The hydrogeological studies concerning the new international railway connection between Lyon and Turin: forecasting groundwater impact during tunnelling

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Abstract: This paper illustrates the state of the hydrogeological studies on the international section of the new railway connection between Lyon (France) and Turin (Italy). The main purposes of these studies are (1) to characterise the hydrogeological formations; (2) to predict the impact of tunnels on the hydrogeological systems, and (3) to forecast groundwater inflow into the tunnel during construction and operation phases. Borehole permeability tests, seismic profiles and chemical and isotopic analyses of spring and borehole water samples allow to characterise groundwater flow systems, together with long term series of measurements of springs discharge and groundwater level in boreholes. This hydrogeological study is an example of applied study of one of the most important deep tunnels in the Alps for the next years.

Key words: hydrogeology, tunnelling, deep groundwater flow systems

Introduction

In the context of the international project of the new railway connection between Lyon and Turin, two deep tunnels will be drilled through the Western Alps, between Saint Jean de Maurienne (F) and Bruzolo (I): the 53 km long "Maurienne-Ambin base-tunnel" and the 12 km long "Bussoleno tunnel". In addition, three inclined adits and a pilot tunnel parallel to the basis tunnel will be excavated. At present, only the Modane inclined adit, started in 2002 and located in the central part of the base-tunnel, is under excavation, reaching as far as 550m from the surface. The aim of this paper is to present the criteria adopted for the hydrogeological studies concerning this main engineering project, which can be compared with others similar projects. Some preliminary results of this ongoing study are also presented.

Regional geology and hydrogeology

From West to East, the two tunnels cross some of the main geological units of the western alpine chain: the Ultradelphinese Zone, the Subbrianzonese, Brianzonese, Piemontese Ophiolitic and the Dora Maira units (see Figure 1). Major tectonic contacts (both ductile and brittle) usually occur at the boundaries of the units, often representing preferential water flow zones. Seven of these main geological boundaries will be crossed by the tunnels. Important fault zones will often be located inside the units, as attested by borehole data and local structural mapping.

Scientific paper

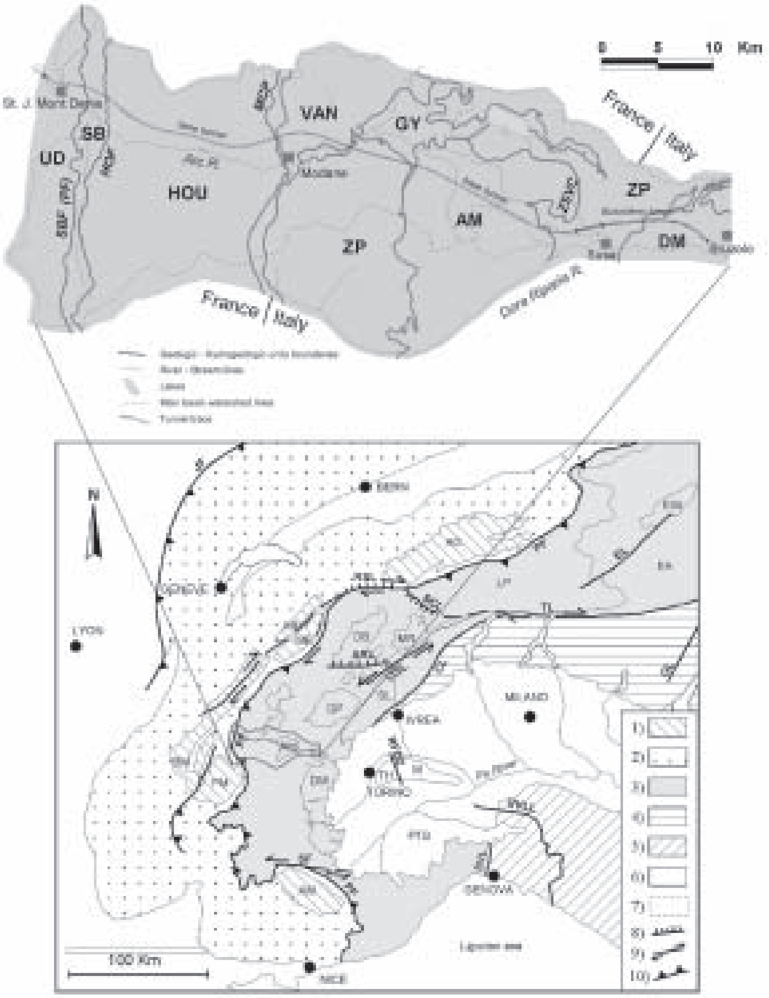

Figure 1. Hydrogeological sketch map with the tunnel trace. UD: Ultradelphinese Zone; SB: Subbriançonnais Unit; HOU: Zone Houillčre; VAN: Vanoise basement and mesozoic covers; GY: "Gypses" zone; ZP: Piemontese ophiolitic unit (schistes lustrés); AMB: Ambin unit; DM: Dora Maira unit; SBF: Subbriançonnais front; HOF: Houillčr Front; MCP: Modane – Chavičre – Pralognan unconformity; ZSVC: Val Cenischia shear zone.
(below): Regional sketch map of the western Alps: 1) Helvetic Cristalline Massifs: AG = Aar-Gothard, MB = Mont Blanc, AR = Aiguilles Rouges, BM = Belledonne, PM = Pelvoux, AM = Argentera; 2) Helvetic Mesozoic/Cenozoic Cover; 3) Austroalpine, Penninic and Briançonnais units: EA = Eastern Austroalpine, EW = Engadine Window, LP = Lower Penninic nappes, MR = Monte Rosa nappe, DB = Dent Blanche nappe, SL = Sesia Lanzo unit, GP = Gran Paradiso massif, AM = Ambin massif, DM = Dora Maira massif; 4) South Alpine units; 5) Appennines 6) Oligocene and Neogene synorogenic sedimentary deposits: TH = Torino Hill, M = Monferrato, PTB = Piedmont Tertiary Basin; 7) Location of the studied area; 8) Normal faults; 9) Strike-slip faults; 10) Thrust faults. JF = Jura Front, PF = Penninic Front, RSL = Rhone-Simplon Line, SCL: Simplon-Centovalli Line, TL: Tonale Line, EL: Engadine Line; Gl: Giudicarie Line, ARL: Aosta-Ranzola Line, OSL = Ospizio Sottile Line, CL = Canavese Line, RFDZ = Rio Freddo Deformation Zone, SF = Stura Fault, VVLL = Villalvernia-Varzi-Levanto Line, SVL = Sestri-Voltaggio Line

Groundwater monitoring and chemical analysis

More than 500 springs and 50 boreholes located along the future tunnel axis are being monitored since 1995 (flow rate, water level, electrical conductivity, pH, water and air temperature). All the collected data are managed through a database connected with a GIS. This database is constantly integrated with daily measures of climatic data (precipitation and air temperature) from 17 climatic stations. The chemical and isotopic study provides 370 water samples, including 300 springs and inflows in shallow tunnels and 70 inflows in deep boreholes. Three main groups of waters can be distinguished: (a) most of the springs exhibit a Ca-(Mg)-HCO_3 composition and electrical conductivity (EC) values in the range of 0.1-0.6 $mScm^{-1}$; (b) some springs belong to the Ca-SO_4 chemical type with EC values in the range of 0.7-2.5 $mScm^{-1}$; (c) borehole water samples (between 100 m and 1200 m below the ground level) include Ca-(Mg)-HCO_3, Ca-SO_4 and Na-rich waters (Na-HCO_3, Na-SO_4 and Na-Cl chemical types), with EC in the range of 5-50 $mScm^{-1}$. The Na-Cl waters are uncommon in the Alps and are probably produced by prolonged water-rock interaction, requiring deep circulation in crystalline rocks. The ^{3}H content of springs displays values between 7 and 20 UT, very similar to the ^{3}H composition of present day rainfall, while water inflows in the boreholes can be subdivided in two groups: samples with ^{3}H values similar to those measured in the springs and samples with ^{3}H values lower than 1UT, typical of very old waters. The dD and the d^{18}O ratio of all sampled waters lie along the worldwide Meteoric Water Line. Only one point displays very high dD ‰ values (-6 ‰ vs. SMOW). This water belongs to the group of the very saline Na-Cl chemical type and its particular isotopic composition might indicate an origin from deep brine pockets present in the crystalline massifs as already highlighted in shield zones. The use of other hydrochemical and isotopic tools in the prosecution of the studies could help to evaluate more precisely the origin, the time of residence and the flow rate of the different groundwater systems.

Hydraulic borehole tests

Exploration boreholes have been tested in several intervals with the classical packer test technique (slug-test, injection test, recovery or build-up test). In this phase of the work, 15 hydraulic tests in 6 boreholes have been analyzed with the package Hytool to interpret the data. From a global perspective, it is rather surprising that most of the tests show a behavior that one can model with an equivalent porous medium. The double porosity model is usually not required, and non-integer flow dimensions are seldom observed. The characterization of the permeability features of the different aquifers is resumed in the box plot shown in Figure 2, which resume all available data from borehole hydraulic tests.

Main hydrogeological problems

Active flow zones: one of the most relevant technical problems is predicting the effects of tunnelling on the groundwater flow systems, and especially on active flow zones. Conversely, another question is whether the drainage of large amounts of water during the excavation phase is going to prejudice the excavation itself. In order to answer these questions a good regional knowledge of the 3D geometrical structure of aquifers is required (i.e. a good knowledge of lithostratigraphic and structural setting). Owing to the wide extension of the area to be studied, this has been achieved mainly by the existing geological maps (scale 1:50.000 to 1:25.000), boreholes, seismic profiles and geochemical data. Structural details of brittle fault zones along the contacts drainage zones at the local scale (i.e. permeable zones) will be the object of future studies and structural geological surveys.

Local geothermal anomalies are related to water circulation. A positive geothermal anomaly was detected in the La Praz region (F) where the higher temperature value measured in boreholes was 44 °C at a depth of 600 m. The geothermometers quartz and Na/K show a temperature range in deep thermal aquifers between 75-81°C. Another zone where high temperatures are expected is the Ambin unit, where the overburden ranges from 1300 m to 2400 m.

The impact of tunnels on actual flow systems is likely to cause a drawdown of the hydrostatic level and a decrease in the discharge of springs and/or wells, a phenomenon that can persist after the construction of the tunnel.

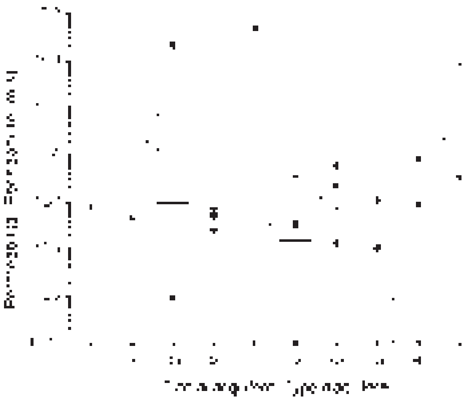

Figure 2. Box plot of 232 in situ hydraulic tests carried out through 36 boreholes. Type of aquifers: 2=Carbonate rocks; 3=Marbly calcschists; 4a=Quartzites; 4b=Metabasites; 5=Micaschists, gneiss and sandstones; 6a=Calchschists and flysch; 6b=Fractured calcschists; 8a=Anhy- drites; 8b=Dolomite marbles (blocks inside the anhydrite masses and dolomitic breccias with anhydritic matrix); Q=Quaternary deposits

The forecast of these phenomena has been realized with an empiric approach; the main problems are expected along the inclined intermediate adits. A probabilistic analysis based on the *systems approach* applied to rock engineering is actually in progress.

The discharge flow values expected into the tunnels have been evaluated by adding the specific drainage of all different aquifers crossed by the tunnels and the localized inflows expected in active flows zones (e.g., fault zones). The expected total discharge is about 3,7 m^3s^{-1}. Another analytical evaluation has been performed with the Dupuit equation for a flow in semi-infinite confined medium and with a linear boundary at atmospheric pressure. The results of this second evaluation are a factor 10 greater than the previous ones and approximate the theoretic maximum discharge values. However, the comparison of the two approaches demonstrates that the controlling factor for the total amount of water inflow into the tunnels is probably the recharge rate (i.e., the infiltration in the catchment basin), and not the permeability and the water head.