Preventing and handling claims for changed conditions in underground works

W. RIEMER[1]

[1] *Consultant. D-54295 Trier, Germany*

Abstract: Tunnelling projects normally have to face problems of uncertainty and variability in geological and geotechnical predictions. This circumstance is prone to lead to claims for Different Site Conditions, to overrun of time and cost estimates. A good preparation of the project helps to contain the risks and should use traditional geological surveys as well as advanced techniques of subsurface exploration. However, constraints imposed on the engineer in the project preparation phase tend to become more rigid.

Although contractor's claims are quite commonly justified by unforeseen geotechnical conditions, they have frequently been caused by totally different factors and have arisen from deficiencies in the contract documents or the contract administration. Bidding procedures, harsh competition and various external factors increasingly create conditions whereby contractors resort to claims.

A Geotechnical Baseline Report constitutes a valuable component of the tender documents. The verification of baselines during construction and their effect on the contract have to be defined.

Contract documents for underground works should allow for a proper range of variation and have clear provisions on how to deal with such variations. A flexible and equitable system for compensation of tunnelling works uses 2- or more-dimensional matrices with excavation and support classes. Conventional rock mass classification systems are considered less suitable as a basis for measurement and payment.

A design-build contract will eliminate some of the risks for the owner but it cannot eliminate Owner-Contractor disputes and the potential cost overrun related to a Different Site Condition.

Appointing a Disputes Review Board has on some projects been viewed as a necessity to cope with claims and the various problems associated with them.

Résumé: Les projets de travaux souterrains rencontrent généralement des difficultés dûes à l'incertitude et à la diversité des prédictions géologiques et géotechniques. Cela conduit à des doléances basées sur des conditions différentes de celles des contrats ainsi qu'à des dépassements de délais et de devis. Une élaboration sérieuse du projet contribue à limiter ces risques et devrait se baser sur des levers géologiques traditionnels ainsi que sur des techniques de pointe de reconnaissance souterraine. Les contraintes imposées aux ingénieurs et concepteurs lors de la phase précédent les travaux tendent cependant à se durcir avec le temps.

Bien que les plaintes des entrepreneurs soient souvent justifiées par les conditions géotechniques rencontrées, elles sont aussi très souvent la conséquence de défaillances dans les documents contractuels et dans l'administration des contrats. Les procédures d'adjudication, une compétition acharnée et d'autre facteurs obligent de plus en plus les entreprises à revendiquer une compensation.

Un rapport contenant toutes les données disponibles représente un élément nécessaire des documents contractuels.

Le contrat pour l'exécution des travaux doit contenir des possibilités d'adaptation aux conditions rencontrées et prévoir des dispositions sur la manière de les mettre en oeuvre. Un système flexible et équitable de compensation recourt à des matrices bi- ou tridimensionelles, avec des classes d'excavation et de support, car les systèmes usuels de classification du sous-sol sont moins bien adaptés comme base de mesure et de payement.

Un contrat combiné "projet-exécution" élimine certains risques pour les Maîtres d'Ouvrage mais ne supprime pas entièrement les disputes et les dépassements de devis consécutifs à des conditions réelles différentes.

Le recours à un "Comité de Réglement des Disputes" s'est avéré nécessaire dans certains cas afin de résoudre les nombreux problèmes qui accompagnent les revendications.

Keywords: engineering geology, rock description, rock mechanics, site investigation, tunnels

INTRODUCTION

Cost estimates and construction performance in underground works decisively depend on a large number of geotechnical parameters. Uncertainty in the prediction as well as the variability of such parameters expose owner, financing agencies, contractor and engineer to significant risks. Claims resulting from these causes delay the progress of work, divert the activities of professionals from the tasks for which they had originally been assigned and may result in large overrun of time and cost and substantial losses of expected benefits.

Problems with underground construction have in several cases assumed spectacular proportions:

- Contractors have filed claims for additional compensation that doubled the original contract price (e. g. Marsyangdi headrace tunnel, Nepal). A major subway project in South America eventually billed three times the original contract price.

- Completion of tunnels has been delayed by one or even several years (Kali Gandaki and Middle Marsyangdi headrace tunnels, Nepal, Yacambu conveyor tunnel, Venezuela, Mohale conveyor tunnel, Lesotho, Urfa conveyor tunnels, Turkey)
- Contracts have been terminated by the owner or the contractor (Yacambu tunnel, Urfa tunnels, Berke headrace)
- Insolvency of the contractor (Urfa tunnels).
- Tunnel boring machines have been trapped or abandoned (Mornos conveyor tunnel, Greece, Pueblo Viejo headrace tunnel, Guatemala, Yacambú conveyor tunnel, Venezuela)
- Owners have sued engineers for large sums because support requirements significantly exceeded contractually foreseen quantities (Chicago, USA) or because the liner failed due to unforeseen geological conditions (Pueblo Viejo, Aguacapa, Guatemala)

Most commonly, "differing site conditions" (DSC) in geological and geotechnical aspects have been cited as causes for the overrun of cost and time. FIDIC defines this as "physical conditions or artificial obstructions which conditions or obstructions could not have been reasonably foreseen by an experienced Contractor". The ground, with all its geological conditions, is the property of the owner and, therefore, as stated in Essex (1997), the DSC clause in the contract "relieves the contractor from assuming the risk of encountering conditions differing materially from those indicated or ordinarily encountered". Thus, to avoid claims for DSC and eliminate potential pretexts for deviations from contractual agreements the conditions must be identified, correctly described, appropriately considered in the design of the structures and the tender/contract documents, verified during construction and quantitatively assessed for their impact.

ENVIRONMENT FOR UNDERGROUND CONSTRUCTION PROJECTS

Problems with geotechnical construction do not exclusively derive from adverse geotechnical conditions or inadequate design; they have to be viewed in a more general context. John (1988) had discussed the potential of rock mechanics and the limitations imposed by specific project environment and pointed out a gap between state-of-the-art in the capacity of investigation and analysis on one side and the resources for practical application and implementation under constraints, primarily of financial nature. Since then, the gap has still widened.

For engineers as well as for contractors, the competition has become more severe. Competition, but also regulations and expectations of owners and financing agencies, have led to costly procedures in prequalification and bid preparation. Bidders have to invest substantial sums in this unproductive phase of the project which will have to be recovered as overhead in the subsequent stages of the project.

Whereas even 30 years ago, the emphasis of a project study was on technical and economical aspects, nowadays environmental, sociological and political aspects assume decisive importance. The costs incurred in relation to the latter items have escalated dramatically in recent years. The change in focus diverts resources from the traditional technical preparation of a project, particularly in the early stages when investments in a project are restricted.

Once the list of pre-qualified bidders is established for a project, the contract will nowadays almost invariably go to the cheapest bidder Under this condition and in consequence of harsh competition, engineers and contractors occasionally underbid, hoping to find possibilities for savings or chances for obtaining additional compensation.. One of the more unfortunate options for savings is on professional staff assignment. Contractors and more especially engineering firms find more difficulty to invest in in-house training of junior staff and offering adequate compensation for senior staff for work in underground construction.

Apart from financial compensation, civil engineering projects no longer offer the social recognition commensurate to the professional responsibility which, especially in the case of underground construction, is often combined with physical hardships. Counterpart personnel, delegated from the owner of the project, may solve some of the staffing problems, provided the counterparts are motivated and fully integrated into the engineer's team. It is, however, quite common to find counterparts bound by other loyalties and following a separate agenda, with the resulting negative effects on the functioning and efficiency of the supervision team.

Particularly during the early stages, when the project infrastructure is still rudimentary, project staff may have to cope with difficult working conditions and have to make sacrifices in quality of life. But these early stages are frequently of decisive importance for subsequent successful development. Although in view of the project cash flow it is attractive to defer investment in exploratory works to later stages when financing has been approved and secured, it has to be realized that such scheduling will also leave unresolved problems that may eventually affect construction time and total cost.

A possibility to reduce the bid price for an engineering study is to delegate part of the work to another contract, for instance leaving the logging of drill cores to the drilling contractor and the logging of the underground excavations to the civil works contractor (whose staff will not necessarily have the specific qualification and may be biased by specific loyalties). The owner of a project should decide if such apparent savings on engineering and construction supervision are in his interest or if it would be to his benefit to leave the responsibility for such work with the engineer or his own staff.

On the side of the civil works contractor, it is becoming more common to use subcontractors. But whereas it may be appropriate to subcontract, for instance, a specialist team from the manufacturer to take care of the maintenance of a TBM, it may prove problematic if major parts of the underground works are subcontracted, where the main contractor has difficulties or limited interest in exercising full control.

With the intention of offering compensation to project affected residents, civil works contractors are frequently obliged to hire labour in the project area. This labour will need to be trained, at the expense of the contractor and the project. At least initially, the labour productivity will be low, the hazard of accidents will be higher and workmanship may affect the project in many respects, particularly in relation to the time schedule.

Last but not least, because interference with large construction projects generates public attention and offers political leverage, such projects have been targeted by trade unions and Non Governmental Organisations (NGO's). Most contracts permit the contractor to recover under price adjustment clauses for compromises with unions. Because some international financing agencies tend to back up NGO's, the concessions made to their demands normally run at the expense of the owner.

In the experience of the author, the various aspects mentioned in this section have negatively affected several projects and resulted in additional costs and over run of time schedule, although in many instances other causes have been cited, primarily "unforeseen" adverse subsurface conditions.

GEOTECHNICAL ACTIVITIES IN THE PREPARATORY STAGES OF A PROJECT

A first step for the investigation of the project of a subsurface structure consists in establishing the geological framework, i. e. the litho-stratigraphical sequence and the geological structure. This involves geological field work. A problem frequently encountered at this stage is the lack of topographical maps of adequate quality. This causes loss of time, inaccuracies and repetitive work when improved maps become available. With modern techniques of surveying and map preparation, such complications should easily be avoided.

Although perceived as "low-tech", it is mandatory that senior staff actively participate in the geological field work because this activity is of decisive importance for the advance identification of potential difficulties, for the planning of detailed investigations, for the layout of the underground structures and the development of the geotechnical model for the design of excavation and support. Especially if a tunnel runs at large depth and is not easily reached by boreholes, the geological mapping will be most essential for the project (Riemer & Thomas 1990).

A good basic geological input, derived from project-specific surveys and/or from existing data on regional geology will help significantly in the planning of subsurface explorations. There are no relevant standards or universally applicable guidelines to decide which volume of work in exploration is necessary or sufficient for a certain tunnelling project. Deere (1981) suggested a minimum of 5 boreholes, to be drilled at the portals and spaced 0.5 – 1 km along the tunnel route. Özdemir & Nilsen (1999) mention a borehole spacing of between 15 and 300 m for tunnels in hard rock and 15-150 m for tunnels in soft rock. Such close spacing of boreholes may be mandatory in an urban environment with complex geology but it is neither technically or economically feasible for long tunnels at large depth. Such a condition either calls for other means to complement the geological subsurface information or to deliberately accept the geological risk. Introducing concepts of an observational approach will then help to manage the risk (Terzaghi, 1925, Peck, 1969).

Useful improvements in the techniques of subsurface exploration developed in recent years should be applied in this context, e. g.:

- New methods of geo-electrical profiling. For the Middle Marsyangdi project, Nepal, this technique provided more accurate information on the bedrock level than refraction seismics, although calibration by boreholes was also needed.
- Directional drilling. The technique proved very useful for the geological investigation of the Gotthard Basis tunnel. In Norway a drilling system developed by SINTEF was successfully applied, among other on the Oslo Fjord tunnel. (Vertical boreholes do not provide fully comprehensive information for a horizontal tunnel.)
- Video logging of boreholes with associated evaluation of structural data.
- Borehole slotting tests for the determination of ambient stresses.

Applying these techniques in conjunction with conventional geological surveys and exploration, the uncertainties are reduced but rarely fully eliminated. A case in point is the Gotthard Basis tunnel in the Bodio drive. Geologists had devoted much effort to assess the probability of encountering fault zones. Eventually, the major complication so far experienced during construction resulted from an entirely unforeseen fault, running at an acute angle to the tunnel and reducing the daily advance rate of the TBM from more than 15 m to less than 2 m per working day (Neuenschwander 2004). For the Gotthard road tunnel, the ventilation tunnel had been driven for a short distance parallel to the main tunnel. But this did not preclude disputes when the tunnel entered the difficult zone of Mesozoic phyllites. There has also been the case in the US where a pilot tunnel had been driven the entire length of a road tunnel but the performance of the rock changed drastically and unpredictedly when the full section of the road tunnel was excavated.

The main objective of the geological and geotechnical exploration is to characterize the subsurface formations for layout, analysis and design of the structures. Frameworks for the geological-geotechnical description of rock masses for tunnelling purposes have been conceived long ago (e. g. Terzaghi, 1946, Stini, 1950, Lauffer, 1958) and became practically standardized with the introduction of the RMR System (Bieniawski, 1973, 1976, 1989) and the NGI Q-System (Barton, Lien & Lunde, 1974). Both systems use the RQD parameter (Deere, 1963). More recently, the Geological Strength Index (GSI, Hoek, Kaiser & Bawden, 1995) is becoming more widely applied. In the context of design and construction of underground structures, the classification systems offer significant benefits:

- The description of the rock mass is reproducible.
- A quantitative rating is obtained.
- The rating permits reference to large data bases and to empirical relationships for rock mass performance.

On the other hand, the apparent simplicity of a classification system risks indiscriminate application. The consequences comprise deficiencies in the prediction of tunnelling conditions, in the design of support and controversies in the interpretation of the encountered conditions. Some caveats to be mentioned in these respects are:

- Neither RMR nor Q consider the mineralogy and lithology of the rock. Although they may have the same rating, the performance of a mudstone and a limestone may differ significantly. Mechanical (TBM) excavation normally is much easier in limestone or basalt than in granite, independent of the usual rating parameters (e. g. Korbin, 1998). These circumstances must be considered in the design of a tunnel and must be expressed in the documents for the construction contract. The charts developed for estimating GSI of specific rock types as proposed by Hoek and Marinos (e. g. Hoek, Marinos & Benissi, 1998) take this aspect into consideration.
- Neither Q nor RMR give a unique classification. Quite different rock types may end up with an identical rating (Riedmüller & Schubert., 1999). A single GSI value can also apply to a range of combinations of structure, habit and discontinuity surface quality. Although corresponding geotechnical parameters may be similar over this range, different conditions may apply for practical construction.
- RMR makes allowance for the orientation of the principal discontinuity set but this mainly applies to the excavation phase. Also during this phase, the condition "drive against dip" is not necessarily as unfavourable as the adjustment by 10 points implies. In practice it will be easier to handle a weak zone if it is first encountered in the invert. Once the tunnel is holed through, the performance of the rock mass is no longer influenced by the direction of the dip. The Q-rating weighs the most adverse set of discontinuities but does not consider the orientation. GSI does not include an orientation parameter. Thus, if rock mass parameters are to be assessed, GSI and Q ratings can directly serve for the classification of a pseudo-continuum. If RMR is to be used, the adjustment for orientation should be left out.
- Essentially, the classifications as discussed in the preceding paragraphs describe the rock mass as an isotropic pseudo-continuum. Sedimentary as well as metamorphic rocks can, however, be highly anisotropic. For a phyllite, for instance, a compressive strength is clearly defined only in direction normal to the foliation. A schematic application of Q-rating to the phyllites of the Kali Gandaki headrace tunnel in Nepal had given a rating of $2<Q<50$ for 84% of the tunnel and led the engineer to consider an unlined tunnel which was rejected by the owner on the basis of experience with other tunnels in similar rock. Eventually, rock mass performance observed during construction of the tunnel mainly corresponded to a rating in the range of $0.4\leq Q\leq 1.0$
- The RMR system rates rock strength either according to uniaxial compressive strength or according to the point load index which, however, are not equivalent. The correlation between these two values varies substantially with the type of rock concerned; the conversion factor ranges from 8 to 45, with most values being between 16 and 24 (Bell, 1992). In both cases the rock should be tested at water saturation corresponding to the expected underground conditions.
- Q and RMR both include RQD, RMR additionally includes joint spacing (which then would not be an entirely independent parameter). RQD applies to a drill core; it is a linear parameter that can vary with the direction of the borehole. Thus, it may become debatable if logged in an underground excavation. Similarly, it needs to be defined, either the joint spacing should refer to an average distance measured on a drill core or is measured in the direction of the normal for each set of discontinuities. A volumetric discontinuity count would be a less ambiguous alternative.
- The classification systems do not account for the effect of non-homogeneity that may significantly distort the stress field (Riedmüller et al., 1999)
- In evaluating the performance of the rock mass in the Gotthard road tunnel, Schneider (1980) found it necessary to adjust the groundwater rating in the RMR system to the strength and quality of the rock. The performance of good quality granite was practically not affected by infiltration.
- With the Q-system Schneider (1980) found a poor definition in the range of fair to good quality rock which he attributed to an over-emphasis on the number of discontinuity sets in relation to the spacing of the discontinuities.
- Various extrapolations from rock mass classifications have been proposed, offering estimates of rock mass modulus and shear strength, stand-up time, unsupported span, etc. Limitations of such correlations should be recognized and the potential variation in the estimates must be taken into consideration.
- On the Akheloos conveyor tunnel in Greece the contractor consulted Prof. Bieniawski on a rock mass quality assessment for a sheared mudstone/shale formation that proved extremely problematic for TBM excavation. Bieniawski concluded that describing this rock by an RMR value would be inappropriate (verbal communication). Incidentally, although the tunnel route had been well studied, the wide shear zone had not been predicted and it nearly rendered impossible excavation with the open TBM.
- Site-specific classifications may be required.
- Among the lithology-related phenomena not being addressed by conventional rock mass classification, degrading rocks (mainly mudstones but also volcanic rocks, Riemer, 2003) need to be mentioned. Based on rock mass classification, the 44 km long transfer tunnel in basalt of the Lesotho Highlands Water Project was

designed as a machine bored, unlined tunnel but, when degrading of the rock started shortly after excavation, it had to be fully concrete lined, with corresponding increase in time and cost.

- The data base for Q- and RMR-systems essentially contains conventional drill-and-blast tunnels. Alber (1998) suggested an adjustment of the RMR rating for TBM excavation:

  $RMR_{TBM} = 0{,}84\ RMR_{D\&B} + 21$

  with $RMR_{D\&B}$ = conventional rating RMR_{TBM} = adjusted for TBM

  Hoek (e. g. Hoek, Carranza-Torres, Corkum, 2002) has introduced the disturbance factor D which, in conjunction with GSI and an empirical failure criterion accounts for the method of excavation. This helps to estimate the support requirements but it does not relate to the penetration rate of the TBM which is a most important aspect. Barton (2000) complements the Q-rating with a factor for abrasiveness and cutter life which to some extent takes the petrographic aspects into consideration that are known to influence TBM performance (e. g. Korbin, 1998).

The preceding discussion is not intended to discourage the application of rock mass classification systems for underground construction but it serves to point out potential ambiguities and deficiencies. Overlooking such limitations is prone to entail omissions in the design and the specifications for the underground works and, eventually, claims for "unforeseen" conditions.

Particular precautions have to be taken if TBM excavation is envisaged. TBM tunnelling does not provide the same flexibility to adjust to adverse conditions as conventional drill-and-blast excavation. The procurement and the installation of a TBM require a heavy initial investment. If rock mass performance and penetration rate differ significantly from the expectations that governed the selection of the type of the machine, either the contractor or the owner will face the costs of unsatisfactory advance and time over-run. The alternatives of an exchange or substantial modification to the machine would not normally be a feasible option. For instance, as Grandori et al., 1995, show, driving with a shielded TBM and pre-cast segment lining would not be economical in good rock but would prove advantageous if weak and unstable rock is encountered that could be prone to paralyze an open TBM. Geological investigation and geotechnical testing for a TBM project will have to go significantly beyond the scope of usual rock mass classification, for instance with Q and RMR rating. Procedures, as described by Bruland (2000), Rostami et al., 1993 or Tarkoy (1975) will also have to be applied.

An aspect which in the context of TBM excavation has to be given more attention than in conventional excavation is the variability in the composition of the rock mass. On small scale, this leads to "mixed face" conditions that have been claimed to reduce penetration, cause machine vibrations and excessive damage to the cutters and cutter head.

GEOTECHNICAL DESIGN FOR UNDERGROUND STRUCTURES

Excavation and support have to be designed against the potential failure mode of the rock mass (and, in the case of pressure tunnels also for internal loads). During the excavation stage, the "safe width of span", as defined by John & Baudendistel, 1981, is a most important variable. It governs the selection of the excavation procedure (sectional, full face), the selection of tunnelling machine and the time schedule. The safe width of span depends on static parameters like rock mass fabric, rock mass strength and ambient stresses but is also time related and can be affected by the construction method eventually adopted by the contractor. The designer must apply particular care in assessing the safe width of span, making the pertinent provisions in the contract and providing the contractor with information and enabling him to select his methods accordingly.

The task is approached by an evaluation of rock mass fabric and can be supported by diagrams relating Q-rating with support (e. g. Barton, 1998) and RMR-rating with stand-up time (e. g. Barton, 1976, Bieniawski, 1976). However, as rock mass classification systems do not very adequately deal with rheological behaviour of rock masses, it is prudent to extend the range to cover quite unfavourable assumptions.

As generally agreed, the design of underground support can only take guidance from a rock mass classification but needs to be based on specific numerical analysis. Barton (1998) favours distinct element models like UDEC or 3DEC which are a good complement for the pseudo-continuum concept underlying the rock mass classification. Using GSI, a link to the "empirical failure criterion" is conveniently established which, in turn, can be introduced into finite element models (Hoek et al., 1995, ROCLAB and Phase2 models by ROCSCIENCE). In addition to failure by shear or tension, analysis should also include failure due to buckling in stratified, slabby or schistose rocks and the failure of wedges or prisms defined by the rock mass fabric (see, for instance, Hoek & Brown. 1980, UNWEGDE model of ROCSCIENCE, SOLIDROCK model of Graf).

TENDER INFORMATION

FIDIC Conditions of Contract request the tenderer to base his bid on "data..as have been supplied by the Employer" and to "satisfy himself (so far as is practicable) .. as to the form and nature of the Site" and to "obtain all necessary information (subject as mentioned above) as to risks contingencies and other circumstances which may influence or affect his Tender.".

Leaving bidders with the responsibility to conduct their own geological and geotechnical investigation of the site has been viewed as a way to avoid claims for "different site conditions". But there are serious objections to such an approach:

- Time available for bid preparation does rarely suffice for appropriate site investigations.
- Cost for the investigation would have to be included in the bid price, adding to the expense of investigations already conducted by owner and engineer.
- In litigation, it is generally judged inadmissible for the owner or engineer to withhold information that would have been decisively important for a bidder in establishing his methods and estimating prices.

Thus, it is practically obligatory to furnish bidders with all factual information, such as geological maps, borehole logs and test results. This information is in the document known as the "Geotechnical Data Report". Such information will officially or indirectly constitute part of the contract documents. On the other hand, interpretative documents such as, for instance, design reports, are either not communicated at all or are explicitly exempted from the contract documents. However, the Technical Specifications as well as the Bill of Quantities are, of necessity, developed from an interpretation of the expected geological and geotechnical conditions. Thus, the engineer and owner are not entirely relieved from the responsibility and risk of interpretation. In this context, a "Geotechnical Baseline Report (GBR)" (Essex, 1997) can serve to define and contain the risk that the owner will accept and will also protect the bidder in the event that a DSC is encountered.

Baselines may, for instance, state the number of faults to be penetrated, the infiltration, the temperature, the drillability index, the cutter live index, bulking factor of muck, etc..

The owner may set the baseline at an expected average or at a higher or lower value, depending on the margin of risk he is prepared to accept for compensating deviations from the baseline. Similarly, the bidder may opt to calculate his price based on the baseline values or to adopt a more pessimistic or optimistic value. In the latter case, he would offer a lower price but assume a higher risk.

The concept of the baseline report is very attractive but in practice it can have its problems, such as:

- Conditions are encountered that are not covered by the baseline report.
- The method of verifying baseline values may be questioned. It can, for instance, be debated if the compressive strength of a rock determined in the laboratory corresponds to the effective strength of the rock under stresses prevailing at depth. Therefore, it must be clearly specified as to what kind of measurement the baseline value refers and how it is to be verified during construction.
- If a baseline is exceeded, the contractor is entitled to claim for compensation. The contract documents should for such case provide adjustment clauses for cost and time. If such clauses are not provided the GBR does not really help to avoid debates on claims.

If the bidders file method statements, these usually also rank as contract documents. In this way, contractor's concepts are practically added to the baselines. It could prove useful to deal with these conditions in the course of the contract negotiations.

Complementing the GBR with a rating system as proposed by John et al., 1981, could help to arrive at a weighted compensation for the incidence of various factors, giving scores for rock conditions, safe width of span, water inflow, excavation and support classes, etc.

CONTRACTUAL ARRANGEMENT

The classical contract follows the principle of "design-bid-construct". There is a trend to substitute this by "design-construct". The latter version eliminates the sometimes strained relations between engineer and contractor and forecloses claims deriving from delays in issuing good-for-construction drawings and for inadequate or defective designs. The design-build contract cannot, however, prevent claims for DSC. The owner will still need a technical team on site for quality assurance. Instructions given by that team may prove as controversial as those issued by the engineer in a more traditional contractual setup. Moreover, the owner may find it more difficult to introduce changes in the design as necessary in the progress of the construction work. From a geological point of view, a design-build contract will probably require better preparation than a conventional contract that more flexible responds to encountered conditions.

Donnelly (1999) describes the concept of a risk insurance covering the owner in the event that significantly more adverse tunnelling conditions are encountered than had been anticipated. But the insurance also has its prize. The engineer will have to seek special protection under the clauses of such insurance. There is precedent that courts (in Australia) have attributed damages resulting from unpredictable, extreme events to design error which would relieve the insurance from its obligation.

Most contracts foresee penalties for time overrun but incentives for improvements on contract performance are rarely provided, although the owner may benefit from the early commissioning of a tunnel. For instance on the Manapouri tailrace tunnel in New Zealand, the owner and contractor jointly offered a bonus to the operators for the rate of utilization of the TBM. The result proved satisfactory to all parties. For local labour a tunnel project may be the only source of income and timely completion of a project for them is rather a disaster than a success. Understandably under such conditions, work may slow down when the project draws to an end (e. g. Matsoku tunnel, Lesotho).

DEFINITIONS FOR MEASUREMENT AND PAYMENT

For a contractor, the cost of constructing a tunnel mainly derives from the time spent for excavation (with time related costs for labour, equipment and installations) and the materials installed for support. Under certain conditions, the overbreak can also constitute a major cost factor, especially if a concrete lining has to fill the added volume.

A system proposed to provide equitable and verifiable compensation to the tunnel contractor considers a matrix of excavation and support classes. The excavation classes are based on the practical concept of "safe span". Full face, length of round, heading-and bench or other sectional excavation should be distinguished. The support is intended to provide at least the temporary stabilization of the rock. The number of classes should reflect the anticipated variability of tunnelling conditions, as for instance shown in Table 1 with 7 classes. More commonly, four support classes would suffice.

In addition to the density of rock bolt spacing, the type and the length of the bolts should also be considered. Swellex, split sets or self-boring bolts are more suitable for short stand-up times than conventional SN-bolts. A similar consideration should apply to steel sets. Frequently, the Bill of Quantities lists only one item for heavy sets, whereas in many cases light sets or lattice girders would also serve the purpose. To make the classification even more flexible, a weighting system for the individual support items can be added. This would allow, for instance, the partial substitution of shotcrete and rock bolts for steel sets (which some more traditional contractors still prefer). The weighting would preclude some options to invalidate contractual provisions and encourage alternative methods with new unit prices or change orders.

Table 1. Sample Specification of Support Classes

SUPPORT ELEMENT		SUPPORT CLASSIFICATION						
Description	Unit	R-1	R-2	R-3	R-4	R-5	R-6	R-7
Fibrecrete	m^3/meter	-	< 0.6	0.6 -1.8	1.8- 4.0	≥4.0	≥4.0	≥4.0
Rock Bolts	Each/meter	≤ 4	5-12	8-16	12 -20	16 -24	>15	>15
Steel Sets	Each/meter	-	-	-	< 0.2	0.2 - 0.8	≥1	≥1
Steel Sets + Invert Struts	Each/meter	-	-	-	-	-	May be rqd.	May be rqd.
Spile Bars		-	-	-	-	-	May be rqd.	May be rqd.
Face Support		-	-	-	-	-	May be rqd.	May be rqd.

Care should be taken in allocating quantities to alternative or equivalent items in preparation of the Bill as well as in the evaluation of bids. Bidders may mark high prices for items with low quantities so that during construction, if the quantities for such item increase, the cost may rise notably.

It is perfectly legitimate for the contractor to try using those excavation and support classes that offer the highest benefits. In most cases that means slow excavation and heavy support. In this situation, applying the principles of the New Austrian Tunnelling Method (NATM), the adequacy of the confinement afforded by the installed support can be verified to eliminate disputes on the support classes. However, the support requirements do not exclusively depend on the geotechnical conditions, the construction methods can have a significant influence. Techniques of drilling and blasting will result in widely varying degrees of rock disturbance, for example, in strain-softening or degrading rocks the support should be installed shortly after excavation and inadequately blocked steel sets and poorly installed bolts do not provide the expected confinement, etc. In these cases the supervision should reject payment of the support and adjust the support classes. But such decisions may oblige the superviser to assume responsibility for the safety of the underground works if controversial decisions on the classification for payment cannot be very solidly defended. Obviously, the supervision will have to incorporate highly qualified and experienced staff.

If the concept of excavation and support classes is adopted, other rock classification systems are contractually irrelevant. Contractor and supervision may use Q, RMR or GSI to assist in selecting the proper classes but the rock mass classification cannot serve to justify compensation below or beyond the technical and geotechnical requirements established in the actual course of construction.

Mechanical excavation calls for an entirely different system of measurement and unit prices. The overall performance of a TBM primarily results from a combination of penetration rate and utilization. The latter parameter includes maintenance, commonly required for such complex machines because of abrasion or other damage to the machine caused by adverse geological conditions, faulty or inefficient operation, handling of muck and installation of support.

For the tunnels in the Karoo basalts of the Lesotho Highlands Project 4 different face classes were defined, depending on the proportions of different types of rock in the face, controlled either by direct inspection of the face or from the muck (shielded machines were used). This approach helped to defend against claims for adverse "mixed face" conditions but no significant correlation between face classes and TBM performance could be established. An important claim was, however, presented for higher than anticipated compressive strength of the rock. Compressive strength of the rock is not necessarily a relevant parameter for TBM excavation (cf. Korbin 1998) but as it is easily determined in the project preparation phase, it shows up prominently in contract documents and may then lead to disputes. Particularly relevant parameters like drillability and cutter life indices are more difficult to determine and other features, like the orientation and persistence of discontinuities in the rock mass can assume decisive importance. For instance, on the Manapouri tunnel slow progress and damage to the cutter head had been attributed to high strength, mixed face and massive rock but a comprehensive analysis identified blocky rock in fault zones as the most adverse factor because, with the large tunnel diameter of 10m, the blocks detached from the face were slow to be picked up by the muck buckets.

With a shielded TBM it becomes difficult or virtually impossible to check out some of the rock mass parameters during construction, as for instance characteristics of the discontinuity fabric. In Switzerland, a concept for TBM contracts is applied that largely avoids problematic determination of not necessarily relevant parameters and still offers equitable compensation to the contractor (for a narrative of the experience in the Gotthard Basis Tunnel see Neuenschwander, 2004). The prices are calculated on a 3-tier system, considering (1) specific rate of penetration as directly determined in the tunnel, (2) abrasiveness of the rock and (3) a further adjustment accounting for support required in the forward range of the machine. With this concept, the penetration tests must be run with defined cutters and at a specified net thrust. A potential problem rests with the determination of the net thrust which, depending on the design of the machine, will differ more or less notably from the gross thrust. Abrasiveness is measured by the CERCHAR index (but other test procedures could also be introduced). Moreover, the contract provides for compensation for dewatering and other factors beyond the control of the Contractor. Such Contracts cover a very wide range of variability in tunnelling conditions and largely eliminates the need for new unit prices (and related disputes) to be determined during construction.

SUPERVISION, QUALITY ASSURANCE, DISPUTES

During construction a team either for comprehensive supervision or for quality assurance should be on site, depending on the type of contract. The team will need multi-disciplinary qualifications, covering geology, rock and/or soil mechanics, tunnelling technology, occupational safety, environmental aspects, contract administration and, in the case of TBM excavation, expertise in mechanical engineering. Supervision of a tunnelling project is rarely a routine job and unconventional decisions involving high responsibility and judgement may be called for. To take such decisions correctly, the team should be fully familiar with the design and the reasons for specific design features. Therefore, it would be desirable to have the design engineer involved in the supervision (Lombardi, 1981, deplored the frequent separation between designer and construction supervision in tunnel construction). In some countries (e. g. Iceland) regulations prevent the designer from also assuming the construction supervision. In other cases, the owner uses his own staff or contracts a resource offering cheaper prices than the design group. Especially the latter solution increases the risks for the owner as well as for the original designer if the designer is no longer competently represented on site .

FIDIC conditions give the engineer authority to decide on disputes (the owner should reserve the right to review such decision before it is issued!). The practice to appoint an additional Disputes Review Board (DRB) has been promoted mainly in the USA. The DRB should comprise representatives for the owner and the contractor. The existence of a DRB can help to prevent a backlog of unsettled disputes and claims building up and can save the complications and costs of arbitration or legal proceedings. It can relieve owner and engineer from the responsibility for controversial decisions. In some countries on public works contracts a decision in favour of the contractor immediately exposes the engineer and the owner's representative to an accusation of corruption. In consequence, the engineer and the owner's representative will in principle reject all claims that the contractor may present. In such situations, the independent analysis of a DRB can prevent a deadlock in the disputes with its paralyzing effect on the works. In essence, however, a DRB is a complication that results from the more strained owner-engineer-contractor relationships.

CONCLUSIONS

Tunnelling projects normally have to face problems of uncertainty and variability. This condition is prone to lead to claims for DSC, based on overrun of time and cost. A good preparation of the project helps to contain the risks and during the early phases of a project, competent geological field work may prove more cost-efficient than sophisticated tests and analysis.

Although claims are quite commonly justified by unforeseen geotechnical conditions, they have frequently been caused by quite different factors and have been encouraged by deficiencies in the contract documents or the contract administration. Contract documents for underground works should allow for a proper range of variation and have clear provisions on how to deal with such variations.

The supervision should have the competence and the authority to handle unusual problems. The owner should support the engineer if decisions of far reaching responsibility have to be taken.

A design-build contract will eliminate some of the risks for the owner but it cannot eliminate the potential costs related to DSC.

Contract conditions should be equitable to the contractor. Offering incentives for good performance can be more effective than imposing penalties for delays.

Acknowledgements: In preparing this contribution, the author could draw on the experience on many colleagues from a large number of constructed projects. Particular credit goes to M. Gavard and A. Krumdieck who critically reviewed the text.

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