It's a Blast

Technology from ANSYS helps to optimize the precise timing of delayed detonations to get the biggest bang for the buck in the mining industry.

By Dale Preece, Global Technology Development, Orica USA Inc., Colorado, U.S.A.

The key to optimal blast performance is a series of well-planned explosions in which rows of explosive-filled holes are set off with electronic detonators in a precise-delay timing sequence measured in milliseconds.

In today's mining operations, explosive blasts are just as much about precision control as brute force. For efficiency, miners must use enough explosives to fragment and move as much material as possible. On the other hand, the amount of explosive energy is constrained by budgetary restrictions as well as limits on blast vibrations that can disturb adjacent mining pits and shake buildings in nearby towns.

The key is a series of well-planned explosions in which rows of explosive-filled blast holes are set off with electronic detonators in a precise-delay timing sequence measured in tenths of millisecond accuracy. If timed just right, shock waves reinforce and amplify one another to produce maximum fragmentation and movement of rock, ore, coal and other materials. Otherwise, the fragmentation-producing tensile waves reflecting from free faces (including the vertical bench face of the mine pit) can be canceled out by compressive waves from adjacent blasts, thereby significantly lowering explosive effectiveness.

The major challenge in this approach is determining the optimal detonation delay, which depends on numerous variables including the compressive strength and brittleness of material being blasted, the type of explosive used, and the diameter, depth and spacing of blast holes. Ordinarily, mining operators try to find the right detonation delay through experience in specific mine fields and considerable trial and error. Even after months of experimentation, however, many companies eventually settle on a delay that gets the job done satisfactorily rather than spending more time trying to find the elusive optimal delay.

The largest supplier of explosives in the mining industry, Orica is studying precise-delay timing as a part of its extensive range of Blasting-Based Services provided to clients in some of the world's largest surface and underground mines. For these studies, one of the tools Orica engineering teams use is the ANSYS AUTODYN nonlinear explicit dynamics software, which the company also employs for risk assessments of explosives manufacturing and distribution to the mining industry.

Major features make the software particularly well-suited to rock blasting fragmentation prediction. Built into the software is a Riedel–Hiermaier–Thoma (RHT) brittle material model for predicting crack densities and fragmentation in rock. RHT accurately represents pressure-dependent and residual failure surfaces, elastic limit surfaces, and strain hardening in a unified model that accumulates damage in tension and in compression — two critical stress states that must be properly coordinated through precise-timing detonation to achieve maximum fragmentation.

The capability to couple Eulerian and Lagrangian frames of reference in ANSYS AUTODYN software is especially
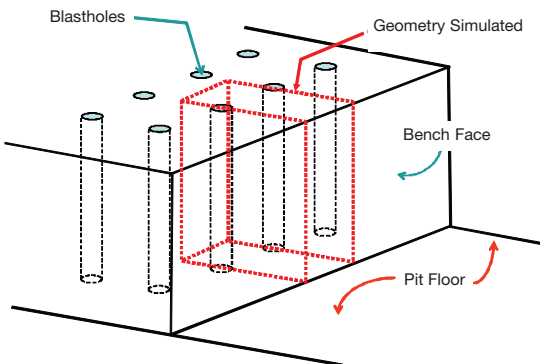
Surface coal mine blast geometry shows portion of the field to undergo 3-D simulation of delayed detonation and rock fragmentation. The vertical bench face denotes the vertical walls of the pit where blasted material moves and is removed by excavators and haulers.
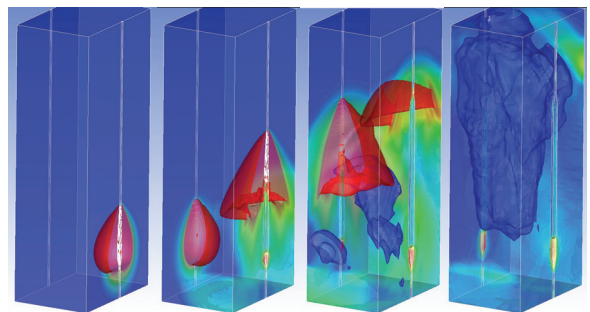
Shock waves and pressure distributions are shown in the blast field with a 2-ms detonation delay between the adjacent blast holes represented. Shock waves (red) progress upward through the blast field and combine next to the bench face and ground surface where individual rock fragments form (dark blue).

helpful in blast field modeling. The Eulerian frame of reference is best suited for representing explosive detonations because the material flows through a geometrically constant grid that can easily handle the large deformations associated with gas and fluid flow. Rock is modeled with the Lagrangian frame of reference best suited for fragmented solids because the mesh moves with the material and allows for realistic deformation and breakage. These two frames of reference are coupled in the ANSYS AUTODYN software so that energy is easily transferred between the two for accurate modeling of the entire blast process.

A compelling ANSYS AUTODYN capability is the incorporation of these features into the three-dimensional simulations, making the software the only logical choice for modeling and analyzing rock blasting. These 3D features were used in a recent simulation of a surface coal mine blast geometry. In this analysis, burden (distance between rows of blast holes) is 32.5 feet, spacing between adjacent holes is 48 feet, and blast hole diameter is 12 inches; the RHT model was adjusted based on an 800 pounds per square inch compressive strength of shale to be blasted apart. The vertical bench face denotes the vertical walls of the pit, where blasted material moves and is removed by excavators and haulers. Two adjacent blast holes are modeled in 3D with different delay times between the holes, including 0 milliseconds (ms) (simultaneous blasts), 2 ms, 8 ms and 15 ms.

Translucent color representations show the predicted progression of shock waves and pressure distributions in the blast field with a 2-ms detonation delay between the adjacent blast holes represented as two vertical lines. Shock waves shown in red emerge from the blast holes, progress upward through the blast field and combine next to the bench face and ground surface at a tensile stress of at least 100 psi — the pressure shown in dark blue at which individual rock fragments form.

What is immediately obvious from this series of snapshots is that damage accumulation significantly lags behind the initial detonation and movement of the shock waves. This occurs because damage and fragmentation are a direct result of crack propagation, the rate of which depends on crack tip velocity. The RHT model correctly treats the crack tip velocity as a fraction (usually about one quarter) of the sonic velocity of the material.

A comparison of damage at 20 ms after the second detonation in a cross-sectional slice through the blast area

0 ms delay   2 ms delay

8 ms delay   15 ms delay
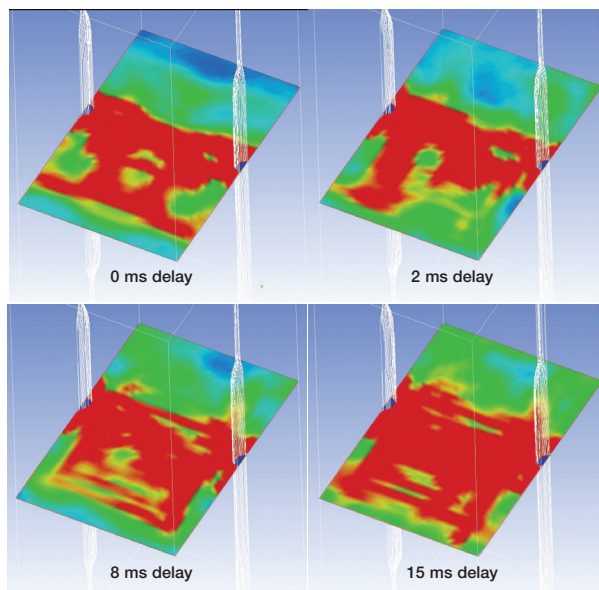
A comparison of damage at 20 ms after the second detonation in a slice through the blast area shows the various detonation delays. Damage moves forward with increasing detonation delays of 2 ms and 8 ms and reaches the pit face at 15 ms, at which maximum fragmentation occurs near the pit face.

shows fragmentation for the various detonation delays. In the accompanying images, the pit face is represented by the bottom-most edge of the rectangular cross-section. Note the symmetrical damage pattern for the 0-ms simultaneous detonation, in which the near-straight sprawl line of fragmentation is uniformly separated from the pit face by a considerable distance. Damage and fragmentation improve with increasing detonation delays of 2 ms and 8 ms, and cover the greatest portion of the rock mass at 15 ms — the delay at which maximum fragmentation occurs. Simulations showed that greater delays demonstrate increasingly degraded blast performance. At delays greater than about 50 ms delay, shock waves from each hole behave fairly individually with little interaction with those of the adjacent hole.

The value of using ANSYS AUTODYN simulation for such studies is that engineers not only can quickly determine optimal detonation delay but also assess the impact of using different explosives and blast hole geometries. As a result, Orica can work more closely with clients and quickly provide valuable insight into leveraging the highest performance possible from mining explosives. ■