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A DESIGN METHOD
FOR PRESPLIT BLASTING

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A Thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science in mining engineering.

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ABSTRACT

A method for determining the optimum conditions for presplit blasting has been developed and experimentally verified. The method is simple, inexpensive and not time consuming.

The presplit blasting design method is based on the concept that the controllable variables, decoupling ratio and hole spacing, have to be tailored to fit the uncontrollable environmental variables, such as the environmental stress and the rock properties. The method is empirical, in that the optimum combination of hole spacing and decoupling ratio is established through field tests under the conditions that exist locally.

The experimental work shows that, for a given explosive, the method is capable of determining the desired optimum set of conditions. It also suggests that there may be certain conditions for which presplitting is economically unfeasible.

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INTRODUCTION

Recent research concerning presplit blasting has been aimed at determining the variables involved in a presplit blast and at formulating theories to explain the phenomena. Very few, if any, of the recent research programs have been aimed at determining a method with which to design a presplit blast round.

Although blasting engineers have designed very successful presplit blasts, the methods they have used are not widely known. There is an immediate need for a versatile method of design which requires very little previous blasting experience and which is applicable to any set of environmental conditions. At the present time, the relationships between the variables involved in a presplit are not defined, and as a consequence a mathematical solution to the problem of design is not available.

The goal of this study was to formulate a simple method of determining presplit design parameters. The method was formulated by examining qualitative presplit blasting theory to establish which of those variables involved in presplitting could be controlled to determine the successful formation of a fracture. Tests were then performed to determine a means by which to choose and control the suitable values of these variables for any set of environmental conditions.

PRESPLIT BLASTING MECHANICS

A simple explanation of presplit blasting mechanics offered by Wilbur I. Duvall, U. S. Bureau of Mines, as quoted by Paine (1965) is as follows:

According to Duvall, the almost simultaneous detonation of two charges of explosives in adjacent holes results in two radial compression strain pulses, one radiating from each hole as shown at A in Figure 1. The length of the arrows indicates the relative magnitude and timing of the particle velocity in accordance with typical strain-time curves obtained in rocks surrounding blasts in various rock types.

Particle motion generated in the rock is radial and outward. This outward motion results in a tangential tensile stress, commonly called hoop stress. The tensile stress does not appear until there is outward motion. As it takes time for the rock to accelerate and move, the first tangential stress to appear is a compression. This tangential compression is produced by the lateral expansion that results from the large radial compression.

After sufficient time, the two radial pulses interfere with each other as shown at B in Figure 1. The light arrows in back of the wave fronts indicate the relative size of the particle velocities. In that section of the medium where the two wave fronts overlapped, the resulting particle velocities, represented by dark arrows, are mainly normal and outward from the plane of the two charged holes. As the rock on one side of the plane (line of centers) is moving in one direction and the rock on the other side is moving in the opposite direction, a plane of tension is generated along the plane of blast hole centers.

Of major importance is that the present theories of presplitting all recognize the presence and the necessity of the tensile stresses proposed by Duvall. Each theory attributes the creation of the presplit fracture to the

effects of this tensile stress. The theories differ only in that the tensile stress is believed to originate from different mechanisms, i.e. the explosive generated strain pulses (Aso, 1966) or the combination of stresses created by the explosive gas pressure within the blast hole (Kutter, 1967).

This tensile stress is schematically represented in Figure 2. This representation displays the decrease of stress magnitude as a function of distance and the superposition of the stresses from adjoining blast holes as described by Duvall.

This figure is a qualitative representation of all of the present theories, and it serves to illustrate the variables involved in a presplit and offers a basis upon which to logically determine the features essential to a sound design method.

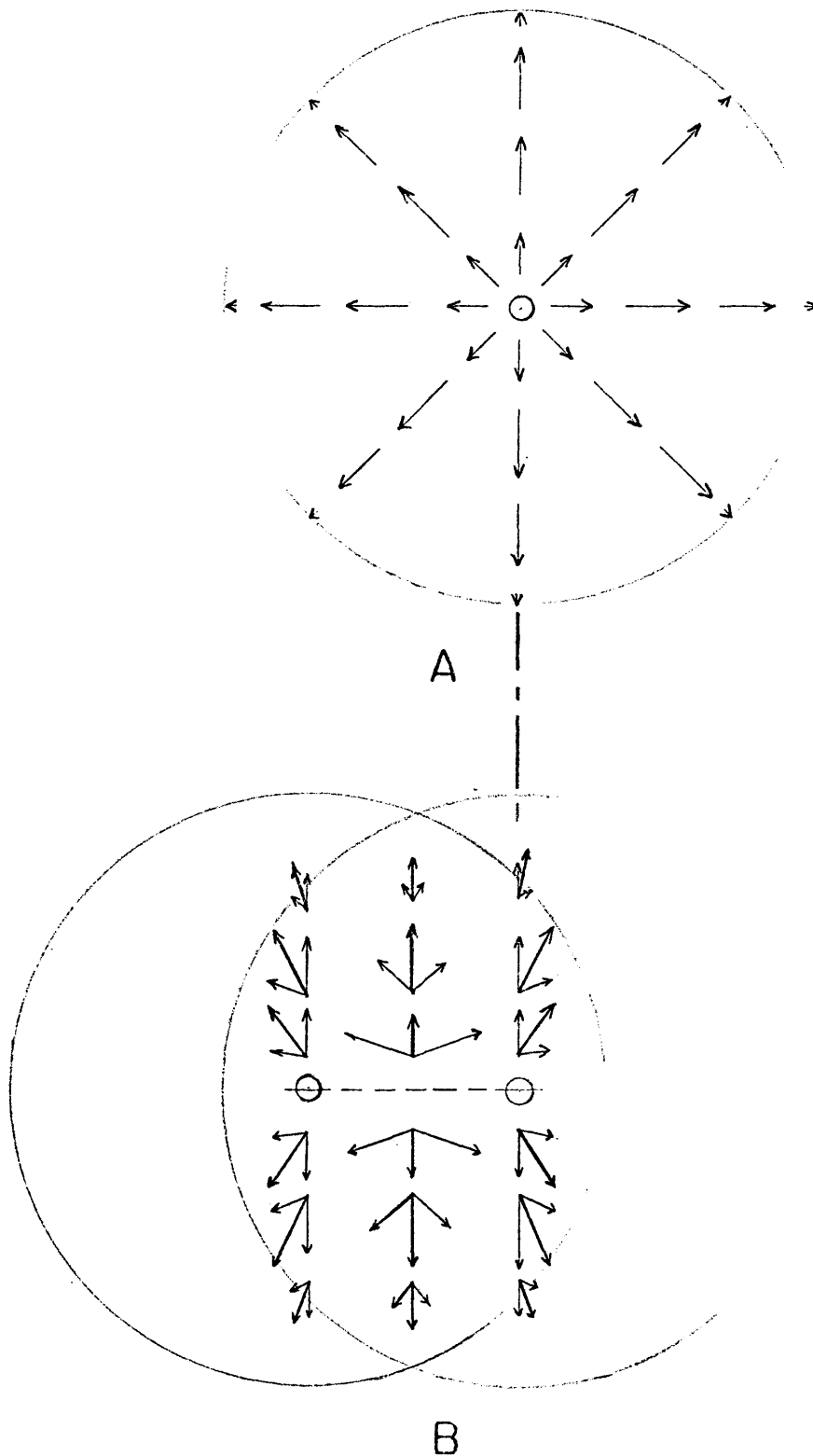


Figure 1. Radial Propagation of Explosion-Generated Strain Pulses From Blast Hole and Vector Forces Resulting From Instantaneous Blasting of Adjacent Holes (After Paine, 1965)

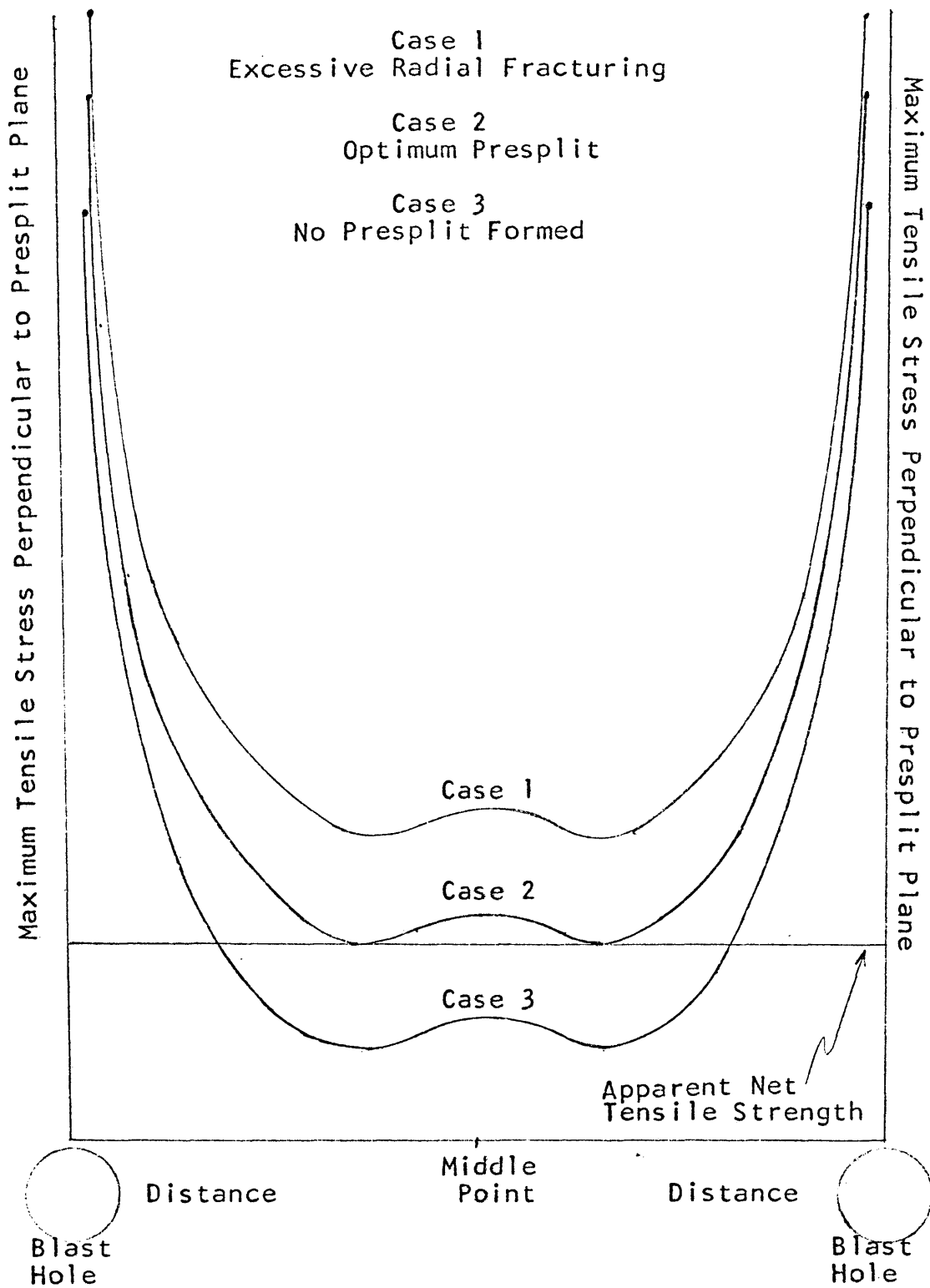


Figure 2a. A Schematic Representation of the Interaction of the Tensile Stresses Created by an Explosion in a Presplit Blast.

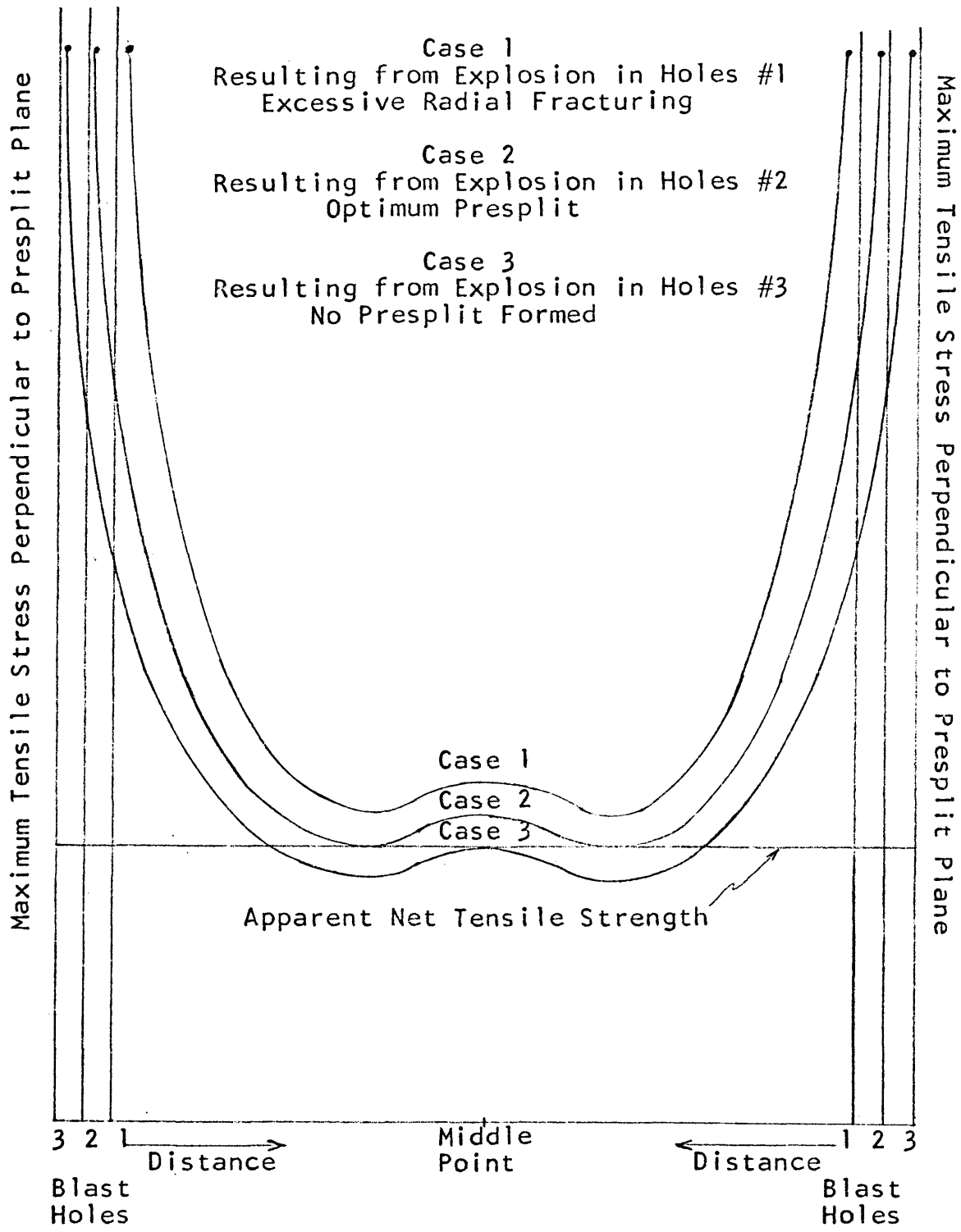


Figure 2b. A Schematic Representation of the Effect of Hole Spacing on the Tensile Stresses Created by an Explosion in a Presplit Blast.

VARIABLES INHERENT TO
A PRESPLIT BLAST

The procedure for obtaining a design method of this type must begin with an analysis of the variables involved in the process, so that the important variables may be distinguished. It is then possible to determine which values must be defined by the design method so that the resulting design parameters will account for the effects of all major variables.

This section, then, deals with a qualitative analysis of the variables involved in presplit blasting. Figure 2a is used to describe these effects, because the effects are made manifest by changes in the slope, shape, and position of the stress curves shown here.

The Environmental Variables.

The environmental variables are those which are uncontrollable by man. These variables are rock type, rock strength, rock structure, and the environmental stress fields within the rock mass.

The slope of the curves representing the stresses in Figure 2a is partly defined by equations describing the decay of a stress as a function of distance from the source of that stress (Kolsky, 1963). These curves are also altered by the rock type and the structure of the rock mass through which a presplit must pass.

Different rock types display different energy absorption characteristics, and therefore, different stress attenuation characteristics (Duvall, 1959). The relationship of a rock type to its absorption characteristics is undefined. Thus it is not possible to predict the slope of the stress curves in Figure 2a.

A feature which may drastically change the shape of the stress curves is rock structure, i.e. the degree to which a rock mass is bedded or jointed. The effect of joints or beds is to offer interfaces which may reflect part of the stress, as shown in Figure 3. This in turn decreases the distance over which the stresses will cause a presplit fracture to form.

A presplit fracture will form if the net tension at the tip of the presplit fracture is equal to or greater than the apparent net tensile strength of the rock. The two features which establish the value of the apparent net tensile strength are the actual tensile strength of the rock and the environmental stress fields. For example, the higher the tensile strength of the rock and the higher the environmental compressive stress oriented perpendicularly to the presplit plane, the higher the tensile stresses required to form a presplit fracture.

The conclusions which may be drawn here, are that different environmental variables offer widely varying

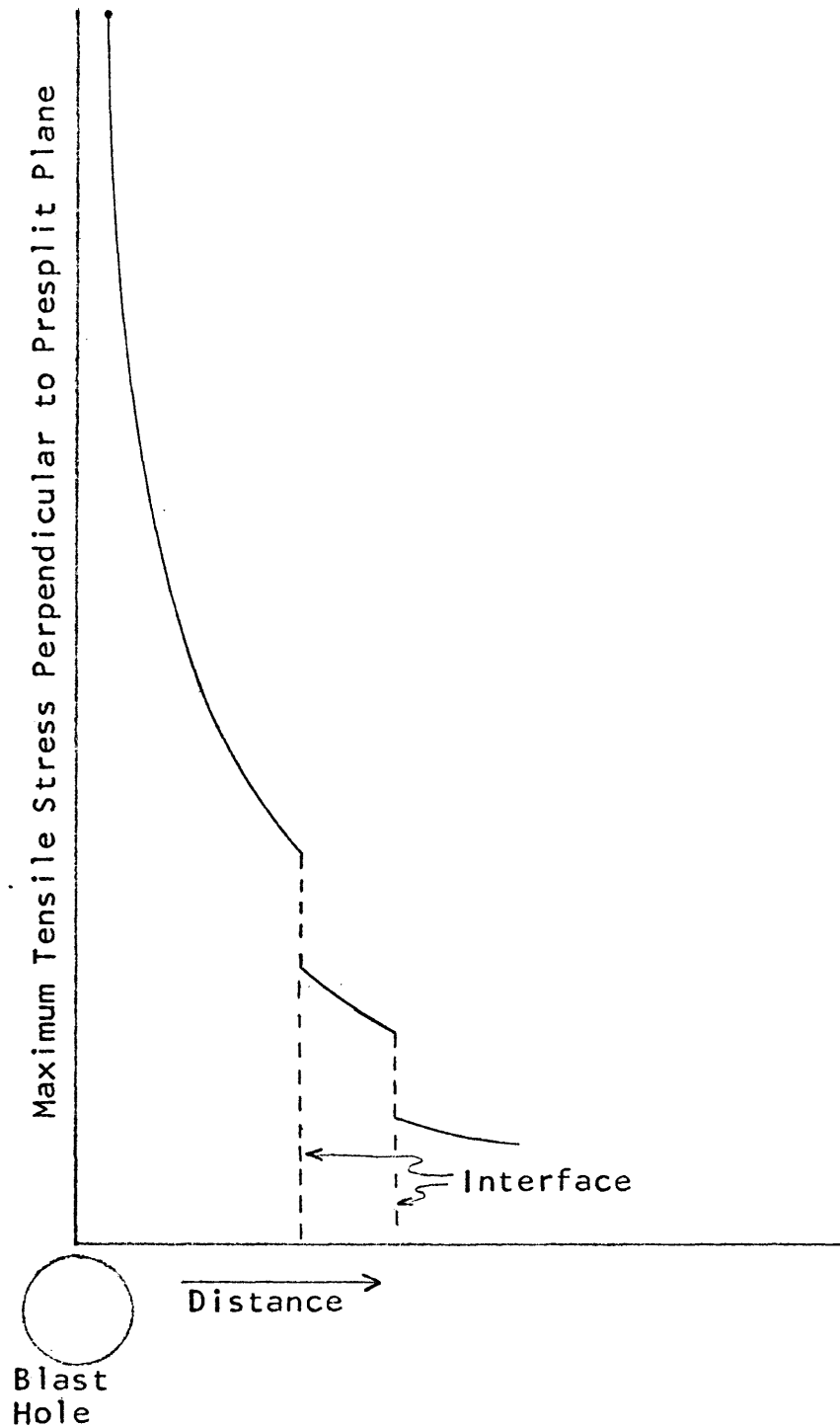


Figure 3. A Schematic Representation of the Effect of Interfaces on the Transmission of Stress Magnitude

effects on the tensile stresses required to create a pre-split and that these effects are unpredictable. It is therefore not possible to predict analytically the distance over which these stresses will cause a presplit.

The Physical Variables

The physical variables, i.e., those variables which man may control, form the axes upon which the decay of the tensile stresses is plotted in Figures 2 a and b. These variables are due to the characteristics of the explosive and the method of its application.

Included in the characteristics of the explosive are the strength, density, and velocity of detonation, features which combine to determine the magnitude and rate of release of the energy contained in the explosive. Since the tensile stress transmitted into the rock is a function of the initial explosive energy (Rinehart, 1960), the characteristics of the explosive present one means of determining the initial magnitude of this stress.

The final control of the transmitted stress level is obtained through the application of the principle of decoupling. Decoupling as used here refers to the control of explosive energy transmission by offering an attenuation mechanism between the explosive and the rock. The attenuation is obtained by leaving an air space between the explosive and the rock, an air space which absorbs energy

as it is compressed. A measure of the degree to which an explosive is decoupled is termed the decoupling ratio, defined as the ratio of the diameter of the explosive to the diameter of the blast hole.

The characteristics and use of the explosive determine the initial tensile stress magnitude transmitted into the rock. The environmental variables alter these stresses and determine the distance over which they are effective. It is necessary to be able to establish the spacing at which the blast holes may be drilled. The spacing of the blast holes is the final physical variable, and its effect is shown in Figure 2b, where all variables but hole spacing are constant. Case 1 represents the tensile stresses created when the blast holes are spaced too closely together. This situation results in excessive radial fracturing. Case 3 represents the tensile stresses created when the blast holes are spaced at too great a distance and no presplit is formed. Case 2 represents the optimum hole spacing where a presplit is formed with a minimum amount of radial fracturing.

Summary

It was shown that Figure 2 schematically represents the resultant tensile stress created by the detonation of a presplit array. Examination of Figure 2 also aids in defining the requirements a design method must fulfill.

A given set of environmental variables determines the

slope and shape of the stress curves and the value of the apparent net tensile strength of the rock.

The physical variables may be used to shift the position of these curves, as shown by Cases 1 through 3 in Figure 2.

A presplit blast design method must establish the values of the physical variables which would result in Case 2, the most efficient presplit blast. The method must determine the maximum amount of initial energy the rock type may be subjected to, and the distance over which the resulting tensile stress will be sufficient to cause a presplit to form, i.e. the maximum spacing at which blast holes may be placed.

Basic qualitative theory has served to determine the requirements of a design method. Application of basic blasting principles and empirical procedures were used to establish the design method.

PRELIMINARY TESTING

Preliminary tests were devised to determine:

1. If environmental stress fields could completely inhibit the creation of a presplit fracture.
2. If decoupling could be used to establish and control the stress level to be transmitted into the rock.
3. If a test could be devised to establish the maximum spacing at which blast holes could be drilled.

Environmental Stress Fields

Nicholls (1966) studied the influence of a static compressive stress field on the formation of a presplit fracture and concluded that it was easiest to create a presplit along a plane parallel to the direction of maximum principal compressive stress.

In an effort to extend this work, laboratory tests were run to determine the effect of compressive stresses oriented perpendicularly to the presplit plane. Different levels of stress were applied to large specimens of Yule Marble, and the maximum hole spacing was established for each stress level. All other variables, such as rock type, rock structure, rock strength, and initial explosive energy were held constant.

The dimensions of the specimens were approximately 2 by 1 by 1 ft. The sides of the specimens were prepared

to obtain flat, parallel surfaces against which to apply a compressive stress.

Stresses were applied by a specially fabricated mechanical press, as depicted in Figure 4. Strain levels were monitored by strain gages mounted on the surface of the specimens.

A total of 14 tests resulted in the data shown in Table 1. The largest spacing at which a presplit was obtained at each stress level is plotted in Figure 5. The plot shows that higher levels of compressive stress perpendicular to the presplit plane require smaller hole spacings for a presplit to be formed. More important, the results indicate that there may be a limiting condition of ground stress at which presplitting will no longer be economically feasible. ←

Decoupling

Atchison (1964), Smith (1965), and Dupont (1964) have established that decoupling is an important feature of any blasting process.

Although sand and gravel have been used effectively as decoupling agents in down holes, their use in horizontal holes may be limited due to the difficulty of installing them in the hole. A test was therefore devised to determine if air would be a suitable decoupling agent if used properly.

The test series employed 7/8 in. diam. TRIMTEX (Dupont) as the explosive. Two arrays of five horizontal

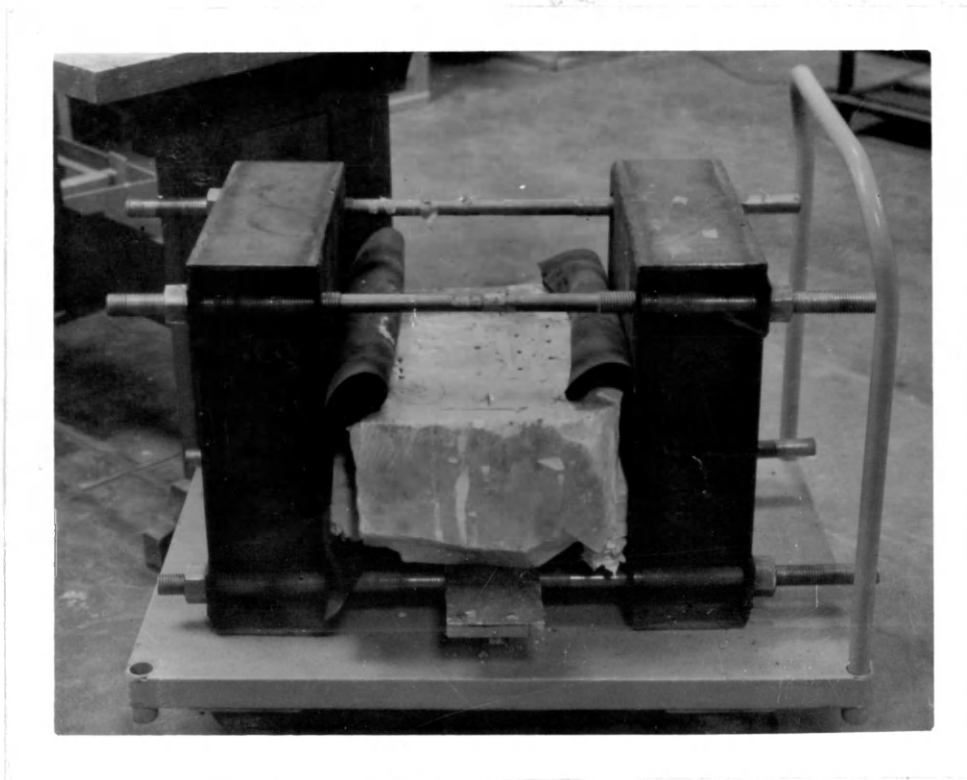


Figure 4. Loading Press Used to Apply Compressive Stress to Specimens for the Effect of Stress Field Studies.

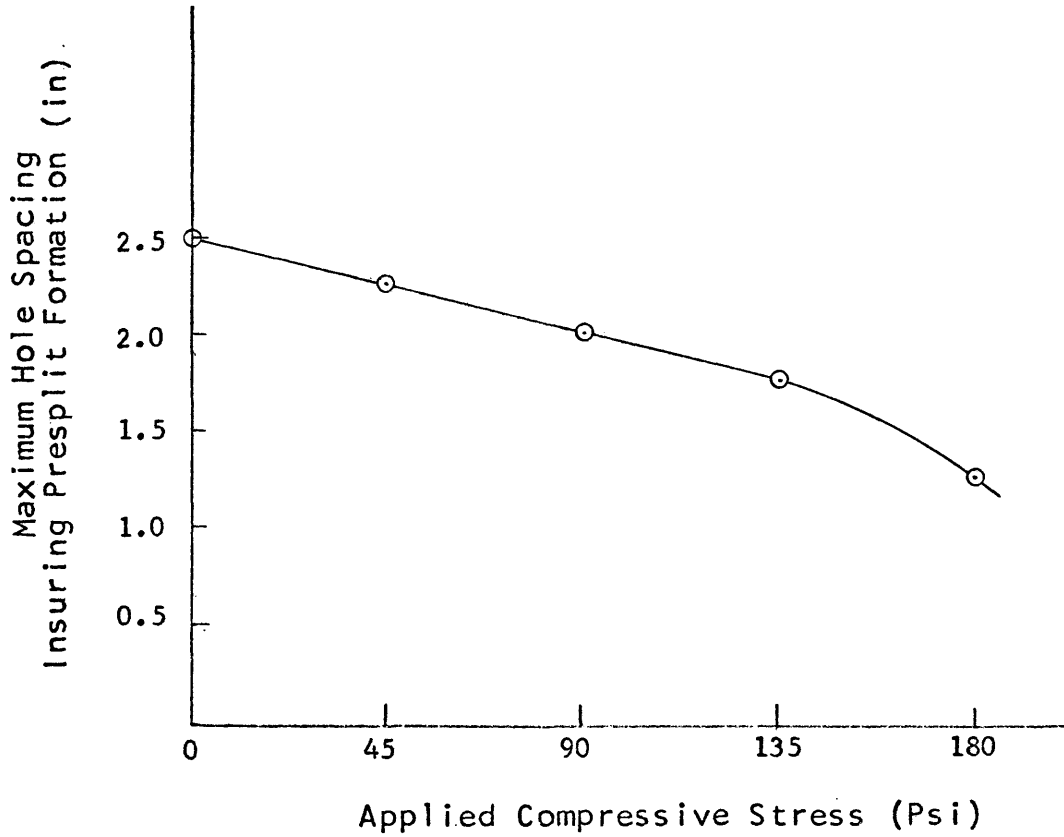


Figure 5. The Effect of Compressive Stress Applied Perpendicular to the Presplit Plane on the Maximum Presplit Blast Hole Spacing insuring Presplit Fracture Formation.

Table #1 - Data obtained from Tests to Determine the Effect of Compressive Stress Fields Oriented Perpendicularly to the Pre-split Plane.

Specimen #	Stress (Psi)	Hole Spacing (in)	Resulting Presplit
1	0	2.25	Good
2	0	2.50	Good
3	0	2.75	None
4	45	2.50	None
5	45	2.25	Good
6	90	2.25	None
7	90	2.00	Good
8	90	2.25	None
9	135	2.00	None
10	135	1.75	Good
11	180	1.75	None
12	180	1.50	None
13	180	1.25	Good
14	180	1.50	None

holes each were drilled.

Each array contained holes of different diameter, i.e., 1-1/4, 1-3/8, 1-1/2, 1-5/8, and 1-3/4 in. Loading these holes with 7/8-in.-diam. TRIMTEX resulted in decoupling ratios of 0.700, 0.636, 0.582, 0.538, and 0.500 respectively.

The results after detonation of the explosive in these holes showed that radial fracturing is greatly reduced, proceeding from large to small decoupling ratios. It was concluded that air could be used as an effective decoupling agent.

The results from the test are represented in Figure 6.

Hole Spacing

A field test was examined to determine if the maximum spacing at which blast holes could be drilled is predictable.

Two lines of holes were drilled at increasing hole spacings, i.e., 1, 1-1/4, 1-1/2, 1-3/4, and 2 ft., and detonated as a presplit array.

The detonation of the explosives resulted in a presplit fracture between holes up to 1-1/2 ft. apart as shown in Figure 7. It was decided to use this test as part of the method discussed in the next section and to determine its reliability when applied to an actual attempted presplit. These results are discussed in the next section.

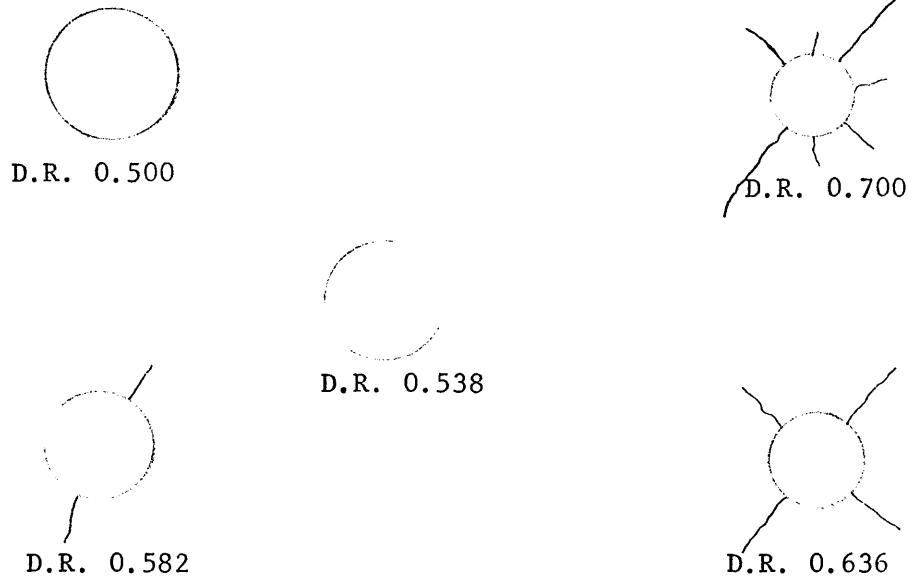


Figure 6. Resulting Fracture Patterns Around Blast Holes, Air Decoupling Test.

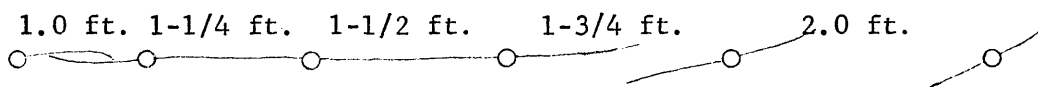


Figure 7. Resulting Fractures From Hole Spacing Test.

Summary

The preliminary testing indicated that:

1. Limiting conditions of ground stress may exist for which presplit blasting may not be economically feasible.
2. The principle of decoupling may be used to control the level of the stresses to be transmitted to the rock.
3. The maximum spacing between presplit blast holes may be established for any set of conditions.

THE METHOD

The design method uses the decoupling test and the hole spacing test to determine the combination of the physical variables best suited to the environmental variables.

Visual Interpretation Criteria

The decoupling test requires interpretation of the visible results of the explosion in each hole. Criteria for the interpretation is based upon presplit definition, which requires that the detonation of a presplit array yield the following results:

1. Shattering and overbreak must be minimal. This insures greater inherent stability of the opening, and consequently, less scaling time and increased safety features.
2. The presplit fracture must be formed consistently from round to round. This avoids secondary blasting.

This information is consistent with Figure 2. It is desirable to avoid cases 1 and 3. Therefore, there must be an upper and a lower limit to the amount of energy to be transmitted to the rock.

The visual criteria must be established on the basis of the amount of radial fracturing and shattering around the holes in the decoupling test after the detonation of the explosive. The visual examination should yield an upper and a lower limit to the energy transmission.

Verification of the Method

In order to verify the method, the decoupling test was performed underground at the Colorado School of Mines Experimental Mine. The procedure was to establish the proper decoupling ratio, perform a hole spacing test using that decoupling ratio, and to then drill a presplit round using the proper decoupling ratio and the resulting hole spacing.

The decoupling test was arranged again as described earlier. The results are as shown in Figure 8a. The decoupling ratio of 0.582 was indicated to be the most desirable in both tests, on the basis of too much radial shattering among the larger ratios and no effect among the smaller ratios.

In order to verify the validity of this choice, the hole spacing test was performed for the decoupling ratios of 0.636, 0.582, and 0.538, as shown in Figure 8b. This was done to insure that presplit geometry would not alter the decoupling effects of the various ratios, i.e., to make sure that the chosen decoupling ratio was the best when employed in a presplit geometry. Both test series showed the initial choice to be the most desirable decoupling ratio. In both test series, the ratios 0.636 and 0.582 presplit the same distance, i.e., 1-1/2 ft. However, the ratio 0.636 displayed obvious radial fracturing. The ratio 0.538 presplit only

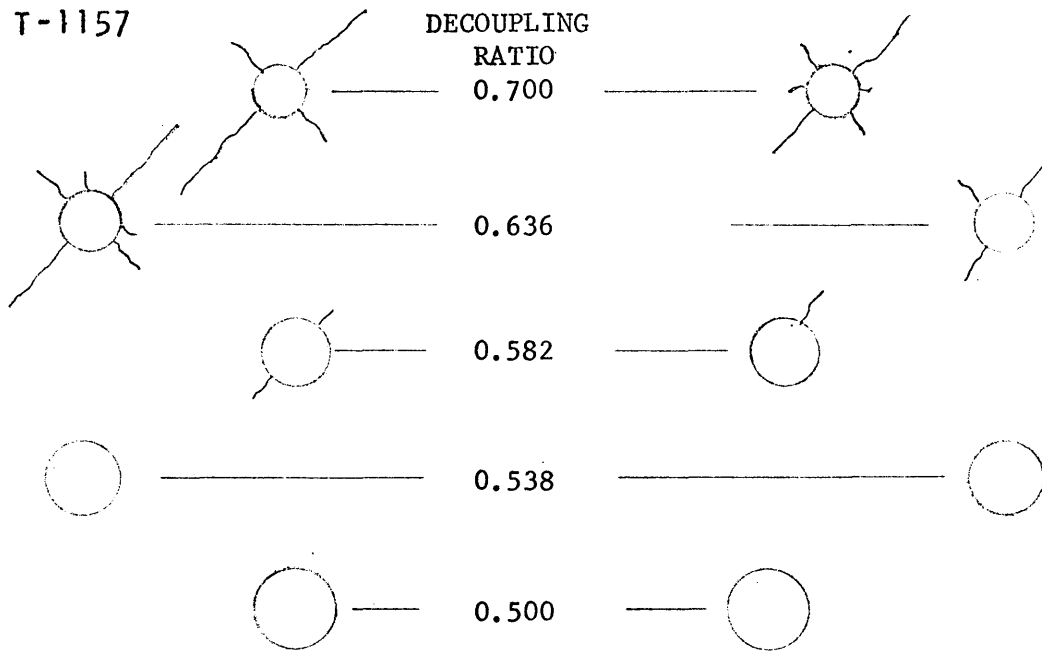


Figure 8a. Resulting Fractures Around Blast Holes in the Verification Decoupling Test.

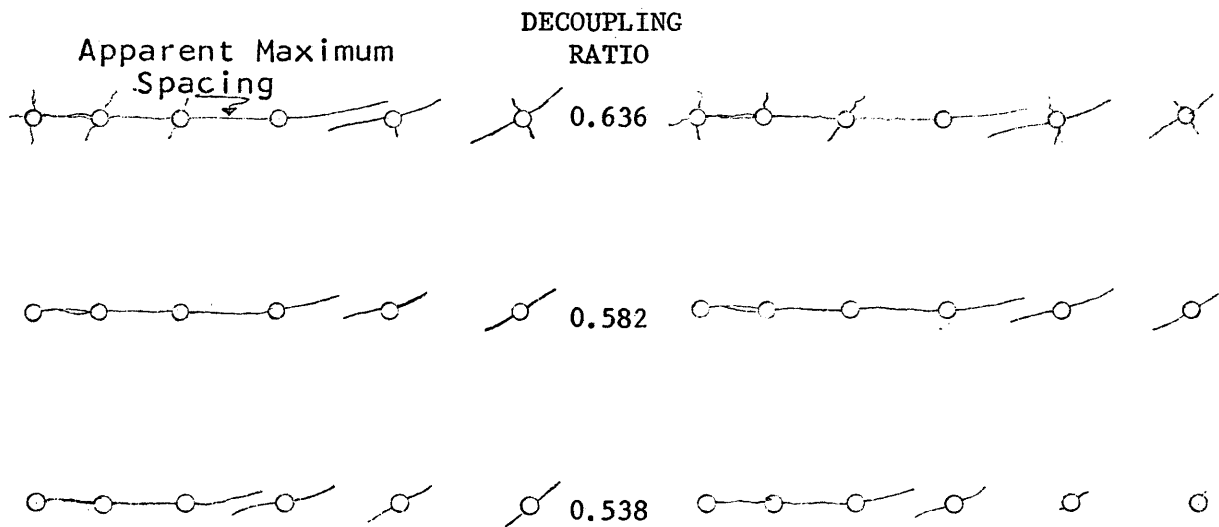


Figure 8b. Resulting Fractures between Blast Holes in the Verification Hole Spacing Test.

1-1/4 ft. Thus, this series established that the proper decoupling ratio could be chosen by a limiting process, in which decoupling ratios displaying extensive radial fracturing and ratios showing no radial fractures could be eliminated as undesirable.

The final step in proving the validity of the method was to insure that the hole spacing test yields a value that is reliable and consistent.

Nicholls (1966) felt that wider hole spacings could be obtained by starting the initial fracture at close hole spacings. Because this is exactly what the hole spacing test does, and in order to insure reliability, the design spacing was chosen as that spacing just less than the apparent maximum spacing, as shown in Figure 8b.

The perimeter of a round was drilled using the decoupling ratio of 0.582. The holes along the right side and the back were drilled at a spacing of 1-1/4 ft. while the left side of the round was drilled at 1-1/2 ft. spacing.

Detonation of the round resulted in a presplit along the right side and the back of the heading while the left side showed no fracture. These results indicate that the choice of the design spacing is justified and that the method yields reliable results.

CONCLUSIONS

At the present time, no mathematical formula fully describes the complex phenomena of presplit blasting. Past research indicates that the variables involved in and effecting a presplit blast are complex and interdependent. These variables may be divided into two groups, i.e., environmental and physical.

The environmental variables are inherent in a presplit as a result of the material through which the presplit must propagate. The material, i.e., rock, may offer widely different characteristics which affect the formation of the presplit fracture. There is no means by which man may control these effects.

The physical variables are those due to the characteristics of the explosive used and the method of its application. These variables may therefore be controlled.

Figure 2, pages 5 and 6, is presented as a schematic representation of the relationships between the two types of variables. The variables are briefly discussed to exemplify the manner in which their effects alter the curves depicted in this figure.

The most important feature with regard to this figure is that it indicates that for a given rock type, stress field, and explosive, a successful presplit is dependent

upon the proper choice of the values of the decoupling ratio and hole spacing. Thus, if the proper values of the physical variables may be determined by some method so that the initial explosive energy is most effectively used and the maximum spacing between blast holes is known, the most effective presplit is insured.

Testing indicated that

1. There are limiting ground stress conditions for which presplitting may not be economically feasible.
2. The principle of decoupling may be used to control the level of the explosive energy transmitted to the rock.
3. The maximum spacing between blast holes may be established.

A method with which to establish and control the initial explosive energy and the corresponding hole spacing was proposed and verified. The method is simple, inexpensive, and not time consuming. The results indicate the size of drill hole to be used, the type and diameter of explosive to be used, and the maximum spacing at which the drill holes may be placed.

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