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WATERPROOFING FREE FLOW CANALS WITH FLEXIBLE SYNTHETIC COMPOSITE MEMBRANE SYSTEMS

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ABSTRACT

Ageing of structures in free-flow canals decreases the efficiency in water transport and the safety of the structure, due mainly to water loss through joints and cracks, to increased hydraulic roughness of the surface, to growth of vegetation, to structure deterioration.

Rehabilitation to restore the canal to its original efficiency can be made by flexible PolyVinylChloride (PVC) liners, mechanically anchored to the existing surface and drained. The system can provide perfect watertightness bridging joints and even large fissures, and very low hydraulic roughness with subsequent documented increase in water flow from 50 to 90 %. The paper addresses main issues, drainage collection and discharge, choice of the liner, anchorage system, additional anchorage or ballast layers.

INTRODUCTION

With the increasing demand in water supply, either for power generation or for irrigation and human consumption, water conveyance structures must guarantee a maximum efficiency, at the lowest construction and maintenance costs. Efficiency is measured on the amount of water transported in safety conditions, which must be as close as possible to the amount of inlet water. Impermeable materials with low hydraulic roughness, and proper section and slope, concur to accomplish an efficient design. Over time, however, operation of the canal changes the original design performance, due to the action of water and of the environment on a structure that is subject to ageing.

PROBLEMS CONNECTED WITH OPERATION

Ageing results in:

a) Water Losses

As most canals and tunnels are masonry or concrete structures, water losses are usually located wherever continuity is interrupted, that is at structure or construction joints, and in correspondence of fissures and voids. Discontinuities can be caused by deterioration of the material due to high hydraulic heads associated with the dynamic action of water, to high thermal ranges, to settlements of the ground. Increased overall porosity of the material, caused by the dynamic and chemical action of water flowing inside the canal, can also produce diffuse water loss.

The most immediate effect is the reduction in water flow and supply: in some cases, almost the total amount of water inlet cannot be distributed to the users. Water losses can also negatively affect the surrounding environment: water infiltrating into the ground alters the original conditions, creates the possibility of soil instability, and may lead to landslides that can cause sinking or collapse of parts of the canal structure. Excess ground moisture can negatively affect crops in agricultural areas, or buildings located near the canal in highly populated zones. Loss of water can foster growth of vegetation in correspondence of joints and fissures.

b) Reduction in Water Flow

Reduction in water flow can be caused by increased roughness of the structure surface, or by growth of algae, microorganisms, vegetation. Roughness in the surface increases with ageing, due to the constant dynamic action of water, or to occasional actions of materials transported by water flow, and of pedestrian, animal or mechanical traffic. Increased roughness, by affecting the Manning coefficient, can significantly affect the water flow in canals and tunnels. The growth of algae, microorganisms, mosses and vegetation, due to water composition and action of the environment, often causes impressive reduction in the water flow, in some cases up to almost total clogging of the canal.

c) Structure Deterioration

As most canals and tunnels are made of cement based materials, either mass concrete or binder used in masonry structures, susceptibility of these materials to hard waters, aggressive chemicals diluted in water, washing, ageing, frost, growth of vegetation, and uplifts, causes deterioration of the structure, reducing its mechanical and perviousness characteristics. The effects of structure deterioration can range from formation of small fissures to loss of stability.

d) Detachment of Lining Materials

When the original canal lining, or subsequent repairs, are made with an unsuitable adherent material, ageing can result in partial or total detachment of the liner. This can be caused by uplifts exerted by water impregnating the natural slopes, by action of frost and vapour trapped behind a glued liner, by improper anchorage.

REHABILITATION OF FREE-FLOW CANALS: AVAILABLE LINERS

Rehabilitation can be made with traditional liners such as concrete, gunite, metal sheets, resin films, bituminous membranes, or with synthetic geomembranes. Evaluation of each solution must consider service conditions and expected performance.

- New concrete layer - it is reliable from the point of view of mechanical resistance and durability, but construction of a new layer significantly reduces the canal cross section and therefore the water flow. Installation is costly and time consuming, and the new concrete will have the same ageing problems (joints, material's cracking and permeability) as the old liner
- Gunite - not so effective as far as watertightness and durability are concerned, it requires long subgrade preparation, it has high hydraulic roughness, and low resistance to dynamic actions, uplifts, frost
- Metal sheet liners - require more expensive and complicated installation, and have high risk of corrosion
- Resin films, bituminous membranes impregnated on site, prefabricated glued bituminous membranes - require careful preparation of the subgrade, have low resistance to dynamic effects and uplifts, are dependent on atmospheric conditions for a good result of the installation, and have short durability
- Synthetic membranes - are a viable option, provided the choice of the material is correct (stiff and low dimensional stability membranes have experienced stress cracking, excessive stresses on the membrane and on the anchorage system, and not totally reliable welding), and the installation concept is suitable (glued, adherent membranes can create problems connected with uplifts, frost and vapor).

FLEXIBLE POLYVINYLCHLORIDE MEMBRANES, MECHANICALLY ANCHORED AND DRAINED

A system installing a flexible polyvinyl chloride (PVC) membrane, mechanically anchored to the subgrade and drained, has demonstrated its effectiveness and reliability in the field with excellent performance in on a great number of installations, over more than 20 years of service.

The system constructs a continuous, low roughness PVC liner on the entire section of the canal, over the deteriorated subgrade, bridging all construction joints and existing fissures, and with capability of accommodating formation of new fissures. The PVC membrane is anchored with a mechanical system maintaining the liner independent from the existing surface.

Mechanical linear anchorage constructs a drainage gap between the PVC liner and the existing canal surface. Water coming from the inside of the structure (accidental seepage), or migrating towards the canal from the surrounding soil, can be drained, collected and discharged outside the structure by means of a suitable drainage system. A high transmissivity HDPE geonet can be installed between the waterproofing liner and the existing surface, to increase drainage capability.

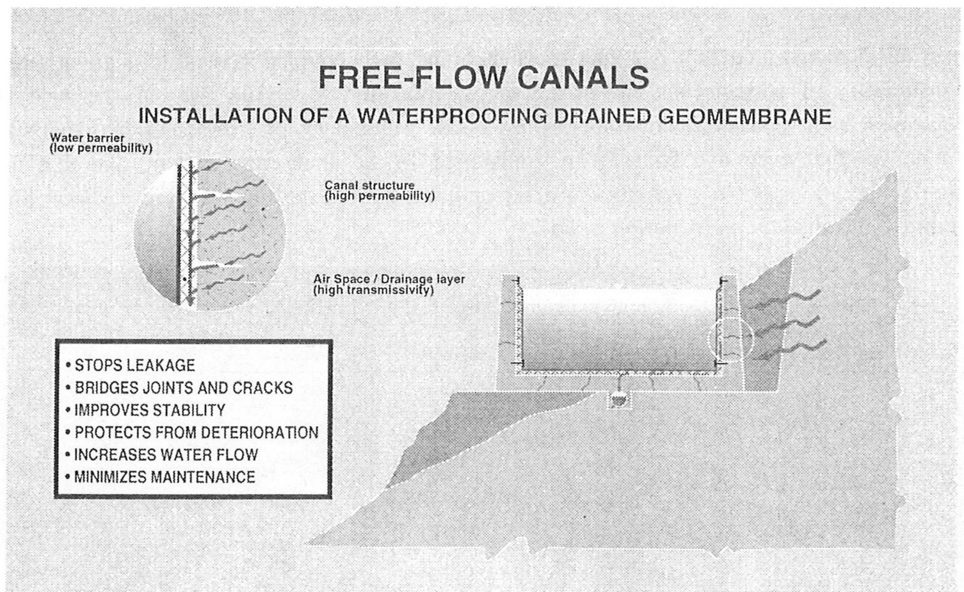

Figure 1. Conceptual scheme of the drained PVC membrane system

Drainage

Drainage capability assures that the liner is protected from uplifts, and that soil stability is improved by the rehabilitation (see also paper by the same Authors on Gandellino pressure tunnel). Drainage occurs in the gap provided behind the liner, and can be facilitated by installation of synthetic materials providing extra in-plane transmissivity. The possibility of coupling the PVC membrane, during manufacturing, to a geotextile for additional drainage capacity, is a favourable characteristic of PVC. Highly transmissive HDPE geonets have been installed under the waterproofing liner, on the bottom of the canal or over its whole cross section, when very high drainage flow is foreseen.

The drainage water collection and discharge system can be made by the existing longitudinal drainage pipes, or be connected to new transversal pipes, or discharge water inside the canal itself, by means of a one-way valve activated by difference in internal and external water pressure.

Continuous and immediate discharge of drained water avoids its build-up behind the membrane, thus eliminating detachment problems. Water migrating towards the canal is also continuously caught, and moisture is thus subtracted from the soil. This feature can be of particular interest in case of canals and tunnels excavated in steep, unstable slopes.

Choice of the Liner

A great number of installations accomplished in Europe have demonstrated that PVC is a dependable and durable material for application on hydraulic structures. Its flexibility, and reliable and easy weldability allow to accommodate any type of canal, and its good mechanical and weathering resistance have been experimented in long term installations on demanding structures. Thickness of the membrane is selected depending on required mechanical or environmental resistance.

Depending on conditions of the substrate, and on foreseen service stresses, a simple membrane or a composite membrane can be selected. Composite membranes, by their coupled geotextile, provide higher dimensional stability, additional anti-puncture protection further reducing need for surface preparation, increased drainage capacity.

Experience has demonstrated that a composite membrane with coupled geotextile is to be preferred to separate installation of a membrane and of a separate transition geotextile, not only because of shorter installation times: as a separate geotextile does not assure transfer of all stresses to the canal's structure, there is a danger that excessive stresses are transferred to the anchorage system, and that in case of membrane damage the geotextile detaches and accumulates behind the liner. Figure 2 shows an exposed PVC membrane installed on an irrigation canal.

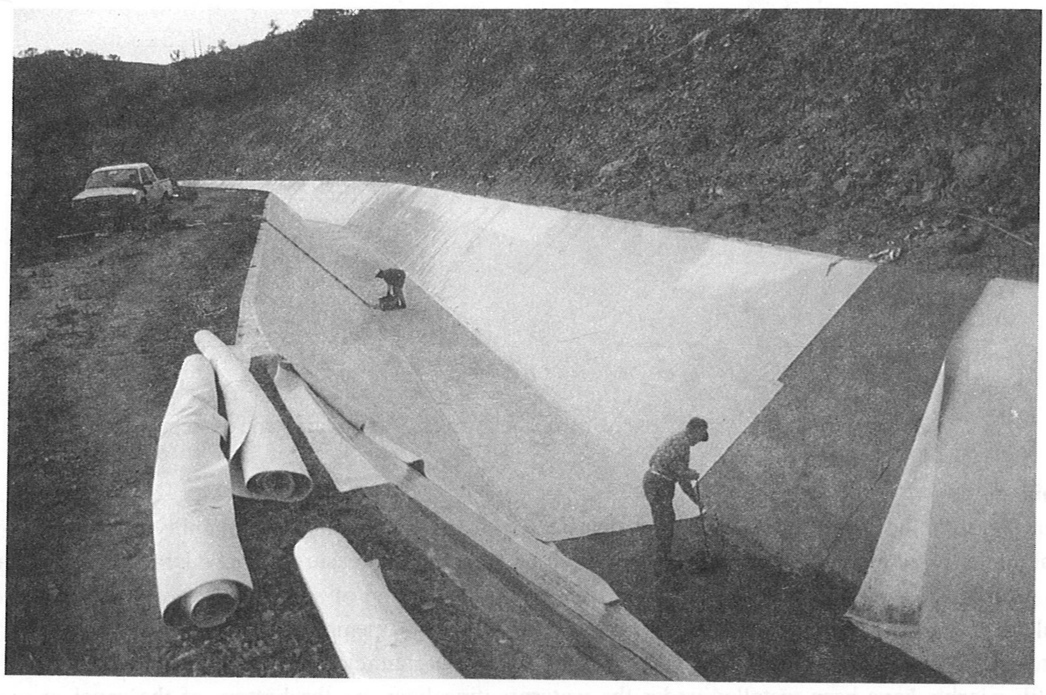

Figure 2. Installation of the PVC waterproofing system at Mira canal

Whenever possible, the PVC membrane is left exposed, to avoid reduction the canal section and to better exploit the low hydraulic roughness of this material. Figure 3 is an example of exposed membrane system. Leaving the membrane exposed can offer as further advantages elimination of vegetation growth, and the possibility of a quick and easy maintenance, as any damage can be immediately and easily detected and repaired.

Figure 4 refers to a concrete canal built in 1968 and waterproofed with an exposed PVC membrane in 1985. In this case, comparison between water flow values recorded in 1974 (with original concrete liner) and in 1990 (5 years after installation of the PVC liner) showed an increase in water flow of 35%. Since 1985, improvements in the system have allowed to attain documented increase in water flow up to 90%.

Figure 3. Exposed composite PVC membrane

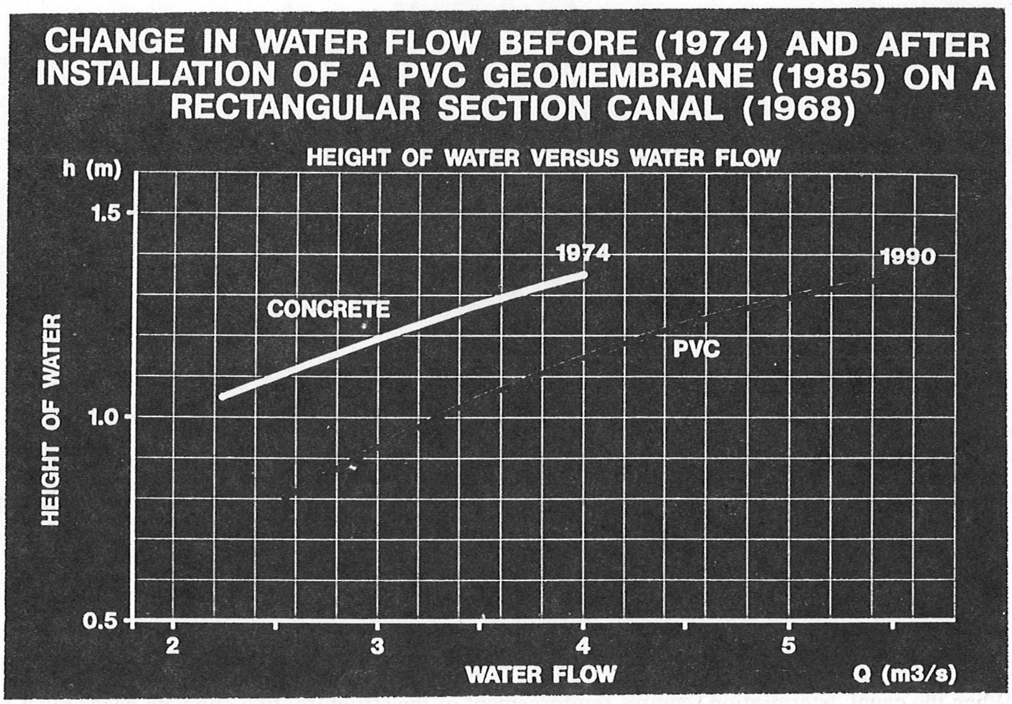

Figure 4. Increase in water flow

Anchorage System

The dynamic action of water, and the action of uplifts from the outside, require not only choice of a good quality PVC of suitable thickness, but also design of a reliable anchorage system.

Anchorage can be accomplished by means of high quality, preferably stainless steel, profiles, suitably dimensioned and positioned, or may require the use of special profiles which also accomplish tensioning of the liner. The use of tensioning profiles makes the liner conform as much as possible to the underlying structure, and is generally adopted in canals of larger cross section, and where water velocity is higher. Anchorage with metal profiles, covered by PVC strips which assure continuity in the waterproofing revetment, allows exploitation of the advantages of an exposed membrane. Additional anchorages, either linear or punctual, can be installed depending on water speed and turbulence. This is required especially in zones where dynamic water action can be more severe.

At the beginning and end of the installation (Figure 5), at the inlet or outlet zones, at spillways, and at any location where there is danger of water penetration behind the membrane, anchorage must be watertight. Watertightness is accomplished by compression of the liner over the substrate. The state of the art foresees rubber gaskets for compression stress distribution, over a regularized plane surface.

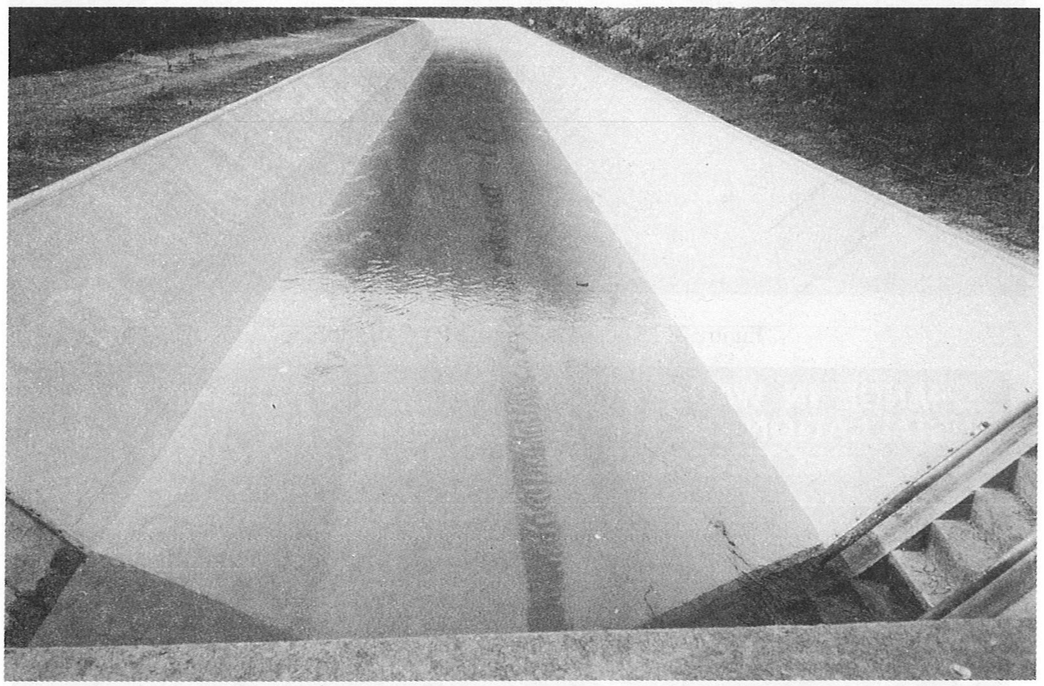

Figure 5. Watertight anchorage at beginning of waterproofed section

Ballasting

The installation of a protection or ballasting concrete layer can be necessary wherever particularly hard service conditions are foreseen, such as in case of heavy traffic or high uplifts. The ballasting structure can be installed on the whole section of the canal, or only in those areas where heavier service conditions are foreseen.

WATERPROOFING AND REINFORCEMENT

At present times, the increasing demand of power production or water supply requires increase in water flow. When the canal deterioration requires reinforcement of the structure, two opposite needs must be met: construction of a new concrete structure, which implies reduction in cross section and water flow, and higher capacity required by the increased demand.

A new solution designed in most recent times takes advantage of the low hydraulic roughness coefficient of PVC to counterbalance the reduction of the canal section due the new reinforcement structure: Sibelon CL.

a PVC geomembrane, smooth on one side and corrugated by PVC ribs to be embedded in concrete during casting on the other side, is set on the formworks before construction of the new reinforcement layer. The PVC ribs provide a diffuse and efficient anchorage of the membrane to the new concrete structure. This anchorage is very reliable, as it can withstand very high water speed and turbulence, and it also provides a very effective drainage system for uplifts waters: the elasticity of PVC (more than 300% of elongation at break) allows deformation of the membrane and creates a thin, self-adjusting drainage gap between the liner and the concrete. The low hydraulic roughness of the smooth side of the PVC membrane in direct contact with water allows the increase in water flow which counterbalances the cross section reduction. This solution has already been adopted by ENEL in high mountain canals (Figure 6).

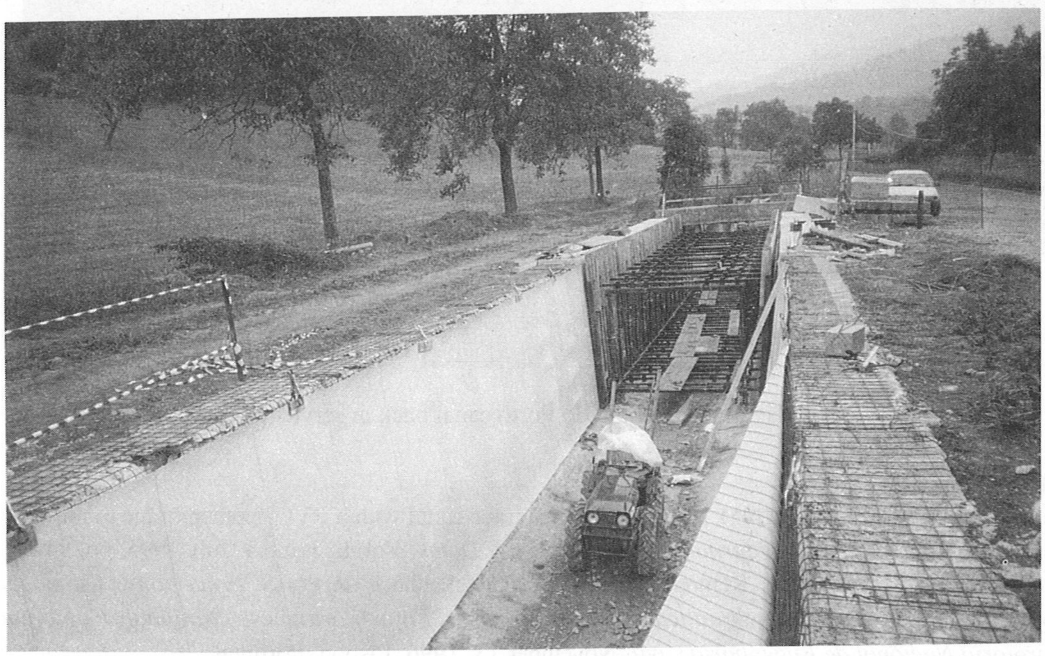

Figure 6. Sibelon CL membrane installed over the Dronero power supply canal

Figure 7 illustrates major projects executed in canals with the described state of the art system.

CONCLUSION

Flexible, drained PVC geomembranes and geocomposites have demonstrated their reliability as waterproofing liners for the rehabilitation of free-flow canals and pressure tunnels in a fairly wide and long term history in installations accomplished in Europe. The illustrated system achieves:

- perfect watertightness, eliminating water losses along the whole canal course
- reduction of head losses to a minimum value
- waterproofing of the entire internal section, joints included
- drainage of water behind the membrane, with subsequent elimination of uplifts
- increase in water flow, from 50 to 90 %
- protection against hard waters and waters with chemicals, and against frost
- elimination of flora
- drastic reduction of maintenance costs
- exceptionally long life
- possibility of underwater installation.

Figure 7. Senhora do Porto canal back in service

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