The Physics of Energy Release and Rock Breakage

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Before addressing the specifics of blast design, it would be helpful to better understand just what happens when explosives are detonated in a borehole and how that process affects the surrounding material. When an explosive charge is detonated, a chemical reaction occurs that rapidly changes the solid or liquid explosive material into a hot gas. This reaction starts at the point of initiation and forms a convex shock wave on its leading-edge that acts on the borehole wall and propagates through the explosive column. The reaction zone where this transformation takes place in the explosive can vary in thickness from about .04" in high-velocity explosives to over 1.0" in products such as AN/FO. (In explosive products containing a large number of aluminum particles, some of the reaction may still be taking place in the hot gasses behind the actual reaction zone.) Ahead of the reaction zone are undetonated explosive products and behind the reaction, the zone is expanding hot gasses (see Figure 1). The faster the detonation process, the quicker the energy, in the form of a shockwave followed by gas pressure, is applied to the borehole wall. It takes rather sophisticated and expensive equipment to measure detonation pressure directly, but it can be roughly approximated using the following equation:

$$P = \frac{(2.16 \times 10^{-4})\,(0.45)\,(pc^2)}{1 + 0.0128\,(p)}$$

where,

P = detonation pressure (lbs / in2)

p = explosive density (lbs / ft3)

c = explosive detonation velocity (ft / sec)

(Note that the above-simplified formula does not take into consideration factors such as pressure decay, the density or sonic velocity of the rock, explosive/rock coupling, or other factors.)

Values for detonation pressures can range from roughly 2,000,000 psi forecast boosters in strong rock to around 100,000 psi for some lower-rate permissible explosives in weaker material.

Analysis of the above equation discloses that, of the two parameters, detonation velocity has more effect on detonation pressure than does the explosive density. While the pressure varies directly with the density, it varies with the square of the velocity. In other words, for explosives with similar densities, the detonation pressure will increase by a factor of four when the detonation velocity is doubled. (The reader is cautioned not to assume that higher detonation velocity explosives are always better. The opposite is often the case, as shall be seen later).

The faster the detonation velocity of the explosive, the quicker the energy is applied to the borehole wall, and usually for a shorter period. Conversely, with a slower detonation velocity, the energy is applied more slowly, and for a longer period.

The degree of coupling between the explosive and the borehole wall will affect how efficiently the shockwave is transmitted into the rock. Pumped or poured explosives will result in better transmission of energy than would cartridge products with an annular space between the cartridge and the borehole wall.

The pressure that builds up in the borehole depends not only upon explosive composition but also on the physical characteristics of the rock. Strong competent rock will result in higher pressures than weak, compressible rock.

When the shock wave reaches the borehole wall the fragmentation process begins. This shock wave, which starts at the velocity of the explosive, decreases quite rapidly once it enters the rock and at a short distance is reduced to the sonic velocity of that particular rock.

Most rock has a compressive strength that is approximately 7 times higher than its tensile strength, i.e. it takes 7 times the amount of energy to crush it as it does to pull it apart. When the shockwave first encounters the borehole wall, the compressive strength of the rock is exceeded by the shockwave, and the zone immediately surrounding the borehole is crushed. As the shockwave radiates outward at declining velocity, its intensity drops below the compressive strength of the rock, and compressive crushing stops. The radius of this crushed zone varies with the compressive strength of the rock and the intensity of the shock wave, but seldom exceeds twice the diameter of the borehole. However, beyond this crushed zone, the intensity is still above the tensile strength of the rock and it causes the surrounding rock mass to expand and fail in tension, resulting in radial cracking. The hot gas following the shockwave expands into the radial cracks and extends them further. This is the zone where most of the fragmentation process takes place. (See Figure 2.)

Additionally, if the compressive shockwave pulse radiating outward from the hole encounters a fracture plane, discontinuity, or a free face, it is reflected and becomes a tension wave with approximately the same energy as the compressive wave. This tension wave can "spall" off a slab of rock (see figure 3). This reflection rock breakage mechanism depends heavily upon three important requirements:

(1) the compressive wave (and resulting reflected tensile wave) must still be of sufficient intensity to exceed the tensile strength of the rock, (2) the material on opposite sides of the fracture plane of discontinuity must have different impedances, (3) the compressive pulse must arrive parallel to, or nearly parallel to, the fracture plane or free face.

If carried to an extreme, when this reflective breakage or "spalling" process occurs at a free face, it can result in a violent throw, a situation that is not desirable. This can be overcome by designing blasts with burden and spacing dimensions that are within reasonable limits.

Once the compressive and tensile stresses caused by the shockwave drop below the tensile strength of the rock, the shock wave becomes a seismic wave that radiates outward at the sonic velocity of the material through which it passes. At this point, it is no longer contributing to the fragmentation process.

Several key points have been learned through the years from studying the physics of energy release and how it applies to the fragmentation process:

1. Within the range of conventional blasting, the physical characteristics of the rock are more important than the characteristics of the explosive and can have a greater impact on the success or failure of a blast.

2. Final-size fragmentation is usually obtained before any appreciable rock movement or throw occurs.

3. Rock can absorb only so much energy and only at a certain maximum rate before it will fail.

4. The final displacement of the bulk of the rock is more a function of the duration of the gas pressure than its intensity.

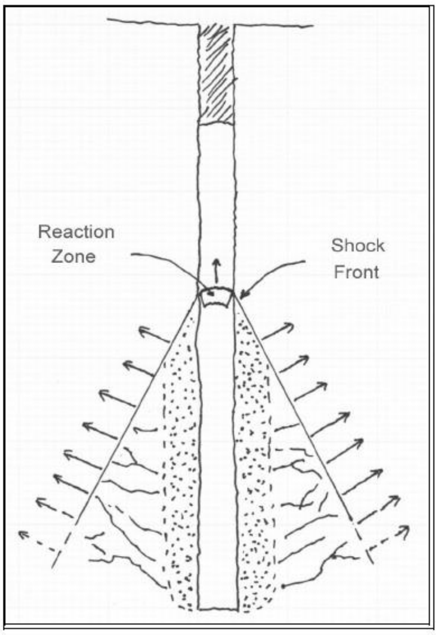

Figure 1

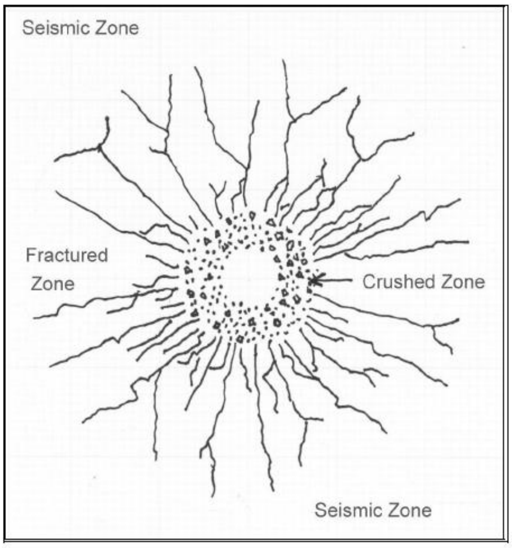

Figure 2

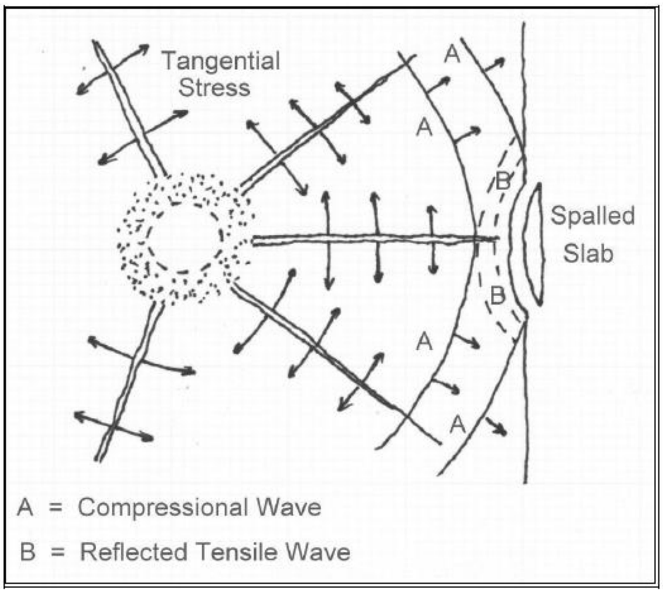

Figure 3