock breaking will still be required. Less efficient blasting will require much more rock breaking.

Whether the improvement in blasting performance by the expanded pattern and loading will result in a 50% reduction in rock breaking hours, or some other figure, I will leave to the judgement of the earthmoving experts. However, the reduction in hammering hours listed, i.e. 550 hours = 55 days = 2.3 months, seems reasonable.

3.4 LESS TRAFFIC STOPPAGES

The reduction in the number of blasts from 35 to 25, using BPUA's figures will result in a 28% reduction in the number of blasts. All other factors being equal, the 28% reduction will also apply to the number of traffic stoppages.

The reduction in the number of blasts and therefore traffic stoppages by 10 will reduce the effect on the 10,700 commuters affected by the project, assuming the reported on-site traffic counter numbers are correct.

3.5 LESS COMPLAINTS, MORE HUMAN COMFORT

If agreement can be reached with enough house occupiers that they will accept higher blast vibration limits than specified in the CoA, and that the CoA are modified to the PPV limits specified in **Table 2**, there is certainly scope for reducing the vibration and noise from other rock extraction activities that will result in a net reduction in the 'Exposure Dose' of the neighbours.

The concept of exposure dose is provided in both vibration and noise evaluation and assessment methods and in my opinion is a valid means of comparing the affect on residents of different construction proposals.

Australian Standard AS2187.2 – 2006 provides for agreements between people affected by air and ground vibration and those conducting blasting operations, to be negotiated and higher ground and airblast levels applied at their residences. The net benefit is reduced blasts and reduced exposure to drilling noise and rock breaking vibration and noise. The insurance against possible increased risk of damage should be an undertaking that any damage resulting during the project will be repaired appropriately.

A blast event results in perceptible vibration for a distance from a blast that lasts about 1-3 seconds in a construction blast situation. The blast holes are drilled by a hydraulic rock drill or airtrack drill that may have audible noise component while drilling but imperceptible vibration.

It is proposed that a higher PPV limit be approved for blasting. The limits proposed will not damage houses and will expedite completion of the earthworks in general and the project in particular.

Increasing the ground vibration limit from 5mm/s to 10mm/s will allow an increase in charge mass (MIC) per hole which will require less holes to be drilled, fewer blasts, less disruption and quicker project completion.

A further benefit is that less secondary breaking of oversize rocks and loosening of muckpiles by hydraulic rock breaker will be required. Many people find the impulsive audible 'noise' from rock breakers very annoying, especially if conducted over extended periods. The potential annoyance from rock breakers are:

- Perceptible ground vibration;
- Audible impact noise.

A regression analysis of the vibration from a typical rock breaker (impactor) from our files is shown in **Figure 6**. Perceptible vibration (0.2 - 0.5mm/s) may be 'felt' from 80-160m from the rock breaking site. However, the vibration is often not the main annoyance from rock breakers. The strongly audible impaction noise of a rock breaker over extended hours is more annoying to more people than either the vibration from rock breaking or from blast vibration itself.

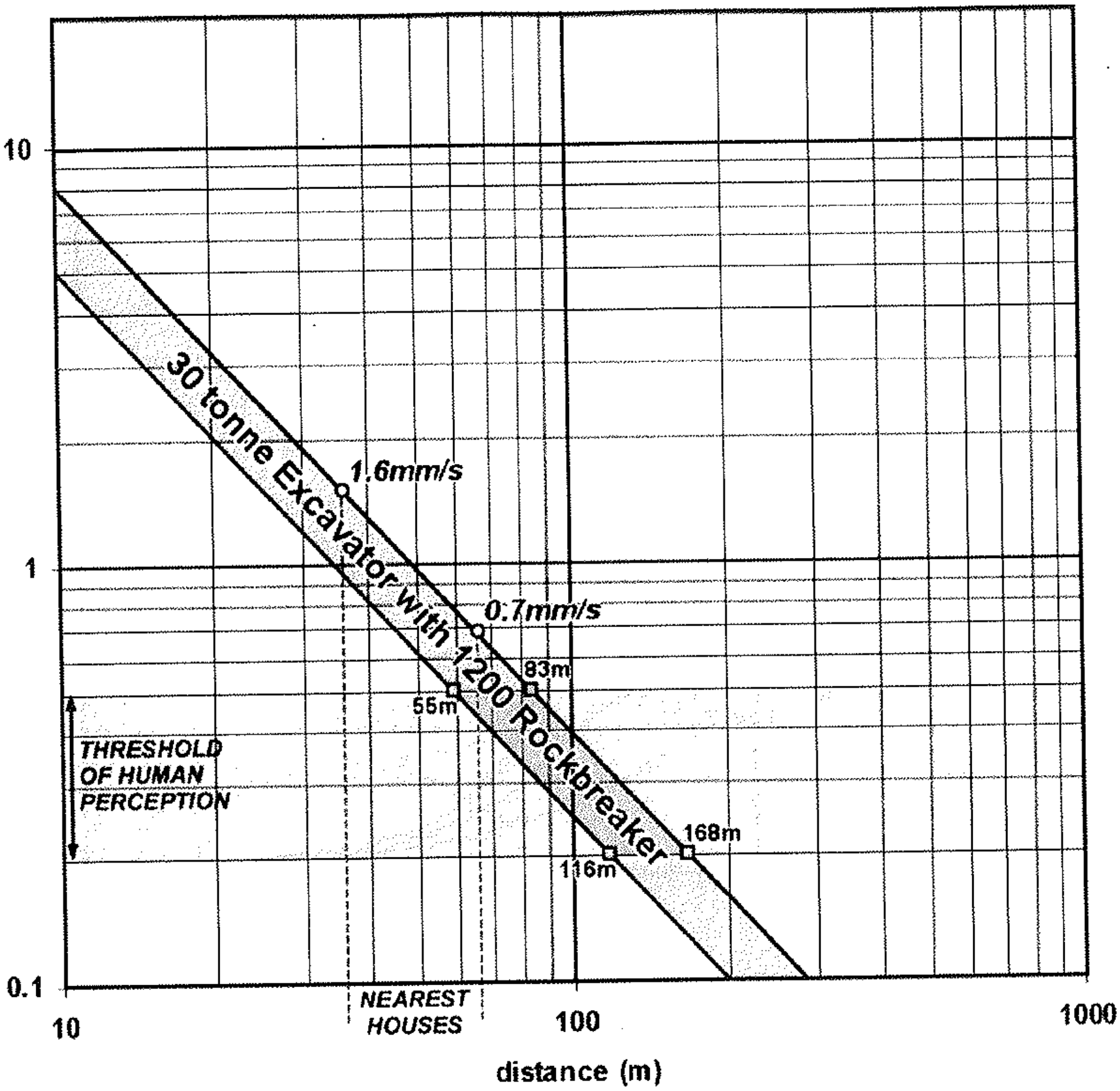


Figure 6 – Regression Analysis of Rockbreaker Vibration

There is certainly a trade-off between the higher blast vibration from twenty-five blasts lasting about 2-3 seconds each, compared to thirty-five blasts at a lower vibration level but resulting in many hours of almost continuous and very annoying noise and vibration from drilling and rock breaking. Quantifying the net gain is an approach that crosses over three disciplines of noise, vibration and blast vibration with their relevant regulatory framework. It is beyond my experience to quantify the reduction in noise and vibration exposure doses other than to say the net gain will be substantial.

4. SCOPE ITEM 3 - REVIEW THE BPUA PROPOSAL AND BLAST MANAGEMENT PLAN AND DETERMINE IF THE INCREASED LIMITS POSE A RISK TO PROPERTY DAMAGE

The structural damage criteria in common usage around the world is the frequency related criteria from either the USBM Alternative Damage Criteria or the Damage Criteria from BS 7385-2. The frequency of blast vibration is predicted to be about 24 hz, being driven by the 42ms echelon row delay sequence, e.g. $1000 \div 42 = 23.9$ hz. In **Figure 2**, the effect of the modification request is to lift the Peak CPV up to the horizontal axis of the graph. The increase to 10mm/s is well below Line 2, the level at which cosmetic damage begins to occur.

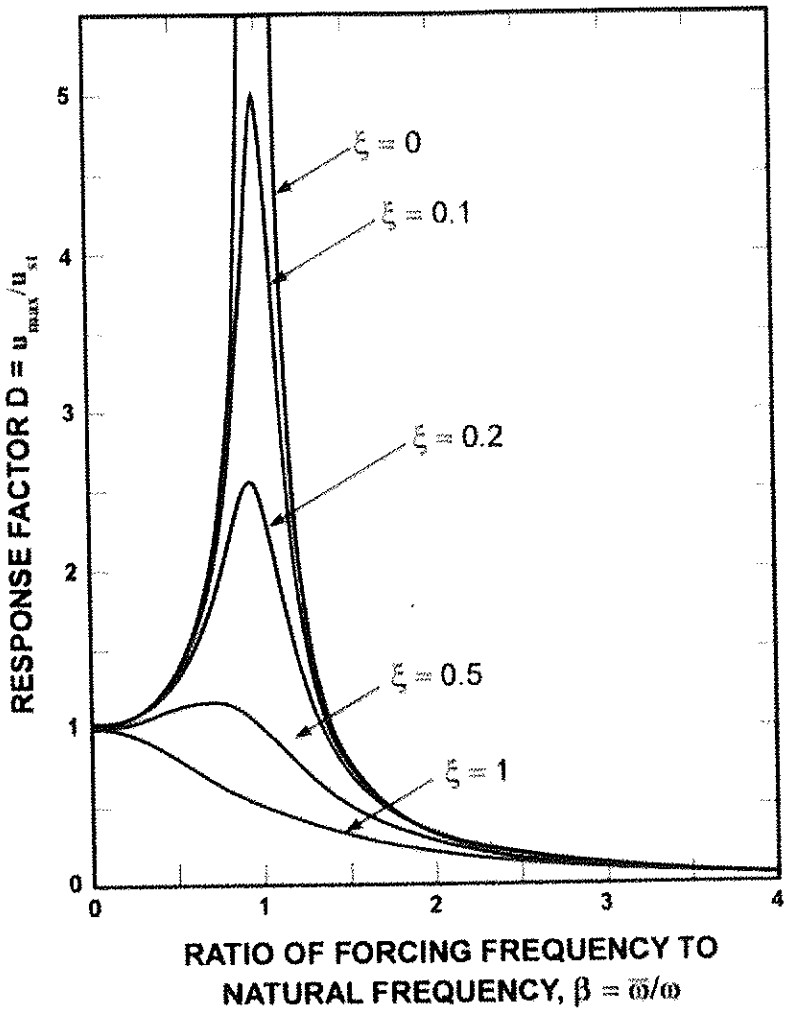


Figure 7 – Amplification Response, forcing frequency and natural frequency

The potential for increased risk of damage to houses can be quantified by the method developed in ACARP C9040 by which the global in plane shear strain in a wall can be predicted using Strain Based Frequency Criteria.

From a Single Degree of Freedom modelling approach, the relationship between vibration amplification by a house is a function of the natural frequency of the house, the damping ratio and the forcing frequency of the excitation vibration. This is shown schematically in **Figure 7**.

The extreme amplifications only occur in a very tight frequency band centred on the natural frequency of houses. The natural frequency of houses is between 6 and 10 hz. At frequencies away from the natural frequency, the maximum amplification reduces to less than 2.

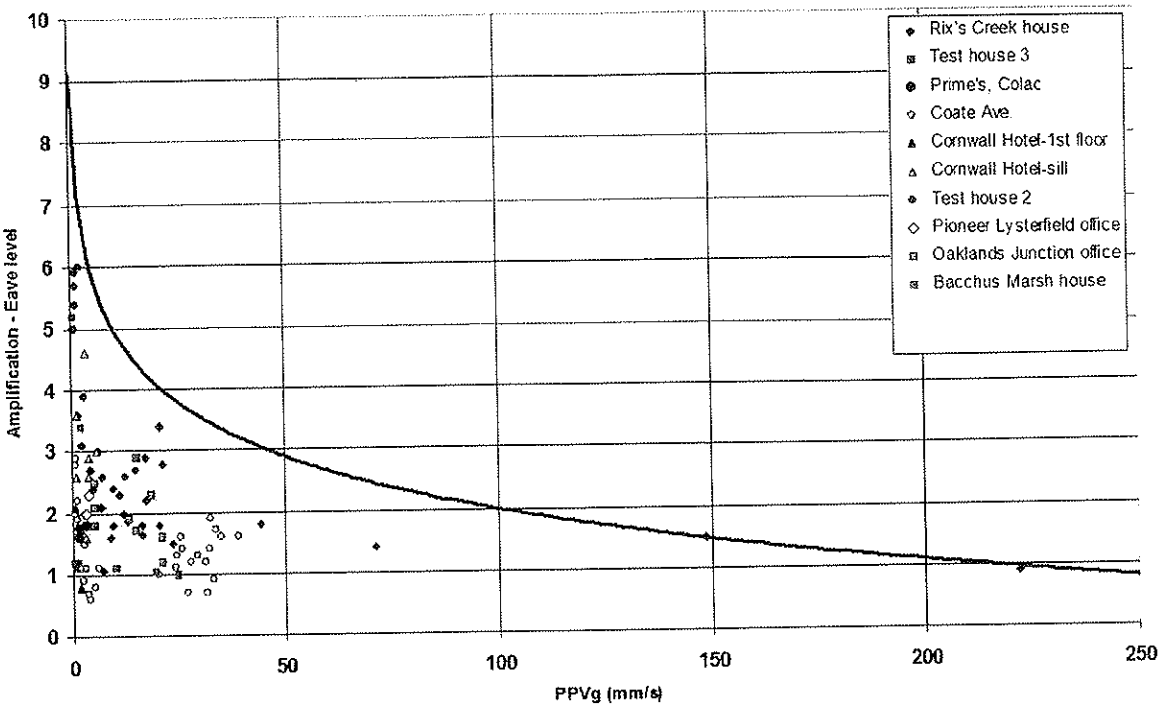


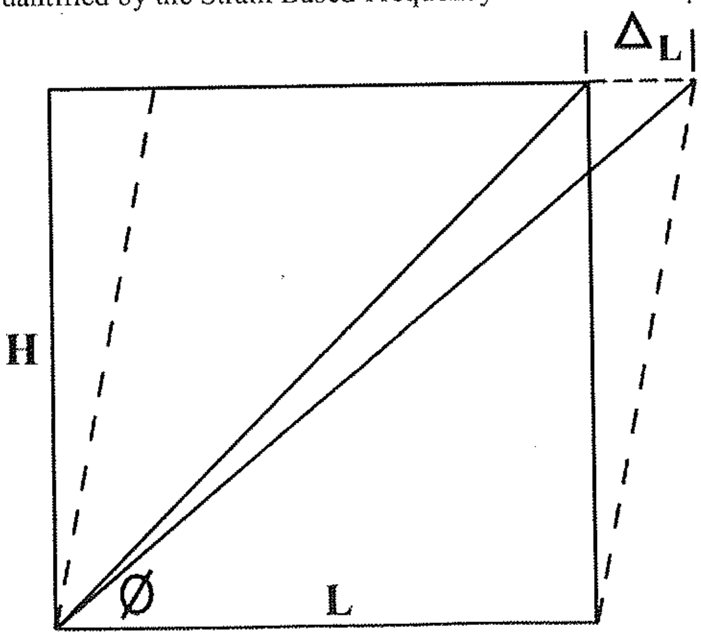
Figure 8 – PPV ground vs Amplification at House Eave Level

The data available at the time of the ACARP investigation required the amplification of the PPV at the eave level of the house to be interpreted as a stepped function compared to the ground PPV level. Further investigations have shown the maximum amplification at the eave level to be a curve of the form:

$Amplification = 8 - 3\log PPV$ as shown in **Figure 8.**

The maximum amplifications occur at the lowest PPVg levels.

The in plane shear developed in a wall due to the eave level displacement ΔL is developed as shown schematically in **Figure 9**. The potential for an increased risk of damage to houses can be quantified by the Strain Based Frequency Criteria developed in ACARP C9040.



Strain $(\varepsilon) = \frac{\Delta L}{H}$ SinØ CosØ

SinØ CosØ is a maximum of 0.5 when Ø = 45^0 or H = L

Figure 9 – Schematic deformation of a wall and global shear strain development

The displacement of ΔL can be determined by multiplying the displacement on the ground times an amplification factor. The displacement on the ground can be determined from the ground PPV, if the frequency is known, by Sine Wave Theory.

i.e. $$PPDe = \frac{PPVg}{2 \bullet \pi f} \bullet A$$

For a typical wall height of 2400mm, $\varepsilon = PPDe \bullet \frac{0.5}{2400}$

The worst case amplification is when the forcing frequency matches the natural frequency. Otherwise the amplification factor is 2.0.

The maximum amplification ranges for 5mm/s and 10mm/s are as follows:

A = 5 (10mm/s); 5.9 (5mm/s)
A = 2 - 5 for 10mm/s PPVg and 2 - 5.9 for 5mm/s

For 24hz;

@ 5mm/s $\varepsilon = 13.8$ to $47\ \mu$

@ 10mm/s $\varepsilon = 27.6$ to $69\ \mu$

These figures are considered to be conservative because walls are generally much longer than their height and SinØ CosØ is usually much less than 0.5.

Plasterboard and its detailing are the building elements most likely to be affected by blast vibration. The failure strain of plasterboard is about 1000μ. The percentage of the failure strain increases from a maximum 1.3 to 4% at 5mm/s to a maximum 2.6 to 7% at 10mm/s. The predictions made by this approach are reinforced by measured strains and the observed damage to the house monitored during the ACARP project. This house first showed signs of plaster-board damage when the PPVg levels exceeded 75mm/s which was due to poor workmanship. When the vibration levels reached 220mm/s. Masonry of the brick veneer house was unaffected by the maximum vibration.

The actual strains that resulted in cosmetic damage can be predicted from this approach:

PPVg = 75mm/s A = 2.37 PPVe = 178mm/s Assume 15hz frequency

@ 75mm/s Cosmetic Damage Strain $\varepsilon = \frac{178}{2 \bullet \pi \bullet 15} \bullet \frac{.5}{2400} = 393\ \mu$

@ 220mm/s PPVe = 220mm/s Cosmetic Damage Strain $\varepsilon = \frac{220}{2 \bullet \pi \bullet 15} \bullet \frac{.5}{2400} = 486\ \mu$

It may be reasonably concluded that there may be a marginal increase in the risk of damage to houses if the ground vibration limit is increased from 5mm/s (95%) to 10mm/s (95%). Any risk to the house owners is negotiated if an undertaking be given to repair any damage resulting from blasting operations.

5. SCOPE ITEM 4 - REVIEW THE BPUA DILAPIDATION REPORT AND COMMUNITY CONSULTATION/COMPLAINTS/CLOSE OUT PROCEDURES FOR ADEQUACY

The Community Consultation Report is well considered and the communication objectives are succinctly expressed. The importance of the requirements for response to complaints, particularly blast vibration and damage complaints cannot be stressed enough, i.e.

- Transparency
- Honesty
- Responsiveness
- Empathy
- Respect and trust.

From my experience, many concerns about vibration or damage can be satisfactorily dealt with by immediate action on people's concerns. As soon as concerns/complaints are expressed, a BPUA representative should visit the house, inspect the damage concerns and if necessary arrange for the damage to be inspected by the person who conducted the dilapidation survey or a person with the necessary structural background.

Measurement of vibration at the complainant's house for the next blast(s) should be offered and an opinion of the 'felt' response encouraged to involve the person in the blasting process. Having a BPUA representative staying inside a house and experiencing the vibration from a blast is often an effective means of developing empathy, respect and trust. Many complainants are seeking assurance that their house is not being damaged by vibration they can feel.

Dilapidation Surveys of houses near a construction site are a requirement but it must be understood that they do not provide complete indemnity and are not the complete answer. To observe and record every single hairline crack or cosmetic defect in a house is a time consuming, onerous job that could involve examination of cracks through a magnifying glass, artificial lighting, access to ceiling cavities, cupboards and crawl spaces. In most cases such a thorough examination is not warranted as most people are reasonable and accept that houses develop cracks over time through a number of different agencies. The obvious failure of the dilapidation survey system is that if a hairline crack was not recorded before the project started, because it was overlooked, and was observed by the owner/occupier after the project commenced, then the immediate conclusion is that it must have been caused by construction activity. This is where the education process is important to inform people that vibration is only one of a number of crack-forming mechanisms.

A house does not exist in a vacuum subjected only to the vibration from construction activities. The natural forces that cause cracks to develop and extend, such as rainfall, footing movement, humidity and temperature change, also act on a house during the project period. It is essential to keep good weather records as these can often be related to crack development.

In my opinion, the Community Consultation, complaints handling and close out procedure adopted for this project are adequate.

6. SCOPE ITEM 5 – REVIEW THE BPUA PROPOSAL AND COMMENT ON ANY IMPROVEMENTS THAT CAN BE MADE TO BETTER ENGAGE THE COMMUNITY AND RESPOND TO THE COMMUNITY ISSUES THROUGHOUT THE PROCESS TO REDUCE TAIL END ISSUES AND COMPLAINTS (PROACTIVE STRATEGY)

The Community Consultation Reports shows that the BPUA has engaged the community in a responsible manner which is in accordance with the communication objectives. In the early stages, the objectives are to consult, educate and engage the community about the planned blasting operations to as many affected people as possible. Ongoing engagement with the community will continue to be by direct consultation with community groups. A complaint/concern system has been developed by BPUA as a database to record the date, time, address and contact details, the nature of the comments and also the team response.

In my opinion, there is a need for a fact sheet and/or information brochure on the vibration from construction blasting and other activities to reinforce the contents of the blasting presentation. Topics explained should include:

- Why does blasting occur?
- What is vibration?
- How is it measured?
- What are the regulatory limits for human response and structural damage?
- Conduct of blasting operations as a controlled process;
- Comparison of the effects of blast vibration with natural events;
- Why cracks develop;
- Complaint procedures/contacts etc.

The brochure can be taken away and kept as a reminder of the contents of the blasting presentations and provide a ready reference for complaint/concern procedures and contacts etc.

7. SCOPE ITEM 6 - REVIEW THE BPUA PROPOSAL AND DETERMINE IF THE APPROACH IS CONSISTENT WITH OTHER HIGH PROFILE PROJECTS (ARE THERE ANY BENCHMARKS)?

The blast vibration limits based on the ANZECC guidelines appear to be routinely applied in NSW to construction projects by Ministers Conditions of Approval and through DECCW Environmental Protection Licences. In Victoria, the ANZECC guideline limits are applied by the Mines and Quarry Inspectorate of the Department of Primary Industries to new mines and quarries or extensions to mines and quarries in sensitive locations. Construction blasting is regulated by Worksafe through the Dangerous Goods (Explosives) Regulations 2000, which enforce vibration limits of AS2187.2. At the time the Regulations were enacted, the vibration limits from AS2187.2 - 1993 were 10mm/s for ground vibration and 120dBL for airblast. The more recent 2006 Standard retains the 10mm/s limit for operations lasting less than 12 months or less than 20 blasts but increases the airblast limit to 120 dBL for 95% of blasts with a maximum of 125 dBL for the same blasts. It also provides for higher ground vibration and airblast limits to apply with the consent of the occupier.

Contractors involved in projects in Victoria are already at an advantage over those in NSW because the vibration limits are virtually double. The application of higher blast vibration limits permitted by AS 21872.2 – 2006 to short term construction projects in Victoria is a compromise that is acceptable to most adjacent neighbours. The higher levels do not eliminate vibration or damage complaints, but have not resulted in damage that can be attributed directly or indirectly to blast vibration.

I am not aware of formal relaxation of regulatory vibration limits for high profile projects, but have been involved with several instances where there has been an informal relaxation by agreement between house owners and construction contractors, usually to reduce the period of disruption. The examples include:

- **Western Ring Road, Sunshine**. A long standing home owner who had experienced the vibration from nearby 1970's quarry blasting considered that 10-20 mm/s exposure to Ring Road project blasting was acceptable compared to what he and his house had endured in the past.
- **Alphington Drainage Tunnel**. The owner of a 80 year old 2 storey weatherboard house agreed to a 50 mm/s limit from a 'pot and drive' tunnel about 6m below the foundations of a brick chimney. A glass plate was placed across the gap between the chimney and the house frame as a witness that no damage would result. This agreement changed what had become a jack pick operation to one where an effective quantity of explosive could be used (½ to 1 plug/hole).
- **Sewerage Trench, Harcourt**. The trench material of granite was hard and tough with widely spaced joints. An impactor had burned off a $1500 pick in a day and had broken about 0.5 cub.m of rock. A blast designed to stay below 10mm/s at a distance of 10m did not break the rock. The owner agreed to a 50mm/s limit so the trench could be dug. The trench was fired in three blasts in preference to an impactor ineffectively hammering beneath his window for hours and days at a time.
- Vibration limits in an adjoining building from a foundation trench were relaxed when it was demonstrated that striking the shared wall with a sledgehammer produced more vibration that the small charges used in the trench.

Generally, the blast vibration limits applied in Australia are low by Standards and Codes that operate throughout the world, the ANZECC guidelines particularly so. The ANZECC guidelines evolved from an investigation by the Tasmanian Department of the Environment about 30 years ago, into complaints resulting from airblast from an urban quarry that was using uncovered detonating cord and secondary blasting several times per week. The highly audible high frequency high pressure airblast was particularly annoying to people beyond 1km from the blasting. An airblast measurement of 132dBL at 1250m was recorded during the investigation. The Department of Environment recommendations following this investigation led to the development of the ANZEC guidelines, which in turn became the ANZECC guidelines.

In my opinion, the ANZECC guidelines are an appropriate control criteria for mines and quarries operating long term and compliance with them is usually not a great issue. However, the automatic application of the guidelines to short term construction projects such as Banora Point seems to counter the aim of the guidelines which is to 'minimise annoyance' and other limits may be more appropriate.

8. CONCLUSIONS

Following this review of the BPUA Modification Request for Blasting Limits and other documents provided, it is concluded that:

1. Relaxation of the blast vibration limits specified in the Ministers Conditions of Approval for the Banora Point Upgrade Project to those listed in the Modification Request will
    - Result in a reduction in drilling of at least 24%; equivalent to 1.5 months of drilling with an airtrack drilling;
    - Result in a 28% reduction in the number of blasts;
    - A considerable reduction in the number of rock breaking hours because of better fragmentation from more efficient blasting (perhaps as high as 50%);
    - The reduced number of blasts will result in a 28% drop in the number of traffic stoppages.

2. There will be a slight but quantifiable increase in the risk of potential cosmetic damage to houses from increasing the ground vibration level from 5mm/s (95%) to 10mm/s (95%).

3. The increased ground vibration from the total of 25 blasts will be experienced for about 2 – 3 seconds for each blast, an exposure of 50 – 75 seconds over many months. The offset is a reduction in audible noise and perceptible vibration from drilling and rock breaking. The 1.5 months of drilling time saved is about 360 hours and 550 less hours of rock breaking. The Net Gain in the reduction of community noise and vibration is obvious.

4. The reduction in the number of rock breaking hours is significant. The highly audible impulsive nature of the rock breaking noise is annoying to many people, especially if conducted continuously for long periods of time. More complaints will be received about the 'noise' than from the vibration.

5. A hydraulic drill rig will produce less audible noise than airtrack. Consideration should be given to using a hydraulic drill as the Site develops and the surface becomes more even.

6. The community consultation process etc. appears to be progressing well and I cannot contribute much in suggesting improvements.

7. Blasting projects in Victoria have an immediate advantage over those in NSW because in Victoria, the vibration limits from AS 2187.2-2006 apply. This virtually doubles the allowable vibration levels and also provides a basis for the negotiation of higher vibration limits with affected owners and occupiers. In NSW, it appears that the automatic application of the ANZECC guidelines as a blasting condition, without regard to other construction activities, places contractors and the community at a disadvantage.

Adrian J. Moore.

Adrian J. Moore
16th December, 2010

REFERENCES

ACARP C9040, 'Structure Response to Blast Vibration'

ANZECC, "Technical Basis for Guidelines to Minimize Annoyance Due to Blasting Over Pressure and Ground Vibration"

AS 2187.2 – 2006, 'Explosives – Storage Transport and Use – Part 2: Use of Explosives'

BPUA Blasting for the BPUA Review of Trial Blasting – Heilig and Partners, August 2010

BPUA Blast Management Plan

BPUA Modification Request for Blasting Limits Rev. 2, 26/11/2010 (with 3 Annexures)

BPU Community Consultation Report – Blasting Proposal 5mm/s – 10mm/s Rev. 1, 27/10/2010 (with 2 Appendices)

BS7385-2 1993, 'Evaluation and Measurement for Vibration in Buildings'

Dangerous Goods (Explosives) Regulations 2000 (Vic.)