Squeezing behaviour: observation and monitoring

Håkan Stille*

Summary

The nature of squeezing ground is complex and partly unknown. The accuracy of the design rules for squeezing ground is limited. The observational procedure is a reliable and useful tool for design of tunnels in such a ground. It is important that the observational procedure is planned and executed in a professional way. The identifying of squeezing ground, instrumentations and monitoring as well as interpretation are all essential steps for a successful design. The regular rock mass classification systems cannot solely be used for identifying squeezing ground. Deformation measurements are normally more reliable and less ambiguous than measurements with stress cells or strain gauges. In order to facilitate the interpretation of measurement results a conceptual model can be useful.

1. Introduction

Observation and monitoring for establishing a safe tunnelling and an adequate tunnel design is used more or less in every underground project.

The nature of the problem like limited pre-investigation, complex geology, complex mechanics, complex technology for tunnel excavation will form the reason for the need of further information during the tunnelling operation.

Squeezing ground is no exception from this condition. Contrary the nature of squeezing ground is to a large extent still unknown. Observation and monitoring may be the only tool to establish an adequate design as stated by PANET [1996]:
"monitoring of convergence during face advance and back analyses of the measurements appear to be the most reliable approach to provide an overall assessment of the behaviour of the rock".

In this paper some comments are given regarding observation and monitoring in general as well as some detailed aspect on the observational procedure for squeezing ground.

2. Observation and monitoring in general

Observation and monitoring of tunnelling projects can provide information useful for:
1) Evaluating tunnel stability.
2) Evaluating adequacy of design of underground openings.
3) Evaluating disturbance and causes of environmental impact.

Many researches and experiences from tunnel projects have pointed out or indicated that special requirements must be raised on observational programs in order to be successful, see for example [CORDING *et al.*, 1975; FRANKLIN, 1977 and KOVARI *et al.*, 1979].

The first requirement is connected to the quality aspect of doing the right thing. The location and type of instrumentation are depending on the actual geology, i.e. the geology, which can cause the instability, has to be identified as well as the instruments must provide adequate measurement results in order to be able to monitor the potential instability. These indicate quite clearly that observation and monitoring is a part in a chain, where all links are working together to a successful result. It is the problem which is intended to be observed that has to govern the observational program independent of the purpose of the program.

The second requirement is that the results of the monitoring like instrument measurements must be correlated to critical observation of significant aspects of geology and construction. Without these critical observation of geology and construction it will be more or less impossible to interpret the measurements. For the most simple application of observational program like by measurements showing that no disturbance has occurred or no ongoing deformations exist limited requirements on critical observation of geology and construction can perhaps be tolerated.

The third requirements is connected to the possibility to make a deeper interpretation of the stability or evaluating the adequacy of the design. In such cases the observation must be related to a conceptual model of the tunnel behaviour so that strictly a confirmation or rejecting can be discussed. The last requirement is related to provide a successful communication concerning the observation results between the involved parties, see for example SAKURAI *et al.* [1993].

* Professor in Soil and Rock Mechanics Royal Institute of Technology, Stockholm, Sweden

An adequate organisation and contracts are necessities for this aspect as well as a good working climate.

Regarding squeezing ground it is obvious that the lack of accuracy of the design rules will emphasise the need of evaluating the adequacy of the design of underground openings during construction.

3. Observational procedure

Design on the basis of the most unfavourable assumptions is inevitably uneconomical. For many tunnel projects it is also impossible or not economically feasible to investigate the ground condition in detail.

The gaps in the available information are filled by observations during construction and the design can be modified in accordance with the findings.

This basis of design has been called the "Observational Procedure" by TERZAGHI *et al.* [1967].

The observational procedure has been practised successfully throughout the years in tunnel engineering more or less instinctively and without any clear basis. PECK [1969] outlined the steps necessary for using the observational procedure for earth works as follows:

1. Exploration sufficient to establish at least the general nature, pattern and properties of the deposits, but not necessarily in detail.
2. Assessment of the most probable conditions and the most unfavourable conceivable deviations from these conditions. In this assessment geology often plays a major role.
3. Establishment of the design based on a working hypothesis of behaviour anticipated under the most probable conditions.
4. Selection of quantities to be observed as construction proceeds and calculation of their anticipated values on the basis of the working hypothesis.
5. Calculation of values of the same quantities under the most unfavourable conditions compatible with the available subsurface data.
6. Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis.
7. Measurement of quantities to be observed and evaluation of actual conditions.
8. Modification of design to suit actual conditions.

For tunnelling the active design concept [STILLE, 1981] has been used which has great similarity with the observational method.

The concepts are described by the following three steps:

Prediction *Observation* *Measurements*

Prediction is the very basis for a successful design. The prediction is based on best possible knowledge of ground condition and the mechanical behaviour of the stability problem. The prediction shall not only establish the design of the behaviour anticipated under the most probable conditions but also likely deviations in both favourable and unfavourable directions. The prediction shall also establish the critical path and significant factors and behaviour of tunnel for guiding of the observation and monitoring.

Tools for the prediction can be both risk analysis (like event and fault tree) and different types of rock mechanical analysis. In order to quality control the design, the prediction must be clearly reported in a design specification.

The observation is the heart in the active design process. The key to success is to be able to identify such tunnel reaches that can have a geology causing the studied instability problem with other words to be on the right place at the right time. Careful geological mapping and visual inspection of the tunnel and initial support is very important.

To be successful the observation program must be related to significant and relevant behaviour of the studied problem (design).

The instruments themselves must not be too complex or difficult to install in time to obtain significant data. Instruments should not become unstable in actual conditions and should not provide results in which the real behaviour of the tunnel is inseparable from instrument error.

An instrumentation program can be successful, even with failure of some instruments, (a) if redundancy is built into the program so that the necessary data can be collected despite instrument failure, (b) if the instrumentation crew can detect spurious data and correct problems in the field, and (c) if the instrument suppliers can respond rapidly and adequately when their instruments do not perform as they should.

Observation is also a question of contract and organisation. Different types of obstacles like general, organisation and human obstacles can prevent that a proper monitoring will be carried out.

The results from observations and monitoring must be handed over to the responsible tunnel designer in time and in such a way that the information is readable. There are many examples when information has not been passed over in time causing delays and frustration for the tunnel work.

The construction procedure must provide adequate support for all possible ground conditions, or it must be adjustable so that it can meet changing ground conditions.

Possible actions to be taken depend on the results of the observation. Actions like increasing or decreasing of amount of support, support type, excavation procedure are all examples of action to be taken during the tunnel operation.

Decisions for adjusting the construction procedure to fit the ground conditions in the heading must in some cases be made immediately and on the spot by those who are responsible for the tunnelling operation.

An engineer or shift foreman, even though in a blocky rock mass, capable of visually evaluating the support requirements in a tunnel, is not able to visually assess the overall stability in a complex geology or of a larger opening.

4. Identification of squeezing ground

The nature of squeezing ground is clearly described in ISRM's definition.

"Squeezing of rock is the time dependent large deformation, which occurs around the tunnel as is essentially associated with creep caused by exceeding a limiting shear stress. Deformation may terminate during construction or continue over a long time period".

This type of behaviour is connected to poorer rock conditions, but it is also important to point out that the contrary is not guilty, i.e. poorer rock will not always show up a squeezing behaviour.

It means that a regular rock mass classification like a low Q or RMR-value will not give the answer to the question if the rock can squeeze.

Squeezing is connected to type of rock and mineralogical contents. Considerable amount of clay mineral is a prerequisite for squeezing [TERZAGHI, 1946]; shale, carbonaceous rock and to clay weathered and altered crushed rock, is example of squeezing ground. Another material like salt and ice show also typical creeping behaviour.

A careful geological mapping with description of rock type, mineral content and amount of clay content is necessary beside ordinary rock classification to identify squeezing ground. Visual inspection of the tunnel and installed support can also give guidance to identify squeezing ground.

Creep tests on rock material can also give valuable information if squeezing is prevailing.

5. Instrumentation for observation of squeezing ground

After a tunnel reach with a possible squeezing nature has been identified adequate instrumentations have to be installed.

Details of different instruments for monitoring are given in textbooks like for example HANNA [1973] and DUNNICLIFF *et al.* [1988].

Due to the nature of squeeezing like ongoing for long time as well as vary from section to section it is recommended to use a system which has a long stability in the measuring device as well as cheap enough to be used in adequate number of measuring sections.

Data from stress cells or strain gauges can be useful but they are essentially point measurement subject to variability in geologic or support conditions. A large number of measurement points will normally be required. Many deformation measuring systems are normally more representative for a larger area. Deformation measurements are therefore more reliable and least ambiguous.

For these reasons it is often preferable to measure deformation with systems for convergence measurement or with extensometers. Integrated measuring technique for rock pressure determination has in several cases shown to give reliable results [KOVARI *et al.*, 1977]. By more or less complex back calculation techniques stress and strain can be found.

6. Examples of field monitoring

The following describes some experiences gained of monitoring squeezing ground in the tailrace tunnel of the Uri Hydro Power project in Kashmir in India. The project and the experiences of rock support in weak rock has been fully described by BRANTMARK [1998].

In the parts of the tunnel which were excavated in the crushed graphitic schist, the rate of convergence was initially extremely high (40-100 mm/week) but after completion of the rock support, including a cast invert on April 1995, the rate of movement decreased in general to 0.5-5 mm/week. This deformation rate was then often continuous for a long time and not until August 1995 were some completely stable sections observed in schist.

In the parts of the tailrace tunnel which were excavated in shale and where the overburden was more than about 300 m, an ongoing time-dependent movement was observed even more than two years after the tunnel excavation was completed. The total convergence was here in general about 100 mm or less and the rate of creep was from fractions of millimeters to a few millimeters per week. The deformation was measured with an ordinary tape extensometer.

The observed ongoing squeezing caused concern for the designer. Since the tunnel ultimately was to be lined with an unreinforced lining, the resulting pressure from squeezing had to be estimated. In order to do so, the future behaviour of the rock mass had to be predicted. The effect of the lining on that behaviour should be included in this analysis.

It was found that this problem could not be solved by calculations only. Therefore two test linings were cast and instrumented in different geologicals conditions. The first lining was cast in May 1994 at chainages 1380-1385. This stretch contained graphitic-phyllitic schist of very poor quality with veins of marble of good quality. The second test lining was cast in mid-April 1995 at chainages 1558-1576. The rock consisted entirely of thinly bedded red shale with high contents of clay.

Measurement sections have been installed at four different locations; in the first lining at chainage 1383 and in the second lining at chainages 1564, 1566, and 1571. In each of the sections the displacement was monitored using two different techniques.

The horizontal convergence of the test lining was monitored using a tape extensometer. Difficulties of keeping the measurement points clean and undisturbed made the accuracy initially poor. The results show that the rate of movement is very low or has completely ceased.

In addition to the tape extensometer, an integrated measuring technique was adopted. Briefly, changes in the tangential strain and curvature were monitored by means of a distometer and a curvometer. Assuming elastic conditions, it is possible to relate monitored deformations to pressure applied by the rock mass. The adopted method was originally designed for steel sets, yet the theories can be used on a concrete lining as well. Measurements using this technique were carried out from June '94 to November '95 at chainage 1383 and from May '95 at chainages 1564 and 1571. At chainage 1566 measurement was started in June '95 and finished in November.

The tangential strain and curvature are measured at 15 to 18, one metre long, sections along the tunnel periphery. The length of each section is monitored using a distometer and the height of the arch is monitored using a curvometer.

The integrated measurement technique requires readings of high accuracy to provide good results. The measurement points in each section consisted of spherical balls, normally made of stainless steel. Since the construction site is located in a remote area, the specified spherical balls were not available and some of the balls installed had to be manufactured on site. These balls could not be made with the highest precision, and the balls were not of stainless steel. In addition, the illumination was sometimes poor and some of the measurement points were hit by machinery. Further, installations such as ventilation, cables, water and air pipes obstructed the reading. The precision of the readings therefore became lower than normally could be expected. The reading accuracy achieved was about ±0.1 mm, which is about 5 times as much as normally desirable.

The reduced accuracy was compensated for by increasing the amount of readings. In general readings were taken once or twice a week. The effect of inaccuracy in readings was then filtered out by manual interpretation of the data.

The stress in the lining can be computed from the measured deformation using the theories developed by KOVARI *et al.* [1977].

The resulting stresses are illustrated in Table I. From the figures it can be concluded that the resulting radial pressure was an average 0.6 MPa in the lining located in shale (chainages 1/564-1/571) whereas it was 2.7 MPa in the part located in crushed schist (chainage 1/388). The corresponding tangential stress in the concrete was on the average 6 MPa with the peak stress of 12 MPa in the lining placed in shale and 17 MPa and 33MPa in the lining located in cruscheded schist.

The measured deformation, deformation rate and stresses were compared with both empirical, analytical and numerical solution on the squeezing ground problem. The conclusion was quite clear "The only reliable prediction of how squeezing affects the installed support is to carry out full scale tests in the tunnel".

Tab. I – Observed pressure on the test linings.
Tab. I – Pressione osservata sui rivestimenti di prova.

	Section 1564-1571 Shale	Section 1388 Crusched Shist
Measured radial pres. (MPa)	0.6	2,7
Measured tangential stress (MPa)	6	17

7. Conclusions

The nature of squeezing ground is complex. The observational procedure has been found to be a reliable and useful tool for design of tunnels in such a ground.

It is, however, very important that observational procedure is planned and executed in a professional way. The identifying of squeezing ground, instrumentations as well as interpretation are all essential steps for a successful design.

References

BRANTMARK J. (1998) – *Rock Support in Weak Rock. – A study based on the Uri Project.* Dr Thesis, Div. of Soil and Rock Mechanics, Royal Institute of Technology, Stockholm.

CORDING E.J. *et al.* (1975) – *Methods for geotechnical observations and instrumentation in tunnelling.* Dept of Civil Eng, Univ of Illinois at Urbana-Champaign, voll. I-II.

DUNNICLIFF J., GREEN G. (1968) – *Geotechnical instrumentation for monitoring field performance*. John Wiley & Sons.

FRANKLIN J.A. (1977) – *The monitoring of structures in rock*. J Rock Mech Mining Sc., vol. XIV, n. 4.

HANNA T.H (1973) - *Foundation instrumentation*. Series on rock and soil mechanics, Transtech Publications, n. 3, vol. I, pp. 1971-73, Clausthal.

KOVARI K., AMSTAD Ch., FRITZ P. (1977) - *Integrated measuring technique for rock pressure determination*. Int Symp on Field Measurements in Rock Mechanics, Zürich.

KOVARI K., AMSTAD, Ch. (1979) – *Decision making and field measurements in tunnelling*. 25th OYO Anniversary Lecture Meeting, Tokyo.

PANET M. (1996) – *Two case histories of tunnels through squeezing rocks*. Rock Mech. Rock Engineering, 29, 3, pp. 155-164.

PECK R.B. (1969) – *Advantages and limitations of observational method in applied soil mechanics*. Géotechnique, vol. XIX, n. 2, pp. 171-187.

SAKURAI S., KAWASHIMA I., OTANI T. (1993) –*A criterion for assessing the stability of tunnels*. Proc. Euroc 1993, Balkema.

STILLE H., OLSSON L., BREDENBERG H. (1981) – *Monitoring of foundation work in urban areas*. STU-information nr 253–1981, Stockholm (in Swedish).

TERZAGHI K. (1946) – *Rock tunnelling with steel supports*. Commercial Shearing Inc.

TERZAGHI K.T., PECK R.B. (1967) – *Soil mechanics in engineering practice*. John Wiley & Sons.

Comportamento spingente: osservazioni e monitoraggio

Sommario

Le caratteristiche del terreno spingente sono complesse e in parte poco note. La capacità di formulare previsioni progettuali attendibili in condizioni di comportamento spingente è limitata. Al contrario, il ricorso all'approccio osservazionale rappresenta un metodo di progettazione attendibile ed utile in queste situazioni. È però essenziale che tale approccio venga pianificato ed applicato in modo rigoroso. I passi essenziali per una progettazione appropriata comprendono l'identificazione del comportamento spingente, il monitoraggio con efficace strumentazione e l'interpretazione dei dati. Il ricorso ai soli metodi di classificazione non rappresenta un mezzo sufficiente per individuare tali modalità di comportamento spingente. Le misure di deformazione sono generalmente più attendibili e meno ambigue del ricorso a misure con celle di carico e celle estensimetriche. Al fine di facilitare l'interpretazione dei risultati delle misure può essere utile l'impiego di un modello concettuale appropriato.