BLASTING AND VIBRATION IMPACT ASSESSMENT REPORT
FOR EXTRACTION OF LIMESTONE FROM EXTENSION AREAS AT
WHITWELL QUARRY

For

Tarmac

MARCH 2016
CONTENTS

1. INTRODUCTION

2. REVIEW OF THE SITE SURROUNDINGS AND PLANNING DOCUMENTATION
   2.1 Potential receptors in the immediate vicinity of the site
   2.2 Planning and development related documents
   2.3 Summary

3. HISTORIC VIBRATION DATA

4. REVIEW AND ANALYSIS OF RECENT VIBRATION DATA COLLECTED FROM ELECTRONIC INITIATED BLASTS AND VIBRATION PREDICTIONS FOR THE PROPOSED EXTENSIONS
   4.1 Data review and analysis
   4.2 Vibration predictions
      4.2.1 North Extension
      4.2.2 North East Extension
      4.2.3 East Extension
      4.2.4 South East Extension

5. VIBRATION LIMITS FOR WHITWELL RAILWAY TUNNEL AND CRESWELL CRAGS AND CONSIDERATION TOWARDS THE USERS OF THE PUBLIC RIGHT OF WAY (PROW)

6. CONCLUSIONS AND RECOMMENDATIONS

TABLES

1. Distance between each location and historic northern blasting and their predicted values using 50% weightings
2. Distance between each location and historic southern blasting and their predicted values using 50% weightings
3. Distance between the nearest location and nearest point of blasting to the North extension and their predicted values using 50% and 95% weightings
4. Distance between the nearest location and nearest point of blasting to the North East extension and their predicted values using 50% and 95% weightings
5. Distance between the nearest location and nearest point of blasting to the East extension and their predicted values using 50% and 95% weightings
6. Distance between the nearest location and nearest point of blasting to the South East extension and their predicted values using 50% and 95% weightings
7. Equivalent distances between the gas pipeline and crags lodge to the nearest point of blasting at the South East extension with the MIC's required and
predicted PPV values using 50% and 95% weightings to comply with vibration limits

**DRAWING**

1. Proximity of nearest structures to proposed Whitwell extension areas
BLASTING AND VIBRATION IMPACT ASSESSMENT REPORT FOR THE EXTRACTION OF LIMESTONE FROM EXTENSION AREAS AT WHITWELL QUARRY, DERBYSHIRE

1. INTRODUCTION

Blast Log Ltd were engaged by MJCA on behalf of Tarmac to undertake a blast and vibration impact assessment for four proposed extensions to Whitwell Quarry [North, North East, East and South East], and provide a report to be included in the Environmental Impact Assessment (EIA) submission. None of the extensions are located outside the existing planning consent boundaries.

In order to secure the ongoing supply of suitable kiln feed limestone from Whitwell Quarry, Tarmac Ltd proposes extracting suitable kiln feed limestone from the extensions using standard quarrying methods currently employed on-site. The civils grade stone underlying the kiln feed grade stone will continue to be extracted for use as aggregate. This will require the continued use of drill and blast techniques. Each face will be worked in three benches. The top two benches will be generally suitable for kiln feed and the bottom bench (referred to as civils grade stone) is suitable for use as aggregate. Extracted civils stone will be crushed, screened and graded before it is transported from the site by road. The consented reserves will continue to be extracted based on the blasting and monitoring schemes agreed with the Mineral Planning Authority (MPA). The schemes are reviewed by an independent advisor to the MPA and the results of all blast monitoring are sent to the independent advisor for consideration.

In assessing the potential blasting and vibration impacts resulting from the proposals for the four extensions to Whitwell Quarry, the following documents have been reviewed:

Existing planning documents:
• Initial Review of Old Planning Permissions (R5/0705/13) (dated 7 July 2006).

Site documents:
• 2D and 3D Models provided by Tarmac of planning boundaries, site layout and surrounding areas.
• Scheme of blasting and blast monitoring for Whitwell Quarry Extension approved by Derbyshire County Council. An environmental impact assessment for the review of the mineral planning permissions for Whitwell Quarry, Derbyshire (Appendix O1) (LAF/WT/LBR/1279/01) (dated July 2005)
• Extensions to Whitwell dolomitic limestone quarry, removal of the Belph colliery tip into the existing quarry and restoration to agriculture, lakes and woodland, land west of the Southfield Lane, at Peter More Hill and west and east of Crags Road Whitwell (LAF/WT/SPH/1430/02/RMFIN) (dated January 2008).
• Specification for safe working in the vicinity of National Grid high pressure gas pipelines and associated installation - requirements for third parties (SSW22) revision 08/06.

Other documents:
• Proposal for the scope and content of an application for planning permissions and an environmental statement for the extraction of limestone from extension areas at Whitwell Quarry, Derbyshire (LT/WTE/LZH/1655/01/SCOPING) (dated June 2015).
• Proposed extraction of limestone from extension areas at Whitwell Quarry, Derbyshire. Scoping Opinion (SCOM/5/59) (dated November 2015).
The areas surrounding the proposed extensions have been considered, as have any pertinent points or issues raised in the planning related documents listed above, in determining potential impacts of the blasting operations on potential receptors.

Historic blasting data adjacent to the proposed extensions was available and used to predict the likely levels of vibration generated from those areas to the potential receptors. This was carried out to determine if there was any impact of blasting induced vibration on the potential receptors in the past.

As the historic blasts were carried out using blasting techniques that are no longer employed on site [i.e. the use of non-electric detonators for initiating the explosives], vibration results from more recent electronically initiated blasts from Whitwell Quarry have been analysed and used to predict vibration levels likely to be generated from the four extensions and received at the identified potential receptors. This has enabled the level of any impact on the potential receptors to be determined and mitigation measures, if required, to be designed.

The remainder of this report presents this work in the following order:

Section 2: A review of the site surroundings, planning documents, and identification of likely possible impacts generated by the proposed site and potential receptors.

Section 3: Review and analysis of historic vibration data collected from non-electric initiated blasts.

Section 4: Review and analysis of recent vibration data collected from electronic initiated blasts and vibration predictions for the proposed extensions.

Section 5: Conclusions and recommendations.

2. REVIEW OF THE SITE SURROUNDINGS AND PLANNING DOCUMENTATION

2.1 Potential receptors in the immediate vicinity of the site

Drawing No. 1 shows the proposed four extensions to Whitwell Quarry [North, North East, East and South East] and its immediate surroundings. The proposed North extension (highlighted in yellow) is located to the south of Whitwell village and to the north east of Whitwell Tunnel. The proposed North East extension (highlighted in purple) is located to the south east of the Whitwell Village and the west of Southfield Lane. The proposed East extension (highlighted in pink) is located to the west of Crags Road and Hennymoor Lane. The proposed South East extension (highlighted in blue) is located to the west of Hennymoor Lane and to the north of Creswell Crags.

As described, villages, structures or industrial sites surround each of the proposed extensions. Below is a list of the closest residential properties, industrial units or structures, in all directions around each of the proposed extensions, which are shown on Drawing No. 1. The distance to these nearest locations has been calculated using the boundary for each extension, determined by Tarmac, which will be the limit of any potential blasting. The distances stated are therefore the shortest possible distances between blasting and the identified location:

NORTH EXTENSION

Residential properties:

1. Lower Mill Farm is located 532m to the south west of this extension.
2. Peter More is located 315m to the west of this extension.
3. No.1 Vine Cottage is located 254m of the north of this extension.
6. No.20 Franklin Avenue is located 203m to the north of the extension and is the nearest occupied structure to this proposed extension.

9. No1. Longhurst View is located 256m to the north east of this extension. This property is the closest residential building in the Southfield Lane housing estate.

11. No.110 Southfield Lane is located 284m to the north east of this extension. This property is the closest residential building in the housing estate east of Southfield Lane and north of the Whitwell railway station.

**Infrastructure:**

3. The telephone exchange building is located 270m to the north west of this extension. This property is the closest structure to the north west of this proposed extension.

12. Whitwell Railway Tunnel (which is an underground structure) is at a distance of 75m to the south of the extension.

**Educational:**

8. Whitwell Primary School is located 426m to the north east of this extension.

**Industrial units:**

10. Trustseal Ltd, in light industrial units located 223m to the north east of this extension and is the closest structure in the Southfield Industrial site.

**Other:**

5. Stables at a distance of 222m to the north of this extension.

7. An unoccupied outbuilding is located 123m to the north of this extension. As the outbuilding is unoccupied it is not regarded as a sensitive structure but it has been included due its proximity to this proposed extension.

**NORTH EAST EXTENSION**

**Residential properties:**

18. Sherwood Cottage is located 728m to the east of this extension.

19. Penny Green Cottages are located 817m to the east of this extension.

30. No.2 Bridge Close is located 273m to the north of this extension. This property is the closest residential building in the Southfield Lane housing estate.

**Educational:**

8. Whitwell Primary School is located 520m to the north of this extension.

**Industrial units:**

13. Bridalcraft UK, in light industrial units located 186m to the north of this extension and is the closest structure in the Southfield Industrial site.

**Commercial:**

15. At a distance of 135m to the north east of the extension is in unoccupied commercial building.
16. Whitwell MOT centre is located 158m to the north east of the extension and it is the closest occupied structure to the extension.

Infrastructure:

12. Whitwell Railway Tunnel (which is an underground structure) is at a distance of 86m to the north west of the extension.

14. The methane gas extractor is located 82m to the north east of the extension. This structure is the closest structure to the proposed extension.

17. At a distance of 342m to the east of the extension is a sewage works.

27. The shortest distance to the gas pipeline is 93m located to the east of the extension.

EAST EXTENSION

Residential properties:

19. Penny Green Cottages are located 872m to the north east of this extension.

20. Springfield Farm is located c.1.0km to the north east of this extension.

21. Hennymoor Farm is located 387m to the south east of the extension and is the closest occupied structure to this extension.

22. Craggs Lodge is located 465m to the south of this extension.

Educational:

23. Creswell Crags Visitors Centre is located 529m to the south east of this extension.

Infrastructure:

28. The shortest distance to the gas pipeline is 39m located to the east of the extension and is the closest structure to this proposed extension.

SOUTH EAST EXTENSION

Residential properties:

21. Hennymoor Farm is located 352m to the east of this extension.

22. Craggs Lodge is located 162m to the south east of the extension and is the closest occupied structure to this extension.

26. Bank House Farm is located 734m to the west of this extension.

Educational:

23. Creswell Crags Visitors Centre is located 328m to the south east of this extension.

Infrastructure:

29. The shortest distance to the gas pipeline is 11m located to the south of this extension and it is the closest structure to this proposed extension.
Other:

24. Mother Grundy’s Parlour Cave (which is an underground structure) is located 309m to the south of this extension.

25. Robin Hoods Cave (which is also an underground structure) is located 380m to the south west of this extension.

The locations which are the closest to the extensions comprise a range of different building types and structures, including residential buildings, commercial buildings, industrial units, infrastructure (underground gas pipeline), two educational buildings, stables, an unoccupied outbuilding and underground structures (Whitwell Tunnel and two caves located at Creswell Crags).

The closest occupied location to the North extension is Location 6, No. 20 Franklin Avenue at a minimum distance of 203m from the extension area. Although the outbuilding (Location 7) is closer than Location 6, this structure is unoccupied and therefore not considered to be a sensitive structure.

For the North East extension, the closest occupied location is Location 16, Whitwell MOT centre, at a minimum distance of 158m from the extension area. The closest unoccupied structure is the methane gas extractor at 82m.

The closest occupied location to the East extension is Location 21, Hennymoor Farm at a minimum distance of 387m from the extension area. The gas pipeline is the closest structure to the proposed extension at a distance of 39m.

For the South East extension, the closest occupied location is Location 22, Craggs Lodge. It is at a minimum distance of 162m from the extension area. The gas pipeline is the closest structure to the proposed extension at a distance of 11m.

Location numbers 19 and 20, shown on Drawing No. 1, are the nearest structures or buildings to the north east of the East extension and are at distances of 872m and c.1km respectively. They are considered to be too distant to require consideration, but for completeness because they are the nearest buildings in a north-easterly direction, vibration predictions have been calculated for these locations. In summary, for the purpose of this assessment all of the locations numbered 1-29 inclusive will be considered in this impact assessment as potential receptors, based on proximity to the extraction area and structure type.

Whilst there are other residential or commercial developments which may be developed in the future in the vicinity of the new extensions, as there currently are no exact details of any such developments, it is not possible or appropriate to consider potential impacts at this time.

2.2 Planning and development related documents

After reviewing the existing planning documents and the site documents listed in Section 1, the following information has been highlighted as being relevant to the impact assessment.

Under Section 8 of the sites existing planning permissions CM5/0206/178 and R5/0705/13 for the site, vibration limits associated with blasting operations are specified. Ground vibration levels at occupied vibration sensitive building are specified in Condition 42 of planning permission reference CM5/0206/178 and Condition 35 of R5/0705/13 and states “Ground vibration as a result of blasting operations measured at or in close proximity to any occupied vibration sensitive building shall not exceed a peak particle velocity of 6mm/second (mm/s or mms⁻¹) in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5mm/second.”

In Condition 43 of planning permission reference CM5/0206/178 and Condition 36 of R5/0705/13, ground vibration levels at commercial and uninhabited vibration sensitive buildings are specified “ground vibration as a result of blasting operations measured at or in close proximity to any offices, workshops, or uninhabited vibration sensitive buildings not in the ownership or control of the applicant, shall not exceed a peak particle velocity of 12.8mm/second in 95% of all blasting events.”

Whitwell Quarry extensions Blasting and Vibration Impact Assessment
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over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 15mm/second.”

Vibration level limits associated with Whitwell Tunnel are specified in Condition 44 of the planning permission reference CMS/0206/178 and Condition 37 of R5/0705/13 “The level of vibration on Whitwell Tunnel (until decommissioned) and at the railway boundary shall not exceed a maximum peak particle velocity of 12mm/second”.

As of 4th April 2016, 94 blasts have been carried out adjacent to Whitwell tunnel. A total of 707 monitoring results have been recorded both by triaxial geophones in deep boreholes adjacent to the tunnel walls and by triaxial geophones bolted directly on to the tunnel wall. In addition 9 blasts have been carried at Brierlow Quarry in the vicinity of Hindlow Tunnel [Derbyshire]. A total of 36 monitoring results have been recorded by triaxial geophones bolted directly on to the tunnel wall. Regular inspections of both tunnels have been carried out by Network Rail and no damage has been reported. Furthermore a definitive study entitled “the prediction of Peak Particle Velocity Vibration Levels in underground structures that arise as the result of surface blasting” was carried out by Dr William Birch B.Sc., M.Sc, Ph.D, C.Eng, F.I.M.M.M. in fulfilment of the requirements for the Degree of Doctor of Philosophy at the University of Leeds. The conclusion of this detailed research was that no damage was recorded at vibration levels less than 46 mm/sec. In view of these facts it is considered that the existing blast vibration limit should be modified to read 12mm/second in 95% of all blasting events over a six month period.

These criteria have been used as the basis of determining the impact on the potential receptors identified in the vicinity of the proposed extensions to Whitwell Quarry.

Under Condition 12 of planning permission reference CMS/0206/178 it was necessary to submit a detailed working scheme for the southern area. As part of this submission a scheme for blasting in the southern area was prepared. The blasting scheme which was approved as part of the working scheme for the southern area in August 2008 stated that ‘all blasts will be designed such that the blast vibrations will remain inside the limit of: 95% of all blasts to produce blast vibrations of 12mm/sec or less when measured at Creswell Caves and 6mm/sec or less when measured at Craggs Lodge’. Measures to protect Creswell Crags are also included in the Section 106 agreement.

As of 4th April 2016, 320 blasts have been monitored at Creswell Caves and at Craggs Lodge. After each blast a survey has been carried out and no damage has been observed to Cresswell Caves. Also no complaints have been registered by the occupants of either Craggs Lodge or the Cresswell Caves visitor centre. It is therefore considered that the existing vibration limits should pertain to this planning application.

Under Condition 41 of planning permission reference CMS/0206/178 it was necessary to submit a scheme of blasting for the eastern area with respect to blasting within 300m of Hennymoor Farm. The blasting scheme was approved on 22 October 2012. Therefore this criteria has been used in assessing the impact of blasting at the proposed extension areas on Creswell Caves.

The methane gas extractor is located 82m to the north east of the North East extension is neither an occupied vibration sensitive building, commercial nor uninhabited vibration sensitive building therefore the above criteria does not apply to this feature. Annex B of BS 5228-2 acknowledges that many types of equipment and processes are sensitive to vibration, for example, turbine shafts in power stations. Vibration limits are recommended for high precision equipment (e.g. electron microscopes) and for medical processes (e.g. cell implant equipment) but not for above ground gas infrastructure.

In the absence of specific criteria for above ground services infrastructure, it is proposed that a robust and conservative approach is adopted for the vibration limit for miscellaneous underground services. It is proposed that 50 mms⁻¹ is used as the vibration limit criteria as this value is in line with vibration levels associated with reinforced or framed structures and industrial and heavy commercial buildings in BS 5228-2.

The gas pipeline is under the management of National Grid and as such has separate requirements for working in its vicinity. Section 8.5 of their Specification for safe working in the vicinity of gas pipelines (document SSW22) states:

“No blasting should be allowed within 250 metres of a pipeline without an assessment of the
Whitwell Quarry extensions Blasting and Vibration Impact Assessment
MJCA

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Whitwell Extension Vibration Report - Main body MJ CA review Blastlog edited - WB.doc09/03/16
Page 6 of 24
vibration levels at the pipeline. The peak particle velocity at the pipeline must be limited to a maximum level of 75 mms\(^{-1}\). Where the peak particle velocity is predicted to exceed 50 mms\(^{-1}\), the ground vibration shall be monitored by the individual/company undertaking the work and the results available to the National Grid responsible person at their request.”

As shown on Drawing No.1, the pipeline passes at a minimum distance of 93m from the nearest potential point of blasting at the North East extension, 39m from the nearest potential point of blasting at the East extension and 11m from the nearest potential point of blasting at the South East extension. Therefore an assessment of vibration levels on the pipeline is included within this assessment.

2.3 **Summary**

The location of the nearest properties, buildings and structures surrounding the site have been identified and are considered to be potential blast and vibration impact receptors for the purpose of this assessment. These twenty nine locations are set out in Section 2.1 and are shown on Drawing No.1.

Vibration limits to be adopted in this impact assessment have been provided by the limits stated in the sites existing planning permissions and guidance documents. In relation to the gas pipeline, an assessment of vibration levels, required by the operating company when blasting within 250m of the pipeline is included within this assessment. In the absence of vibration limit criteria for the methane gas extractor, it is proposed that 50 mms\(^{-1}\) is employed based on the vibration limits used for reinforced or framed structures and industrial and heavy commercial buildings.

### 3. HISTORIC VIBRATION DATA

As blasting operations have been carried out adjacent to the proposed extension areas historically, it was decided that the vibration results together with the blast co-ordinates and Maximum Instantaneous Charge weight (MIC) would be used to predict the level of vibration each location receptor would have received for an actual blast that had taken place. It was thought that this would be useful in determining if the locations that have been selected as sensitive receptors may have previously experienced blasting induced vibrations, especially as historically the bench heights were much greater than those used at present which resulted in the use of deeper blast holes and thus more explosives being placed into each of the holes. This in turn would have produced higher vibration when compared to blasts carried out in the present day.

In addition to the greater bench heights, Whitwell historically employed non-electric detonators to initiate each blast holes [which are no longer used on-site as the basis of primary initiation]. Non-electric detonators employ a pyrotechnic delay element for initiation. These detonators achieve their millisecond delays pyrotechnically by the rapid burning of chemical powder, the greater the length of powder, the longer the delay. Due to the pyrotechnic arrangement of the detonator, there is an inherent detonator delay error whereby two adjacent blast holes designed to initiate to give specific delay times between them, may fire at a shorter delay time than expected or a longer delay time than expected. This can result in the unwanted effect of added vibration being produced from the explosives in the two blast holes interacting together in a manner that would produce a higher level of vibration than expected. When vibration data from non-electric blasts is graphically plotted against distance, there is always an associated ‘data scatter’ due to this inherent delay error. All advertised non-electric detonator firing times represent nominal values and may not accurately represent the precise time of detonation. The stated firing times on such detonators needs to be evaluated statistically based on a normal distribution curve.

Blast Log Ltd holds a substantial database of blast and vibration results from Whitwell Quarry. Historic data relating to non-electric initiated blasting operations were interrogated in the database. The historic data selected for this assessment are based on results collected from blasts that were carried out in the northern and southern areas of the quarry. The vibration results obtained were collected from the seismographs that were positioned at surface level and not at a sub-surface or underground level. It is well known that vibration from blasting attenuate at different rates depending on depth and the medium through which it travels for a given blast, therefore the predictions produced using this historic data will only be valid for surface locations and not underground locations. Thus for the purposes of this historical assessment, the underground locations [No.12 Whitwell Tunnel, No.24 Mother Grundy’s Parlour, No.25 Robin Hood Cave and
No.27-29 Gas pipeline] will be excluded.

The vibration data was then separated into two subsets; northern and southern. This was considered necessary as the vibration produced from blasting in the southern area attenuate at a slower rate than those in the northern area. Furthermore the geology is more variable in the Southern area. The vibration results produced from blasting in the northern area are more predictable than those that result from blasting in the southern area. Using the Scaled Distance and peak particle velocity [PPV] data from each subset and the MIC for the given blasts that had taken place, PPV predictions that were likely to have been received at the location receptors were calculated at 50% probability.

The calculation used to predict the vibration levels [PPVs] at the receptor locations is shown in Equation 1.

\[
PPV = A \times \left( \frac{\text{distance}}{\sqrt{\text{MIC}}} \right)^B
\]

Equation 1. A and B are known as the site factors which are obtained through monitoring and regression analysis.

In equation 1, the distance value is the distance from the blast to the nearest residential/sensitive property or monitoring location.

As with all statistical techniques, there is an error range associated with the estimate. Thus for any value of scaled distance, the predicted PPV using a 50% confidence is the mean estimate of the value such that there is a 50% chance that the actual vibration level will be above the calculated prediction and a 50% chance it will be below this value.

A set of predictions were generated for all location receptors using both the northern and southern datasets. The northern area predictions were based on 20 vibration results and the southern area was based on 28 vibration results. In interpreting these results, caution needs to be exercised as these are considered to be very small data sets. Tables 1 and 2 show these vibration predictions for each receptor excluding the underground locations [No.12 Whitwell Tunnel, No.24 Mother Grundy's Parlour and No.25 Robin Hood Cave] based on the northern data and southern data respectively.

From Table 1, Location 7, the unoccupied outbuilding, had highest predicted value of 3.09 mms\(^{-1}\) at a distance of 229m from the given blast. The nearest occupied structure Location 6, No.20 Franklin Ave, produced a predicted value of 1.68 mms\(^{-1}\) at a distance of 303m. Based on the vibration predictions calculated in Table 1 and the threshold of human perception to vibration from blasting is 0.5 mms\(^{-1}\), it is very likely that Locations 1 to 16 (excluding location 12) received a low but perceptible level of vibration from blasts carried out in the northern area of the quarry. At locations that were at distance in excess of approximately 550m from a given blast carried out in the northern area, it is likely that the level of vibration may not have been perceptible. Such a conclusion was found to be comparable with other “blasting in limestone” data sets.

Based on Table 2, Location 22, Craggs Lodge which is an occupied residential property, produced the highest predicted value of 4.99 mms\(^{-1}\) at a distance of 431m from the given blast. From Table 2, it can be said that all locations (excluding locations, 12, 24 25 and 27 to 29) may have historically received perceptible vibration levels from blasting carried out in the southern area, as all vibration predictions are equal to or above the threshold of human perception to vibration from blasting of 0.5 mms\(^{-1}\).

Overall, based on the historic blast and vibration data, it is highly likely that the locations selected as sensitive receptors (excluding locations, 12, 24, 25 and 27 to 29) received a level of vibration which were perceptible but low.

4. REVIEW AND ANALYSIS OF RECENT VIBRATION DATA COLLECTED FROM ELECTRONIC INITIATED BLASTS AND VIBRATION PREDICTIONS FOR THE PROPOSED EXTENSIONS

As discussed in Section 3, non-electric detonators are no longer employed at Whitwell Quarry as the primary source of blast initiation; due to improvements in detonators, electronic detonators are
used as the alternative. These detonators have a circuit board attached to the fuse head of the
detonator which are user programmable in terms of the delay or initiation timings. As the initiation
timings are carried out electronically, [in contrast to non-electric detonators which are carried out pyrotechnically], there is little to no delay error. Thus the accuracy of initiation is much greater.
The accuracy of an electronic detonator is approximately one tenth of a millisecond or ±0.1
millisecond. As such, in comparison to the non-electric vibration data, there is less data scatter
when the results are plotted. Thus any predictions made using electronic results will be more
accurate than non-electric data. Due to these factors, only data collected from electronic initiated
blasts were used to calculate the predictions for each of the proposed extension areas.

4.1 Data review and analysis
The first stage of the process is to carry out a statistical assessment of the blasting data. This was
carried out to determine the quality of the data, thus if the data was considered to be of high
quality, the predictions made using the data would be of good quality and valid. As was the case
for the historic vibration data, the more recent electronic vibration data collected from
seismographs coupled to the surface was sub-divided into northern and southern areas. In
addition, vibration results have also been collected from the underground structures which were
used in the assessment. These were from monitoring locations associated with Robin Hood’s Cave,
Mother Grundy’s Parlour, together with the north and south walls of Whitwell Tunnel. Results
collected from three monitoring boreholes located adjacent to the existing southern extension were
also reviewed as they were subsequently used to assess the vibration levels associated with the gas
pipeline as both the monitoring boreholes and pipeline are at a sub-surface level.

Figure 1 shows 168 vibration results collected from the northern area in a scaled distance
regression model together with the 50% and 95% confidence lines.

The determination of data quality is dependent on the scatter of the points used to produce the
best fit line (also known as the 50% confidence line). The “measure of the degree of best fit”
relates both to the correlation coefficient (CC) and the Standard Error (SE). It is clear from the
graph that the spread of data or ‘scatter’ is small and this is confirmed by the standard error which
reports a value of 0.35 which is very good. The results show little variability between the individual
data points within each blast as most of the results lie around the 50% prediction line. This suggests that vibrations produced from these blasts attenuated proportionally with increasing distances. In addition, the reported correlation co-efficient of 0.73 is also good. Based on the standard error and correlation co-efficient, it can be said that the 168 results collected from the northern blasts are of very good quality and can be used for predicting surface related vibration in the northern area.

Figure 2 shows 420 vibration results collected from the southern area in a scaled distance regression model together with the 50% and 95% confidence lines.

From a visual inspection of Figure 2, it seems to be very similar to Figure 1 such that the spread of data or ‘scatter’ is small; this is confirmed by the standard error which reports a value of 0.36 which is very good. The results show little variability between the individual data points within each blast as most of the results lie around the 50% prediction line. This suggests that vibrations produced from these blasts attenuated proportionally with increasing distances. In addition, the reported correlation co-efficient is 0.89 is also very good. Based on the standard error and correlation co-efficient, it can be said that the 420 results collected from the southern blasts are of very good quality and can be subsequently used for predicting surface related vibrations in the southern area.

In addition to the surface collected results, results collected from the underground structures were also assessed. Eight tri-axial geophone arrays were installed on the tunnel lining of Whitwell Tunnel in 2010 in agreement with Network Rail to assess the impact of blasting on the tunnel and to determine if the vibrations produced from blasting operations adjacent to the tunnel are below the vibration limit of 12 mms\(^{-1}\) set by Network Rail. Four arrays are located on the northern wall and four are located on the southern wall equidistant along the tunnel. All cabling runs to a central point on the quarry boundary where the cables are attached to a series of monitoring units. At the time of writing, 330 results were collected, of which 178 results were collected from the northern tunnel wall and the remaining 152 results were collected from the southern tunnel wall. It is also worth noting that no vibration result collected in the tunnel has equalled or exceeded the 12 mms\(^{-1}\) limit despite the proximity of the blasting.

Figure 3 shows 178 vibration results collected from the northern tunnel wall in a scaled distance regression model together with the 50% and 95% confidence lines.
From Figure 3, there seems to be some data scatter which is confirmed by the standard error which reports a value of 0.40 which is good and suggests that the results have some variability between the individual data points within each blast as most of the results lie around the 50% prediction line. However, a value of 0.40 is still good and implies that vibrations produced from these blasts attenuated proportionally with increasing distances which is confirmed by the reported correlation co-efficient of 0.91 which is excellent. Based on the standard error and correlation co-efficient, it can be said that the 178 results collected from the northern tunnel wall are of very good quality and can be used for the predicting vibration received on the north wall of Whitwell Tunnel.

Figure 4 shows 152 vibration results collected from the southern tunnel wall in a scaled distance regression model together with the 50% and 95% confidence lines.
From a visual inspection of Figure 4, it appears to be very similar to Figure 3 such that there appears to be some data scatter. This is confirmed by the standard error which reports a value of 0.33 which is very good. This suggests that there is little variability between the individual data points within each blast as most of the results lie around the 50% prediction line. The reported correlation co-efficient of 0.90 is excellent and suggests that vibrations produced from these blasts attenuated proportionally with increasing distances. Based on the standard error and correlation co-efficient, it can be said that the 152 results collected from the southern tunnel wall are of very good quality and can be used for the predicting vibration received on the south wall of Whitwell Tunnel.

Vibration results were also collected from within the caves located at Creswell Crags located south of the quarry. As determined in Section 2.1, Robin Hood Cave and Mother Grundy’s Parlour are potential receptors for the South East extension. At the time of writing, 213 vibration results have been collected from Robin Hood Cave and 188 results have been recorded at Mother Grundy’s Parlour.

Figure 5 shows 213 vibration results collected from Robin Hood Cave in a scaled distance regression model together with the 50% and 95% confidence lines.

From Figure 5, there seems to be a noticeable amount data scatter around the 50% predicted line which is confirmed by the standard error which reports a value of 0.48 which is reasonable. This suggests that the results collected have significant amount of variability between the individual data points within each blast as most of the results lie around the 50% prediction line. The reported correlation co-efficient is 0.52 which is poor, this strongly implies that vibrations produced from these blasts have not attenuated proportionally with increasing distances which is noticeable in Figure 5 by a clumping effect of the data. As described previously, it is known that vibration produced from blasting in the south are different to those produced in the northern area primarily due to the geology in the south having a significant amount of micro-fissures as well as clay "dyke like" and clay filled “swallow hole” features. These geological structures result in vibrations travelling along or through these features and attenuating at different rates. The surface results collected from blasting operations in the southern area shown in Figure 2 demonstrates that this effect did not occur at monitoring locations at surface level, this suggests that this phenomenon primarily affects sub-surface or underground locations such as Robin Hood Cave.

Based on the standard error and correlation co-efficient, it can be said that the results collected from Robin Hood Cave are not of good quality in comparison to the other datasets described previously, however, this is most likely due to the function of geology between the southern blasting area and Robin Hood Cave and therefore the results collected are valid and as such can be used for the predicting vibration received at Robin Hood Cave.
Figure 6 shows 188 vibration results collected from Mother Grundy Parlour in a scaled distance regression model together with the 50% and 95% confidence lines.

From a visual inspection of Figure 6, there seems to be some data scatter which is confirmed by the standard error which reports a value of 0.33 which is very good. The results suggest that there is little variability between the individual data points within each blast as most of the results lie around the 50% prediction line. The reported correlation co-efficient is 0.72 is good and suggests that vibrations produced from these blasts attenuated proportionally with increasing distances. From the statistics, it can be said that the 188 results collected from this cave are of good quality and can be used for the predicting vibration received at Mother Grundy’s Parlour.

A visual comparison between Mother Grundy’s Parlour (Figure 6) and Robin Hood Cave (Figure 5) shows that the clumping effect in Figure 5 does not seem to be present in Figure 6 which is confirmed by the decreased standard error and increase correlation coefficient value. This suggests that the effect of geology in the southern area (i.e. the clay “dyke like” features and micro-fissures) have a smaller effect on Mother Grundy’s Parlour in comparison to Robin Hood Cave.

As determined in Section 2.1, the gas distribution pipeline that runs adjacent to the eastern and southern perimeter of the site is a potential receptor for the North East extension, East extension and South East extension. As the pipeline is buried underground, the vibration results collected from seismographs coupled to the ground, the tunnel and Creswell Caves are not suitable to assess the potential vibrations levels that would be received by the pipeline. However, in order to carry out routine monitoring at the Southern Extension, a series of boreholes were drilled (approximately 12m in depth) and vibration monitoring equipment was placed in each of them to assess the vibrations produced from blasting operations at a sub-surface depth. The results collected from these boreholes have been used to assess the likely impact of blasting on the gas pipeline. This is considered to be appropriate as both the boreholes and the gas pipeline are buried and therefore likely to have a very similar response to vibration produced from blasting. At the time of writing, 253 results have being collected from three boreholes located at the Southern Extension.

Figure 7 shows 253 vibration results collected from the three boreholes at the Southern Extension in a scaled distance regression model together with the 50% and 95% confidence lines.
Figure 7.

From Figure 7, the graph shows some data scatter which is mostly at the closer scaled distances of less than 10m/kg$^{1/2}$. The standard error of the dataset reports a value of 0.41 which is good and suggests that the results have some variability between the individual data points within each blast as most of the results lie around the 50% prediction line. However a value of 0.41 is still good and implies that vibrations produced from these blasts attenuated proportionally with increasing distances. This is confirmed by the reported correlation co-efficient of 0.90 which is excellent. Based on the standard error and correlation co-efficient, it can be said that the 253 results collected from the three boreholes are of very good quality and can be used for the predicting vibration received on the gas pipeline.

Overall, based on the above review and analysis of the data and associated subsets, all datasets are considered to be suitable for use in determining the vibration predictions for selected sensitive receptors.

4.2 Vibration predictions

As a significant amount of vibration data was available from blasting operations carried out adjacent to the proposed extensions, it was decided that these results would be used as the basis for the vibration predictions for each selected receptor. The vibration produced from blasting operations currently being carried out at the northern and southern areas at Whitwell Quarry and their subsequent attenuation characteristics is expected to be similar to that which will be produced by the operations within the proposed extension areas, as the type of blasting employed and geology will be very similar. The findings of Section 4.1 demonstrated that the vibration results collected can be used to generate reliable predictions for the proposed extensions.

Thus vibration predictions for each of the potential receptors of each proposed extension described in Section 2.1 have been calculated. This used all vibration results that were produced from electronically initiated blasts recorded in the northern and southern areas of Whitwell Quarry, up to and including October 2014. Tables 3 to 6 shows these vibration predictions for the potential receptors to each of the proposed extensions based on the nearest point of blasting and a charge weight of 40kg. The 40kg charge weight has been selected as this best reflects current blasting practice at Whitwell Quarry, based on the typical bench heights and blast hole depths, hence best reflect the likely charge weights that will be required. The results for each extension area are described below.
4.2.1 North Extension

Table 3 shows the vibration predictions for each potential receptor to the North extension. The results are summarised below.

- Of the six residential properties (locations 1, 2, 4, 6, 9 and 11) which are regarded as vibration sensitive buildings, the nearest, No.20 Franklin Avenue (203m) had predicted vibration levels of 2.37 mms$^{-1}$ and 4.22 mms$^{-1}$ based on a 50% and 95% weighting respectively. The others are lower.

- Location 7, the outbuilding, which is not regarded as a sensitive structure, is located 79m from the proposed extension and had maximum predicted vibration levels of 4.29 mms$^{-1}$ using a 50% confidence and 7.63 mms$^{-1}$ based on a 95% confidence.

- Location 3, the Telephone exchange, is located 239m from the proposed extension and had maximum predicted vibration levels of 1.69 mms$^{-1}$ using a 50% confidence and 3.02 mms$^{-1}$ based on a 95% confidence.

- The nearest building in the Southfield Industrial Site, Trustseal Ltd (Location 10), is located 192m from the proposed extension and had maximum predicted vibration levels of 2.12 mms$^{-1}$ using a 50% confidence and 3.78 mms$^{-1}$ based on a 95% confidence.

- Location 5, the stables, is located 182m from the proposed extension and had maximum predicted vibration levels of 2.13 mms$^{-1}$ using a 50% confidence and 3.80 mms$^{-1}$ based on a 95% confidence.

- Whitwell Primary School (Location 8) is located 381m from the proposed extension and had maximum predicted vibration levels of 0.99 mms$^{-1}$ using a 50% confidence and 1.76 mms$^{-1}$ based on a 95% confidence.

- The closest distance of blasting operation to Whitwell Tunnel (Location 12) is 75m. Using a charge weight of 40kg the maximum predicted levels of 6.85 mms$^{-1}$ and 13.15 mms$^{-1}$ based on 50% and 95% weighting respectively were calculated, at tunnel. Given that the vibration limit is required to be 12mms$^{-1}$ at the tunnel and the predicted 95% level is above that level, it is recommended that the charge weight used, be reduced to 36kg to “plan to comply” with the 12mms$^{-1}$ limit. This would then reduce the maximum predicted levels to 5.82 mms$^{-1}$ and 11.18 mms$^{-1}$ based on 50% and 95% weighting respectively, based on the distance of 75m from Whitwell Tunnel.

The calculated predictions indicate that the North extension would be able to comply with the vibration limit specified in the site’s existing planning permissions that “Ground vibration as a result of blasting operations measured at or in close proximity to any occupied vibration sensitive building shall not exceed a peak particle velocity of 6mm/second in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5mm/second” as all occupied residential, education, industrial or commercial buildings (locations 1-6 and 8-12) have calculated vibration predictions (both 50% and 95% weighting) at less than 6mm/s$^{-1}$. The highest calculated vibration prediction at these locations is location 6, No. 20 Franklin Avenue where 2.37 mms$^{-1}$ and 4.22 mms$^{-1}$ were predicted based on 50% and 95% weighting respectively. As the predicted level of vibration is above that of the threshold level of human perception (0.5 mms$^{-1}$), blasting operations at the North extension will likely be perceptible at these receptors especially those structures directly north of the North extension. Care will need to be exercised as these predicted vibration levels are considered to be moderate. Although there will be no likelihood of damage to properties, from time to time blasting vibrations experienced by local residents will be noticeable.

The vibration predictions for Location 7, the outbuilding, calculated vibration level greater than 6 mms$^{-1}$ at a 95% confidence level, however this building is unoccupied and therefore the 6 mms$^{-1}$ limit does not apply, and is replaced with a vibration limit of 15 mms$^{-1}$ based on limit for
unoccupied buildings. As the predicted values for the building has been calculated to be less than 15 mms\(^{-1}\), this demonstrates that North extension would comply with the limit set for the unoccupied building and the potential impact of vibration on the identified unoccupied building should be low.

As described in the summary point above, the use of a 40kg charge weight at the closest point of blasting to Whitwell Tunnel of 75m is predicted to receive 6.85 mms\(^{-1}\) and 13.15 mms\(^{-1}\) based on a 50% and 95% confidence respectively. Given that the vibration limit is required to be 12mms\(^{-1}\) at the tunnel and the predicted 95% level is above that level, it is suggested that the charge weight would have to be reduced to approximately 32kg for the closest point of blasting to the tunnel of 75m. This would produce the maximum predicted levels of 5.31 mms\(^{-1}\) and 10.20 mms\(^{-1}\) based on 50% and 95% weighting respectively.

Prediction calculations indicate that the impact of vibration on the identified potential receptors will be moderate. Whilst no additional mitigation measures over and above good blasting design and practice are considered necessary, regular blast vibration monitoring should be considered. Tarmac agreed with the above measures and it is understood that they will carry out monitoring using stand-alone commercial seismographs.

### 4.2.2 North East Extension

Table 4 shows the vibration predictions for each potential receptor to the North East extension. The results are summarised below.

- Location 16 (Whitwell MOT Centre) is regarded as nearest occupied vibration sensitive building at a distance of 158m. This location had maximum predicted vibration levels of 3.19 mms\(^{-1}\) and 5.68 mms\(^{-1}\) based on a 50% and 95% weighting respectively.

- Location 15, the unoccupied building, is regarded as nearest unoccupied vibration sensitive building located 135m from the proposed extension and had maximum predicted vibration levels of 3.84 mms\(^{-1}\) using a 50% confidence and 6.84 mms\(^{-1}\) based on a 95% confidence.

- The nearest building in the Southfield Industrial Site directly north of the extension, Bridalcraft UK (Location 13), is located 186m from the proposed extension and had maximum predicted vibration levels of 2.63 mms\(^{-1}\) using a 50% confidence and 4.68 mms\(^{-1}\) based on a 95% confidence.

- The nearest residential property in the Southfield Lane housing estate, No.2 Bridge Close (location 30) is located 273m from the proposed extension and had predicted vibration levels of 1.67 mms\(^{-1}\) and 2.98 mms\(^{-1}\) based on a 50% and 95% weighting respectively.

- The two closest residential buildings to the east of the proposed extension, Location 18 (Sherwood Cottage) and 19 (Penny Green Cottages), are located 728m and 817m from the site respectively. The closest building, Sherwood Cottage had maximum predicted vibration levels of 0.53 mms\(^{-1}\) using a 50% confidence and 0.94 mms\(^{-1}\) based on a 95% confidence. Penny Green Cottages is further from the site boundary and thus the predicted vibrations are lower. Due to the fact that the distance from the closest point of blasting to each location is in excess of 500m and the vibration predictions at a 50% confidence for Location 18 and 19 are equal to or less than the threshold level of human perception to vibration (0.5 mms\(^{-1}\)), it is highly unlikely that vibrations produced from blasting at the North East extension will be experienced at these receptors.

- The sewage works (Location 17), is located 342m to proposed extension and had maximum predicted vibration levels of 1.28 mms\(^{-1}\) using a 50% confidence and 2.28 mms\(^{-1}\) based on a 95% confidence.
• The closest distance of blasting operations to Whitwell Tunnel (Location 12) is 86m. Based on this distance, the maximum predicted vibration levels of 5.54 mms\(^{-1}\) using a 50% confidence and 10.63 mms\(^{-1}\) based on a 95% confidence.

• The methane gas extractor (Location 14) is regarded as nearest non-residential vibration sensitive structure to the proposed North East extension area with a distance of 82m from the closest point of blasting. The maximum predicted levels are 6.92 mms\(^{-1}\) and 12.31 mms\(^{-1}\) based on 50% and 95% weighting respectively were calculated, at the methane gas extractor.

• Whitwell Primary School (Location 8) is located 520m from the proposed extension and had maximum predicted vibration levels of 0.78 mms\(^{-1}\) using a 50% confidence and 1.39 mms\(^{-1}\) based on a 95% confidence. As the value predicted at the 50% confidence is near to the threshold level of human perception to vibration (0.5 mms\(^{-1}\)) and the closest distance from blasting operations is expected to be greater than 500m, it is very unlikely that blast induced vibration will be experienced at this location.

• The closest distance of blasting operations to the Gas pipeline (Location 27) is 93m. Based on this distance, the maximum predicted vibration levels of 4.03 mms\(^{-1}\) using a 50% confidence and 7.90 mms\(^{-1}\) based on a 95% confidence.

The calculated blast vibration predictions indicate that the North East extension would be able to comply with the vibration limit specified in the site's existing planning permissions that "Ground vibration as a result of blasting operations measured at or in close proximity to any occupied vibration sensitive building shall not exceed a peak particle velocity of 6mm/second in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5mm/second" as all occupied residential, educational, industrial or commercial buildings (locations 8, 13, 16, 18, 19 and 30) have calculated vibration predictions (both 50% and 95% weighting) at less than 6mms\(^{-1}\). The highest calculated vibration prediction at these locations is location 16, Whitwell MOT Centre where 3.19 mms\(^{-1}\) and 5.68 mms\(^{-1}\) were predicted, based on 50% and 95% weighting respectively. Although the level of vibration is above the threshold level of human perception (0.5 mms\(^{-1}\)), in general they are considered to be low therefore it can be said that the potential impact of vibration on these identified buildings should range from low to negligible. However the vibration levels predicted at the Whitwell MOT Centre are considered to be moderate, thus monitoring of vibration levels should be considered. Tarmac agreed with the above measures and it is understood that they will carry out monitoring using stand-alone commercial seismographs.

Vibration predictions for Location 15, the unoccupied building, calculated vibration level greater than 6 mms\(^{-1}\) at a 95% confidence level, however as this building is unoccupied the 6 mms\(^{-1}\) limit does not apply, and is replaced with a vibration limit of 15 mms\(^{-1}\) based on limit for unoccupied buildings. As the predicted values for the building has been calculated less than 15 mms\(^{-1}\), this demonstrates that North East extension would comply with the limit set for the unoccupied building and the potential impact of vibration on the identified unoccupied building should be low.

Vibration predictions for locations 8, 18 and 19 calculated at a 50% confidence were near to or below that of the human perception level of c.0.5 mms\(^{-1}\). As such, it is highly unlikely that vibrations from blasting would be experienced at these three locations or at distances of greater than 500m from the site.

The vibration predictions for the nearest non-residential structure [the methane gas extractor] exceed 6 mms\(^{-1}\) with the closest point of the gas extractor to blasting predicted to receive 6.92 mms\(^{-1}\) and 12.31 mms\(^{-1}\) based on a 50% and 95% confidence respectively. However, both predicted values are significantly lower than the maximum vibration limit of 50 mms\(^{-1}\) employed in this assessment. As such the possible impact of blasting on the gas extractor is considered to be low and the limit of 50 mms\(^{-1}\) should not be exceeded based on the predictions made.

The vibration predictions for Whitwell Tunnel based on the closest point of blasting is predicted to receive 5.54 mms\(^{-1}\) and 10.63 mms\(^{-1}\) based on a 50% and 95% confidence respectively. Both predicted values are lower than the maximum vibration limit of 12 mms\(^{-1}\) specified in site's existing...
planning permissions. Therefore the possible impact of blasting on Whitwell Tunnel is considered to be low.

The vibration predictions for gas pipeline based on the closest point of blasting is predicted to receive 4.03 mms⁻¹ and 7.90 mms⁻¹ based on a 50% and 95% confidence respectively. Both predicted values are significantly lower than the maximum vibration limit of 75 mms⁻¹, stated in Section 8.5 of their Specification for safe working in the vicinity of gas pipelines (document SSW22). As such the possible impact of blasting on the gas main is considered to be low to negligible and the limit of 75 mms⁻¹ should not be exceeded based on the predictions made.

Overall, the prediction calculations indicate that the impact of vibration on the identified potential receptors will be low to negligible and no additional mitigation measures over and above good blasting design and practice are considered necessary.

4.2.3 East Extension

Table 5 shows the vibration predictions for each potential receptor to the East extension. The results are summarised below.

- Of the four residential properties (locations 19, 20, 21 and 22) which are regarded as vibration sensitive buildings the nearest, Hennymoor Farm (at 387m) had predicted vibration levels of 1.16 mms⁻¹ and 2.15 mms⁻¹ based on a 50% and 95% weighting respectively. The distance from the site boundary to the other properties is much further; hence the predicted blast vibrations are lower.

- Location 19 (Penny Green Cottages) and 20 (Springfield Farm), are located 872m and 1016m from the site respectively. The closest structure, Penny Green Cottages had maximum predicted vibration levels of 0.34 mms⁻¹ using a 50% confidence and 0.64 mms⁻¹ based on a 95% confidence. The distance from the closest point of blasting to each location is greater than 500m and the vibration predictions at a 50% confidence for Location 19 and 20 are equal to or less than the threshold level of human perception to vibration (0.5 mms⁻¹). It is therefore highly unlikely that vibrations produced from blasting operations at the East extension will be experienced at these receptors.

- The gas pipeline (Location 28), was determined as the nearest receptor to the proposed East extension area with distance of 39m from the closest point of blasting. The maximum predicted levels are 13.83 mms⁻¹ and 27.14 mms⁻¹ based on 50% and 95% weighting respectively were calculated, at the methane gas extractor.

- Creswell Crags Visitors Centre (Location 23) is located 592m from the proposed extension and had maximum predicted vibration levels of 0.61 mms⁻¹ using a 50% confidence and 1.14 mms⁻¹ based on a 95% confidence.

The calculated predictions indicate that the East extension would be able to comply with the limit specified in the site’s existing planning permissions that “Ground vibration as a result of blasting operations measured at or in close proximity to any occupied vibration sensitive building shall not exceed a peak particle velocity of 6mm/second in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5mm/second” as all residential and educational buildings (locations 19, 20, 21, 22 and 23) have calculated vibration predictions (both 50% and 95% weighting) less than 6mms⁻¹. The highest calculated vibration prediction at any of these locations is location 21, Hennymoor Farm where 1.16 mms⁻¹ and 2.15 mms⁻¹ were predicted based on 50% and 95% weighting respectively. Although the highest calculated level of vibration is above the threshold level of human perception (0.5 mms⁻¹) all values are considered to be very low therefore it can be said that the potential impact of vibration on these identified buildings should be low to negligible.

The vibration predictions for gas pipeline based on the closest point of blasting is predicted to receive 13.83 mms⁻¹ and 27.14 mms⁻¹ based on a 50% and 95% confidence respectively. Both
predicted values are significantly lower than the maximum vibration limit of 75 mm/s\(^2\), stated in Section 8.5 of their Specification for safe working in the vicinity of gas pipelines (document SSW22). As such the possible impact of blasting on the gas main is considered to be low and the limit of 75 mm/s\(^2\) should not be exceeded based on the predictions made. Due to the close proximity of the extension to the gas pipeline, Blast Log recommends that vibration predictions, monitoring and reporting should be taken into consideration when blasting adjacent to the gas pipeline and this is understood by Tarmac.

Similar to the findings of Section 4.2.3, the prediction calculations indicate that the impact of vibration on the identified potential receptors surrounding the East extension will be low to negligible and no additional mitigation measures over and above good blasting design and practice are considered necessary.

### 4.2.4 South East Extension

Table 6 shows the vibration predictions for each potential receptor to the South East extension using an MIC of 40kg. The results are summarised below.

- Based on the three residential properties (locations 21, 22 and 26) which are regarded as vibration sensitive buildings, a 40kg MIC would be suitable for Hennymoor Farm and Bank House Farm as Hennymoor Farm is predicted to receive 1.38 mm/s\(^2\) and 2.49 mm/s\(^2\) based on 50% and 95% weighting respectively. Bank House Farm predicted to receive 0.48 mm/s\(^2\) and 0.86 mm/s\(^2\) based on 50% and 95% weighting respectively.

- The nearest residential property, Craggs Lodge (162m) had predicted vibration levels of 4.20 mm/s\(^2\) and 7.61 mm/s\(^2\) based on a 50% and 95% weighting respectively, using a charge weight of 40kg. Given that the vibration limit is 6 mm/s\(^2\) at 95% confidence and that the predicted 95% level is higher [7.61 mm/s\(^2\)], a 40kg charge weight is unsuitable at a distance of 162m. In order to keep within the 6 mm/s\(^2\) at 95% Confidence limit, the charge weight would have to be reduced to approximately 22kg. This would produce the maximum predicted levels of 2.73 mm/s\(^2\) and 4.95 mm/s\(^2\) based on 50% and 95% weighting respectively.

- The two nearest cave locations, location 24 (Mother Grundy’s Parlour) and 25 (Robin Hood Cave), are located 309m and 280m from the site respectively based on the nearest point of blasting. The closest cave, Mother Grundy’s Parlour had maximum predicted vibration levels of 2.00 mm/s\(^2\) using a 50% confidence and 4.41 mm/s\(^2\) based on a 95% confidence. Robin Hood’s cave is predicted to receive 1.69 mm/s\(^2\) using a 50% confidence and 2.91 mm/s\(^2\) based on a 95% confidence.

- Creswell Crags Visitors Centre (Location 23) is located 328m from the proposed extension and had maximum predicted vibration levels of 1.52 mm/s\(^2\) using a 50% confidence and 2.75 mm/s\(^2\) based on a 95% confidence.

- The gas pipeline (Location 29), was determined as the nearest receptor to the proposed South East extension area with a distance of 11m from the closest point of blasting. The maximum predicted levels calculated were 83.42 mm/s\(^2\) and 163.76 mm/s\(^2\) based on 50% and 95% weighting respectively, at the pipeline. Based on the vibration limit of 75 mm/s\(^2\) and the predicted level is significantly higher than that value, a charge weight 40kg is unsuitable at a distance of 11m. In order to keep the vibration levels below that of 75 mm/s\(^2\), the blast would have to be designed on the basis of a 95% confidence at 50 mm/s\(^2\), this would result in the charge weight being reduced to approximately 7kg. This would produce the maximum predicted levels of 24.20 mm/s\(^2\) and 47.51 mm/s\(^2\) based on 50% and 95% weighting respectively at a distance of 11m. Potentially this may well prove to be a problem. Consideration should be given to monitoring all close range blasts in the vicinity of the gas pipeline.
The calculated predictions indicate that the South East extension would be able to comply with the limit specified in the site's existing planning permissions that "Ground vibration as a result of blasting operations measured at or in close proximity to any occupied vibration sensitive building shall not exceed a peak particle velocity of 6mm/second in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5mm/second" as all residential and educational buildings (locations 21, 22, 23 and 26) have calculated vibration predictions (both 50% and 95% weighting) at less than 6 mms$^{-1}$. The highest calculated vibration prediction at these locations is location 22, Craggs Lodge where 2.73 mms$^{-1}$ and 4.95 mms$^{-1}$ were predicted based on 50% and 95% weighting respectively using a reduced charge weight of 22kg at a distance of 162m. In general, although the level of vibration is above the threshold level of human perception (0.5 mms$^{-1}$) they are considered to be low therefore it can be said that the potential impact of vibration on these identified buildings should be low. However the vibration levels predicted at the Craggs Lodge are considered to be moderate, thus monitoring of vibration levels should be considered.

Creswell Crags was designated as a SSSI in 1981 and a scheduled ancient monument in 1985. Of the two cave locations within Creswell Crags, Mother Grundy's Cave and Robin Hoods Cave (Locations 24 and 25 respectively), the closest [Mother Grundy's Parlour at 309m] had predicted vibration levels of 2.00 mms$^{-1}$ and 4.41 mms$^{-1}$ based on a 50% and 95% weighting respectively. Robin Hood Cave is lower. Both predicted values are lower than the vibration limit of 95% of all blasts to produce blast vibrations of 12 mms$^{-1}$ or less when measured at Creswell Caves. Whilst the possible impact of blasting on the caves is considered to be low, given that this is under consideration as a “UNESCO world heritage site”, monitoring of vibration levels should be considered.

Based on all the distances calculated to each sensitive receptor, the gas pipeline is the nearest structure to the proposed South East extension with the closest possible blast being at a distance of 11m. The gas pipeline lines runs adjacent to the eastern limit of the extension to the southern most point of the extension with closest sub parallel distances from the extension to the pipeline ranging from 40 to 11m and the furthest sub parallel distance is approximately 87m. The pipeline then curves around the southern corner of the extension and then runs south-westerly towards Creswell village. As described in the summary point above, the charge weight required to blast at a distance of 11m from the gas pipeline would be 7kg, the blast would have to be designed on the basis of a 95% confidence at 50 mms$^{-1}$ in order to maintain that the vibration levels on the pipeline is below that of 75 mms$^{-1}$.

Due to the close proximity of the gas pipeline and Craggs Lodge to the proposed extension, the blast design will have to take into account both locations as they have different vibration limits. Table 7 shows both locations starting from their equivalent shortest distance from the extension (11m for the gas pipeline and 162m from Craggs Lodge) and the required MICs to comply with the 75 mms$^{-1}$ limit on the pipeline and the 6 mms$^{-1}$ in 95% for all blasting events at Craggs Lodge. As described above, in order to maintain a vibration level below 75 mms$^{-1}$ at the gas pipeline, a 50 mms$^{-1}$ at a 95% confidence was employed in determining the MICs for the gas pipeline.

From Table 7, a 40kg MIC could be employed at distances no less than 195m to Craggs Lodge to satisfy the 6 mms$^{-1}$ in 95% of all blasting events criteria. This would also be acceptable for the pipeline at the equivalent distance of 36m. Based on the vibration predictions and associated distances, Craggs Lodge is the controlling vibration sensitive structure at distances not less than 171m to Craggs Lodge which is the equivalent distance of 24m from the extension to the gas pipeline. From this point i.e. 24m from the extension to the gas pipeline and closer, the gas pipeline becomes the controlling vibration sensitive location, thus all blasts at distances of 24m or closer to the pipeline will have to be designed on the based a 50 mms$^{-1}$ at a 95% confidence at the pipeline. The closest possible blast is expected to be at 11m from the gas pipeline, at that distance an MIC of 7kg would have to be employed. This would produce the maximum predicted levels of 24.20 mms$^{-1}$ and 47.51 mms$^{-1}$ based on 50% and 95% weighting respectively. Both predicted values are significantly lower than the maximum vibration limit of 75 mms$^{-1}$, stated in Section 8.5 of their Specification for safe working in the vicinity of gas pipelines (document SSW22). As such the
possible impact of blasting on the gas main is considered to be low and the limit of 75 mms\(^{-1}\) should not be exceeded based on the predictions made.

However, operationally this may well cause a problem. In order to achieve a 7kg MIC in a blast hole, it would require that each blast hole is tripled decked and would need to employ a series of air-decks within the blast hole. In addition, it is suggested that the hole diameter is reduced to 76mm (3 inches) to allow greater explosive rise within the blast hole to increase the amount of rock breakage on initiation.

As this type of very close precision blasting, i.e. design and carrying out a blasting operation within 9m of a monitoring location and achieving vibration control, has not taken place at Whitwell Quarry previously, it is suggested that a series of fully instrumented blast trials take place in a non-vibration sensitive area of the quarry to determine if vibration control at 9m is practically achievable using a 7kg charge designed to the above specification. It is also suggested that these trials are carried out prior to the commencement of the South East extension.

Tarmac agreed that the blast trials are necessary and that they should be carried out. A tentative date of Spring/Summer 2016 has been discussed for these trials to be carried out. Tarmac and Blast Log recommend that there should be an initial blasting stand-off of 25m from the gas pipeline, if the vibrations from blasting operations are controllable and as predicted, then the stand-off can be reduced.

Based on the prediction calculations, the impact of vibration on the identified potential receptors [locations 21 to 26 excluding location 29 the gas pipeline] will be low and no additional mitigation measures over and above good blasting design and practice are considered necessary. The impact on the gas pipeline can also be low by using a reduced MIC of 7kg at 11m based on the vibration data assessed. However it is suggested this is determined empirically at Whitwell Quarry prior to the commencement of the extension. Also all close range blasts in the vicinity of the gas pipeline will require to be monitored.

5. **VIBRATION LIMITS FOR WHITWELL RAILWAY TUNNEL AND CRESWELL CRAGS AND CONSIDERATION TOWARDS THE USERS OF THE PUBLIC RIGHT OF WAY (PROW)**

In the Scoping Opinion, it recommends that vibration levels should be discussed and recommended for Whitwell Railway Tunnel and Creswell Crags.

Currently under the existing planning permissions there are vibration level limits associated with Whitwell Tunnel. This is specified in Condition 44 of the planning permission (CMS/0206/178) (dated 23 October 2006) and states “The level of vibration on Whitwell Tunnel (until decommissioned) and at the railway boundary shall not exceed a maximum peak particle velocity of 12mm/second”.

It is proposed that the existing vibration criteria described in the above paragraph is continued for the proposed extensions, albeit it should be modified to read 12mm/second in 95% of all blasting events over a six month period. However failing that, we would recommend employing the PPV limit of 15 mms\(^{-1}\) as set out by British Standard BS7385 Part 2 at any frequency. It is also proposed that no frequency limit or cut-off is used as blast induced ground vibration is generally comprised of a relatively broad range of frequencies interacting together thus rendering it impossible to comply with a specific frequency limit.

As discussed in Section 2.2, there are no vibration limits specified in the planning permission for Creswell Crags and Caves. Document LAF/WT/SPH/1430/02/RMFIN discusses the impact of blasting at the Southern Extension of Whitwell Quarry on Creswell Crags and Caves and states “all blasts will be designed such that the blast vibrations will remain inside the limit of: 95% of all blasts to produce blast vibrations of 12mm/sec or less when measured at Creswell Caves”. It is proposed that this guidance is continued for the proposed extensions.

Whitwell Quarry currently has procedures in place that cover the situation when blasting operations are in the vicinity of public footpaths and takes into consideration the users of the footpaths. These
include positioning quarry staff as sentries on the footpath between the quarry and designated sensitive area. The sentries are in two way communication with the shotfiring team at all times. The initiation of the blast only takes place when the shotfiring team receives communication from the sentries that the footpath is clear of people. The sentries remain in position on the footpath until the post blast inspection has been carried out and the all clear has been given by the shotfiring team. It is suggested that these procedures will be continued to be used for the new extensions.

6. CONCLUSIONS AND RECOMMENDATIONS

The main potential impact associated with blasting at the four proposed extensions [North, North East, East and South East] to Whitwell Quarry is considered to be blast induced vibration at local buildings/structures and is the focus of this report.

Historic vibration data collected from now-defunct non-electric (pyrotechnic) initiated blasts at Whitwell Quarry were used to predict the likely levels that would have previously been received at nearby buildings as historically higher levels of vibration were related to the inherent delay scatter associated with the pyrotechnic delay component of the non-electric detonator, together with the greater bench heights compared to present day which resulted in deeper blast holes and more explosives been placed into each of the holes. This assessment demonstrated that all above ground locations most likely received perceptible but moderate to low levels of vibration. The highest predicted value was 4.99 mm/s at a distance of 431m.

Current blasting operations at Whitwell use electronic detonators for primary initiation which have less associated ‘data scatter’ compared to non-electric detonators. Therefore it was decided that data collected from electronically initiated blasts were used to generate the vibration predictions for the main assessment. In total, 1572 results were employed which were sub-divided into seven datasets. Prior to the calculation of the predictions, the data was first assessed to determine the quality of the data. This assessment determined that each dataset was of high quality thus the predictions made using the data would be of good quality and thus valid.

Vibration predictions for the nearest occupied residential building [No. 20 Franklin Avenue] at 203m to the North extension is moderate with it predicted to receive 2.37 mms^-1 and 3.80 mms^-1 based on a 50% and 95% confidence respectively using a 40kg MIC. This is below the sites existing limit of 6 mms^-1 in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5 mms^-1. In order to keep within the 12mms^-1 limit imposed on Whitwell Tunnel, the charge weight would have to be reduced to approximately 32kg for the closest point of blasting to the tunnel of 75m. This would produce the maximum predicted levels of 5.31 mms^-1 and 10.20 mms^-1 based on 50% and 95% weighting respectively. Blasting operations at the North extension will likely be perceptible at all selected receptors especially those structures located directly north of the North extension. The predicted vibration levels are considered to be moderate to low, therefore it can be said that the potential impact of vibration on these identified buildings are moderate to low. However given the large number of houses in Whitwell village between 203 and 400 metres from the proposed closest blasting location, consideration should be given to how routine blast vibration monitoring can be carried out. This could take the form of a permanent blast vibration monitoring system.

For the North East extension, a 40kg charge weight is suitable to employ in blast design for all selected locations. The nearest occupied building [Whitwell MOT centre] at 158m to the North East extension is predicted to receive 3.19 mms^-1 and 5.68 mms^-1 based on a 50% and 95% confidence respectively. This is below the sites existing limit of 6 mms^-1 in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5 mms^-1. However the vibration levels predicted at the Whitwell MOT Centre are considered to be moderate, thus monitoring of vibration levels should be considered. The nearest residential property in the Southfield Lane housing estate [No.2 Bridge Close] at 273m to the North East extension is predicted to receive 1.67 mms^-1 and 2.98 mms^-1 based on a 50% and 95% weighting respectively. The vibration levels predicted are less than those predicted for the Whitwell MOT centre and as such are considered to be low. The methane gas extractor is the nearest structure to this extension at 82m to the closest point of blasting and is predicted to receive 6.92 mms^-1 and 12.31 mms^-1.
based on a 50% and 95% confidence respectively. Both predicted values are significantly lower than the maximum vibration limit of 50 mms\(^{-1}\) employed in this assessment. The vibration predictions for Whitwell Tunnel based on the closest point of blasting of 86m is predicted to receive 5.54 mms\(^{-1}\) and 10.63 mms\(^{-1}\) based on a 50% and 95% confidence respectively. Both predicted values are lower than the maximum vibration limit of 12 mms\(^{-1}\). However, the levels of vibration are considered to be significant and thus it is recommended that the existing blast vibration monitoring system within the tunnel is maintained. The gas pipeline is predicted to receive 4.03 mms\(^{-1}\) and 7.90 mms\(^{-1}\) based on a 50% and 95% confidence respectively which is significantly lower than the maximum limit of 75 mms\(^{-1}\) for this structure given in Section 8.5 of the Specification for safe working in the vicinity of gas pipelines (document SSW22) and this limit should not be exceeded. Blasting operations at the North East extension will likely be perceptible at all selected receptors less than 500m and the predicted vibration levels at those locations are considered to be low. Therefore it can be said that the potential impact of vibration on these identified structures are low. Vibration predictions for the nearest occupied building [Hennymoor Farm] at 387m to the East extension is very low and is predicted to receive 1.16 mms\(^{-1}\) and 2.15 mms\(^{-1}\) based on a 50% and 95% confidence respectively. Both predicted values are significantly lower than the maximum limit of 75 mms\(^{-1}\) and therefore this limit should not be exceeded. However it is recommended that consideration is given to monitoring of all close range blasts in the vicinity of the gas pipeline.

Similar to the North East extension, blasting operations at the East extension will likely be perceptible at those selected receptors less than 500m [Hennymoor Farm and Craggs Lodge]. Although the predicted vibration levels at those locations are considered to be low. Therefore it can be said that the potential impact of vibration on these identified structures are very low.

Of the four proposed extensions, the South East extension has the closest occupied residential building [Craggs Lodge] at 162m from the extension and the closest structure [the gas pipeline] which is 11m adjacent to the extension at its shortest distance. As Craggs Lodge and the gas pipeline have two different vibration limits [i.e. 6 mms\(^{-1}\) in 95% of all blasting events over a six month period, and no individual blast event shall generate a peak particle velocity in excess of 8.5 mms\(^{-1}\) and should not be exceeded. The closest structure to the extension is the gas pipeline at 39m and it is predicted to receive 13.83 mms\(^{-1}\) and 27.14 mms\(^{-1}\) based on a 50% and 95% confidence respectively. This is significantly lower than the maximum limit of 75 mms\(^{-1}\) and therefore this limit should not be exceeded. However it is recommended that consideration is given to monitoring of all close range blasts in the vicinity of the gas pipeline.

The closest possible South East blast based on the boundary is expected to be at 11m from the gas pipeline, at this distance an MIC of 7kg would have to be employed to produce the maximum predicted levels of 24.20 mms\(^{-1}\) and 47.51 mms\(^{-1}\) based on 50% and 95% weighting respectively. Both predicted values are significantly lower than the maximum vibration limit of 75 mms\(^{-1}\) and as such the impact of blasting on the pipeline will be low. However, it is suggested that prior to the commencement of the South East extension, a series of fully instrumented blast trials take place in a non vibration sensitive area of the quarry to determine if vibration control at 9m is practically achievable using a 5kg charge, as this type of precision blasting has not previously taken place at Whitwell Quarry. It is suggested that the design of the blast is tripled decked and uses a series of air-decks within the blast hole. In addition, it is suggested that the hole diameter is reduced to 76mm (3 inches) to allow for greater rise of the explosives in the blast holes. It is also recommended that there should be an initial blasting stand-off of 25m from the gas pipeline, and
only if the vibrations from blasting operations are found to be controllable and as predicted, then the stand-off can be reduced.

In summary it is considered that blasting operations at the proposed North, North East and East extensions can be designed to comply with the vibration limits used in this assessment. Thus, in general, the impact of blast induced vibration will be low, provided that best practice is employed in blast design and execution. However this will only be effective in "planning to Comply", when used in combination with blast monitoring and regression analysis that seeks to use the results of the analysis to plan all future blasts. It is suggested that:-

1. The number of properties located in the vicinity of the northern area will require a proactive approach to blast monitoring.

2. South East extension will require some additional measures such as blasting test trials in addition to the above measures stated for the other three extension areas.
### Table 1: Distance between each location and historic northern blasting and their predicted values using 50% weightings

<table>
<thead>
<tr>
<th>Location identifier</th>
<th>Location name</th>
<th>Distance (metres)</th>
<th>Predicted PPV values 50% (mm/s⁻¹)</th>
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<td>Outbuilding</td>
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<td>Bridalcraft UK</td>
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<td>0.81</td>
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Table 3: Distance between the nearest location and the nearest point of blasting to the North extension and their predicted values using 50% and 95% weightings

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<th>Location identifier</th>
<th>Location</th>
<th>Distance (metres)</th>
<th>Predicted PPV values</th>
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TABLE 4
DI STANCE BETWEEN THE NEAREST LOCATION AND THE NEAREST POINT OF BLASTING FOR THE NORTH
EAST EXTENSION AND THEIR PREDICTED PPV VALUES USING 50% AND 95% WEIGHTINGS AND 40KG MI C

Table 4: Distance between the nearest location and the nearest point of blasting to the North East extension and their predicted values using 50% and 95% weightings

<table>
<thead>
<tr>
<th>Location identifier</th>
<th>Location name</th>
<th>Distance (metres)</th>
<th>Predicted PPV values</th>
<th>Predicted PPV values</th>
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<td>50%</td>
<td>95%</td>
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<td>(mm/s⁻¹)</td>
<td>(mm/s⁻¹)</td>
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<td>27</td>
<td>Gas Pipeline</td>
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### TABLES 5, 6

DISTANCE BETWEEN THE NEAREST LOCATION AND THE NEAREST POINT OF BLASTING FOR THE EAST EXTENSION AND SOUTH EAST EXTENSION AND THEIR PREDICTED PPV VALUES USING 50% AND 95%WEIGHTINGS 40KG MIC

Table 5: Distance between the nearest location and the nearest point of blasting to the East extension and their predicted values using 50% and 95% weightings

<table>
<thead>
<tr>
<th>Location identifier</th>
<th>Location</th>
<th>Distance (metres)</th>
<th>Predicted PPV values 50%</th>
<th>Predicted PPV values 95%</th>
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<td>Springfield Farm</td>
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<td>28</td>
<td>Gas Pipeline</td>
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Table 6: Distance between the nearest location and the nearest point of blasting to the South East extension and their predicted values using 50% and 95% weightings

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<tr>
<th>Location identifier</th>
<th>Location name</th>
<th>Distance (metres)</th>
<th>Predicted PPV values 50%</th>
<th>Predicted PPV values 95%</th>
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TABLE 7
EQUIVALENT DISTANCES BETWEEN THE GAS PIPELINE AND CRAGGS LODGE TO THE NEAREST POINT OF BLASTING FOR THE SOUTH EAST EXTENSION AND THE MICS REQUIRED WITH THEIR PREDICTED PPV VALUES USING 50% AND 95% WEIGHTINGS TO COMPLY WITH VIBRATION LIMITS

<table>
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<tr>
<th>Distance from Gas Pipeline to South East Extension</th>
<th>MIC (Kg)</th>
<th>Predicted PPV values</th>
<th>Distance from Craggs Lodge to South East Extension</th>
<th>MIC (Kg)</th>
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