

The Effects of Some Structural Properties of Rock on the Design and Results of Blasting

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SUMMARY. This paper describes the effects of porosity, joints, bedding planes and rock type combinations on the design and results of blasting. It also examines means of minimising explosives' energy losses which such discontinuities encourage. Rocks with closely-spaced discontinuities and/or high intergranular porosities should be blasted with well stemmed charges which generate high heave energy:strain wave energy ratios. Best fragmentation is usually obtained where the face is parallel to and on the dip side of principal joints; as the dip flattens however, inclined blastholes may become necessary to maintain front-row toe burdens at their design distance. Where a sub-vertical fault forms the contact between ore and waste within a blast block, initiation should proceed from the stronger into the weaker rock; if a different blasthole pattern is required beyond the contact, only the spacing should be changed, the burden remaining constant. Where softer overburden strata sandwich a hard band, fully-coupled centre-primed charges should be located within the band, the charge being efficiently stemmed at both ends. Band thickness restricts the dimensions of the blasthole pattern. Good fragmentation of thin bands necessitates the use of small patterns which, in turn, encourage the drilling of small diameter blastholes.

1 INTRODUCTION

Shortcomings in our understanding of the effects of rock properties are the major obstacle to progress towards optimum blasting. If rocks were homogenous isotropic media, one could confidently expect more rapid advances towards this goal. But such an assumption, even as a first approximation, is rarely valid. Almost invariably, rocks exhibit numerous natural discontinuities (e.g. joints, bedding planes, faults, soft seams, vughs, pores, etc.) and cracks created by previous detonations. Some of these discontinuities may be extensive and wide; others will be localised and narrow.

Both experiments and practice have indicated that blasting results are influenced by rock properties more than by explosives' properties. But the nature and degree of heterogeneity of the rock affect not only fragmentation, displacement, muck-pile looseness and toe conditions; they also exert a considerable influence upon

1. the selected blast design and
2. the intensities of undesirable side effects such as blast-induced overbreak and slope instability.

Because of its heterogeneity, rock may exhibit planes of preferential fracture oriented in any one of an infinite number of directions. In some cases, the rock's structural features allow the explosive's energy to be wastefully dissipated rather than perform the work intended.

Despite the problems associated with heterogeneity and anisotropy (and contrary to one's prima facie expectations), rock properties are not always an uncontrollable blast parameter. Although there are factors over which the blasting engineer has a much higher degree of control, one should recognise the fact that rock properties can often be controlled to a limited extent. This control may be achieved for example, by designing the blast such that the initial free face and/or the effective free faces (which are created progressively during

the blast) are at the desired angle to dominant joints or bedding planes. This selective ability may enable the operator to improve blasting results.

2 EFFECTS OF POROSITY

2.1 Intermediate Porosity

The vughs which result from dissolution of the primary rock structure by groundwater are much larger and less uniformly distributed than the intergranular pores which are present in rocks such as sandstones. Vughs up to 150mm across can be found in many sulphide ores. Some limestones and iron ores contain vughs which are at least an order of magnitude larger than this.

Vughs tend to reduce blasting efficiency. When intersected, vughs can cause drill steels to jam. Vughs can also cause the following charging problems, especially where bulk ANFO or pumped water gel blasting agents are used.

1. Where a standard weight of explosive is charged into each blasthole, large vughs can result in
 - (a) an excessive charge concentration within the vugh, and
 - (b) a corresponding lack of explosive's energy in the upper part of the blasthole.

When it is possible to obtain stemming rise within that part of the blasthole immediately above the vugh, a separate column charge should be used. If stemming difficulties prevent this procedure, efforts should be made to increase the energy yields of upper parts of charges in surrounding blastholes. Such measures are most easily carried out with bulk water gel mix trucks or with bulk ANFO trucks having an aluminised ANFO capability.

2. When all blastholes are charged to give a constant stemming length, large vughs may allow very heavy charge weights per blasthole with consequent risks of cut-offs, flyrock and/or overbreak.

If the charged section of the blasthole lies near a sizeable vugh, blasting effectiveness is reduced as a result of

1. the premature termination of outward-propagating cracks at the wall of the vugh (see Fig. 1) and
2. the more rapid drop in blasthole pressure as explosion gases jet into the vugh via discontinuities and strain-wave generated cracks (see Fig. 2).

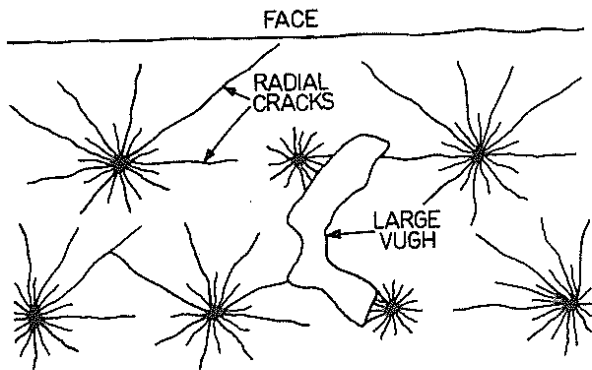


Fig 1 - Premature termination of outward-propagating radial cracks by a vugh

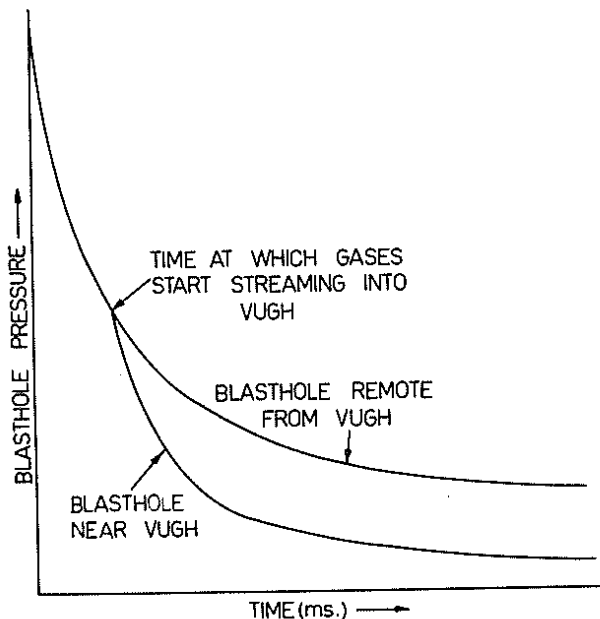


Fig 2 - Effect of nearby vugh on rate of decay of blasthole pressure

Once the explosion gases start to stream through a radial crack or a combination of discontinuities into a nearby vugh, they cease to fully pressurise other radial cracks. For this reason, radial cracks in directions other than towards the vugh then tend to stop propagating (see Fig. 1).

Currently, there is no practical technique to determine whether or not a blasthole is close to a sizeable vugh. As soon as suitable instrumentation for this purpose becomes available (Anon., 1978),

the energies of charges in blastholes surrounding a vugh can be suitably increased either throughout their length or at the appropriate horizon.

2.2 Intergranular Porosity

Increases in intergranular porosity cause

1. greater dissipation of strain wave energy and
2. reductions in dynamic compressive strength and hence, increases in both the amount of crushing and the percentage of fines produced.

The work of fragmenting highly-porous rocks, therefore, is performed almost entirely by the heave energy component of an explosive's total energy output. Consequently, it is important to retain the explosion gases at high pressures until they have completed all the work of which they are capable. This situation is best realised where stemming lengths and burden distances prevent the premature release of energetic explosion gases.

3 EFFECTS OF MACROFISSURES

All rocks contain in-situ macrofissures, the influence of which often outweighs that of the intact rock's mechanical and physical properties. Discontinuities such as joints and weak bedding planes tend to dominate both the nature and extent of the fracture pattern. Indeed, the spacing of discontinuities was found to be the blasting variable having greatest influence on degree of fragmentation and, hence, working cost per cubic metre of rock (Kaufman, 1971).

Blasting can extend discontinuities to great lengths. The longer a discontinuity, the easier it is extended. The formation of new cracks (by explosion-generated strains) in the immediate vicinity of propagating discontinuities is suppressed.

Joints and bedding planes can be tight, open or filled. For this reason, they can exhibit different energy-transmitting abilities. The walls of such discontinuities represent surfaces from which strain waves may be reflected. A strain wave in a heavily jointed or densely bedded rock mass, therefore, suffers greater attenuation and dispersion. The spacing, orientation, persistence, aperture and filler material of the discontinuity all affect the attenuation and continued propagation of the strain wave.

Blast-induced overbreak and overdigging are usually strong functions of the type and number of macrofissures. The degree of success of overbreak-control blasting techniques depends primarily on the structural geology. In strong massive rocks, such techniques are usually successful, but in unconsolidated or highly-fissured strata, consistently good results may not be possible.

The frequency, width, distribution and direction of discontinuities in a face are usually so variable that it is quite impossible to drill two or more blastholes that have identical burdens and degrees of confinement. Hence it is rarely possible to carry out a single test that clearly demonstrates just how much one explosive, initiation system or blasthole pattern is better than another. For this and other reasons, then, one blast does not constitute a trial. Except when there is some drastic difference in results, one usually needs to fire several blasts before the influence of a change in blast design can be accurately assessed.

In many cases, cut-offs are not strongly time-dependent, but are caused by low-friction sliding along joints or bedding planes, especially in the upper bench alongside the stemming column.

3.1 Joints

Provided a joint is closed or well cemented, blast-induced fractures can propagate across it. Fractures will not propagate over an open joint until the joint is closed. Whether new fractures are created beyond the joint depends on the strain in the rock beyond the joint and on the presence of a discontinuity which is long enough to propagate under the reduced strain.

At tight air-filled cracks, water-filled cracks and moderate density changes in the rock, some strain energy is reflected and some refracted. Tight joints parallel to the blasthole may not cause any appreciable reflection of the wave. Because of their inability to transmit tensile stress, however, even tight joints separate under the influence of the tensile wave which returns from an effective free face further out from the blasthole. This may reduce interaction between the reflected wave and the radial cracks, and may even prevent the degree of fragmentation required for satisfactory displacement.

Where a wide air-filled joint is parallel (or nearly so) to the blasthole's axis, the joint is not completely closed by the incident compressive strain wave. Therefore, it introduces an acoustic impedance mismatch and reflects the wave. If the reflected tensile wave is sufficiently strong, internal spalling occurs (see Fig. 3). Radial cracks which the strain wave would have formed in a massive rock are (prematurely) interrupted by the joint. This gives better fragmentation between the blasthole and the joint, but reduces breakage beyond the joint.

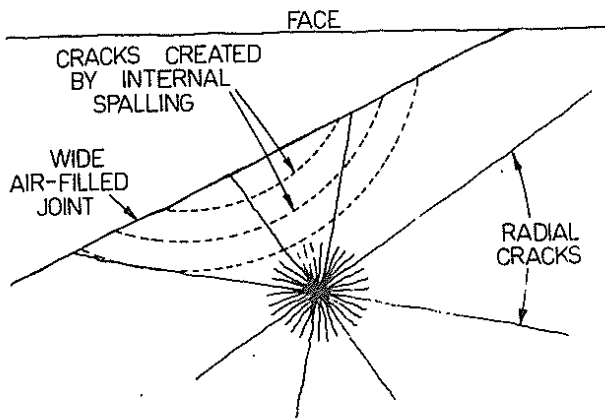


Fig 3 - Termination of radial cracks and creation of internal spalling cracks at wide air-filled joint.

A similar effect is observed where the joint is filled with a material which has an acoustic impedance much less than that of the rock; the percentage of strain energy refracted increases as the filler impedance:rock impedance ratio approaches unity. Experiments have indicated (Seinov and Chevkin, 1968) that fragmentation varies considerably with both the aperture and filling of the discontinuity.

Whenever an open discontinuity is crossed by a

blasthole, explosion gases escape through the discontinuity without performing all the work expected of them. If an open joint intersects the charged section of the blasthole, it allows high gas flows which cause this joint to expand preferentially due to the wedge effect. Loss of gas into the joint causes a rapid drop in blasthole pressure and a consequent reduction in rock breakage by heavy energy. The reduced effectiveness of heavy energy is most critical, of course, where persistent open joints extend from the blasthole to the face and/or top of the bench and allow gases to be vented directly to atmosphere. Premature venting through such discontinuities leads not only to poor overall fragmentation and displacement; it is also often responsible for airblast and/or flyrock problems. Where persistent open joints running normal to the face pass through the blasthole, high pressure gases also tend to open up the joints behind back-row blastholes; breakage often extends beyond the intended excavation boundary, and the newly-formed face can be quite ragged.

Best fragmentation is usually obtained where the face is parallel to and on the dip side of principal joint planes (Belland, 1966). The newly-formed face is then often a joint face, and blasthole spacings appreciably greater than the burden can be used satisfactorily. Where joints are sub-vertical, this configuration also gives minimum toe problems and a relatively high probability of diggable (bonus) overbreak. As the dip flattens, however, the slope of the face tends to follow the dip, and inclined blastholes may become necessary where the horizontal distance between the toe and crest of the bench becomes large. In such situations, vertical blastholes cause considerable variation in the front-row burden from top to bottom of the face.

The major disadvantage of blasting down-dip is usually that of surface overbreak (see Fig. 4). Where this, together with vertical drilling, gives excessive toe burdens on front-row blastholes, better results may well be achieved where the face lies at 45° and 135° to the strike. But when the angle between dominant joint planes and the face lies in the 30° - 60° range, the development of long wide cracks behind back-row blastholes can give an irregular and shattered new face. These cracks are joints which have been opened up

1. by invading explosion gases, and
2. by the levering action associated with forward motion of the burden.

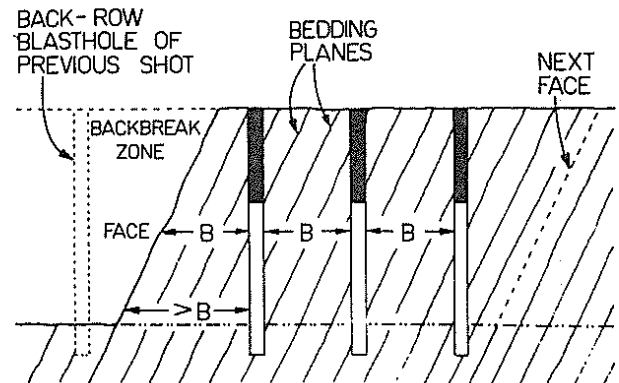


Fig 4 - Excessive toe burden caused by structurally-controlled backbreak zone and face angle

This problem is minimised

1. by initiating V-type patterns from that end of the blast block for which most of the rock moves in the down-dip direction (see Fig. 5) and
2. by using a staggered 'VI' (see Fig. 5) or square 'VI' rather than square 'V' pattern, so that explosion gases from simultaneously-initiated charges cannot act in unison in streaming into, widening and extending backward facing joints (Duffy, 1979).

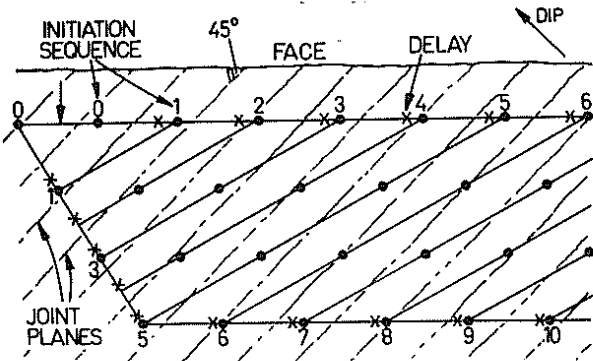


Fig 5 - Shooting down dip with a staggered 'VI' pattern

Blasts in which the strike was normal to the face produced large slabby muck (Belland, 1966).

Joints often have the effect of determining the actual boundaries of the blast block. In vertical crater retreat mining, craters tend to terminate at joints and/or weak bedding planes.

3.2 Bedding Planes

Where a vertical blasthole intercepts weak horizontal bedding planes, the widening and extension of these discontinuities is not assisted by the strain wave. Radial and release-of-load fractures (both of these being in vertical planes) are supplemented by the opening up of these bedding planes by heave energy.

Weak horizontal bedding in bench blasting is often responsible for extensive horizontal displacement of the rock. Where a well-defined bedding plane exists at floor level, very little, if any, sub-drilling is necessary (cf. sub-drilling of about 8 times the blasthole diameter for strong massive rocks). If the sub-drilling in densely bedded/fissured rock is greater than that required, the floor of the bench is highly disrupted by the blast, and drilling of the next lift may become very difficult. If some of the blastholes on the lower bench have to be abandoned, the actual blasthole pattern will then be quite different from the design pattern, and inferior blasting results will be obtained.

4 'FLOATERS'

Mixtures of elastic and plastic-acting rocks can cause formidable blasting problems. Where 'floaters' (i.e. boulders of a relatively elastic rock embedded in a much softer plastic-acting matrix) are encountered, the strain wave propagates with little attenuation in the boulders, but its energy is rapidly dissipated in the matrix. Floaters which do not contain part of the explosive charge receive very little strain energy and,

often, are simply pushed out intact into the muck-pile. When floaters contain some of the charge, the degree of breakage can range from inadequate to excessive depending on the size of the floater, charge location and matrix characteristics.

If the floater is large, the charge located only within the floaters outer shell (as in A3 in Fig. 6) and the matrix highly compressible, breakage will be poor. Where a small floater contains a comparatively long charge (as in A6 in Fig. 6) and the overlying stemming material is relatively efficient, on the other hand, high degrees of breakage result.

The combination of inefficient stemming and a highly compressible matrix reduces the contribution of heave energy to breakage, since rapid "bulling" of the blasthole in the matrix allows an impulsive drop in blasthole pressure. In these conditions, the charge within the floater should be fully-coupled and, preferably, should exhibit a high detonation velocity and high strain energy:heave energy ratio.

5 BEDS OF DIVERSE MATERIALS

5.1 Ore/Waste Blasts in Open Pits

Consider a blast block which contains both ore and waste, the contact being a sub-vertical fault. Where the simplicity of a standard drilling pattern is required, burdens and spacings are usually such that continuous column charges give good blasting results in the stronger rock. Lighter (perhaps decked) charges are used in the weaker rock.

It is usually more difficult to standardise charge weight and then select different blasthole patterns for the ore and waste. If the pattern is altered at the contact, it is advisable to keep the burden constant and change the spacing (see Fig. 7). Where charges are fired in a V-type sequence, this introduces bends in the detonating cord trunkline network (see points A, B, C in Fig. 7) and, therefore, necessitates increased supervision and care in tying in the trunklines. Where both burden and spacing are changed

1. the complexity of drilling and connecting trunklines can become unacceptable, and
2. the newly-created face may be stepped (see Fig. 8), thereby increasing blast design problems in the block immediately behind.

In blasts which include both ore and waste, it is preferable to shoot from the stronger into the weaker rock. If the reverse order is chosen, explosion gases from a charge which lies within that part of the stronger rock alongside the contact can jet through radial cracks and/or natural discontinuities and expand with relative ease into the weaker rock, because this has been already disrupted by charges on an earlier delay (Mathieson, 1979). This causes a higher rate of decay of blasthole pressure which is manifested as reduced breakage and displacement of the harder rock around that particular charge.

The presence of such contacts within a blast tends to increase the probability of cut-offs, especially where the the contact can be mobilised by water or clay-like fillers.

These problems would seem to suggest that operators should blast up to rather than through the contact. But there can be difficulties associated with this alternative approach. In some cases, discrete

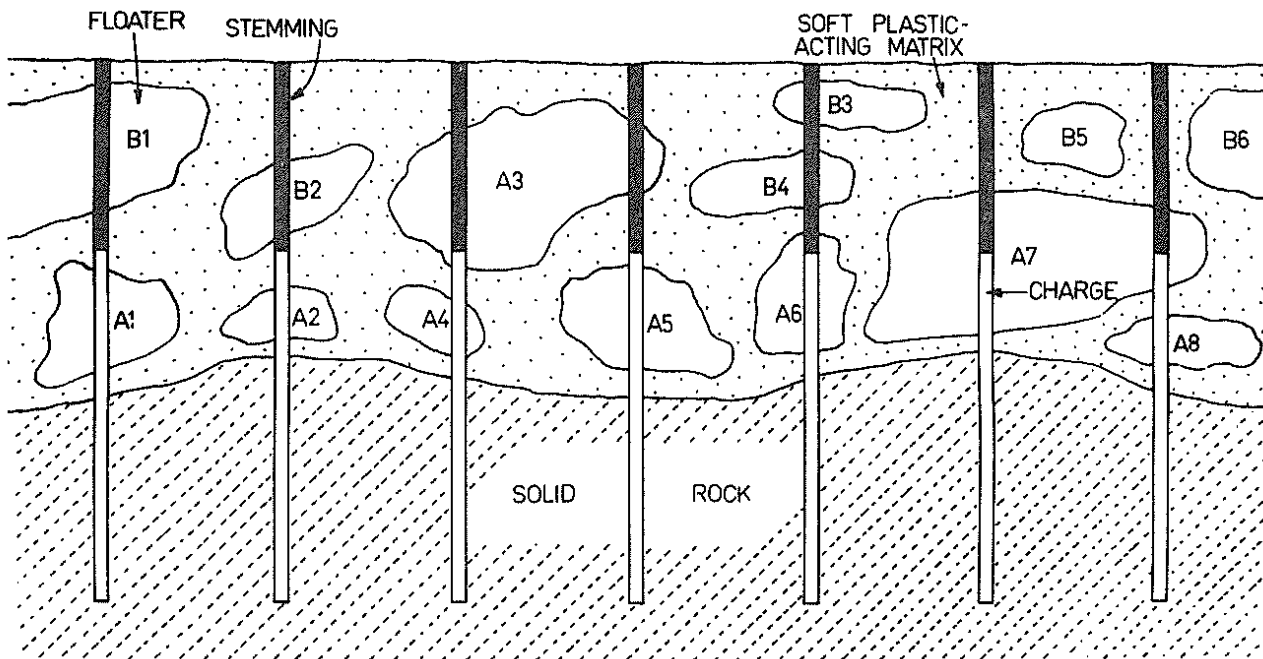


Fig 6 - Blasting of hard boulders embedded in softer plastic-acting matrix

beds or rock types extend over only short distances, and to blast within a single rock type would lead to shots which are too small and/or of unacceptable shape. In cases where ore/waste contacts are shallow-dipping, it is preferable to blast through these contacts in order to avoid

1. overbreak to the contacts and, as a consequence, large boulders, and
2. shallow-dipping faces for subsequent blasts.

Considerable secondary drilling may well be required to correct each of these effects.

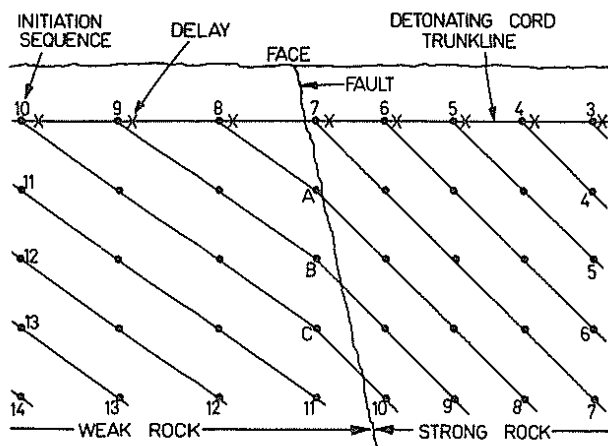


Fig 7 - Recommended change in blasthole pattern of 'V'-type blast at contact between weak and strong rock (or waste and ore)

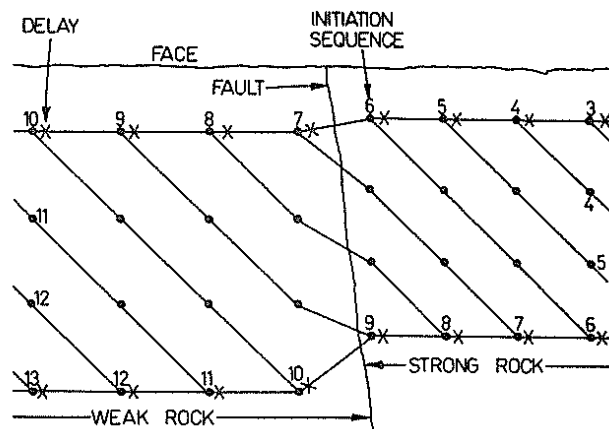


Fig 8 - The type of blasthole pattern change (at contact) which should be avoided

5.2 Overburden Blasts in Surface Coal Mines

Where overburden characteristics are relatively constant from top to bottom of the face, blastholes are usually stopped at or just above the overburden/coal contact, and continuous column charges are normally employed. If soft beds lie immediately above the coal, blastholes can sometimes be bottomed at the base of the lowest hard bed.

Where hard strata occur only at the base of the bench, a single column charge in the bottom of the blasthole is generally used. As the thickness of such hard strata becomes a smaller percentage of face height, however, horizontal blastholes become increasingly attractive.

Where the only hard band lies between softer beds, most effective blasting results are obtained by locating the charge

1. totally within the hard band or
2. within and just below the band.

These charges should be initiated at the points shown in Figs. 9 and 10. This priming geometry ensures that the resultant strain wave intensity in the band is maximised through superposition of waves from those charge elements which are equidistant from the primer. In large diameter blast-holes, where standard 450g cast primers cause relatively long run-up velocity regimes in ANFO, it may well be cost effective to increase the strain energy concentration in the band by locating high-energy, fully slumpable water gel booster charges both below and above the primer. The selected water gel

1. should not be side-initiated by the downline (as this method of initiation increases heave energy at the expense of strain energy) and
2. should attain its steady-state velocity within the shortest possible distance from the primer.

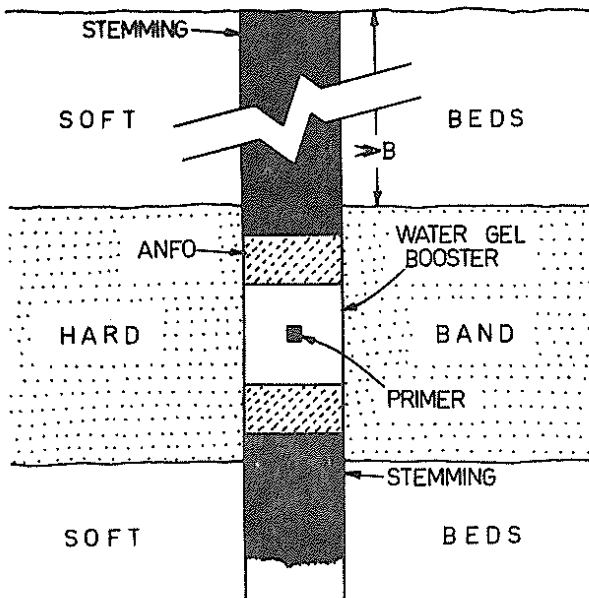


Fig 9 - Charge/priming geometry for thick hard band or thin hard band at depth

Because explosion gases should be retained at their initially high pressures within the hard band for the longest possible time, it is important to increase the efficiency of stemming material both above and below the charge. If the type and/or length of stemming is unsuitable, gases will rapidly escape into the weaker adjacent beds, thereby causing a relatively rapid reduction in blasthole pressure. But even where correctly-positioned charges are well stemmed, the spacing of such charges will be restricted by the thickness of the hard bed. This being the case, it is prudent to select the most efficient type of blasthole pattern (viz. a staggered pattern based on an equilateral triangular grid).

5.2.1 Thick hard bands

Totally enclosed charges (see Fig. 9) are most suitable where the hard band is thick and especially where this is a considerable distance from the top of the bench. Thick beds also allow the

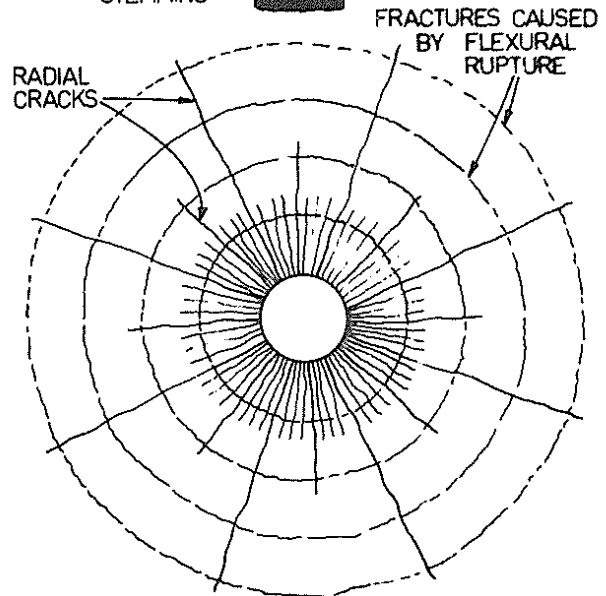
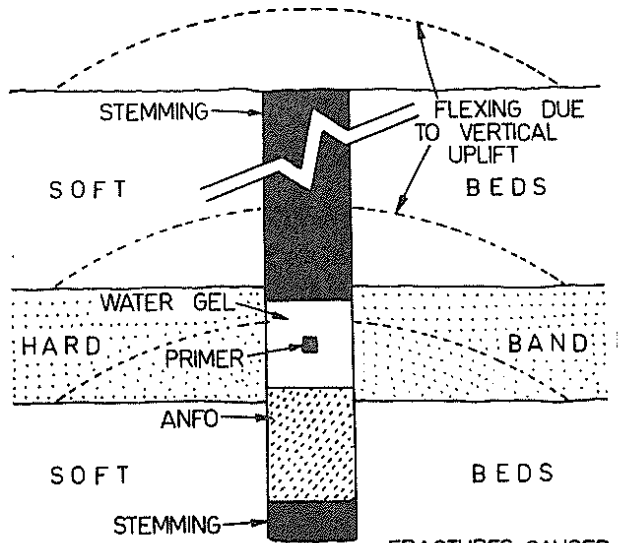


Fig 10 - Recommended charge/priming geometry for thin hard band close to top of bench

effective use of relatively wide blasthole patterns and, hence, larger blasthole diameters.

5.2.2 Thin hard beds at depth

5.2.2.1 Using vertical blastholes

Where a thin hard band lies well below the top of the bench, totally enclosed charges should be used (see Fig. 9). Whatever improvements are incorporated into blast design, such bands can be finely broken only by drilling a relatively close pattern of blastholes. For this reason, large diameter blastholes should be employed

1. only when small diameter blastholes cannot be drilled or are more expensive to drill or
2. where large bucket dimensions reduce the need for a high degree of fragmentation.

Where the distance between blastholes increases beyond about twice the thickness of the band, the upper size range of the fragmented band is

relatively insensitive to variations in the diameter or weight of each charge; further increases in blasthole diameter and, hence, charge weight tend to cause greater deformation and disruption of the softer beds alongside rather than reduce the dimensions of the largest fragment in the band. This effect is important where it is necessary to break up a massive band which lies in softer matrices being worked by bucket wheel excavators. Where a 2m thick band of massive sandstone is to be blasted to produce fragments no longer than 1m, for example, patterns larger than 4m x 4m cannot be expected to give satisfactory results. Such a 4m x 4m pattern would be quite adequately drilled out with blastholes having a diameter of 125mm or less. Larger diameter blastholes would have no technical (or, in most cases, economic) advantage.

5.2.2.2 Using horizontal blastholes

Because they overcome the need to drill through softer strata in order to penetrate the hard band, horizontal blastholes may well be more efficient than vertical blastholes. But even where it is possible to drill horizontal blastholes, the charging of these is considerably more difficult than for vertical blastholes. If long horizontal blastholes are attempted, the drill bit may sag or "wander"; the base of the charge would then be nearer to the bottom than the top of the band. This, of course, would result in less uniform breakage and a greater proportion of larger rock fragments.

Where blasthole length is restricted to prevent such deviations, it may not be possible to keep drilling and blasting operations sufficiently far ahead of the digging equipment. Even where drilling and digging can be well co-ordinated, the diameter of horizontal blastholes is restricted by the thickness of the band. In the ideal case shown in Fig. 11, for example, propagation of radial cracks A, B, C, and D will be retarded as soon as cracks E, F, G, and H intersect contacts WX and YZ and allow high-pressure gases to stream into the weaker strata. Where these softer beds are highly compressible, propagation of cracks A, B, C and D may well be arrested abruptly.

If depth below the horizontal free face prevents upward flexing of the band, charges should be initiated in a delayed sequence so that additional breakage (in vertical planes) is encouraged by flexing in a horizontal plane (see Fig. 12).

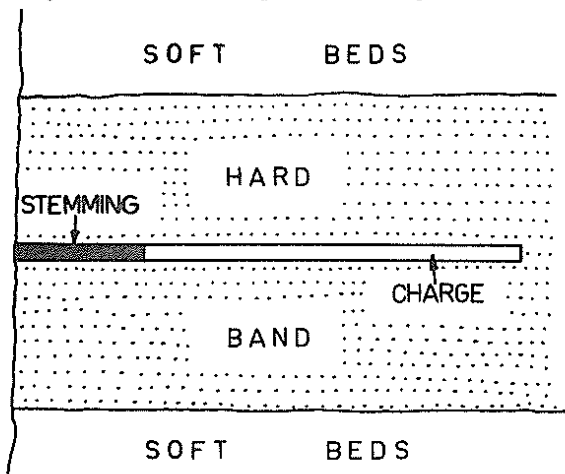


Fig 11 - Premature termination of radially-propagating cracks at contact planes above and below a horizontal blasthole

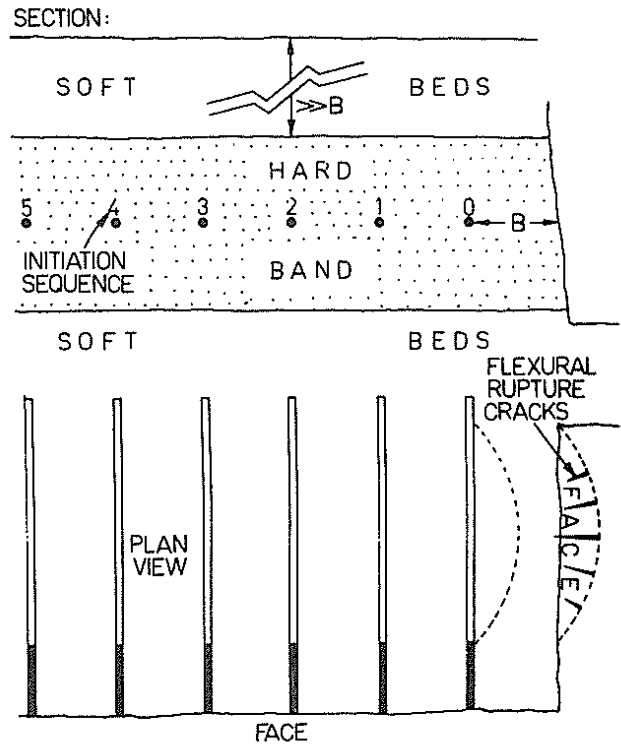
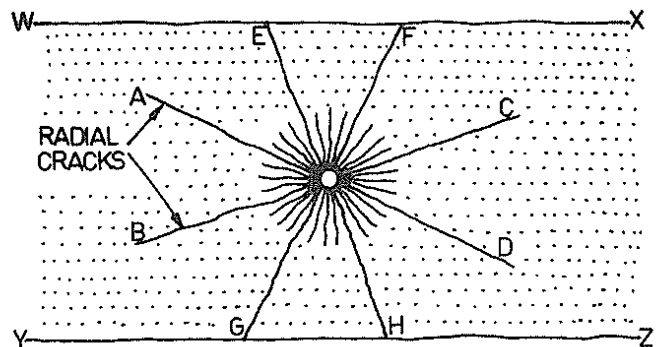


Fig 12 - Breakage of thin hard band at depth by flexural rupture using horizontal blastholes

5.2.3 Thin hard bands near the surface

Where a thin hard band lies relatively close to the top of the bench, the charge should be located both within and immediately below the band (see Fig. 10). The enclosed section of the charge creates a radial crack pattern within the band. These cracks are supplemented by cracks created by flexing of the band due to vertical uplift (see Fig. 10). The amount of flexural breakage increases with the weight of charge beneath the band.



5.3 Quarry Blasts

In some quarries, hard basalt flows overlies relatively soft clays. If blastholes are drilled completely through the basalt and then charged such that the base of the explosive column is at the basalt/clay contact, explosion gases stream into a rapidly expanding cavity in the clay (see Fig. 13a). The rate of expansion is encouraged by bottom priming and by increases in both the plasticity and porosity (up to 50%) of the clay. Because blasthole pressure falls at an unacceptably high rate, fragmentation and displacement of the basalt are usually far from satisfactory.

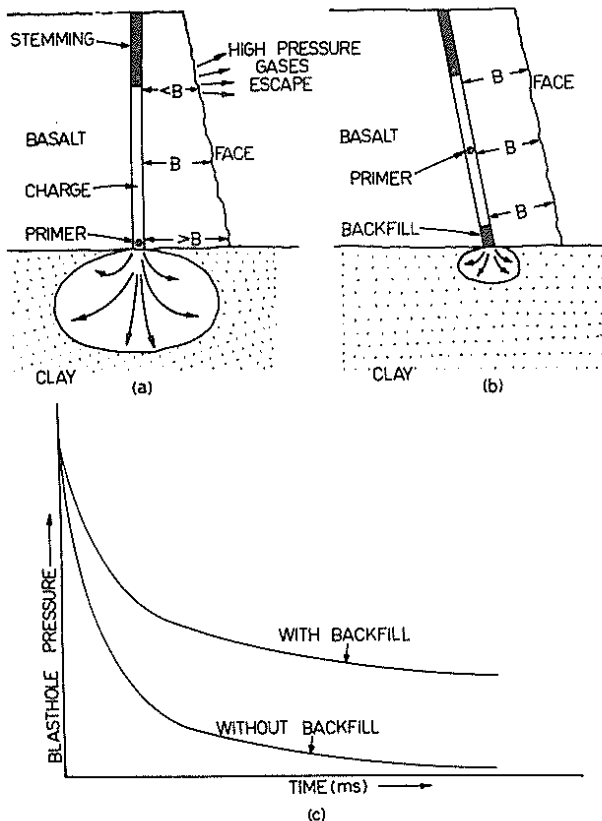


Fig 13 - Plastic deformation of clay beneath basalt flow and associated blasthole pressure-time curves

Improved blasting results are achieved

1. by bottoming blastholes a nominal selected distance above the basalt/clay contact or
2. by drilling to the contact and then backfilling a suitable length of the blasthole with an efficient stemming material (e.g. graded angular crushed rock) before charging (see Fig. 13b).

This will maintain high pressures within the blasthole for a longer period of time (see Fig. 13c) and will reduce energy losses associated with plastic deformation of the clay. Energy losses can be further reduced and muckpile characteristics enhanced by taking the following action.

1. Use a fully-coupled explosive having high detonation velocity and a high strain energy: heave energy ratio.
2. Initiate the charge at its centre (see Fig.

13b), so that the upper and lower halves undergo simultaneous axial detonation (thereby increasing the resultant strain wave intensity through superposition).

3. Prevent premature escape of explosion gases to atmosphere by ensuring that the length of stemming column and the upper burden distance have satisfactory values. Wherever possible, graded angular crushed rock should be used as stemming, the length of the column being at least 20 blasthole diameters. In high and/or shallow-dipping faces, angled blastholes are often necessary if inadequate upper burden distances are to be avoided (see Fig. 13b).

Similarly, where a charge is located totally within a soft seam, the soft material

1. causes considerable attenuation of the explosion-generated strain wave, and
2. is rapidly compressed thereby allowing the blasthole pressure to fall at an excessive rate.

This tends to result in expanding the blasthole to a much larger effective diameter, but with little breakage taking place beyond the soft seam (see Fig. 14).

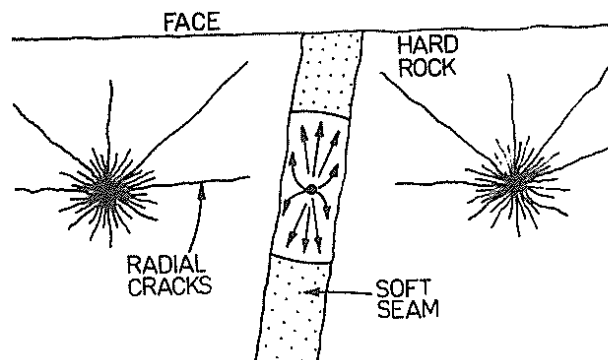


Fig 14 - Poor blasting performance of a charge located within a soft seam

6 CONCLUSIONS

The heterogeneity of rock has a major influence on both the design and results of blasting. Unless the effects of the many structural features of rock are understood and considered when selecting blast parameters, much of the explosive's energy will fail to contribute to the desired muckpile characteristics.

When intersected by blastholes, large vughs can cause charging problems and/or inadequate energy distribution. Whether they are adjacent to or intersected by a blasthole, vughs encourage excessive rates of decay of explosion gas pressures. These are manifested as poor fragmentation and displacement of the rock around the vugh. Although the influence of vughs cannot always be overcome, problems are often minimised by adjusting the amount and distribution of energy liberated by surrounding charges.

Rocks with high intergranular porosity should be blasted with well-stemmed charges which generate high heave energies. The cost effectiveness of explosives with high detonation velocities and high strain wave energies is usually low, an excessive percentage of energy being dissipated in

creating fines.

Open joints and bedding planes arrest the propagation of strain wave-generated fractures. In blocky strata, this usually gives good fragmentation between the blasthole and the discontinuity but inadequate breakage beyond the discontinuity. In highly fissured strata, the suppression of strain wave effects rarely causes a problem, the network of discontinuities being opened up and extended by invading explosion gases.

Best fragmentation is usually obtained where the face is parallel to and on the dip side of principal joints or bedding planes. As the dip flattens, however, the slope of the face tends to follow the dip, and inclined blastholes may become necessary if the toe burdens of front-row blastholes are not to exceed their design distances.

In general, closer wider and more persistent discontinuities cause

1. a decrease in the effectiveness of overbreak control blasting techniques and
2. an increase in the probability of cut-offs.

Where hard massive boulders are embedded in softer, plastic-acting strata, fragmentation of boulders increases with the percentage of boulders within which detonation occurs. Satisfactory breakage may necessitate the reduced blasthole patterns and shorter stemming columns associated with the drilling of smaller diameter blastholes.

Where a sub-vertical fault forms the contact between ore and waste within a blast block, efforts should be made to shoot from the stronger into the weaker rock. If a different blasthole pattern is required beyond the contact, only the spacing should be changed, the burden remaining constant.

When softer overburden strata sandwich a thick hard band or thin hard band at depth, fully

coupled charges should be located within the band. These should be initiated at their centres and efficiently stemmed both below and above. In cases where good fragmentation is essential, ANFO charges may need to be boosted by a fully-slumped, high-energy water gel. Thin hard bands near the surface are best broken by extending the charge below the bottom of the band; this allows rupture by upward flexing (i.e. doming) to supplement radial cracking. The spacing of blastholes is always restricted by the thickness of the band. Good fragmentation of thin bands necessitates the use of small blasthole patterns which, in turn, encourage the drilling of small diameter blastholes.

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