EMBANKMENT DAMS

Rockfill, Earthen, Tailings, and Hardfill

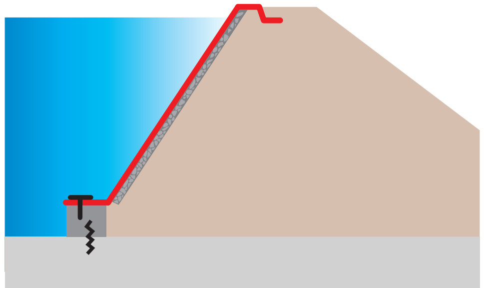
Watertight Protection with Synthetic Geocomposites*

*Using SIBELON® Technology

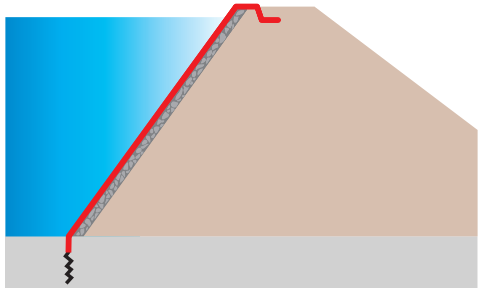
carpi

▲ Carpi completing installation of geocomposite on a new tailings dam.

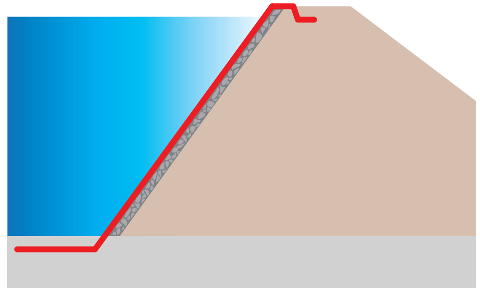
EXPOSED with anchoring at the toe and crest



Geocomposite is anchored to the toe or at a plinth.

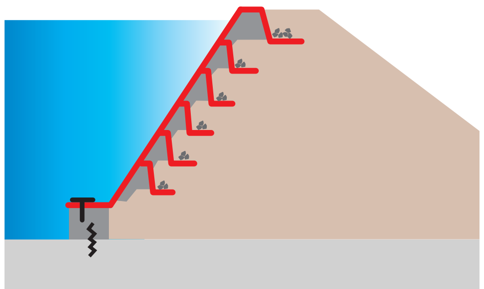


Geocomposite is anchored to positive cutoff at the toe.

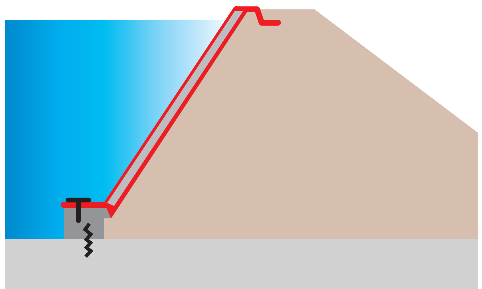


Geocomposite is anchored by burial upstream in the reservoir to create a blanket.

EXPOSED using curbs and trenches for anchorage

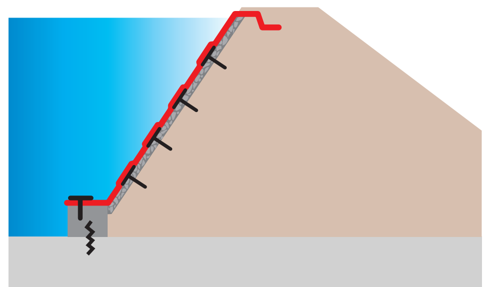


Geocomposites can be integrated into curbs used to form the upstream face.



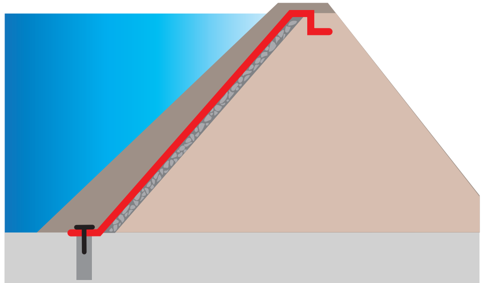
Trenches can be more economical if the sub-grade is stable and easily excavated or formed.

EXPOSED using point anchors

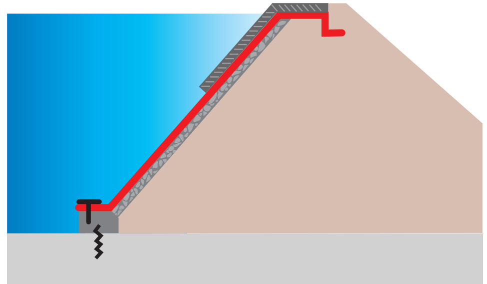


Anchors are embedded or grouted into the slope.

COVERED with concrete or soil ballast

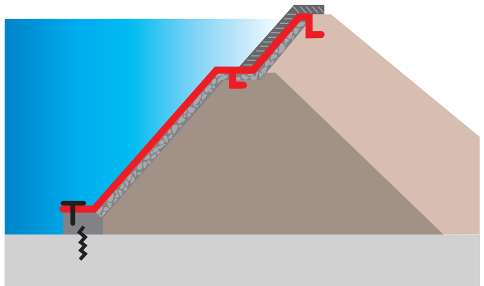


Geocomposite is fully covered.

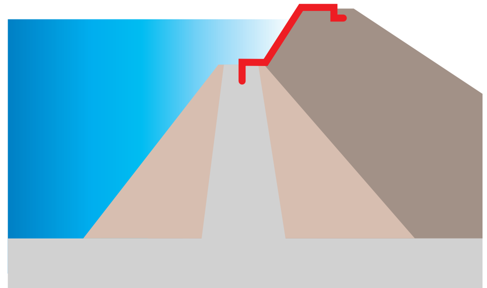


Geocomposite is covered only in the water fluctuation zone.

COVERED or EXPOSED for dam raising

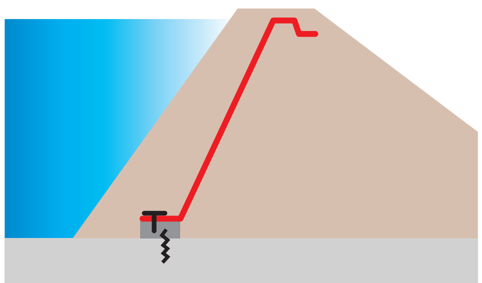


New geocomposite is connected to existing geocomposite and covered.

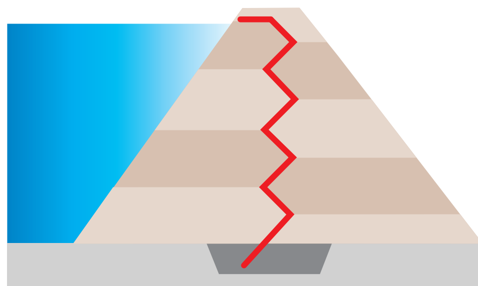


Geocomposite is used to connect new and existing dam sections.

INTERNAL for new construction



Geocomposite forms an internal barrier.



A zig-zag formation between lifts forms an impervious core.

Slope of upstream face and other features are not to scale.

How do **synthetic geocomposites** protect embankment dams?

Synthetic geocomposites are installed on embankment dams to provide watertightness. Appropriate synthetic materials offer superior performance (much lower permeability, higher capability to resist displacements, simpler constructibility) than traditional natural or man-made water barriers consisting of fine graded soils, conventional concrete, or bituminous concrete. Geocomposites eliminate dependence on local, natural materials, and offer a cost-effective alternative to conventional techniques. Geocomposites can be installed upstream, exposed or covered, or as a core. In upstream exposed positions, generally the geocomposite used is one that is formed by a thick watertight PVC geomembrane heat bonded to a non-woven geotextile. The Sibelon® geocomposite used by Carpi is specifically designed to have strength and durability characteristics that yield long-lived solutions requiring no maintenance. Other geomembranes like HDPE and EPDM, or PVC of lower quality, are much inferior in their performance.

PERIMETER ANCHORAGE

Toe and Crest

Anchorage is one of the most important considerations for a geocomposite. Waves and wind exert forces on a geocomposite. Therefore, the key to a long service life is anchorage that is appropriate to the setting. Carpi understands the engineering theory and construction practice of proper anchorage.

Anchorage must be made at the upstream face and along the perimeter. At the toe, anchorage can be accomplished using plinths or cutoff walls. Carpi uses specially designed stainless steel bolts and battens to attach the geocomposite to these concrete structures.

Alternatively, the geocomposite can be anchored in a trench at the toe, or buried upstream in the reservoir to create an impervious blanket. The width and depth of burial is calculated based on site-specific factors.

Similarly, crest anchorage can be accomplished by burying the geocomposite in a carefully designed and constructed trench, or by mechanical anchorage at a concrete wall.

Bolts are installed in the plinth.

Battens are installed over the bolts to complete the geocomposite seal.

A worker is installing geocomposite over the bolts and using epoxy mortar to create a seal.

Burial upstream provides a barrier on the reservoir floor.

Burial at a toe trench provides secure anchorage.

Workers tack the geocomposite into the trench to hold its position during backfilling.

Workers begin filling a trench where geocomposite is to be welded to the protruding side "bands" afterward.

Workers prepare a trench where the geocomposite is installed before the trench is filled.

Once the geocomposite is installed, note how the trenches provide tension such that no wrinkles are formed.

EXPOSED UPSTREAM FACE ANCHORAGE

Trenches and PVC Anchor Bands

Face anchorage of the exposed Sibelon® geocomposite is required to resist wind and waves, and allow more rapid filling and dewatering of the reservoir. Carpi's unique anchorage methods are critical to success and can be used on steep slopes.

For example, trenches and anchor bands can be used for anchorage when the subgrade is not rigid and the dam fill material can be easily excavated or formed. Parallel vertical trenches are created in the finishing/drainage layer with spacing between the trenches calculated by Carpi based on site-specific wind and water loads. A PVC anchor band is embedded in each trench. The trenches are then filled with porous concrete, gravel, rock, or compacted soil as ballast. The geocomposite liner is permanently anchored to the dam by heat seaming it to the PVC anchor bands.

Carpi has developed and patented different configurations allowing tensioning of the geocomposite liner to avoid formation of folds and wrinkles, thus improving durability.

EXPOSED UPSTREAM
FACE ANCHORAGE

Extruded Curbs and PVC Anchor Strips

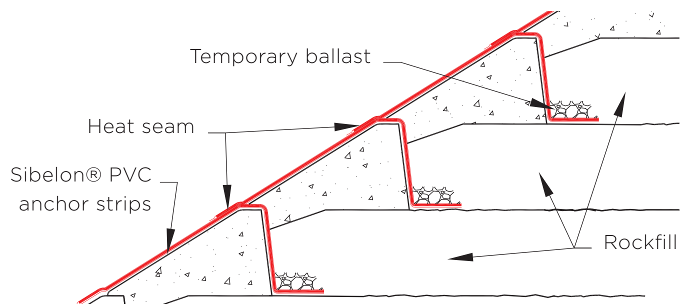
Face anchorage is the key to success for any exposed geocomposite installation. Carpi has mastered and patented several installation techniques for new dams. For example, extruded porous concrete curbs can be installed to provide support for the base layer and the fill. Carpi has developed a patented linear anchorage system consisting of PVC geocomposite strips embedded in the curbs. Each strip overlaps the strip on the curb beneath it and is heat seamed to that strip.

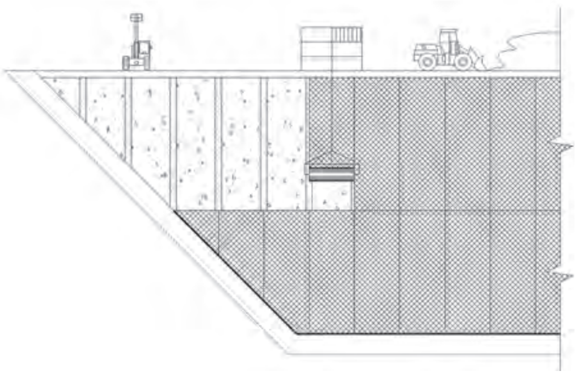
The result is parallel PVC anchor strips placed at regular intervals. The spacing is determined by Carpi using calculations based on wind uplift forces. In the final step, the geocomposite sheets are then deployed and heat seamed to the anchor strips to form a watertight seal.

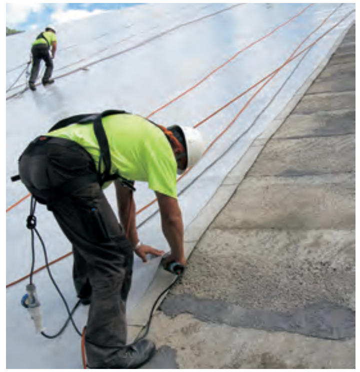
▲ Curb and embankment construction is in progress and anchor strips are installed.

▶ This section shows the extruded curbs.

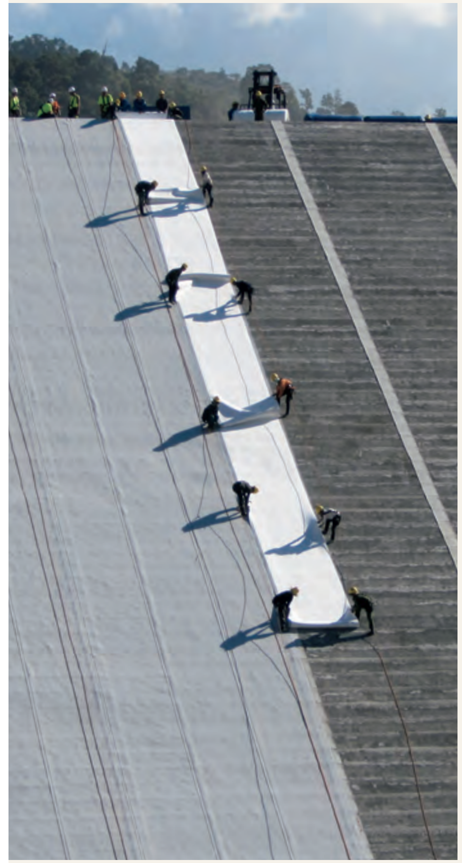
◀ A worker is heat seaming an anchor strip to the strip below.







A worker heat seams a PVC geocomposite sheet to an anchor strip. After 100% quality control of all seams, watertight coverage of the upstream face is achieved.



Geocomposite sheets are being deployed.

Carpi installed anchorage using extruded curbs to provide watertight coverage of the **Nam Ou VI Rockfill Dam** in **Lao PDR** in 2014.

EXPOSED UPSTREAM
FACE ANCHORAGE

Point Anchors

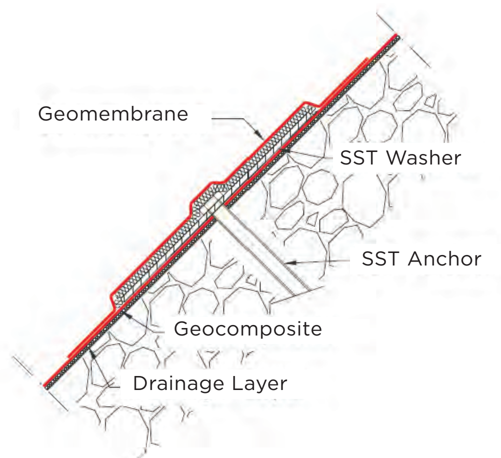
Carpi uses point anchors on embankment dams and reservoirs in cases where soils are not suitable for forming trenches or the subgrade is semi-rigid. Wedge-style anchors can be used depending on soil conditions. The type of anchor and embedment depth must be tailored to site conditions. Carpi performs detailed calculations to anticipate wind uplift and wave forces.

Alternatively, anchors can be grouted in a soil embankment by first creating a 5-10-cm diameter hole, inserting an anchor bar, filling the hole with grout, and allowing it to cure. Then, the geocomposite is installed over the anchor bars which are punched through and secured.

This photo shows a slope using point anchors installed by Carpi for the **Panama Canal Water Saving Basins** in 2015. For this application, not only was it important for the anchorage to endure high winds, but Carpi showed, through extensive laboratory testing and mathematical analysis, that the PVC geomembrane would have a >100-year design life. A photo of 9 of the 18 basins completed by Carpi appears at the centre bottom of the back cover.

This diagram of a point anchor shows a typical setup.

The circular stainless steel washer is bolted and the bar is trimmed. Then the point anchor is covered with a heat-seamed PVC cover cap to ensure watertightness.



At the 58.7-billion litre **C. W. Bill Young Reservoir** in **Tampa**, **USA**, rock drainage and soil layers were placed on top of the geocomposite. In this case, a custom-made geomembrane with heat-bonded geotextile on both faces was used.

At the **Tekapo project**, in **New Zealand**, rock ballast would shatter into shards, so a layer of geotextile was placed to protect the geocomposite.

Workers begin placement of drainage layer on top of geocomposite at **Bill Young Reservoir**.

For the **Bovilla Embankment Dam** in **Albania**, the use of unreinforced concrete slabs ballasted the geocomposite and protected the dam from the impact of boulders from the slopes.

COVERED GEOCOMPOSITE

Concrete or Soil Ballast

Covering the geocomposite with concrete or soil could be desirable in some settings:

- Where there is a need to use ballast as anchorage to external loads or to augment other anchorage.
- Where rocks or other sharp materials are naturally occurring and may settle onto or wash up against the geocomposite.
- Where there is a need to drive equipment over the geocomposite.
- Where vandalism is a realistic concern.
- Where there is a need to prevent the exposure of the geocomposite to UV light (i.e., where desired longevity of the geocomposite is more than 100 years).

Even when ballast is used, only partial coverage of the geocomposite surface may be needed, resulting in significant cost savings.

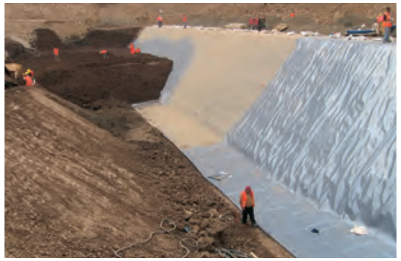
Internal Core

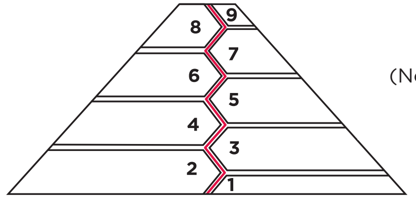
The Carpi geocomposite can be used to create an impervious internal core in the dam. Reasons for using a geocomposite core include:

- Natural impervious material (e.g., clay) is not available.
- Complications with settlement are common with natural impervious core material.
- Repair of settlements with natural materials is difficult.
- Difficulties can occur in assuring the integrity of a natural impervious layer.
- Construction of asphalt concrete cores is expensive, requires special equipment, and is time-consuming.
- Tight construction schedules do not allow sufficient time for placement of a natural impervious core or of an asphalt concrete core.
- A geocomposite allows 100% QC verification of the imperviousness of the core.

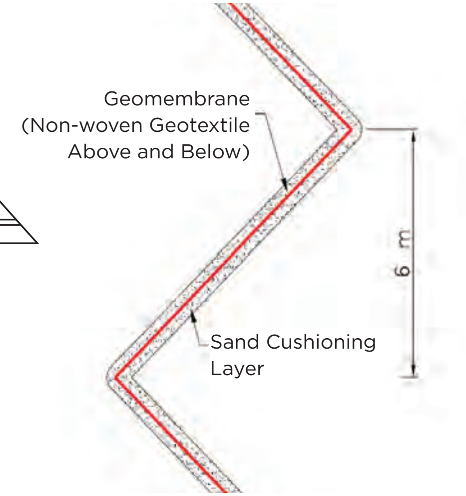
The orientation of the internal barrier will differ depending on the setting and use. A "zig-zag" approach can be used in which the geomembrane crosses back and forth across the dam's centre axis as each lift is placed in alternating layers between upstream and downstream sides of the dam.

At the **Gibe III cofferdam, Ethiopia** (50 m tall), the zig-zag approach was used. Here, the second layer of fill is placed. Below, the fourth layer is placed. The geomembrane layer appears on the right (grey) and the top geotextile appears on the left (white).





Geomembrane sheets are placed as dam lifts are compacted on alternating sides.



Geotextile and sand cushioning layers are placed on either side of the geomembrane. The geomembrane sheets are heat seamed in two parallel tracks.

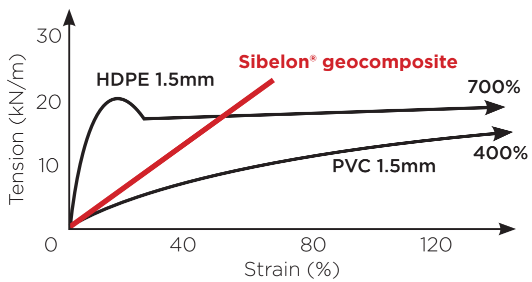
The dual parallel track of the seams allows the integrity to be tested by injecting air between the seams.

The final stage of placement is underway at the **Gibe III upstream cofferdam**.

Hardfill Dams

Today, hardfill dams are being built in greater numbers because they are less expensive, but these dams are pervious. By installing a Carpi geocomposite on the upstream face, Carpi makes the dam surface watertight and protects the exposed surface. When the hardfill deforms, the Carpi geocomposite, with its excellent elongation characteristics, deforms along with the dam and does not tear.

The concept of using a geocomposite on hardfill has been applied on large scale projects, such as the **Filiatrinos Dam in Greece**. The geocomposite withstands wind because grouted anchors secure steel disks that compress the geocomposite to the dam surface.



The ideal waterproofing material for a dam will have a near linear stress-strain curve and an equal amount of strain for each unit of stress. The Sibelon® geocomposite used by Carpi exhibits this relationship.

Hardfill dams are constructed with minimum cement resulting in a dam body that is pervious and must be protected from water.

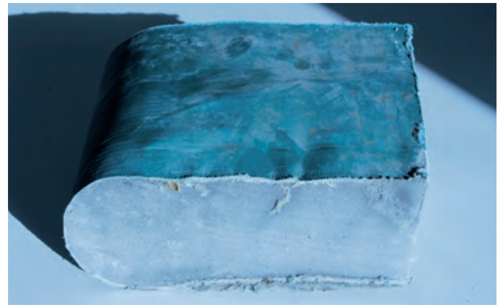
Ambarau Hardfill Dam, Republic of Congo: A steep slope can be constructed with hardfill to reduce dam body mass making the structure less expensive.

Sibelonmat®

When seepage is a concern and the reservoir or canal cannot be dewatered, Carpi has an innovative patented system called Sibelonmat®, designed to be installed underwater without reducing the water level. Water can continue to flow at moderate rates. Sibelonmat® consists of two watertight geomembranes connected together with internal channels forming a single mattress. Once it is in position, the mattress is filled with fluid cement grout. The lower geomembrane provides watertightness, the grout provides ballast, and the upper geomembrane provides containment of the grout while protecting the ballast during operation. When deployed in canals, the smooth upper surface also improves the canal's hydraulic efficiency. Carpi has patented a unique watertight zipper allowing multiple Sibelonmat® sections to be connected underwater. A hydraulic trolley or diver pulls the zipper closed underwater to connect adjacent mattresses. The technology can be applied to embankment dams to create an impermeable upstream face or an impermeable blanket, even on irregular subgrades.

▲ The rolled mattress can be deployed using a customised hydraulic trolley.

▲ Once completed, a Sibelonmat® provides a strong barrier to water seepage. No interruptions to dam/canal operations are required for its installation.



▲ This Sibelonmat® section shows that the grout pumped into the mattress completely fills the voids.

▲ Up to five rolls of geomembrane material can be seamed together to make a mattress roll of up to 10 m wide and custom-made length.

▲ Once the Sibelonmat® is in place underwater, workers fill each section with grout. The tensile properties of the lower geomembrane and the heavy weight of the grout keep the preparation of the subgrade to a minimum.

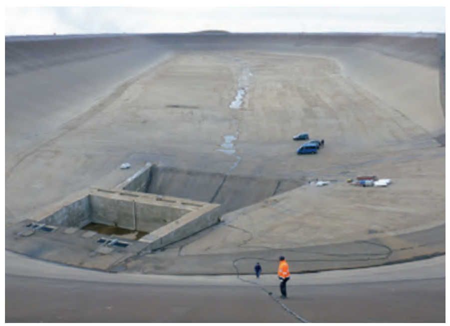
Joints

In dams, joints are designed to allow for natural expansion and contraction of the dam materials. Multiple lines of waterstops are typically used in joints to prevent water inflow. If the joints open beyond the maximum allowable elongation of their unconstrained portion (the portion of the waterstops not embedded in concrete), the waterstops fail and seepage levels can be unacceptable. A Carpi external waterstop system can be installed over joints, either during new construction, or for rehabilitation. The advantage is that the Carpi geocomposite is flexible and free to elongate along its whole width, allowing the joint to maintain its original function. Carpi external waterstop systems can accommodate openings several orders of magnitude larger than traditional waterstops. Connections between rigid concrete structures and the deformable dam body can be made watertight.

At **Angostura CFRD in Chile** (30 m high and 1.6 km long), Carpi's external waterstops were installed during construction to ensure a watertight joint both between the plinth and concrete slabs, and at the vertical joints between concrete slabs. This protected against an anticipated opening of up to 30 cm (horizontal) and 10 cm (vertical), which would destroy the embedded copper waterstops of the dam.

Top: **Bumbuna ACFRD**, **Sierra Leone:** Carpi's external waterstop was installed before impoundment to guarantee watertightness of the perimeter joint between the concrete plinth and the asphalt concrete facing at the left abutment.

Bottom: **Karahnjukar CFRD**, **Iceland:** Carpi's external waterstop was installed at the horizontal joint between phase 1 and phase 2 slabs, and over the toe wall.



Top: Carpi's external waterstop was installed to repair failing joints at **Strawberry CFRD**, **USA**, and to waterproof the joints of the concrete intake structure.

Bottom: Carpi made watertight the joint between the intake and the asphalt concrete facing at the pumped storage reservoir at **Dlouhe Strane**, **Czech Republic**.

Rehabilitation

Over time, cracks, failing joints, and failed repairs can be sources of seepage through concrete facings and bituminous concrete facings of embankment dams. A geocomposite installed on the upstream face can bridge these areas and make them watertight. In addition, the Carpi geocomposite conforms to the substrate and, due to its low elasticity modulus and excellent tensile elastic characteristics, requires minimal surface preparation.

On concrete and asphalt concrete facings, Carpi's patented mechanical tensioning system anchors the geocomposite to avoid wrinkles. Eliminating wrinkles or folds prevents the formation of large capacity infiltration pathways, thus improving longevity. On granular facings, deep earth anchors are used. If piping through the foundation is a risk, the geocomposite can be extended into the reservoir.

A repair using a Carpi geocomposite is designed to last. Carpi geocomposites are custom manufactured to withstand heavy UV exposure, impacts of floating debris, and the actions of waves and wind. Furthermore, ice will slide and not stick to the geocomposite, thus limiting the risk of damage in severe cold.

As shown at the **Pecineagu Dam**, **Romania**, Carpi tensioning profiles keep the PVC geocomposite taut to the surface with no wrinkles or folds, ensuring long service life. Other geosynthetic materials, such as HDPE, are too stiff and do not conform to the subgrade. The resulting folds can lead to large capacity channels between the geocomposite and subgrade and, ultimately, to failure of the liner.

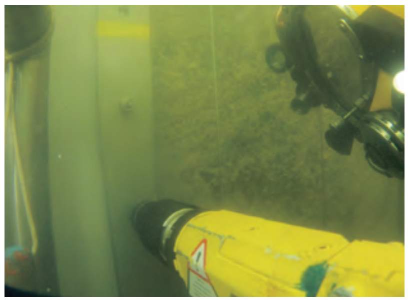
Vaité Dam, **French Polynesia:** In this earthfill dam deep earth anchors resist hurricane conditions (204 km/h wind design speed). The geocomposite is extended upstream into the reservoir, where it is ballasted.

Carpi's exposed tensioned geocomposite system resists ice and performs well in extreme cold weather.

Turimiquire CFRD, **Venezuela** (113 m high)**:** A Carpi geocomposite system was installed to a depth of 65 m. Construction was staged to first repair the areas causing most leakage. Dramatic reduction of leakage was achieved after underwater installation of the geocomposite system on about 1/5 of the upstream face.

Geogrids and geotextiles are used for support over large cavities and to provide anti-puncture protection. This keeps surface preparation to a minimum. Here, a geogrid is installed at the waterline.

Left: At **Lost Creek Dam**, **USA**, a diving crew installs the geocomposite underwater. *Middle:* Before installation of the geocomposite, the downstream face is wet and subject to freeze-thaw deterioration. *Right:* After installation, the face is dry, eliminating deterioration.



Watertight perimeter seals avoid water infiltration behind the geocomposite. At **Olai Dam**, **Italy**, Carpi's external waterstops installed on three failing joints reduced total leakage from > 65 l/s to 0.33 l/s.

Underwater

Carpi geocomposite systems can be installed underwater to ensure no disruption of operations and to limit impacts on the aquatic environment and recreation. Rehabilitation can include the entire upstream face, the areas causing the most leakage, or only joints or cracks. Installation of the geocomposite system is completed at any water depth using equipment specially designed and built for the site. Our Carpi services may also include preliminary underwater surveys with single-beam sonar/multi-beam sonar/ROVs, removal of sediments, and restoration of the functionality of stoplogs and gates. Carpi's extensive experience with underwater installations helps reduce costs and avoids unnecessary complexity. Carpi can perform an underwater installation using a qualified local diving company with Carpi supervision.

Carpi is a specialty contractor providing turn-key services: design, supply, and installation of geocomposite systems for hydraulic structures with comprehensive warranties.

Key Carpi facts:

- Carpi has more than 50 years of experience and more than 1300 projects completed.
- Watertight protection is provided on a variety of hydraulic structures: dams, canals, hydraulic tunnels, shafts, reservoirs, and intake structures.
- Carpi patented systems using flexible Sibelon® geocomposites for dams are used for new construction (embankment, RCC dams, hardfill dams, and cofferdams) and for rehabilitation (gravity, buttress, arch, multiple-arch, embankment, RCC dams).
- Installation can be performed in the dry or underwater, even with water flowing.
- More than 100 significant projects have been completed on reservoirs and tunnels (hydraulic and traffic).

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