Quarry Over-Pressure Control - Through Technology and Innovation

Operating a quarry in urban environments can be a very challenging task. A quarry must ensure that mining and processing noise, dust, blast vibration and blast over-pressure levels are all maintained below the statutory licence requirements. Many quarry operations establish their own self imposed limits which are lower than licence conditions so as to further reduce the effects of their operation on the surrounding community. Linwood Quarry in Adelaide SA is one that applies stricter external blasting limits. To meet these limits a long term blast improvement project has been established to reduce the environmental effects of blasting on the neighbours of the quarry.

The Linwood quarry is supported by an Orica Quarry Services Technical Services Engineer, who has introduced change and used a detailed scientific approach to assess the effectiveness of each change on the blasting outcomes. This paper will focus on the process followed to reduce airblast at the Linwood Quarry.

For the past 2 years the Linwood quarry has gradually increased the size of blasts, but maintained over-pressure levels well below the statutory limit without having to lower bench heights or reduce powder factors. The over-pressure results during the past 3 years display a downward trend, even though the blasts are moving closer to the neighbouring properties. Other quarry sites around Australia, operating at similar distances to sensitive sites (neighbours), are using blasting techniques that involve reducing blast volumes, powder factors and bench heights to attempt to bring the over-pressure under control. These changes often have a significant and detrimental effect on fragmentation, muck pile looseness and profit.

In 2 years the Linwood quarry has only exceeded the 95% over-pressure level of 115 dBL on a single occasion. Utilising Orica’s Rock On Ground (ROG) service the Linwood Quarry has reduced the average over-pressure readings by 24% and reduced the standard deviation of these readings by 33%, enabling improved over-pressure control without negatively affecting other blasting outcomes. Blasting closer to neighbours, with a reduced impact, has been enabled through a complete understanding of the blast physics associated with over-pressure generation and the use of the latest blasting technology.

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The Boral Linwood quarry is located approximately 15 km South West of the city of Adelaide in South Australia. The quarry has been operating for over 100 years by various owners, and was one of the pioneering quarries in the Adelaide metropolitan area. The quarry commenced operations in 1882, providing material to a local cements works. Quarry Industries (now Boral) has operated the Linwood quarry since 1939 and production from the quarry has been continuous since this time (Ward, 2009).

The quarry is currently producing between 900 kT and 1200 MT per annum of aggregates and other quarry products for the use in the Adelaide metropolitan construction market. Over the past 3 decades residential areas have encroached on the quarry, with residential houses, in some areas, being located within 350m of the active quarrying area. Urban encroachment has been driven by the quarry being within 1.4 km of the coast, with most Australians chasing the dream of a sea side property.

The Linwood geology produces aggregates that are of a high quality, suitable for road construction and high strength concretes, making the Linwood Quarry a valuable resource for the sustainability of the Adelaide construction industry. To enable good community relations, Boral has had to lead the Adelaide Quarrying Industry in implementing best practices with all aspects of the quarrying operation that may affect the neighbours of the quarry.

The blasting operations at any quarry can be felt and heard by the surrounding neighbours, and is typically a point of concern for the neighbours of a quarry. Airblast can be defined as the shockwave generated by the detonation of explosives. The Linwood Quarry has a licence condition that requires the airblast to remain under 115 dBL for 95% of blasts (19 out of 20 blasts) and remain under 120 dBL for 100% of blasts, so 1 out of 20 blasts may register airblast between 115 dBL and 120 dBL.

In 2008 the Linwood Quarry had its extractive licence reviewed with tighter licence conditions applied for airblast. The previous licence conditions allowed the Linwood quarry to blast and maintain airblast readings under 120 dBL for 100% of the blasts. The new licence conditions required that 95% of the blasts registered an airblast reading of no greater than 115 dBL and all of the blasts must be under the 120 dBL airblast maximum limit. For the 2008 calendar year, prior to the new licence commencement, the Linwood Quarry had an 84% compliance to the 115 dBL limit.

Airblast is directly related to the distance between a blast and the blast monitor (sensitive structure), charge weight per hole and the direction of blasting. The greater the distance a blast is from a sensitive receiver the lower the airblast reading will be, everything else being the same. The smaller the charge weight per hole the lower the airblast reading, everything else being the same. A blast that is free faced and faces directly towards a sensitive receiver will record a higher airblast reading than a blast with a sensitive receiver at an equal distance behind the blast. An understanding of these three basic principals is essential to be able to develop blasting techniques to reduce the airblast recorded at a sensitive receiver.
The first step to ensuring that airblast is controlled at your quarry is to ensure that blast quality control is being conducted and standards are in place. All column heights must be checked prior to placing stemming material into the blast hole. Measurement ensures that the minimum stemming length is not compromised. If stemming lengths are compromised significantly e.g. more than 200mm under the minimum length in an optimised pattern, the result will be stemming ejection from the blast hole, which will cause a significant airblast event.

When free facing a blast, the face burdens must be measured to ensure that there is sufficient rock between the free face and the face blast holes, known as the face burden. Face burdens are typically measures using laser scanners or theodolites and then the data is imported into a blast design program, where analysis and design tools can be used to design the blast hole positions to ensure face burdens are correct. After the blast holes are drilled a bore tracker is used to measure the blast hole actual position, angle and azimuth. The bore track data is then imported into a blast design program and examined for compliance against design, ensuring that minimum face burdens are not compromised. Where drill deviation results in inadequate face burdens the design engineer can modify loading parameters to reduce energy in the front row.

Airblast can be reduced by moving a blast further away from a sensitive receiver, which most of the time is not practical. Quarry operators should also ensure that their blast monitor, sensitive receiver, is not located at a position that is not representative of the distance to the closest neighbours. It has been quite common to locate a blast monitor at the weigh bridge or office for ease of setting up and removing. If the weigh bridge is not on the boundary of the quarry lease, along with being located between the blast and the closest neighbours, then it would be suggested to relocate the monitor to a more practical position. The airblast measurement recorded should be indicative of the airblast levels that would be experienced at the closest neighbouring property. Always check with your regulatory organisation to ensure that your blast monitoring location (sensitive receiver) is compliant with their licence conditions.

Displayed in Table 1 is an 11 year history of airblast recordings from blasting activities conducted at the Linwood Quarry.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Blasts</th>
<th>Blasts Over 115 dBL</th>
<th>Percentage Under 115 dBL</th>
<th>Average dBL</th>
<th>Licence limit Airblast</th>
<th>Average Tonnes per Blast</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>39</td>
<td>20</td>
<td>49%</td>
<td>113.4</td>
<td>120 dBL</td>
<td>24,708</td>
</tr>
<tr>
<td>2001</td>
<td>44</td>
<td>17</td>
<td>61%</td>
<td>112.9</td>
<td>120 dBL</td>
<td>21,060</td>
</tr>
<tr>
<td>2002</td>
<td>52</td>
<td>7</td>
<td>87%</td>
<td>110.7</td>
<td>120 dBL</td>
<td>25,264</td>
</tr>
<tr>
<td>2003</td>
<td>51</td>
<td>14</td>
<td>73%</td>
<td>111.4</td>
<td>120 dBL</td>
<td>22,324</td>
</tr>
<tr>
<td>2004</td>
<td>30</td>
<td>6</td>
<td>80%</td>
<td>109.5</td>
<td>120 dBL</td>
<td>21,837</td>
</tr>
<tr>
<td>2005</td>
<td>52</td>
<td>5</td>
<td>90%</td>
<td>105.6</td>
<td>120 dBL</td>
<td>22,449</td>
</tr>
<tr>
<td>2006</td>
<td>67</td>
<td>14</td>
<td>79%</td>
<td>112.4</td>
<td>120 dBL</td>
<td>16,807</td>
</tr>
<tr>
<td>2007</td>
<td>51</td>
<td>13</td>
<td>75%</td>
<td>112.5</td>
<td>120 dBL &amp; (95%&lt;115 dBL &amp; 100%&lt;120dBL)</td>
<td>24,574</td>
</tr>
<tr>
<td>2008</td>
<td>51</td>
<td>8</td>
<td>84%</td>
<td>112.3</td>
<td>120 dBL &amp; (95%&lt;115 dBL &amp; 100%&lt;120dBL)</td>
<td>25,310</td>
</tr>
<tr>
<td>2009</td>
<td>62</td>
<td>2</td>
<td>97%</td>
<td>108.5</td>
<td>95%&lt;115 dBL &amp; 100%&lt;120dBL</td>
<td>23,683</td>
</tr>
<tr>
<td>2010</td>
<td>58</td>
<td>1</td>
<td>98%</td>
<td>105.3</td>
<td>95%&lt;115 dBL &amp; 100%&lt;120dBL</td>
<td>20,192</td>
</tr>
<tr>
<td>2011</td>
<td>19</td>
<td>0</td>
<td>100%</td>
<td>106.2</td>
<td>95%&lt;115 dBL &amp; 100%&lt;120dBL</td>
<td>32,943</td>
</tr>
</tbody>
</table>

Table 1 Ten Year Airblast Summary for Linwood Quarry (2011 data to May)

In 2006 the Linwood Quarry engaged technical blasting support to assist in reducing their airblast levels that were being produced from the current blasting practices. The Orica Engineer provided recommendations and mentored the Boral Shotfirer’s through the improvement process.
The theoretical physics of how airblast is produced is explained so as to provide an understanding of why the airblast optimisation project has provided benefits to the Linwood Quarry. Airblast is measured in pressure, the unit being Pascals (Pa). The pressure is a measurement above normal atmospheric pressure, not an absolute value. Due to the large spread of measurements that can be recorded when measuring airblast, the pressure measurement is then converted to a decibel value (dBL). dBL refers to decibels linear, which indicates that the device measuring the airblast measures both audible pressure, humans can hear sound and noise, and the non audible lower frequency pressure that can affect structures. Most often airblast is reported as over pressure in dBL units, which is the measurement of pressure above or below atmospheric pressure, measured in the audible and non audible range.

Pressure is defined as force exerted over a given area, documented in equation 1.

\[
\text{Pressure (P)} = \frac{\text{Force (F)}}{\text{Area (A)}}
\]

Units:

\[
\begin{align*}
\text{F} & = \text{Newtons (N)} \\
\text{A} & = \text{meters}^2 (m^2) \\
\text{P} & = \text{Pascals (Pa)}
\end{align*}
\]

Equation 1: Pressure

With reference to blasting we can influence the force by changing any of the following:

- explosive charge weight;
- explosive product density;
- use decoupled explosive charges (packaged);
- face burdens;
- stemming lengths;
- bench height;
- Initiation timing.

Quite commonly blasting personnel get confused and believe that they can influence the area (A), but this is fallacy as the area is the atmosphere that the force is transmitted to, which should be considered infinite in size when taking into account for airblast considerations. The area (A) is not the rock mass area that the charge weight is distributed over. By reducing the bench height the Shotfirer is reducing the force that is exerted on the atmosphere and therefore a smaller pressure will result at the sensitive receiver.
The Linwood Quarry had previously implemented blast initiation sequencing that controlled airblast using the Exel™ range of Connectadet™ surface delays. Slow face row delay sequencing will provide a reduced airblast when compared to faster face row delay sequencing, e.g. 100ms versus 25ms. A faster face row delay sequence will throw a blast further than when using 100ms delay sequencing and therefore due to the higher face velocity a greater force is exerted on the atmosphere.

When considering a slower face row delay (100ms) and a faster burden delay (17ms), the blast will have a slower face velocity (less face force), but the heave of the blast must also be considered as a high heave (high drill bench force) can cause a high airblast also. When using non electric initiation systems it’s difficult to achieve all the production requirements of the blast and control airblast. Typically both airblast and vibration control are achieved when using non electric initiation systems through limiting blast sizes, e.g. no greater than 3 rows. Examining the airblast results in 2007 and 2008, displayed in Figure 3, during this period the non electric initiation systems were still being used at the Linwood Quarry. It is evident that airblast control to remain under 115 dBL could not be achieved through using initiation sequencing alone.

In early 2007 soft loading techniques were trialled on the first 5 initiating face blast holes. Soft loading incorporates the use of packaged explosives as a substitute for bulk explosives. Soft loading reduces the explosive charge in each blast hole and therefore reduces the force that each blast hole produces, which will reduce the airblast in that section of the blast. The first 5 blast holes are soft loaded, as typically this is the section of the blast that causes the peak airblast reading. The initial air disturbance, pressurisation of the air, caused by the blast can be identified as the cause of the highest airblast readings, in many blasting scenarios. For the Linwood Quarry this was not always true due to the location of the sensitive receivers being behind the blast.

Prior to Orica commencing the technical component of the Airblast Reduction Project at the Linwood Quarry, previous Boral Drill and Blast Management had identified this phenomenon. The airblast peak reading is not produced by a positive pressure pulse e.g. the blast face pressurising the air in front of the blast. At the Linwood Quarry the airblast reading is most commonly a negative pressure caused by air moving into the void (low pressure) caused by the blast.

Figure 1 displays a blast that was divided into two sections. Each half of the blast consisted of 4 rows with 15 holes in each row. The first 5 blast holes to fire were decked to reduce the charge weight to reduce the airblast reading. The second half of the blast was delayed 400ms to reduce ground resonance and consequently reduce the blast vibration, no face blast holes were decked in Section 2. An initiation sequence of 25ms control 65ms down the echelon was used in both sections of the blast.
Figure 1, Airblast Waverform, is the airblast monitor results for the most sensitive receiver for the blast displayed in Blast Plan. The airblast waveform has been annotated so that the airblast caused by each section of the blast can be clearly seen. A section below the horizontal axes has also been highlighted, this is the 400ms delay between the two sections of the blast. Each section of the waveform is highlighted using a dashed rectangle, which is the same length for all three areas. It can be seen that the airblast is reduced in the first section of the blast where the first 5 blast holes were decked, compared to Section 2 of the blast where all of the face holes were full explosive columns. Neither of the actual blast sections produced the peak airblast reading. The peak airblast reading came from the instance, in the middle of the blast, where the blast had stopped. This demonstrates that the rock movement creates an area of low pressure behind the blast, which causes the air to move into the low pressure area, creating a negative airblast. Airblast is considered to be the variance from normal atmospheric condition, whether it is positive or negative. This trial was considered a significant trial, as it provided evidence that decked the first 5 blast holes does reduce the airblast compared to full columns firing and that the rock moving from its original position, as part of the blasting process, causes a low pressure behind the blast. For this blast, the low pressure caused an airblast event, in this case the peak airblast, 109 dBL compared to 107 dBL and 108 dBL for Section 1 and Section 2 respectively.

In late 2007 bulk emulsion trials commenced. Due to the larger force that would be exerted by the bulk emulsion (higher relative energy) compared to a blast hole using ANFO, airblast control techniques had to be trialled and proven. As part of the emulsion trial the decking of the first 5 initiating blast holes was implemented. The site had blast vibration concerns, so as part of this trial the blast was segmented into sections that were fired approximately 200ms apart. The results from 2 emulsion trials reinforced the results that were displayed in Figure 1. As part of the recommendations of the emulsion trials it was suggested that decking the entire face row should be investigated to explore the benefits to reducing airblast. The emulsion trial concluded in early 2008. Displayed in Figure 2 is the annotated airblast waveform result from the second emulsion trial. It can be clearly seen that the face holes that were fired with a full bulk explosives charge produced the peak airblast for the first 3 sections of the blast.
Commencing early 2008 Boral started decking all front row blast holes for all Linwood blasts. They experienced a small positive step change in airblast control, which can be seen in Figure 3. This technique continued until September 2008 when vibration control became a key driver for the site. As part of the vibration control an electronic initiation system was trialled with immediate success. At the same time as the electronic initiation system introduction, Boral contracted Orica to conduct a Rock on Ground (ROG) blasting service. Orica surveyed, designed, loaded and fired the majority of blasts at the Linwood Quarry. By using the electronic initiation system Orica implemented another step change in the airblast control process. The blast design incorporated decked bulk explosives in all blast holes. The decks were separated by enough delay time so that each of the top and bottom decks would fire independently. This technique reduced the force by reducing the charge weight and then reduced the force further by reducing the area of the face that was exerting the force at any one instance. With typical initiation timing the face moves as one, no individual hole can be seen initiating and moving out from their original position.

An analysis of the previous blast results has highlighted that reducing the delay between each section of the blast from 400 ms (figure 1) to 200ms (figure 2), has resulted in wave super positioning. Section 2 (Panel #2) of the blast was initiated at the point where the maximum (negative) pressure was expected from Section 1 (panel 1), see Figure 2. The overall effect is a reduction in the negative airblast pressure. Other factors, such as blast location and orientation can affect airblast readings and should be taken into account when analysing airblast measurements and blast design.
By decking the face and firing the top deck independently from the bottom, e.g. not just a 25ms delay, the pressure pulse created by the face is significantly reduced and the blast movement is not as energetic, which has also reduced the airblast (negative) caused by the blast movement. Figure 4 displays a blast that is using this technique. The top deck fires and the falling rock covers the bottom deck prior to the bottom deck firing, which reduces the pressure pulse produced by the bottom deck. On the top deck individual holes can be seen breaking out as they initiate.
When implemented incorrectly this airblast control technique, highlighted in Figure 4, can lead to misfires from ground dislocation, extreme elevations in airblast and flyrock from using the wrong inter row/inter hole timing and oversize, if an optimised blast pattern is not used. Consultation with appropriately experienced technical consultants would be recommended prior to implementing any changes to airblast control techniques. Quarry licence conditions can be compromised if the wrong blast parameter changes are implemented.

The introduction of the electronic initiation system combined with decked blast holes has made an immediate improvement to airblast control at the Linwood Quarry. In 2009 airblast started to trend downwards when compared to the previous 9 years of data. During this period the quarry’s development was moving closer to the sensitive receivers, so it would be expected that the airblast reading would increase. Combined with the introduction of a step change blast vibration control technology the Linwood Quarry reversed the trend of smaller volume blasts, which had been implemented to reduce the effects of airblast and vibration on the neighbours of the quarry. In 2011 the quarry has been able to increase the average blast size to +32 000 T, which is 9 500 T above the previous 10 year average, a 40% increase in the average blast size. In May 2011 the quarry was able to fire the largest blast in the quarry’s history of 97,000T. The blast registered only 106 dBL. Without the innovative use of electronic initiation sequencing and decking of face row blast holes it would not have been possible to fire the large volume blasts and control the airblast.

Through the use of detailed analysis and refinement when designing and implementing blasts at the Linwood Quarry, Boral has been able to blast closer to their boundaries and reduce the impacts of blasting on the neighbours. Implementing industry best blasting practices, with reference to airblast control, has also enabled the Linwood Quarry to increase the size of blasts with an overall result of reducing the frequency of blasting, which means less blasting events to disturb neighbours. The Linwood Quarry are promoters of innovation and blasting technology and through detailed processes and procedures to improve blast outcomes the quarry has become the industry leaders in controlling the effects of blasting on the community.

Reference:

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