Technical Appendix H

Groundborne Vibration and Air Overpressure Assessment

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ASSESSMENT OF THE POTENTIAL ENVIRONMENTAL IMPACT OF GROUNDBORNE VIBRATION AND AIR OVERPRESSURE FROM THE DEEPENING OF WORKINGS AND TIME EXTENSION AT AGGREGATE INDUSTRIES UK LIMITED BACK LANE QUARRY CARNFORTH LANCASHIRE

Assessment of the Potential Environmental Impact

of

Groundborne Vibration and Air Overpressure

from the

deepening of workings and time extension

at

Back Lane Quarry

Carnforth, Lancashire

As operated by

Aggregate Industries UK Limited

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EXECUTIVE SUMMARY

The use of controlled explosive charges will be necessary in order to produce fragmented rock for processing.

Ground and airborne vibration is always generated even by the best designed and executed of blasts.

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

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

As part of the assessment of the development proposals, monitoring data from typical production blasts at Back Lane Quarry have been reviewed together with current blasting protocols and procedures.

In accordance with current guidance and existing planning conditions which apply to Back Lane Quarry, it is recommended that vibration sensitive buildings or residential premises in the vicinity of the quarry should be limited to a vibration of 6 mms-1 in any mutually perpendicular plane and calculated with a 95% confidence limit. No individual blast shall exceed a peak particle velocity of 9 mms-1 as measured at any vibration sensitive property which is not under the direct control of the applicant / operator.

Current blasting practices at the site ensure that compliance with the recommended vibration criteria is achieved at all inhabited property.

Blast vibration levels at the proposed development at Back Lane Quarry will:-

- be entirely safe with respect to the possibility of cosmetic damage to property and be well below those levels recommended as being satisfactory within British Standard 7385-2: 1993 *'Evaluation and measurement for vibration in buildings - Guide to damage levels from groundborne vibration'*;

- be well below those levels recommended as being satisfactory within British Standard 6472-2: 2008 *'Guide to evaluation of human exposure to vibration in buildings – Blast-induced vibration';* and

- be subject to a monitoring scheme incorporating a detailed blast monitoring programme.

Current blasting operations at Back Lane Quarry comply with the current and proposed planning condition limits. With the exercise of reasonable engineering control over general site operations, Back Lane Quarry will continue to be worked within the blast vibration recognised to be justified for mineral extraction operations, and within the recommendations provided by this assessment.

1. INTRODUCTION

1.1 Aggregate Industries UK Limited (AIUK) is submitting an application for the deepening of existing quarry operations and an extension of time for the quarrying operations to continue until 31 December 2077, with restoration being completed a year later, by 31 December 2078.

1.2 The application boundary is not to increase from the area already permitted under the Review of Mineral Permission (ROMP) granted in 2006 (ref: 1/03/1186) and the extant planning permission for the site (ref: 01/09/0360) and therefore the workings will be no closer to the nearest dwellings.

1.3 The extraction of mineral will be continue to be extracted by drilling and blasting and then loaded and hauled by dump trucks to the existing processing plant for processing.

1.4 Operations are to continue in the existing extraction area to a greater depth (a further 75 metres to minus 37 metres AOD from the currently permitted floor of 38 metres AOD).

1.5 It is not proposed to vary the operating hours of the site from those permitted in the current planning permission for the site (ref: 01/09/0360).

1.6 The intention of this assessment is to establish that the impact of groundborne vibration and air overpressure from blasting operations as a consequence of the continuation of existing site operations would not be expected to result in any additional impact on nearby sensitive properties. Levels of groundborne vibration and air overpressure would be controlled to ensure compliance with extant planning permission conditions.

1.7 Competency and Expertise

1.7.1 The author of this chapter is Kevin Gough. Kevin worked on a number of environmental monitoring projects within local government before moving to the mineral extractive industry in 1986.

He founded Advance Environmental Consulting Limited and has managed environmental monitoring and assessment projects and contracts for clients throughout the UK and Europe. His principal areas of expertise are the monitoring and assessment of environmental noise and ground borne vibration from blasting, which have been developed through over 40 year's practical experience in the field. He served as a regional steering group member and Chairperson of the Institute of Environmental Management and board member. Currently an Honorary Fellow of the Institute of Quarrying where most recently he served as a director and executive board member.

2. SITE DESCRIPTION

2.1 Back Lane Quarry is in the jurisdiction of Lancaster City Council and Lancashire County Council being situated to the south-east of Carnforth in Lancashire.

2.2 The site is bounded to the north by the adjoining Leapers Wood Quarry operated by Tarmac Trading Limited, to the east by woodland, to the south by agricultural land and to the west by woodland, with the M6 beyond.

2.3 Leapers Wood quarry is operated by Tarmac Trading Limited and is immediately adjacent to the site with a common nominal boundary separating the two sites. A concurrent application is being submitted on behalf of Tarmac for the deepening of the workings at Leapers Wood Quarry to the same depth to allow for joint working of the boundary between the two quarries.

2.4 Carnforth is located to the west of the site and is the nearest substantial residential area with the nearest dwellings on the edge of the town being around 400 metres to the north-west of the current permitted extraction area beyond the M6 motorway.

2.5 There are a number of isolated residential properties located within 1 kilometre of the site.

2.6 Hawthorns Caravan Park is located approximately 90 metres to the south-west of the southern-most part of the site (southern site entrance) and approximately 350 metres from the current mineral area.

2.7 Newlands Farm lies approximately 280 metres south-west of the southern site entrance and over 500 metres south of the extraction area.

2.8 Wayside lies approximately 210 metres to the south-east of the southern site entrance and 350 metres south-east of the extraction area.

2.9 The site access is from the west on Back Lane.

2.10 The above properties are already recognised as being the closest to Back Lane quarry, as such, they are subject to extant planning conditions and are used for demonstrating compliance with respective groundborne vibration limits.

3. LEGISLATIVE AND POLICY CONTEXT

3.1 National Planning Policy Framework (NPPF)

3.1.1 The National Planning Policy Framework (NPPF) sets out the Government's planning policies for England. The latest version was published in July 2021.

3.1.2 At the heart of the NPPF is a presumption in favour of sustainable development.

3.1.3 Section 15 of the NPPF (Conserving and enhancing the natural environment) although not specifically referring to the impacts of blasting and vibration does refer to other related sensory impacts, in particular noise, in the following paragraphs:

'174. Planning policies and decisions should contribute to and enhance the natural and local environment by…
(e) preventing new and existing development from contributing to, being put at unacceptable risk from, or being adversely affected by, unacceptable levels of soil, air, water or noise pollution or land instability…'

'185. Planning policies and decisions should also ensure that new development is appropriate for its location taking into account the likely effects (including cumulative effects) of pollution on health, living conditions and the natural environment, as well as the potential sensitivity of the site or the wider area to impacts that could arise from the development. In doing so they should:
a) mitigate and reduce to a minimum potential adverse impacts resulting from noise from new development – and avoid noise giving rise to significant adverse impacts on health and the quality of life;
b) identify and protect tranquil areas which have remained relatively undisturbed by noise and are prized for their recreational and amenity value for this reason…'

3.1.4 Paragraph 187 refers to the integration of new development with existing businesses and facilities:

'187. Planning policies and decisions should ensure that new development can be integrated effectively with existing businesses and community facilities (such as places of worship, pubs, music venues and sports clubs). Existing businesses and facilities should not have unreasonable restrictions placed on them as a result of development permitted after they were established. Where the operation of an existing business or community facility could have a significant adverse effect on new development (including changes of use) in its vicinity, the applicant (or 'agent of change') should be required to provide suitable mitigation before the development has been completed.'

3.2 National Planning Practice Guidance - Minerals (NPPGM)

3.2.1 The *'Minerals'* chapter of the Planning Practice Guidance, under the heading *'Assessing environmental impacts from minerals extraction'* refers to blast vibration under the sub heading; *'What are the environmental issues of minerals working that should be addressed by mineral planning authorities?'*. However, in contrast to its sensory impact counterparts noise, dust and air quality, no further assessment framework or guidance is provided in the NPPGM.

3.2.2 The chapter therefore refers to guidance contained in British Standards and other research documents and recommends vibration criteria which accords with that provided by Mineral Planning Guidance notes MPG 9 and 14, which were withdrawn in 2014 and not replaced.

4. EFFECTS OF BLASTING

4.1 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 best designed and executed of blasts and will radiate away from the blast site attenuating as distance increases.

4.2 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.

4.3 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.

4.4 It is important to note 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 as this substantially increases the efficiency and hence economics of blasting operations.

4.5 The deepening of workings would be conducted in a similar manner to the existing Back Lane Quarry development. However, the optimum blast design will vary from blast to blast and will be decided by the operator with reference to the site specific conditions and in order to comply with the recommended vibration criteria.

5. BLAST VIBRATION TERMINOLOGY

5.1 Ground Vibration

5.1.1 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.

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

5.1.3 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).

5.1.4 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.

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

5.1.6 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

5.1.7 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.

5.1.8 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.

5.1.9 British Standard 7385-2: 1993 'Evaluation and measurement for vibration in buildings - Guide to damage levels from groundborne vibration'; 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.

5.1.10 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.

5.2 Airborne Vibration

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

5.2.2 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.

5.2.3 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 are 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.

5.2.4 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 x 10-6 Pascals, which is accepted as the threshold of human hearing.

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

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

5.2.6 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.

5.2.7 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.

5.2.8 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.

5.2.9 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.

5.2.10 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.

5.2.11 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.

6. VIBRATION CRITERIA

6.1 Damage Levels

Ground Vibration

6.1.1 Various authorities around the world have undertaken detailed research into determining the vibration levels necessary for the possible onset of damage to property. The United States Bureau of Mines (USBM) have reviewed all relevant published data, both theoretical and practical, to augment their own considerable research. They are, therefore, considered to be the foremost authority on this subject.

6.1.2 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.

6.1.3 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.

6.1.4 The comprehensive research programme undertaken by the USBM in the late 1970s (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.

6.1.5 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.

6.1.6 A later publication on this subject (S.E.E. Conference, 1991) reconfirms these safe vibration criteria and states that '… these studies have since been widely adopted by the users and regulators of explosives to develop and demonstrate safe blasting practices.' and that 'In the ten years since their publication, nothing has appeared to replace them or even significantly add to the data base.'

6.1.7 Indeed, within the UK, the Transport and Road Research Laboratory in their Report No. 53 of 1986 recommend the use of these USBM safe vibration criteria for blasting adjacent to residential type structures.

6.1.8 In addition, the British Standards Institution's structural damage committee have investigated blast induced vibration with respect to its damage potential. They contacted some 224 organisations, mainly British, and found no evidence of any blast induced damage at levels less than those recommended by the USBM.

6.1.9 This investigation culminated in British Standard 7385-2: 1993 'Evaluation and measurement for vibration in buildings - Guide to damage levels from groundborne vibration'.

6.1.10 British Standard 7385-2 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.

6.1.11 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.

6.1.12 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:-

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

Air Overpressure

6.1.13 Comprehensive investigations into the nature and effects of air overpressure with particular reference to its damage potential have been undertaken by the USBM who has also reviewed all other published data on this subject (R.I. 8485, 1980).

6.1.14 The weakest parts of most structures that are exposed to air overpressure are windows. Poorly mounted, and hence prestressed 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.).

6.1.15 The latest recommendations by the USBM are reproduced in Table 1. The criteria set 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.

Table 1. United States Bureau of Mines published criteria for air overpressure

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)

6.2 Perception Levels

6.2.1 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.

6.2.2 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.

6.2.3 From experience, 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.

6.2.4 Government guidance was provided on this subject and given within Minerals Planning Guidance Note No. 9 ‘Planning and Compensation Act 1991: Interim Development Order Permissions (IDOS) - Conditions. Department of the Environment, Welsh Office, 1992’ and Minerals Planning Guidance Note No. 14 ‘Environment Act 1995: Review of Mineral Planning Permissions. Department of the Environment, Welsh Office, 1995’. The documents suggested a range of between 6 to 10 mms-1 at a 95% confidence level as measured over any period of 6 months at vibration sensitive buildings with no individual blast exceeding 12 mms-1.

6.2.5 The documents are still widely referenced despite being withdrawn and as yet not replaced.

6.2.6 These same criteria are also recommended within the 1998 Department of the Environment Transport and The Regions (DETR) research publication ‘The Environmental Effects of Production Blasting from Surface Mineral Workings’.

6.2.7 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.’

6.2.8 Indeed, one of the principal findings of the study which lead 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’.

6.2.9 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.

6.210 The British Standards Institution has produced a document relevant to such a discussion entitled British Standard 6472-2: 2008 'Guide to evaluation of human exposure to vibration in buildings – Blast-induced vibration''. 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.

7. PREDICTION AND CONTROL OF VIBRATION LEVELS

7.1 Ground Vibration

7.1.1 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.

7.1.2 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

7.1.3 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.

7.1.4 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

7.1.5 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

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

7.1.7 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.

7.1.8 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.

7.1.9 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 $mkg^{-1/2}$ corresponding to the vibration level required

7.1.10 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.

7.1.11 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.

7.1.12 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.

7.1.13 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.

7.1.14 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.

7.1.15 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.

7.1.16 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.

7.2 Airborne Vibration

7.2.1 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.

7.2.2 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 6 dB. 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.

7.2.3 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 counterproductive 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.

7.2.4 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.

7.2.5 Such a procedure is recommended by the Government in their latest publications on this subject; MPG 9 and MPG 14, 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.

7.2.6 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.

7.2.7 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.

7.2.8 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.

8. ASSESSMENT OF BLAST INDUCED GROUNDBORNE VIBRATION LEVELS

8.1 Blasting procedures and protocols currently employed at Back Lane Quarry will be maintained for all future blasting operations to ensure the impact of groundborne vibration and air overpressure criteria is in line with current guidance, British Standards and planning policy.

8.2 Blasting operations in quarries can be extremely dangerous if the operation is not carried out correctly. The procedures and protocols currently implemented are designed to minimise health and safety risk whilst also maximising the efficiency and hence economics of blasting. This in turn minimises the environmental impact of blasting operations.

8.3 All blasts will be designed to minimise health and safety risk, maximise economy and minimise environmental impact. Full attention will be given to pre-profiling and accuracy of burden and spacing, size of blast, drilling accuracy, initiation system (whereby electronic initiation may give a benefit in some instances), initiation sequence, delay between holes (ie duration of blast), MIC etc. Further consideration will be given to the time of blast, the frequency and regularity of blasting and monitoring.

8.4 Currently, all blasts at Back Lane Quarry are monitored, generally, at the nearest potentially vibration sensitive property to any blasting event. This practice will continue with the deepening of the quarry void.

8.5 A review of data collected over the past three years from existing blasting events at Back Lane Quarry showed that all measured blasts were found to comply with the current permitted blasting limits.

8.6 It would be usual to use the measurement data obtained from compliance monitoring of blasting operations over a period of time to generate a regression curve plot for blasting at Back Lane Quarry. The use of the USBM formula to predict vibration levels calls for the maximum peak particle velocity (PPV) to be plotted against scaled distance (SD) in a logarithmic manner. The latter is defined as:-

$$\text{Scaled Distance } (mkg^{-\frac{1}{2}}) = \frac{\text{blast/receiver separation distance (m)}}{(\text{MIC})}$$

where MIC is the maximum instantaneous charge weight in kg.

8.7 The measured PPV's would be logarithmically plotted against their respective SD's and the line of best fit (50% confidence) would be drawn and the upper 95 % confidence level calculated. This would enable the predicted maximum MIC's for given distances to be determined. However, much of the data collected has been from monitoring at the same or similar location (from a distance perspective) which would not provide a representative spread of data for regression analysis purposes.

8.8 Current blasting practices at the site include predictive modelling which equally ensures that compliance with the recommended vibration criteria is achieved. It is therefore the intention that the current procedures used to predict vibration levels shall be adopted for all future blasts in the proposed extension area. This includes:-

- Identifying and agreeing with the regulatory authorities potentially sensitive properties;
- Utilising the latest blast design software that interfaces with laser profiling scanners;
- Accurately identifying the quarry blast area, undertaking a pre-survey and accurately determining the distance to nearest sensitive property shall be accurately determined using the survey data;
- Calculating the scaled distance (SD) value from the measured distance and proposed maximum instantaneous explosive charge weight (MIC);
- Using the SD to predict the expected peak particle velocity (PPV) (expressed @ 95% confidence) at the identified sensitive property;

- When necessary, accordingly reducing the MIC and recalculating the SD until the predicted PPV is below the permissible levels.

8.9 The author of this chapter therefore contends that continuation of current blasting practices at Back Lane quarry shall ensure that compliance with the recommended vibration criteria will be achieved from operations in the proposed extension area. Data obtained by direct measurement of blasting operations in this area will enable a regression analysis graph to be updated, which can then be used to inform all future blast designs.

9. CUMULATIVE IMPACT

9.1 With the implementation of appropriate control, the cumulative impact of blasting as a consequence of the proposed concurrent deepening of both Back Lane and Leapers Wood quarries, will be negligible with the maintenance, if not improvement to the current status quo.

10. CONCLUSIONS

10.1 In order to regularise a criterion for restricting vibration levels from production blasting whilst addressing the need to protect amenity for nearby residents, it is recommended that the current criterion of 6.0 mm per second (mms-1) for 95% of events is considered a satisfactory magnitude for vibration from blasting at Back Lane Quarry.

10.2 All blasts shall be designed to ensure that ground vibration levels arising from blasting shall not exceed a peak particle velocity of 6 mms-1 in any mutually perpendicular plane and calculated with a 95% confidence limit. No individual blast shall exceed a peak particle velocity of 9 mms-1 as measured at any vibration sensitive property which is not under the direct control of the applicant / operator.

10.3 All vibration will be of a relatively low order of magnitude and would be entirely safe with respect to the possibility of the most cosmetic of plaster cracks.

10.4 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.

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

10.6 If the applicant / operator accords with the recommendations given, there is no reason for blasting operations resulting from the proposed deepening of Back Lane Quarry to give rise to adverse impact due to increased vibration at any of the dwellings or structures in the vicinity. In fact, for blasting operations in the current void, impact should be lower.