Critical Comments on Quantitative Rock Mass Classifications

By Gunter Riedmüller and Wulf Schubert

Quantitative rock mass classifications have been used for decades as one of the most important tools for the design and construction of tunnels (1 to 10). The quantitative classification schemes are based on rock mass parameters which were established to describe the quality of the rock mass in terms of tunnelling. The appropriate supports are determined by a rock mass quality rating calculated from the relevant parameters. The ratings of the parameters were developed from underground hard rock mining and tunnelling histories. As a result, the different multi-parameter classification schemes are only appropriate within the limitations of the case histories from which they have been derived.

Among the quantitative classifications, the most widely used are the Geomechanics Classification or Rock Mass Rating (RMR) system of Bieniawski (4, 11) and Barton et al's Q-System (7). These classification systems result in evaluations based on parameters such as rock strength, discontinuity properties and groundwater conditions with respect to the rock mass quality.

The fundamental difference between the two systems is the deficiency of a strength/stress relationship in the Geomechanics Classification, while the Q-System considers rock strength as it relates to in situ stress. The influence of discontinuity orientation is included in the Geomechanics Classification, whereas the Q-system considers joint orientation implicitly as joint roughness and the alteration parameters (J_r, J_a) are related to the most unfavourably oriented joint set.

Merits and drawbacks of the Geomechanics Classification and Q-System

In our opinion, the advantages of both quantitative classification schemes are the excellent coverage by publications and the simple application of these methods. As a result, this led to international acceptance. The assessment of classification parameters and the calculation of rock mass ratings is uncomplicated, and it has been proven in practice that rock mass ratings are a valuable tool in comparing tunnel alignments quantitatively during the early stages of a project, e.g. feasibility and route selection studies.

However, it is our experience that quantitative classification systems should not be the only method used for determining supports in preliminary planning, as well as detailed design and in particular for the construction of a tunnel. During construction it is absolutely essential to assess the appropriate supports on the basis of geotechnical modelling, supported by the results of monitoring and geological face logging (18).

The main drawbacks to the quantitative classifications are summarized as follows:

- Classification parameters and ratings are universally applied for all rock mass types without considering the specific characteristics of the rock mass and project,
- the complex properties of a rock mass, in particular its anisotropy and time dependent behaviour, can not be sufficiently described by a single number,

Kritische Anmerkungen zu quantitativen Gebirgsklassifikationen

Der Beitrag beschäftigt sich mit der Problematik der quantitativen Klassifizierungssysteme für den Tunnelbau. In einer auf praktischer Erfahrung beruhenden Kritik werden die Vor- und Nachteile sowie Einschränkungen der quantitativen Klassifizierungssysteme aufgezeigt. Die Autoren sind der Überzeugung, daß diese Systeme nur in sehr frühen Projektphasen ihre Berechtigung haben, zum Beispiel um verschiedene Trassen zu vergleichen. An Hand von Beispielen wird dargelegt, daß die quantitative Klassifizierung insbesondere nicht als alleinige Planungsgrundlage bei schlechten und druckhaften Gebirgsverhältnissen verwendet werden soll. Zur technischen und ökonomischen Optimierung von Vortrieb und Stützmaßnahmen werden an Stelle quantitativer Klassifizierungssysteme eine realistische Gebirgsmodellierung unter Berücksichtigung potentieller Versagensmechanismen empfohlen.

The paper deals with the problems associated with quantitative classification systems for the design and construction of tunnels. On the basis of practical experience benefits, drawbacks, and limitations of quantitative classification schemes are shown. The authors are convinced, that these systems can only be applied during early stages of a project, e.g. for route selection studies. Case studies show, that quantitative classifications should not be the only method used for determining supports in detail tunnel design and in particular for the construction of a tunnel. For the economical and technical optimization of excavation and supports we recommend realistic rock mass modelling, including the assessment of potential failure mechanisms instead of schematic quantitative classification.

- the same rock mass ratings can be achieved by various combinations of classification parameters,
- the oversimplified empirical approach, based only on a few classification parameters, does not consider failure mechanisms, deformation and rock support interaction,
- classification parameters are not well enough defined to select adequate design parameters and tunnel support,
- the complex interaction of discontinuity orientation, degree of fracturing, joint shear strength and stress conditions, in particular the relationship between maximum and minimum principal stresses, as main factors influencing rock mass behaviour is not sufficiently considered.

Perhaps the greatest disadvantage of a quantitative classification is that it does not promote the analysis and proper appreciation of rock mass conditions. In particular, their application in heterogeneous ground may result in an inaccurate design, causing economical and technical drawbacks during construction.

Case studies

The shortcomings of quantitative classification schemes can be clearly seen in these following examples from the Austrian Alps.

Underground mine in Schwaz

Large caverns are excavated in the underground mine in Schwaz (Tyrol) to extract dolomite as a raw material for road construction. It has been proven during excavation that the stability of the underground opening is mainly affected by the confining pressure and the development of open joints. Joint set number, degree of fracturing and even joint roughness have only a minor influence. In the case of tight joint wall contacts and sufficient side pressure the unsupported span of the heavily jointed dolomite is in the range of 40 to 70 m. It was found that a decrease of side pressure and opening of joints causes an immediate collapse of the unsupported cavern.

The calculation of rock mass quality Q for these two geotechnically contrasting scenarios results in a Q value of 10 for the tight rock mass and a Q value of 2 for the open jointed rock mass. The maximum unsupported span for the rock mass under sufficient confining pressure was calculated to be 25 m, whereas the open jointed rock mass was calculated to be an unrealistically large free span of 13 m.

Inntaltunnel and Landecker Tunnel

The railroad bypass of Innsbruck ("Inntaltunnel") and the motorway tunnel ("Landecker Tunnel") were excavated in different directions under comparable primary stress conditions (approximately 300 m overburden) in the same phyllite sequence ("Innsbrucker Quarzphyllit"). High radial deformations in the range of 10 to 15 cm as well as stability problems were observed during the construction of the railroad tunnel, which is oriented more or less parallel to the strike of the phyllite. In contrast, the deformation during the construction of the motorway tunnel, which is oriented perpendicular to the foliation was negligible. The RMR ratings for

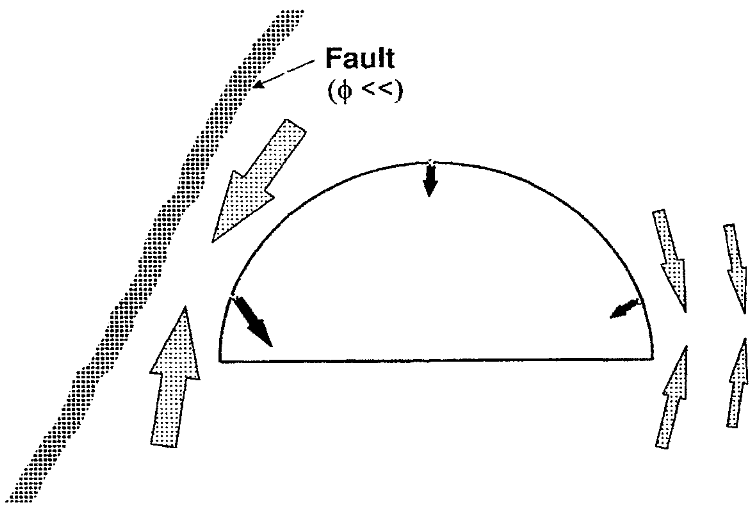

Fig. 1 Model 1: Simplified geological situation of stresses and deformations with the fault above the tunnel.

Bild 1 *Modell 1: vereinfachte geologische, Spannungs- und Deformationsverhältnisse bei Störung im Hangenden des Tunnels.*

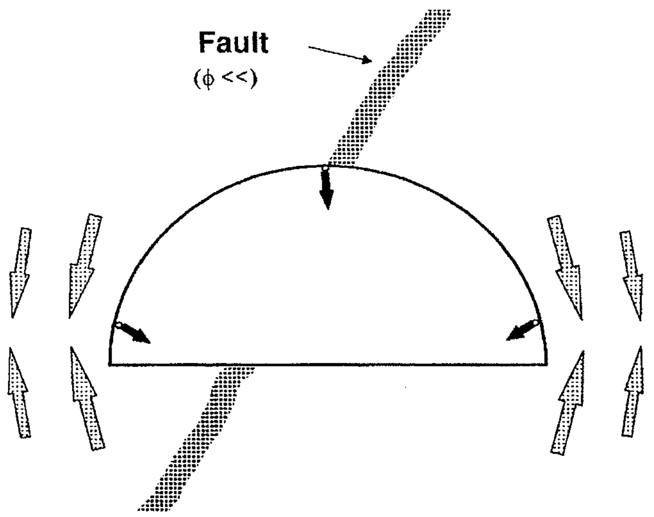

Fig. 2 Model 2: Simplified geological situation of stresses and deformations with the fault cutting the tunnel profile.

Bild 2 *Modell 2: vereinfachte geologische, Spannungs- und Deformationssituation bei Störung im Profil.*

both tunnels fell into the same category of fair rock, thus displaying the inability of the system to reflect the significant differences in rock mass behaviour.

Galgenbergtunnel

This recently completed tunnel is part of the high speed railway through the Austrian Alps (12, 13). The tunnel penetrates a metamorphic basement of high complexity consisting of quartzphyllite, graphitephyllite, greenschist and marble. Major problems during the construction of the tunnel were created by fault zones consisting of alternating stiff and soft rock (14, 15, 16).

To demonstrate the inadequacies of quantitative rock mass classification, RMR-ratings and ground behaviour of a 50 m long section were evaluated. This section was adversely influenced by a fault intersecting the tunnel axis at an acute angle. The foliation of the phyllite strikes parallel to the fault and dips towards the face of the tunnel (17).

Due to the location of the fault in relation to the cross section of the tunnel, three basic geotechnical models are distinguished. These are: the fault zone located above, within and below the tunnel (Figure 1 to Figure 3).

Two-dimensional calculations using distinct element analysis (UDEC) displayed the worst case scenario for model 1 with the fault located above the tunnel resulting in high stresses between the sidewall and fault causing large displacements. To obtain sufficient stability, a considerable increase of support is required. This was achieved using an asymmetric bolting pattern.

When the fault passes through the tunnel cross section, as seen in model 2, the magnitude of displacement decreases and the deformation pattern is more or less symmetrical. Asymmetrical deformation is again calculated for model 3 with the fault located beneath the tunnel cross section. However, due to the more favourable orientation of tangential stress towards the fault the displacements are smaller compared to model 1. The calculated ground behaviour was confirmed by monitoring during construction.

The inadequacies of this system can be seen in an evaluation of the rock mass ratings (RMR) for the three cases. A rock mass rating of 48 was determined for both models 1 and 3, while model 2 was determined to be 22, a poor rock rating.

Discussion and Conclusion

Practice shows that a quantitative rock mass classification is inadequate for support determination and stability evaluation under complex geological conditions. Therefore, the use of these methods should be limited to early design phases, such as feasibility, or route selection studies. For basic, detail, and tender design, as well as during construction, we strongly recommend to implement up to date rock mass modelling instead of, or in addition to rock mass classification (18).

The qualitative rating system is an oversimplification of the complex problems encountered in rock engineering. Designs based on this method are, in most cases, on the conservative side or are simply not an accurate assessment of the problem.

Stability problems, which are controlled by discontinuity failure, require a kinematic analysis. That is the only way to optimize the design of support, such as density, location, length of bolts, spacing of steel ribs and thickness of shotcrete. By using rating methods, an average rock mass quality value for the considered tunnel section is obtained. Any support recommendation, based on the average rock mass rating, must be conservative, because the potential failure mechanism is not incorporated into the quantitative classification scheme.

It is a well known fact in rock engineering that time dependency is one of the most significant parameters of rock mass deformation. The assessment of time dependent tunnel closure is of

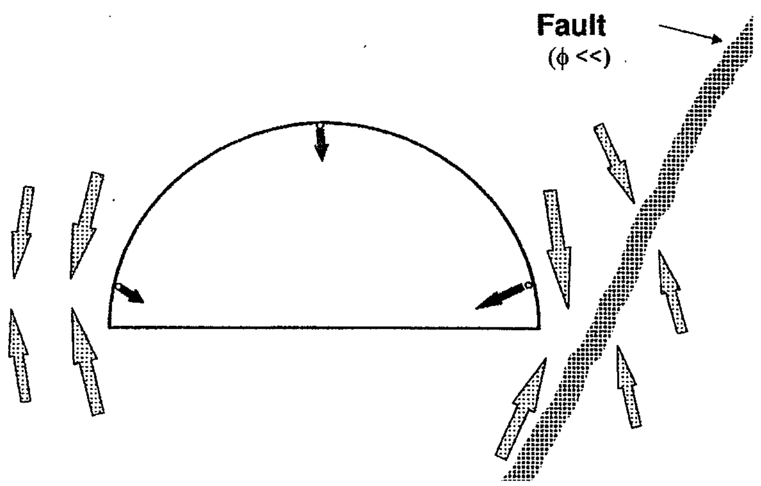

Fig. 3 Model 3: Simplified model of geological situation of stresses and deformations, with the fault below the tunnel.

Bild 3 *Modell 3: vereinfachte geologische, Spannungs- und Deformationssituation bei Störung im Liegenden.*

paramount importance in determining the appropriate supports and optimal time of installation. This essential component of tunnel design is not considered in quantitative classification schemes.

Support recommendations for squeezing rock conditions on the basis of Q-value calculations (10) contradict extensive practical experience in tunnelling (19). Selection of appropriate supports, of the optimal construction sequence and determination of required overexcavation in squeezing ground is extremely difficult. To solve this task short term prediction and displacement control using a realistic ground model must be established. Thus, instead of quantitative rock mass classification we recommend ground modelling by using empirical, analytical and numerical methods (20, 21). Ground modelling enables efficient parametric studies, such as effectiveness of different support types, effects of variations in rock mass parameters or different primary stress conditions (22).

During construction, continuously updating the predicted geotechnical models and short term prediction provides an important tool for technically and economically optimizing the construction of the tunnel (23, 24). We are confident that due to economical and environmental requirements a better appreciation of all the factors involved in tunnelling is of great importance (25, 26). This target can never be achieved by using a quantitative rock mass classification alone, that is based only on a few universally applied rock mass parameters.

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