

PREDICTION OF CUTTER WEAR USING RME

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INTRODUCTION

Rock Mass Excavability Index RME, was firstly presented at ITA WTC Congress in Seoul (2006), while afterwards some modifications were presented at RETEC Toronto (2007). Finally, in Agra WTC Congress (2008) some specific correlations developed to predict the Rate of Advance for open TBMs, double-shields and single-shields, using the RME index were presented.

During 2007 and 2008 Geocontrol continued investigating in order to improve RME applications, in 2008 partially with the financial aid of IMADE and of the Spanish Ministry of Industry's PROFIT programme. As a result of these works, in this article we present three important innovations in the RME:

- Objective criteria to attribute the RME 10 points concerning the homogeneity of the excavation front
- Estimation of the advances of tunnel-boring machines in faults zones
- Estimation of cutters consumption

EVAUATION OF THE FRONT HOMOGENEITY

Homogeneity of the excavation front contributes to the RME with a valuation between 0 and 10 points; being zero in the case the front is mixed, alternating of hard and soft rocks, and reaching 10 points in completely homogeneous situations.

The influence of the front homogeneity on the final rating is considered to be too important for the scarce definition of the current criteria for its validation.

That is the reason it was considered convenient to establish a typology of inhomogeneities of the front assigning to each one of them a value between 0 and 10 points.

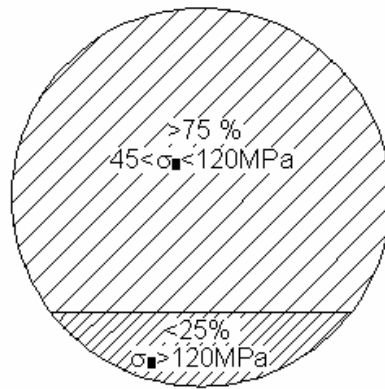
With the objective of having a considerable contrast of values of the compressive strength of the rocks to be excavated, and according to the resistance of their intact rock, they have been divided into the following groups:

- $\sigma_{ci} > 120$ MPa
- $120 \text{ MPa} > \sigma_{ci} > 45$ MPa
- $45 \text{ MPa} > \sigma_{ci}$

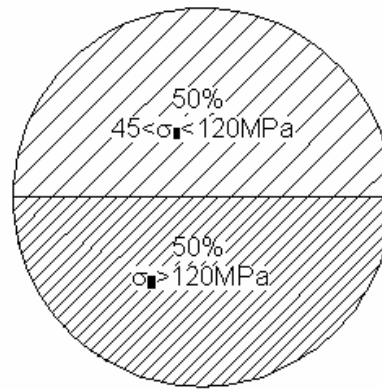
With these limits six representative situations have been selected, which are shown in Figure 1; in which the corresponding values between 0 and 10 points are included.

The maximum rating corresponds to a front in which over 75% is constituted by rock with $\sigma_{ci} > 120$ MPa and the remaining proportion is constituted by a rock with σ_{ci} between 45 and 120 MPa.

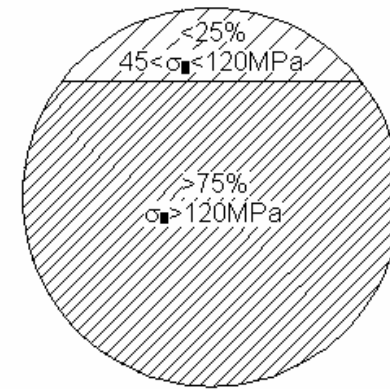
The minimum rating corresponds to a tunnel in which the section to be excavated has more than 75% of rock with $\sigma_{ci} < 45$ MPa and the remaining proportion corresponds to a rock with $\sigma_{ci} > 45$ MPa.



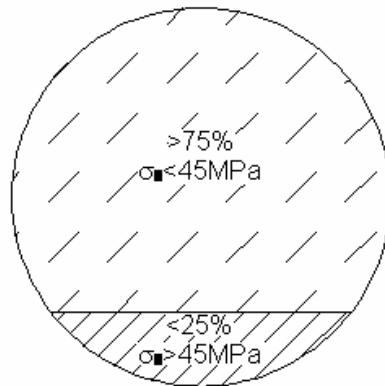
Value: 6 points



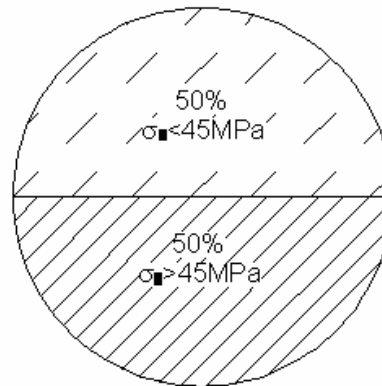
Value: 8 points



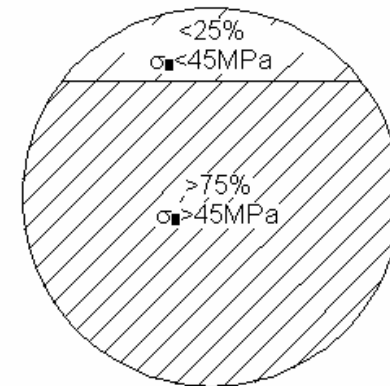
Value: 10 points



Value: 0 points



Value: 2 points



Value: 4 points

Figure 1 – Evaluation criteria of the homogeneity of the excavation front

TBM'S ADVANCE PREVISION IN THOROUGH FAULT ZONES

After analyzing the vast available information about the sections of Guadarrama, San Pedro, Abdalajís, Gilgel Gibe II and Katzenberg tunnels in which fault zone were crossed, certain criteria to estimate the probable speeds of tunnel-boring machines in fault zones were established according to the following parameters:

- Overburden on the tunnel crown
- Water infiltration at the front
- Type of rock

In Table 1 predictable advances in these cases are shown.

OVERBURDEN (m)	< 50			50-200			> 200 (without extreme squeezing)		
WATER AT THE FRONT $\left(\frac{l}{\text{min.m}^2}\right)$	DRY	< 0.1	> 0.1	DRY	< 0.1	> 0.1	DRY	< 0.1	> 0.1
TYPE OF ROCK	Blocks	Clay	Any	Blocks	Clay	Any	Blocks	Clay	Any
AVERAGE ADVANCE WITH SHIELD TBM $\left(\frac{m}{\text{day}}\right)$	10-20	> 40	5-20 1-10	10-20	> 40	5-15 1-5	5-15	20-40	1-10 < 1
AVERAGE ADVANCE WITH TBM $\left(\frac{m}{\text{day}}\right)$	10-15	5-15	1-5	5-15	1-10	1-5	5-10	1-5	< 1

Table 1 – Estimation of possible advances in fault zones

PREDICTION OF CUTTER CONSUMPTION

Cutter consumption is extraordinarily important in tunnel-boring machine advances when these have to excavate hard and abrasive rocks.

RME index is oriented to evaluating rock excavability; but, although its structure is included in the evaluation of the Drilling Rate Index (DRI) of the rock, it is considered that it is necessary to complement the RME of the rock with a specific index related to the abrasivity.

After analyzing several tests currently used to evaluate the rock abrasivity we concluded that the most convenient, because of its excellent representativeness and facility of execution, was the Cerchar Abrasivity Index (CAI). (Nielsen et al, 2006).

The following paragraphs present the results of the abrasivity tests carried out and the correlation of the cutters consumption with RME and CAI, based on the data obtained during the construction of Guadarrama Tunnels (2x28 km) in Spain. (ADIF 2005)

Abrasivity and drillability test

Samples used for the abrasivity tests were obtained from the drillings carried out in Guadarrama Tunnels and the tests done in the laboratories of CEPASA ENSAYOS GEOTÉCNICOS in Fuenlabrada (Madrid).

The distribution of samples of the 91 CAI tests carried out is indicated in Table 2.

LITHOLOGY	TESTED SAMPLES	PROPORTION %
Adamellite	45	49.4
Leucocratic granite	5	5.5
Marble	13	14.3
Ortogneiss	10	11.0
Paragneiss	12	13.2
Granite porphyry	3	3.3
Calcium silicate	3	3.3
TOTAL CERCHAR TESTS CARRIED OUT	91	100.0

Table 2 – Distribution of the abrasivity tests carried out

Table 3 shows the usual levels of CERCHAR abrasivity index and some typical rocks for each level.

CLASSIFICATION	CERCHAR INDEX	TYPICAL ROCKS
Extremely abrasive	> 4.5	Gneiss and pegmatite
Highly abrasive	4.25 – 4.5	Amphibolite
Abrasive	4.0 – 4.25	Granite, gneiss, schist, pyroxenite
Moderately abrasive	3.5 – 4.0	Sandstone
Medium abrasivity	2.5 – 3.5	Californian granite y dolerite
Slightly abrasive	1.2 – 2.5	Portland sandstone
Very slightly abrasive	< 1.2	Limestone

Table 3 – Levels of variation of the CERCHAR abrasivity index

In addition, 37 tests were carried out to determine the Drilling Rate Index (DRI) with some samples of Guadarrama Tunnels in order to contrast the DRI values adopted during the works in some sections of this tunnel, which are integrated in the database and whose representativeness was questionable.

In Table 4 the distribution of the 37 DRI tests carried out is shown.

LITHOLOGY	TESTED SAMPLES	PROPORTION %
Adamellite	9	24.3
Quarz	1	2.7
Episienite	2	5.4
Leucocratic granite	3	8.1
Marble	4	10.8
Microdiorite	1	2.7
Ortogneiss	11	29.8
Granite porphyry	3	8.1
Sienite	3	8.1
TOTAL DRI TEST CARRIED OUT	37	100.0

Table 4 – Distribution of the DRI tests carried out

Correlation between RME and cutter consumption

The following paragraphs present the result of correlating RME to cutter consumption per excavated cubic metre. The first one deals with rocks which have simple compressive strength of intact rock higher than 45 MPa and the second one with those which have it lower.

Cutter consumption in rocks with $\sigma_{ci} > 45$ MPa

In the stretches of Guadarrama Tunnels in which the simple compressive strength of intact rock is higher than 45 MPa the following works have been carried out:

- The value of RME in each stretch has been checked, following the new drillability test (DRI) carried out.
- According to the carried out test, a value of the CERCHAR Abrasivity Index has been assigned.
- The number of cutters changed in each stretch has been determined.

Once these works were done, the obtained results have been presented considering three levels of variation for the CERCHAR Abrasivity Index (CAI).

- CAI > 3
- 1,5 < CAI < 3
- CAI < 1,5

In Figure 2 the obtained results are shown, based on which the following considerations are made:

1. For the RME values lower than 50 points there are no data concerning the use of tunnel-boring machines; as it is already known, (Bieniawski et al 2008), for $\sigma_{ci} > 45$ MPa rocks with RME < 50 cannot be excavated with mechanical means.
2. The specific cutter consumption, defined as $\frac{\text{changed cutters}}{\text{excavated m}^3}$, increases as the RME diminishes and the CERCHAR Abrasivity Index rises.
3. The correlations obtained for the three CAI levels are the following:
 - If CAI > 3

$$\frac{\text{Changed cutters}}{\text{excavated m}^3} = \frac{7 \cdot 10^6}{RME^{4,8}}$$

- If $1,5 < CAI < 3$

$$\frac{\text{Changed cutters}}{\text{excavated } m^3} = \frac{628}{RME^{2,77}}$$

- If $CAI < 1,5$

$$\frac{\text{Changed cutters}}{\text{excavated } m^3} = \frac{15}{RME^{1,96}}$$

- The obtained correlation coefficients are excellent; because in all the three mentioned levels of CAI variation they are greater than the value $R = 0.86$.

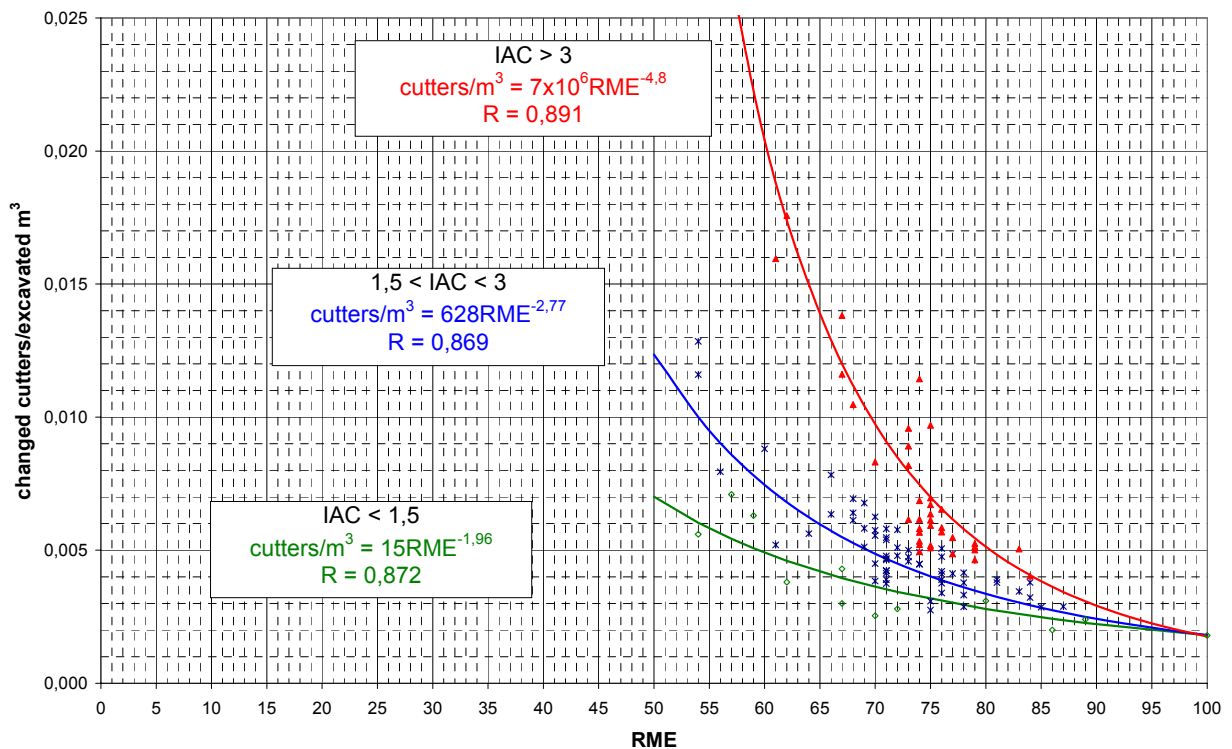


Figure 2 - Specific cutter consumption depending on RME and CAI for $\sigma_{ci} > 45$ MPa

Cutter consumption in rocks with $\sigma_{ci} < 45$ MPa

In order to find the correlation between the RME and the cutter consumption in the rocks with $\sigma_{ci} < 45$ MPa we used a process analogous to the one described in the previous paragraph.

Nevertheless, there is a considerable difference owing to the fact that in Guadarrama Tunnels not many rocks with $\sigma_{ci} < 45$ MPa have been excavated.

This circumstance implied the available information was not so abundant as in the case of rocks with $\sigma_{ci} > 45$ MPa and, consequently, it is considered that the representativeness of the encountered correlations in this case is lower than in the case when $\sigma_{ci} > 45$ MPa.

In Figure 3 the obtained results are shown correlating the RME with the specific cutter consumption for $\sigma_{ci} < 45$ MPa.

In this figure it can be noticed that the higher the CERCHAR Abrasivity Index the higher the cutter consumption, which is coherent with what has previously been explained.

As to the variation in the specific cutter consumption with the RME, in Figure 3 it can be noticed that there is a maximum consumption for the RME values in the environment of 50-60 points and that the consumption is minimum for both maximum and minimum RME values.

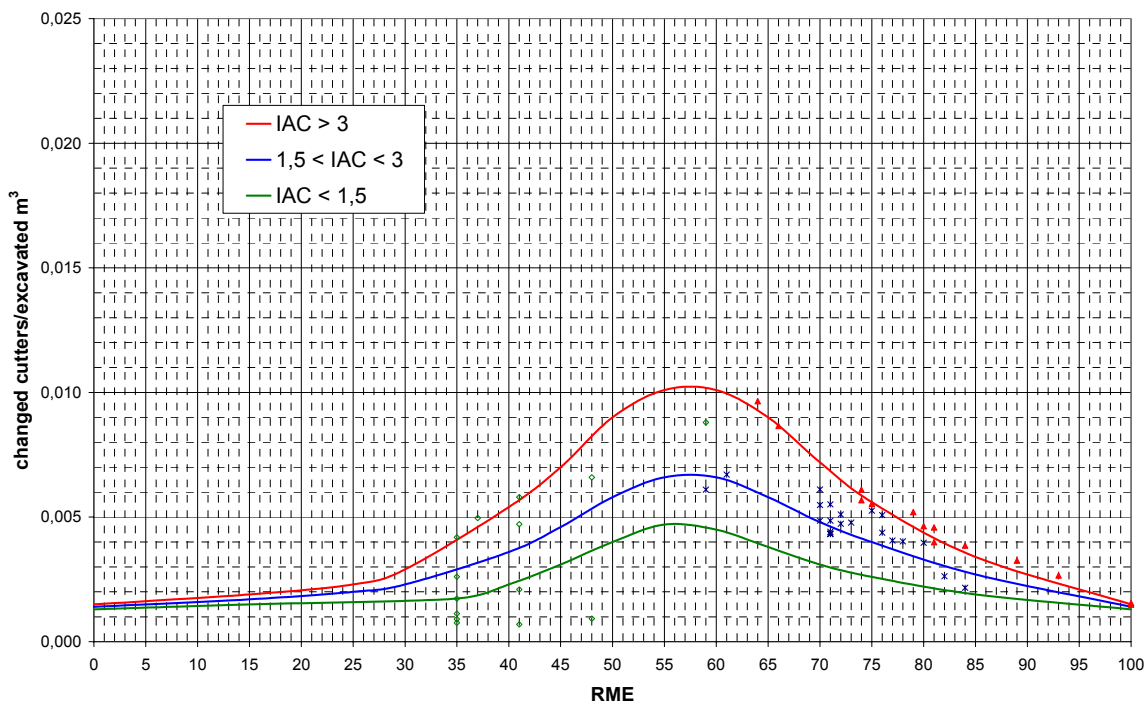


Figure 3 – Specific cutter consumption depending on the RME and CAI for $\sigma_{ci} < 45$ MPa.

CONCLUSIONS

The research works done by Gecontrol in 2007 and 2008 have allowed to improve the criteria to determine the RME calculating with more objectivity the homogeneity of the excavation front in a tunnel-boring machine.

These works have also permitted to evaluate the advances that can be achieved with more usual TBMs on crossing the fault zones.

Finally, the works carried out have allowed establishing a correlation between the RME and CERCHAR Abrasivity Index with the cutter consumption; which is one of the important parameters for studying the viability of the tunnel construction with a tunnel-boring machine.

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