Leakage mitigation in tunnelling, with emphasis on karst

We read at intervals in excellent journals, or publish or lecture about what can go seriously wrong in our challenging underground media. It may be the occasional, easily explained, locally massive failures in single-shell tunnels, or the occasional, easily explained, locally massive failures in double-shell tunnels (or caverns under construction). The former are using the far more frequently used shotcrete and rock bolt methods (tens of thousands of kilometers of mine access, mine roadway, hydropower, economic road and rail each year), as compared to the less frequent shotcrete, bolts, lattice girders, smoothing layer, drainage fleece, membrane, cast concrete tunnels used in our more expensive transport tunnels. We could identify the methods used with various combinations of N's and T's and M's, and perhaps an occasional Q or an R - their geographic origins now masked by more variable use in many, many countries.

Instead of reading or hearing of a hydropower head-loss, or mine accident, or near-miss when driving, it is almost refreshing, though no less serious, to view the muddied train that exited the Lötschberg deep base tunnel recently. A challenging problem perhaps caused by an unknown thickness of immediately surrounding rock in karstic terrain, despite 400m depth, or somehow a serious increase in water pressure (quite feasible in karst caverns) or deformation-caused cracking, and then leakage – the list of possibilities emphasises the hydrogeological risks in our chosen profession, especially in the case of karst. It could on the other hand have been caused by measures taken during construction, that did not, with the benefit of hind-sight, provide a long-term solution.

But there are also risks with Choice of Method. The leakage of water, and mud, serves to warn us of the questionable long-life performance of an easily clogged drainage fleece, if it has to tackle a fluid different from water, or suffer gradual mineralization deposits. We then run in to the problem of the many kilometers of membrane welds per kilometer. (This can be a challenging 12 to 15km of welds/km in a big double-track rail tunnel with a perimeter exceeding 30m). We also have the radial joints in successive concrete pours, and their actual absence when using sufficiently thick longitudinally sprayed shotcrete There are no radial joints with S(fr) and it has extremely low permeability, in the panel-sprayed range of 10E-10 to 10E-12 m/s. This is 40 years-old data. The first Ph.D on S(fr) in Norway from Opsahl, was at the very end of the 1970's, with reporting in 1980, 1981.

So what are the best choices? Frankly it is not felt that the style of 'belts-and-braces' incorporated in double-shell is the right answer – even though when functioning well, it can be, though is expensive and time-consuming. What about another choice of 'belts-and-braces', namely one that automatically includes drilling through the crucial rock surrounding and ahead of the tunnel - clear advantages especially in karstic terrain. So an easily guessed single-shell but with rock mass improvement: systematic high-pressure pre-injection (but with pressure suited to the rock and rock mass). This b-and-b remains a very cheap solution. There are literally millions of kilometers of drill-holes used for the world's large dams: grout curtains are permanent and headed for a 100 years (plus) life. Pre-grouting umbrellas take 24 to 30 hours, and an almost guaranteed 20 hours plus per week full-face tunnel construction – as indeed for high-speed rail tunnels of > 100m2. Grouting is known, and 3D-measured, to cause rotation of the 3D permeability tensors, and their magnitude reduction, and significant modulus and velocity increase. In fact the six Q-parameters may be effectively improved. The risk during construction is reduced dramatically by drilling 1 to 1.5km of holes every 15 to 20 meters of tunnel advance. Eventual damp spots in the shotcrete signal where a local post-injection hole is needed. This is not the case with the double-shell solution.

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