New ductile tunnel lining system

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ABSTRACT: Tunnelling with high overburden in poor or faulted rock masses frequently leads to large displacements, damaging conventional supports. Ductile support systems allow accommodating the large strains imposed on the lining without damage. With an appropriate design and layout of the support, it can develop a controlled resistance, thus reducing displacements. Development of yielding elements has started many years ago, but only during the last 20 years, practical application has become common practice. Various requirements have to be considered in the design of ductile elements, which are integrated in the conventional supports. Among other factors, the time dependent development of the properties of shotcrete, as well as the development of the displacements with time – which again depends on the advance rate - play an important role. Graz University of Technology during the last two decades has worked on the development of ductile elements for shotcrete linings. The paper gives an overview of the development and the current state.

1 INTRODUCTION

Tunnelling in poor or faulted rock is associated with a number of problems. One of the problems, addressed in this paper are the relatively large displacements, incompatible with conventional shotcrete supports. Besides general overstressing of the lining in quasi-homogeneous ground, also shearing along foliation or slickensides and faults can be frequently observed (Figure 1). Such damages are a safety hazard and require extensive repair works.

The traditional method to prevent lining failure is simply leaving open slots in the lining, which are filled once the displacements have come to a halt (Figure 2). This is a pragmatic approach, but results in a poor utilization of the lining, and thus to large strains in the rock mass, which can lead to considerable deterioration of the rock mass quality.

Figure 1. Typical shearing of shotcrete lining along slickenside (Rohtang tunnel, India)

Figure 2. Support with open slots in the lining (Innatltunnel, Austria)

2 BASIC CONSIDERATIONS

Shotcrete has a pronounced time dependent behavior. An increase in stiffness and strength is accompanied by creeping and shrinking, and influenced by temperature, caused by the hydration process. By experience the critical strain of a shotcrete lining has been identified to be in the range of 0.6% to 0.8% (Schubert, 1996).

On the other hand, development of displacements primarily depends on the face advance and only to a minor extent on the time dependent effects. This implies that the imposed strain over time predominantly depends on the advance rate.

This effect has been studied by Sitzwohl (2011) and Radoncic (2011). Considering a maximum utilization of the shotcrete capacity of 80%, the desired capacity of the yielding elements can be calculated in relation to the advance rate of the face. Figure 3 shows an example of such an evaluation, considering the time dependent behavior of shotcrete.

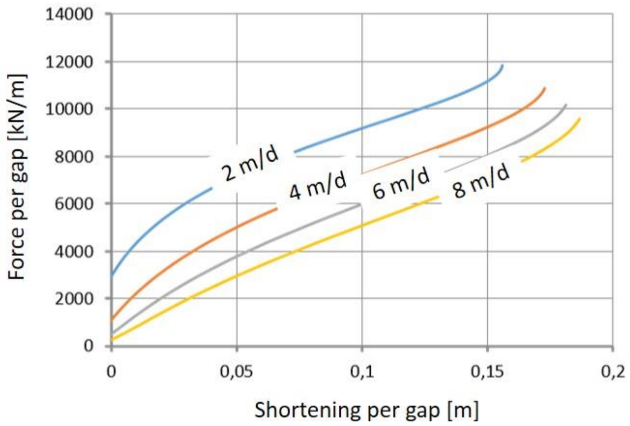

Figure 3. Optimum load lines for yielding elements in relation to the advance rate (Sitzwohl, 2011)

As discussed above, linings with open slots do not develop much resistance against ground deformation. Only friction between the lining and the ground and the shear resistance of the bolts provides a limited amount of support resistance. With integrated yielding elements, the lining´s capacity is much better utilized, thus considerably reducing ground and system displacements. This effect can be clearly demonstrated with the ground reaction curve (Figure).

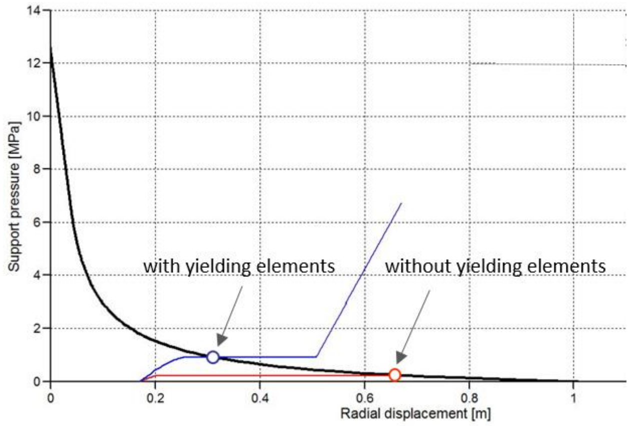

Figure 4. Effect of integrated yielding elements on the displacement of a tunnel (Radoncic, 2011)

Better utilizing the lining capacity not only reduces the displacements and thus the imposed strain of lining and bolts, but also helps in preserving the ground quality. In addition, the lining resistance increases the safety, as the probability of collapses reduces.

3 DEVELOPMENT OF DUCTILE ELEMENTS

3.1 *Historical development*

To better utilize the lining capacity and at the same time reduce displacements, yielding elements, which are integrated in the lining, have been developed.

A first series of such elements has been developed by our institute in the 1990ies. Those elements consisted of a group of axially arranged steel tubes with a head and foot plate (Figure). Those elements worked quite well, but had the disadvantage, that the load line was oscillating in a wide range due to the different

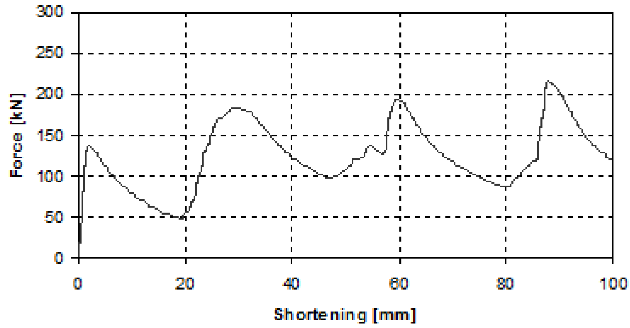

Figure 5. Load-displacement characteristic of original yielding elements (Schubert & Riedmüller, 1995, Moritz, 1999)

stages of formation of the single folds (Figure).

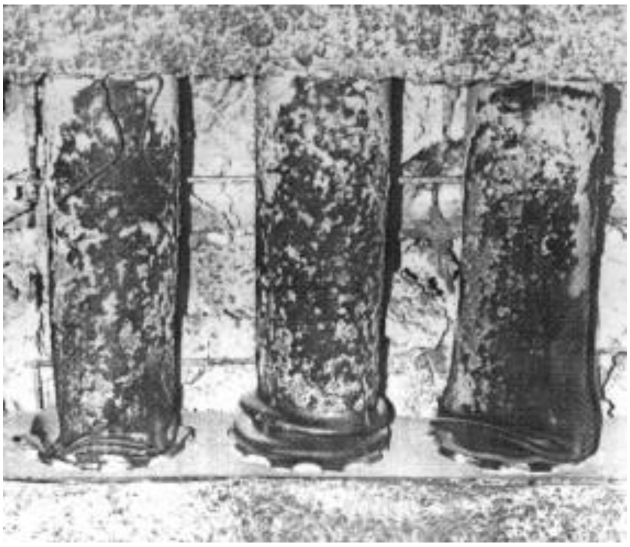

Figure 6. First series of yielding elements integrated into shotcrete lining at the Galgenbergtunnel, Austria

By adding additional restraining tubes, Moritz (1999) has improved the characteristics of the system (Figure). This yielded a much smoother load displacement characteristic (Figure), as well as a higher energy absorption. Those elements were used at many tunnels in various countries under the name LSC (Lining Stress Controllers).

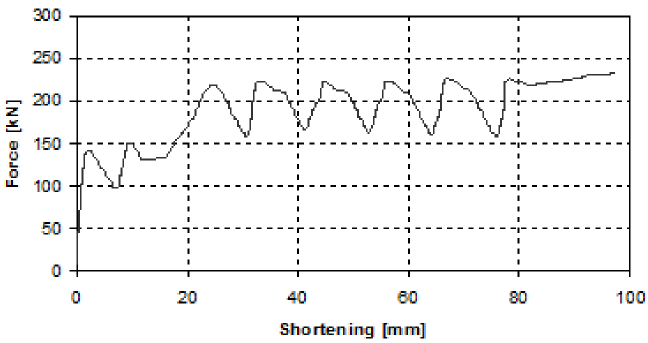

Figure 7. Load-shortening diagram of the improved elements (Moritz, 1999)

Among other projects, the system was also used at the second tube of the Tauerntunnel in Austria (Figure), reducing the displacements by more than 50% compared to the same location in the first tube.

The production of this type of element was relatively complex and required a certain precision in the manufacturing process, as well as during installation. Asymmetrical folding due to imperfections in the production or installation to a certain extent influences the performance of the elements.

Figure 8 Improved yielding element (Moritz, 1999)

Figure 9. Use of yielding elements in the Tauerntunnel, Austria (Photo: Vergeiner)

Realizing the advantages of such yielding supports, different producers introduced their products to the market (Figure 10). Some of those are based on a cementitious porous material, others are using steel only. The disadvantage of the porous material is the fact that in general the initial stiffness is too high, requiring additional soft layers to achieve a satisfying characteristic. The systems based on steel elements have the tendency to be rather heavy, making their installation a challenge for the crew.

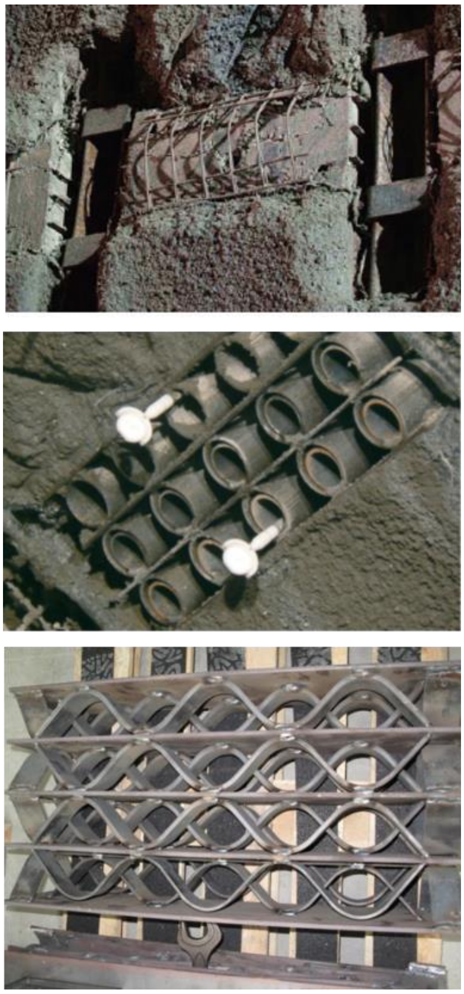

Figure 10. Various different yielding elements; top: System HiDCon (solexperts), center: System Wabe (Eisenhütte Bochum); bottom: System GRA7-A (SZ Streckenausbau)

3.2 *Latest development*

Bearing in mind the advantages and disadvantages of the various systems, our institute recently combined the advantages of the steel systems with the benefits of the porous filler. The result was a system of steel tubes with a porous cement bonded filler. Special steel is required to allow for large strains, as well as a kind of sandwich type composition of the filler in order to come close to the desired behavior.

A considerable number of tests, varying the filler composition, as well as the steel type was required to achieve the desired results (Verient, 2014, Brunnegger, 2017). Figures 11 and 12 show the current result of the development. Optimizations of the systems in terms of material selection and production will follow.

Figure 11. Combination of steel cylinder and porous filler, Type LSC-N after shortening of approximately 65% (Brunnegger, 2017)

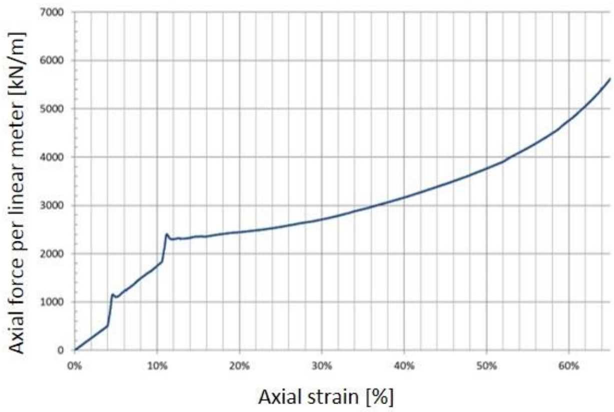

Figure 12. Test result of element type LSC-N, upscaled for one linear meter of tunnel (Brunnegger, 2017)

CONCLUSION

The use of ductile elements in combination with conventional shotcrete and bolt supports has a number of advantages, such as considerable reduction of displacements, while maintaining the integrity of the lining. However, the parameters influencing the layout and composition of ductile elements is manifold. Besides the ground quality and deformation characteristic, shotcrete properties, as well as advance rate of the heading plays an important role. As not all those parameters are completely known prior to construction, a certain potential for modification of the system performance on site should be available. None of the systems currently on the market provides this option in a satisfactory way. There is still room for improvement, and we will follow the topic up.

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