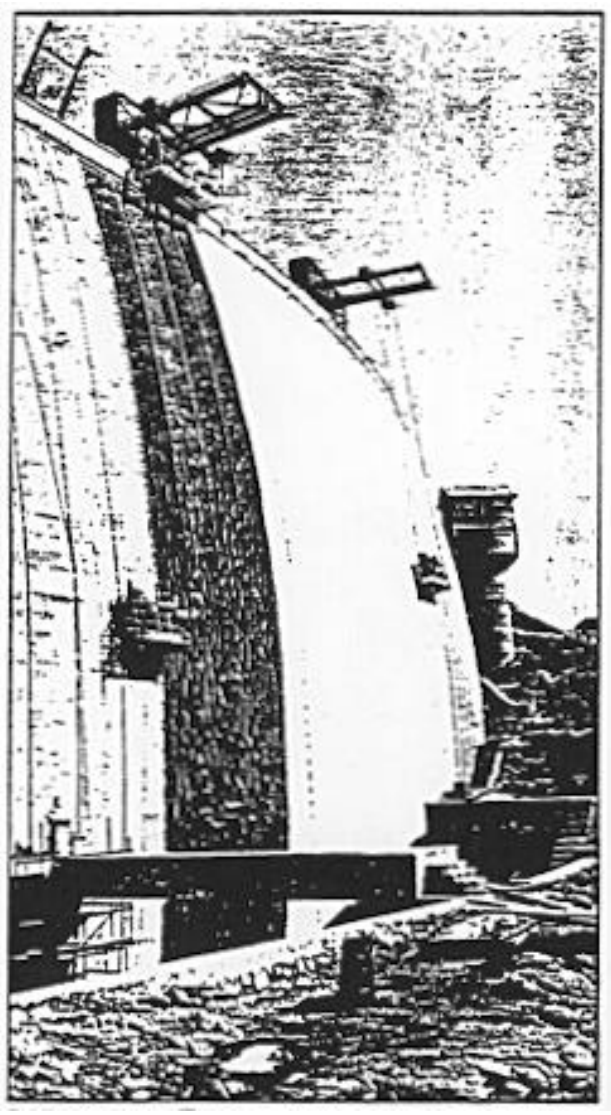
The use of a geomembrane for an arch dam repair



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A geomembrane was recently used in Italy to repair the upstream face of a double curvature arch dam. The authors describe the process, and give details of a number of tests which were conducted in the laboratory to verify properties of the membrane used.

Publino dam, a 40 m-high double curvature arch dam with a crest length of 250 m, was built in 1951. It is located at an elevation of 2135 m. The dam, which is provided with a de-icing plant on the upstream face, has a reservoir capacity of 5×10^6 m^3. It is used as seasonal storage for hydroelectric power generation and pumping. Publino dam can be reached from the valley floor by both cable and narrow gauge railways: most of the route is in tunnels, for an overall length of 11 km.

In 1988 widespread deterioration of the surface of the upstream face of the dam was observed. Further investigation showed that up to 30 percent of the 5500 m^2 cement rendering had become detached. This condition indicated that the permeability of the structure would rapidly increase if no remedial work were carried out.

Although the losses at full storage capacity were only 0.25 l/s. Sondel (the owners of the structure) decided to carry out the rehabilitation of the upstream face as a preventive measure. rather than wait for any further deterioration. It was considered that any delav in this work would make the necessary operations expensive, in terms of both the extent of the operation and the loss of hydro production.

Refurbishment method

On the basis of work carried out previously by ENEL (the Italian national power authority) on gravity dams. Sondel decided to use a synthetic, waterproof, drained membrane to protect the upstream face. Experience had shown that these membranes could be installed rapidly with mechanical anchorage and with minimal preparatory operations on the underlying concrete support. The system adopted was the same as that already used on the Miller, Lago Nero, Piano Barbellino and Cignana Molato dams.

In this system, the impermeable facing is a geocomposite consisting of a very thick flexible synthetic PVC membrane (characterized by a high resistance to ageing) which was prefabricated and heat-welded to a polyester geotextile during production.

Paired stainless-steel sections (ribs), placed vertically and fitted to the body of the dam with small anchors, fasten the geomembrane to the dam face. These pairs of sections also act as non-pressurized drainage collectors for water condensing, behind the membrane. The water collected is conveyed to the heel of the dam, where a perimeter drainage pipe conveys it through the drainage gallery, downstream of the body of the dam.

The membrane is manufactured in sections of sufficient length to cover the whole height of the dam, thus avoiding horizontal joints. The vertical joints and the corresponding mechanical anchorages are covered with an additional strip of the same membrane.

The mechanical anchorage of the membrane makes it possible to keep the protective facing independent of the facing behind, so that construction and expansion joints in the original structure are waterproofed at the same time. (The anchorage ribs are simply placed either side of the joint, and covered with the waterproof facing.)

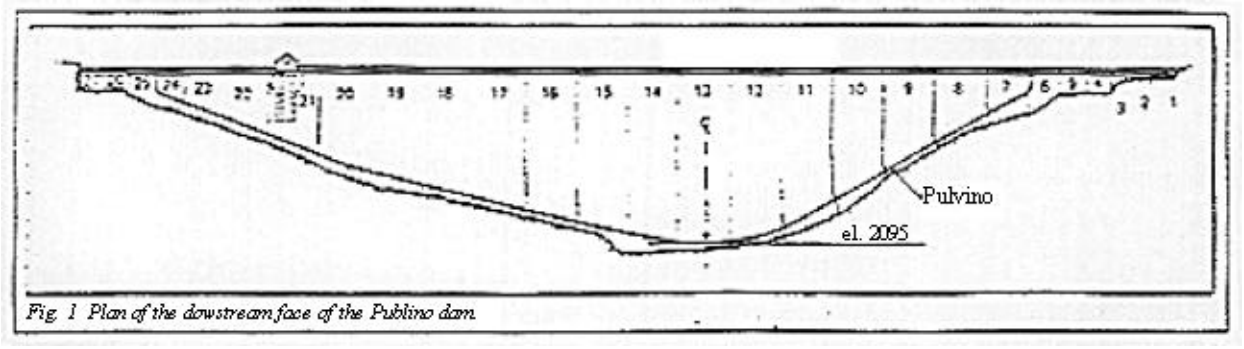


Fig. 1 Plan of the downstream face of the Publino dam

The system constitutes an efficient drainage system for the body of the dam: the presence of the layer of geotextile draws off the water present within the body of the dam, which tends to stabilize its moisture content.

The finished appearance of the installation is satisfactory from an aesthetic point of view: the membrane is a uniform grey colour. The membrane adheres well to the face thanks to the mechanical anchorage, which avoids any sagging or bulging of the material.

The solution adopted does not involve any stability reappraisal, since the membrane itself, and the ribs which support it, are comparatively light.

The drainage collector, installed along the upstream perimeter of the foundation of the Publino dam, is a stainless steel omega-sectioned bar, fixed externally to the body of the dam. This bar also acts as the sealing element for the base of the membrane sections, as well as connecting with all the vertical ribs. The water collected is drained off through one of the original drainage pipes inserted in the body of the dam.

Climatic conditions

From an operational point of view, the system adopted allows work to be carried out even in harsh climatic conditions, which would make the adoption of other solutions (such as mortar with resins) difficult, uncertain, and more expensive. In fact, all the components of the system are manufactured and prepared in the factory under controlled climatic conditions. The only operations which take place on site are of a mechanical nature: with other solutions there could be problems with chemical behaviour (polymerization, gelling, and so on) and physical behaviour (viscosity, distribution, and so on), which are often the cause of poor results.

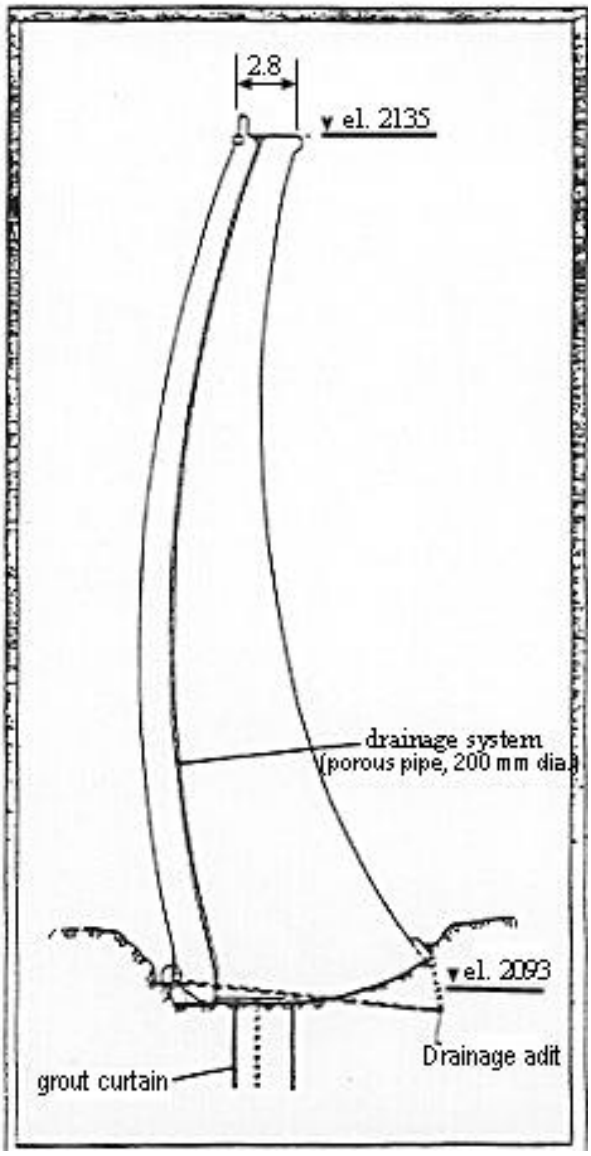
Transportation

The overall quantity of material necessary for the geocomposite solution is relatively small. This makes the solution particularly suitable in cases of difficult access to the site, as at Publino dam. Also, limited volume of equipment is necessary for this method: only suspended platforms (quickly and easily constructed and dismantled) and small tools (drills, welder, and so on) are required.

Installation

In the case of the Publino dam, it was planned to waterproof the entire face, which meant that the reservoir had to be completely emptied. Normally the time required for installing the stainless steel sections is approximately 40 percent of the total time needed for the whole operation. However, this installation can be carried out at various stages, according to the water level in the reservoir, using, platforms suspended from the crest of the dam.

At Publino, in June and July 1988, the deteriorated parts of the cement rendering were removed from the face, the upstream heel of the dam was cleaned, the perimeter drainage pipe was constructed and the lower vertical sections of the support for the geomembrane were installed (working in horizontal bands).



At the same time, other general work was carried out, such as the complete overhaul of the bottom outlet valve.

By the beginning of August, the reservoir was back in operation. The installation of the vertical sections continued, using platforms suspended above the water level, which was continually rising. Placement of the vertical sections continued until October 1988. At the beginning of the summer 1989 season, corresponding with the minimum water level, the reservoir be completely emptied for another month, for the installation of the geocomposite. Therefore, the rehabilitation will be completed over two seasons (representing a total of eight months). The careful planning, of such work should cause minimum interference with the running of the plant and consequently low operational losses.

Concrete face preparation

It was possible to accelerate the overall installation time because the thick geomembrane (2.5 mm) heat bonded to a 500 g/m^2 geotextile, does not require laborious preparation of the concrete face. At Publino, only the deteriorated part of the rendering was removed (using light electric scrapers). The surface after scraping, although rough, is generally considered suitable for laying the geomembrane. A very small amount of patching was done (approximately 3 percent of the total surface), using pozzolan cement, on those parts of the face which were particularly pitted, exposing aggregate with sharp edges. This was decided on the basis of experimental investigations carried out by ENEL at their Hydraulic and Structural Research Centre (ENEL-CRIS).

Durability of the system

The solution adopted has until now proved to be very reliable, since similar installations carried out up to ten years earlier (for example Lago Miller, 1976) have not shown any deterioration compared with their initial performance. Whenever the partial substitution of the waterproof geomembrane becomes necessary, the operation is very quick and inexpensive compared with the initial installation.

The geocomposite

The geocomposite chosen for the Publino dam is designated Sibelon CNT 3750, which consists of a 2.5 mm-thick geomembrane manufactured with a PVC mix, heat-bonded during production to a 500 g/m^2 polyester felt geotextile.

Great care was taken over the choice of the plasticizer added to the basic mix, so as to obtain a geomembrane with good performance in view of the difficult climatic conditions.

The material constituting the membrane has been subjected to an extensive series of laboratory tests, both in Italy, at independent University institutes and independant research centres, and abroad, at laboratories belonging to public institutions. These tests have confirmed the good balance of the material. The geomembrane incorporated in the composite has shown the following mechanical characteristics:

- very low permeability (Darcy coefficient k less than 1 x 10^{-12} cm/s);
- non-degradability;
- good tensile strength (exceeding 285 percent elongation at breaking load);
- excellent flexibility and elasticity (almost complete spring back, even at loads close to breaking load);
- good resistance to low temperatures (no sign of cracking after folding test at -35°C);
- excellent bending fatigue limit (no breakage after 1 x $l0^6$ repeated flexions);
- good resistance to abrasion;
- optimal chemical inertia;
- ice-repellence;
- resistance to damage by flora and fauna: and,
- good performance of the heat-welded joints.

These mechanical characteristics are further enhanced when the geomembrane is heat-bonded to the geotextile. The functions of the heat-bonded to the geotextile are:

- to increase the dimensional stability of the geomembrane;
- to provide diffused drainage of the waterproofed surface, drawing off and then draining the waters of infiltration and condensation; and,
- to cushion the geomembrane and protect it from possible puncture on the rough surface of the existing face.

An interesting laboratory elasticity test was carried out. A sample of geomembrane (2 mm thick, and 20 cm in diameter) used on the Lago Nero dam, was placed on a rigid 5 mm-thick support with a slit in the centre, 50 mm long and 5 mm wide. Hydraulic pressure of 20 bar was applied to the sample. A 1.9 mm deflection was measured on the part of the membrane which corresponded with the slit: this returned to its original position within about 10 min of the pressure ceasing. The performance of the membrane remained constant over several repetitions of the test. This test, carried out on a sample without a geotextile, shows the excellent resistance of the membrane even if it were fixed directly onto very rough or pitted surfaces.

Another laboratory test carried out by ENEL-CRIS involved the application of cycles of hydraulic pressure up to 20 bar on pieces of geomembrane 2 mm thick, bonded to a 200 g/m^2 weight geotextile, placed on samples of very rough surfaces which were taken from the deteriorated faces of existing dams. The membrane behavior was as follows:

- no perforation or laceration occurred, indicating that the membrane had remained waterproof: and,
- immediately after the test, the PVC material showed the imprint of the underlying surface, but within one hour of the end of the test the membrane had returned to its original smooth condition.

Also in connection with the application of PVC geomembranes to dams, ENEL-CRIS carried out a series of tests regerding the ageing of the material, analysing samples, of membrane taken from dams that had been functioning for more than ten years. The samples were taken from areas above the maximum storage level, which had therefore been exposed to the light constantly.

Compared to the initial values, the results of the mechanical tests showed a deterioration of about 22 percent in the tensile strength and approximately 20 percent in the elongation at breaking load: this performance is excellent, considering the high initial values used as the reference.

The possible chemical alteration of the polymer with time was tested by infrared spectrophotometry. Absorption tests were carried out on two different samples, exposed and not exposed to ultraviolet rays: the resulting graphs showed the same pattern. It can be concluded that, as far as ageing in natural conditions is concerned, the PVC geomembranes used so far show no sign of deterioration in their chemical structure, and therefore in the chemical additives which give the material its mechanical performance.

Conclusions

Waterproofing the upstream face with a mechanically anchored PVC geomembrane offers a number of advantages:

- efficient protection of the construction and expansion joints:
- drainage of the body of the dam: and,
- simple and rapid installation which does not require expensive surface preparation and is long-lasting.

In addition, the installation costs are competitive, but, since the membrane does not require maintenance and is durable over a long period of time, the overall costs are well below those of a traditional facing.

Acknowledgement
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