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Drill-split mining with radial-axial loading splitters

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1 INTRODUCTION

A mechanical excavation tool, designed to supplement or supplant drill-blast methods of primary excavation, has been developed and successfully tested by the Bureau. The tool, called a radial-axial loading splitting tool (RASP), is as versatile in its application as drill-blast excavation methods, providing it with great potential while eliminating explosives and their associated hazards from the working environment.

Alternatives to drill-blast excavation methods have in the past been limited in their applications or success. Most mechanical excavation alternatives come in the form of cutting machines. Those capable of excavating hardrock, primarily tunneling machines, are limited by their need to react their cutting forces through frictional contact with the tunnel's periphery. This restricts the size and shape of the openings they can produce, and the maneuverability of the machine itself. Mechanical excavators capable of more flexible operation, such as roadheaders and modified continuous miners, are limited to soft rock applications. All of these machines are massive, complicated, and expensive. The RASP offers distinct advantages over other mechanical excavation machines by reacting its excavation forces internally, by being adaptable in size and capability, by having the capacity to excavate most rocks, and by being low in cost.

In 1981, the Bureau initiated a research effort to investigate the potential of the RASP operated in a drill-split cycle as a primary excavator. This splitting tool, modeled after a tool that was developed by researchers at the Institute CERAC (Cooper, Rhyming, 1980, Cooper, 1978) differs from most splitters in the manner it applies loads to the rock. It was selected for this effort because of its unique excavation action (fig. 1). This action results in a fracture plane that radiates outward from its point of initiation at the leading edge of the feathers. This plane is generally perpendicular to the drill hole and parallel to the rock surface until it diverges to surface around the drill hole. The roughly bowl-shaped, excavated mass is normally fragmented into many pieces . Splitting rock in this manner eliminates the need for a side-free surface to break towards and permits this tool to excavate rock from highly confined places.

2 RASP DEVELOPMENT

The RASP developed by the Bureau integrates a special hydraulic cylinder and three concentric rock-breaking components to achieve its excavation action. The cylinder contains two double-acting pistons capable of independent movement and actuates the wedge and thrust-rod members of the rock-breaking components. The feather is the third member of the rock-breaking components and is itself attached to the cylinder body (fig. 2).

The rock-breaking components are made from heat-treated tool steels and are used to transmit the forces supplied by the hydraulic cylinder to the rock. The thrust rod is centrally located and, as its name implies, is a high-strength rod. The wedge resides between the thrust rod and feathers and has a cone-shaped end that engages with the feather's segments forcing them to move radially. The feather fits around the wedge and is sawn in half lengthwise and once again at right angles to the original cut part way down its length. These segmenting cuts allow the end of the feather to expand radially.

When operating in a predrilled hole, the wedge is drawn back into the feather component forcing its segments radially outward against the hole wall. This radial loading securely anchors the RASP within the hole. After the RASP is anchored, the thrust rod is extended. When it contacts the end of the hole, an axial load is applied to the rock. The resulting stress field caused in the rock by the radial and axial loads causes the rock to fracture.

Three increasing sizes of RASPs were designed by the Bureau and laboratory tested (Anderson, Swanson, 1982, 1987). Those initially tested produced loads of up to 6,500-lb axially and 31,000-lb radially (Anderson, Swanson, 1982). The second pair of RASPs produced up to 11,750-lb of load axially and 57,000-lb radially (Anderson, Swanson, 1987). In contrast to the first two generations of RASPs that were hand size, the third generation RASPs provided up to 71,300-lb of axial and 345,000-lb of radial load. This generation weighed 80-lb and was worked in 1-3/4-in drill holes that were produced by jackleg drills. These RASPs were worked in blocks of concrete, limestone, and granite at depths ranging from less than an inch to over 7 inches.

From those laboratory tests, it was found that on average, the radial-and-axial excavation loads are roughly proportional to the break depth to the 1.5 power. Of significance is that at all depths and in all materials the same characteristic fracture path was produced. The volume excavated by this characteristic path can most easily be quantified in terms of the depth (length measured from the surface to the fracture initiation point), and the average diameter of the excavated mass at the surface. Typically, the ratio of this diameter to depth was 7 to 1. A conservative approximation for the volume of the mass excavated can be made using this ratio and approximating the fracture curve by a straight line. Assuming that a cross section of the fractured mass has a triangular shape, with the base length equal to the depth and the height equal to 3-1/2 times the base length, the volume can be approximated, using solid of revolution method as:

$V = 1/3\ \pi(3.5^2)D^3$,

Where: D equals the depth.

This discussion of fracture path geometry deals with the majority of situations where the RASP would be used. However, the propagating fracture will follow the path of least resistance, and is thereby affected by changes in the relief of the face and discontinuities present in the rock mass. Many times this can work to the advantage of the RASP user. In a situation where a side-free surface is available to break towards, the RASP can be worked in an efficient slabbing operation. Here the fracture would generally take on a planar form splitting the hole axis until it turns away to exit at the free surface.

In a different situation, interaction with a discontinuity or weakness in the rock may be exploited for easier fracturing or to increase the volume removed by the break action. Here the fracture would initiate in, or intersect with, a weakness and follow that weakness until the mass breaks off because of its outward "axial" movement, or until the fracture followed the weakness to the surface.

The situation that is the most demanding for all excavation techniques, including the RASP, is the excavation of a blind heading. Here the nearness of the mass surrounding the heading's face affects the fracture path by causing the fracture to surface before it reaches this relatively infinite mass, thereby reducing the RASP's effectiveness. However, if the tool is sized and applied properly, this difficult situation can be greatly alleviated. In most cases, advancing the center of the heading followed either by slabbing off to this relief, or by turning the RASP 90° from the headings direction, and operating perpendicular to the heading's direction of advance has proven to be effective in the laboratory (Anderson, Swanson, 1982, 1987).

When discussing splitting efficiency and the reduction caused in it by confinement, it is necessary to put splitting in context with other methods. When breaking Indiana limestone in the laboratory, the specific energy due to the splitting process averaged 12-in lb/in^3. This number is negligible when compared to specific energies of over 1,000-in lb/in^3 when using mechanical-cutting methods (Anderson, Morrell, 1987). Because the splitter requires a predrilled hole, the drilling operation must be included in the evaluation of specific energy. Although drilling the hole is energy intensive, the relative volume extracted by drilling is well under 1 percent of the total when excavating at a practical scale. When a large splitter was operated in an underground limestone mine, it produced an average of 1-1/4 ton per break. The 3-in-diameter drill hole required for this splitter's operation averaged 15 inches in depth. Estimating the specific energy to split was 100-in lb/in^3, and that to drill was 24,000-in lb/in^3, the overall specific energy for the drill-split operation is calculated to be 180-in lb/in^3, a number that is a striking improvement over the mechanical cutting methods.

3 FULL-SCALE DEVELOPMENT

The success of the laboratory testing led to the development of a fourth generation RASP and a suitable carrier. This RASP generates up to 270,000 lb of axial and 630,000 lb of radial loading and was fabricated at a cost of $10,000 (1988 dollars). The tool has an 11-3/4-in-outside diameter, a 10-1/2-in-bore diameter and a 48-in overall length. It operates with hydraulic pressures to 3,000 psi in a 3-in-diameter drill hole. Yet in this small size relative to other mechanical excavation machines, it can remove over 4 tons of rock at once.

To permit rapid operation and smooth tool handling during the drill-split cycle, the Bureau developed an indexing mechanism that mounts both the RASP and a drill. This assembly was retrofitted on the boom of an air-track crawler frame for mobility; and the RASP power was generated by a 1-hp, air-driven hydraulic pump that was added to the crawler unit (fig. 3). This retrofit, including the indexing mechanism, cost $15,000 (1988 dollars). When working, this machine's cycle of operations are as follows: 1) position tools for hole, 2) drill hole, 3) index to align RASP with the hole, 4) emplace RASP, 5) split, 6) retract RASP, and 7) index to bring the drill back into the operating position. The indexing, accomplished with a rotary actuator and mechanical stop, is very important as the operational efficiency of the excavation process relies on the quick alignment of the RASP with the drill hole.

Drill-split excavation was tested in the Linwood Mining and Minerals, Corp's. underground limestone mine near Davenport, IA. The mine is operated on two levels by room-and-pillar methods using rubber-tired equipment. Ramps are used to move between levels and the mine access is through an adit developed from surface workings. The splitter was worked in a blind heading on the lower level, 170 ft below the surface, where the roof height was 23 ft and the 40-ft rooms were separated by 30-ft pillars (fig. 4). Normal mining operations were continued during the testing.

During the field test, the radial-axial splitter performed well. Operating about 100 times, it mined approximately 125 ton of ore. The average depth of break was 10 in and break-out loads averaged 65,000 lb for the axial and 170,000 lb for the radial directions. The 1-1/4-ton/break average was larger than that predicted by the empirical relationships developed in the laboratory where the ratio of the surface fracture radius to breaking depth was 3-1/2 times. The majority of the excavated rock fell into a size range from 20 to 300 lb. Mucking of the heading was accomplished with the mine operation's normal mucking equipment, front-end loaders with 6-yd buckets. Mucking was called for when it became difficult to work over the muckpile located at the toe of the face. During mucking the crawler was pulled from the heading, although room existed in this 40-ft-wide heading to do the mucking and drill-split excavation side by side.

Prior to the field test, two critical areas of uncertainty existed. These areas of concern focused on the tool's ability to excavate fractured and fissured rock and on it's ability to completely free the broken pieces from the rock mass. When fractures or fissures are present, the rock mass is free to move under the influence of the rock-breaking components and only a reduced radial or gripping load can be generated. Under these conditions, the potential exists that the tool will not completely fracture the break piece from the mass or, if it was completely severed, it may remain keyed in place by it's surface irregularity. Neither of these situations proved difficult for this splitter, which provided 1/2-in of radial expansion and 3-in of thrust-rod stroke. Occasionally the splitter lost it's grip on part of a break piece because a majority of it fell away. In these cases, a normally-spaced, subsequent break in the area removed the pieces left on the face with no difficulty.

As a part of the field research, a time study was done for the drill-split method. Drill-split operations were broken down into four categories, including the drilling, the indexing that involved all the time taken to replace the drill in the hole with the splitter, the splitting and the repositioning of the machine so that it was ready for drilling once again. The averages for these operations developed as follows:

Operation	Time (sec)
Drilling	50
Indexing	15
Splitting	150
Repositioning	60
TOTAL.............	275

These operations average a total of 275 sec for the entire drill-split cycle with splitting consuming the most time. In the laboratory, it was found that the speed of the splitting process did not affect the quantity of rock excavated. In the field, the splitting operation was slowed because an undersized hydraulic pump was used to power the tool. Splitting times of 15 sec are reasonable for this tool and at such a rate the average total time consumed would be reduced to 140 sec. The best total time achieved during the field test was 206 sec for a 10-in-break depth in which the splitting operation consumed 68 sec. It is assumed that with operator experience and upgrades in equipment, the average total time can be reduced further to about 80 sec.

Another objective of the field research was to evaluate the suitability of using the drill-split technique in an underground environment. All in-mine testing was conducted with personnel in the blind heading during the mine's normal day shift operations. No disruptions were caused to the mines normal activities demonstating the drill-split techniques compatibility with concurrent operations. The underground environment produced by the drill-split operations was analogous to a standard drilling operation. Drilling was performed with water flushing to control the dust from this operation. The splitting operation produced almost no dust at all. While minimal dust was produced by the fall of rock from the face into the muck below, this small quantity caused no problem for the face operations. The greatest potential safety hazard associated with the splitting operation to personnel was the falling rock released by this operation. However, the operator was in little danger just 12 ft from the working face.

4 DRILL-SPLIT TECHNIQUE POTENTIAL

Field testing of the full-scale RASP and tool positioner has shown that it is possible to devise a simple, efficient mechanical excavation machine using drilling and splitting tools. The technique parallels conventional blasting techniques in that both use drilling to gain access to the rock. However, the similarity ends here. Once the drilling has been accomplished, the methods and equipment used to finish the excavation operation diverge greatly.

Drill-blast techniques require specialized blasting personnel, equipment for the loading of holes, storage facilities for explosives, and precautionary measures in handling the explosives before the blast and in guarding against the blast products afterwards. In contrast, drill-split techniques use the same operator for both the drilling and splitting operations. The only piece of excavation equipment involved would be a carrier modified to carry both the drill and RASP tools. Finally, the nonviolent nature of the RASP break action provides a safe working environment that requires minimal precautionary measures at the face and none away from it.

Drill-split mining is envisioned as a continuous excavation technique that is nondisruptive to nearby operations. A key in making this technique continuous is the ability to carry out concurrent excavation and mucking activities. Mucking the rock produced by drill-split methods may be done by various means depending on the excavation needs. Machine configurations that use gathering arms or some other loading system may be incorporated with drill-split equipment to produce a continuous miner that would be used to drive headings or excavate. While other mining scenarios lend themselves to separate excavation and mucking equipment, mucking developments will evolve with drill-split-excavation systems to optimize performance.

The RASP by virtue of its scalable size and capability has widespread potential for application in underground mining. These virtues provide it with the ability to excavate openings of any size, shape, or orientation, and as a result it has the versatility that has been lacking in other alternatives to drill-blast methods of excavation. This versatility should allow the RASP to supplant drill-blast excavation operations with minimal disruption to the mining operation. Of the underground mining methods, only in the caving, long-hole and sublevel stoping methods does the application of this technique appear impractical as the production method. The remaining production methods, as well as development activities and selective mining, are amenable to excavation by drill-split techniques with RASPs. An area of potential not yet mentioned is surface mining. A very desirable feature in this application is the RASP's lack of blast shock and ground vibrations. It is practical to assume that because of the RASP's scalable nature, large versions of the tool capable of excavating very large volumes from the earth could be competitive with other surface mining methods.

5 CONCLUSIONS

Because of the lack of long-term testing the maintenance requirements of RASP technology are not firmly established. The cylinder portion of the tool, although exotic in configuration, has a high degree of reliability. However, the rock-breaking components require further testing before a definitive judgment can be made regarding their reliability. Research should also be conducted to gain a more complete understanding of the feather/rock interplay and to define what mechanical properties of the rock govern the force requirements for fracture.

Testing to date has proved drill-split mining to be a quick, efficient and inherently safe excavation technique. It has low-capital cost and the equipment is simple to operate making it a good candidate for automation. It's best features include the following: A nonviolent nature that generates minimal impact on the mining environment with associated reductions in the demands for ventilation and ground control; the RASP's predictable fracture path and, thereby, excavation capability; a scalable nature, that allows the technique to be applied to both large and small tasks; and the RASP's internal reaction of excavation forces that allows it to be a small, highly maneuverable and versatile excavation tool that can be adaptively mounted to meet the requirements of differing excavation scenarios.

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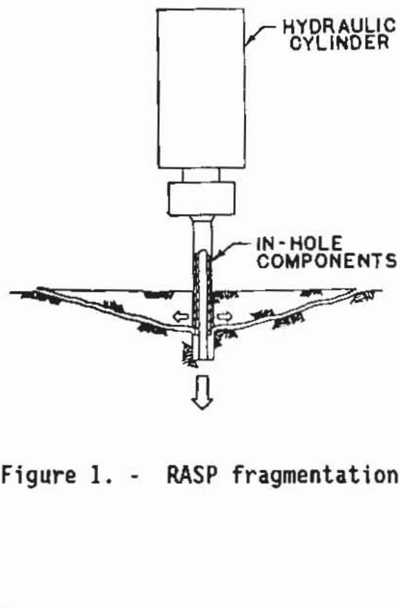

Figure 1. - RASP fragmentation.

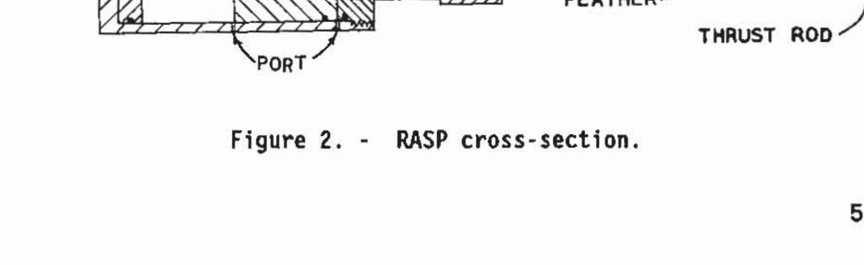

Figure 2. - RASP cross-section.

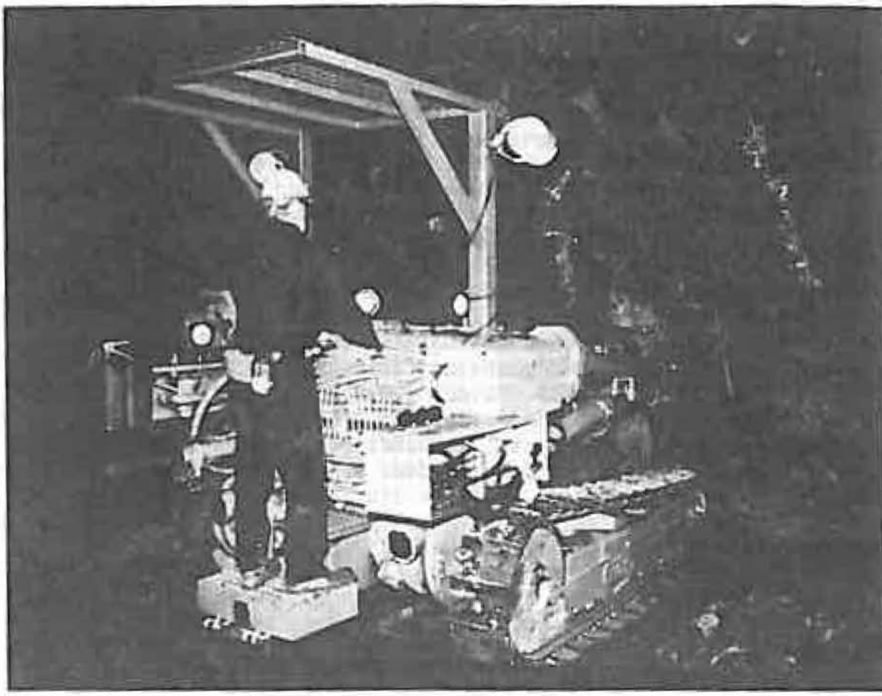

Figure 3. - Drill-split machine.

Figure 4. - Underground testing.

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