Roadheader applications in mining and tunneling industries

H. Copur[1], L. Ozdemir[2], and J. Rostami[3]

[1] Graduate Student, [2] Director and Professor, and [3] Assistant Professor
Earth Mechanics Institute, Colorado School of Mines, Golden, Colorado, 80401

ABSTRACT

Roadheaders offer a unique capability and flexibility for the excavation of soft to medium strength rock formations, therefore, are widely used in underground mining and tunneling operations. A critical issue in successful roadheader application is the ability to develop accurate and reliable estimates of machine production capacity and the associated bit costs. This paper presents and discusses the recent work completed at the Earth Mechanics Institute of Colorado School of Mines on the use of historical data for use as a performance predictor model. The model is based on extensive field data collected from different roadheader operations in a wide variety of geologic formations. The paper also discusses the development of this database and the resultant empirical performance prediction equations derived to estimate roadheader cutting rates and bit consumption.

INTRODUCTION

The more widespread use of the mechanical excavation systems is a trend set by increasing pressure on the mining and civil construction industries to move away from the conventional drill and blast methods to improve productivity and reduce costs. The additional benefits of mechanical mining include significantly improved safety, reduced ground support requirements and fewer personnel. These advantages coupled with recent enhancements in machine performance and reliability have resulted in mechanical miners taking a larger share of the rock excavation market.

Roadheaders are the most widely used underground partial-face excavation machines for soft to medium strength rocks, particularly for sedimentary rocks. They are used for both development and production in soft rock mining industry(i.e. main haulage drifts, roadways, cross-cuts, etc.) particularly in coal, industrial minerals and evaporitic rocks. In civil construction, they find extensive use for excavation of tunnels (railway, roadway, sewer, diversion tunnels, etc.) in soft ground conditions, as well as for enlargement and rehabilitation of various underground structures. Their ability to excavate almost any profile opening also makes them very attractive to those mining and civil construction projects where various opening sizes and profiles need to be constructed.

In addition to their high mobility and versatility, roadheaders are generally low capital cost systems compared to the most other mechanical excavators. Because of higher cutting power density due to a smaller cutting drum, they offer the capability to excavate rocks harder and more abrasive than their counterparts, such as the continuous miners and the borers.

ROADHEADERS IN LAST 50 YEARS

Roadheaders were first developed for mechanical excavation of coal in the early 50s. Today, their application areas have expanded beyond coal mining as a result of continual performance increases brought about by new technological developments and design improvements. The major improvements achieved in the last 50 years consist of steadily increased machine weight, size and cutterhead power, improved design of boom, muck pick up and loading system, more efficient cutterhead design, metallurgical developments in cutting bits, advances in hydraulic and electrical systems, and more widespread use of automation and remote control features. All these have led to drastic enhancements in machine cutting capabilities, system availability and the service life.

Machine weights have reached up to 120 tons providing more stable and stiffer (less vibration, less maintenance) platforms from which higher thrust forces can be generated for attacking harder rock formations. . The cutterhead power has increased significantly, approaching 500 kW to allow for higher torque capacities. Modern machines have the ability to cut cross-sections over 100m^2 from a stationary point. Computer aided cutterhead lacing design has developed to a stage to enable the design of optimal bit layout to achieve the maximum efficiency in the rock and geologic conditions to be encountered. The cutting bits have evolved from simple chisel to robust conical bits. The muck collection and transport systems have also undergone major improvements, increasing attainable production rates. The loading apron can now be manufactured as an extendible piece providing for more mobility and flexibility. The machines can be equipped with rock bolting and automatic dust suppression equipment to enhance the safety of personnel working at the heading. They can also be fitted with laser-guided alignment control systems, computer profile controlling and remote control systems allowing for reduced operator sensitivity coupled with increased efficiency and productivity. Figure-1 shows a picture of a modern transverse type roadheader with telescopic boom and bolting system.

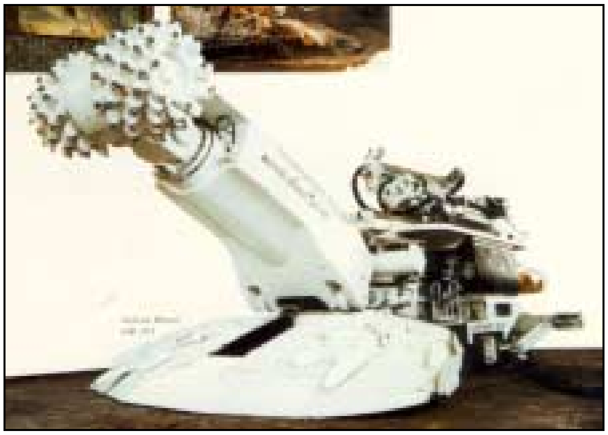

Figure-1: A Transverse Cutterhead Roadheader
(Courtesy of Voest Alpine)

Mobility, flexibility and the selective mining capability constitute some of the most important application advantages of roadheaders leading to cost effective operations. Mobility means easy relocation from one face to another to meet the daily development and production requirements of a mine. Flexibility allows for quick changes in operational conditions such as different opening profiles (horse-shoe, rectangular, etc.), cross-sectional sizes, gradients (up to 20, sometimes 30 degrees), and the turning radius (can make an almost 90 degree turn). Selectivity refers to the ability to excavate different parts of a mixed face where the ore can be mined separately to reduce dilution and to minimize waste handling, both contributing to improved productivity. Since roadheaders are partial-face machines, the face is accessible, and therefore, cutters can be inspected and changed easily, and the roof support can be installed very close to the face. In addition to these, high production rates in favorable ground conditions, improved safety, reduced ground support and ventilation requirements, all resulting in reduced excavation costs are the other important advantages of roadheaders.

The hard rock cutting ability of roadheaders is the most important limiting factor affecting their applications. This is mostly due to the high wear experienced by drag bits in hard, abrasive rocks. The present day, heavy-duty roadheaders can economically cut most rock formations up to 100 MPa (~14,500 psi) uniaxial compressive strength (UCS) and rocks up to 160 MPa (~23,000 psi) UCS if favorable jointing or bedding is present with low RQD numbers. Increasing frequency of joints or other rock weaknesses make the rock excavation easier as the machine simply pulls or rips out the blocks instead of cutting them. If the rock is very abrasive, or the pick consumption rate is more than 1-pick/m^3, then roadheader excavation usually becomes uneconomical due to frequent bit changes coupled with increased machine vibrations and maintenance costs.

A significant amount of effort has been placed over the years on increasing the ability of roadheaders to cut hard rock. Most of these efforts have focused on structural changes in the machines, such as increased weight, stiffer frames and more cutterhead power. Extensive field trials of these machines showed that the cutting tool is still the weakest point in hard rock excavation. Unless a drastic improvement is achieved in bit life, the true hard rock cutting is still beyond the realm of possibility with roadheaders. The Earth Mechanics Institute(EMI) of the Colorado School of Mines has been developing a new cutter technology, the Mini-Disc Cutter, to implement the hard rock cutting ability of disc cutters on roadheaders, as well as other types of mechanical excavators (Ozdemir et al, 1995). The full-scale laboratory tests with a standard transverse cutterhead showed that Mini-Disc Cutters could increase the ability of the roadheaders for hard rock excavation while providing for lesser cutter change and maintenance stoppages. This new cutting technology holds great promise for application on roadheaders to extend their capability into economical excavation of hard rocks. In addition, using the mini-disc cutters, a drum miner concept has been developed by EMI for application to hard rock mine development. A picture of the drum miner during full-scale laboratory testing is shown in Figure-2.

Figure-2: Drum Miner Cutterhead

FIELD PERFORMANCE DATABASE

Performance prediction is an important factor for successful roadheader application. This deals generally with machine selection, production rate and bit cost estimation. Successful application of roadheader technology to any mining operation dictates that accurate and reliable estimates are developed for attainable production rates and the accompanying bit costs. In addition, it is of crucial importance that the bit design and cutterhead layout is optimized for the rock conditions to be encountered during excavation.

Performance prediction encompasses the assessment of instantaneous cutting rates, bit consumption rates and machine utilization for different geological units. The instantaneous cutting rate (ICR) is the production rate during actual cutting time, (tons or m^3 / cutting hour). Pick consumption rate refers to the number of picks changed per unit volume or weight of rock excavated, (picks / m^3 or ton). Machine utilization is the percentage of time used for excavation during the project

The Earth Mechanics Institute of the Colorado School of Mines jointly with the Mining Department of the Istanbul Technical University has established an extensive database related to the field performance of roadheaders with the objective of developing empirical models for accurate and

Table-I: Classification of the Information in the Database

INFORMATION GROUP	DETAILS
General Information	Type/purpose of excavation (roadway, railway, sewer, mining gallery, etc.), contractor, owner, consultant, location, starting and completion date, etc.
Roadheader Information	Manufacturer, condition of the roadheader (new, refurbished, direct reuse), specifications of roadheader, machine weight, cutterhead power and diameter, bit number and type, ancillary equipment (automatic profile control, water sprays, grippers, etc.)
Technical and Operational Information	Excavation length, depth, and gradients, dimensions of excavation profile, operator experience, cutting sequence at the face, daily and weekly mining hours, muck evacuation system, ground support system, etc.
Rock Mass Information For Each Rock Zone	Geological origin, number and character of geological zones, hydrogeological conditions, rock mass classifications, RQD, bedding properties, joint set properties (orientation, spacing, roughness, filling, etc.)
Intact Rock Information For Each Rock Zone	Rock cuttability properties, uniaxial and tensile strength, elasticity modulus, surface hardness, texture (porosity, mineral / quartz content & grain sizes, microfractures, etc.), abrasivity properties, etc.
Performance Records For Each Rock Zone	Cutting rates, bit and holder consumption, roadheader utilization and availability, energy consumption, average and best advance rates (shiftly/daily/weekly/monthly), major obstructions to excavation operation, downtime analysis (roadheader related stoppages, backup system stoppages, ground and support stoppages, etc.)

reliable performance predictions. The database contains field data from numerous mining and civil construction projects worldwide and includes a variety of roadheaders and different geotechnical conditions.

The empirical performance prediction methods are principally based on the past experience and the statistical interpretation of the previously recorded case histories. To obtain the required field data in an usable and meaningful format, a data collection sheet was prepared and sent to major contractors, owners, consultants, and roadheader manufacturers. In addition, data was gathered from available literature on roadheader performance and through actual visits to job sites. This data collection effort is continuing.

The database includes six categories of information, as shown in Table-I. The geological parameters in the database consist generally of rock mass and intact rock properties. The most important and pertinent rock mass properties contained in the database include Rock Quality Designation (RQD), bedding thickness, strike and dip of joint sets and hydrological conditions. The intact rock properties are uniaxial compressive strength, tensile strength, quartz content, texture and abrasivity. The rock formations are divided into separate zones to minimize the variations in the machine performance data to provide for more accurate analysis. This also simplifies the classification of the properties for each zone and the analysis of the field performance data.

The major roadheader parameters included are the machine type (crawler mounted, shielded), machine weight, cutterhead type (axial, transverse), cutterhead power, cutterhead-lacing design, boom type (single, double, telescopic, articulated), and the ancillary equipment (i.e. grippers, automatic profiling, laser guidance, bit cooling and dust suppression by water jets, etc.).

The operational parameters generally affect the performance of the excavator through machine utilization. The most important operational parameters include ground support, back up system (transportation, utility lines, power supply, surveying, etc.), ground treatment (water drainage, grouting, freezing, etc.), labor (availability and quality), and organization of the project (management, shift hours, material supply, etc.).

PERFORMANCE PREDICTION

In a previous study (Copur et al, 1997), it was suggested that instead of developing a universal performance prediction model, separate models for different geological and machine conditions (by classification and subsequent normalization of the field data) should be developed to improve the accuracy and reliability of the performance predictions. This methodology is presented and discussed in this paper for Instantaneous Cutting Rate (ICR) and the Bit Consumption Rate (BCR). Roadheader and cutterhead type, rock mass origin and the rock type are used as principal classification parameters. The uniaxial compressive strength (UCS), cutterhead power (P), roadheader weight (W) and cutterhead diameter (CHD) are used as normalization parameters.

The variation of ICR with UCS, based on the available field performance data, is presented in Figure-3 for all geological conditions encountered and for all types of roadheaders. As expected, the data shows significant scatter with a low correlation coefficient, not allowing any trends to be deduced between UCS and ICR. After separation of the data for the transverse roadheaders in sedimentary rocks, the scatter becomes much smaller, as shown in Figure-4. Still, the correlation coefficient is low, precluding an accurate expression of any relationship between these two variables. Since ICR is directly proportional to P and W and inversely proportional to UCS, after normalization by (P/UCS), (W/UCS) and (PxW/UCS), the correlation is significantly improved, as shown in Figures 5, 6 and 7. As seen, the classification and subsequent normalization has produced some definite trends in the data. But the relationship is still not accurate enough.

Another step of classification was applied to the data in terms of rock group. This contributed to further improvement in the relationship, as shown in Figure-8 for evaporatic rocks.. In this case, the predictive equation derived is as follows:

$$ICR = 27.511 \text{ x } e^{0.0023 \text{ x } (RPI)}$$

$$RPI = P \text{ x } W / UCS$$

Where,

ICR = Instantaneous Cutting Rate, m^3/hr
RPI = Roadheader Penetration Index
UCS = Uniaxial Compressive Strength, MPa W
= Roadheader Weight, metric ton P
= Cutterhead Power, kW e
= Base of the Natural Logarithm

This equation can be used in prediction of ICR for excavation of evaporitic rocks with transverse roadheaders. It can also be used for selection of roadheaders for excavation in evaporites to meet a target production rate. Expanding the database and implementing other normalization parameters can further increase the accuracy of this relationship, a task currently underway. It should be noted that since evaporitic rocks are usually massive without the presence of joints or fractures, any rock mass parameter, such as RQD, was excluded in the normalization process. Obviously, for rock formations exhibiting a high degree of jointing or fracturing, the RQD would be expected to play a major role in machine performance, as previously discussed.

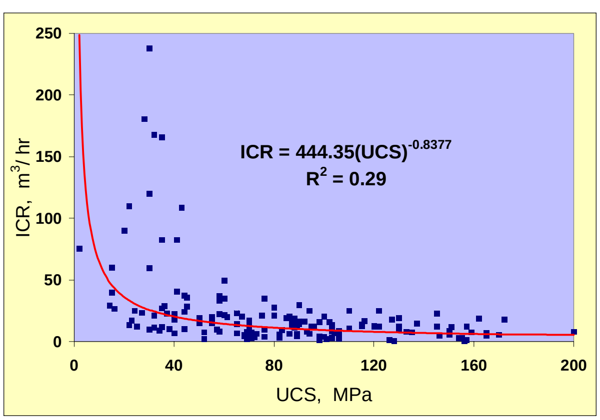

Figure-3: Plot of ICR Vs. UCS for All Geological Conditions and All Types of Roadheaders

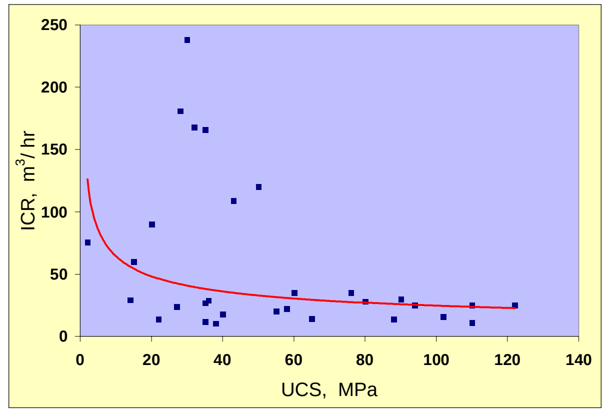

Figure-4: Plot of ICR Vs. UCS for Sedimentary Rocks and Transverse Roadheaders

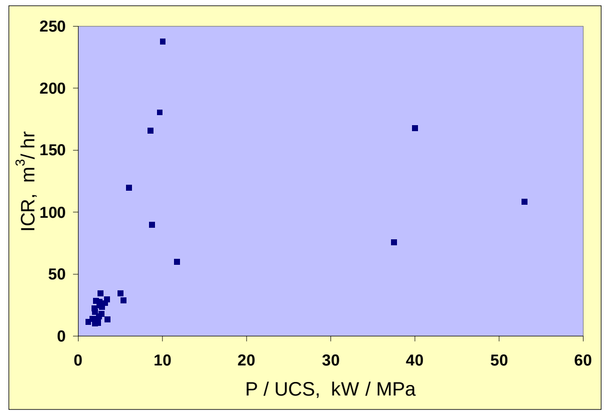

Figure-5: Plot of ICR Vs. P / UCS for Sedimentary Rocks and Transverse Roadheaders

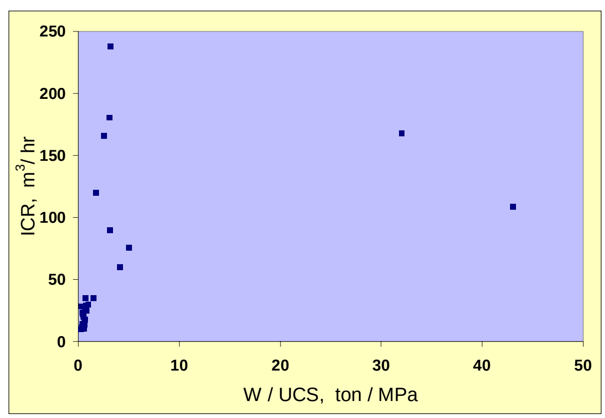

Figure-6: Plot of ICR Vs. W / UCS for Sedimentary Rocks and Transverse Roadheaders

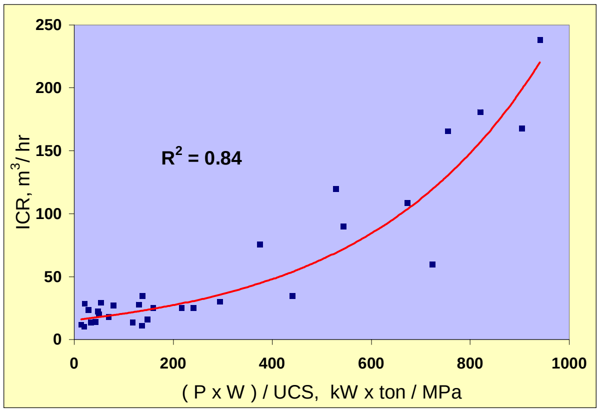

Figure-7: Plot of ICR Vs. (P x W / UCS) for Sedimentary Rocks and Transverse Roadheaders

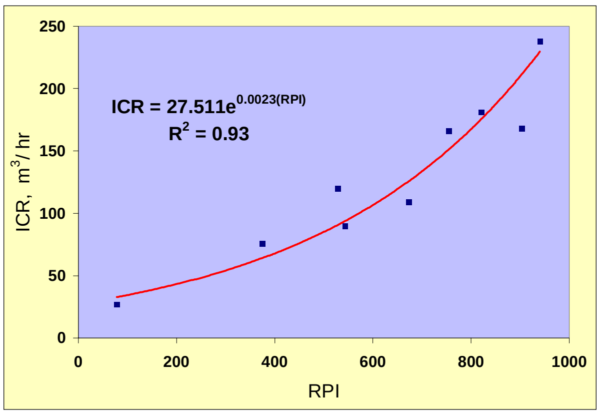

Figure-8: Plot of ICR Vs. RPI for Evaporitic Rocks and Transverse Roadheaders

The same methodology is also applied for bit consumption rate (BCR) predictions. The variation of BCR with UCS is presented in Figure-9. After categorization of data for transverse roadheaders in sedimentary rocks and normalization by UCS, machine weight and cutterhead power, the relationship shows significant improvement, as shown in Figure-10. Since the larger cutterhead diameters are generally used for softer and low-abrasive rocks, the cutterhead diameter can also be used as a normalization parameter. If normalized with cutterhead diameter, a better relationship can be found as shown in Figure-11. In this case, the predictive equation is as follows:

$$BCR = 897.06\,(RCI)^2 + 6.1769\,(RCI)$$

$$RCI = UCS / (P.W.CHD)$$

Where,

BCR = Bit Consumption Rate, bits / m^3
RCI = Roadheader Cutter Consumption Index
UCS = Uniaxial Compressive Strength, MPa
W = Roadheader Weight, metric ton
P = Cutterhead Power, kW
CHD = Cutterhead Diameter, m

The accuracy of this predictive equation can further be increased if some other parameters, such as quartz content of the rocks and grain size are used to classify and normalize the data.

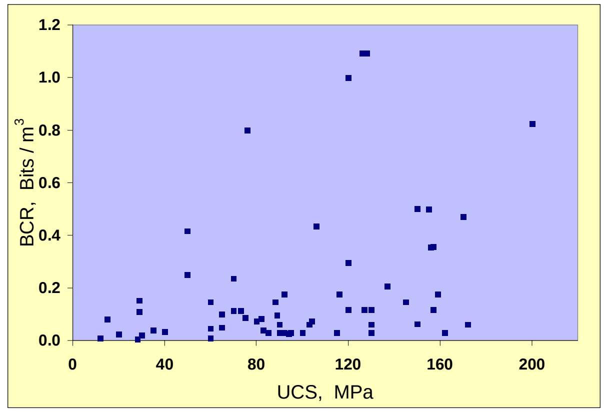

Figure-9: Plot of BCR Vs. UCS for All Geological Conditions and All Types of Roadheaders

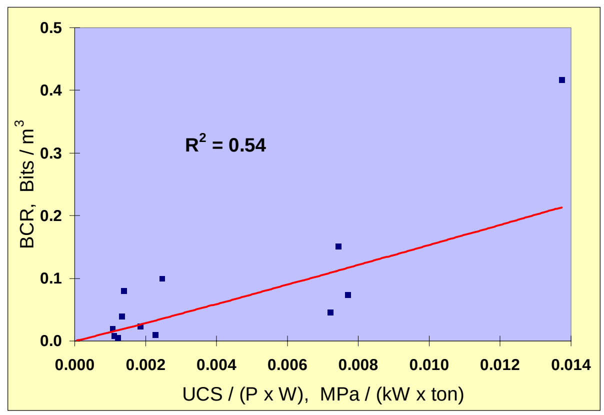

Figure-10: Plot of BCR Vs. UCS / (P x W) for Sedimentary Rocks and Transverse Roadheaders

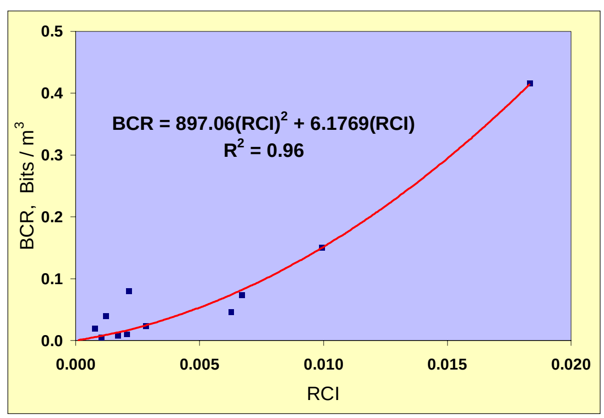

Figure-11: Plot of BCR Vs. RCI for Sedimentary Rocks and Transverse Roadheaders

The results so far have shown that this methodology of applying classification and normalization to the database consistently leads to more accurate predictor equations. At present, work is underway to incorporate additional parameters(i.e. quartz content) into the developed equation to further improve its accuracy and the range of applicability.

CONCLUSIONS

The evaluation and analysis of the data compiled in the roadheader field performance database has successfully yielded a set of equations which can be used to predict the instantaneous cutting rate (ICR) and the bit consumption rate(BCR) for roadheaders. A good relationship was found to exist between these two parameters and the machine power (P), weight (W) and the rock compressive strength (UCS). Equations were developed for these parameters as a function of P, W and UCS. These equations were found mainly applicable to soft rocks of evaporatic origin. The current analysis is being extended to include harder rocks with or without joints to make the equations more universal. In jointed rock, the RQD value will be utilized as a measure of rock mass characteristics from a roadheader cuttability viewpoint. It is believed that these efforts will lead to the formulation of an accurate roadheader performance prediction model which can be used in different rock types where the roadheaders are economically applicable.

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