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WATERPROOFING A PRESSURE TUNNEL WITH A DRAINED POLYVINYLCHLORIDE MEMBRANE COMPOSITE

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ABSTRACT

The paper describes application of a waterproofing drained membrane system to a pressure tunnel in the Italian Alps. The system allowed to restore impermeability and to dehydrate the natural soil of impregnation water, without decreasing the water flow. The system is capable of bridging joints and cracks, even in case of seismic events.

INTRODUCTION

Deterioration of pressure tunnels over time may cause stability problems also in the surrounding soil. This is particularly dangerous in steep mountain areas, and in presence of unfavourable geological conditions: water infiltrating the soil through the deteriorated tunnel structure can jeopardize stability of the natural slopes, and eventually start landslides. The Owners therefore face not only power loss, but risk of partial or total collapse of the tunnel's structure.

Rehabilitation must stop water infiltration into the soil and restore the initial impermeability of the deteriorated structure, to bring the pressure tunnel back to its designed efficiency. The adopted rehabilitation system must also allow drainage of rain water permeating the slopes around the tunnel.

Traditional lining systems have been efficiently and cost-effectively substituted by synthetic membrane systems which exploit some of the favourable characteristics of synthetic materials: very low permeability, which allows use of thin (in the order of a few mm) geomembranes to restore imperviousness, and very high transmissivity, by which a light geotextile or geonet can provide efficient in-plane transmissivity and drainage.

A DRAINED SYNTHETIC MEMBRANE SYSTEM

The use of a prefabricated, low permeability, flexible synthetic membrane allows to construct a drained waterproofing barrier on the whole internal section of the tunnel: if the membrane is mechanically anchored to the existing structure and kept independent from the underlying substrate, water already impregnating the structure and its surrounding soil can flow behind the synthetic liner, flow being facilitated by suitable high in-plane transmissivity materials. This drainage water is collected by a collection system and discharged. The system was conceived in Italy in the late 1960's for waterproofing and protection of dams and canals, as described in these Proceedings by the same Authors, and was developed and applied to pressure tunnels since 1977.

The stability of the tunnel and of the soil were periodically controlled by measuring the convergence of the walls and the displacements between the walls and the soil natural surface. Measured horizontal movements were in the order of 10 cm per year, vertical movements in the order of 1 cm per year. Stability was jeopardized by uplifts due to seepage water through the cracked concrete. Rehabilitation therefore had the objective of stopping further water seepage, and of allowing the tunnel to operate as a drainage structure for the rain water present in the upper part of the natural slopes.

Stability Analysis

The owner performed a stability analysis aimed to ascertain which effects a waterproofing intervention, including a drainage system for the rain water, would have on the static conditions of the tunnel and of the natural slopes.

The stability analysis was performed for the following situations:
1) initial, with no tunnel
2) situation with tunnel, before waterproofing
3) situation with waterproofed tunnel and drainage of surface rain water

Stability analysis was made by taking into consideration circular surfaces of potential sliding and determining, for each of the above situations, the sliding surface having the lowest safety factor. The methods chosen for the stability analysis were the Janbu [1], Bishop [2] and Bell [3] methods. The shear strength of the soil considered a GW-GM soil type, friction angle was 33°

The initial situation, with no tunnel, was the reference value to determine the influence of the tunnel and of the drainage system on the stability of the soil. Different pore pressure conditions in the soil were examined for different values of r_u [2] until the limit value for r_u was determined.

Situation 2, with deteriorated tunnel before waterproofing, was analyzed in the hypothesis that r_u had the maximum value ($r_u = 0.5$), while for situation 3, waterproofed tunnel incorporating a system for drainage of surface water, a good efficiency of the waterproofing and the drainage systems was assumed, therefore the adopted r_u value was 0.1. Figure 2 shows the natural slopes, the tunnel and the sliding surface with the minimum safety factor.

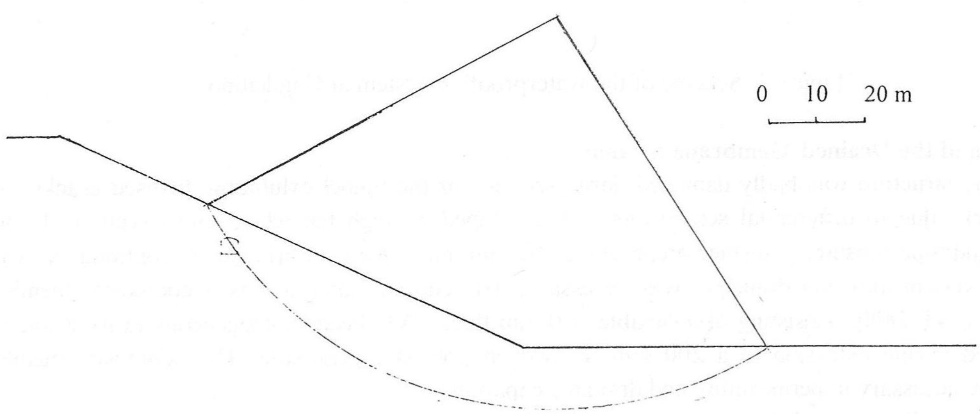


Figure 2. The natural slopes and the sliding surface with minimum safety factor

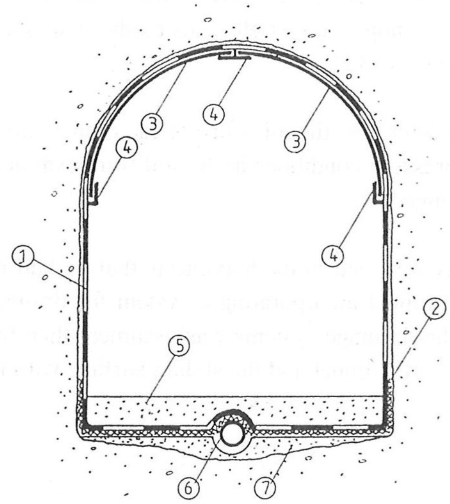
As reported by Giani et al. [4] (who examine the various safety factors for different situations and values of r_u), in situations with tunnel, drainage makes a substantial difference in soil stability: the safety factor is improved to such an extent that stability of the slopes can be considered guaranteed if the tunnel can drain surface water.

Choice of a Drained Membrane System

Continuous drainage of rain water present in the soil layers around the Gandellino tunnel was therefore a mandatory issue for any waterproofing solution. In addition, the owner wanted to avoid reduction in power supply. A thin impermeable system, allowing drainage and discharge of water migrating towards the empty tunnel, was the chosen solution.

At that point, ENEL, the Italian National Power Board, had already experienced a same drained membrane system on hydraulic structures (dams, canals, pressure tunnels, reservoirs). All installations, some dating back to 10 years before, had been successful. The same conceptual system was adopted at Gandellino.

The designed system installs a low permeability PVC composite membrane over the whole internal section of the tunnel. The membrane is mechanically anchored, and drained water flows behind it to a bottom collection and discharge system. A special ballasting anchorage is applied on the vault to sustain the membrane against uplifts (see Figure 3).



1 - Impermeable waterproofing liner, SIBELON CNT 2800
2 - HDPE geonet
3 - Rigid PVC ballasting elements
4 - Stainless steel anchorage profiles
5 - Concrete ballast layer
6 - Microperforated PVC drainage pipe
7 - Regularizing layer

Figure 3. Scheme of the waterproofing system at Gandellino

Installation of the Drained Membrane System

The existing structure was badly damaged, large sections of the tunnel exhibiting diffused cracks. Some bigger cracks due to differential settlements had developed through the whole cross section. To avoid extensive and time consuming surface preparation, a membrane capable of bridging discontinuities, with an anchorage system allowing drainage, was necessary. The chosen material was a composite membrane, SIBELON CNT 2800, consisting of a flexible, 2.0 mm thick PVC layer, homogeneous in its whole mass and coupled during extrusion to a 200 g/m^2 nonwoven polyester geotextile. The composite membrane provides the necessary impermeability and drainage capability.

The drainage collection and discharge system was first constructed: in a regularization concrete layer a trench for installation of the drainage collection pipe was prepared. The microperforated PVC pipe positioned in the trench conveys drained water towards the two ends of the tunnel. To increase drainage capacity on the bottom, a high transmissivity HDPE geonet was positioned on the invert so that drained water can be effectively conveyed towards the PVC pipe. The geonet covers the whole invert and the lowest part of the two walls.

The composite membrane was installed over the geonet. To allow pedestrian and machine traffic for inspection and cleaning, a 5 cm thick protection concrete layer was poured over the membrane waterproofing the invert.

The SIBELON CNT 2800 lining the walls is anchored with a system similar to the one used in underground constructions: rods equipped with a washer and a rigid PVC disk are anchored in the existing concrete structure, and the waterproofing liner is heat welded on the PVC disks. The liner is thus maintained independent from the concrete surface, and a drainage gap is created behind it, in which water migrating from the natural slopes can flow towards bottom collection.

A different anchorage system was required in correspondence of the vault, to sustain the liner in presence of high uplifts and maintain it in contact with the substrate. The designed ballast layer consists of two symmetric rigid PVC elements, shaped to accommodate the shape of the vault. Each element is 4 mm thick (see Figure 4). The rigid ballast elements cover the waterproofing liner on the whole vault, from the springing to the crown.

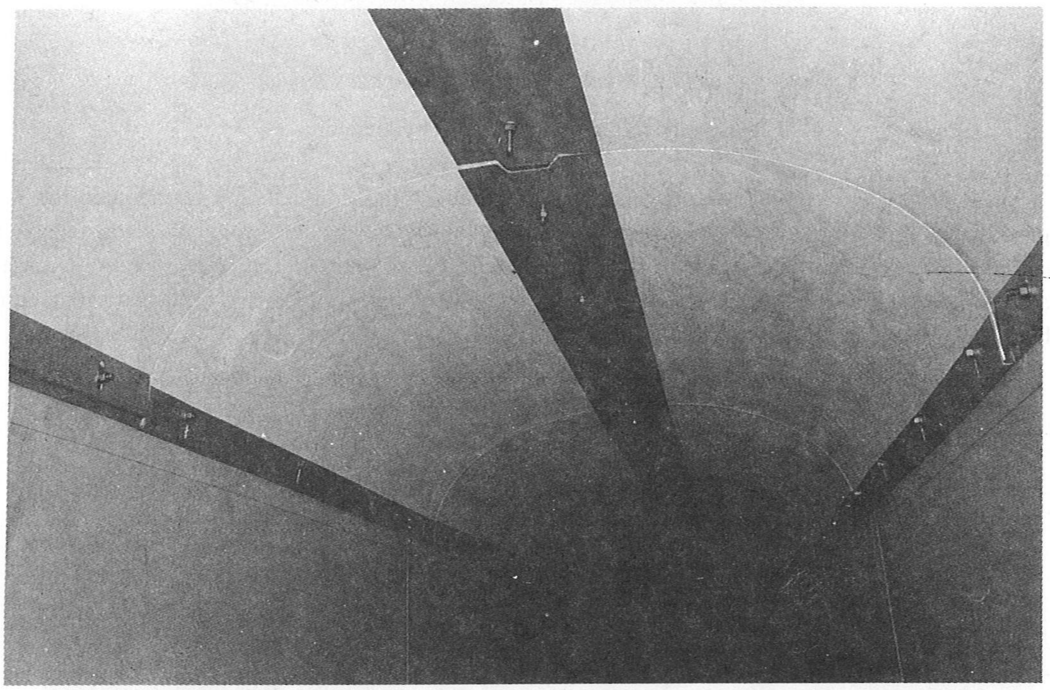


Figure 4. The rigid PVC elements and the anchorage profiles

To anchor the waterproofing liner and the ballast elements, special stainless steel batten strips (profiles) were designed. One type of profile is positioned at each springing of the vault, to sustain the base of one PVC element, and to secure the waterproofing liner, providing it with a continuous anchorage line. Another stainless steel profile is positioned at the crown of the vault, to secure the upper side of each PVC element. All profiles are anchored to the existing concrete structure by threaded rods and chemical phials. The described anchorage system exerts a compression on the rigid PVC elements, to maintain them adherent to the structure of the tunnel, thus minimizing voids between the waterproofing membrane and the existing concrete substrate.

Design and installation of the system were made considering that the water flow can be both ways, as the tunnel acts as a low pressure tunnel for the reservoir, or as a drawoff tunnel of the reservoir when the water flow from the other supply works is higher than the maximum flow of the penstocks. Installation was accomplished in 1983 (Figure 5).

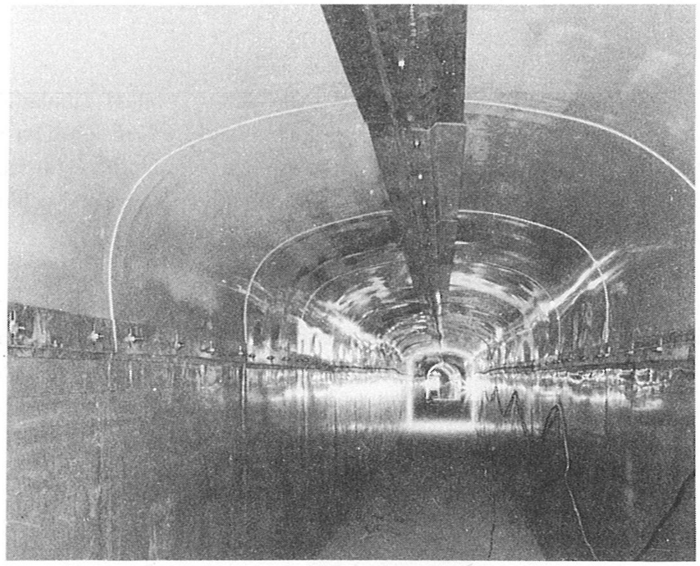


Figure 5. Installation completed at Gandellino

After 5 years of service, in 1988, as performance was totally satisfactory, the owner adopted the same waterproofing system for the same powerplant: a second tunnel, having the same characteristics as the Gandellino one, was rehabilitated with the described system. Up to date, no repairs have been necessary; the water flow is such as required by the owner, and drainage of rain water is accomplished satisfactorily and efficiently even when the tunnel is empty.

Figure 6. A completed installation with the same described system

EXPOSED AND COVERED MEMBRANE SYSTEMS

A cover layer is necessary only to provide protection against excessive stresses: these can be mechanical stresses coming from inside the tunnel, or an uplifting action from the outside. This was the case at Gandellino, where the liner was left exposed on the walls, and ballast layers were installed on the invert and on the vault, only to allow cleaning operations and to protect from uplifts. As concrete protection has proved to cause higher friction losses over time, reducing the capacity of the tunnel, the use of rigid synthetic materials for ballasting can provide higher water flow.

Generally speaking, if the whole liner is left exposed its low hydraulic roughness can be fully exploited, to provide significant increase in water flow. Figure 7 shows recent and successful installation of a totally exposed PVC membrane system, of the same type used at Gandellino.

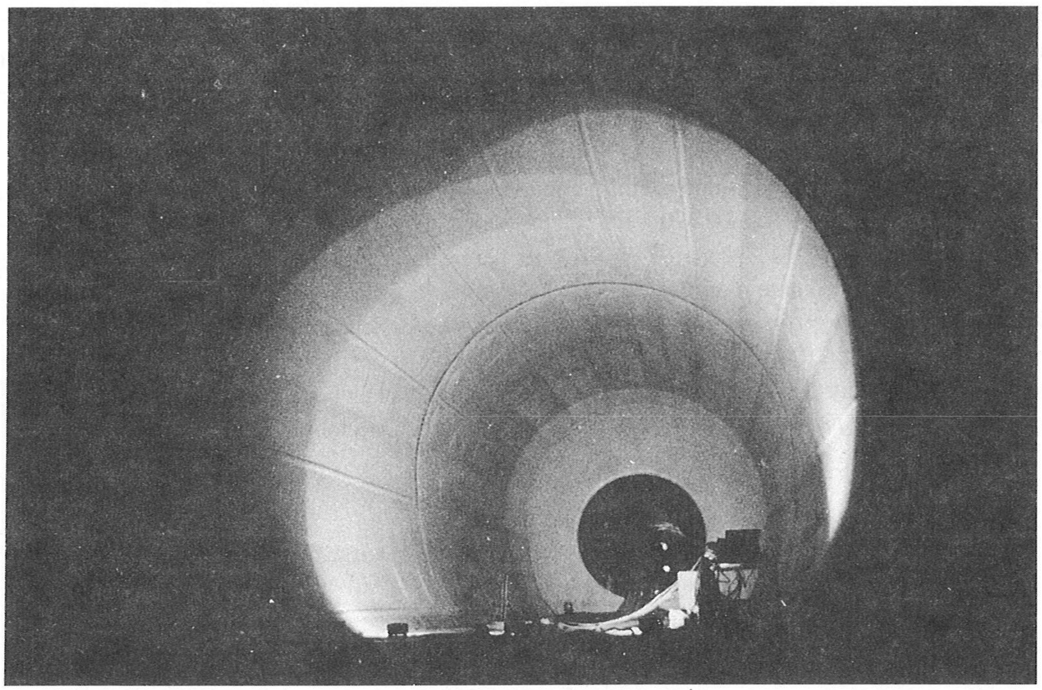


Figure 7. Thissavros pressure tunnel

DURABILITY

Durability is one of the basic parameters for calculation of real costs of a rehabilitation, together with evaluation of a gain in hydropower production, which has proved to be possible in applications of PVC composite membrane systems to water conveyance structures.

Durability of the described system has been proven in the field, by a great number of successful installations on different hydraulic structures. The main issues, that is weathering due to the environment, and dynamic action of water and transported materials, are extensively addressed in installations accomplished on dams and canals in different climates, latitudes and altitudes, where the liners are left exposed to strong U. V. rays and to a highly active environment (ice, frost, vegetation, microorganisms, macroorganisms). Some of these installations date back to the 1970's, as listed by the same Authors in these Proceedings, and are still successfully performing, with no need of repairs. Should repairs be necessary, they are quickly accomplished by simple patching or substitution of an easily and reliably weldable material.

Being the use of synthetic materials for waterproofing of hydraulic structures relatively new as compared to other traditional materials, simulation tests are performed in the lab to predict future behaviour. Among the most recent ones, a research conducted by IREQ, the research institute of Hydro Québec, demonstrated the durability of the described system, which scored first in an extensive laboratory research project focused on the use of synthetic materials for rehabilitation of concrete dams [5]

CONCLUSIONS

The use of a drained geomembrane system on the Gandellino tunnel has proven to be a cost-effective and reliable repair method in its 14 years of service, with no maintenance needed. The presence of a drainage system behind the waterproofing membrane is paramount to exert a dehydrating action on the soil impregnated by rain water, and to avoid uplift pressures build-up.

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