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Controllable Ductile Support System for Tunnels in Squeezing Rock

By Wulf Schubert and Bernd Moritz

When tunnelling through fault zones under high overburden frequently large deformations are observed. The problems associated with the considerable displacements cause a number of problems. One of the problems is the determination of the required amount of overexcavation, a very difficult task especially in heterogeneous ground. Another major problem is the rigidity of conventional tunnel linings, which in many cases leads to severe damages of the supports. The problem is not limited to tunnelling, but is also well known in mines, where frequently in addition to high overburden dynamic loads by the mining process increase deformation of tunnels and galleries.

In the past various techniques have been developed to cope with such conditions. In mining in general steel sets with yielding couplings and low strength backfill or timber blocking are used to account for the expected displacements. Distortions of the lining, floor heaving, as well as considerable closures of the drifts cause problems during mining and operation, frequently requiring repairs and reshaping to maintain the necessary clearance. For the comparatively short life time requirements of such drifts this may be an acceptable approach, while for permanent tunnels necessary repairs and maintenance should be kept to a minimum. In addition stability requirements during excavation of large cross sections call for immediate and efficient support.

A number of alpine tunnels have been successfully constructed by using an approach first introduced by Rabcewicz at the Tauerntunnel (1, 2, 3). Experiencing severe damages of the shotcrete lin-

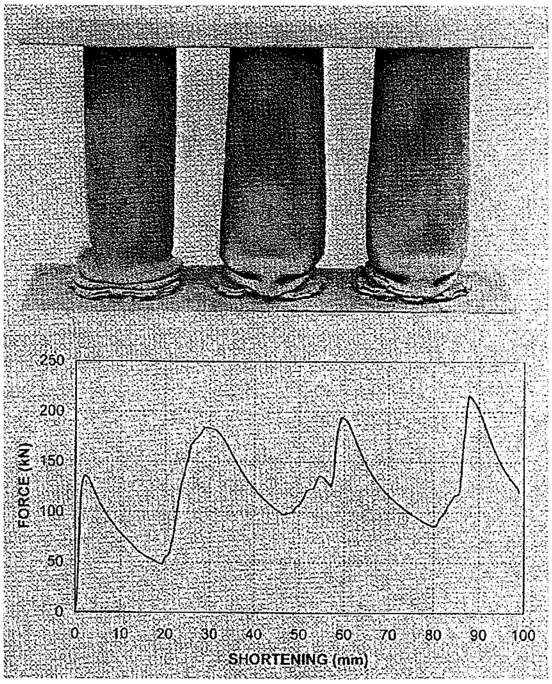

Fig. 1 Yielding steel elements installed at the Galgenbergtunnel (top), and load line of the elements used (bottom).

Bild 1 *Am Galgenbergtunnel eingebaute Stauchelemente (oben) und die Arbeitslinie der dort verwendeten Elemente (unten).*

Kontrollierbares nachgiebiges Ausbausystem für Tunnel im druckhaften Gebirge

Beim Vortrieb von Tunneln und Stollen im druckhaften Gebirge treten häufig große Verformungen auf. Spritzbeton-Ankerausbauten haben sich in der Vergangenheit unter solchen Bedingungen bewährt. Die Größe der auftretenden Verformungen übersteigt allerdings in manchen Fällen die Verformbarkeit herkömmlicher Ausbauelemente wie Spritzbeton oder Stahlbögen. Durch Verformungsschlitze in der Auskleidung in Kombination mit einer dichten Ankerung wurde bei mehreren Alpentunneln die Verformungsfähigkeit der Auskleidung erhöht, was zu einer Minimierung der Schäden während des Deformationsprozesses beiträgt. Der offensichtliche Nachteil dieser Lösung liegt in der schlechten Ausnutzung der Auskleidung und damit verbunden im geringen aktivierten Ausbauwiderstand.

Durch die Entwicklung nachgiebiger, in die Verformungsschlitze eingebauter Stahlelemente konnte der Ausnutzungsgrad der Auskleidung wesentlich erhöht werden. Damit wird eine deutliche Reduktion der Deformationen und Erhöhung der Sicherheit erreicht. Der Einsatz der Stauchelemente ist nicht auf den Spritzbetonausbau beschränkt, sondern kann auch als Lastbegrenzer bei Stahl- oder Tübbingausbauten verwendet werden.

In fault zones excessive deformation during and after tunnel excavation is frequently encountered. Shotcrete in combination with grouted rock bolts in many cases has successfully been used to control the deformation process. The magnitude of deformation frequently exceeds the strain which conventional supports, such as steel sets or shotcrete can sustain. Dividing the shotcrete lining into "segments" and leaving gaps between the segments to accommodate deformation has been used on several occasions in alpine tunnels. The disadvantage of this support system is the missing transfer of axial force between the lining segments, resulting in a rather low radial support resistance.

Recently yielding steel elements, which are installed in the gaps, have been developed, thus increasing lining utilisation and decreasing deformations considerably. The support system can be used with any lining e.g. steel, concrete, segmental concrete, shotcrete lining etc.

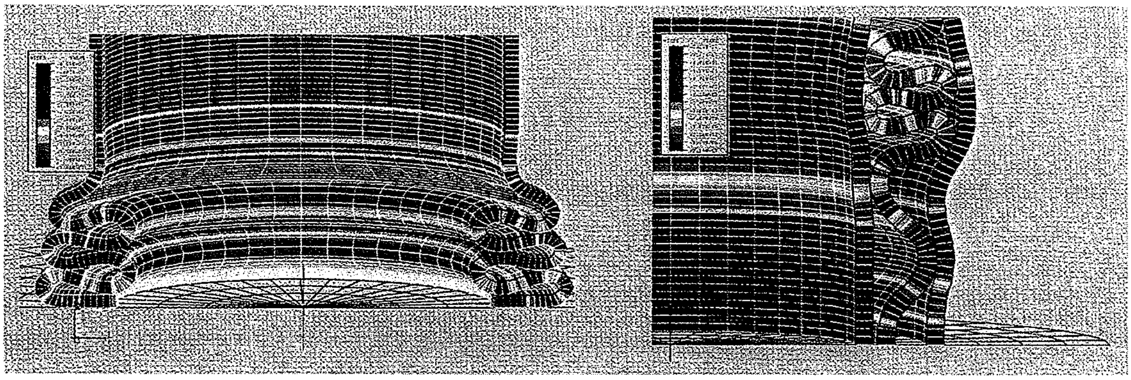

Fig. 2 Numerical simulation of the yielding element as used at the Galgen-bergtunnel (left) and of the improved yielding element (right).
Bild 2 *Computersimulation der am Galgenbergtunnel eingesetzten Elemente (links) und der verbesserten Stauchelemente (rechts).*

ing by large deformations, gaps were left in the lining to allow displacements without damage to the shotcrete. This approach is accompanied by a dense rockbolting in order to increase the shear strength of the rock mass and to reduce unsymmetrical deformation of the tunnel.

Despite the merits of this system, successfully used on a number of tunnels and also in mines (4), a major shortcoming is the low degree of utilisation of the lining capacity.

First use of yielding steel elements

For the very heterogeneous "Haberl Fault" at the Galgenbergtunnel in Austria low cost yielding steel elements have been developed, consisting of groups of steel pipes installed in circumferential direction in the gaps. This system in combination with regroutable rock-bolts led to a considerable reduction in displace-ments, compared to those experienced when tunnelling through other similar fault zones (5, 6) and an increase in safety.

This first system of yielding elements in practice did quite well satisfy the demand of controlling stresses in the lining, while at the same time increasing the support resistance. The load line however was rather uneven due to the different stages of buckling of the steel pipes (Figure 1).

Improved elements

In order to obtain a smoother load line, the system has been further developed. To reduce the strong drops in load during buckling, the folding has been restrained by an inner and outer pipe. For the optimization of the system numerical simulations with the code ABAQUS have been performed, and the results verified by laboratory experiments. Figure 2 shows the simulation results of the system used on the Galgenbergtunnel as well as of the improved system. As can be seen in figure 3, loads of the improved element show much less variation during shortening. The energy absorption increases by 40 to 50%, compared to the element used at the Galgenbergtunnel. Shown in figure 3 is the corresponding yielding element after laboratory test. Results from simulations and laboratory tests corresponded extremely well. This allows a design of elements on the desk, custom tailored to the individual needs of the project.

Effect of yielding support

To verify the effectiveness of the elements, a section of the excavation through the "Hinterberg Fault Zone" of the Galgenbergtunnel, where open gaps in the shotcrete lining had been used was back calculated with the code UDEC. Figure 4 shows a plot of the heavy and unsymmetrical deformation of the tunnel, when using the support as installed in the "Hinterberg Fault Zone". Deformation pattern and amount of displacements, with about 500 mm of radial displacement of the left crown well compare to the conditions on site.

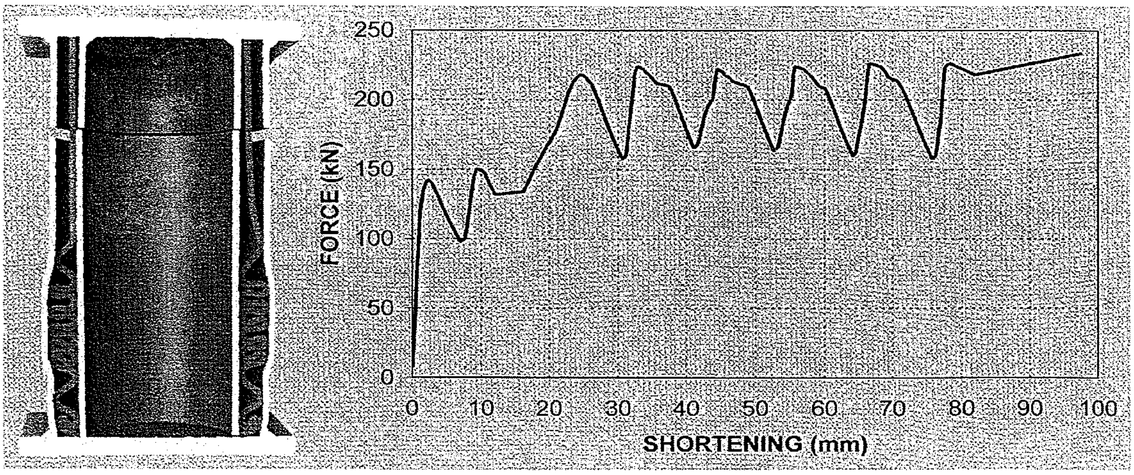

Fig. 3 Improved yielding element after laboratory testing (left), and load line (right).
Bild 3 *Verbessertes System im Labortest (links) und zugehörige Arbeitslinie (rechts).*

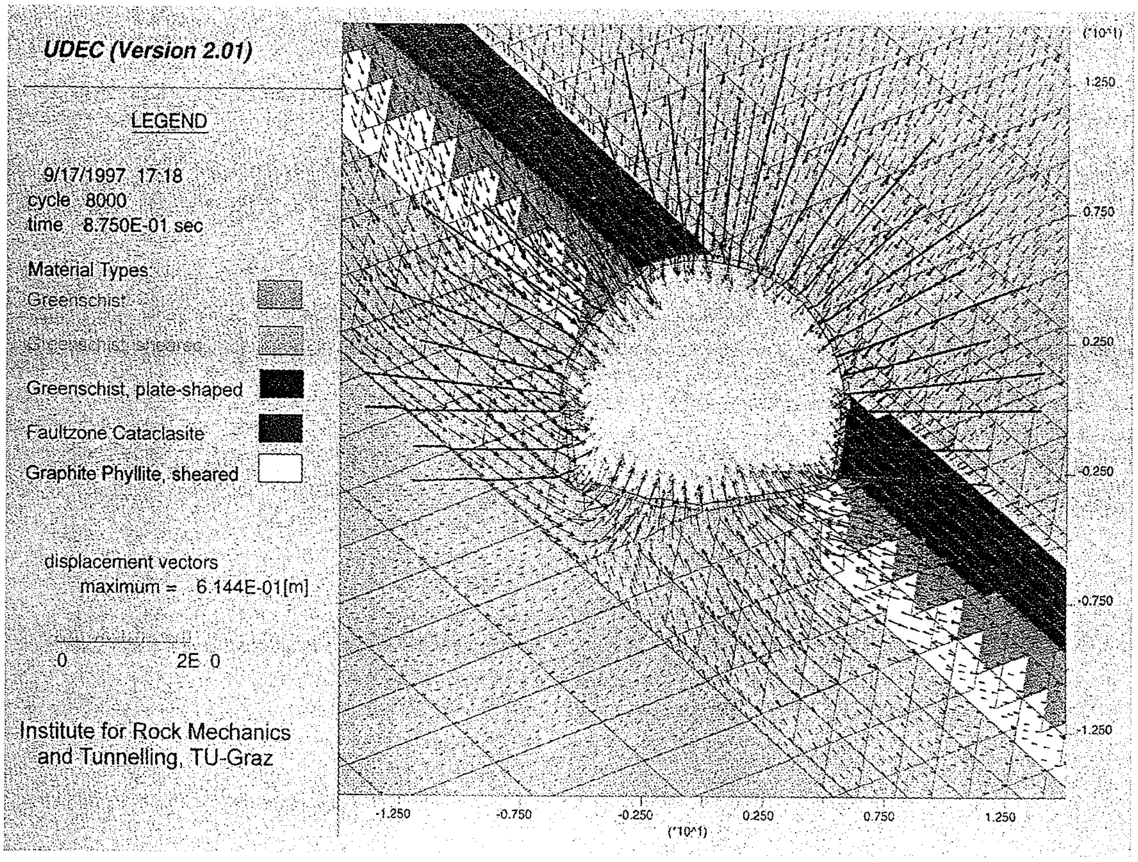

Fig. 4 Back analysis of a section at the Galgenbergtunnel, where open gaps in the lining were used.

Bild 4 *Rückrechnung eines Querschnittes vom Galgenbergtunnel, wo offene Deformationsschlitze verwendet wurden.*

When using the yielding elements in the gaps, with otherwise unchanged support, displacements are reduced to less than 50%, as can be seen from figure 5. Favourable side effects are reduced shear displacements in the rock mass and hence reduction in the rock bolt loads.

Fields of application

The application of the yielding steel elements is not limited to rock bolt-shotcrete support, although for the time being the NATM is most commonly used for tunnels in faulted rock. The elements can be also used for steel supports as yield-

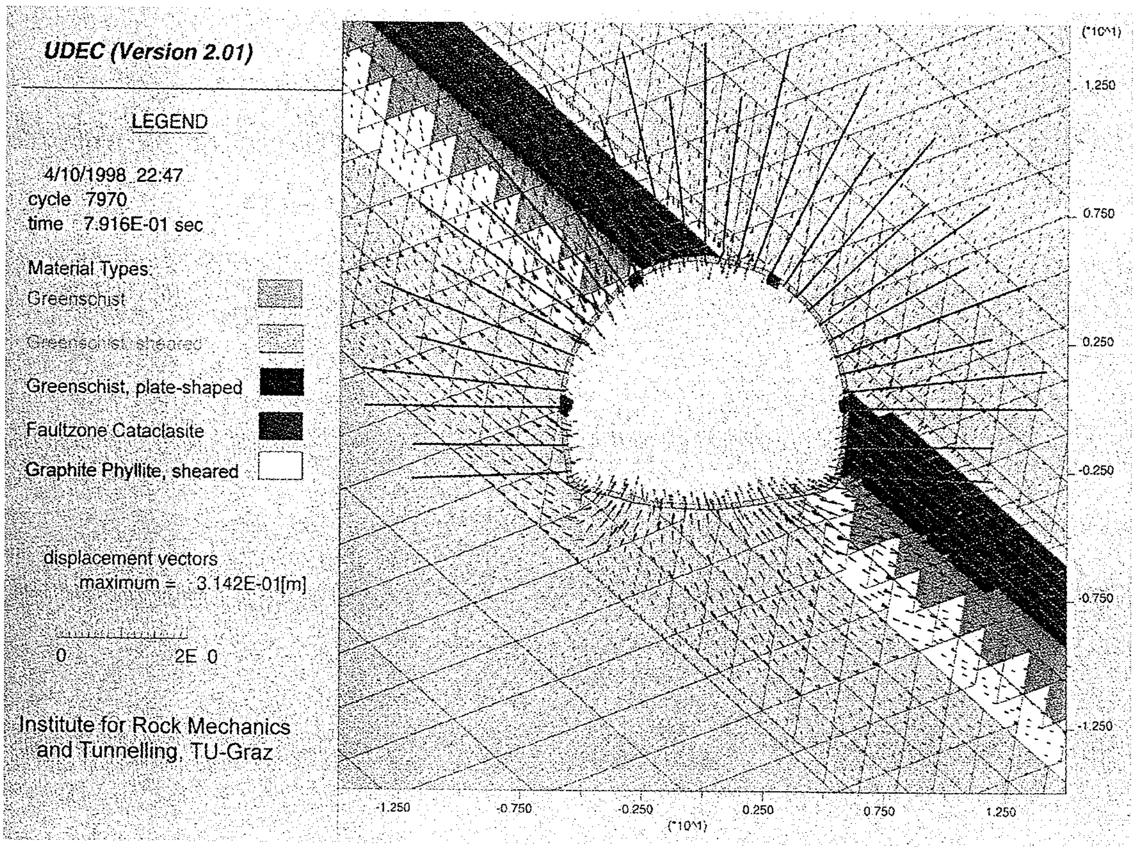

Fig. 5 Analysis of the same section, yielding elements installed in the deformation gaps.

Bild 5 *Vergleichsrechnung am selben Querschnitt bei Einsatz der Stauchelemente.*

ing couplings between the single arch sections. The application with segmental linings seems to be feasible as well, probably helping to extend the application of TBMs also to squeezing ground in future.

The system at low costs allows to effectively control displacements and increase safety. The system has been called "Lining Stress Controller (LSC)" and a patent has been applied for (7).

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