carpi

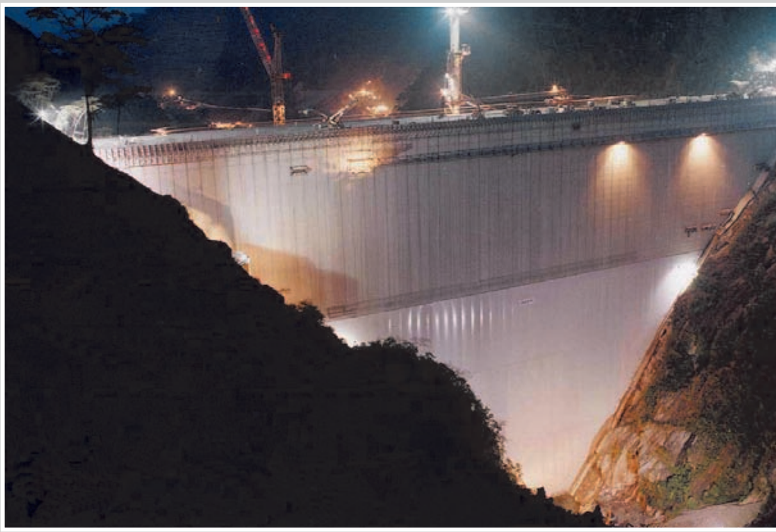
100+ dams of all types (as of 2011)

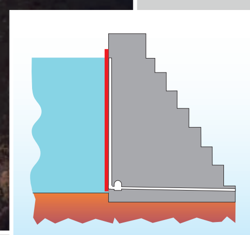
Since 1963

WATERPROOFING SPECIALISTS AND CONTRACTORS WITH GEOMEMBRANES

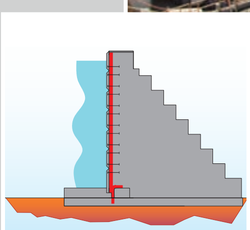
RCC DAMS

WATERPROOFING OF THE UPSTREAM FACE





Exposed geocomposite



Covered geocomposite

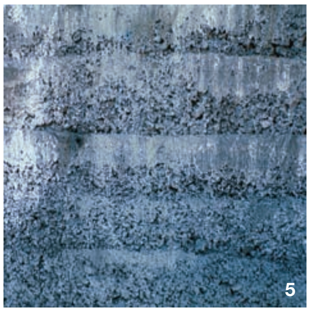
Providing Dry and Underwater Installations

PROBLEMS

The risk of water infiltration in RCC dams is higher than in conventional concrete dams. As with conventional concrete dams, seepage is caused by cracks, poor performance of monolith joint waterstops, and permeability at RCC lift joints. There are typically five to ten times more lift joints in RCC construction than in conventional concrete construction. This amounts to increased path opportunities for seepage.

1/2 - Formation of cracks on the upstream face of RCC dams, creating a new unprotected joint in the dam.

3 - Formation of cracks on the upstream face of RCC dams, creating a new unprotected joint in the dam.
4 - Water infiltrating the gallery through a vertical crack.



5 - In RCC dams the upstream face is frequently made of GEVC (Grouted Enriched Vibrated Concrete).
6 - Diffused water seepage through permeable RCC lift joints on the downstream face.

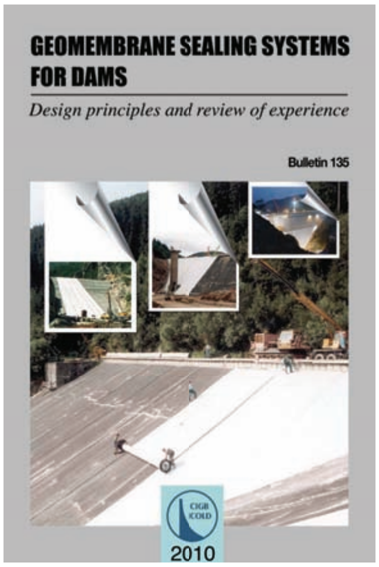
7/8 - Water seeping to the downstream face through cracks.

GEOMEMBRANE BENEFITS

To assure a watertight dam, the waterproofing function is separated from the structural function. The CARPI system consists of installing a prefabricated synthetic geomembrane as the impervious element over the upstream face. Watertightness is therefore assured even if the RCC lift joints and monolith joints are not watertight, or if cracks form. The system has a face drainage system behind the waterproofing geomembrane that reduces uplift and improves structural stability. The CARPI patented systems simplify design and construction procedures. Our systems have over 40 years of success history without the need for maintenance on 100 + dams of all types, also in extreme climates.

BENEFITS PROVIDED BY THE CARPI SYSTEMS*:

- Durable watertight protection of the upstream face, construction joints, induced or unexpected fissures
- Can withstand seismic events
- Simpler design and construction of the vertical induced joints
- Simplified drainage system and reduced uplifts
- Reduced costs for treatment of the horizontal lifts
- Reduction of the cement content in the RCC mixes
- Control of potential AAR
- Possible reduction of dam body volume
- Reduced constraints for RCC placement, green joints, temperature control, cooling plant, use of aggregates
- In the CARPI/RCC method, no interference with construction, no uplift pressures along the horizontal lifts of the dam, no need for bedding mix on upstream face for permeability control, easy monitoring and maintenance
- Installation in the lowest section of the dam can be made as the RCC placement progresses in the upper section, to allow faster construction, earlier completion and impoundment
- Overall shorter construction times, reduced overall costs



Miel I RCC dam, 2002 Columbia, pictured on the cover of the ICOLD Bulletin 135 (2010) Geomembrane Sealing Systems for Dams..

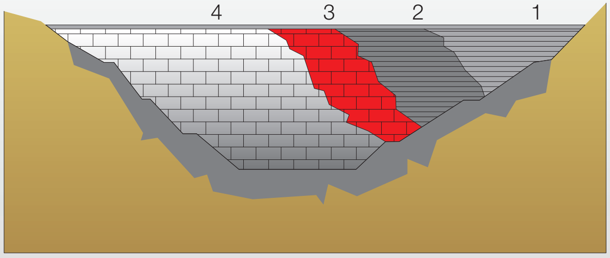
* According to ASTM D4833, geomembrane is a very low permeability synthetic membrane liner or barrier used with any geotechnical engineering related material so as to control fluid migration in a human-made project, structure or system. Geocomposite cited in this text is a composite material consisting of a geomembrane heat-coupled to a geotextile during manufacturing.

THE WATERPROOFING CONCEPTS

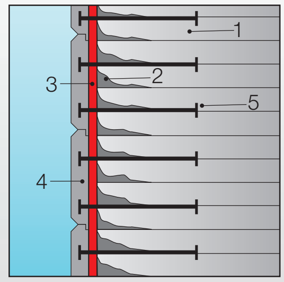
The synthetic flexible geomembrane/geocomposite is installed to waterproof the entire upstream face of the RCC dam, or to waterproof the construction joints/cracks only. The geomembrane can be covered, or it can be left exposed.

COVERED GEOMEMBRANE/GEOCOMPOSITE - THE CARPI/WINCHESTER SYSTEM

A covered geomembrane system is an efficient solution against willful damage, or as additional precaution against a particularly aggressive environment. Since the geomembrane is in contact with the RCC, care must be taken when placing RCC to prevent damage to the geomembrane already in place.

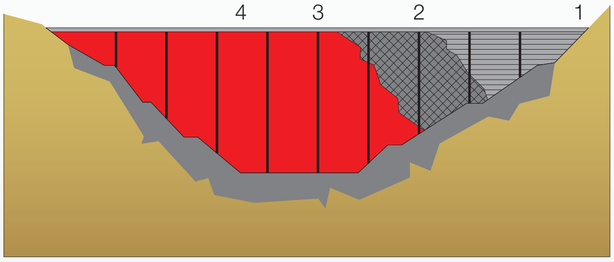


1. RCC lifts
2. Bedding mix (optional)
3. Waterproofing geomembrane/ geocomposite
4. Precast concrete panel
5. Anchoring rods

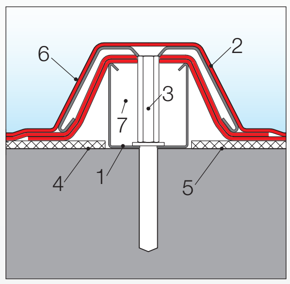


EXPOSED GEOMEMBRANE/GEOCOMPOSITE - THE CARPI/RCC SYSTEM

An exposed geomembrane system minimizes interference with construction of the dam, and allows effective and quick inspection, monitoring and maintenance of the liner.
If there is no perimeter plinth, the exposed geomembrane is sealed at the bottom of the upstream face. If there is a perimeter plinth for contact grouting, the geomembrane on the face is connected to the geomembrane on the plinth and grout curtain. The configuration with the plinth achieves a complete water barrier from crest to the impervious foundation.

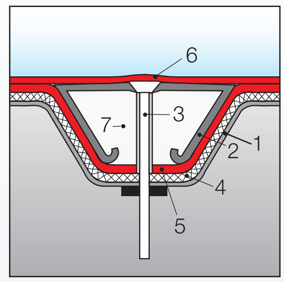


1. RCC lifts
2. Drainage layer (optional)
3. Tensioning profiles
4. Waterproofing geomembrane/geocomposite



External profile

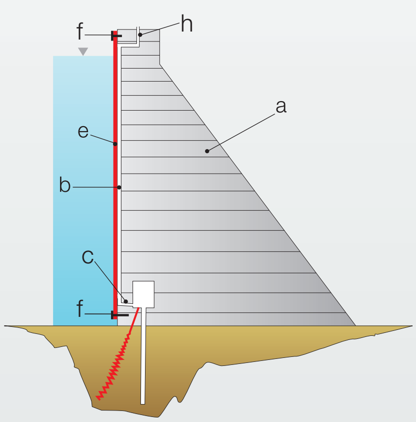
1. Anchoring profile
2. Tensioning profile
3. Attachment system
4. Drainage layer (optional)
5. Waterproofing geomembrane/geo-composite
6. Waterproofing strip
7. Free flow conduit



Embedded profile

TENSIONING PROFILES (CARPI PATENT)

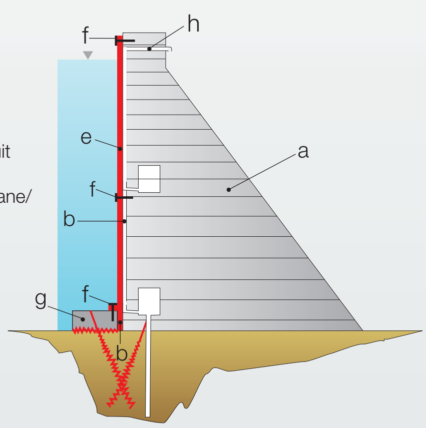
Without plinth

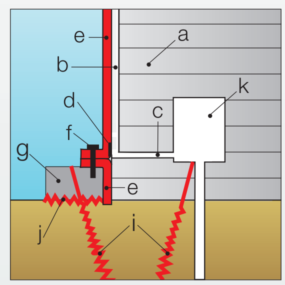


Typical cross sections

a. RCC lifts
b. Drainage layer (optional)
c. Drainage discharge conduit
d. Anti-intrusion plate
e. Waterproofing geomembrane/ geocomposite
f. Perimeter seals
g. Perimeter plinth (optional)
h. Ventilation pipe

With plinth

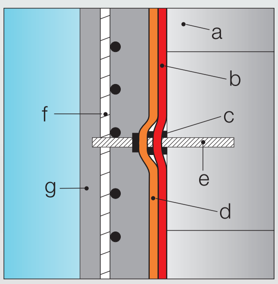




Detail of perimeter plinth

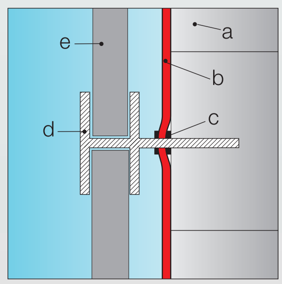
i. Grouting
j. Contact grouting
k. Gallery

Different types of anti-vandalism layers can be installed in the accessible areas of the exposed geomembrane if required.



a. RCC lifts
b. Waterproofing geomembrane/ geocomposite
c. Watertight penetration
d. Anti-puncture geomembrane
e. Steel rod
f. Steel reinforcement
g. Shotcrete

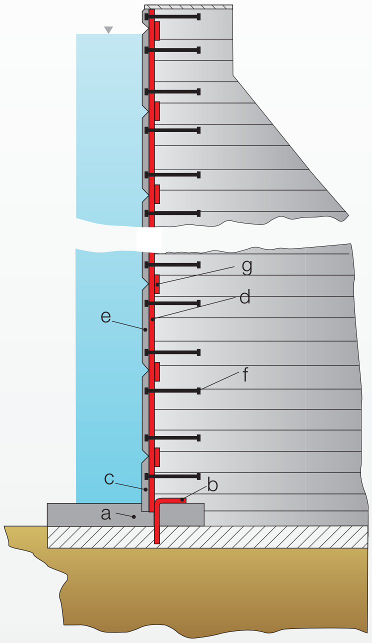
a. RCC lifts
b. Waterproofing geomembrane/ geocomposite
c. Watertight penetration
d. Steel anchor bracket
e. Steel pipes or plates



Anti-vandalism heavy layer (optional)

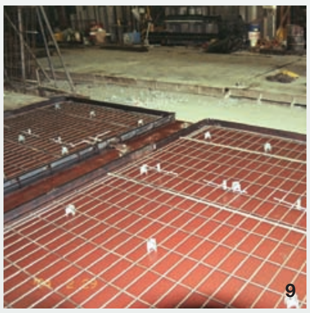
Anti-vandalism light structure (optional)

In the Winchester system the geomembrane, sandwiched between the RCC lifts and the concrete of the prefabricated panels, is permanently covered.



Typical cross section of the Winchester system

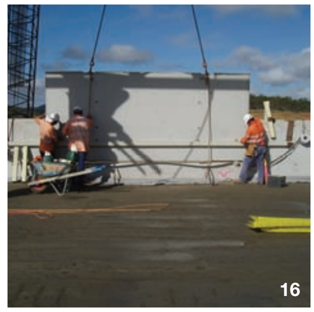
a. Conventional concrete
b. Geomembrane key
c. Starter precast panel
d. Waterproofing geomembrane/geo-composite
e. Precast concrete panel
f. Anchoring rods
g. Waterproofing geomembrane welded strip



9 - Placement of reinforcement and insert plates before casting conventional concrete in the formwork.
10 - The waterproofing PVC geocomposite attached to the concrete to form the watertight element of the panel.

11 - Testing tensile strength of geomembrane strip between panels.
12 - Storage of the prefabricated panels.

13 - The geomembrane key prior to connection to the starter panel.
14 - The geomembrane key welded to the starter panels.



15 - Supports for stabilization of the panels during RCC placement.
16 - Panel installation in superimposed rows.

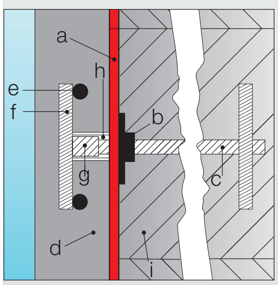
17 - Burnett River dam under construction, 2005 Australia.

18 - Erected panels seen from the downstream of Hughes River dam (30 m), 2001 USA.

19 - Erected panels seen from the upstream of Buckhorn dam, 1998 USA.

20/21 - Welding of PVC geomembrane strips waterproofing the perimeter of the precast concrete panels.

22/23 - Watertightness of all welds is inspected prior to RCC placement.



Detail of precast panel anchoring

a. Waterproofing geomembrane/ geocomposite
b. Watertight penetration
c. Anchoring rod
d. Precast concrete panel
e. Reinforcement steel bar
f. Anchoring steel plate
g. Panel steel insert
h. Insert hole
i. RCC lifts (not to scale)

24 - Burnett River dam (35 m), 2005 Australia: the anchoring rods being installed on the panels.
25 - Anchoring rods.

26 - Hughes River dam (30 m), 2001 USA: placement of precast panels.

27 - The anchoring rods being embedded in the RCC lifts.
28 - Hughes River dam (30 m), 2001 USA: placing of RCC against panels.

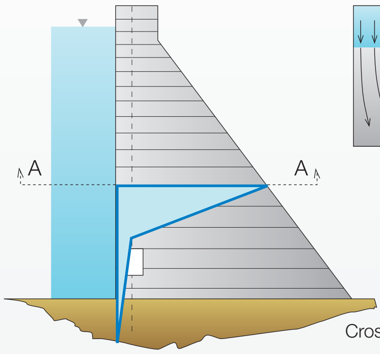
29 - Careful compacting of RCC close to the geomembrane.
30 - Adjacent to the geomembrane, the RCC is compacted with vibrating plate compactors to avoid damaging the synthetic liner.

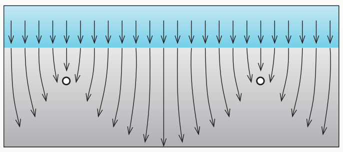
31 - Hickory Log dam (55 m), 2007 USA. Highest RCC dam in the world with Winchester system.

C A R P I   R C C   S Y S T E M

In the CARPI patented RCC system, the exposed geomembrane is equipped with its own independent full face drainage layer, which prevents the infiltration of water in the dam body. Uplift without an impervious facing, and with CARPI upstream drained geomembrane is illustrated in the sketches below.

Uplift without impervious liner

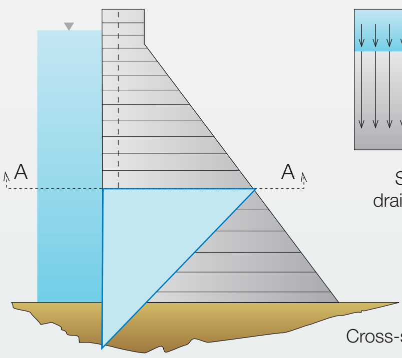


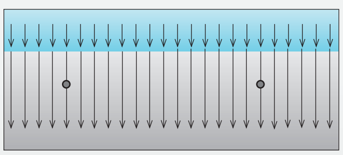


Section A-A: RCC dam with efficient drains, infiltration intercepted partially

Cross-section

Only PART of the water seeping through lift joints and cracks is intercepted by line of vertical drains. Over time, as seepage water distributes through the upstream face and dam body, it saturates the dam, drains become clogged, the uplift pressure changes and the factor of safety to sliding is reduced.

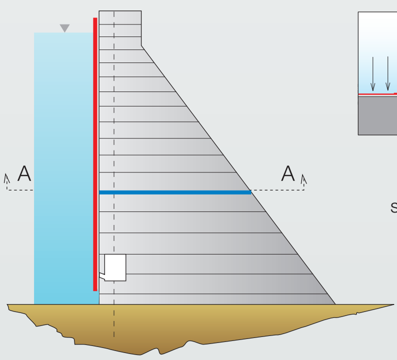


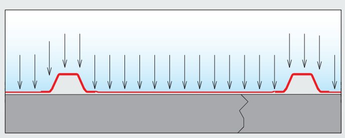


Section A-A: RCC dam with clogged drains, infiltration cannot be intercepted

Cross-section

Uplift with CARPI upstream drained geomembrane





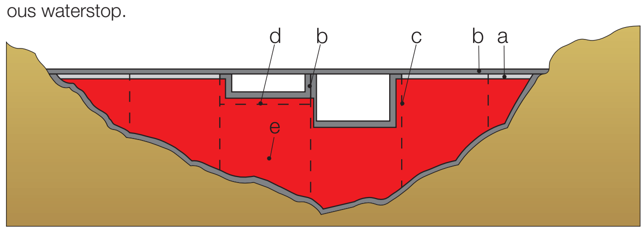
Section A-A: RCC dam with CARPI geomembrane system, infiltration stopped or fully intercepted in case of accidental damage

Cross-section: the formation of cracks after construction does not affect the CARPI system

The face drainage system intercepts all water at the upstream face. Design uplift can be reduced. If a crack occurs, the elongation properties of the PVC geocomposite allow the bridging of it, thus maintaining watertightness at the upstream face.

Over time, the face drainage system of the geocomposite intercepts ALL water seeping through lift joints and existing and/or future cracks. All infiltration water is discharged, and uplift pressures cannot build up. The factor of safety is unchanged over time.

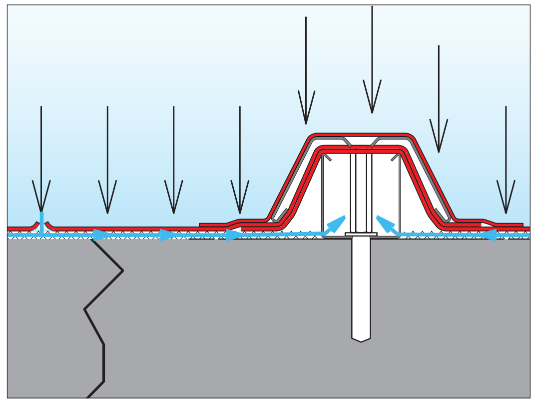
The CARPI impervious geocomposite covers the upstream face, as one continuous waterstop.



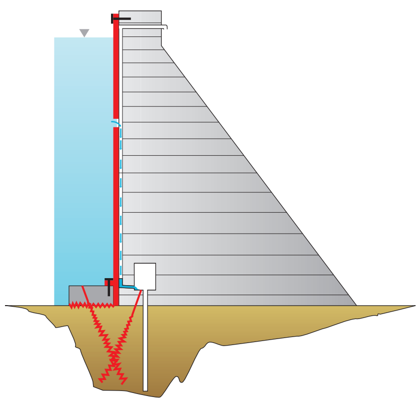
a. RCC
b. Conventional concrete
c. Vertical induced joints in RCC
d. Joints between RCC/conventional concrete
e. Continuous waterproofing geocomposite

32 - Balambano dam (99 m), 1999 Indonesia.

The CARPI patented anchorage system constructs vertical free flow drainage conduits on the face of the dam. In the event of accidental damage to the geocomposite, the face drainage layer and the vertical drainage conduits intercept all unattended water at the upstream face.



Drainage concept (several construction options available)



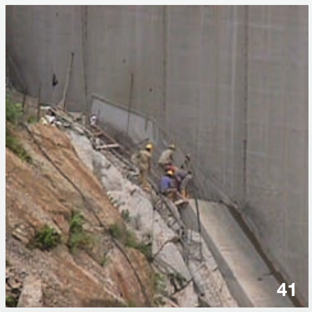
33 - The vertical anchoring steel profile that works as a free-flow drainage conduit is placed against formwork (option with embedded profiles).
34 - Vertical anchoring profiles and box drain installed on the formwork prior to RCC placement (option with embedded profiles).

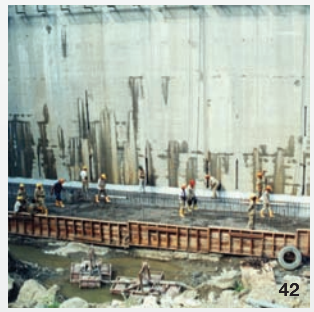
35 - Vertical strips of geonet being installed at Taishir RCC dam, 2007 Mongolia (option with external profiles).
36 - Vertical tensioning profile channel terminating in the bottom geonet collector (option with external profiles).

37/38 - Waterproofing of the perimeter plinth: installation of the geocomposite, and concreting. Use of waterstops avoided.

39 - Meander dam, designed with low cementitious content concrete RCC mix and a waterproofing geomembrane to save the cost of high cementitious content mix.

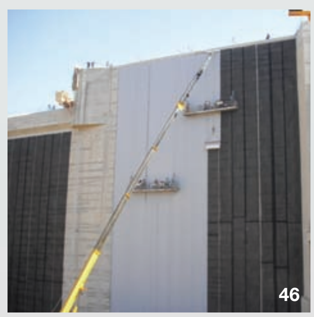
40 - Exposed geocomposite system at Taishir dam (52 m), 2007 Mongolia.





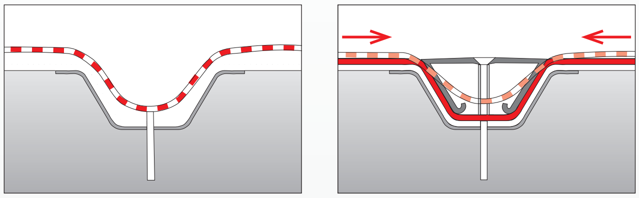
41 - Miel I dam (188 m), 2002 Colombia: completing waterproofing and casting of perimeter plinth at bottom.
42 - Watertightness in RCC dams is as good as the worst lift joint. Here, curing water is leaking out through the lift joints of the GEVC face. The geocomposite will cover all surface including lift joints. Heavy leakages could have occurred if a geomembrane had not been installed.

43 - An unforeseen crack which occurred at Olivenhain dam (95 m), 2003 USA, and which did not require any repair as the geocomposite covered it.
44 - Honeycombs with GEVC that will be covered by the geocomposite.

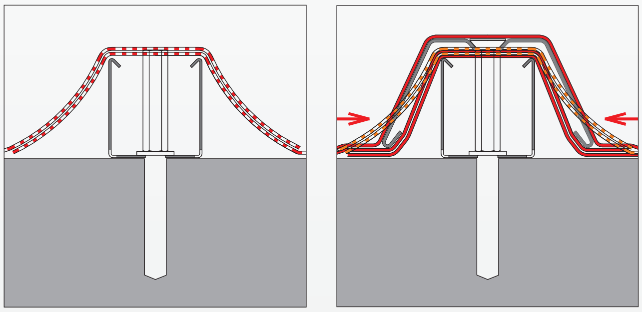


45 - When additional drainage capacity is required, a geonet is installed on the RCC, under the waterproofing liner.
46 - The PVC geocomposite sheets are unrolled from the crest and installed over the drainage geonet at Boussiaba dam, Algeria.

In the CARPI RCC system, the PVC geocomposite is anchored by two patented vertical profiles that tension the geocomposite avoiding slack areas and folds. The profiles hold the geocomposite taut to the face against the force of wind.



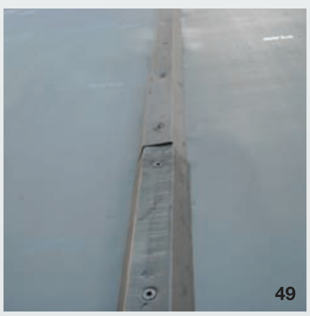
Embedded profile

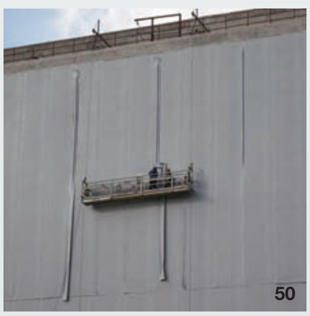


External profile

Untensioned geocomposite
Tensioned geocomposite

47 - Vertical anchoring/tensioning profile for geocomposite (option with external profiles).
48 - The PVC geocomposite is inserted in the profile and punctured over the couplers (option with external profiles).

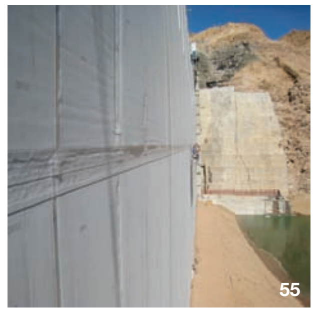




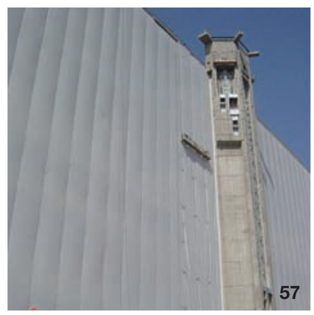
49 - Placing Ω-shaped profiles over punctured geocomposite.
50 - Welding PVC waterproofing geomembrane strips over the tensioning profiles.

51 - Karebbe dam (73 m), Indonesia, waterproofed with CARPI exposed PVC geomembrane.

52 - Additional layers of geocomposite are placed at the vertical induced joints, to support continuous geocomposite.
53 - The perimeter seal at crest.



54 - Perimeter seal at spillway covering joint of RCC/ conventional concrete.
55 - Watertight connection between two sections of geomembrane installed at different stages.



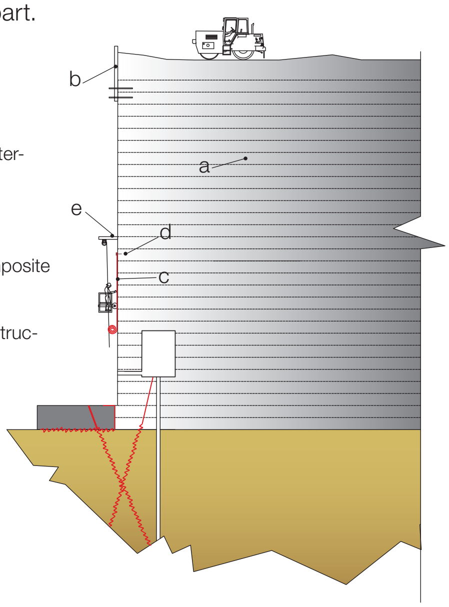
56 - Bottom perimeter seals are watertight against pressure exceeding 250m.
57 - Watertight seal around intake tower of Olivenhain dam, highest RCC dam in USA.

58 - At Nacaome dam (55 m), 1994 Honduras, the geocomposite system withstood hurricane Mitch that destroyed the area in 1998.

CARPI exposed geocomposite system can be installed on the lower completed part of the dam while construction continues in the upper part.

Installation in stages of waterproofing systems

a. RCC lifts
b. Climbing formworks
c. Waterproofing geocomposite
d. Intermediate horizontal watertight seal
e. Temporary protective structure



59 - Taishir dam (52 m), 2007 Mongolia: the waterproofing liner is installed on the lower section while RCC placement continues in the blocks above.
60 - A special railing system allowed installing the waterproofing system at Miel I dam (188 m), 2002 Colombia, in 6 separate horizontal stages.

61 - A special railing system allowed installing the waterproofing system at Miel I dam (188 m), 2002 Colombia, in 6 separate horizontal stages.
62 - At Miel I, the reservoir started impounding while construction works and installation of waterproofing liner were ongoing on upper part.

63 - Custom made platform for installation on inclined faces.

64 - Concepcion dam (70 m), 1991 Honduras, pictured after 14 years of service.

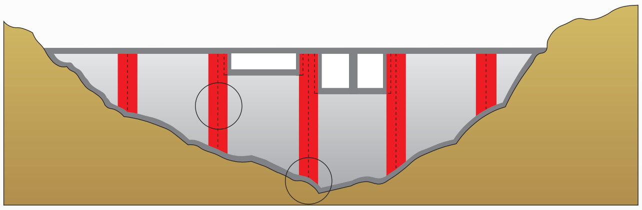
65 - Concepcion dam: inspection gallery totally dry. Picture taken after 14 years of service.
66 - Concepcion dam: total of monitored leaks from upstream face + foundation pictured after 14 years of service (0.20 l/s).

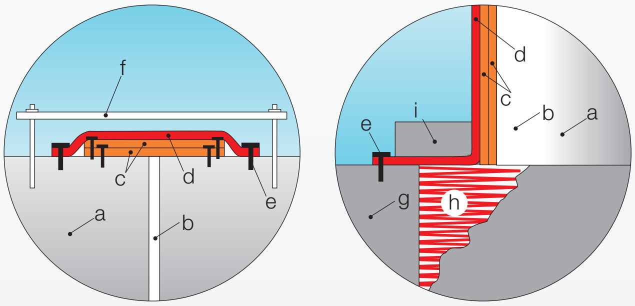
67 - EARTHQUAKE AT OLIVENHAIN DAM (95m), 2003 USA: on 16 June 2004, with reservoir largely full, a 5.5 Richter scale earthquake occurred at 100 Km from the dam. The dam did not suffer any damage or seepage to the CARPI system and the reservoir did not require any dewatering due to the earthquake.

For all the projects presented, CARPI provided:

- Design of waterproofing system
- Materials for waterproofing system
- Installation
- Quality Control
- Management
- WARRANTY FOR COMPLETE SYSTEM

The exposed PVC geocomposite can also be installed to waterproof joints and cracks alone. The CARPI patented external waterstop system has been used in new construction, to waterproof contraction joints, and, in rehabilitation, to repair new joints due to thermal cracking or other.

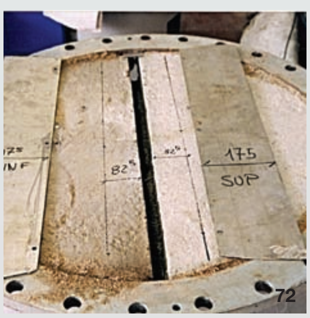




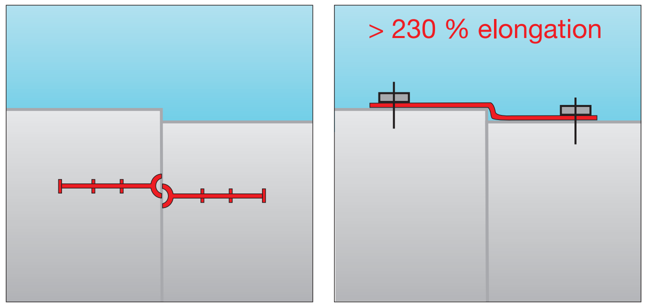
a. RCC lifts
b. Vertical induced joint
c. Anti-intrusion supporting geomembrane/plate (optional)
d. Waterproofing geomembrane/ geocomposite
e. Watertight perimeter seal
f. Covering plate (optional)
g. Concrete foundation
h. Grout
i. Ballast

68 - Thermal cracks form new unprotected joints in the upstream face.
69 - The trial RCC embankment of an RCC dam with conventional concrete face. A crack propagating through the entire trial embankment.

70 - After one winter season, the induced joint in the trial embankment was several cm wide.
71 - Testing the waterproofing system for the joints: the concrete support with the open induced joint is inserted in the hydraulic pressure vessel.



72 - The induced joint in the concrete testing block and the support structure that will impede intrusion of the geocomposite in the joint.
73 - The waterproofing system successfully tested at 250 m.



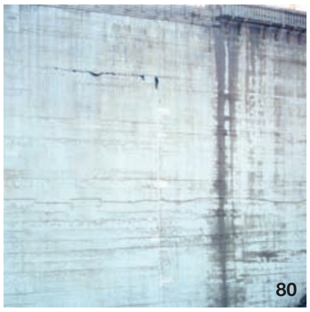
CARPI external waterstops can resist larger movements than traditional embedded waterstops. Their placement does not interfere with construction of the dam.

74 - Porce II dam, 2000 Colombia (118 m): installation of the CARPI system on induced joints.
75 - Platanovryssi dam (95 m), 1998 Greece: grouting operations at bottom, to intercept the propagation of the joint at foundation level.

76 - The layers of an anti-intrusion support made with different geosynthetic materials, the waterproofing geocomposite, the gaskets and the stainless steel batten strips forming the perimeter seal.
77 - Perimeter seal at plinth, watertight connecting the external waterstop with the grouting.

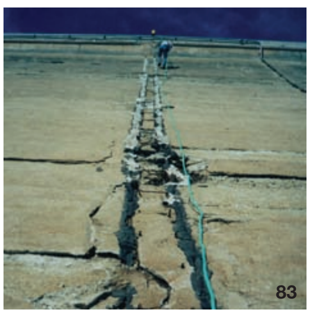
78 - An optional cover plate for protection as precaution for the waterproofed joint can be placed only in the drawdown zone.
79 - Eidsvold Main Weir dam, 2005 Australia: joint at the right abutment, totally exposed.

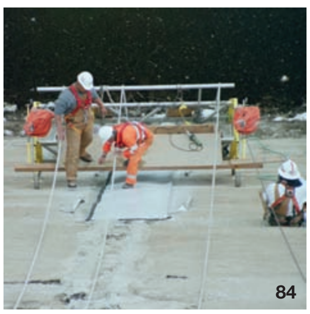
CARPI external waterstops are used also for rehabilitation, when contraction phenomena in RCC and/or in concrete may cause unpredicted opening of contraction joints/cracks in RCC dams. The same system has been used also to repair failing joints of face slabs in Concrete Face Rockfill Dams (CFRD), in Asphalt Concrete Face Dams (ACFD) and cracks in concrete gravity dams.



80/81 - Dona Francisca RCC dam (50 m), Brazil: in 2000, before impoundment, two new contraction joints and two cracks appeared.

82 - CARPI patented external waterstop was installed on the new joints and on the cracks.



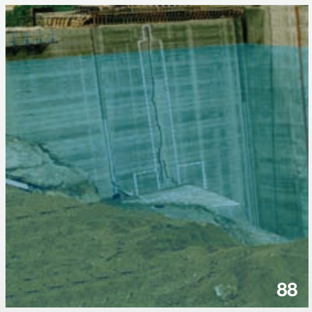


83 - Strawberry CFRD (43 m), 2002 USA: the failing joints between face slabs.
84 - The support layers are placed over the joints.

85 - Joints between face slabs of the CFRD were waterproofed with CARPI external waterstop system.

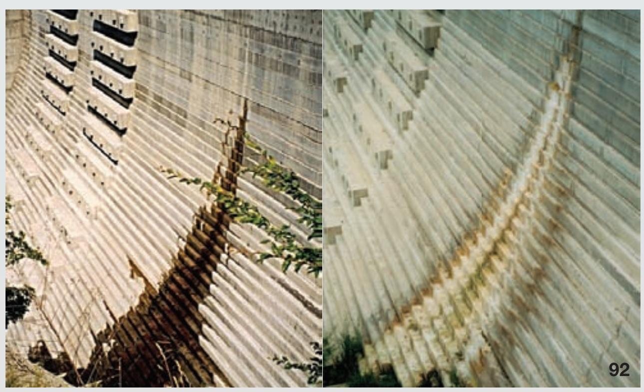
86 - Platanovryssi dam (95 m), 1998 Greece: installation of the CARPI system on induced joints.
87 - Platanovryssi dam (95 m), 1998 Greece: after first impoundment, a 20 m long crack developed at station 98+40 (left part of the upstream face) of the dam. Had the reservoir been emptied for the repairs, the associated Thissavros pumped storage scheme would not have been able to operate, with serious implications to the power grid. Repair works had to be accomplished underwater.

Underwater repair



88 - The CARPI geocomposite system was designed to waterproof the desired area, covering the crack.
89 - Artist's impression shows the location where the CARPI waterproofing PVC geocomposite is sealed along its perimeter.

90 - The waterproofing system was installed on a total length of ~ 20 m 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.
91 - After underwater work, the crack was successfully repaired. More details of the repair can be found in CARPI technical brochure on underwater installation.



92 - The crack dried out a few hours after installation of CARPI external waterstop (wet on the left and dry on the right).

Riou RCC dam - 1990 France, hydropower & recreational

Concepcion RCC dam - 1991 Honduras, water supply

Nacaome RCC dam - 1994 Honduras, water supply

Penn Forest RCC dam - 1998 USA, water supply

Platanovryissi RCC dam - 1998 Greece, hydropower

Balambano RCC dam - 1999 Indonesia, hydropower

Winner of:

- Association of State Dam Safety Officials (ASDSO) of USA: 1999 National Dam Rehabilitation Project of the Year Award

Miel I RCC dam - 2002 Colombia, hydropower

Porce II RCC dam - 2000 Colombia, hydropower

Mujib RCC dam - 2003 Jordan, water supply

Winner of:

- International Commission on Large Dams (ICOLD), Spanish National Committee on Large Dams (SPANCOLD) and Chinese National Committee on Large Dams (CHINCOLD): 2007 International RCC milestone project

Olivenhain RCC dam - 2003 USA, water supply

Burnett River RCC dam - 2005 Australia, water supply

Meander RCC dam - 2007 Australia, water supply

Winner of:

- S. Diego Chapter of the ASCE (American Society of Civil Engineers): 2003 Project of the Year
- California Society of Civil Engineers (California-ASCE): 2004 California Outstanding Civil Engineering Project
- International Commission on Large Dams (ICOLD), Spanish National Committee on Large Dams (SPANCOLD) and Chinese National Committee on Large Dams (CHINCOLD): 2007 International RCC milestone project

Rocky River dam - 2008 USA, hydropower

Taishir RCC dam - 2007 Mongolia, hydropower

Boussiaba RCC dam - 2009 Algeria, hydropower

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

carpi

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