THE MECHANICS OF PRE-SPLITTING

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INTRODUCTION

Pre-split blasting is a technique used to reduce damage to excavation profiles during blasting by pre-forming a continuous fracture between parallel boreholes lightly charged with decoupled explosives along the line of the required surface. Various theories and hypotheses have been presented to explain the phenomenom of pre-split blasting (see for instance Aso, 1966; Carrasco and Saperstein, 1977; Griffin, 1973 and Kutter, 1967) but no totally satisfactory explanation of the mechanics of fracture formation and extension has been provided.

Most previous approaches (Aso, 1966; Griffin, 1973 and Paine, 1961) have tended to concentrate on the mathematics of interaction between stress waves from adjacent sources. Interaction of stresses induced by expanding gases following detonation has been considered of minor importance. However, decoupling introduced during pre-splitting is specifically designed to reduce dynamic effects and to emphasize rock stresses resulting from expansion of detonation products. It could indeed be argued that the phenomenom has more in common with hydrofracture than with the conventional use of high explosives.

MECHANICS OF PRE-SPLITTING

Energy release and transfer to the rock body from an explosive detonating in a borehole in rock is a complex process, being affected partly by the relative impedances of the explosive and rock and the efficiency of the coupling, and partly by the pressures exerted by expanding gases in the borehole. It is useful to differentiate between these two aspects of the process by describing them as the dynamic and quasi-static components of energy release.

The dynamic component comprises initially a plastic headwave, decaying rapidly to form a radially expanding compression wave. The energy in the wave, its shape and velocity are related to the explosive energy and the degree of coupling of the explosive and rock and their relative impedances. The initial high energy in the wave is dissipated by local crushing at the borehole periphery and/or limited radial cracking parallel to the direction of maximum compression. According to Carrasco and Saperstein (1977) these cracks are initiated near to but not at the hole surface. Since the wave velocity is approximately three times the maximum crack propagation velocity (Edgeston and Barstow, 1941), extension of cracks by wave action is minimal and intact rocks generally have a high resistance to transient compression. The main effect of the wave is in loosening discontinuities in the rock through tensile reflection at interfaces which cross the wave path.

As the headwave leaves the zone of the borehole, the borehole itself is pressurised by the build up of the gases which are a byproduct of the rapid combustion characterised by detonation. These exert a high quasi-static pressure on the borehole sidewall. The effect of this pressure is to induce compressive radial and, more important, tensile tangential stresses around the borehole which effectively open the existing limited length cracks produced by the dynamic wave. This results in two effects:

(a) The opening of the crack surfaces on/or near the borehole circumference will induce tensile stresses at the tips of the cracks, creating conditions for crack extension.

(b) Gases of detonation migrating into the opened cracks will cause further crack extension.

Various explanations of the processes involved in crack propagation are available in the literature on hydrofracturing, (see for instance Perkins and Krech, 1966; 1968; Sneddon, 1946; Wong and Farmer, 1973). The principal conclusion is that very high pressures are required to propagate cracks. In the case of detonation gases however, these pressures exist. Initially, the increasing pressure within a crack will result in an increase in the extent of the stress altered region around the crack, maintaining it in a state of elastic stability. However, beyond a critical pressure the system will become unstable and the crack will extend radially until further extension of the stress altered region leads to a return to stability, thus limiting further extension. The differential work in extending cracks is the product of the volume of the cracks created and the pressure increment. This energy is partly stored as reversible strain energy and partly absorbed in creating new crack surfaces.

The preferred direction of crack propagation if a line of boreholes exists will be that in which cracks can be most easily opened and into which the high pressure detonation gases can most easily penetrate. It is evident that the greatest tendency for crack opening will occur where tangential tensile stress zones overlap between neighbouring pressurised boreholes. It is equally evident that less favourable conditions will exist for opening of cracks normal to the borehole line. Where cracks from neighbouring boreholes intersect, a continuous fracture will be formed and subsequently opened, releasing pressure and inhibiting further crack extension except at its extremities.

The interaction of the individual stress fields around boreholes within a pre-split panel will cause the radial crack zones to expand in a slightly elliptical shape with the major axes orientated along the pre-split line. If a discontinuity is present between the holes then the first crack to reach the discontinuity will tend to create a path for further reduction of gas pressure, inhibiting further crack extension. Due to the geometry involved the crack should intersect the discontinuity at approximately 90°. If the discontinuity is closed a stress 'bulb' will be formed on the opposite side, cracks from the adjacent borehole will be induced to extend and curve to that point. If the discontinuity is open the crack will terminate.

where R = radial depth of crack zone

d = borehole diameter

For series (a) A = 45.7, B = +0.589

and for series (b) A = 26.9, B = +0.702

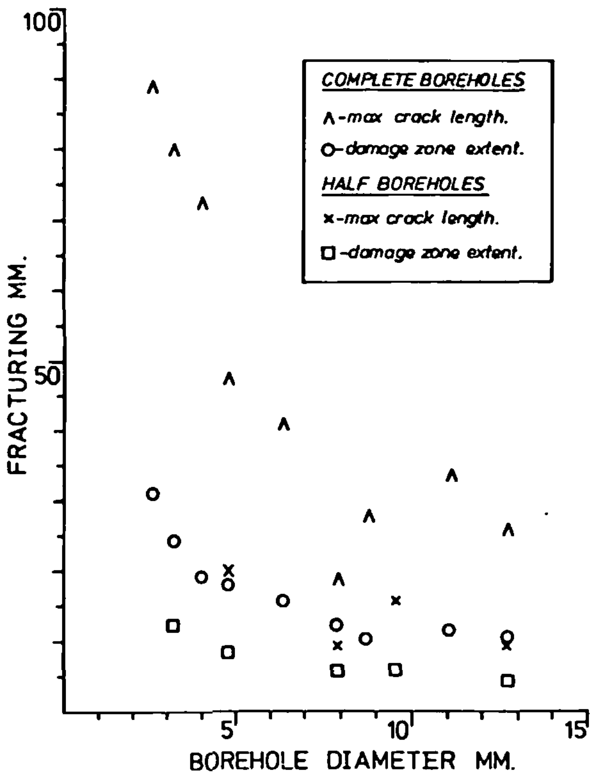

FIGURE 2. Graph of maximum crack length and damage zone extent for single normal series (a), and vented series (b), hole tests.

Since the value of B for series (b) tests is of a greater magnitude than for series (a) tests it is evident that increasing decoupling has a greater reduction on the dynamic component than the quasi-static component. Together the tests in series (a) and (b) demonstrate that for single holes, whilst the dynamic component may be responsible for crack initiation, the quasi-static gas component is the dominant mechanism in crack extension.

The main results of series (c) testing are summarised in Figure 3, which illustrates the maximum successful pre-split borehole separation obtained for various degrees of decoupling, expressed as borehole diameter, for single explosive cord. The relationship obtained was again exponential and was calculated as:

$$d = 372b^{-0.9}$$

where: d = borehole diameter (mm)

and b = maximum borehole separation (mm)

Generally the maximum successful pre-split borehole separation in series (c) was found to be approximately double the maximum crack length from series (a) tests on corresponding borehole diameters.

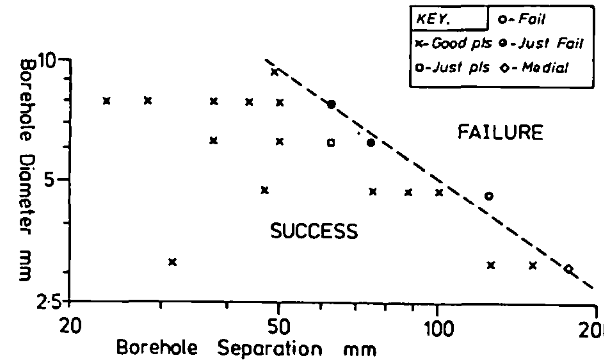

FIGURE 3. Graph of the relationship obtained in series (c) testing between borehole diameter and maximum borehole separation for pre-split (p/s) success.

FIGURE 4. A comparison of the maximum pre-split borehole separations for dynamic component (left) and dynamic plus gas pressure component of explosive energy (right) for 3.2 mm (0.125 in) holes.

The crack geometry dictates that during pre-split blasting the degree of irregularity of the final face is dependant on the discontinuity set orientation. The results show that at a discontinuity intersection angle of less than 60°, irregularities in the pre-split line become marked and if decreased to 15°, a high degree of overbreak will be sustained behind the line of boreholes (see Figure 6). Similar results were obtained for the tests in sandstone but only open cracks were visible.

From series (f) results it was found that dominant cracks are able to cross successive parallel discontinuities, as in Figure 7, but were observed to terminate at the discontinuity located immediately before the next borehole (except for discontinuity intersection angles below 20°). With increasing crack frequency, secondary cracking became less pronounced. Overbreak volume increased with the change from single to multiple discontinuities and with increasing discontinuity frequency up to four discontinuities per borehole spacing where tailing off occurred.

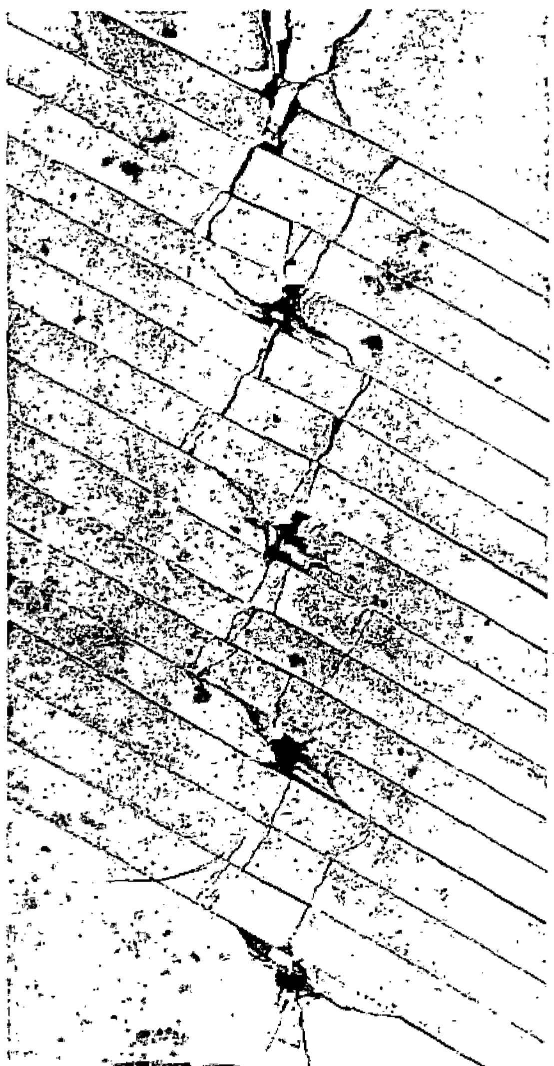

FIGURE 7. Pre-split in sandstone with multiple parallel discontinuities. Illustrating the propagation of dominant fracturing across and perpendicular to successive discontinuities.

FIELD OBSERVATIONS

Early field observations confirmed the trends from Phase I tests but the majority of field work was aimed at examining the effect of geotechnical factors on pre-splitting.

Pre-splitting at various highway construction sites in Scotland (both successful and unsuccessful) in dolerites, basalts, gneisses and schists was visited over the complete spectrum of constructional stages. In addition, various quarries in limestone and sandstone, utilising the technique for the stabilisation of production faces and protection of haul roads, were visited.

Initial discontinuity surveys were made to assess the overall 'intrinsic' stability of the rock mass at the various sites, particularly as affected by major faults and shears. This was followed by an assessment of how individual jointing affected the pre-split face by recording orientations of natural and imposed discontinuities.

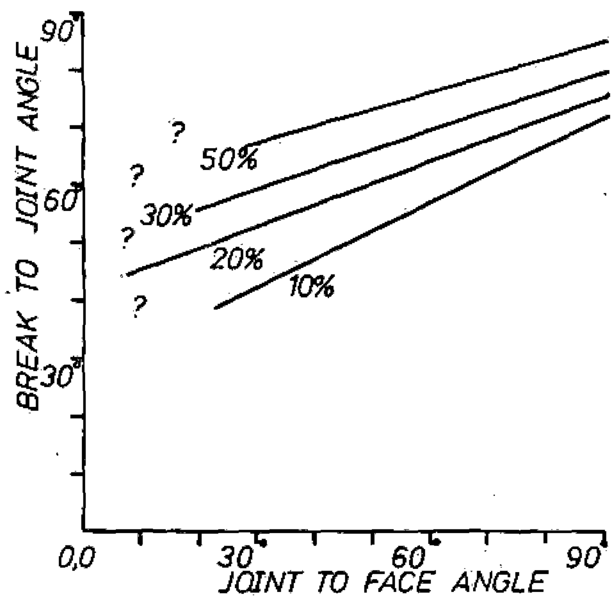

FIGURE 8. Graph of percentage occurrence of a total of 453 sets of fracturing to discontinuity field readings. Illustrating that the majority of fracturing is (sub)perpendicular to jointing. The fanning out of data for lower joint to face angles is attributed to secondary fracturing, and the absence of data below 20° to failure of pre-split.

From field observations it was concluded that if the face was intrinsically unstable either through a tendency to plane or wedge failure or toppling, pre-splitting did not lead to any improvement. Of more fundamental importance, it was shown that the tendency noted in the laboratory for fractures to spread in a direction normal to the direction of discontinuities was repeated. This is illustrated in Figure 8. Curved secondary fractures were also found to be present. This dictated that where continuous discontinuity planes and the pre-split line met at an angle of less than 60° irregularities in the pre-split line became marked. When this angle was decreased to

15°, pre-split blasting was observed to have had no beneficial effect on the resulting slope profile. Field examples of a failure to pre-split due to the presence of medium and large scale near vertical discontinuities at less than 15° to the intended face and a particularly successful pre-split are illustrated in Figure 9.

FIGURE 9. Top: successful pre-splitting with the predominant discontinuity set orientated perpendicular to the face.

Bottom: unsuccessful pre-splitting and high overbreak due to the major joint set being within 15° of the face.

CONCLUSIONS

(a) Although the initiation of cracking around a borehole is generally caused by the dynamic headwave, the majority of cracking is caused exclusively by the quasi-static gas pressure component of explosive energy.

(b) Pre-splitting is primarily caused by the interaction of the tangential tensile stresses induced in the rock by quasi-static gas pressure components from neighbouring boreholes.

(c) A pre-split may be obtained by using the dynamic component only of explosive energy, but the maximum borehole separation for this is less than 1/5th of maximum separation utilising gas pressures.

(d) Pre-split fractures intersect discontinuities in the rock at right angles.

(e) The first crack to reach a discontinuity tends to become dominant, inhibiting further crack propagation.

(f) Dominant cracks may cross successive discontinuities at right angles forming irregular breaks between neighbouring boreholes.

(g) The presence of discontinuities at less than 60° to the proposed pre-split line tends to cause poor line definition. If the angle is less than 15°, pre-split blasting has no effect on slope profiles.

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