Rock Mechanical Aspects of Roadheader Excavation

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Rock excavation with roadheaders does in fact provide unique chances especially for underground excavation in urban areas with harsh limitations regarding handling of explosives or noise and vibration emissions.

A roadheader will allow excavation with minimum vibration emission and precise profiling of the contour.

However, the method is very sensitive to the geomechanical properties of the rock mass and once employed at the project site, the power (transferrable energy) of the machine cannot be increased.

Low performance and increased tool wear as results of unforeseen geological circumstances have in the past often provided the background for bad reputation of this method in tunnelling application.
Comparison of empirical data regarding vibration velocities at various distances from the face for conventional drill & blast excavation (blue line) and roadheader excavation (green line).

Comparison of empirical data regarding geological overbreak in similar rock types for conventional drill & blast excavation (right group of columns) and roadheader excavation (left group of columns).
In order to minimize operational risks for roadheader application, it is mandatory to perform high quality site investigation which takes into account not only the stability of the rock mass but also puts a focus on the specific rock excavatability.

It has proven to contribute to a better understanding of the natural variation of rock and rock mass properties to provide numerical values (e.g. average, standard deviation) and/or graphical information using for instance density distribution diagrams.

In order to deal with these natural variations of properties it is also mandatory for a bidder to perform “average”, “best case” and “worst case” estimates in order to be able to judge on the risks related to the given variation of geotechnical parameters.
Introducing an integrated approach to RH performance assessment

Based on well-established (mostly empirical) models an **integrated approach** to roadheader performance estimation is presented.

The prediction model is quite similar to the methodology of the so-called „GEHRING model“ for TBM performance prediction.

It features the estimation of a „**basic“ Net Cutting rate** [NCR$_1$; m$^3$/h] using intact rock strength (UCS; [MPa]) and machine performance [kW] as input parameters.

Basic NCR$_1$ can then be adjusted to rock and project specific circumstances by applying a number of **adjustment factors** (factors $k_1$ - $k_3$ predefined so far) in order to achieve a best estimate for Net Cutting Rate ("NCR$_{eff}$")

\[
NCR_{eff} = k_1 \cdot k_2 \cdot k_3 \cdot \ldots \cdot k_i \cdot NCR_1
\]

- $k_1$ adjustment factor for rock toughness
- $k_2$ adjustment factor for discontinuity influence
- $k_3$ adjustment factor for stress condition (usually $k_3 = 1.0$)
- $k_i$ - other project specific adjustments possible
- Basic NCR for intact rock
Estimation of Basic NCR
from intact rock strength and machine power

General Equation for basic NCR Assessment:

\[ NCR_{basic} = \frac{7}{UCS} \cdot P \]

with:
UCS – Unconfined Compressive Strength [UCS]
P – Machine Cutterhead Power [kW]

Remark: Besides the use of this general equation we strongly recommend to refer to the empirical, machinery-specific so-called cutting charts provided by the machine manufacturer.
The specific “rock toughness” will determine the ability of an intact rock to withstand fracture propagation. According to empirical data, the specific energy demand required for rock fragmentation will decrease or increase by approximately \( \pm 20 - 25\% \) with an increase (“tough” behaviour) or decrease (“brittle” behaviour) in rock toughness.

A number of rock mechanical concepts may be used for adjusting NCR to the specific toughness of the rock.

Presented here is an assessment based on the ratio of Unconfined Compressive Strength (UCS) and Brazilian Tensile Strength (BTS), also referred to as “Toughness Coefficient” \( (TC = \frac{UCS}{BTS}) \).

<table>
<thead>
<tr>
<th>Toughness Coefficient TC</th>
<th>Classification</th>
<th>Correction factor ( k_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 6 )</td>
<td>very tough</td>
<td>-25 % / 0.75</td>
</tr>
<tr>
<td>6 - 8</td>
<td>tough</td>
<td>-15 % / 0.85</td>
</tr>
<tr>
<td>8 - 15</td>
<td>normal</td>
<td>( \pm 0 % / 1.0 )</td>
</tr>
<tr>
<td>15 - 20</td>
<td>brittle</td>
<td>+10 % / 1.1</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>very brittle</td>
<td>+20 % / 1.2</td>
</tr>
</tbody>
</table>
Spacing, condition and orientation of discontinuities will determine, if the cutterhead of a roadheader is able to rip larger blocks out of the rock surface, or has to apply a much larger amount of energy in order to chip the intact rock into small debris.

Simple empirical models, like the one presented to the right, lucidly depict the general increase in Cutting Rate for a rock mass with a fracture spacing of at least 30 cm and below.

Diagram for the influence of Fracture Spacing on the relative Net Cutting Rate of a roadheader.
The RMCR system is a more complex rating system for the assessment of the effectiveness of pre-existing discontinuities, similar to Bieniawski’s Rock Mass Rating (RMR) system. It takes into account all relevant features of the discontinuity system in a rock mass.

It was introduced by Restner & Gehring, 2002.

\[ \text{RMCR} = R_{\text{UCS}} + R_{\text{BS}} + R_{\text{JC}} + R_{\text{Ori}} \]

- **R\text{UCS}** - Rating of UCS
  - UCS [MPa] | Rating
  - 1 - 5 | 15
  - 5 - 25 | 12
  - 25 - 50 | 7
  - 50 - 100 | 4
  - 100 - 200 | 2
  - > 200 | 1

- **R\text{BS}** - Rating of Block Size
  - Block size [m³] | Rating
  - > 0.6 | 20
  - 0.3 – 0.6 | 16
  - 0.1 – 0.3 | 10
  - 0.06 – 0.1 | 8
  - 0.03 – 0.06 | 5
  - 0.01 – 0.3 | 3
  - < 0.01 | 1
**NCR Correction for Discontinuities**

Factor $k_2$ – RMCR system

### $R_{JC}$ - Rating of joint conditions

<table>
<thead>
<tr>
<th>Surface</th>
<th>Aperture</th>
<th>Wall/Fill</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>rough</td>
<td>closed</td>
<td>hard, dry</td>
<td>30</td>
</tr>
<tr>
<td>slightly rough</td>
<td>&lt; 1 mm</td>
<td>hard, dry</td>
<td>20</td>
</tr>
<tr>
<td>slightly rough</td>
<td>&lt; 1 mm</td>
<td>soft, dry</td>
<td>10</td>
</tr>
<tr>
<td>smooth</td>
<td>1 – 5 mm</td>
<td>soft, damp</td>
<td>5</td>
</tr>
<tr>
<td>very smooth</td>
<td>&gt; 5 mm</td>
<td>soft, wet</td>
<td>0</td>
</tr>
</tbody>
</table>

### $R_{Ori}$ - Orientation of joint sets

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>very favourable</td>
<td>-12</td>
</tr>
<tr>
<td>favourable</td>
<td>-10</td>
</tr>
<tr>
<td>fair (and block size &lt; 0.03 m³)</td>
<td>-5</td>
</tr>
<tr>
<td>unfavourable</td>
<td>-3</td>
</tr>
<tr>
<td>very unfavourable</td>
<td>0</td>
</tr>
</tbody>
</table>

$k_2 = 45.6 \cdot \text{RMCR}^{-0.9821}$  
*(for low cutting speed)*

$k_2 = 9.43 \cdot \text{RMCR}^{-0.5614}$  
*(for high cutting speed)*
Experience has shown, that cutting speed has a significant influence on the activability of pre-existing discontinuities.

For application in jointed rock mass, the use of low cutting speeds (≈ 1.4 m/s) has found to significantly contribute to the activation of discontinuities and to the achievable performance.
Additional factors

**k₃ to kᵢ factors**

- Even if the presented rock and rock mass parameters and dependencies have shown good results for an **appropriate assessment** of Net Cutting Rates, case studies have shown, that there still do exist a number of **additional factors**, which (so far) do not allow easy deterministic or quantitative assessment.

- The **primary stress conditions** in the rock mass and the secondary conditions at the tunnel face have already been identified as a relevant factor and the k_{3} factor is pre-defined for this influence. However, if no specific negative experiences are known, the authors actually recommend to apply a k_{3} = 1.0.

- It is also recommended – if possible – to implement **additional correction factors (kᵢ)** into the model in order to adapt the performance assessment to site and project specific circumstances.

*MT720 roadheader in operation at Markovec tunnel (SLO)*
Thank you for your attention!