Assessment of the Environmental Impact of Blasting Associated with the Proposed Great Oak Surface Coal Mine, Bignall End, Staffordshire

HEATON PLANNING

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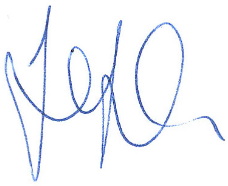	
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1.0 INTRODUCTION

1.1 Heaton Planning on behalf of UK Coal intend to submit a planning application for Great Oak Surface Coal Mine with the relevant Mineral Planning Authorities, Staffordshire County Council.

1.2 Investigation works indicate that blasting is likely to be required at the site to remove overburden and accordingly it has been considered prudent to undertake an assessment regarding the implications of these proposals with respect to blast induced vibration.

1.3 Vibrock Limited, an independent firm of environmental consultants, has been engaged by Heaton Planning on behalf of UK Coal, to undertake this study.

1.4 This study benefits from a site visit undertaken on 14th August 2012.

1.5 This assessment considers the potential effect of blast induced vibration on the occupants of adjacent residential property and the A500 dual carriageway.

2.0 SITE DESCRIPTION

2.1 The proposed site is located approximately 6 kilometres to the north-west of the nearby town of Newcastle-under-Lyme. The nearest residential settlement is Bignall End to the south-west.

2.2 The Great Oak site has a total site area of approximately 80 hectares, with an estimated total tonnage of recoverable coal of up to 450,000 tonnes.

2.3 The site has a varied topography, with the highest elevations to the east at 185 metres AOD, falling to 140 metres AOD towards the west at Bignall End Road.

2.4 A number of sensitive receptors surround the site, including properties on the outskirts of Bignall End and Butters Green, Red Street and properties off Talke Road and Jamage Road. There are also a number of isolated farmstead properties including Diglake Farm, Woodlands Farm and Great Oak Farm.

2.5 The optimum blast design may vary from blast to blast and will necessarily be decided by the 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 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.

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.

5.1.9 This investigation has culminated in British Standard 7385: Part 2: 1993, Evaluation and Measurement for Vibration in Buildings, entitled Guide to Damage Levels from Groundborne Vibration.

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, whist 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:-

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)

5.1.16 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:-

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 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 DISCUSSION

7.1 Introduction

7.1.1 Table 1 details the likely vibration levels at adjacent residential property when blasting is at the nearest distance of approach during four phases of the site utilising an instantaneous explosive charge weight of 40 kg.

7.1.2 Table 2 gives the allowable maximum instantaneous explosive charge weights in order to comply with the recommended vibration criterion of 6 mms^{-1} at the given separation distances. A maximum instantaneous charge weight of 40 kg, could be utilised up to approximately 220 metres from property whilst complying with the recommended vibration criterion.

7.1.3 There are four properties situated within 220 metres of the closest approach of blasting operations, namely Diglake Farmhouse, Woodlands Farm Bungalow, Isaac House and 15 Great Oak Road. When blasting within this distance approach, blast designs will be required to be modified accordingly.

7.1.4 The predicted maximum vibration levels given will only occur when using an instantaneous charge weight of 40 kg at the nearest possible distance of approach to the respective locations.

7.1.5 As such, the vast majority of blasting events within the proposed development areas will be significantly below the levels given.

7.2 Diglake Farmhouse, Bignall End Road

7.2.1 Diglake Farmhouse is the closest property to the proposed site. During extraction in areas B1, B2 and B3 of the works this property is situated within 100 metres at closest approach. The maximum instantaneous charge weight of blasting operations will require to be reduced in line with Table 2 in order to meet the recommended vibration criteria.

7.2.2 A most likely vibration level of 2.8 mms^{-1} with a maximum likely level of 6.0 mms^{-1} at 95% confidence is predicted at Diglake Farmhouse when working at closest approach. This will be completely safe with respect to the likelihood of the most cosmetic of plaster cracking.

7.2.3 Such vibration levels may be perceptible but entirely safe and significantly below the minimum guide value to prevent cosmetic damage of 15 mms^{-1} as detailed in BS 7385.

7.3 Woodlands Farm Bungalow, Bignall End Road

7.3.1 At the closest approach to Woodlands Farm Bungalow, the maximum instantaneous charge weight will require to be reduced in accordance with Table 2 in order to meet the recommended vibration criterion whilst working in area B3. This reduction in explosive charge weight can be achieved by means of decking the explosive charge within the borehole.

7.3.2 A most likely vibration level of 2.8 mms^{-1} with a maximum likely level of 6.0 mms^{-1} at 95% confidence is predicted at Woodlands Farm Bungalow when working at closest approach and will be completely safe with respect to the likelihood of the most cosmetic of plaster cracking.

7.4 Jamage Farm Cottages, Jarnage Road

7.4.1 The predicted vibration levels at Jamage Farm Cottages are 0.5 to 1.0 mms^{-1} during operations in area A of the works at closest approach.

7.4.2 Vibration levels of this magnitude would be barely perceptible and entirely safe with respect to the likelihood of the most cosmetic of plaster cracking.

7.5 Wedgewood House, Talke Road

7.5.1 Wedgewood House is situated approximately 850 metres to the east of the closest approach of blasting operations within area A. Worst case vibration levels at this location are predicted to be no more than 0.7 mms^{-1}. Vibration levels of this magnitude would be barely perceptible.

7.6 292 Audley Road

7.6.1 292 Audley Road is predicted to receive a most likely vibration level of 0.3 mms^{-1} and a maximum likely level of 0.6 mms^{-1} when working at closest approach within area B2.

7.6.2 Such a level of vibration is likely to result in limited perceptible effects and safe with respect to safeguarding such a property against the possibility of cosmetic damage.

7.7 Isaac House, Bignall Hill

7.7.1 A most likely vibration level of 2.8 mms^{-1} with a maximum likely level of 6.0 mms^{-1} at 95% confidence is predicted at Isaac House when working at closest approach (area B2). In order to achieve this, the maximum instantaneous charge weight of blasting operations will require to be reduced in line with Table 2 to comply with the recommended site vibration criterion of 6 mms^{-1}.

7.7.2 Such a magnitude of vibration will be completely safe with respect to the likelihood of the most cosmetic of plaster cracking and is significantly below the minimum guide value to prevent cosmetic damage of 15 mms^{-1} as detailed in BS 7385.

7.8 15 Great Oak Road

7.8.1 At closest approach to 15 Great Oak Road the most likely predicted vibration level is 2.8 mms^{-1}, with a maximum vibration level of 6.0 mms^{-1} at 95% confidence (area B3). In order to achieve this, the maximum instantaneous charge weight of blasting operations will require to be reduced in line with Table 2 to meet the recommended site vibration criterion of 6 mms^{-1}.

7.8.2 Such vibration levels may be perceptible but entirely safe and significantly below the minimum guide value to prevent cosmetic damage of 15 mms^{-1} as detailed in BS 7385.

7.9 Great Oak Farm

7.9.1 Great Oak Farm is situated to the west of the proposed development. The predicted vibration levels at the closest approach of blasting operations are 0.9 to 2.0 mms^{-1} during workings within area B3, which is well within the recommended site vibration criterion of 6 mms^{-1} at a 95% confidence level.

7.10 A500 Dual Carriageway

7.10.1 The A500 dual carriageway is situated to the north of the development, approximately 180 metres at closest approach. Utilising a maximum instantaneous charge weight of 40 kg, the most likely predicted ground vibration level is 3.9 mms^{-1} with a maximum likely vibration level predicted at 8.6 mms^{-1} whilst working in area A of the proposed development.

7.10.2 The Department for Transport's 'Manual of Contract Documents for Highways Works' details a permitted criteria to safeguard structures and earthworks during blasting operations. The document recommends a vibration criteria of 50 mms^{-1}.

7.10.3 The worst case predicted vibration level at closest approach to the A500 is considerably below the 50 mms^{-1} criteria and would be entirely safe during all blasting operations at the proposed development.

8.0 CONCLUSIONS

8.1 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 6 mms^{-1} for 95% of events, as detailed within MPG 9 and MPG 14 as a satisfactory magnitude for vibration from blasting at the proposed Great Oak Surface Coal Mine.

8.2 All blasts at the site shall be designed in order to comply to a vibration criteria of 6 mms^{-1} peak particle velocity at a 95% confidence level as measured in any of the three planes of measurement.

8.3 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.

8.4 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.

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

8.6 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.

8.7 In line with current Government guidance, we recommend that no air overpressure limit is set but rather that a scheme is adopted whereby air overpressure is minimised at source.

9.0 RECOMMENDATIONS

9.1 The following recommendations are presented in order to minimise the vibration impact of blasting operations from the proposed Great Oak Surface Coal Mine to nearby residents.

Ground Vibration - Inhabited Property

9.2 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 relevant British Standard 6472-2: 2008 and will ensure that no individual blast will exceed 12 mms^{-1}.

Air Overpressure

9.3 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.

9.4 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.

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

9.6 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

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

9.8 It is recommended that blast vibration monitoring of production blasting be carried out at adjacent properties. The results obtained should be used to continually update and amend as necessary the blast regression line. The amended regression line should be interpreted so as to always ensure for each successive blast that the correct maximum instantaneous charge weight with respect to the adjacent properties and services is in use.

9.9 With the above control recommendations implemented and the exercise of reasonable engineering control over blasting operations, it is envisaged that the proposed Great Oak Surface Coal Mine will operate within the vibration criteria and without undue annoyance to local residents.

10.0 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 7385: 1993 Evaluation and measurement for vibration in buildings: Part 2. Guide to damage levels from groundborne vibration. British Standards Institution.

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

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

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

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

TABLE 1

PREDICTED GROUND VIBRATION LEVELS – PROPOSED GREAT OAK SURFACE COAL MINE

Considering a maximum instantaneous charge weight of 40 kg utilised in the proposed site then at the nearest distances of approach to the locations considered, the predicted vibration levels are as follows:-

Location	Peak Particle Velocity (mms^{-1})							
	Area A		Area B1		Area B2		Area B3	
	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum
Diglake Farmhouse	0.6	1.3	2.8	6.0*	2.8	6.0*	2.8	6.0*
Woodlands Farm Bungalow	0.7	1.5	1.6	3.4	0.6	1.4	2.8	6.0*
Jamage Farm Cottages	0.5	1.0	0.3	0.5	0.3	0.5	0.3	0.5
Wedgewood House	0.3	0.7	0.2	0.4	0.3	0.5	0.2	0.3
292 Audley Road	0.2	0.4	0.1	0.3	0.3	0.6	0.3	0.5
Isaac House	0.3	0.5	0.8	1.7	2.8	6.0*	1.8	3.8
15 Great Oak Road	0.3	0.5	0.8	1.7	0.8	1.8	2.8	6.0*
Great Oak Farm	0.2	0.4	0.4	0.9	0.3	0.7	0.9	2.0

* Maximum instantaneous explosive charge weights will require to be reduced in order to comply with criteria contained within MPG 9 and MPG 14

TABLE 2

ALLOWABLE MAXIMUM INSTANTANEOUS EXPLOSIVE CHARGE WEIGHTS – INHABITED PROPERTY AT PROPOSED GREAT OAK SURFACE COAL MINE

From the regression line of Figure 1 it is seen that the corresponding scaled distance value for a vibration criterion of 6 mms^{-1} at a 95% confidence level is 35 $mkg^{-½}$.

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

Blast/Receiver Separation Distance (metres)	Allowable Maximum Instantaneous Charge Weight, kg to comply with 6 mms^{-1} at 95% confidence level
50	2
100	8
150	18
200	33
250	51
300	74

FIGURE 1

SENSITIVE RECEPTORS