Assessment of Environmental Impact of Blasting at Proposed Western Extension to Collyweston Quarry, Duddington, Northamptonshire

HEATON PLANNING

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1.0 INTRODUCTION

1.1 At the request of Heaton Planning, Vibrock Limited were commissioned to undertake a blast induced vibration study for a proposed western extension to mineral extraction operations at Collyweston Quarry, Duddington, Northamptonshire.

1.2 It is understood that this report will accompany the application for planning permission to be submitted to the Mineral Planning Authority.

1.3 This study benefits from a site inspection and monitoring of a typical production blast undertaken on 5th June 2013.
2.0 SITE DESCRIPTION

2.1 The current site is located to the east of Duddington village, Northamptonshire.

2.2 The proposed extension area is located to the west of the existing quarry and backfill operations. The land is currently in agricultural use, which reduces in height towards the limit of the western extension. When necessary, the extraction of aggregate will be achieved by blasting the rock through the use of controlled explosive charges with a maximum instantaneous charge (MIC) in the order of 50 kg to 75 kg.

2.3 Site access is gained off the A47, to the north east of Duddington. The current internal haul road is hard surfaced and will run north to south between the current extraction area and the proposed western extension.

2.4 The closest residential properties lie within the village of Duddington, at distances of approximately 210 - 230 metres at closest approach.

2.5 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:-

\[
PV = 2 \pi f a \\
\text{where } PV = \text{particle velocity} \\
\pi = \text{pi} \\
f = \text{frequency} \\
a = \text{amplitude}
\]
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 $20 \times 10^{-6}$ Pascals, which is accepted as the threshold of human hearing.

4.2.5 Air overpressure (AOP) is therefore defined as:

$$AOP, \text{dB} = 20 \log\left(\frac{\text{Measured pressure}}{\text{Reference pressure}}\right)$$
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 Damage Levels

Ground Vibration

5.1.1 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.

5.1.2 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.

5.1.3 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.

5.1.4 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$^{-1}$.

5.1.5 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$^{-1}$. 
5.1.6 Their 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."

5.1.7 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.

5.1.8 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.


5.1.10 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.

5.1.11 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.

5.1.12 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

5.1.13 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 who have also reviewed all other published data on this subject (R.I. 8485, 1980).

5.1.14 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.).

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

<table>
<thead>
<tr>
<th>Instrument Response</th>
<th>Maximum Recommended Level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 Hz high pass</td>
<td>134</td>
</tr>
<tr>
<td>2.0 Hz high pass</td>
<td>133</td>
</tr>
<tr>
<td>5.0 or 6.0 Hz high pass</td>
<td>129</td>
</tr>
<tr>
<td>C-Slow</td>
<td>105 dB (C)</td>
</tr>
</tbody>
</table>

5.1.16 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.

5.2 Perception Levels

5.2.1 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.

5.2.2 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.

5.2.3 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.
5.2.4 Government guidance on this subject is given within Minerals Planning Guidance (MPG) 9, 1992 and MPG 14, 1995 where a range of between 6 to 10 mms$^{-1}$ at a 95% confidence level is suggested as measured over any period of 6 months at vibration sensitive buildings with no individual blast exceeding 12 mms$^{-1}$.

5.2.5 These same criteria are also recommended within the 1998 Department of the Environment Transport and The Regions research publication, The Environmental Effects of Production Blasting from Surface Mineral Workings.

5.2.6 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".

5.2.7 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".

5.2.8 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.

5.2.9 The British Standards Institution have produced a document relevant to such a discussion entitled BS 6472–2: 2008, Guide to evaluation of human exposure to vibration in buildings, Part 2: 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.
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:

\[
\text{Scaled Distance, } SD = DW^{-\frac{1}{2}} \text{ in mkg}^{-\frac{1}{2}}
\]

where

\[
D = \text{Separation distance (blast to receiver) in metres}
\]

\[
W = \text{Maximum Instantaneous Charge (MIC) in kg}
\]

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:

\[
PV = a \times (SD)^b
\]

where

\[
PV = \text{Maximum Peak Particle Velocity in mms}^{-1}
\]

\[
SD = \text{Scaled Distance in mkg}^{-\frac{1}{2}}
\]

\[
a,b = \text{Dimensionless Site Factors}
\]

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

\[
a \text{ is the peak particle velocity intercept at unity scaled distance}
\]

\[
and \quad b \text{ is the slope of the regression line}
\]

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 Lecole 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:

\[
\text{Maximum Instantaneous Charge (MIC)} = (D/SD)^2
\]

\[
\text{Where } D = \text{Separation distance (blast to receiver) in metres}
\]

\[
\text{SD} = \text{Scaled Distance in mkg}^{-\frac{1}{2}} \text{corresponding to the vibration level required}
\]

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 Government in their publications on this subject, 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.

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 BLAST INDUCED VIBRATION MEASUREMENTS

7.1 Survey Dates

7.1.1 Levels of vibration from a production blast were measured from a blast initiated at 1158 hours on 5th June 2013. The instrumentation utilised is given in Appendix 1.

7.1.2 The regression line shows the blast was monitored using ten instruments which were sited at the following locations:

<table>
<thead>
<tr>
<th>Location</th>
<th>Separation Distance (Blast to Monitor in metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 35</td>
<td>35</td>
</tr>
<tr>
<td>Site 50</td>
<td>50</td>
</tr>
<tr>
<td>Site 75</td>
<td>75</td>
</tr>
<tr>
<td>Site 100</td>
<td>100</td>
</tr>
<tr>
<td>Site 125</td>
<td>125</td>
</tr>
<tr>
<td>Site 150</td>
<td>150</td>
</tr>
<tr>
<td>Site 175</td>
<td>175</td>
</tr>
<tr>
<td>Site 200</td>
<td>200</td>
</tr>
<tr>
<td>Site 225</td>
<td>225</td>
</tr>
<tr>
<td>Site 250</td>
<td>250</td>
</tr>
</tbody>
</table>

7.2 Survey Method

7.2.1 The following instrumentation was used for all measurements:

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Instrument</th>
<th>Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibrock</td>
<td>Digital Seismograph</td>
<td>V901</td>
<td>1 no</td>
</tr>
<tr>
<td>Vibrock</td>
<td>Digital Seismograph</td>
<td>BRIC</td>
<td>9 no</td>
</tr>
</tbody>
</table>

7.2.2 The following set-up parameters were used on the seismographs during vibration measurements:

- Trigger Level: 0.5 - 2.5 mms
- Record Length: 2.5 - 5.0 seconds
- Measurement Type: Impulse

7.2.3 For a full description of this instrumentation see Appendix 1.
7.2.4 The instrumentation was located at varying distances from the blast. The data obtained was used to generate a regression curve plot for blasting at Collyweston 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:

\[
\text{Scaled Distance (mkg}^{-\frac{1}{2}}) = \frac{\text{blast/receiver separation distance (m)}}{(\text{MIC})^{0.5}}
\]

where MIC is the maximum instantaneous charge weight in kg.
8.0 RESULTS

8.1 Details of the blast monitored on 5th June 2013 are shown in Table 1.

8.2 A summary of the results obtained is presented in Table 2.

8.3 Table 3 gives the allowable instantaneous explosive charge weights in order to comply with the recommended site vibration criterion.

8.4 Table 4 details the predicted vibration levels when blasting in the proposed extraction area.

8.5 A regression line was plotted for the maximum peak particle velocity in the three planes of measurement. The plot includes the 95% confidence limit and is shown in Figure 1.
9.0 DISCUSSION

9.1 The blast details and vibration recordings from 5th June 2013 are presented in Table 1 respectively.

9.2 The blast design employed on 5th June 2013 is typical of production blasting at Collyweston Quarry.

9.3 The recordings from 5th June 2013 are shown plotted in Figure 1.

9.4 The data has been processed by the least squares analysis method in order to obtain the regression line, which is the mathematical best fit straight line for the data. An indication of the degree of fit of this straight line is obtained by the correlation coefficient, where -1.0 indicates a perfect fit. In this instance the correlation coefficient is -0.95. The upper 95% confidence level is shown plotted for this data.

9.5 Table 3 gives the allowable instantaneous explosive charge weights in order to comply with the currently utilised vibration criterion of 10 mms$^{-1}$ at the given separation distances. A maximum instantaneous charge weight of 75 kg could be used 140 metres from property whilst complying with the recommended vibration criterion.

9.6 The closest residential properties are approximately 210 - 230 metres at closest approach.

9.7 Table 4 details the predicted vibration levels when blasting in the proposed extraction area and employing an instantaneous explosive charge weight of 75 kg, again at the nearest possible distance of approach to the locations given.

9.8 The predicted maximum vibration levels given will only occur when using an instantaneous charge weight of 75 kg at the nearest possible distance of approach to the respective locations.

9.9 As such, the vast majority of blasting events within the current extraction area will be significantly below the levels given.

9.10 The locations chosen for the purposes of this report are those which are the closest residential inhabited property within the neighbouring village of Duddington during the various phases of working.

Robinswood

9.11 Utilising a maximum explosive charge weight of 75 kg the worst case predicted vibration level from blasting operations at closest approach is 5.0 mms$^{-1}$ during Phase 11, which is within the recommended vibration criterion of 10 mms$^{-1}$ at 95% confidence level.
The Pines

9.12 Worst case vibration level at The Pines is predicted to be $5.0 \text{ mms}^{-1}$, utilising a maximum explosive charge weight of 75 kg. This predicted level is within the recommended vibration criterion of $10 \text{ mms}^{-1}$ at 95% confidence level.

Oak Cottage

9.13 Considering the utilisation of instantaneous explosive charge weights of up to 75 kg, a worst case vibration level will be $5.7 \text{ mms}^{-1}$, which is well within the recommended vibration criterion of $10 \text{ mms}^{-1}$ at 95% confidence level.
10.0 CONCLUSIONS

10.1 A criterion for restricting vibration levels from production blasting has been recommended in order to address the need to minimise annoyance to nearby residents. Accordingly, Vibrock recommends a vibration criterion of 10 mms$^{-1}$ for 95% of events, as detailed within MPG 9 and MPG 14 and in line with the current site vibration criterion, as a satisfactory magnitude for vibration from blasting at Collyweston Quarry.

10.2 All blasts at Collyweston Quarry shall be designed in order to comply to a vibration criteria of 10 mms$^{-1}$ peak particle velocity at a 95% confidence level as measured in any of the three planes of measurement.

10.3 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.

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 All vibration will conform to MPG 9 and MPG 14 where illustrative figures of 6 to 10 mms$^{-1}$ at 95% confidence are given.

10.6 If Bullimores Sand and Gravel Limited follow the recommendations given, there is no reason why blasting operations within the proposed extraction area at Collyweston Quarry will give rise to adverse comment due to induced vibration at any of the dwellings or structures in the vicinity.
11.0 RECOMMENDATIONS

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

Ground Vibration - Inhabited Property

11.2 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 10 mms$^{-1}$ peak particle velocity. The limit of 10 mms$^{-1}$ is in line with the current planning conditions at Collyweston Quarry, is successful current practice at numerous similar open pit workings within the United Kingdom and also agrees with the relevant British Standard 6472-2: 2008 and will ensure that no individual blast will exceed 12 mms$^{-1}$.

Air Overpressure

11.3 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.

11.4 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.

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

11.6 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

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

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


TABLE 1

BLAST DETAILS AT COLLYWESTON QUARRY

<table>
<thead>
<tr>
<th>Date:</th>
<th>5th June 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time:</td>
<td>1158 hours</td>
</tr>
<tr>
<td>No of Holes:</td>
<td>15</td>
</tr>
<tr>
<td>Diameter:</td>
<td>110 mm</td>
</tr>
<tr>
<td>Depth:</td>
<td>8 metres</td>
</tr>
<tr>
<td>Burden:</td>
<td>4.5 metres</td>
</tr>
<tr>
<td>Spacing:</td>
<td>4.5 metres</td>
</tr>
<tr>
<td>Explosive Charge Weight per Hole:</td>
<td>43.5 kg</td>
</tr>
<tr>
<td>Maximum Instantaneous Explosive Charge Weight:</td>
<td>43.5 kg</td>
</tr>
<tr>
<td>Total Explosive Charge Weight:</td>
<td>639.5 kg</td>
</tr>
<tr>
<td>Explosive Type:</td>
<td>ANFO</td>
</tr>
<tr>
<td>Initiation:</td>
<td>Non electric system</td>
</tr>
</tbody>
</table>
TABLE 2

RESULTS OBTAINED AT COLLYWESTON QUARRY

<table>
<thead>
<tr>
<th>Monitoring Location</th>
<th>Separation Distance (Blast to Monitor) (metres)</th>
<th>Measurement Axis</th>
<th>Peak Particle Velocity (mms⁻¹)</th>
<th>Air Overpressure (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 35</td>
<td>35</td>
<td>Long Vert Trans</td>
<td>16.8 20.8 29.6</td>
<td>133</td>
</tr>
<tr>
<td>Site 50</td>
<td>50</td>
<td>Long Vert Trans</td>
<td>16.4 10.4 8.8</td>
<td>120</td>
</tr>
<tr>
<td>Site 75</td>
<td>75</td>
<td>Long Vert Trans</td>
<td>6.4 7.2 18.4</td>
<td>117</td>
</tr>
<tr>
<td>Site 100</td>
<td>100</td>
<td>Long Vert Trans</td>
<td>4.5 2.0 2.9</td>
<td>107</td>
</tr>
<tr>
<td>Site 125</td>
<td>125</td>
<td>Long Vert Trans</td>
<td>5.2 3.5 5.0</td>
<td>104</td>
</tr>
<tr>
<td>Site 150</td>
<td>150</td>
<td>Long Vert Trans</td>
<td>3.2 2.3 2.5</td>
<td>115</td>
</tr>
<tr>
<td>Site 175</td>
<td>175</td>
<td>Long Vert Trans</td>
<td>1.7 2.0 2.6</td>
<td>106</td>
</tr>
<tr>
<td>Site 200</td>
<td>200</td>
<td>Long Vert Trans</td>
<td>1.4 2.6 2.1</td>
<td>111</td>
</tr>
<tr>
<td>Site 225</td>
<td>225</td>
<td>Long Vert Trans</td>
<td>2.8 2.3 1.7</td>
<td>118</td>
</tr>
<tr>
<td>Site 250</td>
<td>250</td>
<td>Long Vert Trans</td>
<td>2.5 2.4 1.5</td>
<td>110</td>
</tr>
</tbody>
</table>
TABLE 3

ALLOWABLE MAXIMUM INSTANTANEOUS EXPLOSIVE CHARGE WEIGHTS - INHABITED PROPERTY AT COLLYWESTON QUARRY

From the regression line of Figure 1 it is seen that the corresponding scaled distance value for a vibration criterion of 10 mms$^{-1}$ at a 95% confidence level is 16 mkg$^{-\frac{1}{2}}$.

This gives rise to the following allowable maximum instantaneous charge weights at the given blast/receiver separation distances:

<table>
<thead>
<tr>
<th>Blast/Receiver Separation Distance (metres)</th>
<th>Allowable Maximum Instantaneous Charge Weight, kg to comply with 10 mms$^{-1}$ at 95% confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>75</td>
</tr>
<tr>
<td>150</td>
<td>87</td>
</tr>
<tr>
<td>175</td>
<td>118</td>
</tr>
</tbody>
</table>
### TABLE 4

**PREDICTED VIBRATION LEVELS AT SENSITIVE LOCATIONS**

**COLLYWESTON QUARRY**

Considering a maximum instantaneous charge weight of 75 kg at the nearest distance of approach to the locations considered, the predicted vibration levels are as follows:

<table>
<thead>
<tr>
<th>Location No.</th>
<th>Location</th>
<th>Vibration Level Maximum Peak Particle Velocity (mms⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean 50%</td>
</tr>
<tr>
<td>1</td>
<td>Robinswood</td>
<td>3.2</td>
</tr>
<tr>
<td>2</td>
<td>The Pines</td>
<td>3.2</td>
</tr>
<tr>
<td>3</td>
<td>Oak Cottage</td>
<td>3.6</td>
</tr>
</tbody>
</table>
FIGURE 1

REGRESSION ANALYSIS
FIGURE 2

SENSITIVE RECEPTORS

KEY
1. Robinswood
2. The Pines
3. Oak Cottage

Proposed Western Extension Area
APPENDIX 1

V901 DIGITAL SEISMOGRAPH

Specification:

- Impulse mode for blast monitoring
- Continuous mode for piling, rail and road traffic monitoring
- Tri-axial geophone sensor
- Features: • triggering from 0.1 mm/s
  ▪ single range from 0.1 mm/s to 200 mm/s
  ▪ auto record length from 2 to 18 seconds (in impulse mode)
- Trigger and record PPV, acceleration or displacement parameters
- Air overpressure from 100 to 140 dB Linear Peak
- Memory for about 300 events or 30 days continuous recording
- Battery operated, uses 2 Alkaline ‘D’ cells (or external 12 volt supply)
- Built in timer function
- Instant readout and review of memory event results on LCD
- Download to PC with supplied USB cable and Windows™ based software
- Supplied with Shoulder Bag

BRIC Digital Seismograph

The BRIC Digital Seismograph is a self-triggering computerised portable seismograph for use in the monitoring and recording of ground vibration and air overpressure associated with blasting or any other operations in which vibration is of concern for example piling or demolition. The BRIC is a sealed weatherproof unit designed for operation in hostile conditions, to the same specification as the Vibrock V901.