# Characterisation of permeability distribution for deep tunnel projects: Examples from the Brenner and Lyon-Turin Basis Tunnels

**Antonio Dematteis, Paolo Perello, Riccardo Torri,**
**Mattia Marini & Guido Venturini**

SEA Consulting s.r.l., Via Cernaia 27, 10121 – Torino (Italy)

Forecasts of water inflow into the tunnel and impact on water resources is one of the main challenges in the design of deep and long tunnels in mountain chains like the Alps. Data available for already excavated tunnels demonstrate that inflows span over at least two orders of magnitude (1 l/s/Km to 100 l/s/Km). Great differences in magnitude of the inflow can occur, mainly due to structural heterogeneity and different recharge of deep aquifers from the surface. Examples of spring drawdown occurred during tunnel excavation are also known.

According to the authors experience in deep tunnelling projects a working procedure and related problems are here discussed. Techniques for assessing tunnelling groundwater inflow and impacts on groundwater-circulation were devised during the design phases of underground works such as the Brenner basis tunnel (new Verona-Munchen 54 km railway between Austria and Italy), the Turin-Lyon railway connection (53 km base tunnel between Italy and France in the western Alps), the underground track of Milan–Genoa railway (22 km long tunnel in Apennines, Italy) and the Perthus railway tunnel (8 km long between Spain and France). The methodology effectiveness was then tested during the tunnelling phases related to the Pont Ventoux Hydroelectric power plant (northern Alps in Italy) and the Modane exploration tunnel of the Lyon–Turin railway connection, France).

Hydraulic parameters that mainly affect the hydrogeological conditions into the tunnel are the aquifer recharge-rate, the permeability and the hydraulic head. Transmissivity and storage coefficient (measured in boreholes, wells and springs) are also important for numerical simulations of groundwater flow systems. This presentation mainly aims at a discussion of items concerning the permeability characterisation of the massif to be excavated, since this aspect is certainly a key problem for the water inflow forecast and the aquifers impact prediction.

A first constrain for a reliable characterisation of permeability is the regional scale of those projects. Hydrogeological studies for deep tunnels usually involve vast areas (500 – 1000 Km$^2$). Also the volumes are important, because of the deepness of the tunnel (up to 2000 m from the surface). The densities of data concerning the hydrogeological properties of the aquifers (e.g. field geological survey, boreholes, geophysics, etc.) are limited compared to the volume to be investigated. In this frame the hydrogeological characterisation of deep tunnelling projects should follow four steps.

1. Definition of **hydrogeological complexes**, mainly resting upon lithological and structural data (hydrogeological complexes are 3D hydrogeological elements showing homogeneous hydrogeological behaviour).
2. Identification of **discrete zones** showing anomalous permeability, e.g. fault zones, single fractures, karsts, chemical dissolution horizons; the geometry of discrete zones can crosscut many hydrogeological complexes.
3. Interpretation of data derived from **borehole hydraulic tests**
4. **Permeability characterisation** of hydrogeological complexes and discrete zones by means of a regionalisation of borehole hydraulic tests results, intersected with all geological and hydrogeological survey observations.

In mountain regions like the Alps where aquifers are composed of cohesive rocks, points 1 and 2 are defined according to primary lithological properties and average fracturation state of the rock mass. These therefore strongly depend from geological and structural inputs. Conversely point 3 and 4 are an analysis owing to a complete quantitative hydrogeological characterisation but its realisation depends from a number of critical aspects that are here discussed in some more detail.

Hydraulic tests operated in situ at the tunnel depth (slug tests, *Lugeon* tests) investigate the permeability around the borehole and are very useful because their output is a physical measurement expressed as a number. This output needs therefore to be extrapolated over great rock volumes. In order to do this the lithological and especially the structural context which have been investigated by the test have to be correctly interpreted and understood, otherwise a strong risk of error amplification exists. Besides this, the discrete zones of point 2 are often at the same time the most permeable zones and the less investigate zones by boreholes hydraulic tests. This is because the borehole usually is unstable or it can’t have a regular shape in those difficult geomechanic contexts. For these reasons, data derived from borehole hydraulic tests have very often a bias due to the lack of permeability characterisation of discrete zones.

The permeability characterisation mentioned at point 4 integrates the borehole hydraulic tests with field geological and hydrogeological survey. Geophysics and monitoring of spring discharge are also to be considered. All local features should be taken in account, such as variation of permeability with depth (some time, but not always, the permeability decrease with depth), and the chemical dissolution horizons, which are spread in the alpine context in carbonate rocks associated with brittle tectonic deformation. As far as permeability data extrapolation is concerned, it is important to stress that hydraulic tests are representative only of small rock volumes around the drillholes (meters to decametres). Therefore if only a few tests are available their real value should be carefully weighted.

Summarising, the reliability of permeability characterisation depends not only from the number of borehole tests available for the interpretation, but also, and very strongly, from the reliability of the geological model and from its correct utilisation in the contextualisation of the hydrogeological tests.

The application of a reliable method for permeability characterisation is surely a need for tunnelling design. Several large projects in Austria, Italy, France and Spain are scheduled for the next hears. This method contributes to the definition of the reference hydrogeological model, which is the necessary tool to perform the risk analysis of hydrogeological impacts inside and outside the tunnel. Those studies should also contribute to the design of solutions to preserve or compensate any possible water lost, and to the valorisation and re-utilisation of tunnel groundwater-inflow.