A REVIEW OF THE DESIGN CRITERIA AND PRACTICAL ASPECTS OF DEVELOPING A SUCCESSFUL PRE-SPLIT.

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ABSTRACT

The objective of this paper and presentation is to review the different criteria and methodology used by AEL and other organisations to create a pre-split design which delivers a stable highwall for the life of that part of the mining operation. It will look at the need to adapt and change the way, size and direction of the production blasts as the mining phase approaches the highwall position for which a pre-split has been created.

Key Words: Pre-split; Design; Highwall; Perimeter

1. Introduction

In both surface and underground mining operations there is a need for the use of special blasting techniques to improve highwall stability and reduce overbreak. The names given to these techniques vary, but here the term "Perimeter Blasting" refers to all methods which have the aim of minimizing blast damage to the excavation perimeter by preventing the force of a blast from continuing into the highwall.

Much of the following discussion on controlled blasting techniques has been determined through years of on-the-job testing and evaluation. The results of controlled blasting are primarily a function of the geology, especially the number and orientation of joint and fracture planes and the quality of the final rock surface that is required.

In many circumstances the confined gas energy from explosives can significantly reduce the structural strength of the rock behind and to the sides of the blasted volume. This will also be caused by blasts that have high charge masses per delay. New fractures and planes of weakness are created and joints and bedding planes that may have been stable before the blast but can be opened up. As a result the rock mass stability can be reduced. This can be seen as overbreak and the fractured face is left with a higher likelihood of rock falls, figure 1.
When modified production blasts cause too much damage on final walls, perimeter blasting methods need to be used. The best perimeter blasting results can be achieved in tough massive rocks. In unconsolidated, weathered or highly fissured rocks, problems in obtaining a consistently smooth wall are usually encountered, but the overall result is always much better than the result from production blasts alone.

The perimeter blasting technique used depends on the rock type. Blasting of weak, highly fissured ground requires a more conservative design than blasting in tough massive rock. Blasthole patterns and charge loads will therefore change appreciably with the rock properties encountered.

Perimeter blasting techniques are therefore more costly than re-designed production blasting because of the greater amount of drilling required. It is essential that drilling and charging be carefully supervised because the final result depends heavily on the time spent and accuracy of drilling.

The general approach in Perimeter Blasting is to:

- Reduce backbreak from production blasting
- Reduce charge masses in the perimeter holes and often in the last production or perimeter easer holes as well,
- Drill extra holes in order to compensate for the reduced charge mass per hole and to provide a preferential plane of weakness delineating the final excavation perimeter, and
- Arrange the initiation of the perimeter holes so as to obtain maximum relief of burden and mobilize preferential splitting mechanisms.

2. Reducing backbreak from production blasting

Because perimeter blasting is more expensive than normal blasting, attempts should first be made to reduce backbreak by modifying the standard drilling and charging methods. The following aspects of blast design should be considered when designing blasts to limit overbreak:
• If a continuous column of explosive is too powerful for back-row blastholes, use an air deck to reduce blasthole pressure

• In water-filled blastholes, semi-rigid explosives cartridges should be used in perimeter holes to give charges which build up a continuous column but which are also a loose fit in the blasthole. e.g. Using 45 mm diameter cartridges in 89 mm blastholes would be a suitably de-coupled charge (A coupling ratio of about 25% or less should be aimed for)

• The effective burden on perimeter holes should not be greater than about 25 times the blasthole diameter, preferably about 20 times.

• The best spacing between back-row blastholes is the largest spacing that gives a straight face. The spacing needs to be determined by trials; however it usually lies between 25 and 40 times the blasthole diameter. In multi-row shots, blastholes should be staggered.

• If possible drill angled rather than vertical blastholes at least for the last 3 to 4 rows in front of the final wall. Angled blastholes tend to cause less damage to the crest behind the back row. Angles of 20° - 30° to the vertical are recommended. Be warned however that angled blastholes tend to produce more flyrock.

• For all blastholes except those in the back row, the length of the stemming column is commonly about 25 blasthole diameters. Because of the need to prevent surface overbreak, it is necessary to increase the stemming length in the back row (Figure 2).

• Sub-drilling into the final crest or berm should be minimised because cracks generated by explosion gases will allow water into the berm, therefore increasing the rate of breakdown due to weathering.

• The initiation sequence should be selected so that there are minimum numbers of blastholes firing on the same delay and preferably firing takes place hole by hole.
The blast in figure 2 shows a combination of features, which give reduced overbreak. This design also gives good fragmentation, displacement and looseness of the muckpile. The limited amount of overbreak results from:

- Blastholes firing on individual delays, particularly those in the back row. i.e. hole-by-hole
- Relatively long delays between rows
- Favourable relief for blastholes resulting from development of a wide V
- Angle of blastholes
- Longer stemming columns in back-row blastholes

A good guide as to whether a modified production blast will give a satisfactory final wall is the state of the back wall from current production blasting. If blasthole traces can be seen on the back walls of current production blasts, then good final walls should be fairly easy to achieve. Smoothwall blasting techniques (e.g. pre-splitting) are generally required where the rock is weak or densely fissured, or where it is important to maximise the soundness and stability of the rock wall.

3. Methods

The four most widely used methods of Perimeter Blasting, are as follows:

**Line Drilling:** Consists of drilling a row of closely spaced holes along the final excavation limits and not loading the holes with explosive.

**Pre-splitting:** Before firing the inner holes, the lightly charged perimeter holes are initiated simultaneously, creating a split between the blasting zone and the proposed sidewalls.

**Smooth Blasting:** The back holes are fired last as usual, relying on a reduced charge mass per hole for overbreak control.
Post-splitting: As with Smooth Blasting, but the back holes are simultaneously initiated in a separate blast.

In this paper the general principles behind these techniques will be described, the design and application of the techniques will be dealt with.

3.1 Line Drilling

Line drilling consists of drilling a row of closely spaced holes along the final excavation limits and not loading the holes with explosive. The line-drilled holes provide a plane of weakness to which the final row of blast holes can break and also reflect a portion of the blast’s shock wave. Line drilling is used mostly in small blasting operations and involves small holes in the range of 50 -100 mm in diameter.

Line drilling holes are spaced (centre to centre) two to four diameters apart but are more closely spaced at the corners. The maximum practical depth to which line drilling can be done is governed by how accurately the alignment of the holes can be held at depth, typically 10 to 15 m. To further protect the final perimeter, the blast holes adjacent to the line drill are spaced more closely and loaded more lightly than the rest of the blast, and deck charges are used as necessary. The distance between the back row blastholes and the line of drill holes is between 50 and 75% of the normal burden distance.

Best results are obtained in a homogeneous rock with few joints or bedding planes or when the holes are aligned with a major joint plane. Line drilling is sometimes used in conjunction with pre-splitting where the corners are line drilled and the remainder of the perimeter is pre-split. The use of line drilling is limited to jobs where even a light load of explosives in the perimeter holes would cause unacceptable damage. The results of line drilling are often unpredictable, the cost of drilling is high, and the results depend on the accuracy of the drilling.

3.2 Pre-splitting

It is well known that uniaxial compressive stress in rock induces tensile failure parallel to the stress and inhibits crack growth perpendicular to it. A line of closely spaced, simultaneously detonating
blastholes places the rock between the holes in uniaxial compression as shown in figure 3, resulting in a split forming between the holes without the necessity for a free face. Crack growth beyond the desired limits is inhibited by the closing effect of the radial stresses from neighbouring holes and can be entirely eliminated by using light enough charges. A split so formed is an effective barrier to cracks growing from the primary blast and pre-splitting therefore has the greatest potential of all the methods of perimeter blasting.

Pre-splitting, sometimes called pre-shearing, is similar to line drilling except that the holes are drilled slightly farther apart and are loaded very lightly. Pre-split holes are fired before any of the adjacent main blast holes. The light explosive charges propagate a crack between the holes. In badly fractured rock, unloaded guide holes may be drilled between the loaded holes. The light powder load may be obtained by using specially designed slender cartridges, partial or whole cartridges taped to a detonating cord downline, an explosive cut from a continuous reel, or heavy grain detonating cord. A heavier charge of tamped cartridges is used in the bottom few feet of hole.

The maximum depth for a single pre-split is limited by the accuracy of the drillholes and is usually about 15 to 25 m. A deviation of greater than 150 mm from the desired plane or shear will give inferior results. Avoid pre-splitting too far ahead of the production blast.

Pre-split holes can be stemmed if the noise from the firing of unstemmed holes is likely to cause annoyance to neighbours. However, stemmed pre-split holes will tend to crater and lead to some damage to the crest of the new face. The pre-split hole needs to be blocked at about the normal stemming level before stemming.

Pre-split charges must be fired simultaneously by joining all detonating cord downlines with a trunkline of cord, or by using electronic detonators or instantaneous electric detonators. Pyrotechnic delay detonators, such as those used on Handidets and Excel Benchmasters, will not give the desired results due to scatter of delay times. Where ground vibrations are likely to disturb residents, 17ms HTDs or 12ms Dogbone relays should be inserted into the trunkline at intervals so as to obtain the
consecutive firing of smaller groups of blastholes. Where noise are to be minimised, surface lines of detonating cord should be covered with a minimum of 200 mm of sand or fine drill chippings.

Pre-split blasts are usually fired before the drilling of the production blastholes in front of the pre-split. In some circumstances, it is necessary to fire the pre-split and the production blast in the one shot. A pre-split can only be effective if it is formed before the main blast, so the initiation design needs to ensure that the pre-split fires before the initiation of the main blast. Firing of the pre-split can result in some cratering of the pre-split holes especially where stemming is excessive. This cratering can cause the downlines to the production holes to be cut if sufficient care is not given to the initiation design.

If possible, pre-split a short section and dig that section out so that the quality of the pre-split can be checked. If the pre-split results are unsatisfactory, adjustments can be made in subsequent blasts. Pre-splitting is usually done in a separate operation and well in advance of drilling and loading the main blast. The pre-split holes can be fired with the main blast by firing the pre-split holes on the first delay period. The increased hole spacing compared with line drilling reduces drilling costs.

The spacing of the holes is derived from:

<table>
<thead>
<tr>
<th>Equation 1. Spacing of holes, pre-split</th>
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<tr>
<td>[ S = \frac{M_h}{P} ] metres</td>
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<tr>
<th>Where:</th>
<th>Description</th>
<th>Units</th>
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<tbody>
<tr>
<td>S</td>
<td>Spacing</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>M&lt;sub&gt;h&lt;/sub&gt;</td>
<td>Mass of explosives per hole</td>
<td>Kilograms (kg)</td>
</tr>
<tr>
<td>P</td>
<td>Split factor</td>
<td>Kilograms per metre&lt;sup&gt;2&lt;/sup&gt; (kg/m&lt;sup&gt;2&lt;/sup&gt;)</td>
</tr>
</tbody>
</table>
The recommended values for \( P \), the mass of explosive in kilograms required per square metre of area to be pre-split, are as follows:

- Pre-splitting on surface: \( P = 0.30 – 0.60 \text{ kg/m}^2 \)
- Pre-splitting dimensional stone: \( P = 0.15 – 0.30 \text{ kg/m}^2 \)

For pre-splitting to be effective the hole spacing should be as small as possible and a continuous column of explosives used in the holes. The further away from this ideal we get the poorer will be the results. In short, the quality of the final result is directly proportional to the amount of time and effort (i.e. money) put into the project. For example excellent results will be obtained if holes are drilled less than a metre apart and a continuous line of cartridges taped to a line of Cordtex 10 used. If 45mm diameter cartridges are spaced along the Cordtex with gaps so as to achieve the same total mass of explosives in each hole, then it is likely that the final face will be shattered at the points where the larger cartridges were positioned and barrels visible in-between. The latter may be perfectly acceptable where the intention is to minimise the overbreak in order to reduce the amount of concrete required for lining (e.g. dam spill-ways), but not acceptable if the face is required to remain standing without any additional support for many years (e.g. road cutting). The desired quality of the final result should be discussed and agreed with the customer.

Typical hole spacings for pre-split blasting are 8 – 16 hole diameters

There are however disadvantages to the method and the following aspects should always be considered:

- Existence of prominent slips and joints
  - Cross-slips tend to terminate the developing split and spoil the end effect. Parallel slips act as points of least resistance, to which the excavation tends to break regardless of the pre-split.
• Blasting Vibrations
  
  − The instantaneous firing of the perimeter holes may generate unacceptable levels of ground movement or noise in built-up areas. In such cases the number of holes per delay must be restricted to limit the mass of explosives initiated per delay, but the more numerous the delays incorporated in the pre-split, the more ragged will be the end result. Post-splitting depends to some extent on reflection of the strain waves from the free face for the splitting mechanism and is therefore more tolerant of perimeter delays.

• Transmission of Blasting Vibrations
  
  − The amplitude of blasting vibrations is not significantly reduced during propagation across a pre-split. The newly created surface can therefore be damaged by earth movement, generated by heavily charged holes, which are placed too close to the split. The use of decoupled perimeter easer holes, as described earlier may be considered.

• Possibility of Block Movement
  
  − Pre-splitting should be avoided where the burden is less than 180 hole diameters as movement of the rock mass could take place, interfering with the primary blast. This requirement is less rigid in the tighter conditions such as encountered in tunnelling. Where the possibility of movement exists, for example on hillside cuts, the split must be fired with the primary blast and precautions (such as top and bottom priming) against cut-offs should be taken.

• Curves and Corners
  
  − Pre-splitting can be carried around curves provided that the radius of curvature exceeds 30 hole diameters. Guide holes are required for corners, which must be split in straight sections and not in one blast. (Figure 3.)
3.3 Smooth blasting

The smooth blasting technique uses blastholes drilled on a reduced burden and spacing and charged with a reduced explosive charge to improve the explosives distribution in the rock mass and therefore reduce the amount of damage to the final wall. Final walls from smooth blasting can be of a very high quality, especially if the rock mass is strong, the average joint spacing is greater than about 500 mm and joints are ‘tight’. Joint direction will also influence the result and best results are obtained with strike perpendicular to the face or dipping nearly vertical.

Smooth blast rows may be used as the last row of a production blast to produce a final wall, or a separate cushion blast may be fired after production blasting in the area is completed.

The best burden and spacing for the perimeter holes is determined from trials using the following equations:

<table>
<thead>
<tr>
<th>Equation 2. Spacing of holes and cartridges, smooth blasting</th>
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<tbody>
<tr>
<td>$B \times S = \frac{M_h}{k}$ metres and $D_c = L \times \frac{M_c}{M_h}$</td>
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<th>Where:</th>
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<tr>
<td>$S$</td>
<td>Spacing</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>$B$</td>
<td>Burden</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>$M_h$</td>
<td>Mass of explosives per hole</td>
<td>Kilograms (kg)</td>
</tr>
<tr>
<td>$k$</td>
<td>Powder Factor</td>
<td>Kilograms per metre$^3$ (kg/m$^3$) 0.3 - 0.6 kg/m$^3$</td>
</tr>
<tr>
<td>$D_c$</td>
<td>Centre to centre distance between cartridges</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>$L$</td>
<td>Cartridge length</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>$M_c$</td>
<td>Charge density</td>
<td>kg explosive per metre</td>
</tr>
</tbody>
</table>
Unlike normal blasting practice, the spacing is sometimes made smaller than the burden in smooth blasting. This maximises the distance between the fully charged holes and the perimeter while permitting the maximum co-operation between perimeter holes. This works well in hard competent rock but should not be done in friable weak rock where the increased confinement causes the explosives gases to be forced into the solid rock causing more back-damage.

As a rule, $S = 0.8B - 1.2B$

### 3.4 Post-splitting

Post-split blasting consists of drilling a row of closely spaced blastholes with a spacing to burden ratio greater than 1.0 along the final limit (Figure 5.). All holes are charged with light, well-distributed charges and fired simultaneously using Powercord or Cordtex trunklines to remove the narrow berm left in place after the final production blast in that area has been dug out. To avoid loss of blastholes through caving, post-splitting blastholes should be drilled after firing the adjacent production shot. However, backbreak from the previous blast can sometimes cause difficulties with drilling close to the face.

Post-split blastholes are charged and fired in the same way as those for pre-splitting, so that the detonation tends to split the rock between the holes giving a smooth wall with minimum overbreak.

The burden and spacing is calculated in exactly the same way as for smooth blasting.

### 4. Perimeter blasting with large holes

Backbreak from large holes (150 mm and up) can be extremely severe owing to the concentrated energy released in the blast. As decoupled charges are not readily adapted to such large holes, which are normally loaded with fully coupled ANFO or bulk explosives, the holes should not be drilled...
closer together, nor can they often be simultaneously initiated, as this increases the energy released, with adverse results. Instead, practical ways to decrease the energy concentration must be found, realising that if it is really vital to maintain long-term slope stability and profile, then a 115 or 150 mm drill should be obtained purely for this purpose.

The following steps are recommended:

- Reduce sub-grade drilling as far as possible
- Reduce the burden on the last holes (easers) by 30% and use a lower energy, shorter length toe charge
- Use spaced, decoupled explosives in the upper portion of the hole, taking care to suspend them on the side of the hole opposite the perimeter where possible. Stem the holes with fine sand. The diameter of the decoupled charges should be less than half that of the hole
- In order to approximate to an inclined face, "cushion" holes can be blasted to half the face height behind the last row, figure 6.
- The back holes must be fired individually on a V2 chevron, or delayed on a longer time, to maximise relief of burden between shots

5. Timing

The key to a successful perimeter blast is to limit the thrust, the split up of the energy (back break), control the energy release rate (decoupled/reduce charge mass) and direct the thrust parallel to the slope of the split. (Figure 7.)

This can be achieved, depending upon the rock structure and properties either by increasing the timing between rows particularly the last row against the pre-split in order to control the extent of the backbreak. Or alternatively an oblique angle can be used to reduce the explosive energy running backwards towards the pre-split and induce a cleaning action along the split line.
6. General

Whichever technique is adopted, the following factors need to be considered:

- Drilling Accuracy and parallelism
  - Non-parallel holes will result in loss of profile and impaired breaking at the perimeter. A clino-meter must be used to align the drill correctly. In the event of one hole being drilled off-line, it should be re-drilled. Alternatively, for small deviations, the following holes should be fanned slightly to compensate for lost parallelism and avoid excessive toe spacing

- Angle of perimeter holes
  - An inclined face is more stable than a vertical face. Furthermore, because inclined holes require less sub-drilling and break out more easily, back damage from these is considerably reduced as compared with what is achieved with vertical holes. Wherever possible, therefore, inclined holes should be used in smoothwall blasting techniques on surface

- Sub-drilling
  - In normal surface blasting it is common to sub-drill by as much as 30% of burden to eliminate toes. This practice is most undesirable when perimeter blasting is performed, as the heavy, well-confined charge beneath grade level actually reduces the stability of the face above

- Explosives Coupling Ratio
  - In order to prevent back damage while ensuring positive breaking, the diameter of the charge should ideally be 0.3 – 0.5 times the hole diameter. The ratio of the volume of explosive to the volume of the hole is known as the Coupling Ratio. As volume is proportional to the square of the diameter, a uniform continuous charge of half the diameter of the blasthole gives a coupling ratio of \((0.5)^2 \times 100 = 25\%\). i.e. 25\% of the volume of the charged portion of the blasthole is filled with explosives. Further reduction in coupling (i.e. increased "Decoupling") is effected by spacing the cartridges along the hole. Experience has shown that
provided the diameter of the explosive is less than half that of the hole, the
coupling ratio is less important than the total mass of explosive in the hole. A
smoother profile is obtained, however, with uniform columnar charges.

− The upper half of the bench face is more prone to backbreak than the lower half,
oweing to the effect of sub-drilling from higher benches, or weathering of ground
near the top. It is therefore good practice to use reduced charge masses in this
area, to obtain a lower coupling ratio.

• Explosives type

− Cartridged explosives are ideally suited to perimeter blasting in view of the fact
that the charge mass per unit length of hole can readily be controlled. Having
calculated the required charge distribution, the cartridges are taped onto a
detonating cord downline at the correct interval.

• In calculating the correct cartridge spacing, the information needed is the:

− Mass of explosive per unit length of charge, \( M_c \) (kg/m)
− Mass of explosive required per unit length of hole, \( M_h \) (kg/m)
− Cartridge length, \( L \) (m).

• Stemming of charged holes

− In very weak ground stemming can sometimes give inferior results owing to the
confined explosive gases being forced into pre-existing weak fissures. By and
large however, especially with low coupling ratios, it is recommended that
effective stemming to a length of 10 to 15 hole diameters be used. This serves to
promote the effectiveness of the decoupled charge and, in smooth blasting; it
prevents the cartridges from being prematurely ejected owing to gas migration
from the inner holes. In the event of remnants being left around the collars of the
perimeter holes, a standard cartridge may replace some of the stemming in each
case.
• Guide holes

  – In extreme conditions or around corners, an improved finish can be obtained by drilling extra, unchanged holes between the perimeter holes. Such "guide holes" serve to direct and contain cracks growing from charged holes. If, as often happens in surface mining, the weak rock is confined to a zone in the top part of the bench, the guide holes need only be drilled to the depth of this zone. The diameter of these holes may be reduced to save drilling costs, as shown in figure 8.

  – A useful modification of guide holes is "cushion" holes, which contain only one primed cartridge at the toe, an air space in the centre and effective stemming at the collar. These can be used to advantage in loose, unconsolidated ground where normal methods are unsuccessful.

• Geological factors

  – The effect of perimeter blasting techniques is even more important in very weak rock conditions than in strong rock types, because the reduced concussion effectively "buys time" in which to apply support measures before the newly exposed surface begins to give way. The geological conditions largely determine how much extra drilling is required to achieve the desired result: strong rock can be blasted with wider patterns and increased explosives charges, while weak rock requires the minimum economic spacing of holes, with charges sometimes limited to a few strands of detonating cord.

  – In most cases the best approach is arrived at by conducting trials and modifying the technique until the desired result is achieved. The best results can be obtained in hard, homogenous rock, laminated at right angles (horizontally) to the blast-holes.
• Charging of perimeter easer holes

  − Both the efficiency of the project and the final finish of the perimeter depend to a large extent on the drilling and charging of the perimeter easer holes. If these are drilled too far from the perimeter, poor fragmentation may result, with excessive toe formation in the case of pre-splitting. If drilled close to the perimeter holes, however, unless their charge is well controlled, damage through crack propagation or high vibration levels can extend beyond the planned perimeter. A compromise is therefore necessary and the perimeter easers should initially be drilled 0.5 to 0.7 of the normal burden from the perimeter and charged with a coupling ratio not exceeding 60%. A double delay period between the perimeter easers and the previous row also assists in achieving clean breaking of the perimeter, as effective release of the burden is assured by this measure.

• Scale of operations

  − The energy produced by an explosive varies as the square of diameter, whereas rock strength is independent of hole diameter. It therefore follows that as hole diameter increases (and with it the requirement to increase the drilling pattern and explosives loading) so the potential for good results with perimeter blasting decreases. This factor is a source of difficulty in large open-cast mines where backbreak is a major impediment to controlling stripping ratios and slope stability. The enormous energy released in 380 mm holes, for example, creates deterioration of the rock mass through plain earth shock, quite apart from the normal breaking mechanisms. Such holes are not amenable to decoupled charges, deck charging being the only practical method of reducing the coupling ratio. In general, holes larger than 150 mm and cartridge sizes in excess of 50 mm are not recommended for perimeter blasting.
7. Comment

This paper has defined some of the key considerations in creating a successful split and contributing to a stable highwall. The next step is to create the highwall, assess the results and amend the design accordingly. This should be done to determine the correct method prior to arriving at the final highwall position.

8. Figures

![Diagram](Figure 1. Overbreak in fractured ground)
Figure 2. Reducing overbreak in production blasts

Figure 3. Split formation, in the solid, through instantaneous initiation of closely spaced holes
Figure 4. Guide holes around a curve

Figure 5. Post split (Trim) Blast
Figure 6 Use of “Cushion” holes

Figure 7. Suggestions for timing

Direct: 33/100, increase the delay on the back row

Oblique: 75/42 Low impact
**Figure 8. Guide holes**

9. Acknowledgements

Claude Cunningham
ISEE Blasters’ Handbook