A New Concept for Selective Mechanical Mining of Hard Rock

Brian Asbury[1], Jamal Rostami[1], and Levent Ozdemir[1]

[1] **EARTH MECHANICS INSTITUTE, MINING ENGINEERING DEPARTMENT, COLORADO SCHOOL OF MINES**

ABSTRACT

Over the last several decades mechanical mining machines have developed into highly productive, light weight, mobile machines which are able to economically mine many soft rock ore bodies. Due to the utilization of disc cutters Tunnel Boring Machines, with great mass and limited mobility, have developed the ability to cut the hardest rocks at high production rates. Technological advancements have allowed mini-disc cutters, which require low forces to cut hard rock, to be developed. These mini-disc cutters provide a new option for developing a light weight, mobile machine which can excavate hard rock. This concept and supporting data are presented.

BACKGROUND

Current economically viable mechanical mining machines utilize drag type cutters. Drag type cutters are used because they require relatively low forces to cut rock, therefore may be utilized on lightweight mobile machines. These machines are desirable for mining because their mobility allows them to immediately turn in a heading and produce openings with flat floors. The same drag cutters, which allow mechanical mining machines to be mobile, also, provide the limiting factor for being able to cut hard rock.

The most robust of drag cutters are able to cut intact rock of approximately 10,000 to 12,000 psi compressive strength. If the rock is highly fractured, drag cutters can excavate rock of 14,000-16,000 psi by plucking chunks of the rock out from the joint structure. This limitation is caused by friction and impact force of draging the carbide tipped tool through the rock. The harder and more abrasive rock generates more friction and higher impact forces, thus reducing the life of the drag cutters and their economic viability. Figure 1. Illustrates two types of drag cutters.

Figure 1: A conical (left) and a radial cutter.

While mechanical mining machines have evolved to suit the soft rock mining community, Tunnel Boring Machines (TBM's) have developed into excavators which can advance through hard rock at very fast rates. The ability to excavate hard rock is due to the use of rolling cutters. Large, single disc cutters have developed into the most efficient and economic rolling cutters for hard rock TBM's. The typical disc cutters, 17 inches in diameter, require a large amount of force to be pressed into hard rock. In order to provide the high forces, required for the large disc cutters, TBM's are massive machines which occupy the entire width of the tunnel. In turn the size of the TBM's greatly inhibit their mobility, resulting in turning radii on the order of 100 of feet or more.

Over the last several years, small diameter cantilever mounted disc cutters have developed into useful hard rock cutting tools. This development has been greatly due to advancement in metallurgy and associated bearing technologies. These small (mini-disc) cutters have been used in extensive laboratory tests, cutting rock with compressive strengths of 5,000 to 42,000 psi. Laboratory testing has included 3.25, 5, and 6 inch mini-disc cutters individually and on cutter heads of 8 inches to 3 feet in diameter. The main result of the testing is that, a 5 inch diameter disc cutter requires an average of 1/7th the force to penetrate a given distance into a given hard rock, when compared to the standard 17 inch disc cutter. The difference in force is directly related to the volume of rock being displaced by the cutters. This phenomenon allows for a small, lightweight machine, in the form of a partial face drum excavator, to effectively cut hard rock. Figure 2 presents a typical 17 inch disc cutter ring and a 5" mini-disc.

Figure 2: 17 inch disc cutter (left) and 5" mini-disc

INTRODUCTION OF THE DRUM CONCEPT

The drum excavator is a partial face machine with a cutterhead in the shape of a drum, therefore the name drum excavator. The front of the drum is similar to a miniature TBM and is designed to bore to a specific depth. The side of the drum is also dressed with cutters, which cut the rock in a slewing mode. By slewing the drum parallel to the face and cutting the rock with the cutters that are mounted on the side of the drum, a flat floor is created, which is a great advantage in many underground operations. Also, the face is flat, allowing the machine to work very close to the face which is desirable for machine stability and installing ground control measures.

The first application of this cutting concept was studied for an alcove excavator for the Department of Energy's Yucca Mountain Experimental Study Facility (ESF). For this project, there is a need to excavate alcoves on the side of a TBM bored tunnel while the TBM is operating further down the tunnel. This required a very compact mobile excavator (Figure 3) which could excavate the alcoves with minimum interference to utilities and production in the main tunnel. In support of this project, a 3 foot diameter cutterhead, dressed with 5 inch mini-disc cutters, was designed, built, and tested.

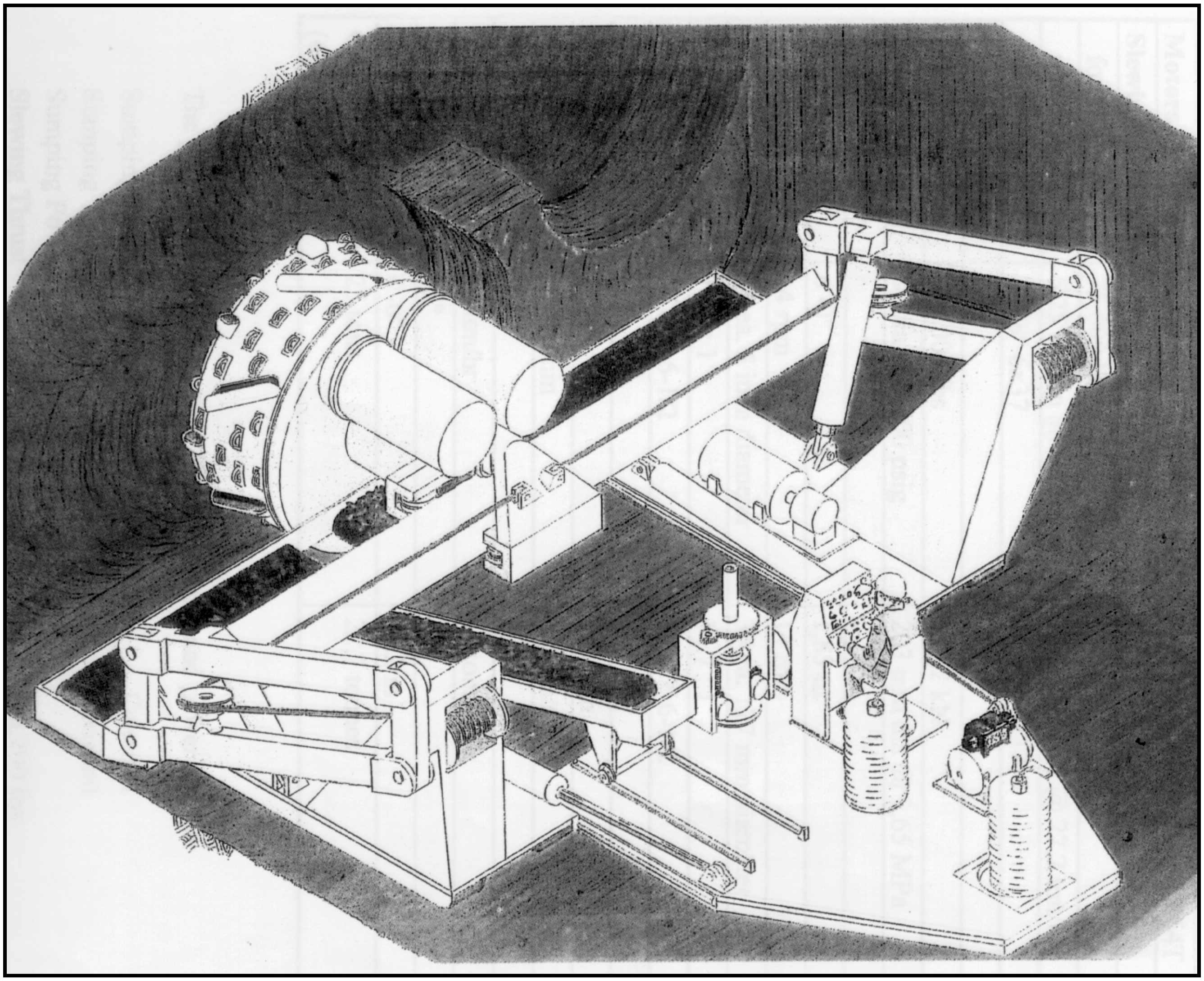

Figure 3: Initial artist rendering of the mobile drum excavator

DESIGN OF THE DRUM CUTTERHEAD

The design of the drum cutter head was based on individual cutter data from the rock to be cut and empirical/theoretical balancing and performance models developed at the Earth Mechanics Institute. Before the drum design could be performed, the force penetration response of the mini-disc working in the target rock had to be well understood. The individual cutter data was generated through a series of linear cutting tests (Figure 4), performed at different spacings and penetrations. The results of this initial test program were used to feed the algorithms of the design models.

Figure 4: 5" MD on LCM

Disc cutters last longer and are more efficient when side load to the cutters are minimized. In order to prevent the face and side cutters from scuffing, when they are not advancing the face, the gage cutter are protruded outward to cut relief. This can be seen in the cutterhead profile, shown in Figure 5. Therefore, when the cutterhead is sumping, the side cutters are not touching the rock, and when the cutterhead is slewing, the face cutters are not in contact.

Disc cutters are known to work best under stable cutting conditions. The design model was therefore used to balance the cutterhead to minimize fluctuations in forces during the cutting action. This is particularly important because the drum cutterhead in slewing mode is a partial face machine since the cutters enter and exit the rock. This results in constantly varying cutter penetration during slewing.

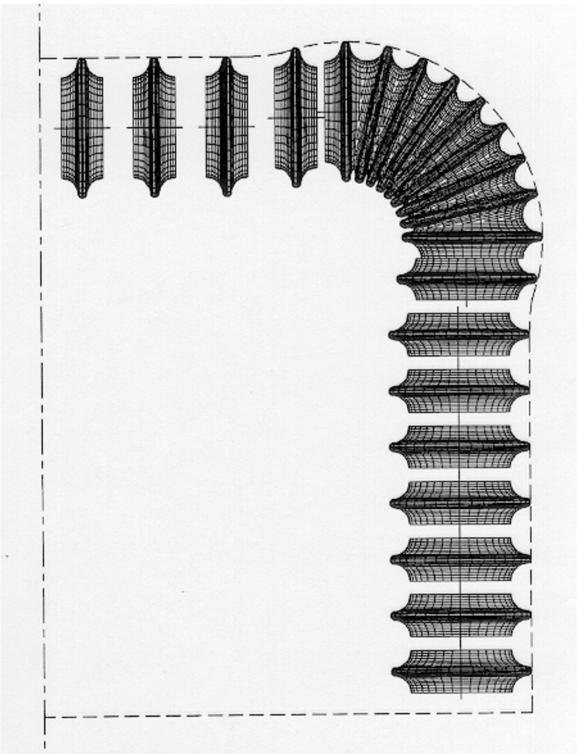

Figure 5: Drum cutterhead profile.

In general, more cutters (close spacing) provide a smoother running and better balanced cutterhead. However, wider spacing requires lower overall force and is more efficient. The goal is to reach the optimum spacing/penetration ratio and to find the largest functional spacing in this region. This results in the most efficient excavation of the rock. Iterations of the design model provide the preferred medium between acceptable force variations and the most efficient cutting, resulting in the highest productivity. Figure 6 is shows the final drum design.

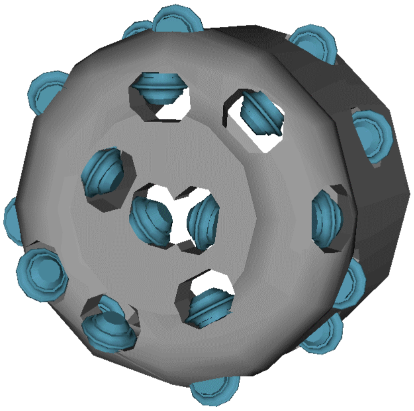

Figure 6: Final 3' cutterhead design

TESTING OF THE DRUM CUTTERHEAD

The drum cutterhead was tested, in both modes of operation, while cutting concrete and welded tuff. The goal of the test program was to validate the drum cutting concept and the computer performance model developed for cutterhead design and balancing. The test data presented here is with the cutterhead turning at approximately 25 rpm.

The laboratory testing of the drum cutting concept was performed on the Drill Test Fixture (DTF) at EMI. The DTF (Figure 7) is able to provide 150 hp of cutting power, 40 tons of thrust/sumping force, and 15 tons of slewing/side cutting force. All operations (i.e. torque, rpm, rpm, and thrust) are measured and recorded by a computer based data acquisition system at a rate of 75 Hz.

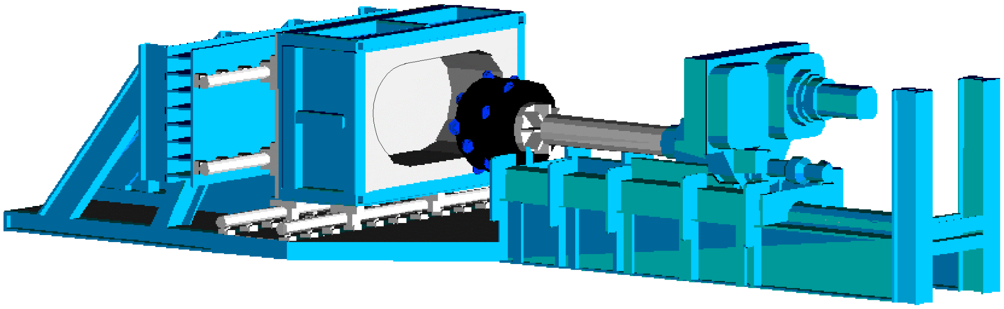

Figure 7: The DTF

Tests in concrete

The first set of testing for the drum cutterhead was performed while cutting concrete. The concrete was a 6 sack construction grade of approximately 6, 000 psi compressive strength, with 1 inch aggregate of 42,000 psi granitic gniess. Sumping test were performed in concrete at several different thrust forces, to provide data to build thrust vs. advance rate vs. power consumption curves. Sumping in concrete reached a maximum penetration rate of 28 ft/hr. This was accomplished with a thrust of only 52,400 lb and a torque of 19,500 ft-lb. This is equivalent to a production rate of 7.3 yd^3/hr with a power consumption of 90 hp.

Due to the structure of the DTF, slewing loads were limited to 30,000 lb. A slewing rate of 33.5 ft/hr was achieved with a slewing force of 28,000 lb and torque of 21,700 ft-lb. The slewing force, torque and their relationship increased linearly with the slewing rate. The power consumption for this slewing rate was 102 hp, corresponding to a production rate of 7.4 yd^3/hr.

Tests in welded tuff

The test sample was prepared using two large blocks of the TSw2 formation obtained from the Yucca Mountain site. The blocks were cast with concrete in a rock box to provide a confined sample. The measured compressive strength of the welded tuff used in the sumping portion of the sample was 42,000 psi. The rock sample used for the slewing test had a measured compressive strength of 28,000 psi. The samples of welded tuff selected were the hardest available from the samples provided to EMI.

During sumping, a thrust of 71,000 lb resulted in the maximum penetration rate of 15.5 ft/hr at a cutterhead speed of 23 rpm, consuming 85 hp. The penetration rate increased at a higher rate as thrust increased. This means the cutting becomes more efficient as the penetration increases and larger chips are produced.

For the slewing tests, a maximum penetration rate of 25 ft/hr was achieved with a slewing force of 29,300 lb and torque of 25,500 ft-lb. This test, with a production rate of 5.5 yd^3/hr, used 108 hp. A picture of the slewing tests with the drum cutterhead in welded tuff is shown in Figure 8. A summary of the maximum test results for cutting concrete and welded tuff is presented in Table 1.

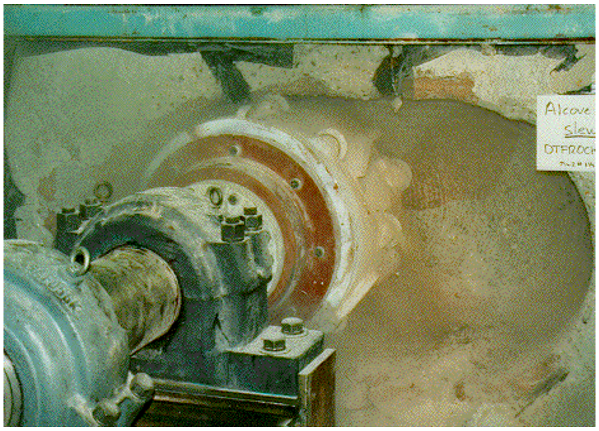

Figure 8: Slewing test in Welded Tuff

Material	Cutting Mode	Thrust (lbf)	Torque (ft-lb)	Power (hp)	Advance (ft/hr)	Production (yd^3/hr)
Concrete	Sump	52,400	19,500	90	28	7.3
Concrete	Slew	28,000	21,700	102	34	7.4
W.Tuff	Sump	71,100	19,200	85	16	4.0
W. Tuff	Slew	29,300	25,500	108	25	5.5

Table 1: Test results of the 36" durm cutterhead.

The laboratory testing of the drum cutterhead in concrete and the welded tuff was very successful. High rates of penetration were achieved with low forces for both sumping and slewing actions. In both cases, the cutting action was observed to be highly efficient with full interaction between adjacent cutter paths. The cutterhead was found to run very smoothly, indicating a well-balanced cutter layout and validating the computer design model used for cutterhead balancing. No cutter failure or noticeable wear was experienced during the entire test program.

The forces imposed on the cutterhead during testing were limited by the available torque and slewing thrust capacities of the test rig. The maximum allowable slew force on the laboratory test rig is 15 tons. The cutterhead is capable of sustaining much higher loads without exceeding the recommended load capacity of individual cutters. This means that much higher penetration and production rates can be attained with a field machine fitted with more power and thrust than the test fixture used in the laboratory. This is especially true for the slewing tests.

MACHINE PRODUCTION ESTIMATES

Initial performance predictions have been made for two different configurations of the mobile mechanical drum miner operating in the 25-30 ksi igneous rock. The configuration is for a 4 foot diameter cutter head. This head would make a 2 foot deep sump before slewing and be provided with 180 hp available for cutting power.

A scenario of mining an 8 foot high by 15 foot wide heading is presented. The 4 foot cutterhead would have to make 2 slewing passes across the face before the machine could advance. A reaction mass of only 41 tons would allow the cutterhead to perform the sumping and slewing actions.

The 4 foot diameter cutterhead is expected to produce 12.9 and 13.7 yd^3/hr instantaneously while sumping and slewing, respectively. Allowing 10 minutes for repositioning each cycle, the miner should advance the heading at a rate of 2.7 ft/hr. These results are presented in Table 2.

Operation	Production
Sumping Rate (yd3/hr)	12.9
Slewing Rate (yd3/hr)	13.7
Heading Advance Rate (ft/hr)	2.7

Table 2: Production rates in 25-30 ksi rock

Assuming a mechanical availability of 90% and a utilization of 80%, the mobile hard rock excavator should be able to advance the heading 16 feet per shift. If the excavator was run two shifts per day, reserving the third shift for maintenance, 32 feet of advance per day could be realized. This is competitive with drill and blast methods.

CONCLUSIONS

There now exists a technically viable, and potentially economic, method for mechanically mining hard rock. This is possible due to the development of the mini-disc cutters and their ability to cut hard rock with relatively low forces. When the mini-disc cutters are utilized with the drum cutting method, hard rock may be mechanically excavated, at reasonable production rates, with a lightweight mobile excavator.

This mechanical option can be competitive and much safer than drill and blast methods. Economic trade off studies, examining mechanical methods, should include the savings generated by many factors; including reduced ground support and ventilation requirements, extended rubber tire life and the elimination of primary crushing.

The next step in this development effort is to build a prototype for full-scale field testing in hard rock. This will provide quantification of the technical and economic viability of the mobile hard rock mechanical excavator.

REFERENCES OF MMA 95 PAPER

Friant, J.E., Ozdemir, L. and Ronnkvist, E., 1994, “Mini-cutter Technology - The Answer to a Truly Mobile Excavator”, *Proc. of North American Tunneling ‘94 Conference and Exhibition*, Denver, Colorado, June 6-9.

Friant, J.E., Rönnkvist, E., Ozdemir, L., 1993, “Alcove Excavator for the Yucca Mountain Experimental Study Facility”, Report prepared for RSN contract # SC-YM-93-159, EMI, CSM.

Ozdemir, L., Rostami, J., 1993, “Testing and Performance Evaluation of 32-inch Diameter Mini-disc Cutterhead for Micro Tunneling Applications”, Report prepared for Excavation Engineering Associates Inc, EMI, CSM.

Rostami, J., Neil, D.M., Ozdemir, L., 1993, “Roadheader Application for the Yucca Mountain Experimental Test Facility”, Report prepared for RSN contract # SC-YM-93-159, EMI, CSM.

Rönnkvist, E., Ozdemir, L., Friant, J.E., 1994, “Testing and Performance Evaluation of a 32 inch Cutterhead using Mini Disc Cutters”, *Proc. of Institute of Shaft Drilling Technology (ISDT) annual technical meeting*, Las Vegas, Nevada, April 18-21.

Rönnkvist, E., Friant, J.E., Ozdemir, L., 1994, “Development of a Mechanical Alcove Excavator for the Yucca Mountain Exploratory Study Facility”, *Proc. International High Level Radioactive Waste Management Conference (HLRWM)*, Las Vegas, Nevada, May 22-26.

A New Concept for Selective Mechanical Mining of Hard Rock

Brian Asbury, Jamal Rostami, and Levent Ozdemir
Earth Mechanics Institute, Mining Engineering Department, Colorado School of Mines