The Use of Geomembranes in Dams

Alberto Scuero[1], Gabriella Vaschetti[1], Marco Bacchelli[1]
1- Carpi Tech, Via Passeggiata 1, 6828 Balerna, Switzerland

Email: gabriella.vaschetti@carpitech.com

Abstract
Geomembranes, and particularly Polyvinylchloride (PVC) geomembranes, used since more than half a century to control seepage in dams, are environmentally friendly rehabilitation technologies. In rehabilitation, geomembrane systems have been applied on all types of dams, to line the entire upstream face of the dam, or only the area/s causing most seepage, or only cracks/failing joints. The geomembrane is placed in exposed position, and is drained behind. In new construction, geomembrane systems have been applied to provide the water barrier in embankment dams and RCC dams, and as external waterstop for joints in CFRDs and for joints between monolith blocks in RCC dams. In RCC dams and fill dams, the geomembrane can be at the upstream face, in exposed or covered position, in fill dams also as a geomembrane core. The paper discusses the available options for rehabilitation and gives some information on new construction, addressing case histories in the dry and underwater. The paper introduces an innovative underwater waterproofing technology, already successfully installed on two canals, which permits repairing embankment dams and canals without impacting on operation: no dewatering, no reduction of water speed. This technology can be considered also for new construction of embankment dams and canals.
Keywords: Geomembrane, Geocomposite, Waterproofing, Dams, Drainage.

1. INTRODUCTION

Geomembrane systems are the most environmentally friendly rehabilitation technologies for dams. They do not require heavy installation equipment or large excavations and processing plants for materials, the components of the system have small volume and light weight, so that transport by helicopter to remote sites not accessible by vehicles is feasible at reasonable costs; environmental impact is very limited, since large areas for site organization and plants are not needed, and there is no heavy transport affecting the environment and the communities; installation is quick and can be carried out in almost any weather condition. Different from technologies using sprayed or in-situ made products, geomembrane systems are installed also underwater and in flowing water, with practically no impact on the operation of the structure, be it a dam or a reservoir or a canal.

Geomembranes are a mature technology: they have been used to control seepage in hydraulic structures starting after World War II in canals, and at the end of the 1950ies in dams, where the first projects aimed to provide a water barrier to the pervious body of new embankment dams. Gradually, different systems were developed to rehabilitate all types of dams, and to waterproof new Roller Compacted Concrete (RCC) dams. The most recent and thorough ICOLD Bulletin dedicated to geomembrane systems [1] discusses materials, anchorage systems, installation, and makes recommendations for specifications and contracts. According to the database created during preparation of the Bulletin, Polyvinylchloride (PVC) geomembranes are by far the material with the oldest and widest experience in rehabilitation as well as in new construction, in exposed as well as in covered position. Table 1 that follows, and excerpt of the Bulletin, summarises the use of different types of geomembranes based on the data available in 2007. An updating of the database in 2009 indicated that the number of dams using a PVC geomembrane system had increased from 153 to 181, and continues increasing, while the number of dams using other types of geomembranes has had a very small increment.

The advantages of PVC geomembranes, and of the numerous systems that have been developed using them for rehabilitation of dams and other hydraulic structures, and for construction of new embankment dams and new RCC dams, have been widely discussed in international literature [respectively 2, 3, 4 for recent references]. Aspects such as performance of PVC geomembrane systems in respect to differential movements, seismic events, thermal cracking, seeping lift joints, uplift, swelling processes, and construction times and costs, were discussed in Tehran by the same authors in 2005 [5].

Table 1. Geomembranes in dams (excerpt of ICOLD Bulletin 135)

Type	Basic material	Abbreviation	Total exposed	Total covered	Total	Oldest exposed	Oldest covered
Polymeric	Polyvinylchloride	PVC-P Plasticised	80	73	153	1974	1960
Polymeric	Polyolefin	LLDPE	0	29	29	-	1970
Polymeric	Polyolefin	HDPE	3	12	15	1994	1978
Polymeric	Elastomeric	Polyisobutylene IIR (Butyl Rubber), EPDM	5	4	9	1982	1959
Polymeric	Chlorosulfonated polyethylene	CSPE	3	5	8	1981	1986
Polymeric	Polyolefin	PP	3	3	6	1995	2000
Polymeric	Chlorinated polyethylene	CPE	0	3	3	-	1970
Bituminous	Oxidized bitumen	Prefabricated GM	7	10	17	1973	1978
Bituminous	Polymeric	SBS, bitumen ethylene, ECB	0	3	3	-	1996

2. PVC GEOMEMBRANE SYSTEMS IN REHABILITATION

In rehabilitation, the geomembrane liner is placed on the upstream face of the dam, generally in exposed position, and with a drainage system behind, to allow discharge of possible backpressure, and monitoring of the performance. PVC geomembrane systems are used for full-face rehabilitation, performed in one or more campaigns, or to waterproof only the area/s causing most seepage, or only cracks/failing joints. The face anchorage and peripheral anchorage of the geomembrane are calculated to resist acting loads such as uplift by wind and waves. Face anchorage on a solid subgrade is generally linear, with a tensioning system, while on a granular subgrade it is made at points, with deep anchors. Ballast anchorage is rarely used. Where needed, additional geosynthetic layers are used to provide anti-puncture protection, or support over cavities in the subgrade, or enhanced drainage capacity. The geomembrane system can be installed in the dry, and underwater when total or partial dewatering of the impounded reservoir is not possible.

All types of dams can be waterproofed, and all types of subgrades accommodated. The chapters that follow give a range of different applications, addressing full-face and partial rehabilitation. In all cases, the waterproofing liner is SIBELON® CNT, a PVC geomembrane heat-bonded during fabrication to a nonwoven geotextile, to form a composite geomembrane, also known as "geocomposite". The flexible elastic PVC geomembrane provides the water barrier, and the geotextile has several functions, the most important ones being enhancing the mechanical properties of the liner, and providing anti-puncture protection.

2.1. FULL-FACE REHABILITATION ON CONCRETE AND ASPHALT CONCRETE SUBGRADES: CHAMBON, PECINEAGU AND MORÁVKA

Dams having a hard subgrade, such as concrete dams and Concrete Face Rockfill Dams (CFRDs), allow using a tensioning assembly anchored to the concrete with stainless steel anchor rods embedded in chemical phials. The assembly consists of two stainless-steel profiles: the first profile, U-shaped, is anchored to the concrete, the PVC geocomposite sheets are placed overlapping on it, and are then covered by the second profile, Omega-shaped, which is fastened the first one achieving fixation and tensioning of the geocomposite, as outlined in the conceptual scheme of Figure 1 - an excerpt of ICOLD Bulletin 135. The profiles, besides providing a pre-tensioning effect avoiding formation of slack areas and folds, allow a drainage gap behind the waterproofing liner, and construct vertical channels acting as vertical drains conveying water that should be present behind the liner to a bottom collection and discharge system.

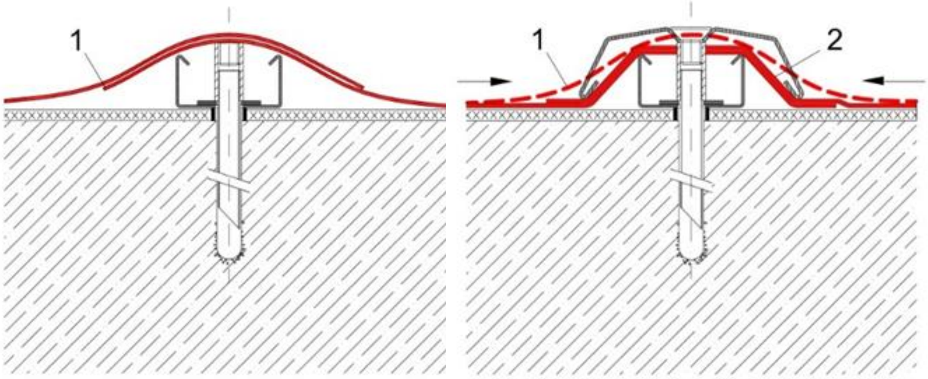

Figure 1. On the left, adjacent PVC geocomposite sheets (continuous red line, 1) overlap on the U profile secured to the dam. On the right, the Omega profile placed on the PVC geocomposite sheets compresses and forces them to change from the previous loose configuration (dotted red line, 1) into a new pre-tensioned configuration (continuous red line, 2). Fig. 85 of ICOLD Bulletin 135: Pretensioning effect of the two profiles (patented)

In concrete dams, typically there is a drainage layer (the gap allowed by the tensioning system described, or a dedicated synthetic layer of high transmissivity) between the concrete and the geocomposite. This configuration was adopted for example at Chambon 137 m high gravity dam in France, one of the most well-known and discussed case of alkali-aggregate reaction. The SIBELON® geocomposite system, installed in 1993/1995 (in separate summer campaigns to minimise outage), was deemed the most adequate because in the event of an earthquake the deformable and elastic geocomposite would bridge the cracks already existing and new cracks that should form due to the seismic stresses, maintaining watertightness and reducing the risk of hydro-jacking, it would stop water infiltrating into the dam body and feeding the AAR, it would avoid the risk of uplift, thus maintaining the stability of the top part of the dam, and it would easily restore watertightness after slot cutting, providing reliable protection of the slots against the risk of leakage. The geocomposite lies on a high in-plane transmissivity drainage geonet, doubled along the bottom periphery to form a longitudinal collector that conveys water to nine transverse pipes discharging into the gallery and allowing separately monitoring the nine drainage compartments. The geocomposite is anchored to the concrete face by the tensioning system discussed above, and at peripheries by seals of the tie-down type, consisting of flat stainless-steel batten strips compressing the geocomposite on the concrete, with suitable gaskets and regularisation layers, and with dimensions and anchors designed in function of the water head acting at each location.

Chambon is an outstanding example of how geomembrane systems can give a major contribution in extending the life of a dam: the system performed successfully for 18 years, and in 2013, when major structural measures were undertaken to further extend the life of the dam, the owner EDF – Electricité de France - selected the same identical system to waterproof again the dam after remedial measures (Figure 2 at left). The old geocomposite, a 2.5 mm thick PVC geomembrane laminated during fabrication to a 200 g/m^2 anti-puncture geotextile, was removed, structural measures were carried out and at the same time a new geocomposite was installed, with mass per unit area of the geotextile increased to 500 g/m^2, to provide higher anti-puncture protection. A large part of the components that were already in place since almost 20 years before were re-used. This is the only known case of a geomembrane system removed to allow performing civil works, and reinstated with the same design, due to its previous successful performance [6].

Pecineagu in Romania is an example of rehabilitation of a CFRD. The dam is 105 m high, with 1V: 1.717H upstream face inclination, slabs' thickness varying between 1.20 m (lower area) and 0.30 m (upper area), and with PVC waterstops and copper waterstops or elasto-plastic bituminous mastic poured in place. The dam is in a difficult environment with temperatures from -21.5°C and +42°C, maximum snow thickness of 100 cm, and approximately 50 cm of ice cover for minimum 4 months/year. Over time, due to settlements of the dam body, the peripheral slabs were subject to significant rotation, joints opened exceeding the elongation capacity of the waterstops, which were locally destroyed, and environmental aggression caused cracking and deterioration of the slabs, increasing leakage and requiring repeated repairs over the years. Due to importance of the dam, which ranks 12th by height and 34th by reservoir working volume, and to the importance of the reservoir that provides drinking water to the capital, Bucharest, as well as flood attenuation and power generation, the owner decided to perform repair works, among which the most important one was to restore watertightness at the concrete slabs.

At Pecineagu, upstream rehabilitation was carried out in stages: in 2011 the reservoir was totally dewatered and the waterproofing geomembrane system was installed on the slabs from the bottom of the dam to elevation 1060 m; in 2012 the reservoir was lowered and the geomembrane system was installed at partially impounded reservoir, from elevation 1060 m to elevation 1095 m, with crews working from travelling platforms or harnessed to the face of the dam (Figure 2 at right). The waterproofing system uses a SIBELON® geocomposite of different thickness depending on the water head: from elevation 1095 m to elevation 1060 m he geocomposite consists of a 2.5 mm thick PVC geomembrane laminated during fabrication to a 500 g/m^2 anti-puncture geotextile, and from elevation 1060 m to bottom the thickness of the PVC geomembrane is increased to 3.0 mm. The geocomposites are anchored to the face of the dam with the same patented anchorage system shown in Figure 1, and with the peripheral seals already discussed. Due to the roughness, deterioration, and rotation of the concrete slabs, instead of a drainage geonet a 2000 g/m^2 anti-puncture geotextile is placed on the slabs, under the PVC geocomposite.

Figure 2. At left, PVC geocomposite sheets under installation on drainage geonet (the black material on top of the tendons and carbon bands mesh used for structural reinforcement) at Chambon dam in France in 2014. At right, PVC geocomposite sheets under installation on anti-puncture geotextile (the white material) in stage 2 at Pecineagu CFRD in Romania in 2012

The use of anti-puncture geotextiles is frequent also in rehabilitation of masonry dams, to protect the waterproofing liner against the roughness of such a type of subgrade. The mass per unit area of the geotextile is selected in function of the aggressiveness of the masonry.

When the subgrade is asphalt concrete, in rockfill dams (ACFRDs) or in earthfill dams, the same tensioning system is used for face anchorage and, if the pull-out strength of the asphalt facing so allows, anchorage of the tensioning profiles is made by chemical phials as it is done in concrete subgrades. In case the pull-out strength is not sufficient, chemical phials may need to be substituted by deep anchors, described in the next chapters. In regards to perimeter seals, if they are made on concrete they are of the tie-down type already mentioned, otherwise the insert-type seal is used, as done at several dams of this type, including Morávka dam in the Czech Republic, a 39 m high earthfill dam with a multi-layer asphalt concrete facing, built in the 1960ies and with 1V:1.75H upstream inclination. Morávka experienced leakage since the first uncontrolled filling in 1965; the reservoir was drawn-down, mastics cover and two new bituminous concrete layers were added to the original ones. At first seepage was reduced, but over time it increased again and despite several repairs defects and seepage continued until in 1997, when the biggest flood in the century caused the water level in the Morávka reservoir to rise to the maximum level. Evaluation of the data collected in that occasion showed that the main cause of the failure of the asphalt sealing had been the long-term erosion of the subgrade at the left bank of the valley, caused by the subsurface water percolating from the left bank and resulting in progressive enlargement of caverns near the surface asphalt sealing.

The owner of the dam decided to perform a total rehabilitation of the dam including also the facing. The technical requirements for the new upstream sealing were resistance to deformations and depressions in the subgrade, proven long-term resistance to changeable weather conditions, frequent freeze/thaw cycles, ice formation, high temperature excursions, and the possibility of monitoring the performance on a continuous basis. The cost-benefit analysis lead to considering as only solutions a new asphalt concrete facing, and a geomembrane facing. The technology of removing the old and placing a new asphalt concrete facing was time consuming, riskier from the point of view of protection of the dam body during the flood, and more expensive. The time allotted for installation in summer 1999 was 90 calendar days, which included 15 days estimated for stoppage due to floods and bad weather. A PVC exposed geomembrane sealing system was deemed the only waterproof facing that could meet the technical requirements and the time constraints. The waterproofing liner is SIBELON® CNT 3750, the same adopted at Chambon in 2014 and at Pecineagu above elevation 1060 m. The asphalt concrete layer provided sufficient pull-out strength for the chemical anchors of the tensioning profiles that constitute the face anchorage of the waterproofing liner.

At Morávka there is a primary perimeter seal placed at the bottom of the asphalt concrete facing, and a secondary perimeter seal placed on the concrete plinth. The primary seal on asphalt concrete is of the insert type: a slot is made in the asphalt concrete, a PVC geocomposite strip is inserted in the slot that is then filled with watertight resin, and the PVC geocomposite waterproofing the upstream face is watertight seamed to the PVC strip. This type of seal has given excellent performance in dams with high water heads. The secondary seal on concrete is of the tie-down type, and has the function of reducing the head on the primary seal and of creating a drainage compartment to intercept water seeping from foundation.

The drainage system consists of the gap created by the anchorage system between the existing asphalt concrete face and the new PVC geocomposite liner. Drained water travels by gravity in this gap to reach a drainage collector consisting of a band of geonet with high in-plane transmissivity placed along the bottom periphery and along the compluvium between the left bank and the straight part of the dam. The drainage system is divided into 11 compartments, and each section is further divided into a primary compartment draining water from the upstream face, and a secondary compartment draining water coming from foundation, thanks to the presence of two bottom perimeter seals. Each compartment has an individual drainage discharge pipe, placed in a hole drilled to reach the inspection gallery, and equipped with a monitoring system.

When the 10-year guarantee was going to the end, the owner of the dam decided to make a final test of the sealing system. The reservoir was filled up to the emergency spillway during snow melting in spring 2009. The owner [7] reports “After the stabilization of the measured values it was proved that the function of the upstream geomembrane sealing system is excellent. The value of seepage was under guarantee limits for water level on the spillway and attained a maximum value of 0.15 l/s from one section and 1.0 l/s in total, well below the minimum acceptable contract leakage of 2.0 l/s for the entire face”.

2.2. FULL-FACE REHABILITATION ON GRANULAR SUBGRADES: VAITÉ

If the characteristics of the subgrade (granular materials, hardfill, asphalt facings with low pull-out strength) do not allow using chemical phials, deep anchors can be used. Deep anchors can be of the “duckbill” type, as adopted at Vaité dam, or of the grouted type, as adopted in hardfill dams and at several hydropower canals. Vaité is a 23 m high earthfill dam in the island of Tahiti, in French Polynesia, used for hydropower. In 1987, the upstream face of the dam was lined with a 1 mm thick PVC geomembrane placed on an anti-puncture geotextile, and anchored at top to the parapet wall, and at the abutments in a trench. The geomembrane was extended on the bottom of the reservoir for about 50 m, and on the abutments, so to provide some waterproofing of the foundations too. In the years 2010-2011 this geomembrane was no longer functional and the owner of the dam decided to perform rehabilitation works. A requirement to the new geomembrane system was to resist 204 km/h winds (hurricane conditions) in the top 1/5 of the section, and 100 km/h winds in the remaining 4/5. The waterproofing liner, SIBELON® CNT 3750, was fastened to the dam face and at the abutments with duckbill anchors placed at depth, pattern and spacing designed to resist the design winds with the required safety factors. The system (patent pending) exploits the technology of deep anchors designed for anchorage in gravel soil, and consists of a stainless-steel tendon and of a rotating duckbill, covered by a suitable capping that guarantees that no water infiltration occurs where the anchor crosses the geocomposite, and that the forces at each anchor are adequately distributed so as to not overstress the geocomposite. The tendon and duckbill are driven into the ground and after the duckbill is in place, an upward pull on the tendon rotates it into a perpendicular "anchor lock" position in the soil that mobilises the resistance of the soil itself.

Figure 3. At left, Morávka dam at wintertime. At right, duckbill anchors being driven into the granular subgrade at Vaité earthfill dam

2.3. REHABILITATION OF FAILING JOINTS/CRACKS

The deformation that a traditional embedded waterstop can sustain is based essentially on the dimensions of the central portion of the bulb, therefore the maximum elongations that it can attain are in the order of a few centimetres. If the opening of the joint exceeds this elongation capability, traditional embedded waterstops fail (Figure 4 at left). Carpi patented external waterstop, conceived to accept much larger openings, is used to provide watertightness on failing joints or cracks. This waterstop is a multi-layered system installed over the joint/crack, exposed to the water of the reservoir, and sealed along the perimeter by a watertight mechanical seal. The various layers, which are site-specific, depend on the type of dam, on the expected opening of the joint, on the water head, and on the conditions of the subgrade. The layers solve different functions:

a) Anti-puncture/sacrifice, to protect against aggressive subgrade - generally, a nonwoven geotextile or a geocomposite

b) Support, to impede that the waterproofing liner intrudes in the active joint and, in case of very large openings and high water head, that it bursts - generally, this function is solved by one or more layers of flexible material, with lower or higher modulus depending on the needs, seldom by a rigid support

c) Anti-friction: to avoid the waterproofing liner being affected by the movements of the under-layers - generally, a flexible layer

d) Waterproofing: a geocomposite SIBELON® CNT.

The waterproofing geocomposite, typically 40 to 70 cm wide, is anchored so that it can elongate over its entire width (Figure 4 at middle). The geotextile having an elongation at break around 60 %, and the PVC geomembrane elongation at break exceeding 250%, joint openings with order of magnitude of tens of centimetres/exceeding one metre are required before respectively the geotextile and then the geomembrane break. Concrete dams, CFRDs, RCC dams, and intake structures of ACFRDs and reservoirs, have been rehabilitated with this external waterstop. The same system has been adopted for new construction, on contraction joints of RCC dams and on peripheral+vertical joints of CFRDs, where it was designed for openings up to 30 cm.

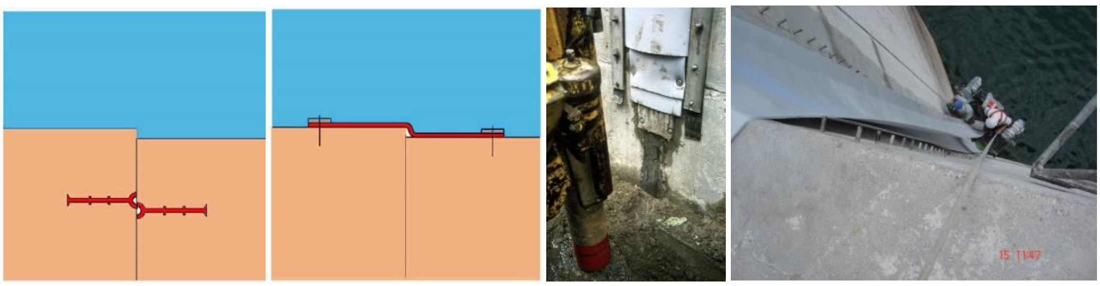

Figure 4. From left to right, conceptual behaviour of embedded waterstop and of Carpi external waterstop, typical layering (Platanovryssi 95 m high RCC dam, Greece 1998), and installation of the sacrificial and waterproofing layers at Usina da Pedra buttress dam, Brazil 2009

3. UNDERWATER INSTALLATION

All rehabilitation systems described above have been installed also in underwater conditions, adapting some anchorage components to the wet environment, for full-face rehabilitation (e.g. Lost Creek dam, USA 1997), for rehabilitation of large leaking areas (e.g. Turimiquire, Venezuela 2010/2011/2017), for repair of joints and cracks (e.g. Olai, Italy 2013, Lom Pangar, Cameroon 2017). At Olai gravity dam, underwater installation of the external water stop on three failing joints reduced seepage from 65 l/s to 0.3333 l/s (Figure 5).

In the last few years, a totally innovative underwater waterproofing technology, SIBELONMAT®, has been developed to restore watertightness in embankment dams and canals without impacting on operation. The system consists of two watertight geomembranes connected to form a mattress. The connection of the geomembranes is designed to allow injecting between the two a ballasting filling material such as inexpensive cement grout. The lower geomembrane provides water tightness, the grout provides the ballast to anchor the mattress, and the upper geomembrane provides containment of the grout, protects the ballast during operation, and in canals improves hydraulic efficiency. SIBELONMAT® is prefabricated in 10 m wide mattresses having custom-made length to minimise junctions and facilitate placement. Adjoining mattresses are joined by watertight heavy-duty zippers pre-attached to each mattress during fabrication. Installation can be performed totally underwater and without stopping operation or reducing water speed.

This new technology has already been successfully installed on two canals with no reduction of water speed (Figure 5 at right). SIBELONMAT® can be considered also for new construction of embankment dams, to provide an impermeable upstream facing or an impermeable blanket even on very aggressive irregular subgrade, and of canals.

Figure 5. From left to right, joint 4-5 at Olai dam before and after underwater installation of Carpi external waterstop, and SIBELONMAT® installed underwater at Ismailia canal, Egypt 2016

4. PVC GEOMEMBRANE SYSTEMS IN NEW CONSTRUCTION

In new construction, PVC geomembranes are used to provide the water barrier in embankment dams and RCC dams, and as external waterstop for peripheral and vertical joints in CFRDs, and contraction joints in RCC dams. The geomembrane can be in exposed or covered upstream position, or as a geomembrane core in fill dams. In new embankment dams, the concept is to avoid the rigid upstream water barrier of CFRDs, and substitute it with a highly deformable exposed PVC geocomposite system, to construct a Geomembrane Facing Rockfill Dam (GFRD) designed to accommodate settlements and differential movements that can occur in the dam and between the deformable dam body and the concrete appurtenances. The upstream SIBELON® geocomposite allows adopting a very simple layering for the dam: zoning is not strictly required, a single fill material can be used, the drainage layer's thickness can generally be reduced, and depending of the design of the dam it can act also as base/anchorage layer for the waterproofing geocomposite.

The face anchorage can have different configurations. If the upstream base layer is made by extruded porous concrete curbs, the anchorage system consists of PVC anchor strips embedded in the extruded porous concrete curbs, to which the waterproofing geocomposite is heat-seamed, as shown in Figure 6.

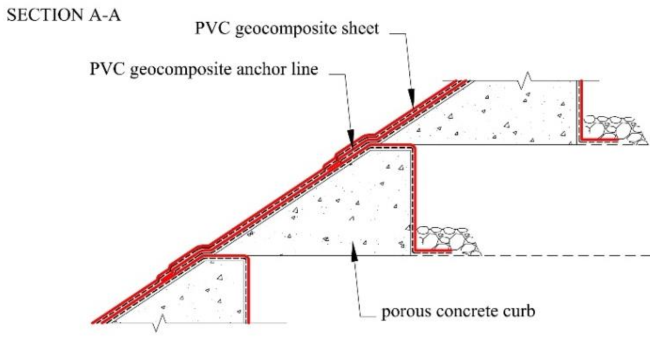

Figure 6. Face anchorage with PVC anchor strips embedded in curbs: concept and staged installation at Nam Ou VI 88 m high rockfill dam in Lao PDR

If curbs are not used, the PVC anchor strips are embedded in trenches excavated in the base layer, as shown in Figure 7. In alternative, anchorage can be made at points, by duckbill anchors or by deep grouted anchors as installed in hardfill dams and for rehabilitation of canals. Anchorage systems with deep anchors can be installed in any kind of subgrade, quickly and without any inconvenience.

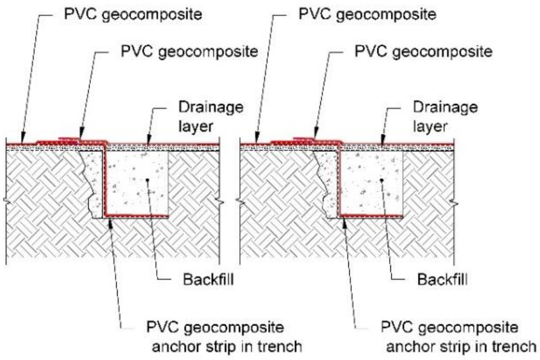

Figure 5. Face anchorage with PVC anchor strips embedded in trenches: concept and installation at Bulga new earthfill dam, Australia

All these methods have been successfully applied in several dams, allowing constructing very quickly, and at low cost, impervious dams consisting of compacted fill providing stability, and of a flexible upstream liner providing imperviousness, and capable of accommodating settlements and differential movements.
In new RCC dams, the full-face waterproofing system is like the one described in rehabilitation of concrete dams; a covered option with concrete panels embedding the waterproofing geocomposite has also been adopted in several dams.

5. CONCLUSIONS

PVC geomembrane systems effectively restore watertightness in all types of leaking dams and joints, with little or no impact on operation of the dam, resisting demanding environmental conditions. They provide water barriers in new embankment dams and RCC dams. Their elongation capabilities allow resisting movements that would destroy other types of water barriers.

6. References

1. ICOLD Bulletin 135 (2010), “*Geomembrane Sealing Systems for Dams - Design principles and review of experience*”, ICOLD, France.
2. Scuero, A., Vaschetti, G. and Subramanian, V. (2017), “*Geomembranes for long-term rehabilitation of dams*”, Proc. of Workshop on Latest Repair & Rehabilitation Technologies for Dams, Colombo.
3. Wilkes, J., Scuero, A. and Vaschetti, G. (2017), “*Geomembranes to Waterproof Embankment Dams*”, Proc. of USSD Annual Meeting and Conference, Anaheim.
4. Scuero, A. M., and Vaschetti, G.L. (2017), “*Three recent geomembrane projects on new RCC dams*”, Proc. of the 6th International Symposium on RCC dams, Zaragoza.
5. Scuero, A. M., and Vaschetti, G. L. (2005), “*Tackling uncertainties with geomembranes*”, Proc. of the 73rd Annual Meeting of ICOLD, Tehran.
6. Scuero, A., Vaschetti, G. and Machado do Vale, J. (2016). “*A unique case: new works at Chambon dam*”, Proc. of the 84th ICOLD Annual Meeting Symposium, Johannesburg.
7. Kratochvil, D., et al. (2011). “*Exposed geomembrane system at Moravka dam: 10 years performance*”, Proc. of Hydro 2011: Practical Solutions for a Sustainable Future, Prague.1