Indian experience in flexible geomembrane for watertightness of ageing dams

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ABSTRACT:

Watertightness is one of the key issues to ensure safe operation and durability of dams. The installation of geomembranes on the upstream face of large dams is in practice in India since early 2000ies with Kadamparai, a 67 m high masonry dam, that was brought back to its full operational capacity. Since 14 years of installation, the Pumped Storage Hydro Electric Generation station has gained full efficiency and is generating to its full capacity of 400 MW power limiting the leakage within the permissible limit, paving the way for similar installations in other dams. The second project was Servalar dam under DRIP – Dam Rehabilitation and Improvement Project of the Government of India, in 2018. Carpi braved the challenges posed due to erratic weather conditions and successfully installed with the same level of result of the first project. The third one, at Upper Bhavani dam also under DRIP, an 80 m high stone masonry dam providing water to a series of power houses generating over 800 MW; the same geomembrane system is being installed in phases getting completed in 2020. The paper provides details of these projects, focusing on how the geomembrane technology is proven suitable and adaptable to any kind of environment and at the same time provides the most durable solution for watertightness.

1. INTRODUCTION

Water is an integral part of our daily life and essential for rising population, industrialization, urbanization, modernization of agriculture, etc. Since water is one of Earth's most limited resource, conservation of water has become a growing problem around the globe today. Hydraulic structures like dams, canals, tunnels, reservoirs constructed to conserve water must be rehabilitated in the best way to guarantee safety and minimum water losses.

Geomembranes are prefabricated synthetic materials produced in thin flexible sheets, whose function in dams and other hydraulic structures is to construct a water barrier, due to their being practically watertight. In some of the pioneer projects in large dams, the geomembrane installed system was covered. Over time, following the good behaviour of geomembranes already installed, and the improvements achieved in materials' composition and manufacturing procedures, and in design and installation techniques, confidence in these systems increased. At the beginning of 1970ies geomembranes started to be used in exposed position, in new construction as well as in rehabilitation of dams.

The developments in design of materials and of anchorage systems in new installation methodologies based on modern equipment allow constructing safe and long-lasting waterproof systems that can be installed in a short time, reducing costs, and allowing earlier exploitation of the structure, a substantial asset in countries where the need for water and power has become an emergency.

1.1 ***ICOLD guidelines***

The most authoritative international body dealing with dams, ICOLD, the International Commission on Large Dams, has since the end of the 1970ies been addressing the use of geomembrane in dams. Dedicated bulletins have been issued to provide information and guidelines in 1981, 1991 and 2010. The most recent one, Bulletin 135, "Geomembrane Sealing Systems for dams – Design principles and review of experience", is the world's reference guideline for design, installations and behaviour of geomembrane systems. Bulletin 135 also gives guidance to technical contents of contracts, and the contract guidelines to be met by the bidding contractors.

This paper will be of use to understand how geomembranes with an effective installation technique can be the best repair method for any kind of water leakage problem in dams that need installation in dry as well as in underwater conditions. This paper presents case studies where the Carpi's geomembrane waterproofing system was installed in masonry dams in India.

- Kadamparai masonry dam of Tamil Nadu Electricity Board (TNEB)in the year 2005
- Servalar masonry dam of Tamil Nadu Generation and Distribution Corporation (TANGEDCO) in the year 2017-2018
- Upper Bhavani masonry dam of Tamil Nadu Generation and Distribution Corporation (TANGEDCO) (ongoing).

The paper gives a complete insight into how the three projects were envisaged by the client and the acceptance of the system in each of the projects after a series of attempts put forth by the client prior to adoption of a geomembrane technology.

Each case discussed in this project has a unique background on the benefits attained. Though the objective lies in preserving the structure, the positive results and success attained has done justice to the investment made on rehabilitation.

2 EXPERIENCE IN INDIAN SOIL – KADAMPARAI DAM, INDIA

Kadamparai dam in the state of Tamil Nadu in India, owned by Tamil Nadu Electricity Board (TNEB), was constructed in 1983 and is a composite structure consisting of a central stone masonry gravity section and two earthen embankment sections. The masonry section is 67 m high and 478 m long, with a central spillway, a scour vent tower and one inspection gallery.

The dam is used as a forebay reservoir for the Kadamparai pumped-storage plant, which has an installed capacity of 400 MW. The gross storage capacity is 26.85 X 10^6 m^3. As a result of the pumping operation, the water level may vary by about 4 to 5 metre per day.

2.1 ***Seepage history***

In the first impoundment in 1984, the maximum measured seepage was 1120 l/minute. Most of the seepage was observed through the shafts inside the gallery and the seepage sources included:

- Distributed seepage entering the masonry facing system, at deteriorated joints between rocks and through cavities that formed in the masonry
- Concentrated seepage at joints between monoliths, Seepage through the foundation rock
- Seepage through the embankment section into or around the gravity section was estimated to be very small.

2.2 *Remedial measures*

Remedial measures were carried out repeatedly over the years, mostly requiring partial dewatering of the reservoir, with significant impact on operation of the pumped storage scheme and consequent financial losses.

Table 1. Remedial measures carried out in Kadamparai dam since first impoundment.

Period of repair	Remedial measures taken
1990 – 1996	Packing and pointing was carried out at selective locations on the upstream face where leakage had been identified and vertical drilling and grouting was done
1999 – 2000	Underwater treatment of the leaking areas was done using chemicals and cement and this reduced the leakage from 4200 to 800 litres per minute
2000 – 2003	Again packing and pointing was carried out. The seepage in 2003 touched 11,800 litres per minute at El 1140.55 (around 10 metres below Full Reservoir Level)

2.3 *Selection of rehabilitation method*

As all the conventional methods already adopted had failed at Kadamparai, a suitable long-term solution was sought by the client. Reputed institutes like IIT's, Anna University were approached for their expert opinion on this issue and installation of geomembrane on the upstream face was suggested by these institutes. After a detailed analysis of the market, the client TANGEDCO contacted Carpi Tech, a Switzerland based company for the study of the leakage and a proposal to address the problem. Carpi then was with 40 years of experience in the use of geomembrane systems on dams experiencing such large leakage. The client did a cost benefit ratio of the generation loss versus the repair cost and it was concluded to line the exposed masonry face leaving the embankment section. Also, no excavation was planned to expose the foundation level as records indicated the quantum of leakage from the foundation drains were very minimal and the time constraint to excavate already hardened silt deposit.

2.4 *Beginning of the repair works*

The contract was awarded to Carpi in July 2004 through an international bidding process. Before the geomembrane works started, Carpi made a detailed study of the dam and suggested basic structural improvement works that included a) Additional drilling and grouting from the crest, b) Removal of sediments at the heel of the dam, c) Stabilizing some part of the masonry face which got withered off.

The design of the waterproofing system avoided extensive civil works for preparation of the upstream surface. After the removal of debris and sediments at heel, the loose and detached stone blocks were repositioned. A specialized treatment was carried out on the lower part of the joint near to the ground level to minimize water infiltration from below the watertight perimeter seal through the 12 construction joints.

The major elements included the anti-puncture geotextile layer of 2000 g/m^2, installed on the entire upstream face of the dam to reduce risk of puncture by the very aggressive surface of the stone masonry blocks. The nonwoven needle-punched geotextile made of pure polyester fibre was anchored to the face (Figure 1 at left).

Figure 1. Installation of anti-puncture geotextile and of waterproofing geocomposite.

The main waterproofing liner is a geocomposite, consisting of an impervious flexible SIBELON® geomembrane 2.5 mm thick, formulated with a special compound of polyvinylchloride plasticised with high molecular weight branched plasticisers and heat-bonded during extrusion to a non-woven, needle punched 500 g/m^2 geotextile that provides drainage and further anti-puncture protection. The geocomposite is secured to the dam body by a patented fastening system spaced at 5.7 m designed intervals and consists of two stainless-steel components, one anchored to the dam body and the upper one holding the geocomposite in contact to the dam body. These vertical anchorage lines on the upstream face also work as free-flow drainage conduits. A watertight perimeter anchorage completes the system.

The geocomposite sheets were lowered from the dam crest and positioned on the upstream face by crews working from suspended platforms (Figure 1 at right). On the masonry face large offsets were observed and at the bottom perimeter seal area a layer of shotcrete was done to allow even adhesion of the stainless-steel element to the dam body.

2.5 *Monitoring system*

The efficiency of the geocomposite system is checked by monitoring the water drained behind the geocomposite. A drainage geonet band conveys the drained water into a special conduit pipe into the gallery. A piezometer was installed inside the gallery which helps to record the quantum of leaked water. An Optical Fibre Cable (OFC) was installed along the bottom periphery of the entire masonry dam to detect if there is any leakage occurring behind the geocomposite. This works by Heat Pulse Method (HPM) wherein the difference of temperature caused by seeping water is signalled and conveyed by the OFC.

2.6 *Performance and cost economics*

The entire work was completed in 4 months' time, 6 weeks ahead of the schedule and with a result far better than the expectation of the client. The total area of 17,300 square metres was installed in a record 16 weeks' time. The scope covered design, supply, installation, equipment, quality control, management, commissioning, patent fees and 10 years warranty.

The client has confirmed "the results that the leakage of the order of 30,000 litres/minute has been reduced to 100 litres/minute. The overall cost has been kept within the announced limits and the entire work was completed ahead of the time allowing earlier generation of power house".

2.7 *Results after 15 years of operation*

The result of the geocomposite installation at Kadamparai dam in 2018/2019 is still sound with the leakage still around the same levels. The first geomembrane project has more than satisfied the client in terms of the results, and since its installation the dam is now filled up to the FRL (Full Reservoir Level) thereby allowing full generation power of 400 MW, which was not possible before geomembrane works as the dam was operated at nearly 10 metre below FRL

Figure 2. Upstream face of the dam before and after geomembrane installation.

Carpi was awarded the India Power Award for the year 2008 for this project in recognition for "Excellence in Water & Energy Management"

Figure 3. Drainage gallery before and after geomembrane installation.

Figure 4. Kadamparai dam after installation of the geomembrane system.

3 SERVALAR DAM (UNDER WORLD BANK FUNDED DRIP)

Servalar dam is a masonry dam constructed in the year 1984 for the purpose of drinking water, irrigation and power generation and owned by Tamil Nadu Generation Distribution and Corporation Ltd (TANGEDCO). This is one of the two reservoirs that supplies water to the entire districts of Tirunelveli and Tuticorin, in the state of Tamil Nadu. The dam is constructed across the Thamirabarani river (one of the perennial rivers in Tamil Nadu). The dam has an installed power capacity of 20 MW. The operation of the power house is as per water demand on the downstream side of the dam monitored by Public Works Department (PWD). The storage capacity of the dam is 35 million cubic metres.

3.1 *Problems in the dam*

The major problem in Servalar dam is the high seepage collected inside the gallery through the vertical shafts and the extremely wet downstream side. The left flank of the dam experienced heavy seepage (Figure 5) when compared to that to the right flank, while a complete wet and oozing downstream side is visibly seen and goes unmeasured. The problem is attributed majorly to the poor quality of construction. The leakage which has been continuing for many years now has resulted in many of the drainage shafts getting choked, and heavy calcination was observed both inside the gallery as well on the downstream side of the dam.

Earlier attempts by the maintenance wing of TANGEDCO (Generation Team) consisted of racking/packing with cement mortar, racking/packing with chemical epoxy/mortar, grouting and joint chemical treatment. The attempts to control the seepage did not give a permanent solution and instead the leakage continued to rise every year. With the available data and observation, the water oozing out from the downstream side should be more than 5,000 l/minute(approximately) from the left and spillway blocks.

Figure 5. Heavy seepage on left flank.

Any kind of repair works on hydraulic structures with chemical or cementitious material or ceramic material has a limited life time and durability, forcing the clients to go in for permanent long-term solution. Geomembrane waterproofing systems have proven to be a long-term solution in the field: an exposed geomembrane system installed at Lago Nero dam in the Italian Alps, in 2020 will be have a 40 years’ history with no maintenance. Thus, the need for a geomembrane waterproofing system arose.

The total leakage measured in the vertical shafts before geomembrane works is around 1,200 l/minute taken by Carpi in 2017 December (before geomembrane works) and the critically leaking shafts are provided in table below.

Table 2. Leakage recorded in vertical shafts before geomembrane installation.

Vertical Shaft	Leakage recorded litres/min	Vertical Shaft	Leakage recorded litres/min	Vertical Shaft	Leakage recorded litres/min	Vertical Shaft	Leakage recorded litres/min
11	28	15	600	25	215	40	6.25
13	20	18	24	32	25	43	5
14	40	20	49	37	13		

Total leakage recorded in vertical shafts before geomembrane installation is 1025 litres/minute.

The last recorded leakage by DRIP in 2014, before the remediation works, was 743 l/minute and a complete wet downstream side (which is unmeasured – which can be approximated as around 6,000 l/minute). Most of the vertical drain shafts were choked. This continued leakage resulted in bulging of the entire dam on the left flank downstream which posed a serious risk to the dam.

3.2 *Remedial measures*

Every 2/3 years attempts to control leakage were undertaken by the client TANGEDCO which consisted of racking/packing and pointing with cement mortar and chemical mortar/epoxy, grouting and joint chemical treatment, and all such methods could not get a long-lasting solution. In between 2007 and 2010, TANGEDCO had done repairs with epoxy pointing at a cost of 40 million Indian rupees and within years the leakage started to increase.

3.3 *Selection of rehabilitation method*

A detailed study of the problem at Servalar was made and the most sophisticated design was adopted to install the SIBELON® geomembrane system. With the introduction of DRIP (Dam Rehabilitation and Improvement Project) Team in Tamil Nadu, this work of rehabilitation of Servalar dam was covered. Under the DRIP initiative, a preliminary proposal was submitted by Carpi Tech B.V, Amsterdam, Balerna Branch. Goal of the rehabilitation works was to reduce leakage at the dam, with the ultimate goal to make the dam watertight. The system proposed by Carpi for Servalar dam had to create a continuous water barrier by means of a flexible SIBELON® composite liner (=geocomposite), consisting of a watertight geomembrane heat-bonded during extrusion to an anti-puncture geotextile. The 10,200 m^2 upstream face was proposed to be waterproofed in the dry condition for the left flank and spillway portion.

The contract was awarded to Carpi in November 2016, and the scope of works consisted of desilting near the dam face to install the geomembrane lining down to the foundation of the dam, filling of cavities, if any observed on the upstream face of the dam, racking/packing and pointing, drilling and cement grouting in critical sections to fill the porous sections and design / supply / installation of a SIBELON® geomembrane system at the left flank and spillway

3.4 *Preparatory works*

Loose and weak zones were identified using hydro-jetting method whereby water applied at high pressure around 150 bar is used to clear off the loose materials in the mortar joints. The weak ones withered off and racking and packing and pointing were carried out to fill the racked mortar joints. Wherever large superficial cavities and honey combs were found, they were filled with mortar and proper curing and packing was done.

3.5 *Geomembrane waterproofing components*

A very thick geotextile of 2000 g/m^2 was initially laid over the entire upstream face of the stone masonry dam to protect the geocomposite from puncture as well as to provide some drainage capability. The waterproofing liner is a flexible synthetic geocomposite, SIBELON® CNT 3750, consisting of a 2.5 mm thick SIBELON® geomembrane heat-bonded during extrusion to a non-woven, needle punched 500 g/m^2 polypropylene geotextile. Each sheet has a length such as to cover the dam section where it is placed.

Face anchorage of the SIBELON® CNT geocomposite to the dam is obtained by the Carpi patented system of stainless-steel tensioning profiles allowing continuous linear fastening and pre-tensioning of the geocomposite. The tensioning profiles are placed at 5.70 m spacing and waterproofed with a cover strip of SIBELON® C 3250 geomembrane (the same material composing the SIBELON® CNT 3750 geocomposite, but without geotextile) 2.5 mm thick. All welding of the waterproofing geocomposite and geomembrane cover strips has been done by the "hot air" method, using manual one-track welding gun.

Submerged perimeter seals (at heel and around the inlet gates - scourvent and power vent) are made with 80x8 mm flat stainless-steel profiles tied to the dam with anchor rods embedded in chemical phials. Even compression is achieved with 80x3 mm EPDM rubber gaskets, and stainless-steel splice plates. In the areas where the seals are made the surface is regularized by a layer of mortar. The perimeter seal at crest is made with 50 x 3 mm flat stainless-steel batten strips tied to the dam with mechanical anchors. In the area where the seal is made the surface is regularized by a layer of mortar. And around the crest of the spillway gates with 80X8 mm flat water tight seals.

3.6 *Drainage system*.

The drainage system was divided into 6 separate compartments: 4 upper compartments collecting water drained from the upstream face, and 2 lower compartments collecting water coming from the area between the primary and secondary bottom perimeter seals. Drained water is discharged into the gallery by 10 transverse pipes, 6 pipes discharging in the upper gallery and 4 pipes discharging in the lower gallery acting also as a ventilation conduit.

3.7 *Results and comparison*

The entire work was completed on 14thof October 2018 and an inspection of the gallery was done on 15th of October jointly with the client and Carpi. Leakage from shaft reduced from 1,200 litres/minute to 1.31 litres/minute. The downstream face is now completely dry with water level almost close to FRL. The recorded leakage through the vertical shafts is1.31 litres/minute on 09.11.2018 at water level 257.14 m.

Table 3. Leakage recorded in vertical shafts after geomembrane installation.

Vertical Shaft No.	Leakage recorded in litres/minute
Vertical Shaft 14	0.00
Vertical Shaft 15	0.00
Vertical Shaft 20	0.00
Vertical Shaft 25	0.00
Vertical Shaft 32	0.00
Vertical Shaft 37	0.05
Vertical Shaft 40	0.98
Vertical Shaft 43	0.28
Total leakage recorded	1.31

3.8 *Conclusion*

The installation of the exposed SIBELON® geocomposite, mechanically anchored and drained, has more than confirmed the expectations of TANEGDCO when it selected the system as a rehabilitation measure to provide efficient seepage control. Seepage that was in the order of 7,000 litres/minute has been reduced to around 20 litres/minute. A geomembrane system, adequately designed and installed, has once again proved to be advantageous and hence is a preferred alternative to traditional repair systems in Indian soil, in terms of technical and financial effectiveness.

The rehabilitation of Servalar dam using an exposed geomembrane is the second project of its kind in India and the first in DRIP projects and has been proved to be an effective way of reducing seepage in dams and hydraulic structures. The foundation gallery which was flooded before geomembrane works is now accessible and has significantly reduced the impact of uplift pressure on the gravity dam.

3.9 ***Results***

Figure 6. Downstream side before and after geomembrane installation.

Figure 7. Vertical shaft leakage before and after geomembrane installation.

The results achieved is yet another proof of effective and professional design of geomembrane waterproofing system on large dams. A dam which was leaking at a rate of > 6,000 litres/minute is now reduced to just < 2 litres/minute on the left and spillway section.

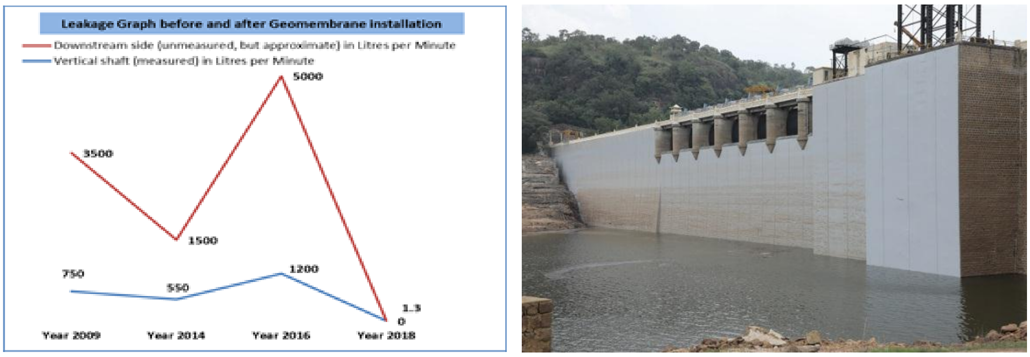

Figure 8. Leakage pattern before and after geomembrane installation. At right, Servalar dam after geomembrane installation.

4 UPPER BHAVANI DAM, (UNDER DRIP - ONGOING)

Upper Bhavani dam, a stone masonry dam of 80 m height, located in the Nilgiris District, Tamil Nadu (India) is the third project in India for Carpi and the second project in the DRIP program (Dam Rehabilitation and Improvement Project). The dam, constructed in the year 1965, started leaking badly since the early 2000ies. Leakage started increasing thereafter and especially the region surrounding the spillway started leaking very badly. Around 8,000 l/minute has been recorded as the leakage from the two shafts surrounding the spillway alone. Various repair attempts were made between 2003 and 2010 and the dam has been declared as the most distressed dam in spite of the conventional repair works carried out, which again did not provide good results. Ultimately it was decided to install a geomembrane waterproofing system citing the previous success stories of the Kadamparai and Servalar projects. The project is being executed in two phases out of which 20% of geomembrane installation has been completed in the first phase between April and June 2019. The next phase will commence by February 2020 once the monsoon ends by December 2019. Despite the challenges of extreme cold weather and location of the dam in a deep reserved forest, the balance work has been planned to get completed in second phase between Jan and June 2020. The water from the Upper Bhavani dam acts as the main source for a series of cascaded power houses with a total power generation capacity of > 600 MW. Thus, saving water is of utmost importance for the client TANGEDCO.

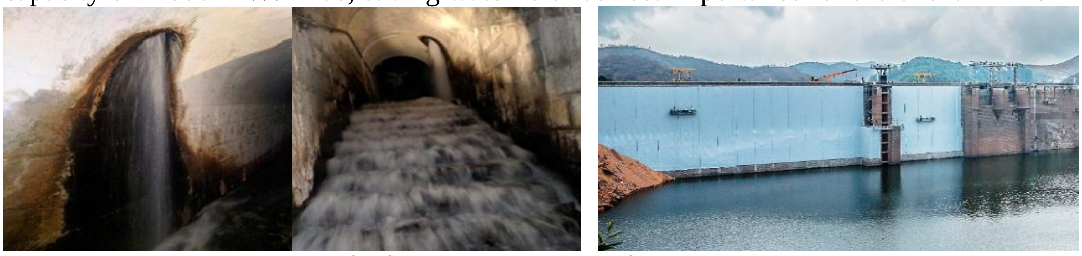

Figure 9.Leakage in vertical shaft of drainage gallery at left. At right, geomembrane lined on the upstream face of the dam as of June 2019.

5 CONCLUSIONS

Geomembrane systems effectively restore watertightness in all types of leaking dams and joints, with little or no impact on operation of the dam, adhering to the demanding environmental conditions. They provide water tight barriers in all types of dams. Their elongation capabilities allow resisting movements that would destroy other types of water barriers. In all the installation done so far, it is to be noted that meticulous planning and designing has always played the key role in success of the project. With > 160 installation on dams all over the world, every installation confirms to the guidelines stipulated by ICOLD and thereby achieving the goal in each and every project.

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