

An initial and historically significant breakthrough has been made just recently in the first and probably the most critical of the underground excavation subsystems—rock disintegration with a continuous-mining machine. This does not imply that, prior to this breakthrough, rock was particularly hard to break. Egyptian slaves were able to break rock in a tunnel many centuries ago by driving wooden wedges into cracks of the rock face and wetting them so they would swell and dislodge fragments. But the manner and rate of breaking the rock is generally the governing factor in determining the performance of the total excavation system. Drilling and blasting, the rock-breaking method generally used for tunneling in the harder rocks, is a cyclic, essentially manual operation, in which one act must be completed before the next is started, thus establishing limits on the performance of the other subsystems and of the total excavation system.

Because of the built-in cyclic nature of the drill-blast method, a truly rapid and continuous excavation system could never be developed around this method. Nevertheless, even with these severe limitations, the drill-blast method can be used to illustrate what can be accomplished in time through refinement and development of the crude model existing at the brink of an important breakthrough. In the 1860's, when mechanical drilling and high-explosive dynamite were introduced for tunneling, the rate of advance was about 20 feet per week. This was about twice as fast as the era's conventional method of manual drilling and blasting with low-explosive black powder. But even though the tunneling speed was doubled, the cost of drilling with the first generation of mechanical drills was three times that of manual drilling. Now, after 100 years of haphazard and unsystematic development of this method, tunnels can be advanced about 250 feet per week which is more than a 12-fold increase. This improvement is attributed primarily to semiautomation of the drills, better material for the drill unit and rock bits, more efficient transfer of energy to the rock bit, upgrading the explosives, and improving the other elements of the system built around and supporting the drill-blast rock-disintegration subsystem.

The recent introduction of the mechanical boring machine is considered just as significant as the introduction of mechanical drilling and high explosives. It provides an entirely new concept around which a rapid tunneling system can be developed. The attractive feature of this method is that it breaks and loads the rock continuously and simultaneously, thereby eliminating the slow and costly periodic interruptions of the cycle. With continuous breaking, work can now begin toward making continuous and concurrent the other three subsystems. This opens the way to spectacular increases in speed and reductions in cost. In addition, serious consideration can be given to remote control and guidance, which are essentially precluded at present by the cyclic nature of drill-blast methods.

Today's mechanical boring machines, although impressive, are still in an early stage of development, perhaps at the same crude stage of the first mechanical drills a century ago. Until now, they have not been successful in very hard rock. Even so, in rock where they are applicable, they are already outperforming the conventional drill-blast method. An important point to remember is that these boring machines have been incorporated into a system built around the cyclic drill-blast method of breaking rock. Both the materials handling and the ground support subsystems used with the continuous-boring machines are the same cyclic methods developed for the cyclic drill-blast method. Obviously continuous materials handling and ground support must be developed. Based upon experience to date, if a method could be developed to continuously transport the rock broken by current boring machines, their efficiency would probably be increased 50 percent without any other improvement in the system. Actually, higher-capacity continuous materials handling systems must be developed to match the output of the future boring machines. It can be stated confidently that both the machine performance and the range of effectiveness of the mechanical boring can be improved substantially by the application of new scientific and engineering knowledge developed in the rapidly advancing fields of materials science and applied mechanics. For example, current machines apply static thrust and a rotating head with fixed or rolling cutting bits to bore through earth or the softer rocks. With better materials and mechanical design, a machine could probably be designed using dynamic thrust to bore through the hardest rocks. The latter principle has proved to be one of the best methods for drilling small-diameter holes in hard rock.

Also, many other attractive possibilities exist for accomplishing continuously and rapidly this first key step in the excavation process. The Bureau of Mines and others are experimenting in an exploratory way with unconventional energy