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Dealing with Squeezing Conditions in Alpine Tunnels

By

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Summary

In fault zones, excessive deformation during and after tunnel excavation is frequently encountered. Shotcrete in combination with grouted rock bolts has successfully been used in many applications to control the deformation process. The magnitude of deformation frequently exceeds the deformability of the shotcrete lining. In the past, this problem has been solved by dividing the shotcrete lining into "segments" and leaving gaps between the segments to accommodate deformation without damage to the lining. The need for minimizing deformation in an extremely heterogeneous fault zone at the Galgenbergtunnel (Austria) led to the development of low cost yielding elements, installed between the shotcrete "segments" and the use of a new type of re-groutable rock bolts. New techniques in evaluating the results of displacement monitoring have improved the short term prediction.

General

Squeezing rock is frequently encountered in phyllitic schists, argillaceous schists, clays, marls, or tectonically altered gneiss.

Radial deformation of up to 100 mm caused by quasi-plastic deformation of the rock mass during and after the tunnel excavation has been observed in several places (Rabcewicz and Hackl, 1965; John, 1976; Schubert and Marinko, 1989; Schubert, 1992). The problems with support caused by the excessive deformations have been well known for decades. As early as 60 years ago deformable supports, consisting of segments with intermediate timber to provide ductility, and timber block supports were used in mining (Lenk, 1930; Rabcewicz, 1944). Rabcewicz (1950), who had considerable experience in squeezing rock conditions, proposed a system of concrete with intermediate deformable timber elements. One of the main problems at that time was the unsymmetric deformation of the lining, which in general, required a reshaping prior to final support installation.

With the NATM approach of using a flexible lining, many tunnels in squeezing rock conditions have been successfully constructed. Rock bolting in combination with a flexible shotcrete lining minimized the problem of unsymmetrical deformation and loosening of rock, as well as improved the overall stability.

Although it is well known that shotcrete, especially when still "green", has a high potential for creep deformation (Rohkar and Lux, 1987; Schubert, 1988), regular shotcrete is not able to sustain strains of the magnitude developing in fault zones without failure. Radial displacements of the lining of 200 to 600 mm have been observed frequently in fault zones. Experience shows that shotcrete starts shearing at an average strain of less than 1 %, corresponding to a radial displacement of less than 60 mm for a heading of a 12 m diameter tunnel. Efforts to prevent deformation from the very beginning by means of a stiff support result in spectacular shear failures of the shotcrete lining only. Although overall stability of the opening in case of sufficient rock bolting is generally no problem, the sheared lining is a potential hazard for everyone working in the area. Smaller or larger pieces of the broken lining may fall down and injure people below. Up to now, no lining material has been developed to cope with high rates and excessive amount of deformation at reasonable costs. A characteristic feature of fault zones in the Alps is a frequent change in rock stiffness within the fault material. During tunnel excavation, this leads to unfavourable stress concentrations in the stiffer parts of the rock mass, which may fail suddenly. On the other hand, prediction of transitions to zones of soft rock is difficult. Delayed increase of the extent of overexcavation is frequently the consequence, requiring costly reshaping of the profile in order to maintain clearance.

Previous Practice in Austria

A low cost solution of dividing the shotcrete liner into several segments and leaving gaps between the segments in connection with yielding steel arch couplings was first applied in the Tauerntunnel by Rabcewicz (1973), later at the Arlbergtunnel (John, 1976) and the Karawankentunnel in Austria. In the absence of any better solution, this method has also been used in fault zones at the Inntaltunnel and most recently at the Galgenbergtunnel (Schubert and Riedmüller, 1995).

For the Inntaltunnel, where absolute displacement measurements have been performed, the shortening of the excavation line could be approximated. Figure 1 shows the recalculated average strains of the excavation line of the top heading. Because deformation in the area under consideration was rather unsymmetric, local strains will have considerably exceeded the average values shown. The "critical strain" level in the diagram is based on experience, and should indicate the average strain at which the shotcrete lining usually starts shearing. Some improvements in the construction of the joints and rock bolt heads have increased comfort, safety, as well as improved functionality, but did not significantly change the approach.

Shortcomings of the System

The missing thrust transmission between the single segments reduces the action of the lining to bigger anchor plates until the gaps are closed either by deformation or

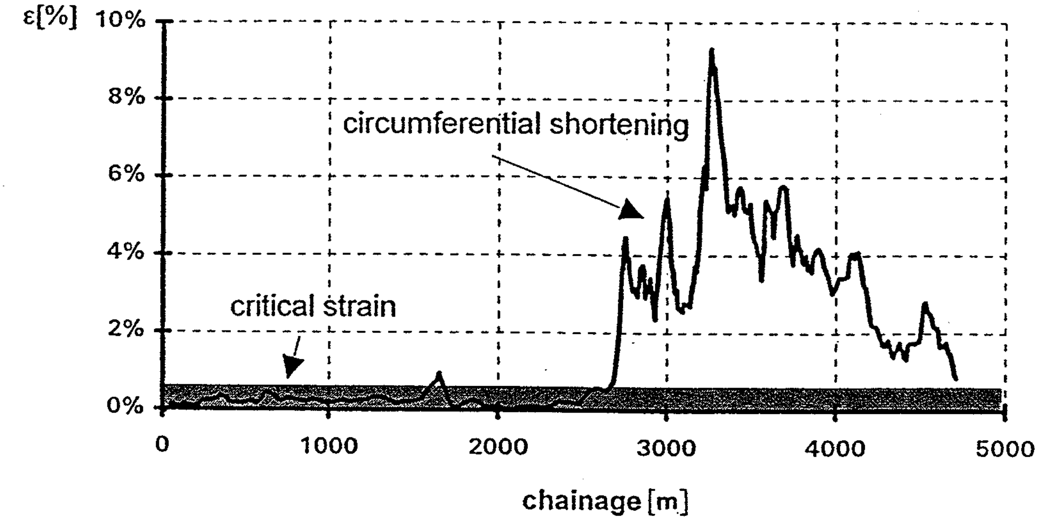

Fig. 1. Recalculated average strains in the lining of the top heading (Inntaltunnel)

by filling them with shotcrete. In rock showing a tendency of loosening, a certain thrust transmission between the segments would be favorable, especially at an early stage, when rock bolts are not yet fully acting. In very heterogeneous rock, a reduction of displacement will also be required to reduce stress concentrations in stiffer rock parts.

The optimum support for such conditions should be easily adjustable to the required deformability, which is a function of rock mass quality, support capacity, tunnel size and time.

Recent Experiences

The segmental shotcrete lining approach was also used recently for the 5 km long double track Galgenbergtunnel in Austria, when crossing an approx. 400 m wide fault zone. The support concept was very similar to the one applied at the Inntaltunnel, where approximately 2.000 m fault zone have been very economically and successfully excavated. Within the fault zone at the Galgenbergtunnel, stiffness of the rock mass in short intervals varied extremely. This led to stress concentrations in the stiffer rock portions and unusual variations in principal stress directions around the excavation. A collapse, caused by the failure of an overloaded rock "pillar" embedded in a soft matrix of completely tectonized rock in combination with an unusual primary stress direction, led to a reconsideration of the support concept.

Improved Support System

In order to reduce the effect of stress concentrations of the stiffer rock portions especially when situated close to the excavation boundary, deformation in the area of excavation has to be reduced as far as possible. This goal was obtained by a combination of modifications in excavation and support. Besides reducing excavation height, self-drilling bolts with the possibility of repeated grouting (IBI R 38/51) were used instead of the conventional SN type grouted bolts. To increase the efficiency of the shotcrete lining, while maintaining a sufficient ductility to prevent shearing of shotcrete, low cost "absorbing elements" for installation in the gaps between the shotcrete segments were developed.

For this purpose, steel pipes were tested under axial load in the laboratory. Preliminary tests on a 100 mm dia. pipe showed, that prior to buckling the peak load was approx. 250 kN. With increasing deformation, the load varied between 100 and approx. 200 kN, depending on the state of buckling. To reduce the peak before the first buckling, the steel pipe was perforated by several drillings at one end (Figs. 2, 3).

Fig. 2. Yielding steel elements in the laboratory test; left: at the beginning of buckling, right: after approx. 120 mm of axial deformation

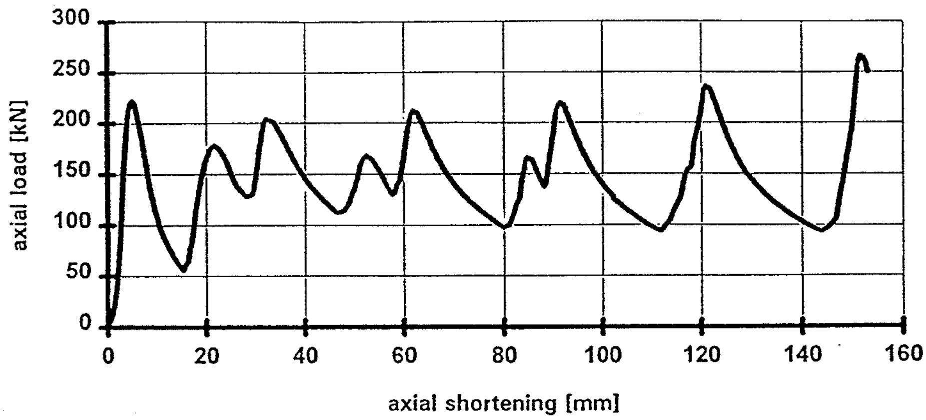

Fig. 3. Load line of perforated yielding element

In order to be used on the site, steel pipes were assembled in groups, connected to a base and top plate, and installed in the lining. Final adjustment of the system to the shearing capacity of the shotcrete lining was performed on site by varying the number and the dimension of the steel pipes.

On-site experience is extremely positive. Approximately 300 m of excavation have been completed using this kind of support in extremely difficult ground conditions. In combination with the other modifications in support and excavation, deformation in the area of excavation could be reduced considerably. Reshaping was not required at all. Currently we are working on some modifications of the elements in order to smoothen the load line.

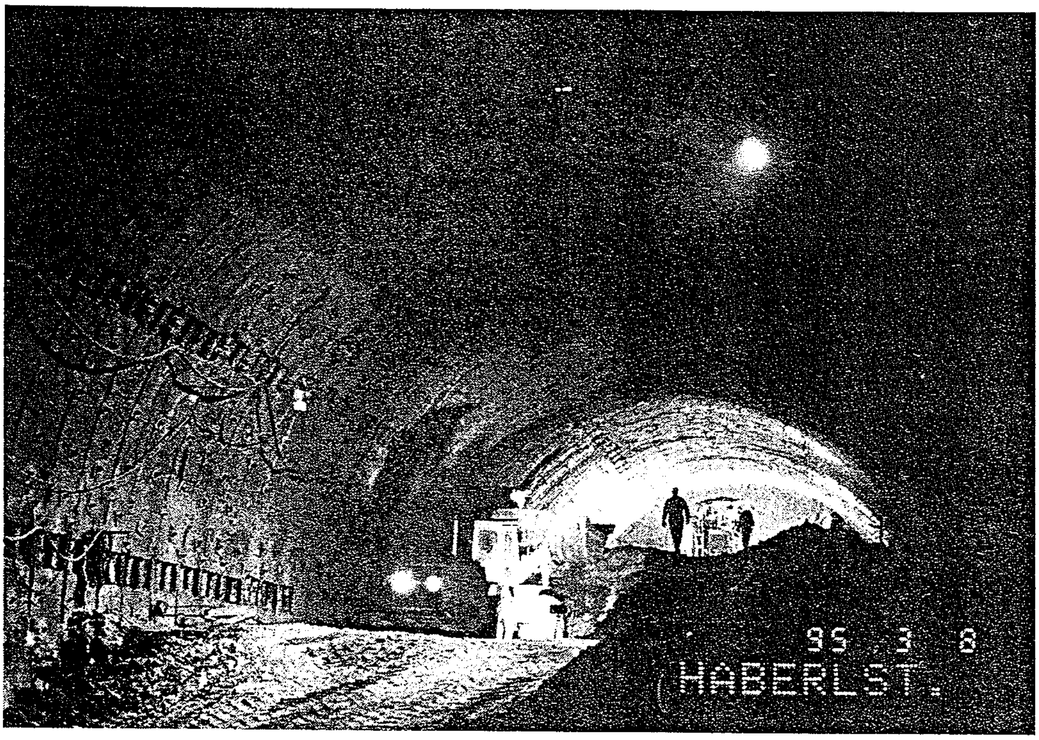

Fig. 4. Modified support system with integrated yielding steel elements

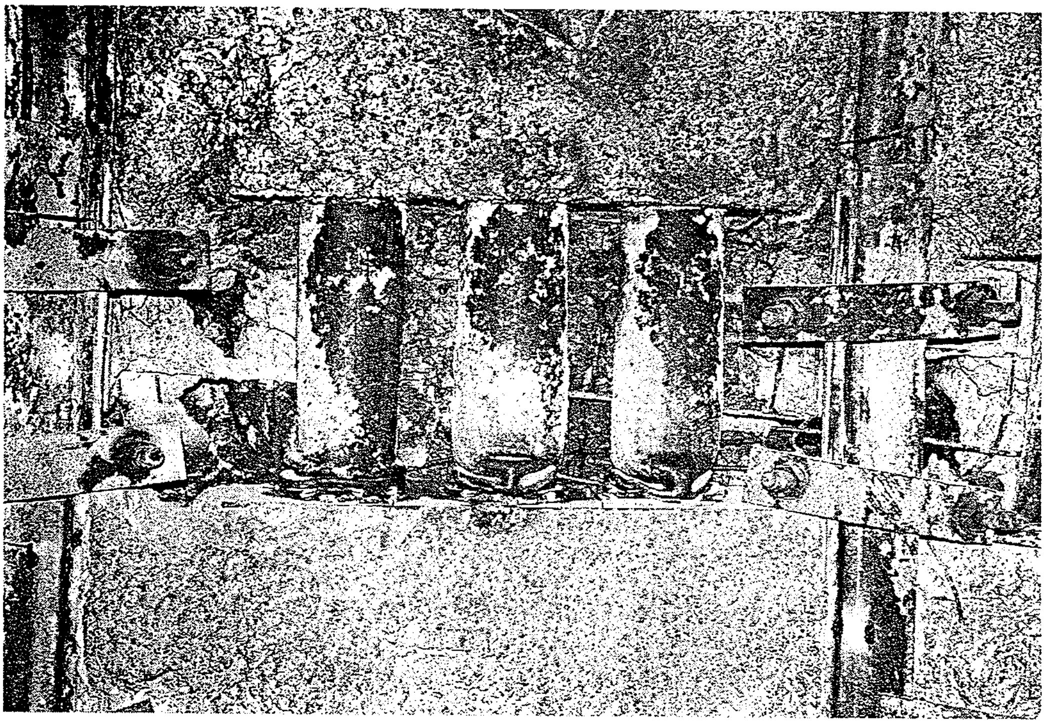

Fig. 5. Yielding steel elements installed in the lining

Performance of Rock Bolts in Squeezing Rock

Fully-grouted bolts are commonly used in poor rock conditions in order to increase shearing resistance of the rock and reduce and harmonize deformations. Observations at the collapse area of the Galgenbergtunnel showed, that perfectly grouted bolts had been pulled out of the grout even more than 20 hours after installation. As we expected a severe disturbance of the bond between the bolt and the grout, caused by the relatively high displacement rates right from the beginning of installation, an investigation was initiated at the Institute of Rock Mechanics and Tunnelling at the Technical University of Graz. Laboratory results from Blümel (1996) show significant differences in the performance of different bolt types, as well as different grouts. In these tests, a constant displacement rate was imposed on the bolts, beginning immediately after the installation. Figure 5 shows the load development of different rock bolt types of the same diameter, but different rib geometry. Results show, that especially when expecting high initial deformation rates after tunnel excavation, selection of rock bolt and group types has to be made very carefully.

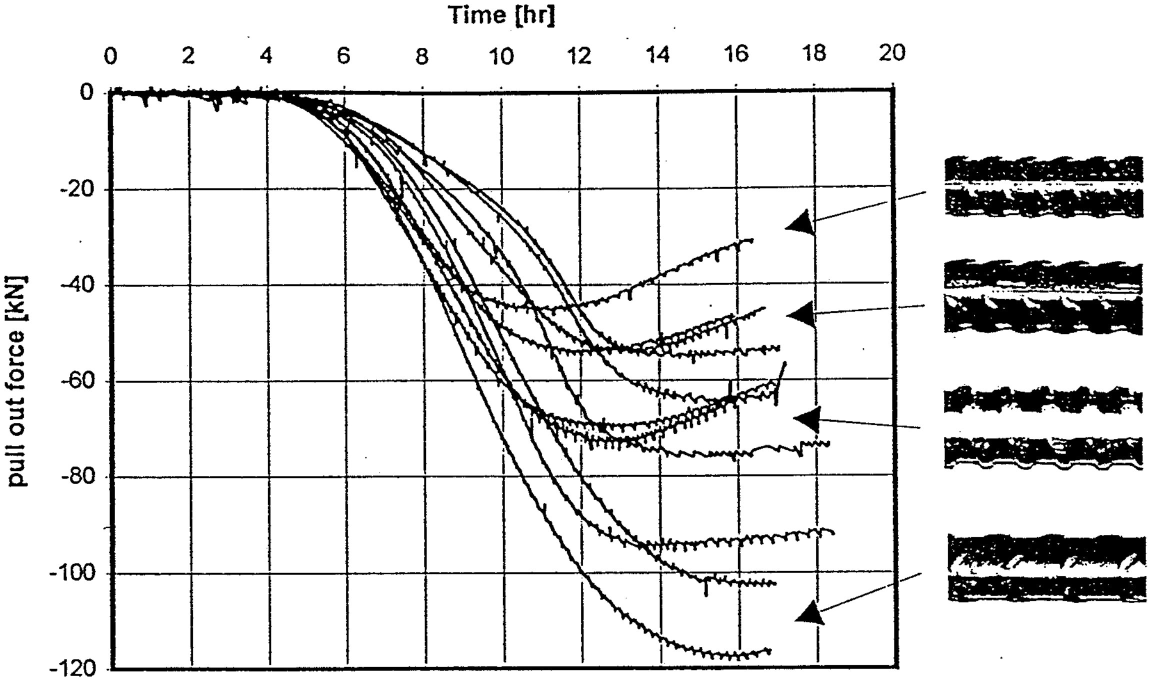

Fig. 6. Results from pull-out tests on different rock bolt types

Monitoring Technique

Observation of the behaviour of the rock mass-support structure and the continuous adaptation of construction and support to changing ground conditions have contributed to the economical success of the NATM. Determination of the absolute displacements during tunnel excavation by geodetic methods has, to a large extent, replaced relative displacement measurements in Austria during the last decade. The increase in information has led to additional possibilities in data evaluation and visualization. The plotting of lines of influence, trend lines along the tunnel axis (Vavrovsky, 1988) or displacement vectors in a plane perpendicular to the tunnel axis in addition to time histories have become common practice in many places. These improved tools have led to a better understanding of geomechanical processes during tunnel excavation. Better adjustment of excavation and support to the geotechnical conditions, as well as a certain ability of ground reaction prediction ahead of the tunnel face is possible with the help of the improved methods of data evaluation.

At the 12.7 km long Innsbruck railway bypass tunnel, the displacement component in the longitudinal direction has been used for the first time for the interpretation of monitoring data. The displacements measured in the longitudinal direction in an extensive fault zone were considerable. In addition, the evaluation showed, that the ratio between radial and longitudinal displacement varied in a wide range. Comparing the observed phenomena with the geological documentation, it was found that deviations of the ratio from the "normal" could be used as indicators for changes in rock mass stiffness (Schubert, 1993).

On the basis of the observations at the Innsbruck bypass tunnel, a research project was initiated. It was observed that, when using the orientation of the displacement vectors in space, changes in rock mass stiffness can be detected several diameters ahead of the face. Monitoring data of a fault zone at the recently completed 5.3 km Galgenbergtunnel in Austria showed that deviations in primary stress orientation can also be identified (Schubert and Budil, 1995). Based on these findings, new techniques have been developed to evaluate and display monitoring data. A trend line of the displacement vector orientation of the crown along a fault zone is shown in Fig. 7.

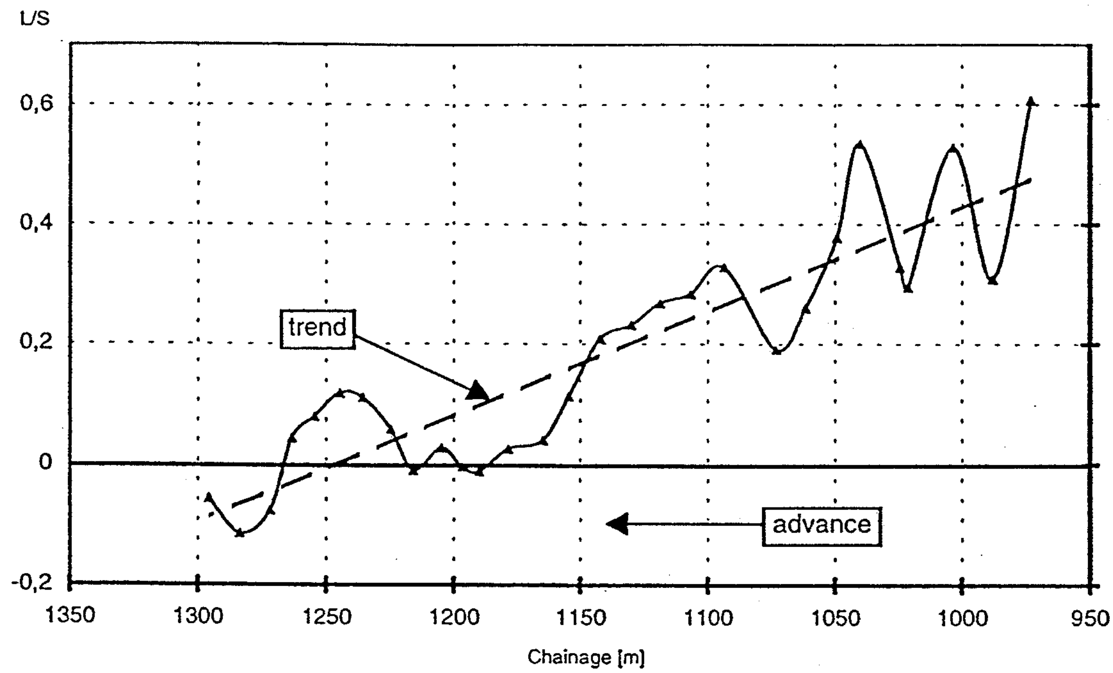

Fig. 7. Trend of relation of longitudinal (L) to vertical displacemement (S) along the "Hinterbergfault" of the Galgenbergtunnel

The clear trend indicates an unusual primary stress situation. The fault material is wedged between two relatively solid abutments and laterally can expand towards the valley. As a consequence, stresses develop in the form of arches between the abutments. It was found to be useful to display displacement vector orientation in space by means of stereographic projection (Fig. 8), as the influence of the rock

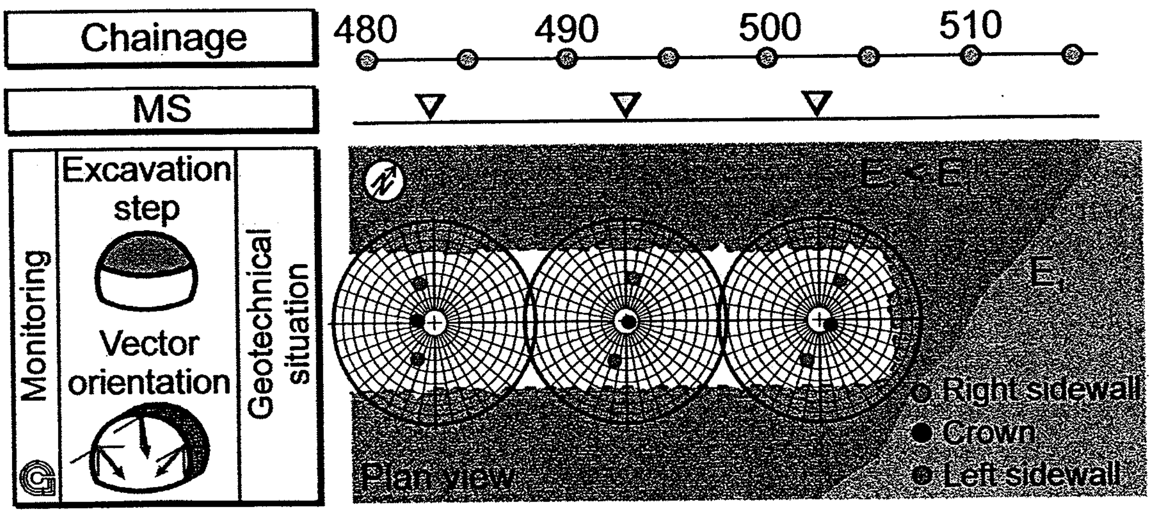

Fig. 8. Displacement vector orientation in stereographic projection (schematic for 3 monitoring points in top heading)

mass structure on the displacement pattern can be easily determined (Schubert and Steindorfer, 1996).

Part of the findings from the evaluation of the data were meanwhile verified by numerical simulations. With the tools for site application currently under development, we hope to improve the short term prediction of changes in the rock mass stiffness in situ. Together with the improved support system, risk could be further reduced when tunnelling through fault zones.

Acknowledgement

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