CONTROLLING THE ENVIRONMETAL IMPACT OF BLASTING AT THE FFOS-Y-FRAN RECLAMATION SCHEME

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Abstract

There are environmental impacts associated with blasting aside from vibration and air overpressure and it is important to determine the key impacts and to have the ability to control their effects. This paper describes how an open cast coal mining operation in South Wales has successfully achieved this by establishing an environmental baseline, identifying the key blast related impacts, and then developed an environmental monitoring regime to achieve environmental control.

The site determined that the development and expansion of cracking at residential properties (internal and external) was of concern to the neighbouring residents. To develop a baseline a series of detailed house surveys using photographs and schematic diagrams to identify any pre-existing cracking about the property were produced. The data obtained was input into a bespoke electronic database for safe storage and future reference.

Following the baseline study, an environmental monitoring regime using two bespoke, permanent seismographs and two mobile seismographs was established to determine the key blasting parameters such as explosive charge weights and distances to local receptors. A blast monitoring protocol was developed for use with the monitoring equipment to ensure that every blast has at least one monitored result. In addition the Blast Log database was employed to control operations by uploading blasting data periodically to give more accurate predictions and hence control.

Birch, W.J., Hosein, S. and Mason, D., 2011. Controlling the environmental impacts of blasting at the Ffos-y-fran Land Reclamation scheme. Pp. 173-179 in Hunger. E. and Walton, G. (Eds.)
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Introduction

The Ffos-y-fran Land Reclamation Scheme is a major opencast coaling operation to the north-east of Merthyr Tydfil located in South Wales, UK (shown on Figure 1). The site will extract approximately 10 million tonnes of coal over 15 years of which a significant proportion of the revenues will be used to redevelop the current and former industrial workings to bring them back into residential and recreational use.

During the planning stages, the proposed opencast coal mine had many objections at both a local and national level, including objections on the close proximity of housing to the site. The nearest residential estate is less than 100m from the site boundary. Due to the proximity of the properties, Ffos-y-fran placed a self imposed blast exclusion zone within the site (shown on Figure 2), meaning that no blasting operations could take place within 300m of any property whether residential or industrial. The Mineral Planning Authority (MPA), which regulates mines and quarries in the UK, agreed with the blast exclusion zone and the MPA set a statutory vibration limit that 95% of all blasts must be below a PPV (Peak Particle Velocity) level of 6mm/s recorded at the nearest property. In an earlier study conducted in south Wales, White *et al* (1993) found that the lowest peak particle vibration level from blasting operations that resulted in an extension of a pre-existing crack occurred at 14.3 mm/s.

Figure 1. *Aerial oblique photograph of the Ffos-y-fran reclamation scheme taken from the South-West.*

As the vibration limit is significantly lower than that damage level, no damage should occur if all blasts carried out adhered to the 6 mm/s limit. However, local residents were still concerned that the resulting vibrations produced from the blasting operations may affect their property and cause damage even though the mine would be working to a vibration limit at which damage to properties should not occur.

The need to be able to demonstrate best blasting practice resulted in the site management at Ffos-y-fran requiring a system that would clearly demonstrate to the regulator and residents that they were complying with the vibration limit set in the planning permission for the site.

Establishing the environmental base line

The first stage was to establish an environmental baseline of the surrounding area prior to the commencement of blasting operations. This began with carrying out a detailed desk study to determine the geological and manmade structure of the surrounding area and to determine the type of properties present within a 400m radius of the site boundary.

Specifically, the proposed blasting scheme, including blasting areas were reviewed. The geology (strata type, dip, faults), hydrogeology and locations of former backfilled surfaced workings and old deep mine workings, shafts and adits were investigated, as they were considered to be the most likely conduits of any blast vibrations. This data was then reviewed in relation to the location of properties within the vicinity of the site. This process identified six residential areas located to the north, south and west of the mine, where the proximity of geological or historic mining structures meant that there was some possibility of blast vibrations having an impact on the area and therefore were to be considered for further survey work. These areas were Dowlais Top, Incline Top, Bradley Gardens, Mountain Hare, Mount View and Incline Side (shown on Figure 2).

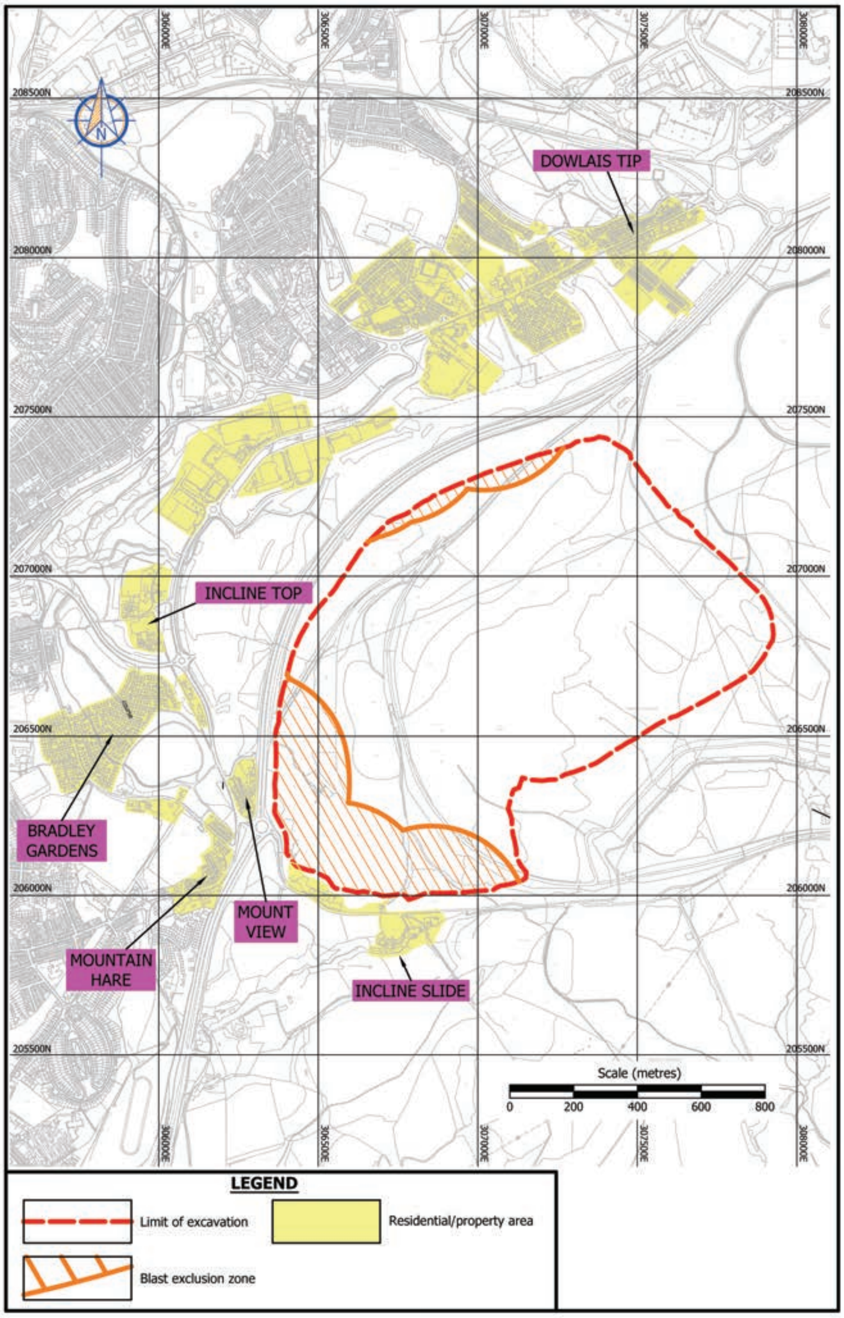

Figure 2. Site plan of Ffos-y-fran showing residential areas of interest and the blast exclusion zone, set at 300m from residential properties.

The next step of the desk study was to carry out a house inventory by viewing the properties in the identified areas and noting the house type (terrace, detached etc), approximate age of the build, whether the houses were individually built or a part of a development/estate and the property use (residential, commercial, public or industrial). After identifying groups of similar properties within the different areas, a representative sample of properties (34 in total) from the different groups were recommended for further survey work.

The results of the study were conveyed to the residents (*via* the residents liaison committee) and the operator at community interaction meetings. This was with a view to keeping the residents as fully informed and involved as practicably possible with all decisions being made and to recommend a series of property condition surveys on the identified properties.

The liaison committee agreed with the methodology of the desk study undertaken and the results of it and once permission was given by the individual home owners, property condition surveys were conducted on the 34 identified properties. These detailed house condition surveys were carried out to record the existing condition of each selected property prior to any blasting taking place. This involved logging and photographing the outside walls and all interior walls of a house, indentifying and noting any cracks, discolorations or defects. They were not full structural surveys and were not carried out by a structural engineer.

The basis for the condition survey was twofold, firstly, each property would be a reference house for that type of house, in that area, such that if a resident presumed that a crack had formed in their property due to vibrations produced from blasting operations, the data from the reference house could be assessed to determine whether the cracking was present before blasting operations. Secondly, the survey data would be used for comparison with condition survey data recorded at the same location after all blasting operations have ceased to determine if there had been any changes within the properties over the lifetime of blasting operations.

The houses surveyed varied greatly in type and size from 5 roomed pre World War II terraced properties (Figure 3) to 24 roomed post-2000 properties (Figure 4).

The site management's requirement was for a database system to provide long-term secure storage and retrieval of all crack survey records with time. It was essential that the public should have confidence in the independence and integrity of the system for it to be effective as a means of resolving any future disputes involving the development of cracks during the life of mine. It was decided to use Microsoft Access, which was readily available and likely to be supported for the length of the operation, to create a relational database in which to store descriptions, sketch drawings and photographic records for every crack or group of cracks identified by the survey team. An unambiguous location of each crack was established by tagging each crack record by wall, room, floor and house name, cross-referenced to a position on floor plans. Date of survey, name of surveyor and a host of other attributes were also recorded. User-friendly forms provided easy data entry and the ability to browse, query and report on the stored

Figure 3. *Example of pre World War II terraced property.*

Figure 4. *Example of post-2000 property.*

data (as shown in Figure 5 and 6). The database security model was programmed to give only named individuals rights to add, edit or delete data, and to record automatically all such actions so that data changes could be audited (as shown in Figure 7) if necessary. To maintain data integrity, the client's copy of the final populated database allowed read-only access. Only the independent database developer (GWP Consultants LLP) retaining the ability to make changes.

For each property, three identical printed and bound reports were produced, one for the resident, another for the operator and one is kept by the house condition survey team. This was carried out in order to disseminate the information as transparently as possible to all relevant parties associated with the house surveying process.

ESTABLISHING AN ENVIRONMENTAL MONITORING REGIME

The environmental baseline work identified the key locations adjacent to the site where blasting operations had the potential to cause an impact on properties from vibration. As such, a blast monitoring protocol was developed to ensure that every blast had at least two real, monitored vibration results which could be used to update the site regression model and the calculated Maximum Instantaneous Charge weight (MIC) for use in subsequent blast design.

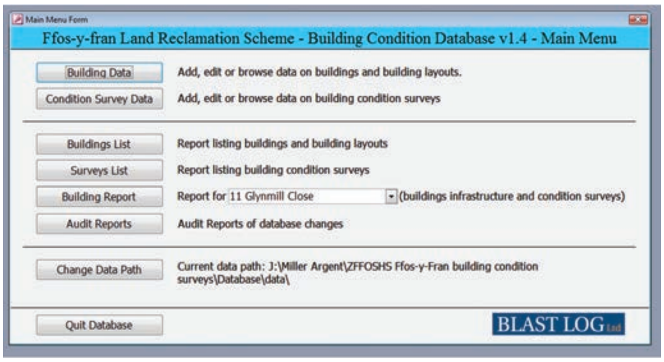

Figure 5. *Main menu screen of building condition database.*

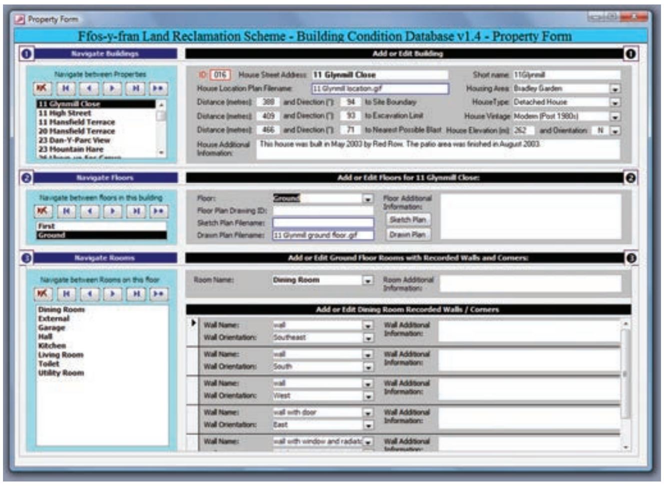

Figure 6. *Property form screen of Building Condition Database.*

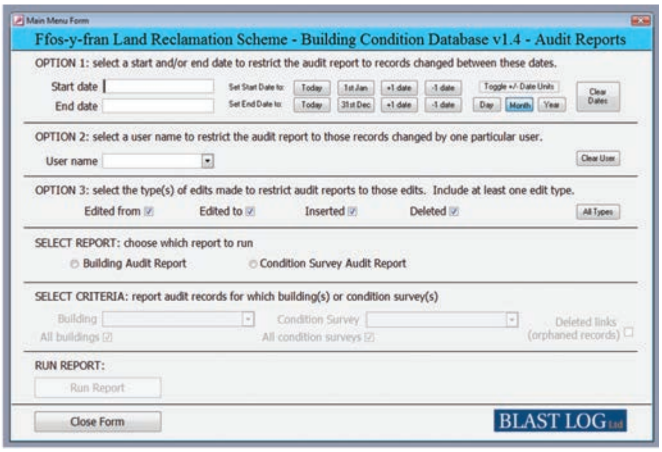

Figure 7. *Audit report screen of Building Condition Database.*

To acquire this vibration monitoring data, two permanent off-site monitoring locations and two mobile seismographs, used within the site, were (and are) deployed for each blast by the shot-firing crew. One unit is deployed at an accurately surveyed point between 30 to 40 metres from the nearest hole of the blast. The other unit is deployed at a second accurately surveyed point at an intermediate distance on a line from the nearest blast hole to the nearest property.

The two permanent locations selected for vibration and air overpressure monitoring are situated within the two closest residential areas to the site. These are Incline Side and Mount View located adjacent to the southern and western boundaries of the site respectively.

Given that the distance from the Incline side to the edge of the blasting exclusion zone is over 300m, a bespoke blast monitor was constructed and installed rather than using a commercial seismograph. The system is based on a design by Birch *et al* (2007).

The advantages of selecting a bespoke monitor were as follows:

1) The system can record from up to 16 channels, thus allowing 4 tri-axial arrays, an air overpressure microphone and a trigger geophone to be deployed. In contrast most commercial units have only one tri-axial geophone and a single air overpressure sensor.

2) The data storage component is a personal computer resulting in a storage capability that is only limited by the capacity of the hard drive. In contrast, in commercial systems, the amount of signal storage memory is restricted by the portability of the system, setting limits on sampling frequency, sample length and number of stored records.

3) Lower signal to noise ratio. The bespoke system employs active amplified tri-axial geophone arrays. Power is supplied to the transducer using 2-core wiring with the signal from the geophone being used to modulate the current draw along the power cable (to industry standard 4-20mA levels). The modulated current signal is then converted to a voltage signal at the system end and fed into an acquisition board. This results in exceptionally clear signals which can be transmitted along very long cables (>200m), with little deterioration in quality. See Birch *et al* (2008) for further detail on active tri-axial geophones.

4) The system records on a common time base which allows analysis of arrival times between the individual tri-axial arrays and the air overpressure microphone.

5) The system has a trigger geophone especially design to respond to very low levels of vibration which is "tuned" to respond to the frequency spectrum usually associated with blasting.

The authors wanted to examine the effect of blast induced vibrations as they enter a property from the exterior and propagate throughout the house. This was achieved by positioning a tri-axial geophone array within the property on each level (ground floor, upper floor and loft) and one tri-axial array was placed outside the property toward the mine. The trigger geophone was also positioned externally adjacent to the exterior tri-axial array. All arrays and geophones were securely coupled in their respective locations, the interior units were bolted to the wall (Figure 8) and the exterior units were buried underneath 0.5m of compacted soil. Figure 9 shows the tri-axial array and trigger geophone in position prior to burial.

The bespoke system also has remote access capabilities via an internet connection. This allows the system to be accessed at anytime to check results, download data or run a system diagnostic without being physically present. Figure 10 show the bespoke system.

The Mount View monitoring location was situated within an enclosed compound adjacent to residential

***Figure 8.** Tri-axial array bolted onto ground floor wall.*

***Figure 9.** Tri-axial array and trigger geophone located outside the property prior to burial.*

***Figure 10.** Bespoke blast monitor situated at Incline Side property.*

properties. However, unlike the Incline Side location, there was no mains power or an internet connection, therefore a bespoke monitoring system would not have been a practical solution. The solution was to use a commercial 'White' seismograph with a portable battery pack, a mobile telephone modem, and transmitter to send and receive data. The tri-axial array was buried approximately 0.3m below the ground surface and the air overpressure microphone was mounted to a pre-existing post positioned in the direction to the mine.

All vibration results collected on-site and off-site are necessary in order to produce the Peak Particle Velocity versus the Scaled Distance charts, which will be used as the basis for the blast design in determining the maximum instantaneous charge weights that can be loaded and hence demonstrate compliance to the regulating authorities.

Achieving environmental control

Many operators in the UK dutifully carry out regular vibration monitoring in accordance with their statutory requirements by monitoring at the nearest occupied premises (often time after time at the same location). Post blast, the seismograph is returned, downloaded and the resulting readings verified for compliance. Having thus proven compliance, the results are then noted and archived. This procedure can be regarded as 'Monitoring for Compliance' (Pegden & Birch, 2005).

Seemingly, it may appear that nothing is wrong with this approach and that maybe the case until the day a problem arises. For an operator who normally experiences a relative harmonious existence with local residents, the sudden onset of blasting complaints together with the possible threat of litigation will be alarming. The full implication of 'Monitoring for Compliance' only becomes clear following a review of the previous blasting events when an updated scaled-distance regression model is constructed that reveals the true problem.

Figure 11 illustrates a fairly extreme example of a scaled-distance regression model for a site that has been 'monitored for compliance'. A visual inspection of the regression curve highlights the problem, all the data has been recorded at the same location and the range of the results in terms of scaled distance is so small that the data points present themselves as a 'ball' or 'clump'. This in turn provides minimal correlation evidence for regression modelling due to the dataset's clustered form, resulting in the correlation coefficient value of 0.08, which is extremely poor.

As a consequence the prediction and charge weight determination made from this data are very poor and inaccurate. For example, if this data was used to determine the MIC of a blast where the nearest property is 300m from the blast and the vibration limit requires 95% of all blast to be below 6 mm/s, the amount of explosives that could be used is 527,251 kg using the data from Figure 11. This is clearly a ridiculous result, made even more so by the fact that the highest level recorded was 4 mm/s at a scaled distance of less than 100m.

A methodology was developed to achieve both environmental control and compliance at Ffos-y-fran by design, and to avoid the possible occurrence of the above situation. This included:

1) Employing more than one seismograph at any one time. At Ffos-y-fran, there is a minimum of two units or a maximum of four (depending on whether the off-site units trigger) that will record any one blast which will increase the range of PPVs recorded.
2) Variation is introduced in terms of scaled distance to avoid the 'clump' effect as the mobile seismographs are placed at a range of distances (near and mid distances).

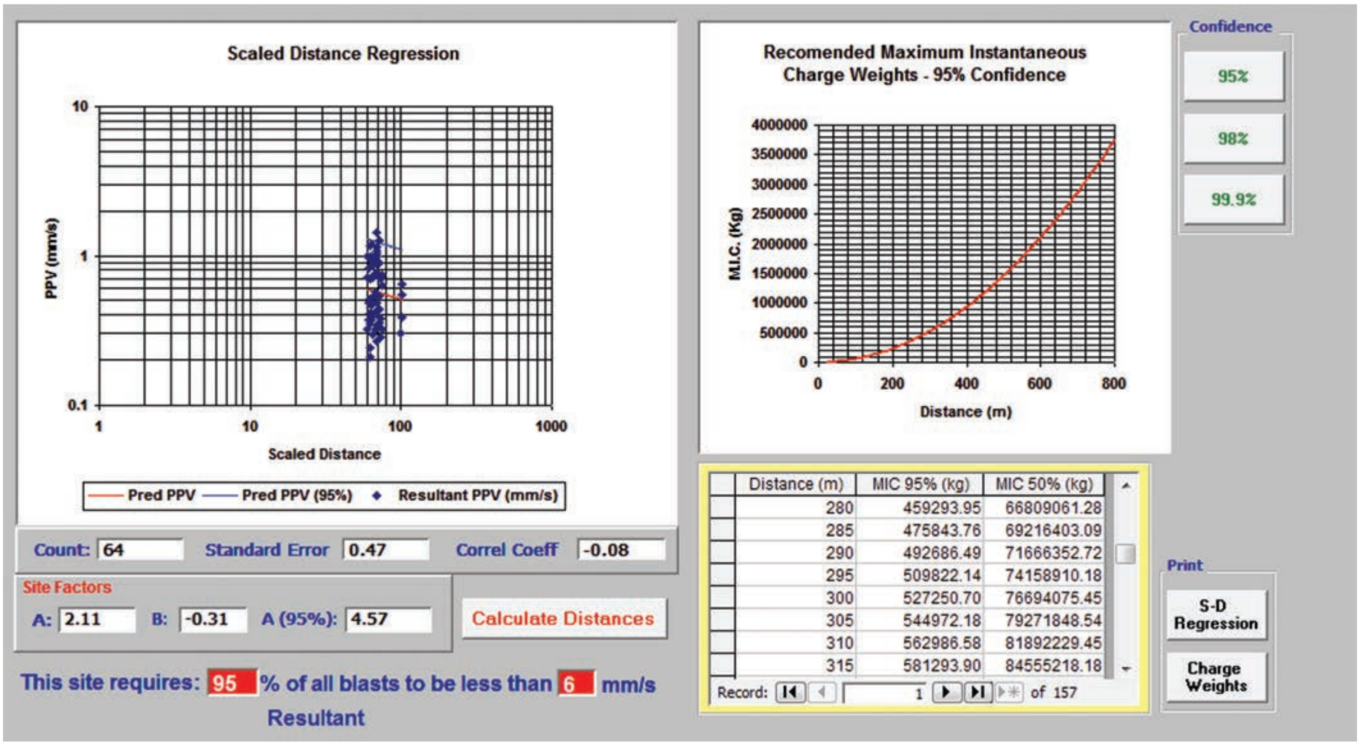

Figure 11. *Example of "clumping" of data points on a blasting regression curve and the table of useable charge weights verses distance.*

3) The regression model is updated on a regular (almost day by day) basis, for calculating permitted MIC and vibration prediction thus any anomalies in the data can be identified and the blast design can be changed accordingly.

4) By continually reviewing the data, any issues or problems with the blasting process can be identified and corrected, and the operator and blasting engineer are constantly learning from every blast that is carried out.

In order to facilitate the described methodology, the Blast Log database was employed to control blasting operations by uploading the key blasting data [i.e. MIC, PPV, blast and monitoring co-ordinates] on a regular basis to give more accurate predictions and hence control. The Blast Log database was first developed by Birch, W.J., Pegden, M. and Stothard, P. (2001) with the aim of developing an information management system for improved blasting practice and environmental compliance. Since 2001, the database has expanded to incorporate a wide range of statistical and analytical tools such as:

1) The ability to analyse data in terms of rock type, area (single or multiple), horizon (single or multiple), detonator type and blast type (test or production blast),

2) The ability to determine whether a monitored location has a different response to the general trend of data (Birch, W.J. and Pegden, M., 2001),

3) The application of likelihood ratio testing to determine whether one blasting dataset is statically similar to another (Birch, W.J., Pegden, M., West, R, and White, T.J., 2004).

The database produces a scaled distance regression chart to statistically evaluate the blast data plus a table of permissible charge weights (based on the blast data and the site licence vibration limit of 95% of all blasts to be below 6 mm/s). An example is shown in Figure 11. The database converts this information in to a simple PDF report which is sent to the operators and regulators to demonstrate that the site is complying with their given vibration limit.

Conclusion

The "Planning to Comply" protocol and methodology used has been successful in delivering a process that can be seen to be transparent, accountable, and quantifiable, in minimising environmental impact whilst not compromising the efficiency of the blasting operations.

To date, the site has carried out over 300 blasts and none of which have exceeded 3 mm/s off-site due to the rigorous environmental monitoring scheme adopted.

By establishing an environmental baseline, the key areas surrounding the site which blasting could affect were identified and then reference houses in those areas were selected for surveying in order to determine the condition of each selected property prior to any blasting being carried out. The data from the surveys was stored in a dedicated database where the data can be accessed and viewed if a resident suspects a crack has formed due to blasting operations.

A series of blast monitors are employed at a range of distances to ensure that at least two vibration recordings are taken from every blast that can then be used in the blast design process. This is necessary so as to avoid data 'clumping' in the scaled distance regression model, which in turn can result in inaccurate prediction and inappropriate charge weights being determined.

The Blast Log database is employed to store and analyse the collected blasting data which is subsequently used for designing each blast. The data is also reported to the operator and regulator to ensure that the site is meeting its statutory vibration limit and in turn demonstrating that environmental control of blasting has been achieved.

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