T&T INTERNATIONAL

Predicting roadh

Problems with the accurate prediction of excavation rates in soft and hard rock include geological difficulties leading to high bit consumption and the low cutting performance of roadheaders. K Thuro and R J Plinninger, Department of General, Applied & Engineering Geology, Technical University of Munich, examine the connection between geological features, cutting performance and bit wear through four German case histories in different geological settings.

Roadheaders are being used to an increasing extent in different types of geology, which demonstrates some specific problems and limits in hard and abrasive rock as well as in soft ground. The accurate assessment of rock conditions and the geomechanical properties of the rock mass is of crucial importance for cutting performance and bit wear. Although many machine manufacturers have invested a great deal of time and money in studies to predict rock excavation rates, tool wear and derived costs, ground conditions seem too variable to keep up with.

Prediction of tunnel stability is usually the main thrust of preliminary site investigations. While the choice of an economic tunnelling method is normally given a certain priority, special investigations for rock fragmentation - e.g. the cutting performance or the wear of the cutters - are not carried out very often so that problems on site often have to be solved during tunnel excavation rather than in the design period. The kind of problems encountered in the different processes of roadheader excavation are given in Table 1.

Cutting and drilling performance, as well as the wear of tools and equipment, are decisive factors in the progress of excavation works. Estimating these parameters in predicted rock conditions might bear an extensive risk of costs, so an improvement in the prediction of cutting performance and bit consumption is desirable. For some years, basic rock drilling processes and bit wear have been studied in drill+blast tunnelling[3].

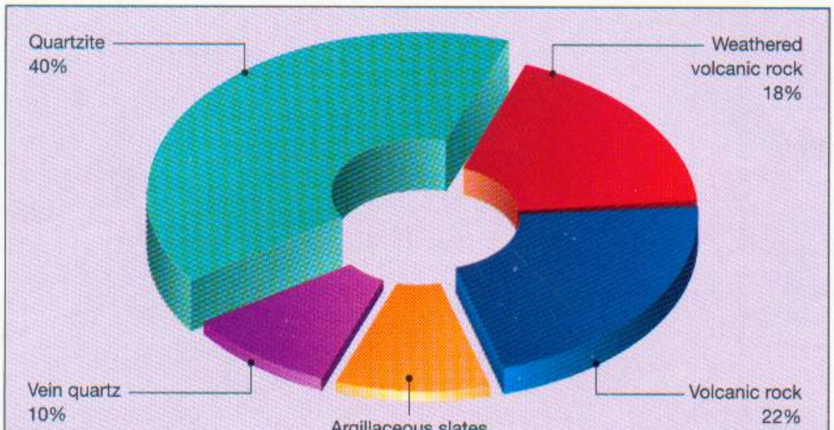
While performance is mainly influenced by macroscopic qualities such as rock strength; toughness (deformability); anisotropy; jointing; or the weathering stage of rock mass[2], tool wear is predominantly affected by microscopic rock properties like equivalent quartz content and the degree of mineral interlocking.

Apart from conventional rock properties, some special characteristics may hit the excavation process quite badly. For example: in apparently good rock with easy cutting of soft sandstones and clay-siltstones, even a low water inflow can lead to a total disaster: in one case, the cutterhead was locked by clay and in another, mucking of the excavated material was nearly impossible due to the behaviour of the mud.

Table 1. Main problems in roadheader excavation.

Process	Problem
Cutting	Poor cutting performance high bit consumption = high tool wear, no cutterhead penetration smudging of the cutterhead
Mucking	Soft soil behaviour & water = water saturated mud Excavated blocks too big for haulage / conveyor belt
Support	According to stability problems (not discussed here)

Fig 1 (below). Composition of the Permian fanglomerate of the Waderner Formation (Idar Oberstein)



CASE HISTORIES

Altenbergtunnel, Idar-Oberstein

In 1990, the 320m long Altenbergtunnel was built near Idar-Oberstein, cutting through a curve of the River Nahe en route to the federal highway B 41. All along the tunnel section, Permian fanglomerates of the Saar-Nahe-Basin were encountered (Fig 1). The fanglomerate, a typical alluvial fan deposit, consists of sub-angular to well rounded components with diameters of up to 1m (typical 200-500mm) such as very hard and dense quartzites and vein quartz; argillaceous slates; and weathered volcanic rock.

In order to choose an economic tunnelling method, a test excavation with an Atlas Copco Eickhoff 300kW roadheader with a cross cutterhead was performed. The outer bits of the cutterhead were worn off immediately when they penetrated the hard, quartzite bearing rock mass. The roadheader suffered not only from enormous bit consumption but also from an exceptionally poor penetration and cutting performance. Although the compressive strength of the fanglomerate is 20-80MPa, the hardest components (quartzites) reach 230MPa.

During the site investigations, only samples of the whole fanglomerate were tested, not single components. To be able to predict cutting performance in the context of compressive strength, a diagram of the like the one in Fig 2 is usually devised. For a mean UCS of 50MPa, the cutting performance would have been economical, but for the highest values of more than 200MPa, the performance was not good enough. Subsequently, the roadheader was removed

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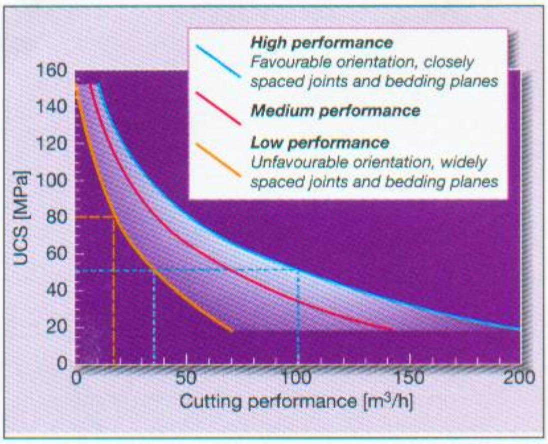


Fig 2. Cutting performance of the Atlas Copco Eickhoff 300kW roadheader vs. compressive strength on the Altenbergtunnel. On the blue line, the UCS of the fanglomerate and the mean cutting performance are estimated with approximately 35m^3/h

from the site and drill+blast tunnelling was used instead.

Meisterntunnel, Bad Wildbad

In 1994 to 1996, the 1684m long Meisterntunnel was built as a bypass for Bad Wildbad, a health resort in the Black Forest. The excavation work encountered fanglomerates, sandstones and clay-siltstones of the Upper Permian (Fig 3). There were also layers of calcrete up to several hundred millimetres thick, consisting of both dolomite and light yellow 'Carneole' (cryptocrystalline silica) having an extremely dense texture with a compressive strength of up to 150MPa.

Excavation with a roadheader was supposed to meet both requirements, so a Paurat E 242 B with 300kW of power and a total weight of 120 tonnes was brought to the site. After assembly, two cutting tests were carried out in December 1994 (Fig 4). Even after the cutterhead was improved, the machine achieved only low performance of about 13m^3 (solid)/h. It was removed from site and drill+blast tunnelling was used instead.

A detailed geotechnical investigation was subsequently carried out to reveal the causes of this financial disaster. Although the mean values of the UCS is 59MPa, the typical UCS for the hard layer is 90MPa, with the highest values over 150MPa! It became evident that the unfortunate combination of high compressive strength and very widely spaced joints and bedding planes had brought the roadheader 'to its knees' (compare with cutting performance diagram in Fig 2). For the typical UCS of 90MPa, the cutting performance of 13m^3/h was not economical.

Zeulenroda sewage tunnel,

In 1994-1995, a 2.4km long sewage tunnel was built in the vicinity of Zeulenroda, Thuringia. Rock conditions were characterised by Ordovician slates and quartzites of the Thuringian Slate Mountains. The slates were typically black to grey and laminated to massive, sometimes closely folded and frequently mica bearing. The slates alternated with hard grey quartzites of high compressive strength.

Although the cross section of the tunnel was only 11m^2, a 132kW roadheader could be installed (Atlas Copco Eickhoff ET 120). In the first 800m, the quartzites dominated the slate-quartzite layers, so cutting performance dropped from 22m^3/h to a minimum of less than 5m^3/h (Fig 5). At first, the cutterhead had to be changed from a longitudinal to a cross cutter. Subsequently, the cross cutter had to be repaired several times due to damage of the bearing.

Bit consumption was extremely high, rising from about 0.1 bits/m^3 to over 5 bits/m^3 (extreme value 15 bits/m^3 - 150 bits in 11m^3). These values were far from those expected. Performance according to the maximum compressive strength of 30MPa was estimated to be 15-30m^3/h. The actual values ranged from below 10MPa (slates) to over 120MPa (quartzites), causing the low cutting performance mentioned above.

Additionally, the quartz content was much higher than expected, especially in the hard quartzites, which were much more dominant than anticipated. In order to prove the influence of the quartzites, a wear

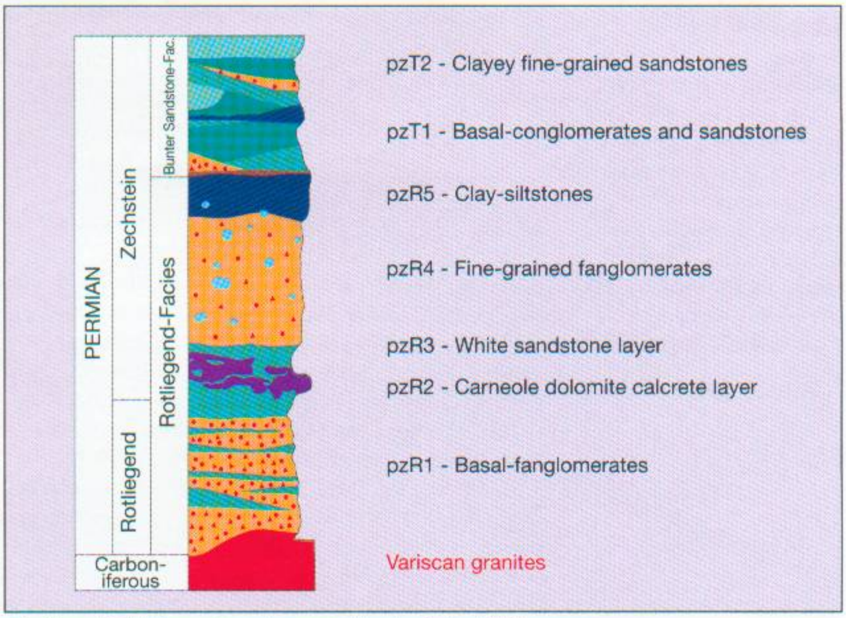
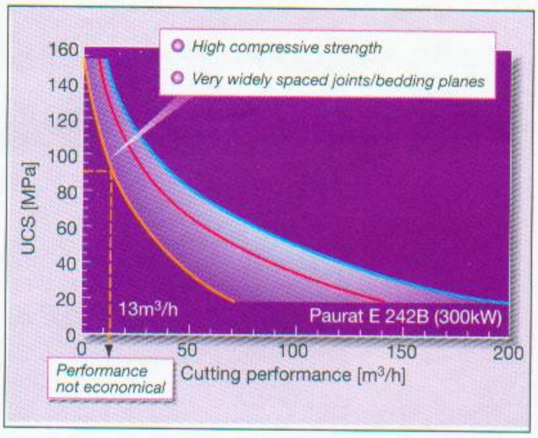


Fig 3. Generalised scheme of the Permian rocks, encountered during the excavation works for the Meisterntunnel, Bad Wildbad

Typical asymmetric wear of the outer cutterhead bits of the Atlas Copco Eickhoff 300kW roadheader used on the Altenbergtunnel



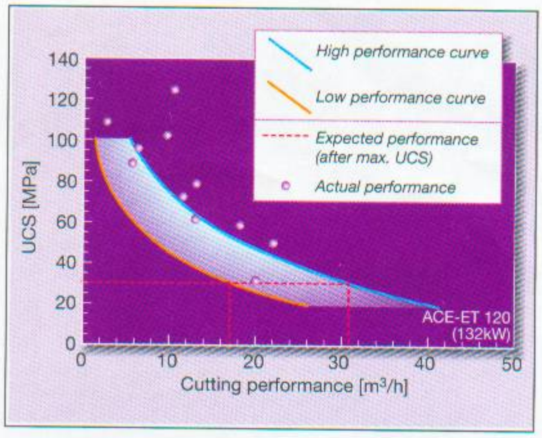


Fig 4 (right). Cutting performance of the Paurat E 242B (300kW) roadheader vs. compressive strength. Actual performance in the Meisterntunnel is plotted in the blue line ($13m^3/h$)

Fig 5 (far right). Cutting performance of the Atlas Copco Eickhoff ET 120 (132kW) roadheader vs. compressive strength. Expected and actual performance in the Zeulenroda sewage tunnel

characteristic of the used bits was developed (Fig 6). Bit wear characteristic derived from field studies in Germany, Austria and Switzerland may be used to identify both abrasivity of rock and problems of cutting. Breakage and damage of bits were common.

The investigations prove not only how abrasive the quartzite is but also reveal the effects of the jerky movement of the cutter on the tunnel face. Further on, where the rock is hard, scraping of the rock surface leads to high temperatures, which have an unfavourable influence on the steel and tungsten carbide: the hardness of tungsten carbide decreases rapidly with increasing temperature so that between 600°C and 800°C, quartz is harder than tungsten carbide[1]. Wear resistance thus decreases at high temperatures. The problem at the site investigation stage was apparently an insufficient sample rate and an insufficent number of rock tests.

Further excavation was affected by a large fault zone (Weissendorf Fault) with typically faulted and fractured material, fault gauge and heavy jointing of the related vicinity. Support works dominated the excavation rate (per day). However, net cutting rates increased with decreasing spacing of discontinuities.

At least two processes are taking place during cutting: as long as the rock is massive, scraping and cutting of material is dominant. Much energy is needed to cut the rock, resulting in a relatively low cutting performance. With closer joints, the cutterhead can rip out blocks or at least larger pieces of rock which are already pre-cracked by small fissures.

This process consumes less energy and the cutting performance is much higher. Although the net cutting rate in the fault material was excellent, the time taken to install the support increased much more, so that the advance per day necessarily dropped.

Nuremberg underground system

For a better connection to the city's airport, the underground system of Nuremberg (Bavaria) had to be extended. In 1995, excavation of 3.3km of new underground tunnels was begun. The tunnels were built in sandstones and clay-siltstones of the Upper Triassic (Keuper). Very hard dolomitic and calcitic calcretes ('Quacken') appear in some horizons (Fig 7).

ATLAS COPCO Eickhoff ET 380 L/Q roadheaders (200kW power, 105 tonnes total weight) were used on various lots of the new underground line. The excavation method was mostly successful, but in some areas, roadheaders suffered from severe problems with bit consumption or mucking so that the whole excavation process was taken to the limit of its effectiveness.

In one lot, the performance of the roadheader proved to be far behind that expected. It was discovered through field studies that this was not the result of poor cutting performance but was a problem associated with the roadheader's mucking system.

It was evident that the mucking problem was related to the amount of clay and silt excavated. Roadheader performance generally decreases with an increase in the percentage of clay and silt. During excavation, the clay and siltstone layers were cut into small pieces by the roadheader. These were mixed with sand from the sandstone layers, that, unfortunately, were highly water permeable. In combination with the water inflow of 2-5 litres/s it seemed that this would be the right mixture to form water saturated mud and this material could no longer be mucked by the roadheader's muck haulage system.

This model can also explain the flattening of the curve at higher amounts of clay and silt (Fig 8), With a decrease in the amount of sand, the material becomes less permeable to inflowing water.

During excavation on another lot, the roadheader suffered from bit consumption of up to 508 bits/day. Relative to the excavated rock mass quantity (solid), bit consumption reached values up to 4 bits/m^3. An examination of 100 used bits showed that, in most cases, the hard metal bit was broken or even broken out of the bit's steel body. This pointed to highly abrasive rock with a high compressive strength. There was in fact a clear connection between huge bit consumption and the appearance of thicker calcrete layers. The highest bit wear was achieved in an area where two unjointed layers of calcrete were encountered having a thickness of 0.9m and 0.5m.

Although the investigations gave evidence of a high quartz content (up to 60%) and a compressive strength of up to 180MPa in these concretions, the

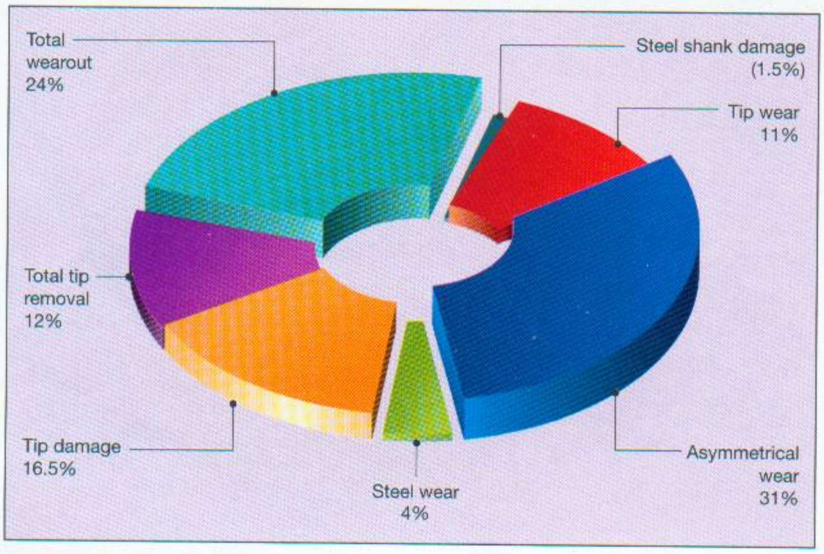


Fig 6. Bit wear characteristics of 274 bits on the Atlas Copco Eickhoff ET 120 machine used in the Zeulenroda sewage tunnel

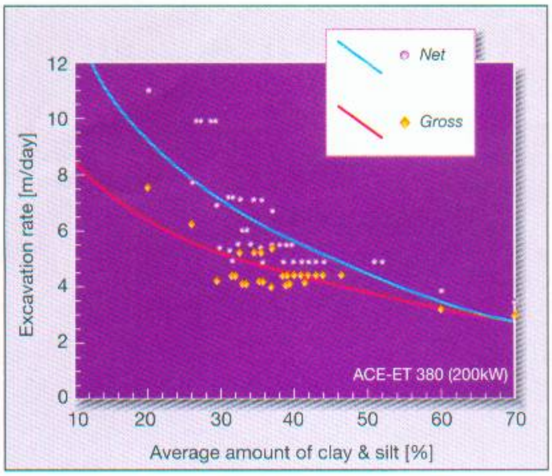


Fig 8. Net and gross excavation rates vs. average amount of clay and silt in the Keuper sediments

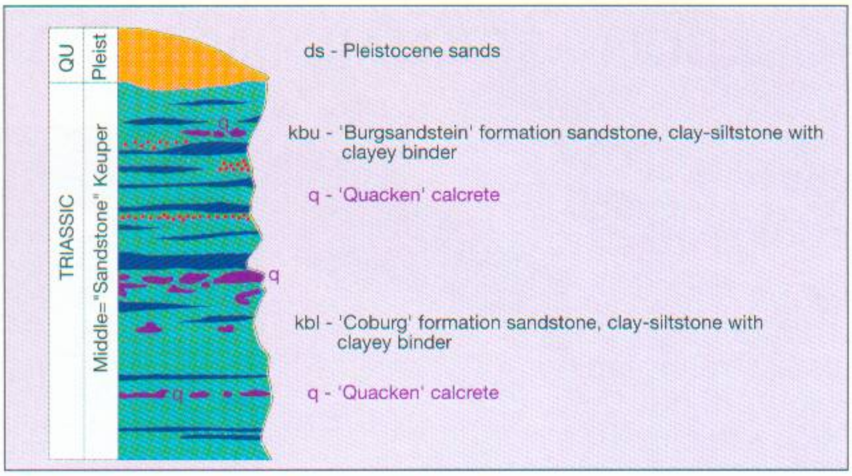


Fig 7. Generalised scheme of the Keuper sediments encountered while excavating the Nuremberg tunnels

large bit consumption was not the result of the abrading properties of the calcretes alone. The interchanging series of relatively soft sandstones and calcretes with a compressive strength of up to 100MPa led to increased breaking of the bits' hard metal inserts. While the tungsten carbide inserts are relatively resistant to grinding, their brittle behaviour makes them susceptible to hits, obtained when the cutterhead leaves a softer sandstone layer and moves into a hard layer of calcrete. Since the broken or broken out inserts can no longer protect the bits' steel body from abrasion, the wear of such bits increases rapidly.

Conclusions

1. The hardest inclusion, not the mean value, dominates cutting performance and tool wear, especially in rock of heterogeneous composition

2. Soft clayey sandstone forms mud with a distinct amount of water and cannot be removed by the roadheader's haulage system

3. Representative sampling should contain the average and the maximum values

4. Site investigations for rock fragmentation dealing with problems in the range of several centimetres must be completely different from those concerning tunnel stability, which deals with ranges of about 10-20m

5. A geological phenomenon may cause much more trouble for the excavation process than 'just' higher rock strength values. Both geological-petrographical and geotechnical aspects should be taken into account to raise the level of geological contributions to underground construction. T&T

References

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