Gebirgslösung im Tunnelbau

Bei den geotechnischen Voruntersuchungen zu großen Tunnelprojekten steht üblicherweise die Vorhersage der Stabilität des auszubrechenden Hohlraums im Vordergrund. Probleme der Gebirgslösung – also der Bohr-, Spreng-, Fräs- oder Schneidbarkeit – fristen demgegenüber eher ein Schattendasein.

In vorliegender Arbeit werden die technischen Grundlagen für drei wichtige Tunnelvortriebsarten in Festgesteinen – Bohr- und Sprengvortrieb, Vortrieb mit Teilschnittmaschinen und Vortrieb mit Tunnelbohrmaschinen (Vollschnittmaschinen) – beschrieben und die erfassbaren Leistungsparameter (Bohr-, Fräs- und Schneidgeschwindigkeit sowie Sprengstoffverbrauch) und Verschleißparameter (Bohrkronenstandzeit, Rundschaftmeißelverbrauch sowie Diskenrollweg) vorgestellt.

Bei der sog. „Basis-Gebirgslösbarkeit" werden die felsmechanischen und petrographischen Kennwerte, insbesondere die spezifische Zerstörungsarbeit, die einaxiale Druckfestigkeit und der äquivalente Quarzgehalt, auf ihre Korrelation mit diesen technischen Parametern hin untersucht. Die wichtigsten geologischen Faktoren, welche sowohl steuernd als auch limitierend für Vortriebsleistung und Werkzeugverschleiß wirken, werden aufgeführt und schließlich ihre Einflüsse auf die Prozesse bei der Gebirgslösung beschrieben. Für einige – jedoch längst nicht alle – Faktoren lassen sich Leitparameter definieren, mit denen auch eine Quantifizierung möglich ist. Die Auswirkungen des Trennflächengefüges und dessen Orientierung (Anisotropie) bilden einen Schwerpunkt der Arbeit.

Die vielfältigen Wechselwirkungen geologischer Faktoren werden häufig erst bei der Ausführung von Bauprojekten augenscheinlich. Deswegen müssen die eigentlich komplexen geologischen Faktoren – der Einfluss der Verwitterung & hydrothermalen Alteration (Zersetzung), die Auswirkungen hoher Primärspannungen, die Behinderung durch veränderlich feste Gesteine und die Beeinflussung durch die Inhomogenität des Gebirges – in ausgesuchten Fallbeispielen deutlich gemacht werden.

Abschließend kann festgestellt werden, dass Voruntersuchungen zur Gebirgslösung heutzutage einen wertvollen Beitrag zur Risikominderung bei der Bauausführung liefern können. Vorschläge für ein Untersuchungsprogramm, das auf die Gebirgslösung abgestimmt ist, werden gemacht und Probleme einer Prognose diskutiert.

Excavatability in Tunnelling (Abstract)

Determining tunnel stability is a key issue during preliminary site investigation. In contrast, problems of excavatability have been largely ignored. While the choice of an economic tunnelling method is admittedly a clear priority in the planning stage, special investigations focussing on rock fragmentation (e.g. drilling or cutting performance, rock mass blastability or tool wear) are rarely carried out. This thesis explores possibilities to quantify key parameters for rock mass excavatability in drilling, blasting and cutting by TBMs and roadheaders.

What is Excavatability?

Excavatability is a term used in underground construction to describe the influence of a number of parameters on the drilling, blasting or cutting rate (excavation performance) and the tool wear of a drilling rig, roadheader or TBM (wear or usage criterion). The interaction of the main factors involved is illustrated in Fig. 1. These terms are used in underground as well as in surface construction. In this thesis, only the aspects relating to tunnelling are discussed.

In the first interaction, the excavation performance is influenced by the machine parameters of the chosen tunnelling rig – the installed power, the type of drilling rig or cutter head and the rock cutting tools mounted. Apart from technical parameters, the geological parameters may especially influence the cutting performance and tool wear. The specific characteristics of intact rock and rock mass material may be at

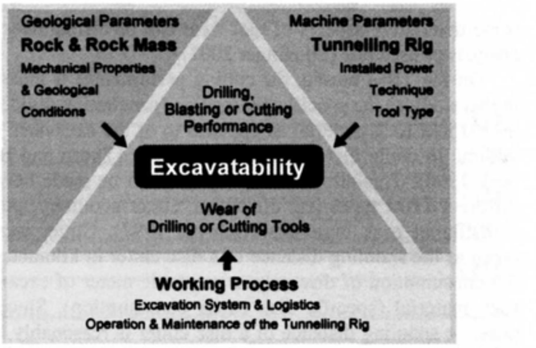

Fig. 1: Conceptual overview of the three main parameters influencing excavatability.

least partly put into figures with the help of mechanical rock properties. But rock mass conditions also highly depend on the geological history, weathering conditions, hydrothermal decomposition and the structure of discontinuities.

The last important factor influencing rock excavation performance is the working process itself. Firstly, smooth operation and permanent maintenance of the tunnelling rig contributes to a successful cutting performance. Secondly, a high penetration rate at the tunnel face does not automatically lead to a high performance of the tunnel heading (Thuro and Spaun 1996a). Therefore, it is a matter of understanding the entire excavation system before applying expertise to the investigation of excavation performance.

Excavation Techniques

For further discussion some elementary terms of underground excavation techniques must be explaned. The term "drillability" is used in the context of drill and blast tunnelling when drifting blastholes for explosives and rock bolting for support with diameters ranging from 32 to 100 mm. To study drillability, two key parameters have proved to be most valuable (Thuro 1997): the (net) drilling rate in meters per minute (i.e. the drilling performance, derived from the time of drilling one single borehole); and the bit life span in meters per drilling bit that can be drilled in a homogeneous tunnel section. Since wear occurs in six basic forms, generally in accord with rock mass conditions, some qualitative aspects of tool wear can be distinguished by analysis of worn-out drilling bits (Plinninger 2002).

The term "blastability" is only used in the context of drill and blast tunnelling and the consumption of explosives. Quality aspects of blasting and/or control of material fragmentation were not included. As a property relating to blastability, the specific consumption of explosives was recorded in the crown heading along homogeneous rock mass sections. The specific explosives consumed can be derived from the total consumption of explosives in one blow divided through the volume blasted. As a statistical value, the specific consumption of explosives only shows the amount of explosives needed to blast a certain rock mass volume. Since the blasting engineer has to estimate this amount according to rock mass conditons (quality of rock, discontinuity spacing etc.), experience shows that there is quite a variation in the used quantity and therfore in the values of specific explosives consumed.

The term "cuttability" is used both when excavating with roadheaders or with TBMs. In principle, the term is also valid for similar techniques using trench and dredge cutting (Deketh 1995, Verhoef 1997) and road pavement shaping. Analogous to drillability, two key parameters are invoked to describe roadheader cuttability (Thuro and Plinninger 1998, 1999a, b). In roadheader excavation the cutting performance is measured as the excavated rock volume in cubic meters per working hour, and the bit wear is determined by the number of worn-out bits that have to be changed after cutting a cubic meter of rock (specific bit consumption). Since roadheader bit wear occurs in seven basic forms, relating to rock mass conditions, some qualitative aspects of tool wear can be distinguished by analysis of used bits (Plinninger 2002).

During TBM boring, the cutting performance is measured in this study as the specific penetration (penetration divided by thrust) in a rock material as opposed to of the excavated rock volume in cubic meters per working hour (Thuro and Brodbeck 1998). This allows for comparison to be made between different TBM types (eg. diameters, cutter geometry, power) in different rock materials (Gehring 1997). Cutter wear is taken as the spooling distance of a disc cutter in kilometers or the consumption of disc cutters per cubic meter of excavated rock material (specific disk cutter consumption). Since the possible spooling distance of a disc cutter is reasonably high, the resolution with respect to geological and petrographical variations is quite poor and not applicable to rock mass characterization.

Basic Excavatability – Mechanical rock properties

For the investigation of excavatability there has to be distinguished the basic excavatability controlled by the intact rock and the general excavatability controlled by the rock mass properties. In other words, the general rock mass excavatability also takes into account the discontinuity pattern and characteristics, and water seepage/flow. If the rock mass is homogeneous and isotropic, rock properties could be directly correlated with excavation performance and petrographic properties (e.g. equivalent quartz content, Thuro 1997) or index properties (e.g. rock abrasivity index, Plinninger 2002) with tool wear.

In earlier papers the suitability of different rock properties for correlation with drilling rates have been discussed in detail (Thuro 1997, Thuro and Spaun 1996). Also when applying these techniques to other excavation processes, the best correlations were encountered using destruction work (strain energy, Thuro and Spaun 1996 b). From the physical point of view, the integral of the stress-strain-curve is a measure of energy (or work) related to the deformation volume. Because this is the work required for destruction of the rock sample, the newly defined rock property has been determined as "*specific destruction work* W_d [kJ/m^2]" (in short: destruction work), which is also referred to as *strain energy*. As a product of both stress and strain, destruction work represents the work of shape altering of the rock sample including the post failure region.

Fig. 2 shows the correlation between destruction work and cutting performance in roadheader excavation with R^2 = 89% (square of correlation coefficient). In contrast, the significance of the correlation with unconfined compressive strength (Fig. 3) is not as good (R^2 = 62%). Also a good correlation is found with TBM performance, when specific penetration rate is plotted against destruction work (Fig. 4, R^2 = 87%). To obtain better correlations, only TBM pulls in those tunnel sections were included where fracturing by joints was low and orientation of foliation was constant. In drill and blast tunnelling a fair correlation was also encountered for the specific consumption of explosives (Fig. 5) with destruction work. It is important to evaluate only homogeneous tunnel sections and explosives with comparable detonation characteristics (energy, velocity) and comparable blasting conditions (here: wedge cut, face profile & volume).

In summary, mechanical rock properties, especially destruction work, can be used as a good measure for excavation performance and therefore provide useful information when carrying out site investigations in regard to excavatability. The limitation is that the prerequisites, homogeneous and isotropic rock mass sections without changing geological structures are only very rarely encountered.

Although rock mechanical properties play a key role, geological parameters are rarely fully included in most projects. In some cases, the influence of geological features on rock fragmentation can be much higher than varying rock properties. Geological difficulties can have a high impact on the economics of an underground construction project, especially when the chosen excavation system turns out to be unsuitable for the conditions encountered. Thus it can be argued that the geological and petrological characteristics of the rock mass should be evaluated with the same degree of effort as that for the geotechnical prognosis. Furthermore, mechanical parameters are of limited value, if the rock mass is composed of anisotropic and inhomogenious material. Inhomogeneity and anisotropy obviously play a key role during the process of rock fragmantation. In the last part of this thesis, these aspects are worked out in six case studies.

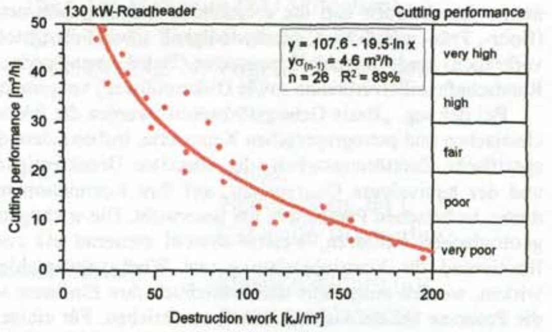

Fig. 2. Cutting performance, correlated with destruction work (Slates and quartzites, Sewage tunnel Zeulenroda).

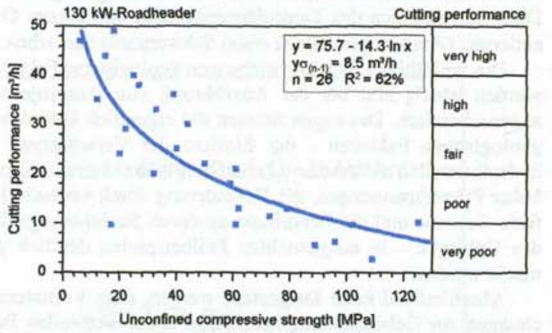

Fig. 3. Cutting performance, correlated with compressive strength (Slates and quartzites, Sewage tunnel Zeulenroda).

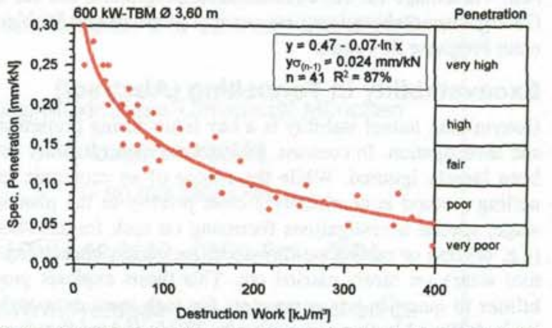

Fig. 4. Specific penetration, correlated with destruction work (Phyllites & carbonate schists, Schönberg tunnel, Schwarzach).

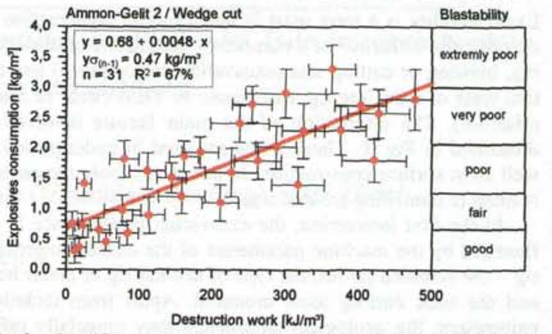

Fig. 5. Specific consumption of explosives, correlated with compressive strength (31 case studies from 8 tunnel projects). Standard deviation as error margins.