Since 1963

WATERPROOFING SPECIALISTS AND CONTRACTORS
WITH GEOMEMBRANES

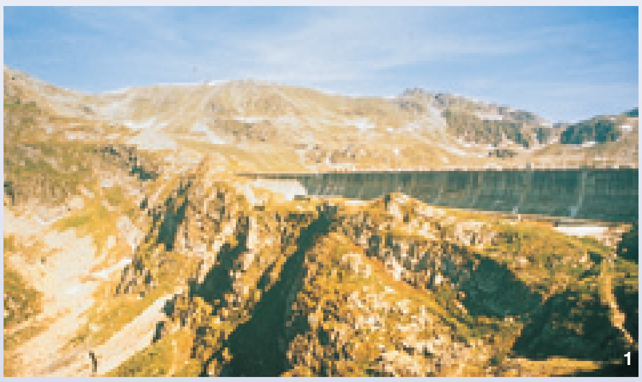
UNDERWATER INSTALLATION

WATERPROOFING OF HYDRAULIC STRUCTURES

Providing Dry
and Underwater Installations

THE CONCEPT

Over the last 30 years CARPI has developed patented systems for waterproofing hydraulic structures (dams, canals, tunnels, reservoirs, etc.) providing protection from the deterioration caused by seepage of water into the structure. The installation of the waterproofing geomembrane system is performed either in the dry or underwater negating the need to dewater the reservoir.



1 - Illsee dam (Switzerland) before intervention.

Primary benefits of a CARPI waterproofing system include:

- Stop water seepage and deterioration
- Restore impermeability of the deteriorated dam face
- Reduce uplift in the dam body
- Dehydrate the dam body from entrained water
- Restore safety factors to original values
- Negate the need to dewater reservoir
- Environmental disruption is minimal during rehabilitation

2 - Illsee dam (Switzerland) after intervention.

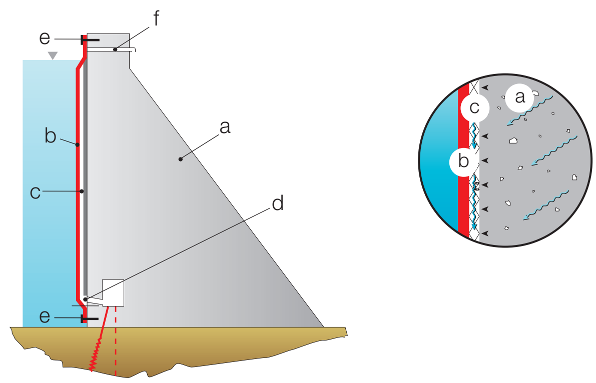
The above benefits are achieved by installing a continuous impermeable barrier from the crest to the heel of the dam. The barrier can be connected with the foundation and the grout curtain. A continuous face drainage system installed between the waterproofing geomembrane and the dam face collects and discharges the water from seepage and dehydration.

The CARPI system's impermeable water barrier consists of an exposed flexible polyvinylchloride (PVC) geocomposite (impervious geomembrane + anti-puncture heat-coupled geotextile). The perimeter of the installation, along the dam foundation and across the top of the upstream face, uses a watertight stainless steel batten strip anchorage preventing water intrusion from the reservoir. The vertical sheets of PVC geocomposite across the upstream face are joined by a patented stainless steel clamping system called profiles (shown in figure to right) which applies a uniform tension along the full vertical geocomposite sheet preventing point stresses on the geocomposite.

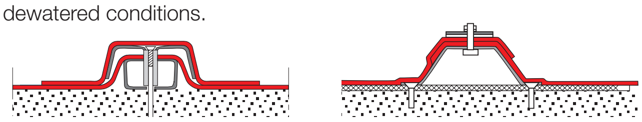
PRIMARY COMPONENTS OF THE CARPI SYSTEM

a. Dam body (high permeability)
b. CARPI waterproofing liner
c. Vertical anchorage and face drainage for geocomposite (high transmissivity)
d. Perimeter drainage collection system
e. Perimeter seals
f. Ventilation pipe (optional)

The perimeter collection system at the heel of the dam allows discharge of the drained water. All components are manufactured in the controlled environment of a factory to ensure quality and uniformity. Operations on site are thereby limited to quick and easy assembly of prefabricated elements.



CARPI patented steel profile fastening system pretensions the geomembrane insuring geomembrane will remain taut even in dewatered conditions.

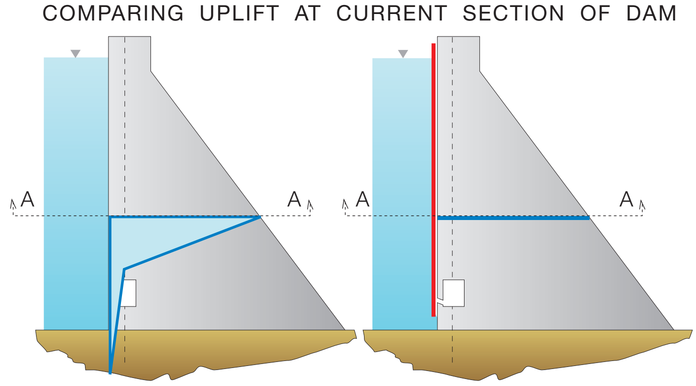


At left, the CARPI system as reported by ICOLD – International Commission on Large Dams – Bulletin 78 on Waterproofing Geomembranes. At right, the profiles developed for the underwatwer installation.

THE DRAINED WATERPROOFING SYSTEM CONTROLS UPLIFT AND ALLOWS DEHYDRATION

Since the entire surface of the geocomposite is not attached to the dam face, the system allows drainage of any seepage water, thus providing full effective reduction and control of uplift in the dam body. Additionally, water saturating the dam body will exit through the drainage system, dehydrating the dam body improving the stability factor.

COMPARING UPLIFT AT CURRENT SECTION OF DAM



Without geomembrane | With CARPI drained geomembrane system

The CARPI patented system is used to waterproof the entire face of the dam, or to waterproof localised areas such as cracks or joints.

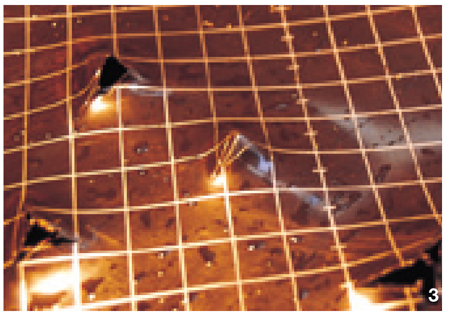
R E S E A R C H

5 - The test structure used for underwater testing of the CARPI system.

A research project in 1995 and 1996, funded by the U.S. Army Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi was conducted by OCEANEERING and CARPI. The objective of the research was to develop an adaptation of the CARPI patented dam rehabilitation system for underwater installation.

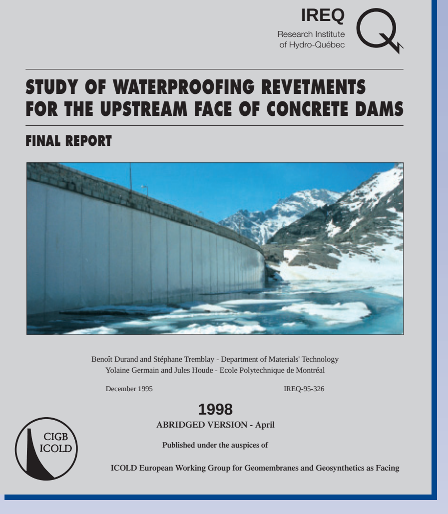
The adapted system was developed and demonstrated on a test structure which simulated features likely to be encountered while repairing an actual hydraulic structure (i.e., rough surface, construction joints, complex corners, etc.). Furthermore, the study investigated 21 geomembranes and geocomposites (HDPE, EPDM, CSPE, PP, PVC, etc.) for various properties at varying water pressures. The CARPI PVC geocomposite received the highest ranking from testing as demonstrated by pictures to the right. The efficiency of the CARPI synthetic membrane system was tested at various hydrostatic heads.

This project received a Federal Laboratory Consortium Award.



3 - HDPE after rupture at 0.15 MPa with poor conformability.

4 - CARPI PVC after 24 hours at 1.0 MPa with good conformability and no failure.



The Campo Secco dam, pictured on the Hydro-Québec report cover, was rehabilitated by CARPI in 1993.

Hydro-Québec, one of the largest dam owners in the world, undertook in 1995 a yearlong research study to determine the most effective method to waterproof the upstream face of concrete dams in cold climates. The research investigated 5 systems: shotcrete, metal sheets, bituminous liners, sprayed synthetic geomembranes, and synthetic geomembranes in sheets. The IREQ testing included freeze-thaw cycling, U.V. rays, low temperature, tensile, puncture, tear and ice action. The conclusion was "due to the importance of a drainage layer behind the geomembrane, and to experience, the PVC-B (CARPI system) geomembrane is deemed more adequate". Subsequently, the original 200+ page report was translated from French to English. The ICOLD European Working Group for Geomembranes and Geosynthetics as Facing Materials prepared an abridged version of the report which was published for distribution because of the significance and thoroughness of the research.

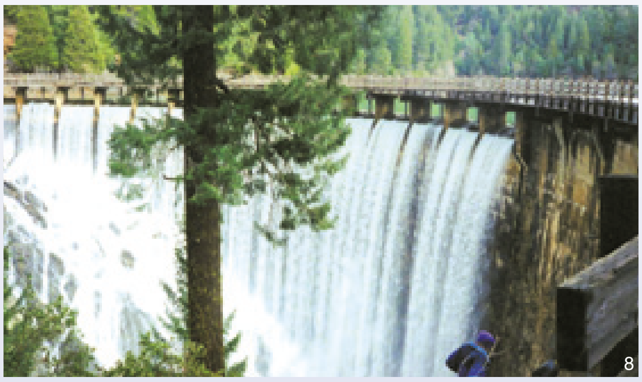
T H E   A L L I A N C E

Underwater installations are accomplished with underwater services companies around the world. Services provided include underwater work

6 - Diving services worldwide.

OCEANEERING and VRIENS, who helped CARPI in developing the patented technology, operate worldwide. Their activities include underwater work on dams and appurtenant structures, on outfalls, bridges, pipelines, cables, mooring, caissons, construction of special foundations, and a wide range of inland, offshore and coastal structures. Their services include design, project management, underwater construction, maintenance and repair, inspections and surveys, salvage and recovery.

7 - Diving bell and decompression chamber.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8 - Lost Creek Dam pictured is a thin arch concrete dam built in 1924 that is 36 meters tall with a crest of 134 meters. The dam is located in the mountains of California at an elevation exceeding 950 meters. The concrete in the dam was porous so that seepage was occurring across the entire upstream face.
Prior to rehabilitation, the downstream face of Lost Creek Dam was wet and saturated due to seepage, and as a result it had suffered freeze/thaw deterioration.
The concrete on the downstream face was spalling and lost its strength up to a depth of 10 percent. The owner OWID (Oroville-Wyandotte Irrigation District) studied 8 different solutions. Ultimately, they focused on 3 alternatives. An RCC buttress on downstream face which was too expensive. A drainage layer with shotcrete on downstream face which did not stop the seepage. Similar installations nearby had shown the shotcrete would deteriorate quickly. The final solution selected was the CARPI geomembrane system installed partially underwater.

The CARPI system was selected because it had the lowest acquisition cost of the alternatives and the lifecycle cost analysis showed the CARPI system resulted in more than a 37% savings over the other alternatives.

Furthermore, the geomembrane installation involved a negligible environmental impact.
The final design and the underwater works were accomplished with the services of the associated specialist contractor Oceaneering (USA). The contract was awarded on July 15,1997.

9 - The reservoir at Lost Creek Dam with the Oceaneering diving crew dredging upstream of the dam foundation in preparation for geomembrane installation.

10 - The upstream face of Lost Creek Dam on September 18, 1997 as the crews begin work on face repair, perimeter seal, and geonet installation.

11 - The first task of the waterproofing system was the installation of a geonet drainage layer on the entire surface of the dam face.

12 - The geomembrane is installed and attached to vertical anchorage as pictured. Then the perimeter seal at the dam foundation is completed.


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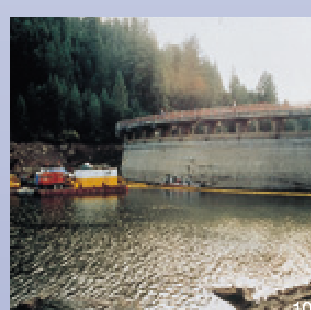
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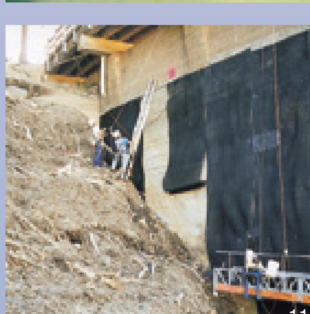
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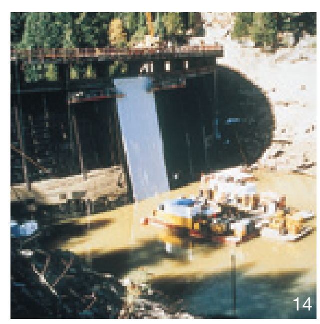
13 - Installation of the first panel into the water. This process requires close coordination between the above water crew and the diving crew. The geomembrane must be deployed by crane from the crest of the dam, unrolled and then aligned before lowering into the water.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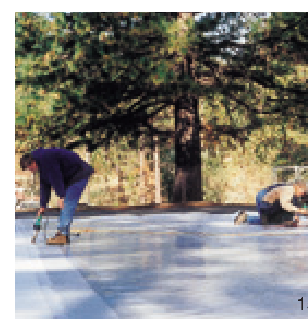
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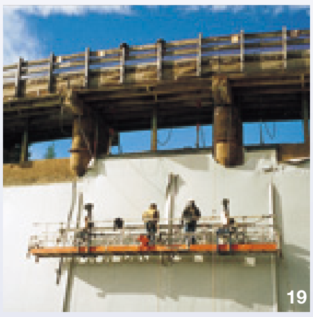
14 - The geomembrane roll completely deployed with divers beginning underwater attachment. It is important that the panels are properly aligned prior to lowering into the water because the divers are working with limited visibility.

15 - In order to insure a watertight seal at the perimeter of the geomembrane installation the geotextile must be removed from the backside to prevent a wicking action of water. In the picture above the crew is stripping the geotextile to match the dam foundation following the underwater survey after completion of dredging.

16 - Each roll of geomembrane weighed more than 900 kilograms. Therefore, to stage the rolls required careful planning as it required a large forklift, boom truck, tractor-trailer, and several people to move the rolls.

17 - Many dams such as Lost Creek have curvature from the top to the bottom of the face. This complicates the installation of the vertical geomembrane attachment hardware where two panels of geomembrane overlap. CARPI custom sawcut each piece of attachment hardware to conform to the curvature existing at Lost Creek Dam and then ground the hardware to insure a flush, smooth support for the overlapping geomembrane panels to insure a watertight seal.

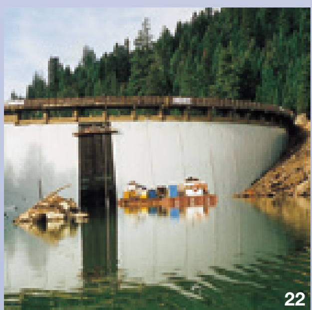


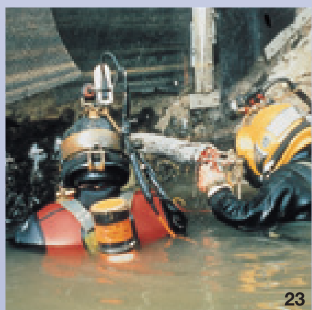
18 - The 8 meter wide geomembrane panels were deployed in alternating sections to insure proper alignment and evenly distribute work for the crews above and below waterline.

19 - The CARPI crew performing the above water installation from suspended platforms. The crew is installing the top perimeter seal just below the pillars of the bridge.

20 - The crew preparing to deploy a geomembrane panel near the left abutment. The white geotextile material underneath the black geonet covered rough spots on the dam face negating the need for concrete face repairs.

21 - Pictured is the conduit installed behind the geomembrane to measure the water level in the drainage layer placed on the upstream face. The water level in the drainage layer is one of the acceptance criteria for the project. Readings from the piezometer have continuously shown the dam face is completely dry.





22 - The geomembrane installation is nearly complete as the crew prepares to deploy the panel in the deepest portion of the reservoir over the piezometer conduit for measuring the water level in the drainage layer behind geomembrane.

23 - Oceaneering divers at the air/water interface installing the perimeter seal anchor bolts along foundation.

24 - The drainage pipe for the drainage layer behind the geomembrane was installed by drilling through the dam from the downstream face and grouting a pipe in place. The picture shows the crew preparing to drill through the dam.

25 - The project was completed on November 26, 1997 with more than 25% of the work performed underwater. Underwater installation was the only option, as the reservoir could not be dewatered for environmental concerns. Pictured is the geomembrane installation completed on November 26, 1997, while the crew is beginning demobilization approximately 2 months after the geomembrane installation began on the 2,600+ square meter surface.

26 - Eliminating the water contacting the upstream face has halted the freeze/thaw deterioration. As reported by Richard Harlan, Consulting Engineer to OWID, *"Successfully sealing the upstream face of a dam to reduce leakage and mitigate downstream face deterioration without dewatering the reservoir has been a dream of dam engineers for many years. Even though the underwater geomembrane installation at Lost Creek Dam in 1997 was unprecedented, it was completed on schedule (critical, because it had to be done during a scheduled power outage). The work also was completed for the originally quoted budget.*

Performance of the membrane sealing has been excellent. The downstream face is dry and deterioration of the downstream face concrete due to freezing and thawing of the seeping water has been completely stopped." (Richard Harlan, Consulting Engineer to OWID)

"Latest measurement, November 2002, of leakage through the entire 2,600+square meters of membrane covering the entire face of the dam, is only 0.22 gallons (0.8 liters) per minute."

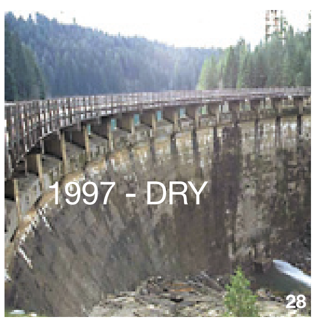
27 - The second acceptance criteria was measuring the water flow from behind the geomembrane. The photo provided by Richard Harlan, Consulting Engineer to OWID, in November 2002, shows the total seepage after 5 years of installation. The Lost Creek geomembrane installation received the 1998 ASDSO West Region Award of Merit and the 1999 Hydro Achievement Award from the NHA.

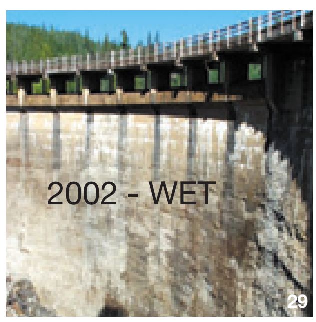
28 - 1997, before works. The downstream concrete was so deteriorated that it could be removed with a hand pick down to a depth of > 30 cm.

29 - 2002, after works.

In the spring of 1999, the California Division of Safety of Dams inspected Lost Creek and found the downstream face to be "the driest ever seen",

as pictured in 2002.

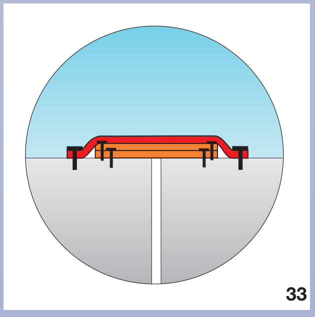


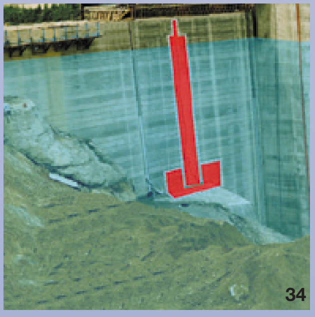


PLATANOVRYSSI RCC DAM - REPA

The waterproofing system used for underwater repair of joints and cracks is an evolution of the CARPI systems illustrated in the previous pages, and of the patented CARPI waterproofing system for joints. The PVC waterproofing geomembrane is installed as a strip centred on the crack/joint, and sealed along the periphery by a watertight mechanical anchorage.
The underwater installation of the system for repair of cracks was performed on the recently completed Platanovryssi RCC Dam, in Greece.

30 - Platanovryssi Dam in Northern Greece, constructed in 1998, at 95m is the highest RCC Dam in Europe. As described by the Public Power Corporation of Greece (PPC), owner of the dam, in the article "Seepage evolution and underwater repairs at Platanovryssi", Hydropower & Dams, Issue Six, 2002, *"The faces of the dam are not considered to be the impermeable membrane; the RCC placed between the facing elements in the center of the dam is designed to be the water barrier."* Cracks in the facing were anticipated, but they were not expected to propagate into the body of the dam, which was designed to be impervious. The contraction joints in the dam are at variable centers, generally no more than 30 m. During construction of the dam these joints were sealed with an external waterstop system, the patented CARPI system for waterproofing of joints, consisting of a PVC geocomposite placed over three sacrificial geosynthetic layers. The external waterstop system, used in alternative to the conventional PVC waterstops embedded in concrete, was designed and tested to resist a joint opening of 25 mm, under a hydraulic head of 200 m. As reported by PPC, *"The initial expectation for the long term seepage at Platanovryssi was 5 to 10 l/s. The pool level was reached on 14 November 1998. For one month, through until mid December, seepage was 11 l/s. After mid December 1999, total seepage started increasing and reached more than 21 l/s at the end of May (...) followed by a maximum of 30.56 l/s on 10 October 2000 (...). In fact, what happened was that a crack, parallel to the flow, started to form at station 101, practically in the middle of one of the shorter dam monoliths, on the left abutment. At first it was noticed as a hairline crack on the upstream wall of the upper gallery, which developed and appeared in the gallery walls, ceiling and floor, and then on the upstream face and downstream face, producing leakage both in the gallery and through, reaching the downstream face."*





31 - Pictured is water leakage inside the gallery. Subsequent to increase in leakage, an underwater survey was conducted to ascertain the dimensions and extension of the crack. Inspection revealed a crack starting from the crest of the dam, then dividing into 2 cracks, running nearly 2 m apart from each other. The crack extended from elevation 227.50 m to elevation 208 m, with a maximum width of 25 mm.
The dimensions of the crack increased and decreased under temperature changes through the year. As reported by PPC

"Leakage attributed to the crack alone reached values of almost 20 l/s both on February 2000 and February 2002. Lowering the reservoir to fix the crack would have been unthinkable, because not only Platanovryssi would have to be out of service for several months, but also the pumps at the much larger Thissavros scheme upstream would have been affected, causing serious implications for the production system."

Underwater installation of the same patented CARPI system that has proved effective on the contraction joints was evaluated. Conclusions by PPC were that:

"It was considerably more cost effective to do the work underwater." The CARPI system was selected for underwater installation.

32 - The picture shows artist's impression of the path of the crack, as it was patterned by the underwater survey.
33 - The waterproofing PVC geocomposite is installed over a flexible and elastic support made with two layers of sacrifice PVC geocomposite. The sacrifice layers avoid that the waterproofing liner is nibbled by the crack under temperature changes and full water head. The support layers and the waterproofing geocomposite are fastened separately to the dam face, to allow independent movement. The PVC geocomposite is sealed along the perimeter by a watertight seal avoiding water infiltration.
34 - The CARPI PVC geocomposite system (the red area) follows the path of the cracks to totally cover them.

35 - The waterproofing system was installed in the dry from crest level at 227.50 m to elevation 225 m, and underwater from elevation 225 m down to elevation 208 m. The final design and the underwater works were accomplished with the services of the associated specialist contractor Vriens Diving International BV (Holland).

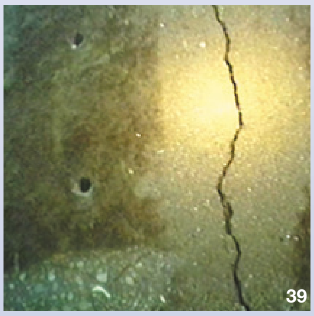
36 - A multipurpose drilling template was constructed to facilitate underwater installation.


37


38

37 - The template is used to exactly position the holes for the perimeter bolts, and as a scaffolding to hold the divers in position while performing underwater drilling, cleaning with high pressure water jet, and installing the CARPI system.

38 - The sacrifice PVC geocomposite sheets are cut and assembled so as to be lowered into the water in one single big "patch", covering the path of the fissure. Pictured is the drilling template used to lower into position the sacrifice layers.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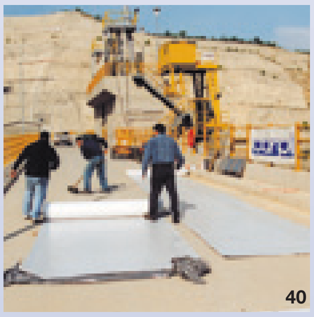
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39 - The sacrifice layers span the area over the fissure that is within the perimeter seal.

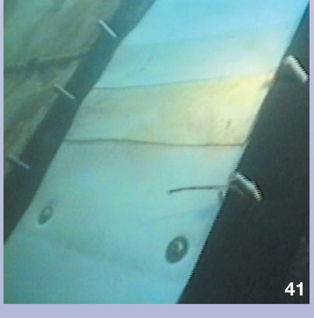
40 - The waterproofing PVC geocomposite sheets are cut and assembled in one single big "patch", corresponding to the red area in figure 34.

41 - The rubber gaskets for the perimeter seal are placed over the concrete surface regularized by grinding, to achieve a better seal. Pictured are the sacrifice geocomposites attached to the dam face by impact anchors, and the rubber gasket punctured over the anchor bolts of the perimeter seal.

42 - The waterproofing PVC geocomposite is prepared for underwater installation.

43 - The waterproofing PVC geocomposite placed on the drilling template is lowered to underwater position.

44 - The perimeter seal is made by puncturing the waterproofing PVC geocomposite over the anchor rods and by compressing it on the RCC with stainless steel batten strips and rubber gaskets.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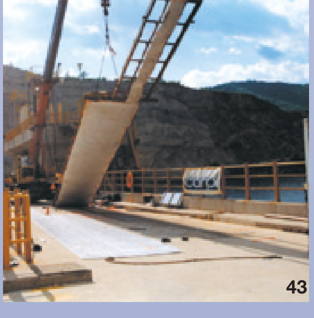
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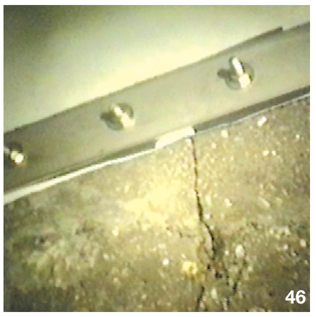
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45 - The drilling template facilitated the final underwater work of installing the stainless steel batten strips and of tightening the nuts to achieve the seal at the perimeter. The photo details the holes in the steel frame corresponding to the tightened nuts at the perimeter of the dry part.

46 - The contract was awarded on April 11, 2002. Works started on April 22, 2002 and were completed on May 23, 2002. During this time, the divers also provided a full mapping and description of the crack, following it to a depth of 35 m below the surface. This crack, which is not seen on the downstream side as it is intercepted by the inspection gallery, is responsible for leakage still occurring in the inspection gallery, below elevation 208 m. Therefore, additional repair is now under consideration to stop the leakage at that level. Full mapping will allow PPC "to make a good estimate of further work needed to seal the crack completely down to its full length, which was some 15 m more."


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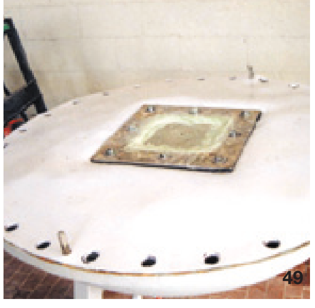
47/48

> As reported by PPC
> "It was interesting to see downstream face leakage dry up immediately (within hours rather than days) as the nuts of the sealing system were finally fastened into place, from top to bottom".
> (from "Seepage evolution and underwater repairs at Platanovryssi", Hydropower & Dams, Issue Six, 2002).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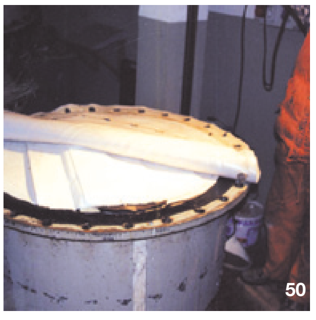
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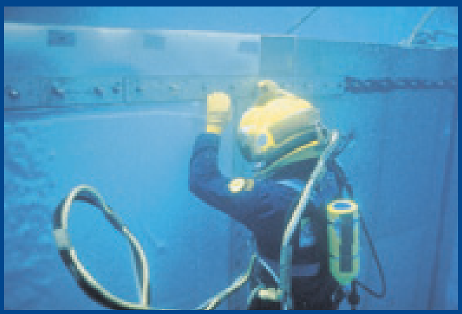
49 - The CARPI perimeter seal has been tested and approved by ISMES in a full scale test performed in a pressure vessel, applying water heads up to 25 bar.

50 - The configuration for the support layers has been tested and approved by ISMES in a full scale test performed in a pressure vessel, applying water heads up to 25 bar.

> As reported by ISMES the tests "satisfied the specifications of the project". The sacrifice layers avoid intrusion of the waterproofing geocomposite into the fissure and the CARPI system is watertight.



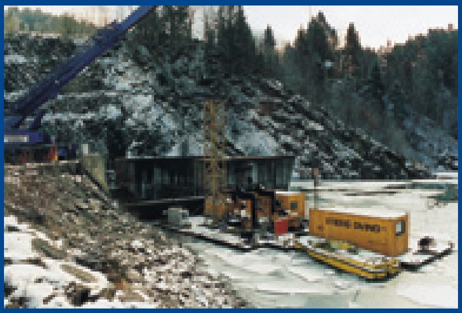
U.S. Army Corps of Engineers - U.S.A. 1995, research

Lost Creek - U.S.A. 1997, hydropower

Platanovryssi - Greece 1998 and 2002, hydropower

Beli Iskar - Bulgaria 2002, water supply

Malvaglia - Switzerland 1992, hydropower



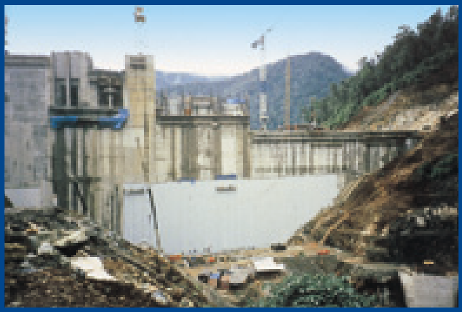
Bolgenach - Austria 1995, hydropower

Miel I - Colombia 2002, hydropower

Winscar - United Kingdom 2001, water supply

Concepcion - Honduras 1991, hydropower

Itutinga - Brazil 1996, hydropower



Balambano - Indonesia 1999, hydropower

Brändbach - Germany 2000, hydropower & recreational

More than 1,200 CARPI installations performed worldwide with projects already completed in Europe, Africa, Asia, North, Central and South America.

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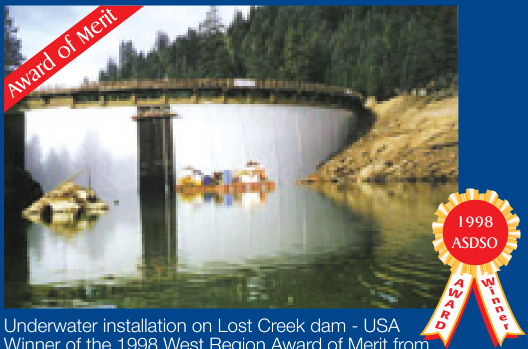

Underwater installation on Lost Creek dam - USA
Winner of the 1998 West Region Award of Merit from
the Association of State Dam Safety Officials (ASDSO)