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Incidence of the Change of Cutters on the Costs of MTBM Pipe Jacking Excavation Method

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Abstract **–** The performance of a micro tunnel excavated by Pipe Jacking method will be determined by the correct choice of the construction method, based on a series of parameters, together with the estimation of the change of the cutters, related to their useful life, due to the important repercussion it has in time and in the total cost of the project. Replacing worn or broken cutters is very expensive. When changing a disc in a micro-tunnel, the cost of downtime, as well as the cost of renewing or replacing the cutter itself, must be considered. Therefore, the evaluation of the cutters cost represents an important part of the total cost of construction in tunnelling projects with micro-tunnelling machines. This work intends to be an empirical approximation, and for different types of terrain, of the cost related to the consumption of cutters in micro-tunnelling works based on Pipe Jacking.

Keywords**:** Cutters, Wear, Costs, MTBM, Pipe Jacking

1. Introduction

The Pipe Jacking is a method of construction of micro tunnels and simultaneous placement of underground pipelines. The pipes are pushed into the ground by hydraulic cylinders from a thrust pit (Fig. 1) to the reception pit. Together with this push, the soil is excavated by means of a micro-tunnelling machine (MTBM) and the material is transported.

MTBMs apply the same principle as conventional tunnel boring machines (TBMs), the sufficient thrust of a cutting disc against the rock, to produce a break in the rock. with the exception that the size of these discs is much smaller.

Fig. 1: Thrust Pit (Photo by Geosa)

The micro-tunnelling machines used in the works that support this study are of the mix-shield type, and correspond to Herrenknecht's AVN series (Fig. 2). These are all-terrain machines with a closed front and a hydraulic sludge circuit.

Fig. 2: AVN 1200 – AVN 1800 (Photo by Geosa)

The concept of excavation with sludge support allows these machines to work in all types of soils ranging from clays and silts to gravel and rocks, through no cohesive soils. The cutting head adapts to the existing geology, making it possible to use it in almost all conditions.

Disc cutters are an essential part of micro-tunnelling machines, and especially for rock excavation.

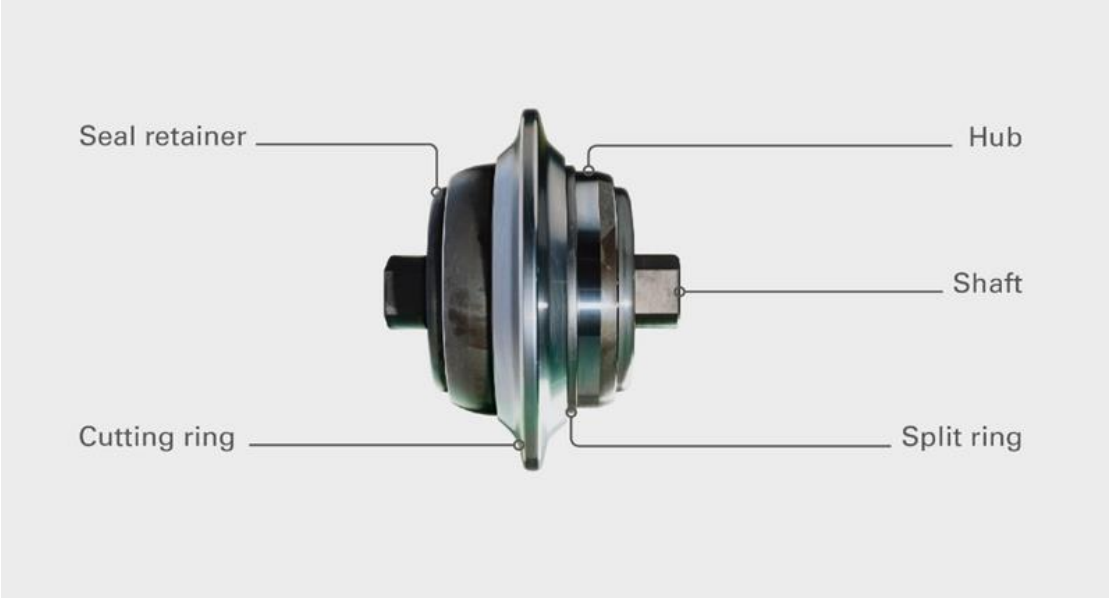

Fig. 3: Disc Cutter (Herrenknecht)

Changing cutters has always represented and will always represent a cost intensive and critical performance factor in rock excavation. Wear or breakage not only directly influences a project, for example through the price of the discs and the personnel involved in replacing them, but also affects the duty cycle and performance of the soil excavation process.

For these reasons, a number of studies have been carried out in the past in order to estimate the cutting tool wearing both tunnelling and mining machines (some examples, both classical and more recent, are [1] to [7]).

Manufacturers of disc cutters have tried to use various methods to improve the service life of these. On one hand, trying to maintain a lower cost of consumables in projects through the use of improved lubricants. On the other hand, to meet the requirements of hard rock excavation, the diameter of the cutter and its corresponding load capacity have been constantly extended over the years, etc.

The wear of the cutters is influenced by two different groups of factors, namely the geological conditions (intact rock parameters, rock mass parameters, and environmental factors) and the operating parameters of the micro-tunnelling machine (speed of rotation, torque and thrust of the drill head).

Due to the relatively rapid development of drilling technology, and in particular that which involves pipe jacking, a model for estimating the wear of the cutters for drilling should not be many years old before being revised based on the new information available.

That is why, with authentic and reliable data that help to minimize the deviation in the result, it is a question of predicting the profitability, both in the project study phase and in execution, in micro-tunnel with pipe driving for different types of terrain.

There are numerous studies in the field of pipe jacking, and on very varied subjects, in some cases really complex. Nevertheless, as far as authors know, little or nothing has been written on the cutters or, to be more exact, on the incidence of the change of cutters on the costs of the pipe jacking. This is what an article of this kind is trying to contribute to.

2. Criteria for changing cutters

The criteria for carrying out the change of cutters in micro-tunnelling machines affect the production personnel in charge of the execution of the pipe jacking, from the team leader to the production manager in charge of controlling the change of cutters.

In this work, only the criteria established for the change of the cutting discs will be taken into account, not including the changes of strips or rippers.

Those responsible persons must plan the change works, taking into account all requirements and provisions that must be met, and apply all measures of operational control, monitoring and measurement established.

The cutting tools are a fundamental part in the execution of closed shield pipe jacking by means of micro-tunnelling machines. From some information, as the model and manufacturer of the micro-tunnelling machine, pipe diameter and the conditions of the terrain to be drilled (type of material, presence of aggressive water, etc.) the characteristics of cutting tools will be defined, as well as a specific arrangement of them in the cutting wheel. As already mentioned, only tunnels executed with Herrenknecht's AVN series machines have been studied for this work.

It is very important in the efficiency of the maintenance and change operations, the accessibility to the cutting tools, both for the entrance opening and the interior space of the cutting wheel, as well as for the transport of these tools to it.

In order to define the criteria for changing cutting discs, it will be necessary to study the following aspects.

2.1. Identification of cutting tools

Depending on the type and model of MTBM machine, and the diameter of the pipe to be driven, a certain cutting wheel will be installed in the machine, which entails a specific distribution of the disc cutters.

Control parameters are established:

- Disc number
- Type of disc
- Position of the disc in an identifying plane
- Quantity according to identification plan

● Number of tracks on the disc
● Separation between disc blades
● Item number in the manufacturer's position list
● Item reference number in the manufacturer's reference list

Drawings and tables will be detailed for each case, depending on the diameter of the pipe to be jacked and the machine used.

2.2. Planning changes to cutting tools

The managers will develop a plan for the estimated consumption of cutting tools, among which the disc cutters stand out.

The criteria that will be used when planning the consumption of cutters will depend mainly on the type of terrain to be drilled and its conditions.

The consumption of the disc cutters will be analysed under premises for two possible scenarios: consumption for an acceptable scenario, and consumption for a good scenario.

In these plans will be defined the frequency to make the change, the type of cutter, and the units of the same to replace.

Evidently, these plans are estimates, and as such respond to replacement of discs by wear of them.

The replacement of disc cutters due to unforeseen causes will not be considered in this planning.

2.3. Establishment of tolerances for changing cutters

The criteria to establish to determine the change of discs can be classified according to:

● Change due to wear. The tolerances for determining the quantitative criteria for changing a disc cutter are defined mainly by the difference between the gauges fixed by both the strip and the corresponding disc.

Each of them defines an external diameter, and the difference between them must never be less than a certain value, since in that case the disc would not have any thickness for the cut in its blade, and the cutter would have suffered an excessive wear that could endanger the pipe jacking, since, if there is a continuous wear of the strip, the surface of the cutting wheel itself would be reached.

This situation is alarming in the case of strips and gauge disc cutters as their wear would cause a reduction in the external cutting diameter below that required for the passage of the external diameter of the tubes to be jacked.

Determining the minimum value to be maintained in the thickness of the cutter, in combination with the relationship described above, depends to a large extent on the type of terrain to be drilled and its properties (resistance to compression, hardness, abrasiveness, etc.).

As a general rule, it is possible to establish as a criterion of wear in the thickness of the cutter ring a value that is always less than 50% of the value resulting from the difference between the cutting diameters defined by the cutter and the corresponding ripper.

$$D_{cutter} - D_{ripper} = x \cdot 0.5 \quad (1)$$

Thus, in the case of a gauge disc cutter with a cutting diameter of 2.265 mm and its corresponding ripper with a diameter of 2.245 mm, the maximum allowable wear for that disc cutter would be: 2.265 - 2.245= 20 mm, of which 50% is 10 mm. That is to say, the disc will be replaced whenever it has lost 10 mm or more of its diameter.

In order to be able to carry out measurements on the disc cutters on site, calibres or measuring gauges will be available (Fig. 4) in order to be able to establish the verification effectively and quickly.

Fig. 4: Caliber or Gauger (Phot by Geosa)

● Change due to exceptional situations. Changes due to breaks or flattening (Fig. 5) of the cutters would constitute another type of adverse situation to what is a change due to wear and tear.

These situations are unpredictable and unexpected in the development of the execution of a pipe jacking. Although experience shows that when driving long and competent rock you have to foresee this type of situation, there is no cause-effect correlation that can be specified in a previous estimate.

Fig. 5: Flat / Breakage (Photo by Geosa)

Exceptional situations of this type are usually detected or intuited mainly by the appearance or combination of any of the following parameters:

- Considerable and instantaneous increase in thrust forces.
- Significant and rapid increase in cutter wheel pressure.
- Blocking of the cutter wheel rotation. No speed or very low speed.
- Appearance of steel fragments in the outlet of solids in the separator plant.

3. Assessment of the cost due to consumption of cutter discs

The present work has consisted in the study and treatment of an enormous amount of data from 98 different micro tunnelling works with pipe jacking through different types of rocks trying to give an overview of the problem. For this purpose 254 sections of a total of 44,194 metres of micro tunnel have been analysed.

The diameters of excavation have varied for the jacking of pipes of DN600, DN800, DN1000, DN1200, DN1500, DN1800, and DN2000, having been executed mainly for DN1200, followed by DN1800.

The study methodology consisted of measuring the length at which it was necessary to change the cutters which, knowing the price of the set of cutters, allowed us to obtain the cost per linear meter. As is to be expected, the data are variable, even for the same diameters in similar types of rock, so average values of the cost grouped by families of rocks has been determined (Table 1). The costs are for work carried out mainly in Europe (more concretely in Spain).

It is proven that, in general terms, for a given excavation diameter the average total cost spent on disc cutters will depend fundamentally on the type of terrain on which the excavation is being carried out (Fig. 6).

Table 1: Data Overview

	MTBMs						
	AVN600XC	AVN800XC		AVN1200TB		AVN1800TB	
ROCK TYPES	DN600	DN800	DN1000	DN1200	DN1500	DN1800	DN2000
	Average Cost in € of Changing Cutters per Linear Metre of Perforation						
Soft Rocks	36	41	48	67	75	110	130
Middle Rocks	55	60	67	87	97	130	160
Hard/Abrasive Rocks	134	149	169	250	266	443	469

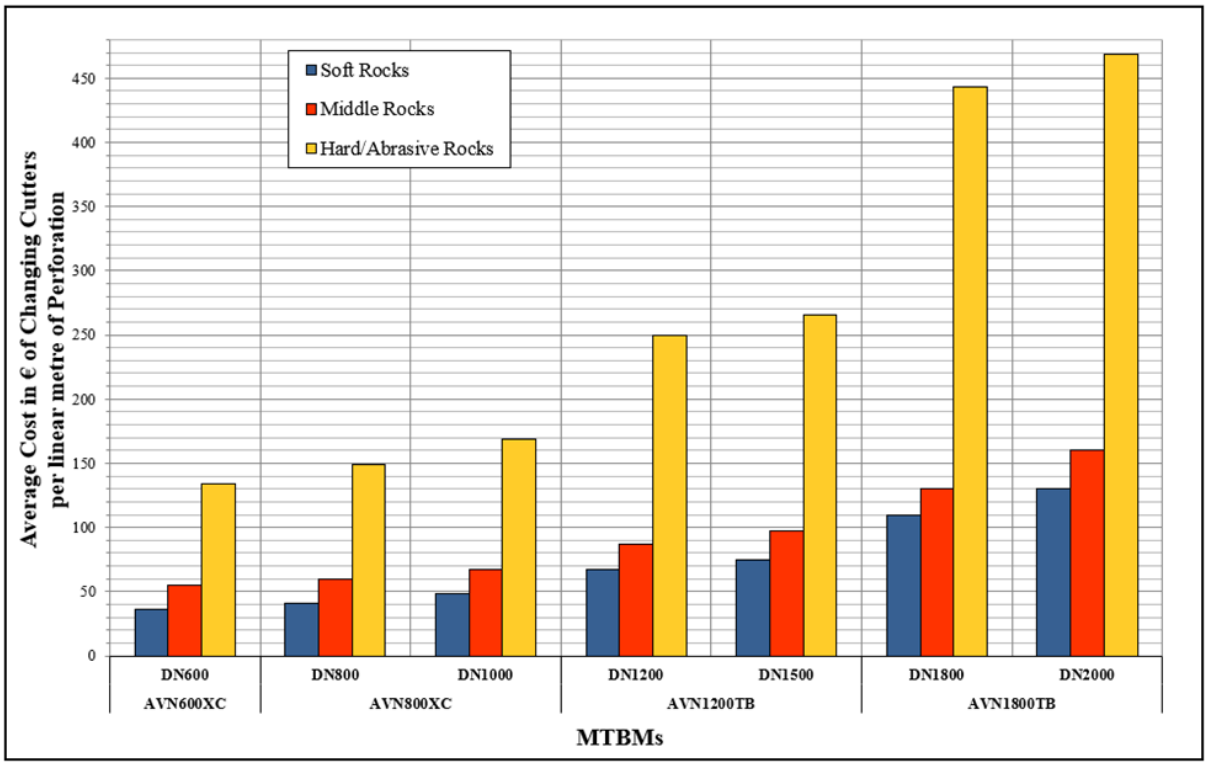

Fig. 6: Graphical Representation of the Data

In the case of large diameter TBMs, there are predicting methods which predict that the cutters consumption is approximately proportional to the volume of excavated rock and consequently proportional to the nominal pipe diameter D to the second power:

$$C_u = k \times D^2 \tag{1}$$

Nevertheless, this relationship is true only for diameters bigger than 1500 mm as it can be seen in Fig. 7. For diameters under 1500 mm, the actual linear cost is bigger than predicted one.

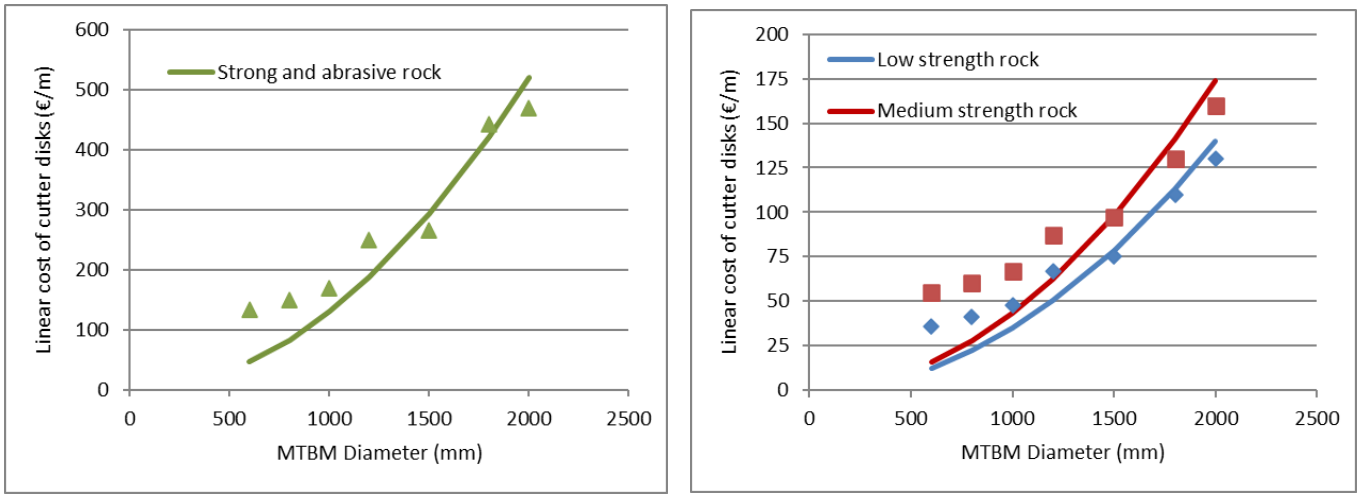

Fig. 7: Graphical representation of the data and Prediction according to Eq. (1).

Taking this into the mind, the following empirical formula to determine the linear cost due to the cutter consumption C_u (in €/m) is proposed:

$$C_u = k \times (1 + D^2) \tag{2}$$

Where D is the nominal pipe diameter (in m) and k is an empirical parameter which value is 25.5, 32.1 or 95.0 for soft, medium and hard and abrasive rock respectively (correlation coefficient $r^2 > 0.99$ in all cases). As it can be seen in Fig. 8, the Eq. (2) fits much better with the actual dada. It seems that cutters consumption trends to be more constant for small diameters (less than 1500 mm) or, in other words, it tends to be more independent of the diameter.

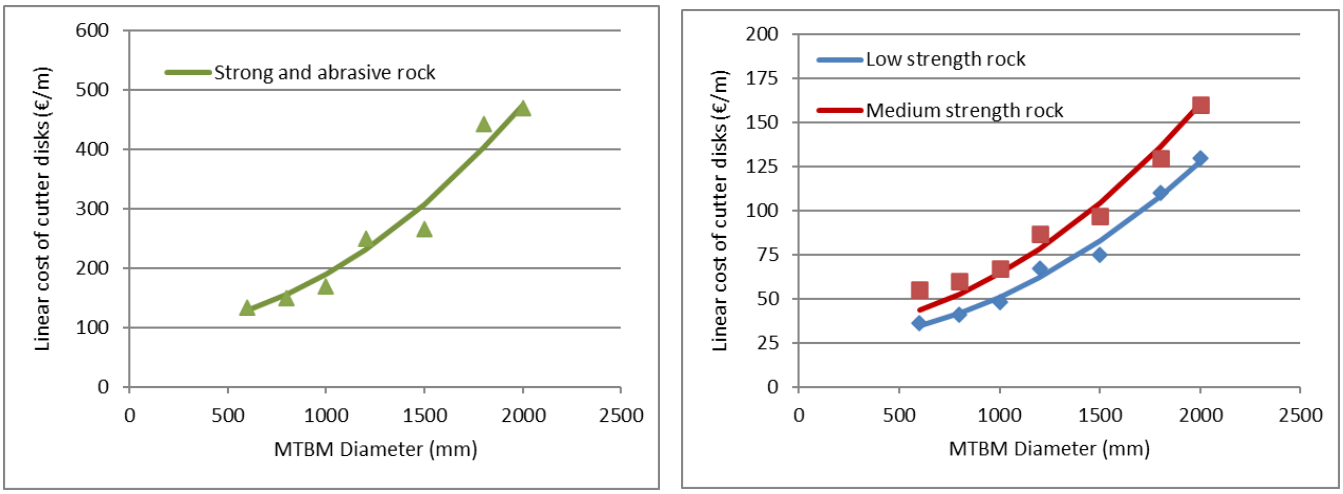

Fig. 8: Graphical Representation of the Data and Prediction according to Eq. (2)

In this way, the cost due to cutters consumption excavating a micro tunnel for a pipe DN1200 through a medium strong rock will be approximately $32.1 \times (1+ 1.2^2) = 78.3$ €/m while this cost will be of about $95 \times (1+ 2.0^2) = 475$ €/m in the case of a micro tunnel for a pipe DN2000 excavated through strong and abrasive granite.

4. Conclusion

This study tries to be an approximation to the resolution of the problem of the estimation of the costs of the change of cutters and, through the table of data, graph or formula that are presented, to approach the technicians of the sector to an appraisal of the matter that occupies us, hence its importance.

In practice, this study is designed so that a company that has carry out a pipe jacking project can estimate, approximately, and in a simple and quick way, the cost of changing cutters that it is going to assume in order to budget and undertake a work with less risk of assuming economic losses with the change of these.

The bad geological and geotechnical characterization present in the constructive projects, and on which we must insist that resources are invested given their importance, has a considerable influence on the performance of the works. These works pushes to be prepared for any eventuality, with an estimate, as accurate as possible, of the costs that the change of cutters is going to suppose, since the evaluation of them represents an important part of the total amount of construction in the micro tunnelling projects.

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