Abrasivity of soils in TBM tunnelling

In the first of a series of three articles, B Nilsen, from the Norwegian University of Science and Technology (NTNU), F Dahl, of SINTEF Rock and Soil Mechanics, J Holzhäuser, of Babendererde Ingenieure, and P Raleigh, of Babendererde Engineers, discuss the impact of abrasive ground on TBM tunnelling

TBM excavation has become increasingly common, despite the fact that precise evaluation of certain risks has not kept pace with the use of these machines. One of the risks easily overlooked by Engineer and Contractor alike are the effects of abrasive ground on the costs and schedule of a given project. The impacts of worn and damaged TBM cutterheads have been observed on hundreds of tunnel projects around the world. It would appear that a reliable prognosis of the abrasiveness of ground on a project would be of great importance for designers, clients and contractors alike.

Several well acknowledged test and prognosis methods already exist for rock; however, there is only very limited knowledge available to describe the abrasiveness of soil and its impact on wear on soft ground TBMs. This three-part article examines existing approaches to the problem and suggests a new approach based on a current project undergoing design.

Defining wear

For the purposes of the following discussion it is necessary to define the terms to be used, primary wear and secondary wear. By primary wear we refer to the wear on the excavation tools and surfaces such as drag bits, disc cutters, scrapers and buckets, etc., which are designed for excavation and to be replaced at appropriate intervals. Secondary wear, on the other hand, occurs when the primary wear on the cutting tools described above is excessive, which leads to wear of the structures designed to hold or support the tools in place, such as cutting head spokes or cutter mounting saddles, and wear on other surfaces not anticipated by the designers and TBM manufacturers (Herrenknecht and Frenzel, 2005[1]).

Impact of abrasive ground

In abrasive ground wear can occur on several parts of the TBM, including wear on the excavation tools, in addition to front, rear and periphery of the cutterhead structure, bulkhead and plunging wall structures, and on outlet devices such as screw conveyors on EPB TBMs or slurry pipes, valves and pumps on Slurry-TBMs.

It is clear that during the design phase, TBM manufacturers should have access to objective wear characteristics of the ground to be encountered in order that a rational approach to TBM component selection and wear protection may be adopted.

Moreover, during the operational phase when the TBM components are exposed to abrasive ground, scheduled inspections and maintenance should be strictly adhered to. Daily cutterhead inspections are common in hard rock TBM drives where cutter head access is relatively easy, but cutterhead inspections on soft ground TBM projects are typically executed where convenient or as indicated due to reduced TBM performance. Typically the presence of groundwater in soft ground tunnels makes cutterhead interventions more complicated and time consuming compared to hard rock tunnels.

The examples in figures 1 and 2 illustrate the extent of wear that can be observed on soft ground TBM tunnel projects. If primary

Fig 1 - Excessive wear on the cutterhead of the Wesertunnel's Ø11.7m Slurry-TBM

Fig 2 - Excessive wear on the outside cutterhead rim of one of the Ø4.7m ECIS EPB TBMs

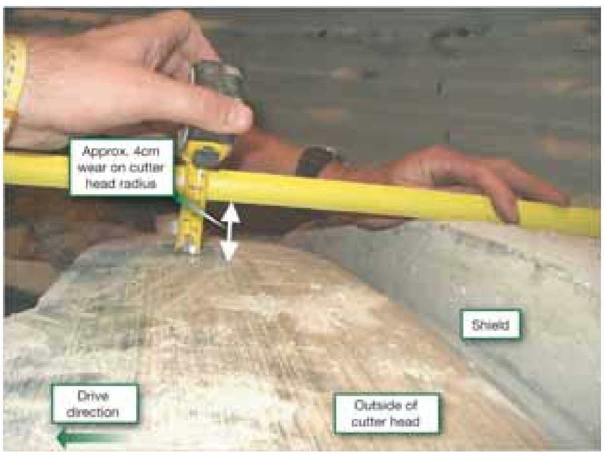
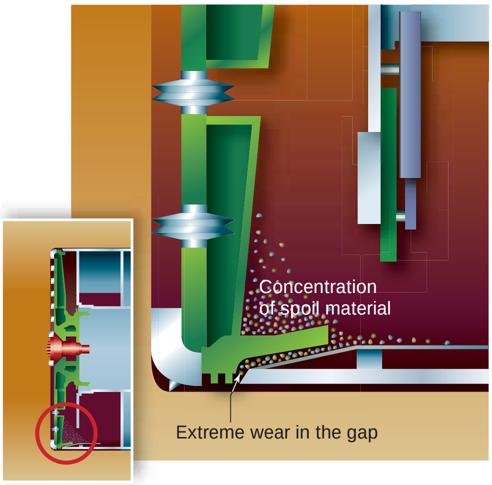


Fig 3 - Wear between cutterhead rim and shield rim



wear remains undetected and the carbide inserts on drag bits or the disc cutter ring steel and hub body of these tools fitted to the face of the cutterhead become excessively worn, subsequent secondary wear on the cutterhead structure itself can develop rapidly, as observed on the periphery of the cutterhead after breakthrough of the first tube on the Wesertunnel in Germany (see figure 1). As shown, sticky clay can block disc cutters from rotating, so that they are immobilised in one position and are ground down on one side (flat-spotted).

Wear on the outside of the cutterhead rim caused by inappropriate gauge cutter material, which permitted failure and loss of originally fitted chromium carbide wear plate on the cutterhead rim, is shown in figure 2 (as observed on the ECIS project in Los Angeles, US). Here the cutterhead radius shows the loss of 2cm of carbide plate in addition to 2cm of structural wear. This loss increased the required thrust force and slowed the TBM progress rate. Extensive underground repair works were required, delaying the works for several months.

On Slurry-TBMs secondary wear can occur if the rear part of the cutterhead turns within the shield (figure 3). The excavated material drops down into the bottom of the excavation chamber where the cutterhead must then plough through a volume of accumulated spoil (Babendererde et al., 2000[2]).

For example on the 4th Elbe tunnel project in Germany (bore diameter 14.2m) severe wear occurred in this area of the TBM and had ground down the steel structure of the cutterhead from 80mm thickness to just 15mm (Wallis, 2000[3]).

On EPB TBM tunnel drives significant secondary wear can occur while the excavation chamber is filled with excavated material and pressurised. As the pressure within the excavation chamber increases, the secondary wear increases as a function of pressure, as has been observed on major projects in such places as the Porto Metro, in Portugal, and the MTA, in Singapore.

Figure 4 illustrates the peripheral area of the cutterhead before and after repairs had been affected underground adjacent to the 24 do Agosto station, on the Porto Metro. The wear was largely due to the abrasive Porto granite in its various states of weathering. The use of closed mode (EPB) operation where the TBM excavated mixed soil conditions also contributed to the observed wear, which required some six weeks of around-the-clock working in order to complete the cutterhead refurbishment.

Figure 5 compares cutter consumption, with the ground conditioning used and the actual ground encountered along the Porto Metro line S. The ground conditions range from G1- fresh granite to G6 – residual ground. As can be noted there does not appear to be a great difference between the types of ground conditioning employed, but the degree of weathering seems to play a crucial role in determining wear. It was quite typical to change four to five cutters per day, which required almost an entire shift to accomplish, thus permitting only 7.5m to 9m per day of advance, a considerable reduction from the 12m to 15m per day advance rate originally envisaged by the contractor.

The examples described above give some indication of the variety of wear problems in soft ground TBM tunnelling. Up to now there

Fig 4 - Bucket tool before repair showing wear through fixing bolts (left) and after repair (right)

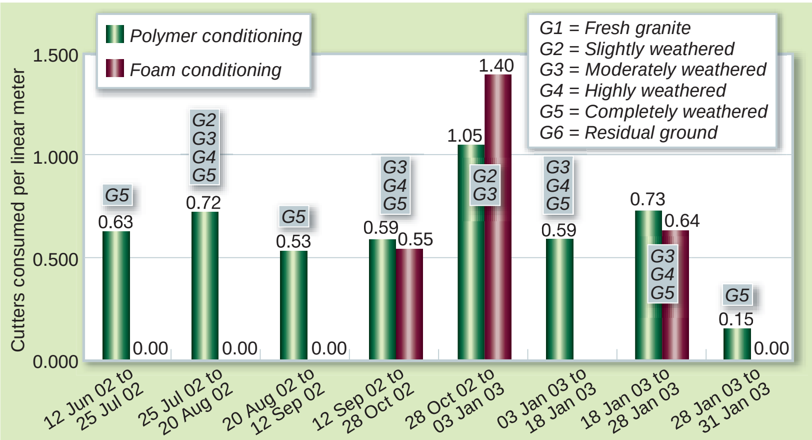
Part 2 of this article (April issue) examines existing test methods to describe the abrasiveness of rock and soil. Part 3 provides an introduction to a new NTNU Soil Abrasion Test (SAT).

has been no generally acceptable method for estimating the amount of wear to be expected in relation to objectively measured soil properties, other than recourse to the anecdotal references of adjacent projects.

It is clear that the ground abrasiveness characteristic is only one of the factors that affect both the primary and secondary wear observed. TBM operational modes, the type of TBM be it EPB or slurry, and the additives used for ground conditioning, as well as timely maintenance are among other important factors.

However, the characterisation of the abrasive properties of the ground plays the most important role in the development of effective strategies for dealing with the problem of wear. T&T

Fig 5 - Disc cutter consumption for polymer and foam ground conditioning in the various weathered granites found along the Porto Metro line S



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