Geosynthetics in Dams, Forty Years of Experience
by J.P. Giroud

ASDSO
ORLANDO, SEPTEMBER 2005

GEOSYNTHETICS IN DAMS
FORTY YEARS OF EXPERIENCE

J.P. GIROUD

Geosynthetics:
- GEOMEMBRANES
- GEOTEXTILES
- GEOMATS
- GEONETS
- GEOCOMPOSITES
- GEOGRIDS
- etc.

GEOMEMBRANES
Used as liquid barriers

GEOTEXTILES
- WOVEN GEOTEXTILE
  Used as filters or for soil reinforcement
- MICROPHOTOGRAPH OF NONWOVEN GEOTEXTILE
  Used in numerous applications, e.g. filters or cushions for geomembrane protection
All types of geosynthetics are used in dams.

Geosynthetics can perform a variety of functions in dams and can be used at a variety of locations in a dam.
### APPLICATIONS OF GEOSYNTHETICS IN DAMS

- Water barrier (GEOMEMBRANE)
- Internal filter (GEOTEXTILE)
- Drainage (GEOCOMPOSITE)

These are the essential functions, the functions involved in seepage control.

### APPLICATIONS OF GEOSYNTHETICS IN DAMS

- Reinforcement (GEOGRID, GEOTEXTILE)
- Bank protection (GEOTEXTILE)
- Erosion control (GEOMAT, GEOCELL)
- Cushioning (GEOTEXTILE)

These functions/applications are important, but not essential.

### GEOMEMBRANE BARRIERS IN DAMS

**CONTRADA SABETTA DAM (ITALY) 1959**

- 32.5 m high (106 ft), 1H/1V
- Dry masonry
- Polyisobutylene geomembrane
- 2 mm thick
- Underlain by drainage layer
- Protected by concrete slabs, 2 m x 2 m x 0.2 m with 1 mm joints.

### CONTRADA SABETTA DAM

- Samples of the geomembrane were taken 38 years after construction.
- Polyisobutylene geomembrane still in good condition.

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**Photo 38 years after construction**
In 1960, Terzaghi used a PVC membrane at Mission Dam (now Terzaghi Dam), with some problems.

MIEL DAM (1968) 13 m (43 ft)

Butyl rubber, 1 mm

L’OSPEDALE DAM, 85 ft (1978)

Bituminous geomembrane, 4 mm

L’OSPEDALE DAM

GEOMEMBRANE CONNECTION AT TOE BEAM

BATTEN STRIP

CONCRETE PAVER BLOCKS FOR GEOMEMBRANE PROTECTION

INTERLOCKING PAVERS: 8 in. long 3 in. thick
Four years after construction, a storm removed some pavers. The geomembrane was not damaged.

CONCLUSION OF THE INCIDENT

• The geotextile cushion between the geomembrane and the paver blocks performed its function and the geomembrane was not damaged.
• Repair was done with the same interlocking blocks and concrete.
• In subsequent dams, concrete slabs will be preferred.

L’OSPEDALE DAM
Leakage Rate, liters/second
CODOLE DAM 28 m (93 ft) 1983
Upstream slope 1.7H:1V

CODOLE DAM, 93 ft (1983)
PVC 1.9 mm thick, bonded to needle-punched nonwoven geotextile

CONNECTION WITH TOE BEAM
Specially developed smooth batten strip, embedded into concrete.

CONSTRUCTION OF CONCRETE SLAB TO PROTECT THE GEOMEMBRANE

Geomembrane around smooth batten strip, prior to embedment into concrete.
CONSTRUCTION OF CONCRETE SLAB

Reinforced concrete, 5 in. thick

POLYSTYRENE JOINTS
20 mm thick

CODOLE DAM, 1.7H/1V

CODOLE DAM
Leakage Rate, liters/second

FIGARI DAM 35 m (115 ft) 1991
Upstream slope 1.7H:1V

FIGARI DAM
CONSTRUCTION PROBLEMS

- The PVC geomembrane was independent from the underlying geotextile.
- This made installation easier, but caused two major problems.
- The geomembrane crept down the slope during construction.
- The geomembrane was uplifted by the wind with no damage but the geotextile was displaced under the geomembrane.
- The geomembrane had to be removed to reposition the geotextile, and 50% of the geomembrane had to be discarded.
**FIGARI DAM**

**LESSON LEARNED**

- Non-reinforced PVC geomembranes should not be used on steep slopes.
- If geomembrane uplift by wind is likely to occur during construction, the geotextile underlying the geomembrane should be either bonded to the geomembrane or bonded to the underlying material (assuming this material is rigid).

**BORFLOC’H DAM 19 m (62 ft) 1993**

Bituminous geomembrane 4 mm thick, bonded to the underlying permeable asphalt concrete (one point every 3 m).

**BORFLOC’H DAM**

**BOVILLA DAM, 187 ft (1996)**

1.55H/1V

**BOVILLA DAM**

- PVC geomembrane, 3 mm thick, heat-bonded to a polypropylene continuous filament needle-punched nonwoven geotextile, 700 g/m².
- Interface friction angle between this geotextile and granular material support is 38°: factor of safety of 1.2 for the 1.55H/1V slope.

**BOVILLA DAM CONCRETE PROTECTION**

- Protection by cast-in-place unreinforced concrete.
- Thick (0.2 m) protection due to risk of rock fall from the sides.
- Concrete thickness 0.3 m in lower central face where slab length exceeds 50 m.
**BOVILLA DAM**

**CONCRETE PROTECTION STABILITY**
- Independent polypropylene continuous filament needle-punched nonwoven geotextile, 800 g/m² between geomembrane and concrete.
- Interface friction angle 22° between this geotextile and the geomembrane.
- Slope angle: 33° at top and 32° at toe.
- Concrete slab supported by peripheral beam at toe.

**BOVILLA DAM**

**CONCRETE PROTECTION DRAINAGE**
- Joints along the slope between concrete panels to release pressure in case of rapid drawdown.
- Joints along the slope filled with three layers of polypropylene continuous filament needle-punched nonwoven geotextile, 350 g/m².
- Horizontal joints between concrete panels filled with one layer of same geotextile to ensure flexibility of concrete slab.

Another example of concrete slab placement
La Galaube Dam (2000)

Concrete Slab Protection

<table>
<thead>
<tr>
<th>Dam</th>
<th>Year</th>
<th>Height (m)</th>
<th>Slope</th>
<th>Thickness (cm)</th>
<th>Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrada Sabetta</td>
<td>1959</td>
<td>28</td>
<td>1.0H/1V</td>
<td>20</td>
<td>None</td>
</tr>
<tr>
<td>Coisole</td>
<td>1983</td>
<td>25</td>
<td>1.2H/1V</td>
<td>14</td>
<td>Steel mesh</td>
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<tr>
<td>Figari</td>
<td>1991</td>
<td>35</td>
<td>1.7H/1V</td>
<td>14</td>
<td>PP fibers</td>
</tr>
<tr>
<td>Ortolo</td>
<td>1993</td>
<td>37</td>
<td>1.7H/1V</td>
<td>14</td>
<td>PP fibers</td>
</tr>
<tr>
<td>Galaube</td>
<td>2000</td>
<td>42</td>
<td>2.0H/1V</td>
<td>10</td>
<td>PP fibers</td>
</tr>
<tr>
<td>Bovilla</td>
<td>1998</td>
<td>81</td>
<td>1.6H/1V</td>
<td>20</td>
<td>None</td>
</tr>
</tbody>
</table>

Other possibilities:
- Interlocking concrete blocks (poor performance in large dams)
- Articulated concrete blocks (small dams)
- Soil and rock protection (slopes less steep than 2H/1V)
- No protection (anchorage/bonding against wind uplift)
MUD LAKE DAM (NEVADA), 2H/1V (2000)

3 in. deep geocell filled with concrete, on geotextile (16 oz/sq.yd) and reinforced polypropylene geomembrane

AUBRAC DAM 15 m (49 ft) 1986

2.5H/1V

- 0.5 m (20 in.) rockfill 100-300 mm (4-12 in.)
- 0.2 m (8 in.) gravel 0-25 mm (0-1 in.)
- needle-punched nonwoven geotextile (500 g/m²) (15 oz/sq.yd)
- 1.2 mm (47 mil) PVC geomembrane
- needle-punched nonwoven geotextile (500 g/m²) (15 oz/sq.yd)
- 0.2 m (8 in.) drainage layer, gravel 0-25 mm (0-1 in.)

AUBRAC DAM 15 m (49 ft) 1986

Slide of the soil cover over 1000 m² during placement of soil cover at interface between PVC geomembrane and underlying geotextile.

AUBRAC DAM 15 m (49 ft) 1986

This slide has not been well explained

- Interface friction angle:
  shear box (high normal stress) 34°
  inclined plane (low normal stress) 28°
- Slope angle 22°
- Influence of moist interface: –3°
  Influence of vibrations: –3°
PVC geomembrane (1.2 mm) from Aubrac Dam

**PLASTICIZER CONTENT**

- Plasticizer loss is limited.
- Plasticizer loss is greater above water level than below.
- The rate of plasticizer loss seems to decrease after a few years.
- Plasticizer loss is about the same for geomembrane below water level and geomembrane in storage.

And the thickness was only 1.2 mm (47 mils).

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PVC geomembrane from Aubrac Dam

Multiaxial tensile test on samples taken 14 years after construction

### SYMVOULOS DAM, 121 ft (1990)

- **HDPE**
- **3.5 mm**

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**HEIGHTENING OF PACTOLA DAM (1987)**

- **SOUH DAKOTA**
- **HDPE geomembrane, 1 mm (40 mils)**
- **Geotextile cushion, 400 g/m² (12 oz/sq.yd)**

**PLACEMENT OF GEOMEMBRANE AND GEOTEXTILE CUSHION**

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ASDSO Conference
Orlando

2005.09.26
In spite of construction problems, Signal Buttes Flood Retention Structure is considered in better condition than conventional homogeneous flood retention structures in the same district, which are generally cracked.

Using a geomembrane is clearly the best solution for earth dikes that are susceptible to cracking because they are not exposed to water most of the time.

The Signal Buttes Flood Retention Structure is a rare example of dam with internal geomembrane.

A multi-stage construction is a better strategy than the accordion shape.
Concrete can be deteriorated by frost or aggregate-alkali reaction.

DAM FACE REHABILITATED USING GEOSYNTHETICS

REHABILITATION IN PROGRESS

CONCRETE REPAIRED LOCALLY

PHOTO TAKEN 10 YEARS LATER (today 16 years)

CONCRETE REPAIRED LOCALLY

GEOMEMBRANE

GEONET
**REHABILITATION CONCEPT**

- The geomembrane provides impermeability.
- A geonet or a thick geotextile placed between the geomembrane and the concrete is acting as a drain.
- The main purpose of the system is to allow the concrete to progressively dry.
- Removing water from concrete decreases to a negligible level frost action and alkali-aggregate reaction.
- The geomembrane also decreases to a negligible level the leakage associated with concrete deterioration.

**DURABILITY**

- Durability is a major consideration in this application.
- In the rehabilitated dams, the concrete had deteriorated to a critical level in 40-60 years.

**GEOSYNTHETIC DURABILITY**

- In this application, the geosynthetics are exposed to harsh conditions (sunlight, weather, floating debris).
- To ensure durability, the geosynthetics have been carefully selected.
- To check durability, the geosynthetics are tested periodically.

- Based on 20 years of testing, a durability of 50 years is predicted.

**SYSTEM DURABILITY**

- The geosynthetics on the dam face can be easily replaced at the end of their service life.
- This increases the durability of the dam indefinitely.

A good example of complementarity between geosynthetics and traditional construction materials.

**DISTRIBUTION IN EUROPE**

<table>
<thead>
<tr>
<th>Geomembrane Type</th>
<th>Total</th>
<th>New</th>
<th>Repair</th>
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<tbody>
<tr>
<td>PVC</td>
<td>55%</td>
<td>20%</td>
<td>35%</td>
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<tr>
<td>Bituminous</td>
<td>15%</td>
<td>12%</td>
<td>3%</td>
</tr>
<tr>
<td>In situ</td>
<td>11%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elastomers</td>
<td>5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>14%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

More than 150 large dams worldwide (including 90 in Europe) have been constructed with a geomembrane.

PVC geomembrane used on all types of dams.
Bituminous geomembrane used mostly on embankment dams.
Drainage is present under geomembrane in most cases.
In all the large dams where a geomembrane is used on the upstream face, the geomembrane is the only line of defense. and the resulting leakage rate is very small.

### LEAKAGE THROUGH DAMS

<table>
<thead>
<tr>
<th>Dam</th>
<th>Height (m)</th>
<th>GM</th>
<th>Thick (mm)</th>
<th>Leakage (l/hr/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ospedale</td>
<td>26</td>
<td>Bitu</td>
<td>5</td>
<td>2.4</td>
</tr>
<tr>
<td>Codole</td>
<td>28</td>
<td>PVC</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td>Mauriac</td>
<td>14</td>
<td>Bitu</td>
<td>4</td>
<td>0.9</td>
</tr>
<tr>
<td>Figari</td>
<td>35</td>
<td>PVC</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>Madone</td>
<td>18</td>
<td>PVC</td>
<td>2</td>
<td>0.3</td>
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<td>Borfloc'h</td>
<td>19</td>
<td>Bitu</td>
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<td>Empurany</td>
<td>19</td>
<td>PVC</td>
<td>1</td>
<td>11.0</td>
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<tr>
<td>Ortolo</td>
<td>37</td>
<td>Bitu</td>
<td>5</td>
<td>7.0</td>
</tr>
</tbody>
</table>

### COMMENTS ON LEAKAGE RATES

- Observed leakage rate of the order of 1 liter/hr/m² (if accurate).
- One defect per 1000 m² with a diameter of 2 mm would give a leakage rate of the order of 0.1 liter/hr/m².
- Leakage at connections may explain the difference.

### GEOTEXTILE FILTERS IN DAMS

### VALCROS DAM, 55 ft (1970)
**VALCROS DAM, 55 ft (1970)**

First dam with a geotextile filter

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**VALCROS DAM**

**DESCRIPTION**

- 55 ft high
- Homogeneous dam
- Silty sand, 30% < 0.075 mm (#200 sieve)
- Polyester continuous filaments needle-punched nonwoven geotextile, 300 g/m² (9 oz/sq.yd)

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**VALCROS DAM**

**PERFORMANCE**

- Constant trickle of clean water for 35 years (traces of suspensions were noticeable in the water only for a few days after filling of the reservoir)
- Less than 0.1 liter/hr/m² of dam (which is consistent with the hydraulic conductivity of the embankment soil, $k = 1 \times 10^{-7}$ m/s)
- No seepage of water ever observed through the downstream slope.

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**GEOTEXTILE DURABILITY**

Samples of geotextile have been removed from the actual filter, 6 years and 22 years after construction.

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**VALCROS DAM**

**TEST RESULTS**

- Slight decrease in tensile strength from year 0 to year 6, and no change between year 6 and year 22.
- Same hydraulic conductivity in year 6 and year 22.
- Particles entrapped, less than 5% by weight.
VALCROS DAM

This outstanding performance can be explained.

SIDI BEN TAIBA DAM (Algeria) 2003

horizontal gravel drains in upstream embankment

Geotextile filter around these horizontal gravel drains
Two-layer needle-punched nonwoven geotextile filter
Opening size 80 µm  Number of constrictions 25-40

SIDI BEN TAIBA DAM (Algeria)

SIDI BEN TAIBA DAM (Algeria) 2003

SAMIRA DAM (Niger)
18 m high, 1000 m long

Very fine lateritic soil requires small opening size
Needle-punched nonwoven geotextile
Opening size 80 µm  Number of constrictions 25-40

SAMIRA DAM (Niger)
18 m high

(1) Geotextile filter on both sides of chimney drain
(2) Geotextile filter on both sides of blanket drain
(3) Geotextile filter under rip rap
SAMIRA DAM

CHIMNEY DRAIN

BLANKET DRAIN

MONTAUBRY DAM, 20 m high built in the mid 19th century.

Homogeneous earth dam with masonry face

MONTAUBRY DAM, REHABILITATION (2001)

(1) Sand filter-drain
(2) Downstream backfill
(3) Geotextile filter on gravel blanket drain
(4) Geotextile filter on downstream rockfill

Geotextile wrapping downstream rockfill

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Geotextile under downstream blanket drain

LA PARADE DAM, 43 ft

LA PARADE DAM

Thick three-layer nonwoven geotextile

FRAUENAU DAM, 282 ft (1980)

Thick nonwoven geotextile

Dual function
Fortunately, the Valcros Dam filter was not designed using classical filter criteria.

Fortunately, the Valcros Dam filter was not designed using classical filter criteria.

VALCROS DAM
FILTER
The outstanding performance of Valcros Dam can be explained.

Fortunately, the Valcros Dam filter was not designed using classical filter criteria.

COEFFICIENT OF UNIFORMITY
\( C_u = 90 \)
\( C_u = 53 \)

TRADITIONAL FILTER RETENTION CRITERION
\( O_F < d_{85S} \)

One may object that, so far, I used the retention criterion for cohesionless soils, whereas the soil in Valcros Dam has 30% particles smaller than 0.075 mm (#200 sieve).

Sherard proposed a retention criterion depending on the percentage of particles smaller than 0.075 mm. I used Sherard’s criterion and obtained: 2.67 mm.

I used it again on the truncated particle size distribution curve. I found: 0.83 mm.

The soil in Valcros Dam seems to defy all retention criteria.

This problem with soils having a large coefficient of uniformity is known by geotechnical engineers.

Traditional solution: TRUNCATION

USE OF ADVANCED RETENTION CRITERION

Application to the Valcros Dam soil
\( O_F < \frac{18 \ d_{85S}}{(C_u')^2} \)

Application to the truncated particle size distribution curve

With \( d_{85S} = 6.4 \text{ mm} \) and \( C_u' = 53 \)
\( O_F < \frac{(18 \times 6.4)}{(53^2)} = 0.135 \text{ mm} \)

With \( d_{85S} = 1.8 \text{ mm} \) and \( C_u' = 25 \)
\( O_F < \frac{(18 \times 1.8)}{(25^2)} = 0.135 \text{ mm} \)

This remarkable result confirms the validity of the advanced retention criterion.
We have found we needed a geotextile filter opening size of 0.135 mm.

What was the geotextile filter opening size at Valcros Dam?

It was not measured, but today (knowing the physical characteristics of the geotextile) we can calculate it using the following equation:

\[ \frac{O_n}{d} = \frac{1}{\sqrt[4]{1 - \frac{20 \times \mu}{\rho}} - 1} + \frac{10 \times \rho \ d_n}{\mu} \]

The calculation gives: 0.099 mm, which is smaller than 0.135 mm.

We can do even more.

Research in mid-1990s has shown that the risk of clogging of a geotextile filter is minimized if the number of constrictions is between 25 and 40.

\[ m = \frac{\mu}{\rho \ d_n \sqrt[4]{1 - \frac{20 \times \mu}{\rho}}} \]

For the geotextile filter used at Valcros dam, the calculation gives 28.

CONCLUSION

FORTY YEARS OF EXPERIENCE

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CONCLUSION

• Geomembranes are now well accepted and are the material of choice for waterproofing the upstream face of all types of dams.
• The function of geotextiles filters inside dams is more subtle than the function of geomembranes on the upstream face of dams.

GEOMEMBRANES
• Rubber 46 years 106 ft
• Bituminous 27 years 138 ft
• PVC 27 years 571 ft
• HDPE 20 years 121 ft

GEOTEXTILES 35 years 106 ft

CHALLENGES REGARDING GEOTEXTILE FILTERS IN DAMS
• The geosynthetics engineering community should better inform the dam/geotechnical community about its research and development on geotextile filters.
• The geosynthetics engineering community should provide information on geotextile durability that is as good as the information developed in the past two decades on geomembrane durability.
IMPRESSIVE ACHIEVEMENTS

Thank you