PRELIMINARY ASSESSMENT OF ROADHEADERS EFFICIENCY BASED ON EMPIRICAL METHODS AND INDEX OF EQUIVALENT ROCK STRENGTH

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ABSTRACT

Purpose. The choice of a proper roadheader is a critically important step in planning of a project or some of its stages. Nowadays various manufacturers produce numerous models of these vehicles, hence it is unreasonable to conduct a thorough analysis of each model’s parameters in terms of their adequacy for the successful implementation of the project. Therefore, it is necessary to develop quite simple and easy-to-use assessment of roadheaders efficiency at the project preliminary stages.

Methods. The widely used model of the Colorado School of Mines based on numerous laboratory tests has been applied as the basic model for determining theoretical efficiency of rock mass destruction. Since domestic scientists are accustomed to using rock strength parameters, which differ from values $\sigma_c$ and $\sigma_t$ accepted everywhere (including Russia), we represented dependencies that allow to convert values of some indicators to the values of other indicators.

Findings. Calculating the efficiency of roadheaders’ use for each geological section with homogeneous rock can take unreasonably long time. Thus, it is necessary to have a simple integrated strength index for the whole excavation or even enterprise, which can be interpreted through the generally accepted values such as the uniaxial compressive strength $\sigma_c$ and tensile strength $\sigma_t$. Jointing of rocks is also an important parameter in a feasibility study of roadheaders’ efficiency.

Originality. The equivalent rock strength index was applied as a simple integrated strength index for the whole excavation. This parameter is established on the basis of integrated assessment index of mining operations complexity, which comprises the sum of the uniaxial compressive strength $\sigma_c$ and rock jointing for the whole excavation or even mining enterprise.

Practical implications. The results of this paper can serve as a preliminary scientifically grounded method of selecting equipment for a particular project in mining industry or underground construction by the efficiency criterion. Its main advantage is simplicity and clarity. However, it should be noted that this method should not be applied at the stage of the project final feasibility study, especially without considering other production factors (compatibility with other equipment, availability of the personnel with adequate qualification for operation and maintenance of the chosen machine etc.).

Keywords: roadheader, efficiency, empirical method, preliminary assessment, integrated complexity assessment, equivalent strength

1. INTRODUCTION

High advance rate of excavation works allows early access to mineral deposits in mining or fast construction of such socially significant infrastructure objects in civil engineering as subways, tunnels, engineering communications, and utilities lines. Thus, advance rate is an important parameter for feasibility study in the practice of mining and civil construction companies (Seker & Ocak, 2017; Zhabin, Polyakov, & Averin, 2018b). One of the most wide-spread technical means for excavation is roadheaders. Their main advantages are mobility, flexibility, and selective mining ability, while the disadvantage is relatively limited destructive force in respect to the rock of strength up to 100 – 120 MPa of uniaxial
compressive strength $\sigma_c$ (Ozfirat, Malli, Ozfirat, & Kahraman, 2017).

The choice of a proper roadheader is a critically important step in planning a project or some of its stages. The variety of models of these machines produced by various manufacturers at present is large, which makes it unreasonable to carefully analyze each model from the point of view of its adequacy for successful implementation of the project parameters. Therefore, there is a need in a sufficiently simple and easy-to-use assessment of roadheaders’ efficiency at preliminary stages of the project implementation in mining and civil construction.

2. ANALYSIS AND CHOICE OF A BASIC EMPIRICAL METHOD

The task described above is usually solved by decision-makers on the basis of their experience of designing mining enterprises, which are highly individual and subjective. Therefore, it may lead to a non-optimal decision taken. At the same time, over the past decades, a great deal of scientific and practical experience has been accumulated that allows to build statistically valid mathematical models to determine the productivity of mining operations depending on the key parameters (Table 1).

Table 1 presents the following parameters: $P_{\text{inst}}$ – the roadheader’s installed cutterhead power; $k$ – the energy transfer ratio; $\sigma_c$ – the Brazilian tensile strength; $\sigma_t$ – the uniaxial compressive strength; RQD – the rock quality designation.

As seen from the Table 1, universal methods for determination of roadheaders performance include such parameters as installed cutterhead power and the energy transfer ratio, which depends on the cutterhead type.

As the basic model for determining the net cutting rate of the destruction of a rock massif, one can use the formula proposed in (Rostami, Ozdemir, & Neil, 1994) – the model of the Colorado School of Mines, which is based on numerous laboratory tests and has been widely used in practice:

$$ICR = k \cdot \frac{P_{\text{inst}}}{SE_{\text{opt}}},$$

where:

- $ICR$ – the instantaneous (net) cutting rate, $\text{m}^3/\text{h}$;
- $P_{\text{inst}}$ – the installed roadheader power, $\text{kW}$;
- $SE_{\text{opt}}$ – the optimum specific energy obtained from full-scale linear cutting tests, $\text{kW-h/m}^2$;
- $k$ – energy transfer coefficient.

Table 1. Summary of empirical methods to determine roadheader performance

<table>
<thead>
<tr>
<th>Reference</th>
<th>Mining &amp; geological parameters</th>
<th>Roadheader’s parameters</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gehring, 1989</td>
<td>$\sigma_c$</td>
<td>—</td>
<td>Developed for heavy-weight axial and transverse roadheaders operating in coal bearing strata. It needs correction for lighter roadheaders and other rock masses. It also needs size correction for UCS values.</td>
</tr>
<tr>
<td>Natau, Mutschler, &amp; Lempp, 1991</td>
<td>$\sigma_c, \sigma_t$</td>
<td>$P_{\text{inst}}$</td>
<td>Developed for transverse roadheaders in different power classes and different types of rocks. It needs correction for axial roadheaders.</td>
</tr>
<tr>
<td>Rostami, Ozdemir, &amp; Neil, 1994</td>
<td>$SE_{\text{opt}}$</td>
<td>$P_{\text{inst}}, k$</td>
<td>Developed for axial and transverse roadheaders in different power and weight classes, and different types of rocks. The type of roadheader is not specified. $k$ value of 0.45 works for axial type and the value of 0.55 works for transverse type.</td>
</tr>
<tr>
<td>Copur, Ozdemir, &amp; Rostami, 1998</td>
<td>$\sigma_c$</td>
<td>$P_{\text{inst}}, \text{weight}$</td>
<td>Developed for transverse roadheaders in different power and weight classes for excavation of especially evaporitic (non-abrasive) rocks with up to 60 MPa compressive resistance.</td>
</tr>
<tr>
<td>Çopur, Tunçdemir, Bilgin, &amp; Dinçer, 2001</td>
<td>$\sigma_c, \sigma_t$</td>
<td>$P_{\text{inst}}, k$</td>
<td>Developed for different types of massive rocks. It works for transverse types of roadheaders.</td>
</tr>
<tr>
<td>Balci, Demircin, Copur, &amp; Tunçdemir, 2004</td>
<td>$\sigma_c, \sigma_t$</td>
<td>$P_{\text{inst}}, k$</td>
<td>Developed for axial and transverse roadheaders in different weight, power classes, and different types of rocks. Dynamic and static elasticity modulus, and Schmidt hammer can also be used in the model.</td>
</tr>
<tr>
<td>Bilgin et al., 2006</td>
<td>$\sigma_c$ or $\sigma_t$</td>
<td>$P_{\text{inst}}, k$</td>
<td>Developed for axial and transverse roadheaders in different weight and power classes, and different types of rocks. The type of roadheader is not specified. Dynamic and static elasticity modulus, as well as Schmidt hammer values can also be used in the model.</td>
</tr>
<tr>
<td>Ocak &amp; Bilgin, 2010</td>
<td>$\sigma_c$</td>
<td>—</td>
<td>Developed for only one type of transverse roadheader and different types of rocks. It needs correction for other types and classes of roadheaders.</td>
</tr>
<tr>
<td>Ebrahimabadi, Goshtasbi, Shahriar, &amp; Seifabad, 2011</td>
<td>$\sigma_c, \sigma_t, \text{RQD}$</td>
<td>—</td>
<td>Developed for only one type of light-weight axial roadheader and coal bearing strata. It needs correction for other types, weight, and power classes of roadheaders, and other rock masses.</td>
</tr>
</tbody>
</table>
3. DEVELOPMENT OF THE METHOD FOR PRELIMINARY ESTIMATION OF ROADHEADER PERFORMANCE IN A PROJECT

Uniaxial compressive strength and Brazilian tensile strength in Eq. (2) are broadly applied worldwide including Russia, which is also evidenced by the state standards for determining these values (GOST 21153.3-85 and GOST 21153.2-84) acting in this country. However, in practice, domestic specialists also often use such strength indicators as the contact strength $P_k$ and the spall fracture toughness $P_{sp}$. For the contact strength and spall fracture toughness, the following correlation dependencies with the uniaxial compressive strength have been established (Nistratova, 1998), which can be used for calculations in the presented model:

$$P_k = 13 \cdot \sigma_c^{0.94}; \quad (3)$$
$$P_{sp} = 4.22 \cdot \sigma_c^{1.25}. \quad (4)$$

Correlation indexes for Eqs. (3) and (4) are 0.82 and 0.86, respectively.

All these indicators reflect the strength properties of only one rock formation, and therefore are applicable in a limited section of working or mining enterprise. Calculating the efficiency of roadheaders use for each such section with subsequent separation or, conversely, integration of the relevant information can take unreasonably long time. Hence, it is necessary to have a simple integrated strength index for the whole excavation or even enterprise, which can be interpreted through the generally accepted value such as the uniaxial compressive strength $\sigma_c$. Equivalent rock strength can be applied as such indicator (Zhabin, Averin, & Polyakov, 2018) which is established by integrated assessment of the complexity of mining operations at the site (Zhabin, Averin, & Polyakov, 2017).

To obtain this assessment, all excavations of the project are divided into sections that are relatively homogeneous in terms of mining-geological conditions. Then the difficulty of mining each section $c_i$ is evaluated. For this purpose, sections are assigned a category after dividing the compressive strength by 30 and rounding the resulting value to the nearest bigger integer (if $\sigma_c > 270$ MPa, then the category is 10). Then, the category is amended according to the criterion of rock fracturing at the excavation site:

<table>
<thead>
<tr>
<th>Type of Rocks</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competent</td>
<td>+1</td>
</tr>
<tr>
<td>Slightly fractured</td>
<td>+1</td>
</tr>
<tr>
<td>Fractured</td>
<td>0</td>
</tr>
<tr>
<td>Highly fractured</td>
<td>−1</td>
</tr>
<tr>
<td>Extremely fractured</td>
<td>−1</td>
</tr>
</tbody>
</table>

The integrated assessment is determined by the following equation:

$$C_{int} = \frac{\sum c_i}{L}, \quad (5)$$

where:

- $C_{int}$ – the integrated assessment of the whole excavation complexity;
- $c_i$ – the assessment of complexity for $i$-excavation site;
- $L$ – the length of the whole excavation.

The value obtained from Eq. (5) should be multiplied by 30 (since values of uniaxial compressive strength $\sigma_c$ of rocks for each excavation site were previously divided by 30). This is the index of equivalent rock strength:

$$\sigma_{c_{eq}} = 30 \cdot C_{int}. \quad (6)$$

For evaluation of Brazilian tensile strength, it is reasonable to use recommendations given in (Kahraman, Fener, & Kozman, 2012). It states that there is linear correlation between uniaxial compressive strength and Brazilian tensile strength for different rocks. Specifically, the value of Brazilian tensile strength is 10.61 times less than uniaxial compressive strength. Satisfactory results from the use of this formula were confirmed in (Nazir, Momeni, Armaghani, & Amin, 2013).

After performing the calculation using Eq. (6), and, if necessary Eqs. (3) or (4), and then successively Eqs. (2) and (1), we get an approximate value of the theoretical performance of the roadheader during the project. Knowing the value of the instantaneous (net) cutting rate, we can determine the volume of the destroyed rock in cubic meters per day of work:

$$V_{exc} = ICR \cdot MUT \cdot S_{day} \cdot H_{shift}, \quad (7)$$

where:

- $MUT$ – the machine utilization time, %/100;
- $S_{day}$ – the number of working shifts per day;
- $H_{shift}$ – the duration of a working shift, hours.

Machine utilization time $MUT$ shows a part from the total time spent on doing the work, which is spent only on mining operations. This coefficient depends on many factors and is usually 0.25 – 0.50 (Kahraman & Kahraman, 2016).

Then daily mining rate is:

$$AR = \frac{V_{exc}}{A_{face}}, \quad (8)$$

where:

- $A_{face}$ – the face cross-section area, m².
4. CONCLUSIONS

The discussed method, which takes into account the generalized international experience in the field of mining operations with the use of roadheaders, can serve as a preliminary scientifically grounded approach to selecting equipment for a particular project in mining industry or underground construction by the performance criterion. Its main advantage is simplicity and clarity. For domestic specialists who are accustomed to the use of rock strength parameters in their activities, which differ from everywhere (including Russia), the accepted values of $\sigma_c$ and $\rho_t$ are the dependencies that allow to convert the values of some indicators to the values of other indicators. However, it should be noted that the above methodology should not be applied at the stage of the project final feasibility study, especially without considering other production factors (compatibility with other equipment, availability of the personnel with adequate qualification for operation and maintenance of the chosen machine etc.).

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REFERENCES


ПРЕДВАРИТЕЛЬНАЯ ОЦЕНКА ПРОИЗВОДИТЕЛЬНОСТИ ПРОХОДЧЕСКИХ КОМБАЙНОВ НА ОСНОВЕ ЭМПИРИЧЕСКИХ МЕТОДОВ И ЭКВИВАЛЕНТНОЙ ПРОЧНОСТИ ГОРНЫХ ПОРОД

Е. Аверин, А. Жабин, А. Поляков, Ю. Линник, В. Линник

Цель. Выбор конкретного проходческого комбайна является критически важным шагом в планировании работ по проекту или какому-либо из его этапов. При этом номенклатура машин, выпускаемых различными производителями, выпуклая и разнообразна. Кроме того, необходимо учитывать, что производители в настоящее время, необычайно велика, что делает ввиду многообразия используемых в своей деятельности прочностных показателей горных пород.

Методика. В качестве основной модели для определения теоретической производительности разрушения горного массива была использована методика Колорадского горного университета, которая основана на многочисленных лабораторных испытаниях и прошла широкую апробацию на практике. Для отечественных специалистов, привыкших к использованию в своей деятельности прочностных показателей, важным параметром являлось предварительное обоснование проекта предварительной оценке машин уже на предпроектной стадии.

Результаты. Вычисленные значения эффективности использования проходческих комбайнов для каждого геологического участка с однородными породами может занять неоправданно много времени. В связи с чем возникает необходимость в простоте, интегральном для всей выработки, показателю, который может быть интерпретирован через общепризнанное значение прочности на растяжение, предел прочности на растяжение).

Научная новизна. В качестве простейшего комплексного показателя прочности пород методика Колорадского горного университета, которая основана на многочисленных лабораторных испытаниях и прошла широкую апробацию на практике. Для отечественных специалистов, привыкших к использованию в своей деятельности прочностных показателей, важным параметром являлось предварительное обоснование проекта предварительной оценке машин уже на предпроектной стадии.

Практическая значимость. Полученные результаты могут служить в качестве предварительного научно обоснованного способа выбора техники для конкретного проекта в горнодобывающей отрасли или подземном строительстве по критерию производительности. Ее основным достоинством является простота и понятность. Однако стоит отметить, что рассмотренная методика не следует применять на этапе окончательного технико-экономического обоснования проекта, тем более в отрыве от других производственных факторов.

Ключевые слова: проходческий комбайн, производительность, эмпирический метод, предварительная оценка, интегральная оценка прочности, эквивалентная прочность.
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