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# A new method to monitor seepages during tunnel construction

## *Nuevo método para medir filtraciones durante la construcción de túneles*

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## ABSTRACT

*We present a new method for measuring water flow through a free surface of a tunnel. The objetive of the work is to fulfill the requirements of a new tunnel construction in a granitic rock mass. This tunnel is excavated for a full scale hydro-therma-mechanical experiment over a long time. the method and materials thus resulting are cheap, easy to use, and proved to be reliable. Independent measurement showed it to be comparable to other more expensive and shophisticated methods.*

## RESUMEN

*Se ha desarrollado un nuevo método para medir el flujo de agua hacia la cara libre del túnel. El trabajo tiene como objetivo satisfacer los requerimientos de la construcción de un túnel en un macizo granítico. Dicho túnel es para un experimento hidro-termo-mecánico a gran escala durante un periodo largo de tiempo. El método desarrollado es fácil de aplicar, muy barato y ha ofrecido resultados muy fiables, siendo comparable con otros desarrollos mucho más caros y sofisticados.*

**Key words:** *Instrumentación de túneles, medios poco permeables, residuos radiactivos, granitos, hidrogeología.*

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### Aims and scope

Stable geological formations are potential hosts for radioactive wastes. Such a solution is rather well accepted in surface or moderate deep repositories for low level wastes. The final fate in several countries for high level wastes is a deep (> 500 m), confined repository in a low permeability rock. For safety reasons, geological formations must be stable and display low permeability, since groundwater is the main carrier of radionuclides to the biosphere.

Igneous and metamorphic rocks, clays and salts have deserved a vast amount of field and laboratory characterisation and modeling of flow, transport, mechanics and thermal phenomena. In this framework, the FEBEX project (Full scale Engineering Barrier EXperiment) is a big step ahead since will serve to validate the concept of deep repository. Summarizing, the test plan (ENRESA, 1995) consists of a small dimension tunnel under 400 m of granite in the Swiss Alps (Grimsel Test Site, operated by NAGRA). The excavation method is by tunnel boring machine (TBM) and blasting

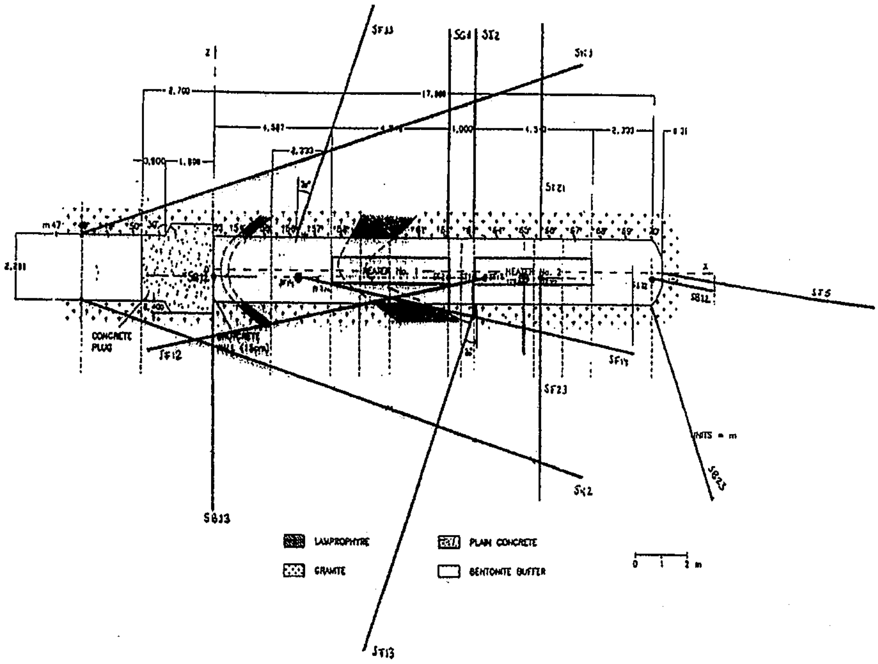

**Fig. 1.- Experimental layout showing the tunnel, surrounding boreholes and heaters, and synthetic geology**

***Fig. 1.- Esquema del tunel del experimento, junto con los sondeos de control y calentadores. Se muestra de forma sucinta la geología del entorno.***

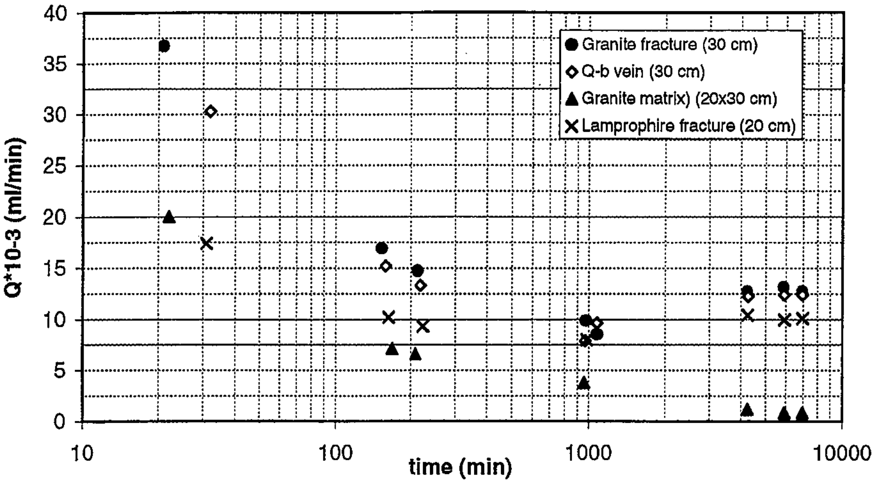

**Fig. 2.- Flow rate measurements taken over different time spans.**

*Fig. 2.- Medidas de caudal tomadas durante diferentes tiempos*

is avoided. Two cylindric heaters will be placed in the center of the tunnel and will be surrounded by bentonite bricks. A concrete plug will close the experiment area (Figure 1). It is expected to monitor the hydro-thermal-mechanical behaviour of the system during a period of several years at the near field environment (engineered barrier) and at the far field (granite). Therefore, a fully automatic data acquisition system will record humidity, pore pressure, temperature and stress data, among others. Summing-up, the project will integrate geomechanical and hydrogeological characterisation and modeling efforts.

A key point for the success of the project is to ensure that the water saturation front will move from the tunnel wall towards the bentonite to some extent. For that, the tunnel construction had to stop at a certain length were the groundwater flow attained 4-30 ml/min over some 13 m of tunnel. That is, the extension of the test zone.

Before tunnel excavation, hydraulic testing produced information over 4 boreholes drilled nearby the area. Moreover, presence and orientation of major flow paths (fractures and dykes) were also available. However, such information was not so quantitative to forecast the outflows in the tunnel, and direct measurements during construction were needed.

Existing methods for measuring groundwater inflows to a tunnel are usually developed for long term experiments (Thorne 1990). Abelin *et al.* (1991) describe the use of plastic sheets to collect tracers injected in borehole sections some meters apart. To assess the bulk hydraulic conductivity of a rock mass, ventilation tests have been run in several *in situ* rock laboratories (Brewitz *et al.*, 1984; Wilson *et al.*, 1981; Bossart and Meier, 1993). Recently, direct evaporation methodologies account for point measurements of inflows from a rock mass towards a free-face of a tunnel (Meier *et al.* 1992; Gimmi *et al.*, 1992 and Schneebeli *et al.*, 1995). Summarizing, quantifying natural outflow of a fracture, fracture set or even from the fresh rock mass is achievable after the tunnel construction.

However, we had to provide data to select the test zone during the tunnel construction and TBM could not be stopped for a long time. Therefore, we developed a new method to assess the total inflows.

The objective of this paper is to describe the new methodology and the purpose of this new method was to provide semiquantitative criteria to stop the tunnel excavation.

## Materials and method

The new method consists of locating a dry sheet of water absorbing material at a seeping surface during a certain period. After such a period, we remove the sheet and weight it. The difference in dry-wet weight divided by time, results in flowrate.

Inherent problems to the methodology are: (a) During the tunnel excavation - and therefore, during the measurements- flowrate is decreasing with time. (b) Dry absorbing materials may absorb air humidity. (c) Suction difference between the dry sheet and the tunnel wall may desaturate the rock. (d) The «water absorption capacity» of any material will usually decrease as a function of moisture content. We concentrated the methodology development to overcome to some extent the restrictions mentioned above.

Water flowing to a tunnel follows the hydraulic behaviour of a pumping at a constant head extraction, thus decreasing flowrate with time. Jacob and Lohman (Lohman 1972) provided the type curves for the problem (G (α) function). In a medium like the fractured granite, ($k \cong 10^{-10}$ m/s; $S_s \cong 10^{-6} m^{-1}$) initial flowrate was expected to decrease to half value in several days and to continue decreasing asymptotically.

Material selection considered any material capable to absorb water. Finally, we concentrated on blotting paper and cellulose. From one side, the cellulose bulk

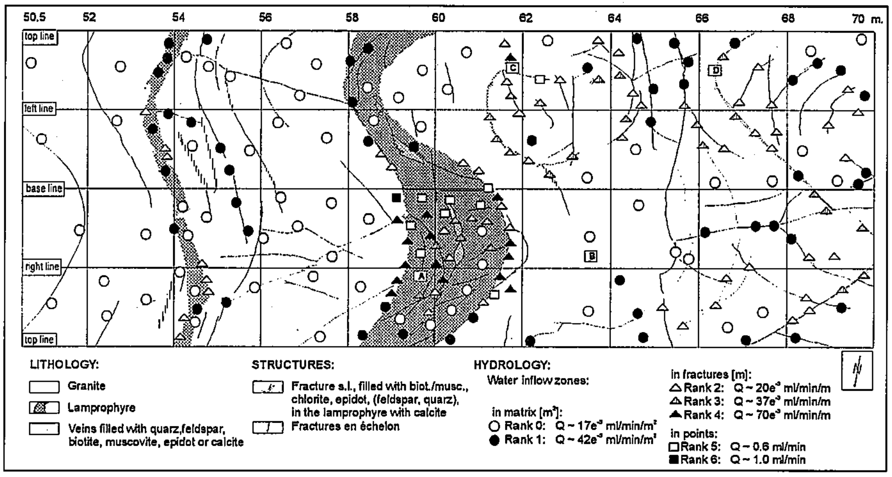

**Fig. 3.- Simplified hydro-geo-mapping of the FEBEX experimental area.(after Ortuño, Pardillo and Döllinger, 1995, unpub). A to D, direct measurements during tunnel excavtion. Symbols used to estimate water inflows according to flowrate measurements.**

*Fig. 3.- Esquema geológico de las zonas de rezume en el tramo del experimento FEBEX. (mapa realizado por Ortuño, Pardillo y Döllinger, 1995, no publicado). A a D, medidas directas hechas durante la excavación del túnel. Los símbolos se refieren a observaciones a las que se asigna un valor según los rangos de caudal establecidos.*

volume of saturation is one order of magnitude higher than the paper one. Besides, cellulose attached to plastic sheets are commercially available (diapers). Having one side of the sheet covered by plastic, prevents evaporation during the measurements. Therefore, we decided to use cellulose.

Before starting any measurement we minimised air moisture absorption experimentally, adding 5 ml of water to the cellulose sheet.

The dust at the tunnel wall and the seeping water were carefully removed before measurements.

The cellulose sheet was placed at the tunnel wall, attached to a metal plate. Then, a small pressure maintained the sheet and the plate in contact to the wall, the plate distributing the pressure homogeneously along the cellulose. To calibrate the method, we performed several measurements at a given point with different and with constant contact times (15 min). Repetitiveness and dependence of the measurements with time were crucial for the method. All tests were carried out monitoring environment conditions (air temperature and humidity) to ensure external boundary conditions.

Repetitiveness was ensured since the measurements with constant periods of time resulted in 0.341 ml/min ± 0.045 (standard deviation, $\sigma$). As long as extreme values are disregarded, $\sigma$ decreases to 0.024.

Figure 2 shows the dependence of measured flowrate with time. These measurements were carried out over wall zones off different geology at the FEBEX tunnel, putting several cellulose sheet's during different times.

Suction at the cellulose rules the water absorption rate as a consequence of the retention curve (suction versus moisture content). Low moisture contents at the cellulose, results in high water absorption rates. On the contrary, high moisture contents induce low absorption rates.

No specific tests were done, such as determining the cellulose retention curves -which, in addition would be influenced by the compactness-. Measurements covered 3 log periods, and the slopes are too steep at the early times (up to 100 min) and too gentle for late times (more than 1000 min). Therefore, we decided to use those measures lasting among 100 and 1000 min. Besides, given that the possibility of desaturating the rock wall increase with the time span, long measurement's period should be avoided.

After calibrating the method, we checked it against independent values. For that, we performed several measurements at different zones of the GTS, where inflow through tunnel walls was measured by different methods: evapometer, tunnel ventilation and radial flow. Measurements taken by means of cellulose sheets at selected evapometer locations resulted in flowrates of $1.66\times10^{-5}$ ml/min/cm$^2$ and $4\text{-}8\times10^{-6}$ ml/min/cm$^2$. Evapometer measurements resulted in $5.98\times10^{-6}$ ml/min/cm$^2$ and $4.27\times10^{-6}$ ml/min/cm$^2$ respectively. Ventilation tests showed a range of hydraulic conductivities from $10^{-11}$ to $2\times10^{-10}$ m/s. Boreholes parallel to the tunnel provided information on hydraulic gradient. Thus, steady state flow resulted in $1\text{-}2\times10^{-6}$ ml/min/cm$^2$ for $K = 10^{-11}$ m/s. Flowrates measured by means of cellulose sheets ranged from $1\text{-}2\times10^{-5}$ ml/min/cm$^2$; results are on the same order of magnitude if the variability of K is accounted for.

## Application to the FEBEX tunnel

During the tunnel construction, the method was applied quite successfully. However, due to the presence of the tunnel machine, some parts of the excavation remained inaccessible. Therefore, the first estimates were quite qualitative. When the TBM was finally retrieved, we produced a detailed hydro-geo-mapping (Figure 3). Due to the difficulty of covering the whole tunnel area with cellulose sheets, several flowrate ranges were established for matrix and fracture flow. Averaging the areas and measurements thus obtained, resulted in a total flow of $\cong$ 8-10 ml/min (8.5 ml/min) for a tunnel section of 13 m. One month after the work, a direct measurement was taken at the tunnel by using a small scale gauge. Measured flowrate was then 4-6 ml/min.

## Discussion and conclusions

The new method for estimating seepage from tunnel walls proved to be realistic and of great use under the strict conditions of the project. In addition, it has demonstrate to be comparable to other more sophisticated and expensive methods. We recommend its use in combination to such sophisticated methods given its simplicity and low cost. In the current circumstances, the method is only valid for measuring flow in liquid phase.

However, the dependence of the measurement with time and the need to calibrate each commercial cellulose, set some constraints on the method. That could be overcome by using a combination of cellulose and silica gel, which maintains the suction constant over long periods of time.

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