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MASTER

A TECHNIQUE TO ENHANCE CRACK GROWTH
AND INCREASE PERMEABILITY IN GEOLOGICAL MEDIA

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A TECHNIQUE TO ENHANCE CRACK GROWTH AND INCREASE PERMEABILITY IN GEOLOGICAL MEDIA

ABSTRACT

Results from a series of high explosive tests in Playa alluvium at the Nevada Test Site are examined. Based on these results, an explosive fracture technique (using high explosives and rocket propellant) is proposed to enhance crack growth and increase the permeability of geological media. Late-time cavity gases provided by the propellant should sustain crack growth. Five experiments are designed to further explore the technique.

INTRODUCTION

This report describes a proposed technique to enhance crack growth and increase the permeability of geological media. The technique was developed from postshot examination of a series of high explosive (HE) tests in the Playa alluvium deposits of Yucca Lake at the Nevada Test Site. Information from those HE tests helped define the basic mechanisms and characteristics of crack formation when HE is detonated at sufficient depth of burial (DOB) to be contained. Determination of the basic mechanisms and characteristics of crack formation is fundamental to those programs (e. g., coal gasification, gas stimulation, nuclear containment, etc.) where increased fracture and permeability is a major concern.

EXPERIMENTAL BACKGROUND

In the summer of 1974, the seismic research group of K-Division conducted a series¹ of small-scale HE tests (designated Series III A) at NTS in support of the seismic evasion program. The composition (Comp.) C4 charges varied in weight from 50 to 450 g, were buried at depths between 1 and 6 ft, and were detonated singly or in groups of three. Figure 1 gives this information and the HE placement pattern. The Comp. C4 and detonator were contained in hollow nonmetallic cylinders, 1 to 1.5 in. in diameter, and, depending on the size of the charge, from 5 to 12 in. long. Reference 1 gives additional test details.

Following completion of the Series IIIA tests, a trench, parallel to the third row (Fig. 1), was carefully dug so that it approximately bisected the explosive cavities left by the detonated charges. Photographs² of the explosive cavities and surrounding media exhibited some interesting features.³ The 50-g shots (Nos. 10 and 14) had very few cracks that extended more than a few inches beyond the inner cavity radius. The three 100-g charges (No. 7) that were fired simultaneously

Series III A

Fig. 1. Series IIIA emplacement plan.

exhibited only one extensive horizontal crack and that was associated with the charge located nearest the free surface. Possibly, it was partially induced by the rarefactional tensile wave from the free surface. However, the three 150-g shots (Nos. 8, 9, and 12) all exhibited radial cracks that extended more than one-cavity radius beyond the cavity wall. An obvious conclusion is that a definite Comp. G4 HE-charge threshold exists for any significant crack generation. This threshold appears to be between 100 and 150 g for Playa alluvium.

One very disturbing factor was the pronounced difference in the crack patterns for the three 150-g shots (Nos. 8, 9, and 12). Figure 2 is a sketch of the crack patterns determined from the photographs. The DOB was the only variable between the three tests as supposedly all other factors (e.g., HE charge configuration, emplacement technique, etc.) were held constant. To explain the discrepancy, the author went to NTS to inspect the cavities and surrounding exposed media. The reason for the crack pattern variance is related to the emplacement hole below the device.⁴ Figure 3 shows the crack patterns for shots 8, 9, and 12. Many of the features noted in the figure were not visible in the photographs but were carefully uncovered by hand excavation. The dimensions given in this figure all relate to the cavity center which is assumed to coincide with the original charge center. Figure 3 (a) shows shot 8 for which only one small crack at about 10 o'clock was visible from the photographs. The other two cracks (shaded areas) lie in the vertical plane and were uncovered by hand since they were close to the exposed wall of the trench. Note the crosshatched half-cylinder area extending below the cavity. This area represents a half-section of the original borehole which extended below the charge location. Down to the 17-in. distance shown, there was a heavy carbon deposit on the walls of the borehole. This strongly suggests that the borehole below the charge was loosely stemmed (uncompacted backfill) before the detonation and HE gases expanded into this region. Fig. 3 (b and c) shows a similar result to a progressively small degree. Expansion of HE gases into the emplacement hole region reduces pressure in the cavity and causes a reduction in the crack's propagation into the surrounding medium. We conclude that to maximize crack formation, all voids near the HE charge should be backfilled with a competent medium. Plaster of Paris appears to be adequate for this purpose in Playa alluvium.

The crack dimensions given in Fig. 3 were determined by measuring the distance from the cavity center that carbon deposits from the HE gases were observed in the cracks. Although the initial 150-g charge for shots 8, 9, and 12 had an aspect ratio (length/diameter) of four, the cavities formed from detonation were essentially spherical with a radius of about 6 in. At regular intervals about the vertical axis, there existed vertical crack planes that extended one- to two-cavity radii beyond the cavity wall. The cavities and vertical crack planes are formed at early times by expansion of the HE gases and consequently do not appear to be seriously affected by the sand stemmed hole below the charge. It is in the more extensive cracks, with lengths greater than two-cavity radii (e.g., shot 12), where the emplacement hole

Shot 8

Shot 9

Shot 12

Fig. 2. Crack patterns for shots 8, 9, and 12, determined from examination of photographs. Charge weight for each shot was 150 g. DOB was 5 ft for shot 8, 6 ft for shot 9, and 4 ft for shot 12.

Fig. 3. Fracture patterns for shots 8, 9, and 12, determined by on-site examination. Charge weight for each shot was 150 g. Shaded areas are crack surfaces that lie in the vertical plane. The crosshatched areas show the emplacement hole area blackened by deposition of HE gas products. (a) Shot 8, DOB was 5 ft. (b) Shot 9, DOB was 6 ft. (c) Shot 12, DOB was 4 ft.

effect becomes important. From these observations, we conclude that late-time high-energy gases are the basic driving force in the production of extensive cracks. (Late time is defined as time after cessation of cavity growth.) The proposed technique, presented in the following section, exploits this phenomenon.

It may appear that the above conclusions were based on a minimum of experimental evidence. However, additional excavations and observations of the Series IIIA tests have been consistent with the conclusions cited. For brevity they have not been included but may be found in Refs. 3 and 4.

In summary, the major conclusions are:

- A definite charge threshold, between 100 and 150 g HE (Comp. C4), exists for significant crack generation in Playa alluvium.
- The charge region should be backfilled with a competent material to eliminate any void volumes that might exist. Plaster of Paris appears adequate for this purpose in Playa alluvium.
- Vertical crack planes occur at regular intervals about the vertical axis. These vertical crack planes extend one- to two-cavity radii beyond the cavity wall.
- The cracks extending beyond two-cavity radii (e. g., shot 12) are produced by late-time cavity gases.

PROPOSED TECHNIQUE AND EXPERIMENTAL PROGRAM

The technique to be investigated consists of boosting the quantity of high-energy gases in the HE cavity at late times. Basically, in this method, the HE charge would produce the initial cavity and start the crack formation. Crack growth would be sustained by the late-time cavity gases supplied by rocket propellant. Figure 4, which illustrates one example of this method, shows a 150-g cylindrical charge of Comp. C4 located between two 150-g cylinders of solid rocket propellant. The detonator would be located at the center of the C4 charge as in the Series IIIA tests. The detonation wave in the C4 would initiate burn of the rocket propellant. The propellant contains its own oxidation agent and need not be exposed to air to sustain burn. Rocket propellant provides a source of high-temperature ($> 3000^{\circ}\text{K}$), high-density ($1.5\text{-}2.0\text{ g/cm}^3$) gas that would add to the quantity of gas in the HE cavity at late times. Using the ideal gas equation $P = nkt$, a pressure of $\approx 16\text{ Kbar}$ was calculated for the propellant burn. This is sufficient pressure to cause some radial expansion of the emplacement hole walls surrounding the propellant, but the gases from the burnt propellant should expand into the HE cavity rapidly enough to reduce this effect. Also, this additional volume will be negligible compared to the volume of the HE cavity. The use of rocket propellant should nearly triple the amount of late-time gases in the HE cavity. Additional propellant can be added if further cracking is desired. A more direct approach would be to select a HE that would optimize late-time cavity pressures. However a preliminary examination of this approach⁵ shows it to be less encouraging than the propellant technique.

Fig. 4. Emplacement approach envisioned for the HE-charge enhancement technique (test 3).

To test the above hypothesis, five experiments have been designed. Uncertainties associated with the stemming in the Series IIIA tests will hopefully be eliminated by giving special attention to the backfilling operation for the emplacement holes that will be used. For this purpose, plaster of Paris will be used as backfill below, around, and above each charge to eliminate any air-filled voids near each charge. In all tests, the distance from the surface to the center of the charge (i. e., detonator) will be 6 ft. This DOB was chosen to minimize surface effects and is still shallow enough to permit normal excavation techniques (e. g., backhoe) and safety precautions (e. g., benching) to be employed.

- Tests 1 and 2 consist of the detonation of a 150-g cylindrical charge of Comp. C4. The first test will be primarily a standard of comparison for subsequent tests. Test 2 will be as identical to Test 1 as is physically possible and will check the general repeatability of the fracture pattern. Since the emplacement configuration, detonator, and HE assembly can be tightly controlled, this test represents a check of the uniformity of the Playa alluvium in which the tests are conducted. Hopefully, any variation in the results of the first two tests will be insignificant compared to the variation in results for subsequent tests.

- Test 3 consists of the HE charge and rocket propellant configuration shown in Fig. 4 and would be the first test of the propellant concept.

- Test 4 is based on a suggestion⁶ that we burn a pure 450-g cylindrical charge of rocket propellant. The propellant will be ignited at the center (6-ft DOB) and be allowed to burn in both directions. This will test the effectiveness of using only propellant gases in initiating cracks and sustaining their growth. Playa alluvium is a rather weak medium and propellant gases may be effective in crack formation and growth. Even if this pure propellant burn approach succeeds, there remains the question of how effective it might be in more competent (e. g., oil shale, coal, gas-bearing sandstone) medium.

- Test 5 consists of detonating a 450-g cylindrical charge of Comp. C4. This detonation will be initiated at the center (6-ft DOB) of the charge and allowed to burn in both directions. This test will provide an indication of crack lengths as a function of HE charge weight. It also represents a standard with which to compare Test 3. The expectations are that the cracks produced in Test 3 will be more extensive than those produced by a comparable weight of pure HE.

The results of the above tests will be determined by postshot measurement of cavity sizes and crack formations. These five tests constitute a basic minimum HE test program, primarily aimed at providing data for numerical simulation studies and investigating the enhancement technique for late-time cavity pressures. Some preliminary tests at Site 300 may be required to investigate using HE detonation shocks to initiate solid propellant burn in confined geometries. Experience⁷ in this area indicates this should not represent a formidable barrier.

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