INTRODUCTION

Geosynthetics have been used in hydraulic structures for over 60 years, i.e., in small to large earth or concrete dams, for water storage, and in water transport structures. However, conventional materials have maintained their dominancy for a variety of reasons, sometimes cultural / well-anchored habits, or because of the lack of knowledge about the availability of alternative solutions. With the global interest in reducing the carbon footprint of human activities, the use of low-carbon technologies has become a priority in several industries. This concern, combined with the limitations of conventional construction materials and techniques, has brought geosynthetics at the forefront of technologies with high growth potential. They can substantially contribute to improving water supply and accessibility for people and farmers, at a relatively low cost, short construction time, and much lighter carbon footprint.

About the International Geosynthetics Society (IGS): The IGS is a learned society dedicated to the scientific and engineering development of geotextiles, geomembranes, related products, and associated technologies. The purpose of the IGS is to provide the understanding of and promote the appropriate use of geosynthetics throughout the world.

SCOPE AND OBJECTIVE

The technical program of this side-event was developed by the Technical Committee on Hydraulics of the International Geosynthetics Society to provide an overview of the applications of geosynthetics in hydraulic structures and irrigation infrastructure. The purpose of this event is to introduce the experience gathered using geosynthetics in hydraulic structures such as dams, levees, water reservoir and canals, with a focus on seepage control and water transport within irrigation schemes, as well as for erosion control and bank stabilization. The various types of products and their applications will be introduced. Basic elements of design with geosynthetics and important aspects of quality control and installation quality assurance will be delivered. The contribution of geosynthetics will be approached considering the development of new infrastructures, as well as for the retrofitting of aging structures. Their contribution to sustainable construction practices will be analysed, considering their reduced carbon footprint, and often reduced costs compared to traditional lining methods. Finally, case studies will be presented to illustrate their applicability, their durability, as well as their economic and technical benefits based on projects executed in various regions of the world.

Coordinator: Eric Blond (Email: eric@ericblond.com)
## Final Program

### Side Event: Water Management and Storage with Geosynthetics

**Date**: 04 November 2023, 9:30-11:00 hours (Session 1) and 11:30-13:00 hours (Session 2)

**Venue**: Room – SA, Raddison Blu Resort, Vishakhapatnam (Vizag), India

<table>
<thead>
<tr>
<th>Time</th>
<th>Session – Particulars</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30-9:50</td>
<td>Welcome and introduction to the Side Event, introduction to geosynthetics</td>
<td>Eric Blond</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consultant</td>
</tr>
<tr>
<td>9:50-10:10</td>
<td>Geosynthetics as Membrane and Reinforcement in Canals</td>
<td>Vivek Kapadia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Government of Gujarat</td>
</tr>
<tr>
<td>10:10-10:25</td>
<td>Use of Geosynthetics for Water Conservation – Experience in Asia</td>
<td>Kiran Kumar Rumandla</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solmax</td>
</tr>
<tr>
<td>10:25-10:40</td>
<td>Use of Geosynthetic Cementitious Composite Mats (GCCMs) for erosion and seepage control in water transport infrastructures</td>
<td>Darren Hugues</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete Canvas</td>
</tr>
<tr>
<td>10:40-10:55</td>
<td>Service life of Geosynthetics in Hydraulic Applications</td>
<td>Eric Blond</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consultant</td>
</tr>
<tr>
<td>10:55-11:00</td>
<td>Questions / Answers, closure</td>
<td></td>
</tr>
<tr>
<td>11:00-11:30</td>
<td>Health Break</td>
<td></td>
</tr>
<tr>
<td>11:30-11:50</td>
<td>Reflections on canal lining experience from a global perspective</td>
<td>Amal Talbi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>World Bank</td>
</tr>
<tr>
<td>11:50-12:10</td>
<td>Geosynthetics for Design of Energy Dissipation Components in Dams</td>
<td>Vivek Kapadia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Government of Gujarat</td>
</tr>
<tr>
<td>12:10-12:25</td>
<td>Sustainable solutions for riverbank protection</td>
<td>Rudra Budhbhatti</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maccaferri</td>
</tr>
<tr>
<td>12:25-12:40</td>
<td>Case study on the use of Concrete Mattress in India, showcasing the Taldanda Main Canal &amp; the Dhakrani Power Channel</td>
<td>Karan Vyas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Signet Enertech (Huesker)</td>
</tr>
<tr>
<td>12:40-12:55</td>
<td>Flexible polymeric geomembranes to arrest leakages in Dams and Canals enabling effective usage of water for irrigation and human needs</td>
<td>Jagadeesan Subramaniam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carpi Tech</td>
</tr>
<tr>
<td>12:55-13:00</td>
<td>Questions / Answers, closure</td>
<td></td>
</tr>
</tbody>
</table>

**Coordinator**: Eric Blond (Email: eric@ericblond.com)
Chairman, Technical Committee on Hydraulics, International Geosynthetics Society
[https://www.geosyntheticssociety.org/](https://www.geosyntheticssociety.org/)

**Registration**: [https://icid25congress.in/registration.html](https://icid25congress.in/registration.html)
The International Geosynthetics Society (est. 1983)

The IGS is a learned society dedicated to the scientific and engineering development of geotextiles, geomembranes, related products and associated technologies.

Mission (est. 2010)
› The core purpose of the IGS is to provide an understanding and promote the appropriate use of geosynthetic technology throughout the world.

Vision (est. 2018)
› The vision of the IGS is that geosynthetics be recognized to be fundamental to sustainable development by providing technological and engineering solutions to answer societal and environmental challenges.
Geosynthetics:
• Geotextiles
• Geomembrane
• Geosynthetic Clay Liner
• Geogrid, Geostrap
• Geonet and Geocomposite Drains
• Geocells
• Geobags
• etc…

2023 IGS Membership

45 Chapters
2,600+ Individuals
500+ Students
177 Corporate
IGS Structure

- IGS Officers and 1/2 of the Council are elected every 4 years, in concert with the International Conference (2010, 2014, 2018, 2022, 2026).
- The other 1/2 of Council is elected in an alternate 4-year cycle (2012, 2016, 2020, 2024).
- ALL Individual Members of the IGS are eligible to run for council!
- Council Members are committed! 1-2 Meetings per year, their own effort, time and money.

Technical Committees
- TC Hydraulic
- TC Stabilization
- TC Reinforcement
- TC Barriers

Corporate Membership

By becoming a member of the IGS you will help support our aims and become part of a community where designers, manufacturers and users exchange new ideas and develop new contacts.

The society brings together individual and corporate members from all parts of the world, who are involved in the design, manufacture, sale, use or testing of geotextiles, geomembranes, related products and associated technologies, or who teach or conduct research about such products.

The strength of the IGS lies in diversity and strong local leadership. Our society is comprised of 45 hard-working National and Regional Chapters and includes members from over 70 countries! New Chapters are regularly being formed and existing ones continue to grow.
Conferences of the IGS

**International Conferences**
- Once every 4 years
- Hosted and Managed by a Chapter
- **Next Conference:** 2026 Montreal

**Regional Conferences**
- Held every 4 years, alternate years to the International Conference
- Chapters bid for the event
- Chapters grow membership, involvement, community and geosynthetics success when they host either a regional or international IGS Conference
- Regional conferences leave the majority of the proceeds with the chapter!

- **European Regional**
  - 2025: Lille, France
  - 2022: Warsaw, Poland
  - 2016: Istanbul, Turkey
  - 2012: Valencia, Spain
  - 2008: Edinburgh, Scotland
  - 2004: Munich, Germany
  - 2000: Bologna, Italy

- **Asian Regional**
  - 2025: Brisbane, Australia
  - 2022: Taipei, Taiwan
  - 2016: New Delhi, India
  - 2012: Bangkok, Thailand
  - 2008: Shanghai, China
  - 2004: Seoul, South Korea
  - 2000: Kuala Lumpur, Malaysia

- **PanAm Regional**
  - 2024: Toronto, Canada
  - 2020: Rio de Janeiro, Brazil
  - 2016: Miami, USA
  - 2012: Lima, Peru
  - 2008: Cancun, Mexico

- **African Regional**
  - 2025-2026: Gauteng, South Africa
  - 2022: Cairo, Egypt
  - 2017: Marrakesh, Morocco
  - 2013: Accra, Ghana
  - 2009: Cape Town, South Africa

Upcoming Conferences of the IGS

- **April 28 – May 1, 2024**
  - GeoAmericas 2024 – 5th PanAmerican Regional Conference on Geosynthetics
    - **Toronto, Canada**

- **June 10-13, 2025**
  - GeoAsia 8 – 8th Asian Regional Conference on Geosynthetics
    - **Brisbane, Australia**

- **September 15 - 17, 2025**
  - EuroGeo 8 – 8th European Regional Conference on Geosynthetics
    - **Lille, France**

- **September 13-17, 2026**
  - 13 ICG – 13th International Conference on Geosynthetics
    - **Montreal, Canada**
IGS Events and Initiatives – Meeting the Mission

IGS Technical Committee (TC) Initiatives

› 4 TCs: Barriers, Stabilization, Hydraulics & Soil Reinforcement
› Hold workshops in odd years to propel high-level development.
› Development of collateral to support teaching
› Creation of short-courses and technical sessions in activities in sister-societies events
› TCs may be formed by a group of IGS Members with interest in addressing a topic or issue
› Join a TC and work with your peers from around the world and move the technical understanding and use of geosynthetics forward internationally and nationally

Past collaborations between IGS and ICID

• 2011 – ICID Congress (Teheran) - Signature of MoU
• 2017 – ICID Congress (Mexico
• 2018 – ICID Congress (Saskatoon)
• 2019 – ICID Congress (Bali)
• 2021 – Virtual Webinar on Canal lining
• 2021 – Hybrid Session at the 5th African Regional Congress (Marrakesh, Morroco)
• 2022 – ICID Micro-Irrigation Conference (Dakhla, Morroco)
• 2022 – ICID Congress (Adelaide, Australia)
• 2023 – IGS GeoAfrica Conference (Cairo, Egypt)
• 2023 – ICID India (Visakhapatnam, India)
• …
IGS Events and Initiatives – Meeting the Mission

IGS Communications
› Dedicated to developing and disseminating news and information to the IGS membership
› IGS News
  › Publish your Chapters’ events to the 9,000+ international readers
› IGS Website
  › Member Directory – Access to contact information to 1,000s of the worlds geosynthetics experts
  › Proceedings – Access to searchable & indexed proceedings from past IGS events. Valued at thousands of dollars available at no cost to members.
  › Technical Documents, developed by the Education Committee and the various technical committees this segment of the site will see significant growth in the next few years.

Educate the Educators
› Request through the Regional Activities Committee
› IGS Provides the curriculum and funds speaker travel to teach the EtE
› Typically a 2-day course, taught in local language
› Approximately 40 professors are accepted via an application process
› Chapters raise sponsorship resources and organize the logistics
› On-site attendee expenses are paid through funding of the EtE Program, professors only need to pay their transportation to the event.
› Professors return to their universities with the ability to implement geosynthetic curriculum immediately into their courses.
› Attendees are provided presentations, sample books and collateral materials to use in their classrooms
› Start an Educate the Educators task group in your chapter and help grow the acceptance of geosynthetics for every engineering student in your country!

Training events targeted at providing professors the materials and understanding to easily include geosynthetics in their UNDERGRAD Curriculum and some advance courses.
Sister Societies of the IGS

The IGS has a very well established and highly productive relationship and a strategic partnership with each of the societies listed below. Through Sister Society Agreements, possible collaboration in the areas of membership, publications, technical meetings, and various joint activities are promoted. If you are aware of sister society relationships that should be considered, or you would like to learn more about developing such a relationship, please contact the IGS Secretariat.

Benefits of Joining the IGS

- Online access to the IGS Membership Directory
- Subscription to the IGS News newsletter, published online monthly
- Online access to the IGS Digital Library
- FREE Access to Geosynthetics International and Geotextiles & Geomembranes, valued at over $1,000 US
- Discount rates for any IGS publications and at all international, regional or national conferences organized by the IGS or under its auspices
- Eligible to be granted an IGS Award
IGS Events and Initiatives – Meeting the Mission

IGS Video on Geosynthetics & Sustainability

› Target Audience: Engineers, regulators, administrators, etc.
› Purpose: To improved the comprehension of the value of geosynthetics among non-experts.
› This video and other translated version can be found on the IGS YouTube Channel

https://www.youtube.com/watch?v=LIH-7djSPO0
25th International Congress on Irrigation and Drainage & 74th International Executive Council meeting

**Theme:**
Tackling Water Scarcity in Agriculture

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GEOSYNTHETICS AS MEMBRANE AND REINFORCEMENT IN CANALS: CASE STUDIES OF SARDAR SAROVAR PROJECT, INDIA

Vivek P. Kapadia
vivekpkapadia@gmail.com
vpk@vivekpkapadia.info
4th November 2023
CASE STUDY – 1

RESTORATION OF BREACHED SECTION OF NARMADA MAIN CANAL

- Carrying capacity of 1133 cubic meter per second at the off-take point.
- From Ch. 269 km to Ch. 271.5 km - total bank height above the ground level is about 9 m
- Canal bed is 53.70 m wide and the full supply depth (FSD) is 6.5 m
- Designed discharge is 583.57 m³/s
- Canal side slopes are 2 (H) : 1 (V)

<table>
<thead>
<tr>
<th>Side of the Bank</th>
<th>Date of Occurrence of Failure</th>
<th>Chainage in km</th>
</tr>
</thead>
</table>
CASE STUDY – 1
DIAGNOSIS OF FAILURE

Shear failure of lining suggests subsidence

CASE STUDY – 1
DIAGNOSIS OF FAILURE

Piping

Devastation in Vicinity of Canal
CASE STUDY – 1
DIAGNOSIS OF FAILURE

No zones with specific soil properties as per design

Obligatory technical specifications for laying and compacting the soils totally neglected - numerous locations and bands of loose or inadequately compacted soil zones

No chimney filter or horizontal filter blankets to protect the soil and prevent migration of particles outside.

Due to very loose soil bands there was substantial subsidence of the earthwork - lining, as a result, cracked irregularly, even big hollows at some locations

Canal water entering the embankment with relatively high pressure caused dislodgment of particles in the inadequately compacted soil due to high seepage forces resulting into piping and progressive failure ultimately
CASE STUDY – 1

DIAGNOSIS OF FAILURE

Slip circle modelling can not be taken as stratification of soil and therefore Finite Element modelling as steady unconfined seepage type problem.

Steady Unconfined Seepage Problem

CASE STUDY – 1

CONSTRAINTS IN RESTORATION

- Time of only 10 days was there - drinking water for many towns and villages depending up on the main canal
- Rainfall had already occurred once, borrow areas were not available and the soil available was predominantly sand with small amount of clay
  - for zoning and for filters suitable material was not available
- In given time and small length proper compaction was a matter of doubt
- Bonding with the surrounding parts of the canal was difficult
- Other than technical issues like people’s wrath, political intervention, movement of media, etc. were adding fuel to fire.
CASE STUDY – 1

GEOREINFORCED EMBANKMENT

Section for Restoration of Main Canal Embankment

Preparation for repairs - Longitudinal view from outer side

Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>g/m²</td>
<td>270</td>
</tr>
<tr>
<td>Wide Width Tensile</td>
<td>kN/m²</td>
<td>50</td>
</tr>
<tr>
<td>Wide Width Elongation</td>
<td>%</td>
<td>15</td>
</tr>
<tr>
<td>Trapezoidal Tear Strength</td>
<td>kN</td>
<td>0.50</td>
</tr>
<tr>
<td>CBR Puncture resistance</td>
<td>kN</td>
<td>6.0</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>l/ m²/min</td>
<td>260</td>
</tr>
<tr>
<td>UV Resistance</td>
<td>%/hrs</td>
<td>70 / 500</td>
</tr>
</tbody>
</table>
CASE STUDY – 1

GEOREINFORCED EMBANKMENT

Restored Main Canal Embankment

CASE STUDY – 2

CONSTRUCTION OF CANALS IN SANDY SOILS

- Tail Branch Canals of Sardar Sarovar Project passing through sandy soil and their command areas adjoining dessert
  - Capacity about 15 cumec and length about 20 Kilometer
  - All the canals have cutting, partial banking and banking – banking up to 3.5 meter
  - SM soil with almost uniform particles and hence compaction the biggest problem

25th International Congress on Irrigation and Drainage & 74th IEC Meeting
1-8 November 2023, Vizag, Andhra Pradesh State, India
ISSUES WITH SANDY SOILS

CASE STUDY – 2

- Fluctuations in water levels – variations in pore pressure
- Sudden variations in pore pressure may cause spreading or dispersion failure of the embankment

Checking seepage and addressing the issue of dispersal failure was anyhow needed
### SOLUTIONS

**GCL checks the seepage path**

**Geogrid checks the disintegration of sand particles**

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### CASE STUDY – 2

#### REINFORCEMENT AND MEMBRANE

Three levels of Geogrid:
- 1st Layer at [CBL – 0.30] m level
- 2nd Layer at [CBL + 0.40] m level
- 3rd Layer at [FSL - 0.40] m level

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Unit</th>
<th>TG U-60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile Strength</td>
<td>MD CD</td>
<td>kN/m</td>
<td>60</td>
</tr>
<tr>
<td>Reduction Factor (RF) and Machine Direction Long Term Design Strength (LTDS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creep</td>
<td></td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>Installation Damage</td>
<td>Sand/ Silt/ Clay</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>pH – 4 to 9</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>LTDS – 120 Years, 40° C : Sand/ Silt/ Clay : pH – 4 to 9</td>
<td>kN/m</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>LTDS – 120 Years, 40° C : Gravel &lt; 7.5 mm : pH – 4 to 9</td>
<td>kN/m</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>Aperture (± 2 mm)</td>
<td>mm</td>
<td>30 X 25</td>
<td></td>
</tr>
</tbody>
</table>

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*25th International Congress on Irrigation and Drainage & 74th IEC Meeting*

1-8 November 2023, Vizag, Andhra Pradesh State, India
CASE STUDY – 2
REINFORCEMENT AND MEMBRANE

First Stage of Concrete Lining With Paver Machine

GCL and 0.5 mm thick HDPE as a protective layer

Second Stage of Lining With Paver Machine

Imperviousness and integrability – both added

IGS Side Event at the 25th ICID Congress,
Visakhapatnam, India, November 4 2023
Thank You
25th International Congress on Irrigation and Drainage &
74th International Executive Council meeting

Theme:
Tackling Water Scarcity in Agriculture

Use of Geosynthetics for Water Conservation – Experience in Asia

Kiran Kumar Rumandla

04/11/2023
Introduction

As clean water becomes more expensive to acquire, the need for secure water containment and transport grows.

Conserving water is important and an effective conveyance of water is through the canal or a channel.

Canals can be constructed either unlined (earthen structure) or lined (concrete, bricks, geomembranes, combination, etc.)

Linings are provided on the bed and sides of canal to improve the service life and discharge capacity of canal. Over time, concrete-lined canals may crack, resulting in a significant loss of water and earthen canals are often subjected to erosion and leakage problems.

Geosynthetics provides an effective and economical solution to control and prevent loss of conveying water in existing canals and construction of new irrigation projects.
The Challenges

Stability concerns of canal banks.
- Erosion
- Soil stability

Maintenance
- Side vegetation, weed growth & silting
- Time and cost of repairs.

Reduced seepage & loss of water
- Leakage & seepage problem.
- Effectiveness of the hydraulic barrier.

GEOSYNTHETICS LINING SOLUTION

Product Types
- HDPE Geomembranes
- LLDPE Geomembranes
- Specialty Geomembranes
- Geotextiles as cushion protection
Why Polyethylene Geomembrane?

- Unique material characteristics & performance:
  - Very low permeability ($k_v < 10^{-12}$ cm/sec)
  - Most chemical resistant liner materials
  - Quick install & easily repaired if damaged
  - Established welding technology
  - Strong, High mechanical properties due to polymerization
  - Excellent UV resistance (with CB & stabilizers)
  - Longevity: successfully used since 1970’s, last for hundreds of years (buried), and several decades (when exposed).
  - Lower cost, compared to other liners

Textured Geomembrane on Slope

Roughened surface geomembrane provides:
- Better Slippery prevention
- Enhanced interface frictional properties and improve liner system stability on side slope applications
- Better grips and stability for concrete cover

Example: Single – Textured Geomembrane

- Top layer/ prime finish
- Standard Black
- Textured surface
Types of geomembrane lined canals

Canal with geomembrane

Covered

Exposed

HDPE/LLDPE Textured geomembrane

Shotcrete or cast concrete (as per engineer)

1.5mm Single textured HDPE / LLDPE geomembrane

Specialty Geomembranes

- White Surfaced (Smooth or Textured)
- High Performance (Smooth or Textured)
- Leak Location (electrically conductive base) Layer
White Reflective Surfaced Geomembrane

1. Easier Damage Detection
2. Aesthetic Look
3. Less heat absorp, reduce Thermal Expansion and Contraction
4. Less Wrinkle
5. Reduce Leakage Rate
6. Better Flow
7. Extend Service Life
8. Easy for installation

Buffalo rapids main canal, Montana, US

- Lining Layer:
  - 1.5mm White textured HDPE geomembrane
  - 10 oz/yd2 (335gsm) NW geotextile as cushion layer
OUR EXPERIENCES

Liner System:
- Leveled soil base layer
- 200 gsm non-woven geotextile
- 1.0mm smooth HDPE geomembrane
- 200gsm non-woven geotextile
- 15cm thick concrete layer

Warna Canal, Maharashtra, India

25th International Congress on Irrigation and Drainage & 74th IEC Meeting
1-8 November 2023, Vizag, Andhra Pradesh State, India
HDPE Geomembrane sandwiched between two non-woven geotextile layers was used. 1mm HDPE membrane and 250gsm nonwoven geotextiles were used in this project.

Geomembrane was lined on the bottom side and the side slopes of the canal.

Integrated Shrimp Aquaculture Park, Malaysia

HDPE as primary barrier layer
Summary

Geomembrane is lined at the base and the side slopes of the canal, it improves the service life and discharge capacity of canal.

**Few considerations in geomembrane selection:**

- HDPE geomembranes: Outstanding chemical resistance & mechanical strength, endurance to exposed conditions.
- White surfaced geomembrane: UV light reflection, cooler surface, wrinkle reduction, helps to keep a low Manning coefficient, longer lifespan under exposed conditions.
- LLDPE geomembranes: Excellent flexibility; allows the prefabrication of customized panels and easier installation, last long if using highly stabilized formulation with enhanced UV resistance for exposed applications.
- Smooth PE geomembranes offers a low manning coefficient
- Textured geomembrane provides greater Stability on side slope design

THANK YOU
Introduction to Geosynthetic Cementitious Composite Mats, a low-carbon approach to lining hydraulic structures.

4th November 2023

Presented By: Darren Hughes
Concrete Canvas Ltd.

Current Challenges with Lining Canals

Conventional concrete solutions are problematic

- In-service
  - Ground-heave / settlement causes cracking
  - Cracking leads to water seepage
  - Seepage can cause
    - Salination of soils
    - Waterlogging
    - Undermining leading to total collapse

- Installation
  - Time consuming
  - On-site quality control
  - Side slope angle limitation (<1:1.5 without formwork)
Current Challenges with Lining Canals

Concrete also has its advantages...

So why is concrete still used?
“concrete linings remain the preferred method of lining canals, because engineers and agencies are familiar with concrete linings”

Giroud & Plusquellec 2017

- Hard-wearing
- Durable
- UV Resistant

Geomembrane Canal Lining: Benefit / Cost Comparison

In 2002 the US Department of Reclamation completed a 10 year trial on 34 canal lining test sections across 11 irrigation districts. The 34 sections are divided into 4 generic categories.

<table>
<thead>
<tr>
<th>Type of Lining</th>
<th>Durability</th>
<th>Maintenance Cost</th>
<th>Effectiveness at Seepage Reduction</th>
<th>Benefit/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid Applied Membrane</td>
<td>10-15</td>
<td>0.01</td>
<td>90</td>
<td>0.2-1.5</td>
</tr>
<tr>
<td>Concrete Alone [Shotcrete]</td>
<td>40-60</td>
<td>0.005</td>
<td>70</td>
<td>3.0-3.5</td>
</tr>
<tr>
<td>Exposed Geomembrane</td>
<td>10-25</td>
<td>0.01</td>
<td>90</td>
<td>1.9-3.2</td>
</tr>
<tr>
<td>Geomembrane with Concrete Cover</td>
<td>40-60</td>
<td>0.005</td>
<td>95</td>
<td>3.5-3.7</td>
</tr>
</tbody>
</table>

USBR 10yr Research Project
### Ideal Canal Lining Solution

Dual Challenges of:

**FUNCTION:**
- Waterproofing
- Protection / Erosion Control

**PROPERTIES:**
- Impermeable
- Durable & Hard-wearing

---

### Geosynthetic Solutions

New Class of Materials: **GCCMs (Geosynthetic Cementitious Composite Mats)**

- [https://www.ccportal.co.uk/s/qfHndkm6K3pdCcB](https://www.ccportal.co.uk/s/qfHndkm6K3pdCcB)
- [https://www.ccportal.co.uk/s/x5Mox7tJ8QdPsRA](https://www.ccportal.co.uk/s/x5Mox7tJ8QdPsRA)

GCCMs change from flexible to rigid on hydration
Low-Carbon Solution

1 GCCM Roll provides the equivalent coverage area of two ready-mix trucks

- Reduced vehicle movements
- Over 60% CO₂ savings
- Full Life-cycle-analysis
GCCM’s Are Already Widely Used in India

- Rail Embankments
- Drainage Channels
- LHS Waterproofing

DRC Canal Lining Case Study
CONGO CASE STUDY

Case Study Location & Parameters

±50km from Kolwezi in the Southern DR Congo

Underground copper mine requiring continuous pumping of sub-terrane water. Pumped water collects in settling ponds and then canalised 4km to river outlet.

The drainage canal from settling ponds was previously unlined but water was permeating back into the underground mine.


CCX-M selected based on:
- Provision of erosion control and improved hydraulics
- Speed and ease of installation
- Reduced permeability of joints
- Turnkey supply solution
- Ability to provide on-site installation training

DRC Canal Lining Case Study

Drainage Canal

- Distance from settling ponds to river of ±4km
- Canal profile width of ±8m
- Total of 32,000m² GCCM
- Overlaps were thermally bonded and screw fixed.
- Intermediate pegging incorporated for hot weather conditions
- Installation rate of 1000sqm per day
DRC Canal Lining Case Study

Installation Preparation

Before commencement of installation, the canal profile had to be prepared in accordance with the GCCM specification.

Section 6.2 References:

- De-vegetation
- Removing of oversize, sharp and loose objects
- Uniform Profiling & Compaction
- Anchor trench detailing

DRC Canal Lining Case Study

GCCM Deployment

50m long 1.90m wide GCCM rolls weighing 1400kg’s each were deployed by double width spreader beam attached to a 30 T excavator bucket.

The excavator was selected based on reach of the boom to far side of the canal.

The material is rigged into place by hand to achieve the specified overlap across each length.
DRC Canal Lining Case Study

Installation Details

Overlaps are thermally bonded with a Leister Triac AT hot air welder at a rate of 1m/min with a 60mm wide perforated nozzle to reduce joint permeability.

Joint mechanical strength was achieved by inserting 30mm long stainless steel collated screws at 100mm spacing, 30-50mm from the material edge.

Intermediate pegs were installed to the underlap of each joint at each transition from floor to side slope.

Overlaps were pegged within each anchor trench. Anchor trenches were a minimum of 150mm deep and 150mm from canal crest.

Galvanised, 250mm long, 12mm Ø ribbed rebar peg with 4mm thick, 50mm Ø round head.
Hydration in Hot, Dry Weather

The temperatures on site are typically between 25 and 30°C with a drying wind. The GCCM was hydrated 3 times at 30 minutes intervals to saturation, in accordance with the warmer weather guidance. To ensure sufficient curing, an additional hydration was provided at the end of each days’ installation.
Canal de provence video
https://www.youtube.com/watch?v=mL0Ok9N9C8M

Thank You
IGS-TCB / IGS-TCH Webinar

Service life of Geosynthetics in Hydraulic Applications

June 1, 2023 (31 May in North-America)

Eric Blond, Eng., M.Sc.A.
Eric Blond Consultant Inc.
Montréal, Québec, Canada

Eric Blond is an independent consultant offering technical services to the geosynthetics and engineered construction material industries. His key expertise are soil filtration and drainage with geosynthetics; durability of geosynthetics and construction materials; geosynthetics lining materials and systems, and other applications of Geosynthetics.

Eric Blond is actively involved in several technical committees and Industry associations:

- ASTM D35 on Geosynthetics: Past-Chairman of subcommittee D35.02 on endurance properties of geosynthetics
- ISO TC221 on Geosynthetics: Chairman of the Canadian Mirror Committee, WG6-PG3 on Designing for Filtration
- IGS – International Geosynthetics Society: chairman of the Technical Committee on Hydraulics, council member (2010-2016)
- IGS-NA – North-American Chapter of the IGS: Secretary
- CGS – The Canadian Geotechnical Society: vice-President
- CCCME – Canadian Commission on Construction Material Evaluation: member of the commission
- CSA A123 on Bituminous roofing materials – member of the committee

Eric Blond is committed to education and introduction of geosynthetics technologies. He has authored more than 100 technical papers, conferences and courses. He is lecturer at Ecole Polytechnique de Montreal. He also offers custom trainings to engineering firms, and regularly contributes to pre-conference short courses and other training events.

He is a professional engineer, member of the OIQ (Quebec) and APEGA (Alberta). With more than 25 years of experience and projects conducted in Canada, the USA, South-America, Europe and the Middle-East, Eric Blond holds one of the most comprehensive independent expertise in geosynthetics and polymeric materials used in the construction industry.
Fitness for purpose of concrete as a single lining material

Concrete offers a low permeability with:

- Ideal subgrade conditions, perfect compaction of the subgrade
- Concrete veneer thickness of 150 mm or more
- Perfect installation
- Adequate management of the thermal expansion of the concrete (~10^-5 mm/mm/°C)
- A water table always lower than the canal
- ...

Under these conditions, a concrete veneer may hypothetically not crack and remain watertight for many decades.

HOWEVER...

Fitness for purpose of concrete as a single lining material

This concrete liner almost made it to the second year
Fitness for purpose of concrete as a single lining material

Using reinforcement may reduce the occurrence of problems
...when the reinforcement is well designed and located in the right place
...when the thermal expansion of concrete can be managed
($$$)

(photo Hervé Plusquellec)
Geocells may preserve concrete from excessive cracking / collapsing by creating an articulated mattress, and potentially mitigate problems associated with the thermal expansion of concrete.

Geocells could help make an effective use of concrete:
- Without geomembrane, when seepage control is not a critical concern?
- To cover a geomembrane?

Concrete is widely used for canal lining. But is it actually ‘fit for purpose’?

For concrete to preserve its watertightness:
- It must not crack. Therefore, the concrete layer must be designed to resist reasonable soil settlement: it must be thick and reinforced. A thin layer of concrete will crack and will not preserve its watertightness.
- It must not degrade over time. The formulation must be selected to resist permanent exposition to water.

Despite broadly used in hydraulic structures, concrete is not a material that is fit to control seepage!
**Fitness for purpose of concrete as a single lining (?) material**

A ‘synthetic’ veneer is often used to protect concrete from premature degradation. The concrete is, then, only used for its structural properties.

Even concrete users acknowledge that synthetic materials are suitable to protect the concrete for many decades (and contain water doing so), especially in hydraulic structures.

---

**Concrete panels laid over a geomembrane?**

35-years old canal in Ghana

The concrete cover is essentially gone.

But the geomembrane seems to be holding water, still! (surprisingly)
• Synthetic materials can provide a durable sealing function – and are widely used for that purpose across many industries, from electric cable (shielding) to automotives and aircrafts.

• ‘Synthetic materials’ used in construction, or ‘geosynthetics’, must be formulated to meet the service conditions encountered in these applications.

• The structure must then be designed considering the properties – and limitations – of the geosynthetic material.

Using **geosynthetics** in hydraulic applications

The selection, and formulation of geosynthetics must consider the service conditions of the structure, and in particular its exposition to the sun.

Piggybacking on their experience with other ‘plastic’ materials, a frequent question asked by designers is: “how long do geosynthetics last”

A better way to express this concern is:
Do geosynthetic liners offer a sufficient service-life for hydraulic structures?
- When exposed?
- When covered?

[Proceedings of GeoAfrica2023 Conference with open-source access to Giroud’s paper (and others)](https://www.e3s-conferences.org/articles/e3sconf/abs/2023/05/contents/contents.html)
The service life of geosynthetics can be estimated

• Based on field observations, i.e. learning from the performance (and failure mechanisms) of existing structures

• Based on laboratory projections, i.e. using available science on aging mechanisms of geosynthetic materials

Service life of a geomembrane

The criteria defining the ‘end of life’ of a geomembrane is when it leaks. This end-of-life can be reached:

• During construction (when detected on time, most leaks can be repaired) **Survivability**

• When service conditions are beyond what the material can handle (improper design) **Performance**

• When the material has lost its intrinsic properties and fails under normal service conditions **Durability**
1- Designing for Survivability

Essentially based on field experience

Assessment of the ability of the geomembrane to survive involves a holistic approach to the construction process:

- Storage and handling
- Construction and installation technique (competency / experience of the stakeholders)
- Mechanical properties of the geomembrane
- Use of cushioning materials, such as geotextiles
- Design of the structure
- Quality assurance? Electrical Leak Location?

Improper storage and handling may affect the properties, hence the performance of the product

Survivability heavily depends on onsite storage and handling techniques:

- Use experienced installers!
1- Designing for Survivability

For canal lining:
- Minimum thickness 1.0 mm – may be increased to 1.5 mm under warm climate
  - Ease / reliability of welding is essential, which is facilitated using thicker products (up to some extent)
- Minimizing the development of wrinkles caused by thermal expansion reduces the risk of accidental puncture
  - White-surfaced geomembranes

2- Designing for Performance

Design guidance focusing on geosynthetics are available:
- Hydraulic (water flow) considerations
- Soil / geosynthetic interaction
- Some issues specific to geosynthetic in canals
  - Flowing water!
  - Varying level of water / of water table
  - Boat traffic?
  - Etc
- Leakage management

- Paper by Giroud et al (GeoAfrica 2023) open access [https://doi.org/10.1051/e3sconf/202336801001](https://doi.org/10.1051/e3sconf/202336801001)
- Complete book to be published in 2024
2- Designing for Performance

• Longitudinal anchors

![Longitudinal anchors](Photo_Nortene-Engepol)

2- Designing for Performance

• Transversal anchors

![Transversal anchors](Photo_Nortene-Engepol)
2- Designing for Performance

Drainage under the geomembrane

(Credit: Nortene - Engepol)

2- Designing for Performance

Canal Safety

(Credit: Nortene - Engepol)
2- Designing for Performance

- Derivation
- Connection to other structures

Gravel puncture resistance
- ASTM D5514 to observe gravel / geomembrane interaction
2- Designing for Performance

Several other design considerations
- Interface friction properties
- Surface erosion
- Elongation over crack
- ...

25th International Congress on Irrigation and Drainage & 74th IEC Meeting
1-8 November 2023, Vizag, Andhra Pradesh State, India

2- Designing for Performance

IGS Video Library

https://library.geosyntheticssociety.org/

Many hours of training – recordings
- IGS webinar on geosynthetics in canals, 2021:
  - J.P. Giroud
  - Ragab (ICID)
  - Minister of Water and Irrigation of Egypt
  - H. Plusquellec
  - N. Touze
  + Case studies
- ICID 5th African Conference, 2022 (reservoirs)
  - J.P. Giroud
  + Case studies
3- Durability

Importance of material properties, service conditions and design choices!

Example of bitumen used as a sealing product

- Bitumen used in Roman aqueducts (protected from sun and heat) lasted for centuries.
- However, bituminous roofing products must be replaced periodically, typically every 15 to 30 years.

This observation applies to essentially every geomembrane:

- Aging of most materials is faster when they are exposed to heat and UV radiation

HOWEVER, the use of exposed geomembranes may be interesting for other reasons: e.g., to facilitate periodic replacement, which is easier if it is not covered by concrete.

Noticeable (old) projects with geosynthetics

Field experience with geosynthetics shows their ability to perform for >50 years in dams

Table 1 - Oldest Geomembrane Installations by Type of Geomembrane (after Scueri, 2005)

<table>
<thead>
<tr>
<th>Type</th>
<th>Basic material</th>
<th>Abbreviation</th>
<th>Total exposed</th>
<th>Total covered</th>
<th>Oldest exposed</th>
<th>Oldest covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymeric</td>
<td>Polyvinyl chloride</td>
<td>PVC-P</td>
<td>73</td>
<td>70</td>
<td>1974</td>
<td>1960 (Terzaghi Dam, Canada)</td>
</tr>
<tr>
<td>Polymeric</td>
<td>Polyethylene</td>
<td>LLDPE</td>
<td>0</td>
<td>28</td>
<td>-</td>
<td>1970 (Abshulin, Kurgan)</td>
</tr>
<tr>
<td>Polymeric</td>
<td>Polyolefin</td>
<td>HDPE</td>
<td>2</td>
<td>11</td>
<td>Not known</td>
<td>1978 (Beihburg, Germany)</td>
</tr>
<tr>
<td>Polymeric</td>
<td>Elastomeric</td>
<td>Polyisobutylene IIR</td>
<td>5</td>
<td>4</td>
<td>1982</td>
<td>1959 (Cantusola Sabetta, Italy)</td>
</tr>
<tr>
<td>Polymeric</td>
<td>Chlorosulfonated Polyethylene</td>
<td>CSPE</td>
<td>3</td>
<td>5</td>
<td>Not known</td>
<td>1981 (Koloshnik Amur)</td>
</tr>
<tr>
<td>Polymeric</td>
<td>Polyolefin</td>
<td>PP</td>
<td>1</td>
<td>2</td>
<td>Not known</td>
<td>1970 (Odell-Perrill, Spain)</td>
</tr>
<tr>
<td>Polymeric</td>
<td>Chlorinated Polyethylene</td>
<td>CPE</td>
<td>0</td>
<td>3</td>
<td>-</td>
<td>1973 (Bauzegon, France)</td>
</tr>
<tr>
<td>Bituminous</td>
<td>Oxidized bitumen</td>
<td>Prefabricated GM</td>
<td>7</td>
<td>10</td>
<td>1973</td>
<td>1978</td>
</tr>
<tr>
<td>Bituminous</td>
<td>Polymer bitumen</td>
<td>SBS</td>
<td>0</td>
<td>1</td>
<td>-</td>
<td>1996</td>
</tr>
</tbody>
</table>

Oldest project: 63 years
Literature relating the actual performance of geomembranes after:

- Bituminous: ~30 years
- EPDM: 30-40 years? Based on Butyl Rubber
- PVC: 40-50 years
- HDPE (including in environments harsher than water): ~40-50 years

There are many positive experiences demonstrating ~50-years of service life is a realistic (verified) assumption

A lifetime can be predicted based on the degradation mechanisms of the geomembrane, which depends on the type of polymer and the environment of service:

- Temperature
- Chemical environment
- Exposure to UV
- Stress
- ...

Typical end-of-life criteria: 50% property-loss on a property related to performance e.g., elongation at break for a waterproofing membrane
A lot of literature is available documenting the performance and durability of geosynthetics.

Many research has focused on geomembranes.

Standards are available:

- ASTM D35
- ISO TC221
- CEN TC189

HDPE, EPDM, and high-performing grades of fPP and PVC geomembranes have predicted lifetimes in excess of 30 years—with tests still ongoing.

These results are supported with the performance observed on actual projects:

- PVC (1974)
- Butyl (1982)
- Bituminous (1973)
Covering geomembranes

Several solutions are available to cover a geomembrane.

A critical component of the design is to select the adequate solution considering size, available materials, workmanship, subgrade, cost, etc.

Covering geomembranes

Exposed geomembranes are also exposed to UV and the weather, drag stress from water flowing, wind uplift, etc.

Exposed geomembranes may also be exposed to unexpected stresses, vandalism and wildlife.

Temperature of exposed geomembranes will be close to, or higher than (in the case of black geomembranes) the air temperature, therefore, it will age faster.

It is often better to cover a geomembrane:

• To increase its service life
• To minimize its exposure to accidental damages
The service life of HDPE geomembranes in covered applications depends on the temperature. The lifetime prediction for typical HDPE geomembrane is as follows:

**Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures**

<table>
<thead>
<tr>
<th>In Service Temperature (°C)</th>
<th>Stage “A” (years)</th>
<th>Stage “B” (years)</th>
<th>Stage “C” (years)</th>
<th>Total Prediction* (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard OIT</td>
<td>High Press. OIT</td>
<td>Average OIT</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>200</td>
<td>215</td>
<td>208</td>
<td>30</td>
</tr>
<tr>
<td>25</td>
<td>135</td>
<td>144</td>
<td>140</td>
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<td>30</td>
<td>95</td>
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<tr>
<td>40</td>
<td>45</td>
<td>47</td>
<td>46</td>
<td>10</td>
</tr>
</tbody>
</table>

*Total = Stage A (average) + Stage B + Stage C

The temperature of the geomembrane can often be estimated considering the temperature of the soil. For canals, this temperature is typically lower than 30° (especially if the geomembrane is covered). Therefore, the predicted lifetime for a HDPE geomembrane can be considered to be in exceed of ~160 years for most hydraulic applications.
Final remarks (1/2)

Geomembranes are more suitable than concrete to act as a sealing material.

Geomembranes are, in fact, the most suitable materials for sealing canals.

To maximize their service lives, geomembranes should be protected against accidental degradation, vandalism, exposition to UV and excessive heat. Poured concrete, concrete pavers, or other protection materials can be used for that purpose.

Final remarks (2/2)

Some EXPOSED geomembranes can offer a service life in excess of 50 years. Most PROTECTED geomembranes can offer a service life in excess of 100 years.

To offer such a performance, the geomembrane must be adequately sized and formulated.

To offer such a performance, the structure must be adequately designed.

To offer such a performance, the geomembrane must be adequately installed.
Questions?

Service life of Geosynthetics in Hydraulic Structures

Case studies
‘Heritage’ geomembranes: impregnated geotextile, Butyl Rubber

Giroud (2014)

- Pont-de-Claix, French Alps, 1974
- First double liner system
  - Secondary liner: spray-in-place bitumen, on a geotextile
  - Primary (exposed) liner: Butyl Rubber
    (none of these products still exist)
- 2 holes observed in ~49 years
  - 2004 (after 30 years): 5 meters underwater in a high stress region, repaired by gluing a different membrane under water.
  - 2011: on the permanently exposed portion of the pond.
- Closest modern product
  - Butyl Rubber: EPDM
  - Impregnated GX: Bituminous geomembrane

EPDM

Noval (2015)

- 1.5 mm EPDM Geomembrane
- Reservoir, Canary Islands, 21 years old
- Key Performance indicators, to monitor post-vulcanization and oxidation
  - Hardness
  - Mechanical properties
  - Additives / plasticizers

Exposed geomembrane facing the sun >>>

No loss of functionality at the time the paper was published
**BGM – Oxidized Bitumen**

Gourc (2017)

- Rockfill dam upstream geomembrane sealing system, covered by concrete blocks
- 4.8 mm oxidized bitumen installed in 1979 (44 years), between 2 layers of NW-GX (400 g/m²)
- Key performance indicators:
  - Bitumen softening point increased
  - Asphaltene content increased
  - Tensile properties unchanged
  - Permeability maintained

**BGM – Elastomeric Bitumen**

Benchet et al. (2011)

- Pond, east of France (-13°C to +39°C)
- Elastomeric bituminous geomembrane, ~4.1 mm
- Monitoring after 6, 10, 15 and 30 years
- Performance indicators
  - Alligator cracking
  - SBS Content, molecular weight
  - No loss of strength
  - Remains watertight
**PVC-P**

**Cazzuffi (2020)**
- 2.0 to 2.5 mm PVC geocomposite with non-woven geotextile backing
- Several dams, Northern Italy, monitored over up to 25 years
- High altitude – high UV irradiance
- Key performance indicator:
  - Loss of plasticizers
  - Tensile properties

Projected service lives: 35 to 45 years
Modern formulations are even better, with plasticizers less prone to be leached out

**Blanco (2022)**
- 1.5 mm PVC
- Reservoir, Tenerife (Canary Islands), installed 1986, observed 30 years after (2016)
- Key performance indicators:
  - Low temperature flexibility
  - Loss of plasticizers – observation of the performance of different plasticizers, validation of >400 g/mol criteria, definition of a 15% minimum plasticizer content as an end-of-life criterion
**PVC-P**

Lago Nero’s dam (Carpi Case study)
- Degraded, then repaired concrete substrate
- Installed 1980 (43 years)
- No maintenance since then.

**HDPE**

Tarnowski, Baldauf (2014)
- 2.5 mm HDPE (linear PE with α-olefin- C8 copolymer)
- Reservoir installed in 1975
- Iran, altitude 3000 meters
  - -26 to +38°C
  - 290 kly annual solar energy
- Performance indicators:
  - OIT
  - SP-NCTL
- Tests performed after 25 years exhibit excellent retention of properties

<table>
<thead>
<tr>
<th>Table 3. SP-NCTL (ASTM D 5397) and OIT (DIN EN 728, 190°C) after outdoor weathering/initial properties (in brackets)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>SP-NCTL [k]</td>
</tr>
<tr>
<td>OIT [min]</td>
</tr>
</tbody>
</table>

* tests were terminated after 1000 h

Sarchesmeh Reservoir, Iran (1975)
**HDPE**

**Putah Canal (Solmax Case study)**

- 80 mils (~2.0 mm) textured HDPE, installed 1989 (34 years) and 1993, Vacaville, California (USA)
- Covered by 2” (50mm) of shotcrete with reinforcing fibers

Maskal (2014): Long-term Integrity of Canals Lined with Geosynthetics, IGS TCH Webinar on Improving the Performance of Canals with Geosynthetics (IGS Video Library)

**Putah Canal**

- Condition in 2021 (32 years):
  - Expansion joints perform as planned
  - No leak detected

Good design!
**HDPE**

**Buffalo Rapid Irrigation**
- White Textured HDPE, **2001** (22 years)
- Terry, Montana, USA
- No testing done so far

The canal performs as planned

---

**USBR Report, 2019**
- 25 years in central Oregon
- HDPE, LLDPE, EPDM, CSPE, PVC, RCC, Shotcrete
- Small channels

Geotextile impregnated with bitumen
Several failures (caused by poor design?), with 7 out of 24 test sections removed from the study

- Anchorage
- Tear
- Wrong product used (SPUF, exposed GCL)

Most successful solutions (excellent condition + 95% seepage reduction):

- Bitumen-impregnated geotextile + 3” shotcrete
- VLDPE + GX + 3” shotcrete
- HDPE 80 mils, exposed
- PVC + 3” grout-filled mattress
- 3” grout-filled mattress
- (12 other solutions not described)

The method used to project the durability is not clear in the report, it appears to focus on the structure more than the product.
Agricultural water management changes to feed people on a livable planet

Amal Talbi-Jordan
Global Lead for Climate Resilient Irrigation
November 4, 2023

Reflections on canal lining experience from a global perspective

Amal Talbi-Jordan
Global Lead for Climate Resilient Irrigation
November 4, 2023
World Bank’s mission

End extreme poverty and boost shared prosperity on a livable planet

Water Group Vision: A water secure world for all

- Sustain Water Resources
- Deliver Services
- Build Resilience
The World Bank is the Largest Public Financier of Water Globally

Currently financing 155 projects with 27.3 billion USD

320 staff
50% in country offices

The CRI Lending Portfolio Overview (Active as of March

56 active lending projects with at least 25% I&D (major I&D), with a total commitment of $9.7B and $5.7B dedicated to I&D components, of which:

- 56 IPFs
- 37 funded by IDA, 14 funded by IBRD, 5 by other sources

By Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Total Number of Projects</th>
<th>Total Bank Commitment</th>
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</thead>
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<td>SAR</td>
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<tr>
<td>AFE</td>
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The Lending Portfolio Overview (Pipeline as of March 2023)

- 13 pipeline lending projects with at least 25% I&D (major I&D), totaling $2.4 B, with $0.8 B dedicated to I&D, of which:
  - 12 IPFs, 1 PforR
  - 5 are funded by IDA, 6 by IBRD, 2 by other sources

Number of active (blue) and pipeline (green) major I&D projects by region

Number of active (blue) and pipeline (green) major I&D projects by country
Developing sustainable irrigation can feed an additional people on a livable planet.

- Countries need to proactively implement policies and investments for sustainable irrigation and increasing yields in rainfed agriculture.
- Many studies have shown the potential of developing sustainable irrigation to feed additional people up to 1.4 billion people depending on assumptions.


The process of deterioration of rigid concrete canal lining: from cracking to collapsing..
PHYSICAL FAILURE: FREEZING/THAWING

successful canal lining with rigid concrete

FIBER-REINFORCED CONCRETE

MOROCCO: 50-YEAR OLD LINING- PRE-STRESSED CONCRETE OF SEMI-CIRCULAR SECTION IN KARSTIC AREA
Example of use of geomembranes example dam

The rehabilitation of the Studena dam was carried out while the dam remained fully operational, and reduction in water level for rehabilitation was not permitted, requiring development of innovative approaches.

For example, the geomembrane was put in place by divers and the supervising engineers had to develop special technology so that they could supervise installation of the geomembrane underwater.

Rehabilitating the structure while it remained in operation increased the overall implementation timeline, however it allowed the municipality to retain the benefit of flow regulation and dry-season water supply during the Project period, which has both economic and societal benefits.

Bulgaria Municipal Infrastructure Development, Studena Dam

Some reflections

- Use of geomembranes in irrigation in the canal lining, and also increasingly in the regulation reservoirs (increasingly) to help stabilize flow and provide pressure.
- Not a high demand of canal lining to the World Bank with projects increasing in regions such as the Africa region and capacity evolved in countries that have been working for a long time with partners.
- A development of farmer led irrigation, groundwater irrigation, modernization of irrigation requiring pressure, and improving operations/governance and increased private sector participation.
- Use of geomembranes in dams not a major part of the demand from clients to the World Bank for example increasing demand on dam safety with safety concerns related to aging dams.
World Bank’s mission: End extreme poverty and boost shared prosperity on a livable planet

Water Group Vision: A water secure world for all

- Sustain Water Resources
- Deliver Services
- Build Resilience

Thank You
25th International Congress on Irrigation and Drainage & 74th International Executive Council meeting

Theme:
Tackling Water Scarcity in Agriculture

GEOSYNTHETICS FOR DESIGN OF ENERGY DISSIPATION IN DAMS

Vivek P. Kapadia
vivekpkapadia@gmail.com
vpk@vivekpkapadia.info
4th November 2023
Divide Bund between Tail Race Channel and Spillway Gorge

Ukai Dam, Tapi River, Gujarat, India

- Gross Storage: 7414.29 Mm3
- Gates: Radial, 22, 15.55 m x 14.783 m
- Maximum Discharge: 46269 m3/s

25th International Congress on Irrigation and Drainage & 74th IEC Meeting
1-8 November 2023, Vizag, Andhra Pradesh State, India

Cyclical dynamic loads and wave rebounding and refraction – disintegration of pitching, rubble and earthen bank

Embarkment having no support at toes is unstable
Divide Bund between Tail Race Channel and Spillway Gorge

Dispersion of Impact using Different Materials and Multilayer Mechanism

Force Resolution and Stability Aspects

Performance of divide bund during monsoon of 2019 – no progressive deterioration
Energy Dissipation: Secondary Apron

- Kadana dam - constructed in 1978 on Mahi River in Gujarat state of India
- Storage capacity - 1542 million m$^3$
- Main spillway - 406 m long, rubble masonry with reinforced concrete lamination
- Design flood - 31,063 m$^3$/s
- Ogee fall height from the crest of the dam - 37 m
- Energy dissipation - solid roller bucket type with exposed basalt floor in the downstream

Transport of bed material is a typical problem – rocky bed is preferred

Surface roller and Ground roller

Progressive retrogression of pit in downstream of roller bucket

Schematic details of secondary apron as an impact resistant mechanism
**Energy Dissipation: Secondary Apron**

Froude number being in range of 2.5 to 4.5, energy dissipation may occur between 20 and 40%.

Energy before and after hydraulic jump:

\[ E_2 = y_2 + \frac{v_2^2}{2g} \quad E_1 = y_1 + \frac{v_1^2}{2g} \]

Location of surface roller and its velocity depends on discharge released.

Plunge pool may not be there during initial discharge.

Hydraulic jump formation on gabions disallows bed erosion.

**Stress Dispersion with and without Geosynthetics in Road**

Bending stresses are shared by biaxial geogrid and apron which reduces the thickness of apron.

Surface hardener chemicals used for avoiding pitting on surface.

Thick concrete apron is designed for impact-compression.

Pit filled up with rubble and sand cushion permit some displacement and hence relatively thin apron designed for bending.

**Comparison of Reaction Patterns for Aprons on Rigid and Flexible Bases**
Energy Dissipation: Secondary Apron

- During construction flood required to be released and some damage occurred

Conclusion
Several dam components subjected to dynamic loads may be designed using flexible or semi-flexible systems instead of conventional rigid heavy blocks; not only to save the cost, but also to make them longevous and maintenance-free
Watercourse management is one of the biggest challenges of the 21st century.

Water hazards are consistently identified as among the highest global risks in terms of impact.

Hydraulic engineers are called to design new solutions that help to manage water resources, enhance people’s safety while defending the ecosystems.
INTRODUCTION

A green thought has driven our engineering mindset.

For over 140 years, we have developed solutions that enhance river ecosystem resilience including the social ability to recover quickly from catastrophic events (flood, natural disasters).

Origins: Bank protection along the River Reno at Casalecchio (Bologna, Italy).

Case study on riverbank protection on Gandak river at Valmikinagar, Bihar

Client: WRD Bihar
Contractor: NNT Developers
Technology provider: Maccaferri

Protection zone:
Left and right bank on upstream
Of Gandak barrage
(Total scope on right bank – 3.3km)

Construction period: 2018-19/2019-21 (2 phases)
for completed portion
PROJECT FEATURES

- Heavy water flow during monsoon
- Severe erosion on left bank resulted in slope failure with near vertical cuts
- Excessive erosion leads to increase in bed load and resulting in damage to barrage gates and increase in maintenance requirements for the gates and canal operations
- Deposition of material further downstream can change the river flow pattern and meandering

- Being located upstream of Gandak barrage, water level always present. Limited construction window (6 months) - LWL condition.
- Located in seismic zone V
- Stones/boulders are scarce and expensive
- Eco-sensitive zone – Tiger reserve area
- Department initially was planning for boulder pitching of 1.8m thickness for slope protection
- Requirement of public promenade development

Max Discharge  
$Q = 24100$ cumecs  
Width of the River  
$= 520m$ to $800m$  
BL - $102.74m$  
HFL - $113m$  
LWL - $104m$  
Flow velocity = $3m/s$
PROPOSED SOLUTION

- Reinforced soil wall (Paramesh) of up to 12m height
- Gabion mattress as launching apron for scour protection
- 3D reinforced erosion control mat (Macmat R) + Hydromulching (MacFlex and Macganics) for erosion protection of embankment slope

PROPOSED SOLUTION

- Flexible solution suitable for high seismic zone and water front structure
- Permeable structure - minimize pore water pressure development
- Durable & eco-friendly
- Use of locally available fill material
- Minimized requirement of stones/boulders
- Optimized overall project costing
- Requirement of retention/problem of slope instability addressed
Geotechnical stability checks can be carried out with MacStARS software. Hydraulic analysis can be done using MacRA design software newly launched online with free registration on https://edesign.maccaferri.com

CONSTRUCTION PHASE
CONSTRUCTION PHASE

COMPLETED PHOTOS
Performing well through several monsoon seasons…
PROJECT COVERAGE & SOCIAL IMPACT

What we can offer:

- Product supplies
- Technical solution formulation
- Site assistance
- Installation services

INNOVATIVE * SUSTAINABLE * ENVIRONMENTALLY FRIENDLY

b.rudra@maccaferri.com

Ecopark also developed along the banks

Courtesy: @with.param (online)
Theme: Tackling Water Scarcity in Agriculture

CASE STUDY ON THE USE OF CONCRETE MATTRESS IN INDIA - SHOWCASING TALADANDA MAIN CANAL AND DHAKRANI POWER CHANNEL

Amruth Chand B
Presentation Date: 04th November 2023
Introduction

- Signet- Indian Geosynthetics Company
- Offers expertise in Geotechnical, Hydraulics and Environmental issues
- Experts in solving complex issues using creativity and tenacity.
- Sustainable and Ecofriendly Solution- making a difference to our Clients, Country and Planet.
- Develop simple and effective concepts to serve people
- Aim on Conserving Energy and Environment at same time
- Focus on R&D, new products with innovative ideas for better future

---

Key Geosynthetic Solutions

- CCGM: **Cementitious Composite Geo-synthetic Mattress**- for quick, uniform, perfect lining for canal including lining underwater

- CCGC: **Cementitious Composite Geo-synthetic Carpet**- for slope protection and landslide mitigation- Faster installation with minimum equipment and manpower with ZERO compromises on quality, loss of time
Key Geosynthetic Solutions

- **No Flood Barrier:** Synthetic tube, filled with flood water to protect from all types of flood
- **Rubber Dams:** Air Filled Rubber Dam as Weirs for irrigation, water supply, power generation, flood control, Tourism and recreation
- **Geotextile Tubes:** Coastal Protection, revetments, dykes, etc. Uses the locally available sand to fill and doesn’t make any damage to the environment

What is CCGM? (Cementitious Composite Geosynthetic Mattress)

- CCGM is a geotextile and concrete combination
- Spacing binders internally connect two layers of synthetic fabrics
- By varying length of these spacing elements, thickness of mattress is controlled
- Internal space created is filled with concrete by pumping method

**Features of CCGM:**

- Combined lining and erosion control
- Vertical ties arrangement maximizes filling height
- Constant thickness, also on uneven base
- Low hydraulic roughness compared to other concrete mattresses
Case study on Taladanda Main Canal

- **Taladanda Main Canal**- one of the oldest canals in Odisha
- Constructed more than 150 years back during British era
- Off taking from River Mahanadi at Jobra and running upto Paradeep in Odisha
- Passes through millennium city of Cuttack.

**Challenge:**
- Canal bed is silted due to lack of adequate maintenance
- Silt and waste debris in Canal bed by locals obstructing flow of water
- Technical issues like seepage on canal slopes, sliding of earth due to higher water table in the river etc.
- Slope and Bed of canal filled with garbage
- Various drainage outlets of hospital and municipality fall into the Taladanda Canal

**Solution:**
- Signet recommended Cementitious Composite Geosynthetic Mattress (CCGM)
- CCGM has no effect of UV rays and is used across the world for canal sealing, lining & remediation work
- Quality and cost effective and requiring less time
- Lining in Taladanda Main Canal:
  - Slope up to Top Bank Level with a suitable key wall on top
  - Extending maximum up to 3 metres in canal bed in either side
  - Leaving central portion of bed unlined for sub-soil drainage and pressure release
Case study on Taladanda Main Canal

Before

After

Taladanda Main Canal – CM & Dept. (Tweets)

Dept. of Water Resources @deepesh_1984

DoWR and team made hard work to transform Taladanda Canal. Cutback into a new look in a short period of 3 months by using CGCM lining technology. @RaghurandeDass86 @jaunparg

Taladanda Canal: Cutback got new look in a short period of 3 months by DoWR using CGCM lining technology. @RaghurandeDass86 @jaunparg

Taladanda Main Canal – CM & Dept. (Tweets)
Case study on Damaged Power Channel at Dhakrani

- **Dhakrani Power House**: erected in the Yamuna and Tons rivers, Dhakrani town, Dehradun, Uttarakhand, India
- **Weir on a Canal**: which is a part of the Yamuna Hydel Scheme and one dam powerhouse

**Challenge:**
- Canal closure is costly in terms of loss of power generation.
- Untimely continuous rain for five days and dewatering
- Canal in a deep cutting, the slope is eroded/failed over the period, and heavy back water pressure

**Solution:**
- Signet recommended Cementitious Composite Geosynthetic Mattress (CCGM)
- Quality, Speed and cost-effective
- CCGM needed just 10% of the time compared to conventional method
- Zero leakage and loss- more important for power channels
Appreciation letter from UJVNL for the successful completion of the project

Project was completed in a record time of 25 days, which was challenging due to untimely continuous rain for five days and dewatering.

Advantages of CCGM

- Can resist very high flow velocities >7 m/s
- Can be installed even underwater
- Minimum closure time required for canals
- Flexible system-adapts to the ground profile
- High hydraulic resistance.
- Installation on steep slopes possible.
- Long term durability- life of CCGM is > 50 years
A quick look at the other innovation areas of Signet

Civil Engineering

Daylight Systems

Geosynthetic Solutions

Rubber Dam & Water Conservation

Himawari
Sunpipe
No Flood Barrier

25th International Congress on Irrigation and Drainage & 74th IEC Meeting
1-8 November 2023, Vizag, Andhra Pradesh State, India

Thank You
Flexible polymeric geomembranes to arrest leakages in Dams and Canals enabling effective usage of water for irrigation and human needs

S.JAGADEESAN
BU Manager, Carpi India

4TH November 2023
# ABOUT CARPI: What we do

<table>
<thead>
<tr>
<th>Type of structure</th>
<th>Number of projects</th>
<th>Geomembrane installed [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAMS</td>
<td>194</td>
<td>2,314,534</td>
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<tr>
<td>RESERVOIRS</td>
<td>51</td>
<td>2,868,756</td>
</tr>
<tr>
<td>CANALS</td>
<td>45</td>
<td>1,778,066</td>
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<tr>
<td>HYDRO TUNNELS</td>
<td>24</td>
<td>92,316</td>
</tr>
<tr>
<td>TRAFFIC TUNNELS</td>
<td>45</td>
<td>1,589,948</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>359</strong></td>
<td><strong>8,643,620</strong></td>
</tr>
</tbody>
</table>
Carpi Geomembranes have been used in

- Dams
- Reservoirs
- Hydraulic Pressure Tunnels
- Canals and aqueducts
- Floating covers
- Traffic tunnels

Key Properties

Flexibility, with ultimate deformation ≈300%
Durability, long functional life even when exposed in severe environment
- >45 years from field experience (in the Alps, at >2,000 m a.s.l.)
- >100 years from analytical extrapolations of accelerated ageing tests
- Same durability in India projects with high temperature zones

Steady performance in cold/hot climates
Highly Elastic and Flexibility
PVC geocomposite is capable of deforming, reducing stresses in the material
Key Properties – Puncture and Burst Resistance

PVC geomembranes are tested on very aggressive substrates in hydraulic vessel

Pressure vessels apply water heads up to 250 m

Key Properties – Impact Resistance

Impact by floating trees, Salt Springs CFRD dam, USA

PVC geomembrane resists impact by covering rocks
Carpi Geomembrane in Dams and Canals

- Carpi is in India since 2004 and 3 Large dams have been rehabilitated by Carpi resulting in saving of nearly 99% of the water in all these hydraulic structures
- In India – Servalar Dam – Multipurpose Dam (Feeding water for nearly 5 M people and over 40,000 Acres)

Quick Insight into Dams and Canals

- Dams in India - Greater than 25,000 Dams of varying dimensions
  - > 60% of them have crossed 40 years
  - Ageing in Dams phenomenon increases the leakage and seepage thereby effective utilization of water reduces
  - Continued siltation in Dams also reduces the utilization of water from the dam

- Canals in India – Over 2,50,000 km length of canals in India (both lined and unlined canals) and several kms under construction
  - Over 40% of water is lost due to seepage in the canal path
SERVALAR DAM

57m high Stone masonry dam and length 465 m.

Purpose:
Drinking Water/Irrigation/Power Generation
Owner: TANGEDCO

Generation is dependent on the water needs.

Heavy Seepage in the dam

Leakage from several sources
Drainage Gallery
Downstream Side
Foundation gallery

Only the gallery was measured at 743 lpm in 2009

Porous shafts were choked resulting in saturation of dam body and leakage observed on the downstream side of the dam.
Part of the Dam – Left Flank and Spillway

Leakage Contributing Zones

Problems at Servalar Dam

Flooded Foundation Gallery

Choked Vertical Drains
Desilting Works + Waterproofing Works

Carpi’s Solution consisted in removal of silt and debris to expose the deepest portion of the upstream stone face.

Volumes of > 50,000 cum of silt was removed

Placing of Anti puncture Geotextile

Once the Top seal is fixed, the geotextile is rolled from the top till the bottom and fixed by Impact Anchors. Geotextile acts like an anti puncture layer (also assists in drainage layer)
Drainage Geonet

High Transmissive geonet is fixed just above the first perimeter seal and also between the first and second perimeter seal.

Another innovation and advancement is the usage of new geonet which has filter material on both the sides or on one side, depending on the application.

The purpose is to filter the water and convey the water at ease thereby preventing congestion of the water path.

Rolling and Installation of Geocomposite

Geocomposite rolls are unrolled using the lifting mechanism inbuilt in the suspended platforms. The lowered rolls are put in place by the installers in the platforms.

3 GM rolls between two Tensioning Profile
Geocomposite Welding

Multiple Rolls of Geocomposite are welded by Hot Air Welding.

Fixation of Cover Strips

The Upper Tensioning Profile is further covered with PVC Geomembrane Cover strip.
Fixation of Bottom Perimeter Seal

The Bottom Perimeter Seal is made of thick Stainless Steel (80x8mm) material. The geocomposite sheets from the top is connected to the perimeter seal at the bottom and high bonding adhesive resin is used with rubber gaskets and seals to prevent entry of water from the bottom.

Grouting at Joints

To prevent seepage from below the Contraction joints, Grout holes of 50 mm are drilled till the construction joint copper stops and PU resin grout is injected into the holes.
6 No of Drainage holes were drilled from the upstream face of the dam up to the gallery. The drain holes convey the water collected behind the membrane and discharge it into the gallery.

Final Phase of Installation
Results of Geomembrane Waterproofing System

Before Geomembrane Installation – In 2014
After Geomembrane Installation – In Aug 2018

Gallery View

Before Geomembrane
After Geomembrane
Leakage Results

Leakage Pattern before and After Geomembrane Installation

- Vertical Shaft (Measured) in Liters/Per Minute
- Downstream Side* (Unmeasured, but approximate) Liters/Per Minute

Year 2009 to Year 2018

THIS IS THE ONLY PRODUCT THAT CARPI SELLS

After nearly 4.5 Years of Service

Faced 5 Floods in the four years
Durability of Carpi’s Geomembrane System

Kadamparai Dam
Geomembrane installed in 2005 is still in good condition (After 2 decades)

Stone Masonry Dam of height 67 meter

A Dam on the verge of decommissioning (for excessive leakage) was brought back to life after installation of Geomembrane System in 2005

Kadamparai Dam In July 2022 – System still in tact after 17 years
Leakage still around 100 lpm
NO MAINTENANCE IN THE LAST 19 years
Upper Bhavani Dam - Largest Masonry Dam lined with Geomembrane in the world

Condition of Dam Before Rehabilitation

Leakage
- 9000 Lpm (at 9 M Below FRL)
- > 15,000 Lpm (At FRL)

DECLARED AS DISTRESSED DAM IN 2005 BY THE DAM SAFETY PANEL OF CWC/CLIENT
Results Of Waterproofing

Vertical Drain Shaft (Right Spillway) Before and After GM Installation

Before Geomembrane in 2019

After Geomembrane in 2021
### Conclusions (Indian Case Studies)

<table>
<thead>
<tr>
<th>Name of the Dam</th>
<th>Year of Installation</th>
<th>Area of Installation</th>
<th>Leakage Before Geomembrane</th>
<th>Leakage After Geomembrane</th>
<th>Present Service Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kadamparai Dam</td>
<td>2005</td>
<td>17,303 Sqm</td>
<td>38,000 Lpm</td>
<td>&lt; 80 Lpm (99.8% Savings )</td>
<td>18 years</td>
</tr>
<tr>
<td>Servalar Dam</td>
<td>2018</td>
<td>9854 Sqm</td>
<td>5,000-6,000 Lpm</td>
<td>&lt; 30 Lpm (99.6% Savings)</td>
<td>5 Years</td>
</tr>
<tr>
<td>Upper Bhavani Dam</td>
<td>2021</td>
<td>17,904 Sqm</td>
<td>8,000-12,000 Lpm</td>
<td>&lt; 80 Lpm (99.5% Savings)</td>
<td>2 Year</td>
</tr>
</tbody>
</table>

**UNDERWATER INSTALLATION**

CARPI started the first study and tests under a contract for the US Army Corps of Engineers in 1995/1996
The first project in the USA in 1997, was a rehabilitation of the full face of Lost Creek arch dam.

Leakage reduced from 9,800 l/s to 2,400 l/s

First large project in Venezuela, 2010/2011 for the rehabilitation of some 20% of Turimiquire upstream face. Maximum diving depth 65 m

Leakage reduced from 9,800 l/s to 2,400 l/s
Studena buttress dam-Underwater installation

Owned by the Ministry of Regional Development and Public Works, Bulgaria, Funds by The World Bank. Total surface 5,200 m², Contract amount: 16,309,000 Euros. Only geomembrane works: 39%
National Hydroelectric Power Corporation – NHPC
Tanakpur, India 2008
Water velocity 2.2 m/s
Problem: loss through deteriorated concrete lining
Design of anchors following pull-out tests
Carpi patented tensioning system

The Dynamic loads of flowing water can severely deteriorate canals
The main benefits of PVC geocomposite systems in canals are:

- They are completely watertight over the entire surface, including joints
- They withstand action of UV, ice, debris
- They withstand differential settlements
- Because of their smoothness, they allow increase of water flow
- They allow for monitoring of the performance

Exposed PVC geocomposites are smooth and allow increase of water flow
Concepts for anchoring PVC Geocomposites in canals

Examples

PVC Geocomposite fully exposed

Mittlere Isar Strogenerbauwerk, Germany 2000
In earthen canals, for various type of subgrade, different anchoring and ballasting solutions are available.

**PVC Geocomposite Partially Exposed**

ballast in berm  
external ballast

Tekapo canal remediation, New Zealand, 470,000 m² Installation in 12 weeks
For installation of geomembranes in canals and watercourses with flowing water, & to reduce costs by avoiding underwater installation of stainless-steel profiles, Carpi developed a revolutionary solution:

**An innovative impermeable heavy-duty zip**
For waterproofing of canals, where excavation of berms is not convenient, Carpi has developed a watertight mattress:

The **SIBELONMAT®**
Installation of PVC geomembrane systems can be performed totally underwater
- At any depth, at water velocity up to 1 m/s, on the full section of the canal
- No impact on canal operation
- Effective long-lasting solution to stop leakage
- Can be installed to repair canals and embankment dams, or as upstream blanket
- Can be used in new construction of embankment dams and canals
Lower Maintenance Costs for Carpi geocomposites

- No scheduled or preventative maintenance for geocomposite system
- No moving components that can fail
- Monitoring system to locate any damaged area within less than 1 square meter.
- After more than 1,800,000 square meters of installations with more than 500 years of cumulated service history, Customers have experienced $0 maintenance costs

Thank You