AGENDA ITEM 6

APPENDIX 7

2018/0151/DET

BLASTING AND VIBRATION ASSESSMENT

Chapter 9.0
Blasting and Vibration Assessment

Assessment of Environmental Impact of Blasting at Dalwhinnie Quarry, Highland

JOHNSON POOLE AND BLOOMER

R18.9894/2/AF
Date of Report: 13 March 2018

QUALITY MANAGEMENT

Report Title:	Assessment of Environmental Impact of Blasting at Dalwhinnie Quarry, Highland
Client:	Johnson Poole and Bloomer
Report Number:	R18.9894/2/AF
Issue Date:	13 March 2018

Prepared By:	**Checked By:**
[redacted]	[redacted]
A Findlay **Consultant**	**J Henderson** **Consultant**

Vibrock Limited
Shanakiel
Ilkeston Road, Heanor
Derbyshire, DE75 7DR
Tel: +44 (0) 1773 711211
Fax: +44 (0) 1773 711311
Email: vibrock@vibrock.com
Web: www.vibrock.com

CONTENTS

TABLES

FIGURE

1.0 INTRODUCTION

1.1 The author of this report is Allan Findlay, a consultant for over 20 years with Vibrock Limited and who has completed numerous similar assessments for surface mineral workings. He became a corporate member of the Institution of Civil Engineers in June 1988. Following successful completion of the Safety and Legislation and Quarry Operations modules of the Institute of Quarrying professional examination in May 1985 he became a full member of the Institute of Quarrying in June 1992. In June 1997 he successfully completed the Institute of Acoustics Diploma in Acoustics and Noise Control course and following a further period of working in the acoustics industry became a member of the Institute of Acoustics in June 1999. Other training he has undertaken that is relevant to the preparation of this report are qualifications in Shotfiring Operations and Blast Design.

1.2 It is proposed by Leiths Scotland Limited that Dalwhinnie Quarry is re-opened to produce aggregates for the local building and construction industries.

1.3 The planning application for the re-opening of Dalwhinnie Quarry is being prepared on behalf of Leiths by Johnson Poole and Bloomer (JPB).

1.4 Drilling and blasting of the mineral deposit will be the first stage of the rock extraction process once competent material is encountered. Accordingly it has been considered prudent to undertake an assessment regarding the implications of these proposals with respect to blast induced vibration.

1.5 Vibrock Limited, a national, independent firm of environmental consultants, has been engaged by JPB to undertake this study.

1.6 Even the most well designed and executed of blasts must generate a certain amount of energy in the form of both ground vibration and airborne vibration.

1.7 As such, it is not unusual for the operators of such sites to be required to comply with a condition that limits ground vibration at the nearest sensitive locations. Airborne vibration limits are not usual for reasons detailed within this report.

1.8 The assessment of the implications of blasting operations within Dalwhinnie Quarry considered: -

1. The potential effect of blast induced vibration upon the occupants of residential property and other sensitive structures.

2. Production of allowable instantaneous explosive charge weights for given separation distances.

3. Recommendations for any mitigation / minimisation measures that should be adopted.

1.9 Vibration predictions within this report have been based upon a knowledge of the blast designs proposed for the quarry and data from monitoring production blast at quarries where similar rock strata is worked.

2.0 SITE DESCRIPTION

2.1 The proposed Dalwhinnie Quarry is located some 1.2km north of the village of Dalwhinnie. At a closer separation distance is the Dalwhinnie distillery and associated dwellings and buildings.

2.2 The Perth to Inverness rail line runs just to the north of the village and distillery, passing under the A889 to the north east of the distillery. The recently constructed Beauly to Denny overhead pylon line runs to the east of the quarry.

2.3 The proposal is to develop a quarry to the north and east of its current position. Most of the working will see a single bench formed down to a floor level of 385m above Ordnance datum (AOD). An upper bench will be formed as required at a level of 397m AOD.

2.4 The larger explosive charges will therefore be used on the 12m high face, where the anticipated charge would be some 120kg.

2.5 However, the optimum blast design may vary from blast to blast and will necessarily be decided by the quarry operator with reference to the site specific conditions and in order to comply with the recommended vibration criteria.

3.0 EFFECTS OF BLASTING

3.1 When an explosive detonates within a borehole stress waves are generated causing very localised distortion and cracking. Outside of this immediate vicinity, however, permanent deformation does not occur. Instead, the rapidly decaying stress waves cause the ground to exhibit elastic properties whereby the rock particles are returned to their original position following the passage of the stress waves. Such vibration is always generated even by the most well designed and executed of blasts and will radiate away from the blast site attenuating as distance increases.

3.2 With experience and knowledge of the factors which influence ground vibration, such as blast type and design, site geology and receiving structure, the magnitude and significance of these waves can be accurately predicted at any location.

3.3 Vibration is also generated within the atmosphere where the term air overpressure is used to encompass both its audible and sub-audible frequency components. Again, experience and knowledge of blast type and design enables prediction of levels and an assessment of their significance. In this instance, predictions can be made less certain by the fact that air overpressure levels may be significantly influenced by atmospheric conditions. Hence the most effective method of control is its minimisation at source.

3.4 It is important to realise that for any given blast it is very much in the operator's interest to always reduce vibration, both ground and airborne to the minimum possible in that this substantially increases the efficiency and hence economy of blasting operations.

4.0 BLAST VIBRATION TERMINOLOGY

4.1 Ground Vibration

4.1.1 Vibration can be generated within the ground by a dynamic source of sufficient energy. It will be composed of various wave types of differing characteristics and significance collectively known as seismic waves.

4.1.2 These seismic waves will spread radially from the vibration source decaying rapidly as distance increases.

4.1.3 There are four interrelated parameters that may be used in order to define ground vibration magnitude at any location. These are:-

Displacement - the distance that a particle moves before returning to its original position, measured in millimetres (mm).

Velocity - the rate at which particle displacement changes, measured in millimetres per second (mms^{-1}).

Acceleration - the rate at which the particle velocity changes, measured in millimetres per second squared (mms^{-2}) or in terms of the acceleration due to the earth's gravity (g).

Frequency - the number of oscillations per second that a particle undergoes measured in Hertz (Hz).

4.1.4 Much investigation has been undertaken, both practical and theoretical, into the damage potential of blast induced ground vibration. Among the most eminent of such research authorities are the United States Bureau of Mines (USBM), Langefors and Kihlström, and Edwards and Northwood. All have concluded that the vibration parameter best suited as a damage index is particle velocity.

4.1.5 Studies by the USBM have clearly shown the importance of adopting a monitoring approach that also includes frequency.

4.1.6 Thus the parameters most commonly used in assessing the significance of an impulsive vibration are those of particle velocity and frequency which are related for sinusoidal motion as follows:-

$$PV = 2 \pi f a$$

where PV = particle velocity
π = pi
f = frequency
a = amplitude

4.1.7 It is the maximum value of particle velocity in a vibration event, termed the peak particle velocity, that is of most significance and this will usually be measured in three independent, mutually perpendicular directions at any one location in order to ensure that the true peak value is captured. These directions are longitudinal (or radial), vertical and transverse.

4.1.8 Such maximum of any one plane measurements is the accepted standard worldwide and as recommended by the British Standards Institution and the International Standards Institute amongst others. It is also the basis for all the recognised investigations into satisfactory vibration levels with respect to damage of structures and human perception.

4.1.9 British Standard 7385 states that there is little probability of fatigue damage occurring in residential building structures due to blasting. The increase of the component stress levels due to imposed vibration is relatively nominal and the number of cycles applied at a repeated high level of vibration is relatively low. Non-structural components (such as plaster) should incur dynamic stresses which are typically well below, i.e. only 5% of, component yield and ultimate strengths.

4.1.10 All research and previous work undertaken has indicated that any vibration induced damage will occur immediately if the damage threshold has been exceeded and that there is no evidence of long term effects.

4.2 Airborne Vibration

4.2.1 Whenever an explosive is detonated transient airborne pressure waves are generated.

4.2.2 As these waves pass a given position, the pressure of the air rises very rapidly to a value above the atmospheric or ambient pressure. It then falls more slowly to a value below atmospheric before returning to the ambient value after a series of oscillations. The maximum pressure above atmospheric is known as the peak air overpressure.

4.2.3 These pressure waves will comprise of energy over a wide frequency range. Energy above 20 Hz is perceptible to the human ear as sound, whilst that below 20 Hz is inaudible, however, it can be sensed in the form of concussion. The sound and concussion together is known as air overpressure which is measured in terms of decibels (dB) or pounds per square inch (p.s.i.) over the required frequency range.

4.2.4 The decibel scale expresses the logarithm of the ratio of a level (greater or less) relative to a given base value. In acoustics, this reference value is taken as 20×10^{-6} Pascals, which is accepted as the threshold of human hearing.

4.2.5 Air overpressure (AOP) is therefore defined as:-

$$\text{AOP, dB} = 20 \text{ Log } \frac{\text{(Measured pressure)}}{\text{(Reference pressure)}}$$

4.2.6 Since both high and low frequencies are of importance no frequency weighting network is applied, unlike in the case of noise measurement when an A - weighted filter is employed.

4.2.7 All frequency components, both audible and inaudible, can cause a structure to vibrate in a way which can be confused with the effects of ground vibrations.

4.2.8 The lower, inaudible, frequencies are much less attenuated by distance, buildings and natural barriers. Consequently, air overpressure effects at these frequencies can be significant over greater distances, and more readily excite a response within structures.

4.2.9 Should there be perceptible effects they are commonly due to the air overpressure inducing vibrations of a higher, audible frequency within a property and it is these secondary rattles of windows or crockery that can give rise to comment.

4.2.10 In a blast, airborne pressure waves are produced from five main sources:-

(i) Rock displacement from the face.
(ii) Ground induced airborne vibration.
(iii) Release of gases through natural fissures.
(iv) Release of gases through stemming.
(v) Insufficiently confined explosive charges.

4.2.11 Meteorological factors over which an operator has no control can influence the intensity of air overpressure levels at any given location. Thus, wind speed and direction, temperature and humidity at various altitudes can have an effect upon air overpressure.

5.0 VIBRATION CRITERIA

5.1 Introduction

5.1.1 When defining damage to residential type structures the following classifications are used:-

Cosmetic or threshold	-	the formation of hairline cracks or the growth of existing cracks in plaster, drywall surfaces or mortar joints.
Minor	-	the formation of large cracks or loosening and falling of plaster on drywall surfaces, or cracks through bricks/concrete blocks.
Major or structural	-	damage to structural elements of a building.

5.1.2 Published damage criteria will not necessarily differentiate between these damage types but rather give levels to preclude cosmetic damage and therefore automatically prevent any more severe damage.

5.2 United States Bureau of Mines

5.2.1 The comprehensive research programme undertaken by the United States Bureau of Mines (USBM) (R.I. 8507, 1980) determined that vibration values well in excess of 50 mms^{-1} are necessary to produce structural damage to residential type structures. The onset of cosmetic damage can be associated with lower vibration levels, especially at very low vibration frequencies, and a limit of 12.7 mms^{-1} is therefore recommended for such relatively unusual vibration. For the type of vibration associated with open pit blasting in this country, the safe vibration levels are seen to be from 19 - 50 mms^{-1}.

5.2.2 A further USBM publication (Bureau of Mines Technology Transfer Seminar, 1987) states that these safe vibration levels are "....for the worst case of structure conditions....", and that they are "....independent of the number of blasting events and their durations", and that no damage has occurred in any of the published data at vibration levels less than 12.7 mms^{-1}.

5.2.3 Any doubt that such low levels of vibration are perfectly safe should be dispelled by considering the strain induced within a residential type property from daily environmental changes and domestic activities. This is confirmed within the 1987 USBM publication which quotes that daily changes in humidity and temperature can readily induce strain of the order that is equivalent to blast induced vibration of from 30 - 75 mms^{-1}. Typical domestic activities will produce strain levels corresponding to vibration of up to 20 mms^{-1} and greater.

5.2.4 It is for this reason that many domestic properties will exhibit cracks that may be wrongly attributed to blasting activities. There are many additional reasons why properties will develop cracks, for example:-

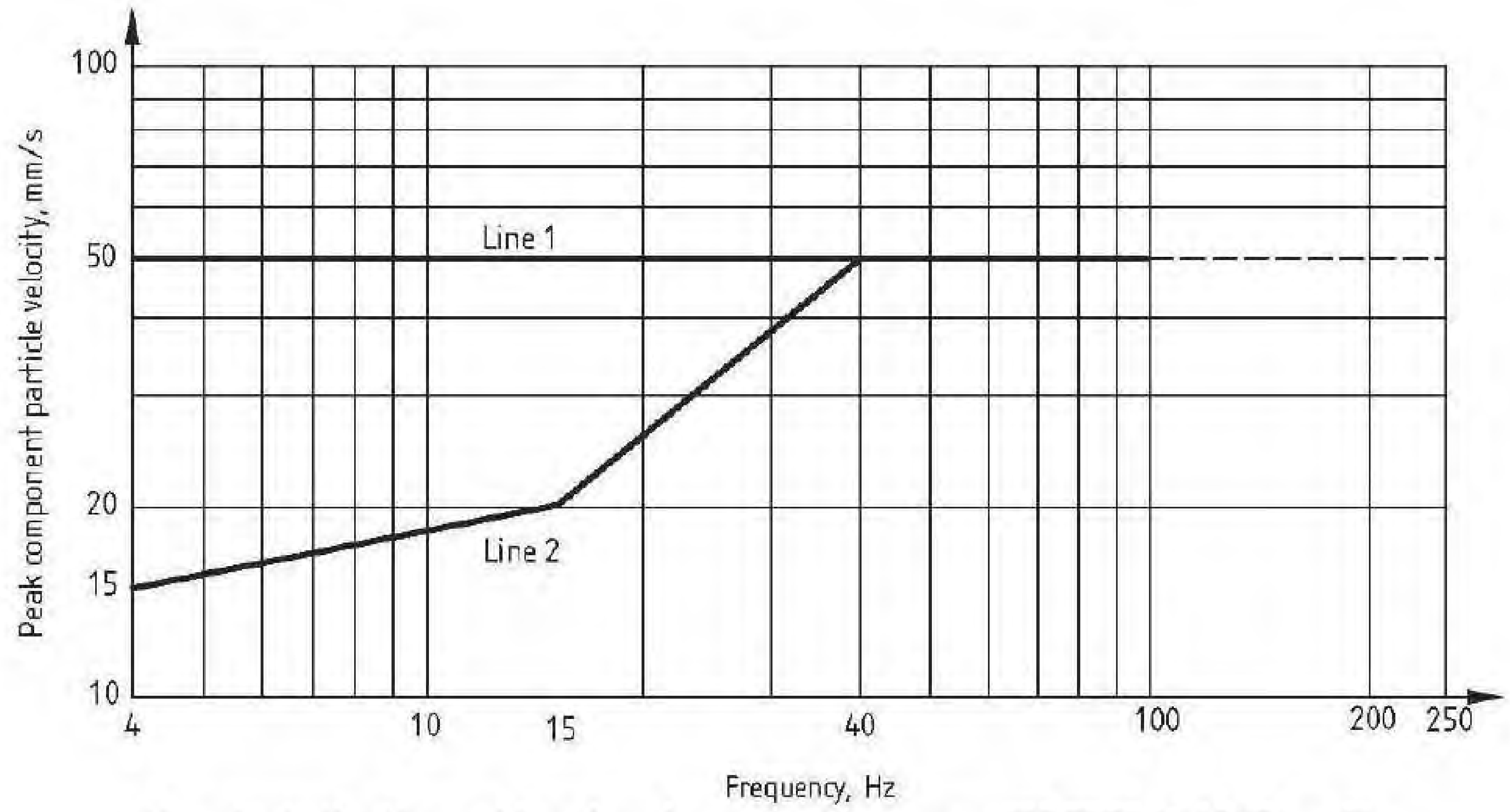
a) Fatigue and ageing of wall coverings;
b) Drying out of plaster finishes;
c) Shrinkage and swelling of wood;
d) Chemical changes in mortar, bricks, plaster and stucco;
e) Structural overloading;
f) Differential foundation settlement - particularly after times of prolonged dry spells.

5.3 British Standard 7385-2: 1993 - Evaluation and Measurement for Vibration in Buildings: Guide to Damage Levels from Groundborne Vibration

5.3.1 The British Standards Institution's structural damage committee have investigated impulsive vibration with respect to its damage potential. They contacted some 224 organisations, mainly British, and found no evidence of any damage at levels less than those recommended by the USBM. The investigation culminated in British Standard 7385: Part 2: 1993.

5.3.2 British Standard 7385 gives guide values to prevent cosmetic damage to property. Between 4 Hz and 15 Hz, a guide value of 15 - 20 mms^{-1} is recommended, whilst above 40 Hz the guide value is 50 mms^{-1}. These vibration criteria reconfirm those of the USBM:

<table>
<tr><th rowspan="2">Line</th><th rowspan="2">Type of Building</th><th colspan="2">Peak component particle velocity in frequency range of predominant pulse</th></tr>
<tr><th>4 Hz to 15 Hz</th><th>15 Hz and above</th></tr>
<tr><td rowspan="2">1</td><td>Reinforced or framed structures</td><td rowspan="2">50 mms^{-1} at 4 Hz and above</td><td rowspan="2">50 mms^{-1} at 4 Hz and above</td></tr>
<tr><td>Industrial and heavy commercial buildings</td></tr>
<tr><td rowspan="2">2</td><td>Unreinforced or light framed structures</td><td rowspan="2">15 mms^{-1} at 4 Hz increasing to 20 mms^{-1} at 15 Hz</td><td rowspan="2">20 mms^{-1} at 15 Hz increasing to 50 mms^{-1} at 40 Hz and above</td></tr>
<tr><td>Residential or light commercial buildings</td></tr>
<tr><td colspan="4">Note 1 – values referred to are at the base of the building
Note 2 – for line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) is not to be exceeded</td></tr>
</table>



Transient vibration guide values for cosmetic damage (BS 7385-2: 1993, pg 6)

5.3.3 All research and previous work undertaken has indicated that any vibration induced damage will occur immediately if the damage threshold has been exceeded and that there is no evidence of long term effects.

5.3.4 Whilst cosmetic damage levels range from 15 to 50 mms^{-1}, according to BS 7385: Part 2, "Minor damage is possible at vibration magnitudes which are greater than twice those given for cosmetic damage, and major damage to a building structure may occur at values greater than four times the tabulated values". Hence vibration levels necessary for structural damage within property are accepted to be around 200 mms^{-1} and above.

5.4 BS 5228-2: 2009, Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration

5.4.1 Damage threshold criteria for transient vibration within British Standard 5228-2: 2009 is guided by the tabulated levels contained within BS 7385-2: 1993.

5.4.2 Guidance values are provided for frequencies of 4 Hz and above. Below a frequency of 4 Hz where a high displacement is coupled with a low particle velocity a maximum displacement of 0.6 mm (zero to peak) should be used. Although extremely rare, the allowable peak particle velocity at a frequency of 2 Hz relates to 7.5 mms^{-1}.

5.5 The Environmental Effects of Production Blasting from Surface Mineral Workings, DETR (Vibrock Limited)

5.5.1 The object of this report was to provide guidance to the Department of the Environment, local authorities and the minerals industry on how best to minimise the adverse effects which may arise during production blasting from surface mineral workings whilst still maintaining viable and economic production.

5.5.2 In relation to allowable vibration levels the report recommended ground vibration limits of 6 to 10 mms^{-1} in 95% of all blasts over a specified period, with none greater than 12 mms^{-1}.

5.5.3 This same DETR publication also notes that "It would appear that over the years conditions have become progressively more stringent. No doubt this is as a result of MPAs seeking to reduce the number of complaints and by operators seeking to resolve issues more quickly. However, a reduction in complaints will not necessarily follow".

5.5.4 Indeed, one of the principal findings of the study which led to this publication is "Once the threshold of perception had been crossed the magnitude of vibration seemed to bear little relation to the level of resulting complaint".

5.5.5 An explanation of the necessity to use explosives and the likely effects as perceived by a site's neighbours can allay the concern of a significant proportion of those inhabitants of neighbouring property. It is invariably the case that an operator will consider the perception threshold level prior to the design of each and every blast at a particular site.

5.6 Planning Advice Note 50, Annex D

5.6.1 Planning Advice Note (PAN) 50 Annex D entitled "The Control of Blasting at Surface Mineral Workings" issued by the Scottish Executive Development Department in February 2000, is based on the DETR commissioned research by Vibrock Limited. This document provides the most recent guidance on the subject of surface mineral blasting for developments in Scotland.

5.6.2 In terms of ground vibration, PAN 50 Annex D confirms that limits for peak particle velocity in the range 6 – 10 mms^{-1} in 95% of all blasts measured over any reference period, with no individual blast exceeding a higher peak particle velocity, 12 mms^{-1} being suggested as a limit, will provide suitable and adequate control of operations.

5.7 Air Overpressure

5.7.1 Comprehensive investigations into the nature and effects of air overpressure with particular reference to its damage potential have been undertaken by the United States Bureau of Mines (R.I. 8485, 1980).

5.7.2 The weakest parts of most structures that are exposed to air overpressure are windows. Poorly mounted, and hence pre-stressed windows might crack at around 150 dB (0.1 p.s.i.) with most cracking at 170 dB (1.0 p.s.i.). Structural damage can be expected at 180 dB (3.0 p.s.i.).

5.7.3 The recommendations by the United States Bureau of Mines are as follows:-

Instrument Response	Maximum Recommended Level (dB)
0.1 Hz high pass	134
2.0 Hz high pass	133
5.0 or 6.0 Hz high pass	129
C- Slow	105 dB (C)

5.7.4 This set of criteria is based on minimal probability of the most superficial type of damage in residential-type structures, the single best descriptor being recommended as the 2 Hz high pass system (R.I. 8485, 1980).

5.7.5 Satisfactory air overpressure levels are contained within BS 6472-2: 2008, which states the previously discussed research by USBM. According to BS 6472-2: 2008, "air overpressure levels measured at properties near quarries in the United Kingdom are generally around 120 dB(lin), which is 30 dB(lin) below, or only 3% of, the limit for cracking pre-stressed poorly mounted windows".

5.7.6 Current guidance contained within PAN 50 Annex D does not recommend an air overpressure limit, rather the operator should submit methods to minimise air overpressure to the Planning Authority.

5.7.7 With a sensible ground vibration limitation the economics of safe and efficient blasting will automatically ensure that air overpressures are kept to reasonable levels.

5.8 Perception Levels

5.8.1 The fact that the human body is very sensitive to vibration can result in subjective concern being expressed at energy levels well below the threshold of damage.

5.8.2 A person will generally become aware of blast induced vibration at levels of around 1.5 mms^{-1}, although under some circumstances this can be as low as 0.5 mms^{-1}. Even though such vibration is routinely generated within any property and is also entirely safe, when it is induced by blasting activities it is not unusual for such a level to give rise to subjective concern. Such concern is also frequently the result of the recent discovery of cracked plaster or brickwork that in fact has either been present for some time or has occurred due to natural processes.

5.8.3 It is our experience that virtually all complaints regarding blasting arise because of the concern over the possibility of damage to owner-occupied properties. Such complaints are largely independent of the vibration level. In fact, once an individual's perception threshold is attained, complaints can result from 3% to 4% of the total number of blasts, irrespective of their magnitude.

5.9 British Standard 6472–2: 2008 - Guide to evaluation of human exposure to vibration in buildings: Part 2: Blast-induced vibration

5.9.1 This document discusses how and where to measure blast-induced vibration and gives maximum satisfactory magnitudes of vibration with respect to human response. Satisfactory magnitudes are given as 6 to 10 mms^{-1} at a 90% confidence level as measured outside of a building on a well-founded hard surface as close to the building as possible.

5.9.2 Maximum satisfactory magnitudes of vibration with respect to human response for up to three blast vibration events per day are detailed within Table 1 of BS 6472-2: 2008:

Place	Time	Satisfactory magnitude A) (ppv mms^{-1})
Residential	Day D)	6.0 to 10.0 C)
	Night D)	2.0
	Other times D)	4.5
Offices B)	Any time	14.0
Workshops B)	Any time	14.0

A) The satisfactory magnitudes are the same for the working day and the rest day unless otherwise stated;
B) Critical working areas where delicate tasks impose more stringent criteria than human comfort are outside the scope of this standard;
C) With residential properties people exhibit a wide variation of tolerance to vibration. Specific values are dependent upon social and cultural factors, psychological attitudes and the expected degree of intrusion. In practice the lower satisfactory magnitude should be used with the higher magnitude being justified on a case-by-case basis;
D) For the purpose of blasting, daytime is considered to be 08h00 to 18h00 Monday to Friday and 08h00 to 13h00 Saturday. Routine blasting would not normally be considered on Sundays or Public Holidays. Other times cover the period outside of the working day but exclude night-time, which is defined as 23h00 to 07h00.

6.0 PREDICTION AND CONTROL OF VIBRATION LEVELS

6.1 Ground Vibration

6.1.1 The accepted method of predicting peak particle velocity for any given situation is to use a scaling approach utilising separation distances and instantaneous charge weights. This method allows the derivation of the site specific relationship between ground vibration level and separation distance from a blast.

6.1.2 A scaled distance value for any location may be calculated as follows:-

Scaled Distance, SD = $DW^{-½}$ in $mkg^{-½}$

where

D = Separation distance (blast to receiver) in metres
W = Maximum Instantaneous Charge (MIC) in kg
i.e. maximum weight of explosive per delay interval in kg

6.1.3 For each measurement location the maximum peak particle velocity from either the longitudinal, vertical or transverse axis is plotted against its respective scaled distance value on logarithmic graph paper.

6.1.4 An empirical relationship derived by the USBM relates ground vibration level to scaled distance as follows:-

$$PV = a\,(SD)^{b}$$

where

PV = Maximum Peak Particle Velocity in mms^{-1}
SD = Scaled Distance in $mkg^{-½}$
a,b = Dimensionless Site Factors

6.1.5 The site factors a and b allow for the influence of local geology upon vibration attenuation as well as geometrical spreading. The values of a and b are derived for a specific site from least squares regression analysis of the logarithmic plot of peak particle velocity against scaled distance which results in the mathematical best fit straight line where

a is the peak particle velocity intercept at unity scaled distance
and b is the slope of the regression line

6.1.6 In almost all cases, a certain amount of data scatter will be evident, and as such statistical confidence levels are also calculated and plotted.

6.1.7 The statistical method adopted in assessing the vibration data is that used by Lucole and Dowding. The data is presented in the form of a graph showing the attenuation of ground vibration with scaled distance and results from log - normal modelling of the velocity distribution at any given scaled distance. The best fit or mean (50%) line as well as the upper 95% confidence level are plotted.

6.1.8 The process for calculating the best fit line is the least squares analysis method. The upper 95% confidence level is found by multiplying the mean line value by 1.645 times 10 raised to the power of the standard deviation of the data above the mean line. A log - normal distribution of vibration data will mean that the peak particle velocity at any scaled distance tends to group at lower values.

6.1.9 From the logarithmic plot of peak particle velocity against scaled distance, for any required vibration level it is possible to relate the maximum instantaneous charge and separation distance as follows:-

Maximum Instantaneous Charge (MIC) = $(D/SD)^2$

Where D	=	Separation distance (blast to receiver) in metres
SD	=	Scaled Distance in $mkg^{-½}$ corresponding to the vibration level required

6.1.10 The scaled distance approach assumes that blast design remains similar between those shots used to determine the scaling relationship between vibration level and separation distance and those for which prediction is required. For prediction purposes, the scaling relationship will be most accurate when calculations are derived from similar charge weight and distance values.

6.1.11 The main factors in blast design that can affect the scaling relationship are the maximum instantaneous charge weight, blast ratio, free face reflection, delay interval, initiation direction and blast geometry associated with burden, spacing, stemming and subdrill.

6.1.12 Although the instantaneous explosive charge weight has perhaps the greatest effect upon vibration level, it cannot be considered alone, and is connected to most aspects of blast design through the parameter blast ratio.

6.1.13 The blast ratio is a measure of the amount of work expected per unit of explosive, measured for example in tonnes of rock per kilogramme of explosive detonated (tonnes/kg), and results from virtually all aspects of a blast design i.e. hole diameter, depth, burden, spacing, loading density and initiation technique.

6.1.14 The scaled distance approach is also strictly valid only for the specific geology in the direction monitored. This is evident when considering the main mechanisms which contribute to ground motion dissipation:-

(i) Damping of ground vibrations, causing lower ground vibration frequencies with increasing distance.
(ii) Discontinuities causing reflection, refraction and diffraction.
(iii) Internal friction causing frequency dependent attenuation, which is greater for coarser grained rocks.
(iv) Geometrical spreading.

6.1.15 In practice similar rates of vibration attenuation may occur in different directions, however, where necessary these factors should be routinely checked by monitoring, especially on sites where geology is known to alter.

6.1.16 Where it is predicted that the received levels of vibration will exceed the relevant criteria the operator will have to reduce the maximum instantaneous explosive charge weight. One method of achieving such a reduction is to deck the explosives within the borehole. This technique splits the column of explosives in two, separated by inert material. If blasting is required at closer distances than that where double decking would be a successful strategy, other charge reduction methods would have to be employed. These could be more complex decking strategies or changes to the blast geometry and / or the use of smaller diameter boreholes.

6.2 Airborne Vibration

6.2.1 Airborne vibration waves can be considered as sound waves of a higher intensity and will, therefore, be transmitted through the atmosphere in a similar manner. Thus meteorological conditions such as wind speed, wind direction, temperature, humidity and cloud cover and how these vary with altitude, can affect the level of the air overpressure value experienced at a distance from any blast.

6.2.2 If a blast is fired in a motionless atmosphere in which the temperature remains constant with altitude then the air overpressure intensity will decrease purely as a function of distance. In fact, each time the distance doubles the air overpressure level will decrease by 6dB. However, such conditions are very rare and it is more likely that a combination of the factors mentioned above will increase the expected intensity in some areas and decrease it in others.

6.2.3 Given sufficient meteorological data it is possible to predict these increases or decreases. However, to be of use this data must be both site specific and of relevance to the proposed blasting time. In practice this is not possible because the data is obtained from meteorological stations at some distance from the blast site and necessarily at some time before the blast is to be detonated. The ever changing British weather therefore causes such data to be rather limited in value and its use clearly counter productive if it is not relevant to the blast site at the detonation time. In addition, it would not normally be safe practice to leave charged holes standing for an unknown period of time.

6.2.4 It is because of the variability of British weather that it is standard good practice to control air overpressure at source and hence minimise its magnitude at distance, even under relatively unfavourable conditions.

6.2.5 Such a procedure is recommended by the UK Government in their publications on this subject, Mineral Planning Guidance (MPG) 9 of 1992 and MPG 14 of 1995, where it is suggested that no air overpressure limit be defined but rather that methods to be employed to minimise air overpressure are submitted for approval. This approach is also recommended within the previously mentioned 1998 DETR publication and PAN 50 Annex D.

6.2.6 Such control is achieved in a well designed and executed blast in which all explosive material is adequately confined. Thus particular attention must be given to accurate face profiling and the subsequent drilling and correct placement of explosive within any borehole, having due regard to any localised weaknesses in the strata including overbreak from a previous shot, clay joints and fissured ground.

6.2.7 Stemming material should be of sufficient quantity and quality to adequately confine the explosives, and care should be taken in deciding upon the optimum detonation technique for the specific site circumstances.

6.2.8 Although there will always be a significant variation in observed air overpressure levels at a particular site it is possible to predict a range of likely values given sufficient background information and/or experience. In this respect, past recordings may be analysed according to the cube root scaled distance approach to provide a useful indication of future levels.

7.0 VIBRATION DATA

7.1 Blast vibration data monitored at quarries working similar strata to that at Dalwhinnie Quarry have been accessed from the Vibrock database.

7.2 The data has been used together with the USBM formula to predict vibration levels. This calls for the maximum peak particle velocity (PPV) to be plotted against scaled distance (SD) in a logarithmic manner. The latter is defined as: -

$$\text{Scaled Distance } (\text{mkg}^{-½}) = \frac{\text{blast/receiver separation distance (m)}}{(\text{MIC})^{0.5}}$$

where MIC is the maximum instantaneous charge weight in kg.

8.0 DISCUSSION

8.1 Introduction

8.1.1 Table 1 gives the allowable instantaneous charge weights in order to comply with a vibration criterion of 6 mms^{-1} at a 95% confidence level. This is the vibration criterion recommended for residential property situated in the vicinity of the quarry. It is at the lower end of the range identified in PAN 50 Annex D.

8.1.2 Referring to Table 1, this indicates that a blast design utilising a 120kg explosive charge, the maximum anticipated, can be undertaken up to a separation distance of approximately 390 m from any vibration sensitive residential premises whilst complying with the recommended criterion.

8.1.3 Table 2 details the predicted vibration levels at the closest sensitive receptors from blasting in the quarry. To give an indication of how the received vibration effects will change with time predictions have been undertaken at the closest approach and also assuming a blast in the centre of the quarry; at grid reference 263800E / 786400N. In Table 2 the levels shown as the "mean" relate to the value the regression analysis evaluates as being the most likely vibration effect whilst the "maximum" is the predicted upper 95% confidence level.

8.1.4 The predicted maximum vibration levels given will only occur when using a 120kg instantaneous explosive charge at the nearest possible distance of approach to the respective locations.

8.1.5 As such, the vast majority of blasting events will result in vibration effects below the levels given.

8.2 Allt an t'Sluic Lodge

8.2.1 This receptor is located some 1km west of the quarry, access being gained from the A889. There are several outbuildings at the property.

8.2.2 Given the separation distance, as shown on Table 2, the predicted vibration levels from blasting at closest approach when using a 120 kg explosive charge are in the range 0.4 to 0.9 mms^{-1}. We consider that these levels would be imperceptible and are clearly below the recommended vibration criterion; 6 mms^{-1} at a 95% confidence level.

8.3 Distillery House

8.3.1 This receptor, as the name suggests, is located close to Dalwhinnie distillery and is one of several dwellings positioned close to the commercial operation. It is south of the quarry, the minimum separation distance to blasting being 700 metres.

8.3.2 Considering the use of the anticipated maximum charge of 120kg at this closest approach distance then the range of received vibration levels is 0.7 to 1.6 mms^{-1}. These effects may just be perceptible on very limited occasions. As blasting takes place further away then the vibration levels received are likely to be imperceptible. However, in all cases the levels are significantly below the recommended criterion that is at the lower end of the range given as guidance in PAN 50 Annex D; 6 to 10 mms^{-1} at a 95% confidence level.

8.4 Rail Bridge

8.4.1 Between Dalwhinnie and the quarry runs the Perth to Inverness rail line and north east of the distillery the A889 crosses over the rail line on a bridge. This engineered structure will be considered vibration sensitive by Network Rail.

8.4.2 Our experience of such structures in the past suggests that the vibration criterion Network Rail would look to have on the structure is 12 mms^{-1} at a 95% confidence level, more than 75% lower than the guideline level given in BS 5228-2 for engineered structures; 50 mms^{-1}.

8.4.3 The highest predicted levels at the bridge are in the range 1.2 to 2.7 mms^{-1}, which arise from the use of a 120kg explosive charge at the minimum separation distance. These levels are significantly below the limit likely to be suggested for the structure by Network Rail.

8.5 Beauly to Denny Pylon Line

8.5.1 Running to the east of the quarry is the recently constructed Beauly to Denny overhead power line. It is the pylon bases that are vibration sensitive.

8.5.2 The guidance from BS 5228-2, as was the case for the rail bridge, suggests that a suitable vibration criterion for these sorts of structures would be 50 mms^{-1}. However, in the past where we have assessed blast vibration impacts on overhead pylon lines Scottish Power Energy Networks, one of the owners of this line, have recommended a limit of 30 mms^{-1} at a 95% confidence level.

8.5.3 The use of a 120kg explosive charge at the closest approach distance to the pylon base will result in vibration levels in the range 1.8 to 4.2 mms^{-1}, with lower levels predicted when the separation distance increases. All of the vibration effects will be below the BS 5228-2 limit and the lower criterion that has been recommended by the line owners at other sites.

8.6 Hydro Structure

8.6.1 To the west of the south west corner of the quarry there is a concrete structure that impounds the Allt an t'Sluic burn. Further from the quarry there is another structure, again mainly of concrete, that we understand is the intake of a water supply to Dalwhinnie Distillery. These engineered structures are relatively insensitive to vibration and we recommend a suitable criterion would be 50 mms^{-1} at a 95% confidence level, from BS 5228-2.

8.6.2 Blasting in the south west corner of the quarry utilising a 120 kg explosive charge would result in vibration levels in the range 5.1 to 12.1 mms^{-1}. These levels are significantly below the recommended criterion. As blasting moves further from the closest approach distance there is a corresponding fall off in received vibration levels.

9.0 CONCLUSIONS

9.1 A criterion for restricting vibration levels from production blasting from the proposed development has been recommended in order to address the need to minimise annoyance to nearby residents. Accordingly, Vibrock recommends a vibration criterion, for existing residential dwellings of 6 mms^{-1} for 95% of events, as detailed in PAN 50 Annex D, as a satisfactory magnitude for vibration from blasting at Dalwhinnie Quarry. Higher limits are considered appropriate for engineered structures located close to the site, all as discussed above.

9.2 All blasts at Dalwhinnie Quarry shall be designed in order to comply with the above peak particle velocity vibration criteria at a 95% confidence level, as measured in any of the three planes of measurement at existing residential property or structures.

9.3 In relation to residential receptors, all vibration will be of a low order of magnitude and would be entirely safe with respect to the possibility of the most cosmetic of plaster cracks.

9.4 All vibration will also be well below those levels recommended for blast induced vibration as being satisfactory within the previously discussed British Standard Guide BS 6472-2: 2008.

9.5 In respect of residential receptors, all vibration will conform to PAN 50 Annex D where illustrative figures of 6 to 10 mms^{-1} at 95% confidence are given.

9.6 With such low ground vibration levels accompanying air overpressure would also be of a very low and hence safe level, although possibly perceptible on occasions at the closest of properties.

9.7 If Leiths Scotland Limited follow the recommendations given, there is no reason why blasting operations within the proposed extraction area at Dalwhinnie Quarry will give rise to adverse comment due to induced vibration at any of the dwellings or structures in the vicinity.

10.0 RECOMMENDATIONS

10.1 The following recommendations are presented in order to minimise the vibration impact of blasting operations from Dalwhinnie Quarry to nearby residents.

Ground Vibration – Residential Property

10.2 We recommend that a ground vibration limit is chosen that not only is perfectly safe for the integrity of structures, but also takes into account the physiological effects on adjacent neighbours. As such we recommend a vibration limit of 6 mms^{-1} peak particle velocity. The limit of 6 mms^{-1} is in line with successful current practice at numerous similar open pit workings within the United Kingdom and also agrees with the guidance contained within PAN 50 Annex D, February 2000 and British Standard 6472-2: 2008.

Ground Vibration – Engineered Structures

10.3 These receptors are less sensitive to vibration than residential locations and as such we recommend the following vibration limits, based on our experience of their owners requirements on other mineral sites where blasting is carried out:

Rail Bridge	12 mms^{-1} at a 95% confidence level
Pylon Bases	30 mms^{-1} at a 95% confidence level
Hydro Structure	50 mms^{-1} at a 95% confidence level

Air Overpressure

10.4 Our considerable past experience of air overpressure measurement and control leads us to the firm conclusion that it is totally impracticable to set a maximum air overpressure limit, with or without an appropriate percentile of exceedances being allowed, simply because of the significant and unpredictable effect of variable weather conditions.

10.5 This point is clearly recognised by the Government guidelines issued by the Department of the Environment in MPG 9 and MPG 14, which recommend that the operator should submit methods to minimise air overpressure to the Mineral Planning Authority. They do not recommend an air overpressure limit.

10.6 With a sensible ground vibration limitation the economics of safe and efficient blasting will automatically ensure that air overpressures are kept to reasonable levels.

10.7 We therefore recommend that in line with the current best accepted modern practice in the extraction industries that safe and practical measures are adopted that ensure the minimisation of air overpressure generated by blasting at source, considering such factors as initiation technique.

Monitoring and Control

10.8 The mineral operator should design blasting operations, taking into account the findings of this report.

10.9 A programme of blast monitoring should be introduced as part of the control of blasting operations. The results of such monitoring will indicate whether or not there is compliance with the vibration criterion, and they can also be used to continually update the regression analysis and thus provide valuable input to the design of future blasts.

10.10 With the above control recommendations implemented and the exercise of reasonable engineering control over quarry blasting operations, it is envisaged that the quarry will work within the vibration criteria and without undue annoyance to local residents.

11.0 REFERENCES

1. BS ISO 4866: 2010. Mechanical vibration and shock – Vibration of fixed structures – Guidelines for the measurement of vibrations and evaluation of their effects on structures. British Standards Institution.

2. BS 6472-2: 2008. Guide to evaluation of human exposure to vibration in buildings, Part 2: Blast-induced vibration. British Standards Institution.

3. BS 7385: 1993 Evaluation and measurement for vibration in buildings: Part 2. Guide to damage levels from groundborne vibration. British Standards Institution.

4. BS 5228-2: 2009, Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration.

5. Minerals Planning Guidance Note No. 9, 1992 Planning and Compensation Act 1991: Interim Development Order Permissions (IDOS) - Conditions. Department of the Environment, Welsh Office.

6. Minerals Planning Guidance Note No. 14, 1995 Environment Act 1995: Review of Mineral Planning Permissions. Department of the Environment, Welsh Office.

7. The Environmental Effects of Production Blasting from Surface Mineral Workings, Vibrock Report on behalf of the DETR, 1998.

8. Planning Advice Note 50, Annex D: The Control of Blasting at Surface Mineral Workings, Scottish Executive Development Department, February 2000.

TABLE 1

ALLOWABLE MAXIMUM INSTANTANEOUS EXPLOSIVE CHARGE WEIGHTS – INHABITED PROPERTY AT DALWHINNIE QUARRY

The following allowable maximum instantaneous charge weights at the given blast/receiver separation distances have been generated from recordings undertaken at quarries working similar strata to that at the proposed development:-

Blast/Receiver Separation Distance (metres)	Allowable Maximum Instantaneous Charge Weight, kg to comply with 6 mms^{-1} at 95% confidence level
200	32
250	50
300	72
350	98
400	127
450	161
500	199
550	241
600	287

TABLE 2

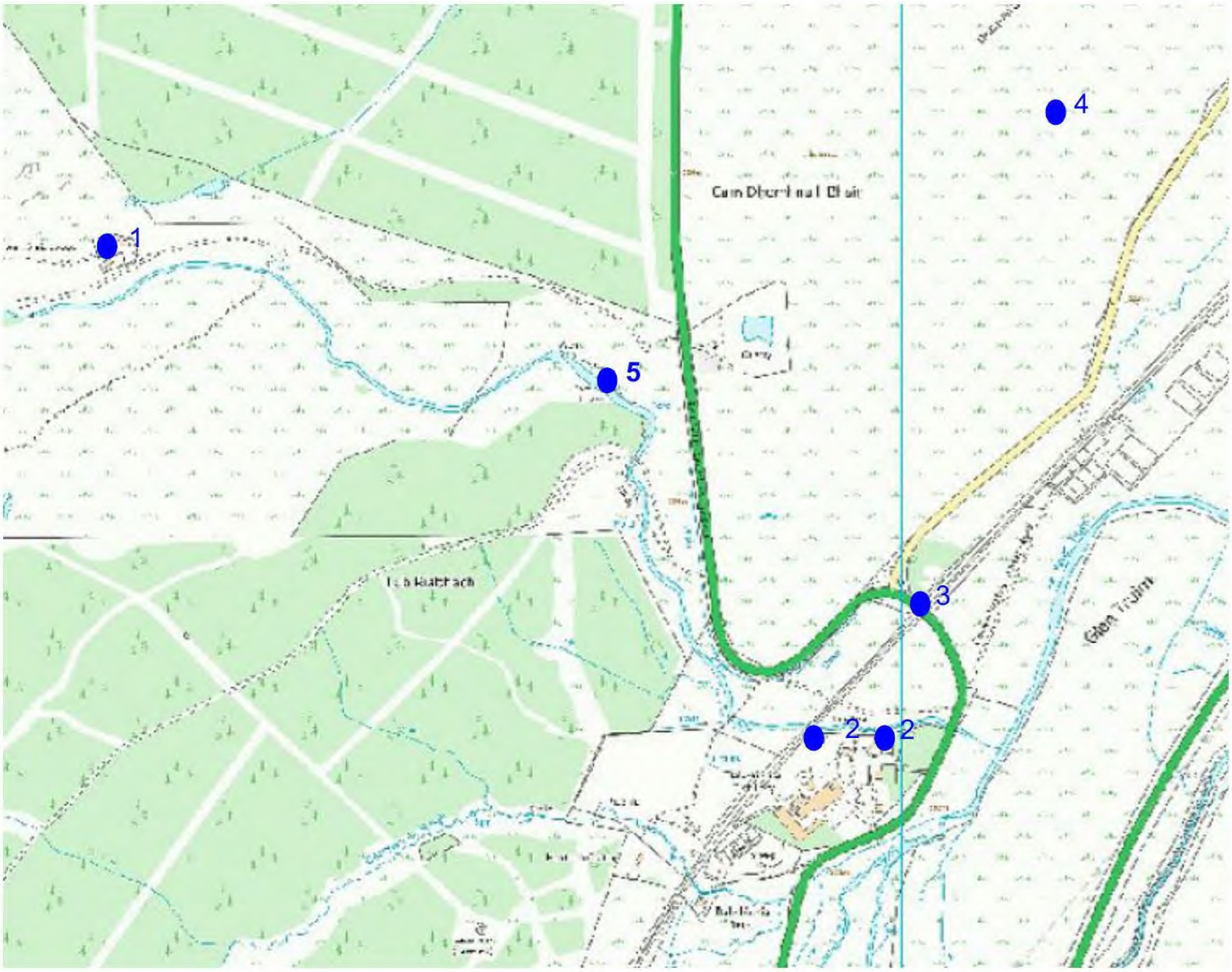
PREDICTED VIBRATION LEVELS -
VIBRATION RECEPTORS AT DALWHINNIE QUARRY

Considering the varying instantaneous explosive charges anticipated at the development, the following vibration levels are predicted for blasting operations during phased working.

Location	Vibration Level Peak Particle Velocity (mms^{-1})			
	Closest Approach		Centre of Quarry	
	Mean	Max'm	Mean	Max'm
Allt an t'Sluic Lodge	0.4	0.9	0.3	0.7
Distillery House	0.7	1.6	0.5	1.1
Rail Bridge	1.2	2.7	0.8	1.7
Beauly to Denny Pylon	1.8	4.2	0.9	2.0
Hydro Structure	5.1	12.1	2.5	5.9

FIGURE 1

VIBRATION RECEPTORS



Assessment Locations

1 Allt an t'Sluic Lodge
2 Distillery House
3 Rail Bridge
4 Beauly to Denny Pylon
5 Hydro Structure