International Geosynthetics Society

ICID 5th African Regional Conference
Marrakech, Morocco

GEOSYNTHETICS FOR WATER CONSERVATION

J.P. GIROUD

2021.11.25

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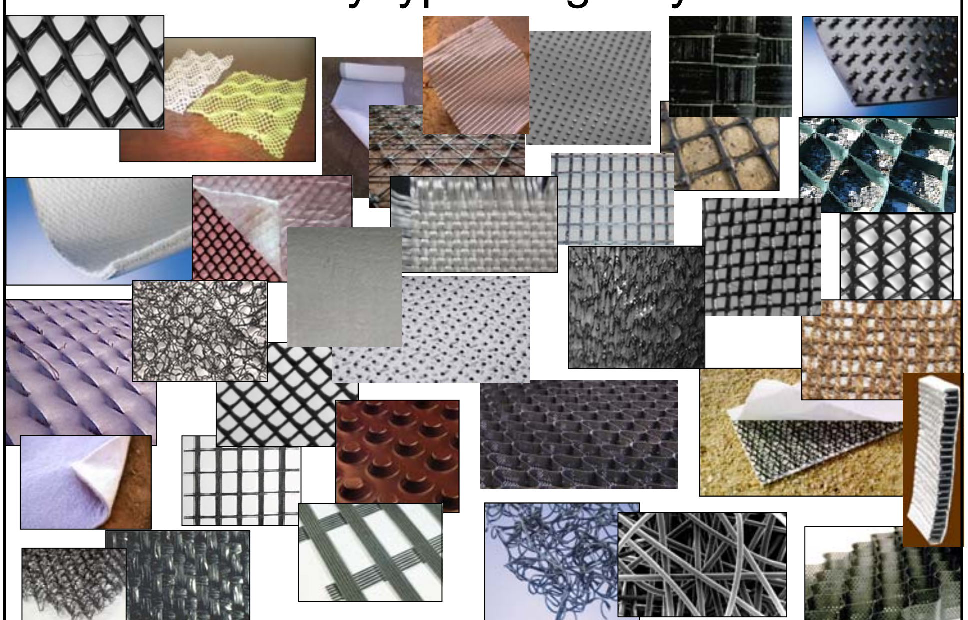
There are many types of geosynthetics.



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And more types of geosynthetics !

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I will mostly talk about **geomembranes** because they are **watertight geosynthetics**.

Indeed, **watertightness** is an **essential property for water conservation**.

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Geomembranes are **flexible** sheets of **watertight** material, generally polymeric (sometimes bituminous).

POLYMERIC GEOMEMBRANES | BITUMINOUS GEOMEMBRANES

Courtesy Firestone

Courtesy Coletanche

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The **flexibility** of geomembranes is evident on these photos.

POLYMERIC GEOMEMBRANES | BITUMINOUS GEOMEMBRANES

Courtesy Firestone

Courtesy Coletanche

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Geomembranes are produced in rolls.
Here:
rolls delivered to the site.
Photo J.P. Giroud
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The rolls are unrolled
to form flat panels . . .
which are, then, seamed together.
Photo J.P. Giroud
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Geomembrane panels are seamed together in the field to form large liners.

Photo J.P. Giroud

SEAMING MACHINE

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Rolls can also be seamed together in a factory

Courtesy F. Rohe
Environmental Protection, Inc.

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to form large panels that are packed

Courtesy F. Rohe
Environmental Protection, Inc.

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and delivered to the construction site,

Courtesy F. Rohe
Environmental Protection, Inc.

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where they are deployed.

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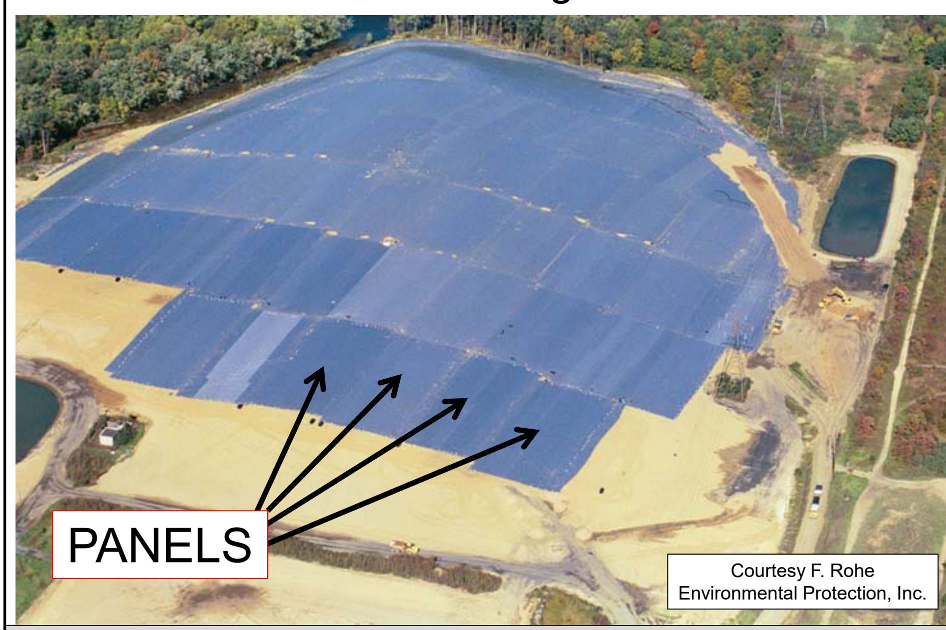
Panels are then seamed together in the field.



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In many applications, **geomembranes** are associated with **geotextiles**.

Generally the geotextile is used to protect the geomembrane.

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Some **composite geomembranes** consist of a geomembrane bonded to a geotextile.

Photo Carpi

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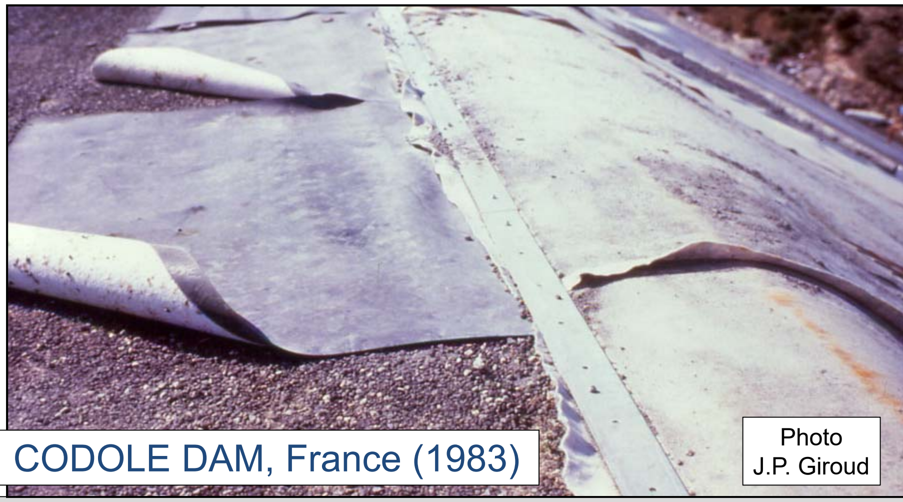
Example of a PVC geomembrane bonded to a nonwoven geotextile on the face of a rockfill dam.



CODOLE DAM, France (1983)

Photo J.P. Giroud

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The surface of a geomembrane is important:

- If **low friction** is desired: a geomembrane with a **smooth surface** is used.
- If **high friction** is desired: a geomembrane with a **rough surface** is used.

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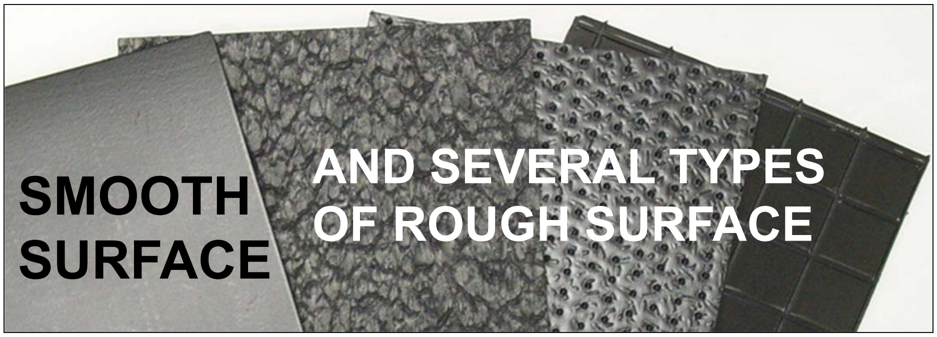
EXAMPLES OF GEOMEMBRANE SURFACE

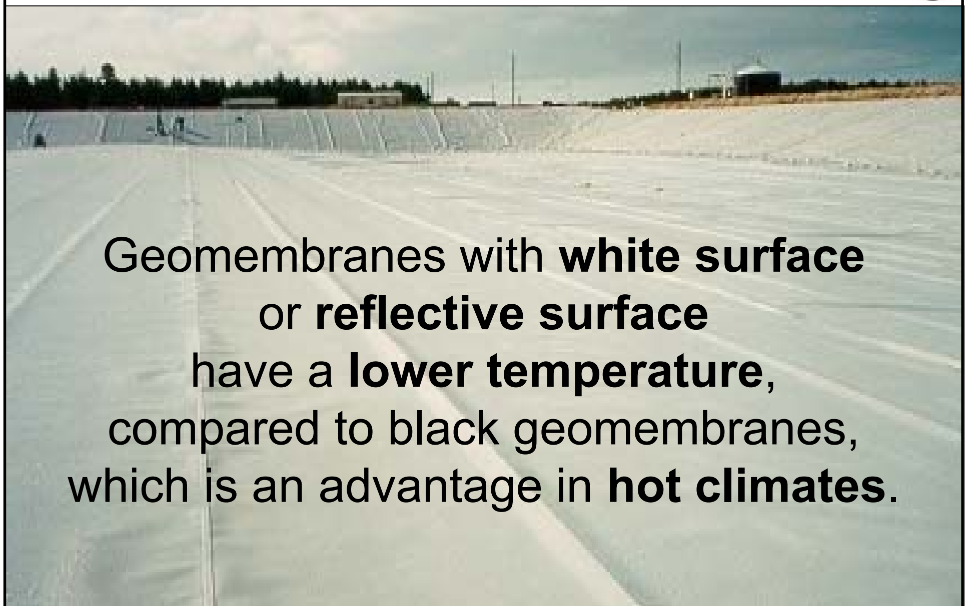
HDPE Geomembranes



Another important aspect of **geomembrane surface** is the **color**.

Geomembranes are generally **black**,
because they are protected
from ultra violet radiation by **carbon black**,
which consists of fine particles of carbon
mixed with the polymer
at the manufacturing stage.

But **black color** exposed to sunlight
results in **high temperature**,
which has detrimental effects,
such as accelerated aging and thermal expansion.



Geomembranes with **white surface** or **reflective surface** have a **lower temperature**, compared to black geomembranes, which is an advantage in **hot climates**.

Courtesy GSE

Geomembranes are used in a variety of applications to **contain water**.

In these applications, all types of geomembranes are used:

- **Polymeric geomembranes**: HDPE, PVC, Polypropylene, EPDM, etc.
- **Bituminous geomembranes**.


Courtesy
Firestone
IRRIGATION RESERVOIR
LINED WITH GEOMEMBRANE
Saint-Pierre-le-Vieux, France, 2006
EPDM
Geomembrane
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IRRIGATION RESERVOIR
LINED WITH GEOMEMBRANE
Kopa Reservoir, Kazakstan, 2018
Bituminous geomembrane
Courtesy
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WASTEWATER RESERVOIR
LINED WITH GEOMEMBRANE
Bituminous geomembrane
Courtesy
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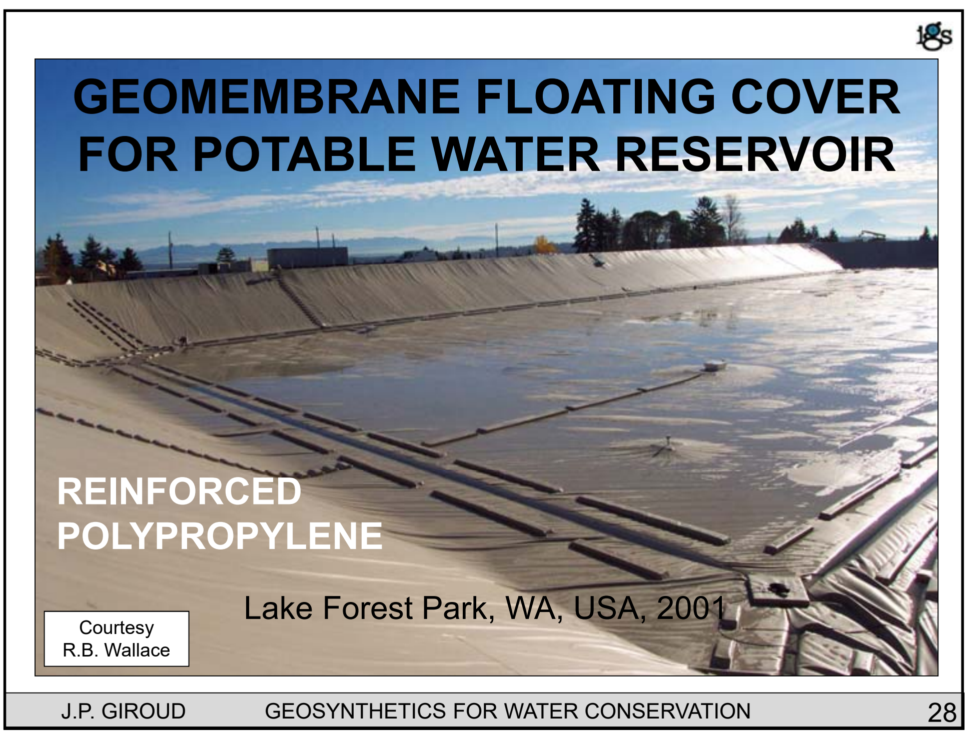
GEOMEMBRANE FLOATING COVER
FOR POTABLE WATER RESERVOIR
REINFORCED
POLYPROPYLENE
Lake Forest Park, WA, USA, 2001
Courtesy
R.B. Wallace
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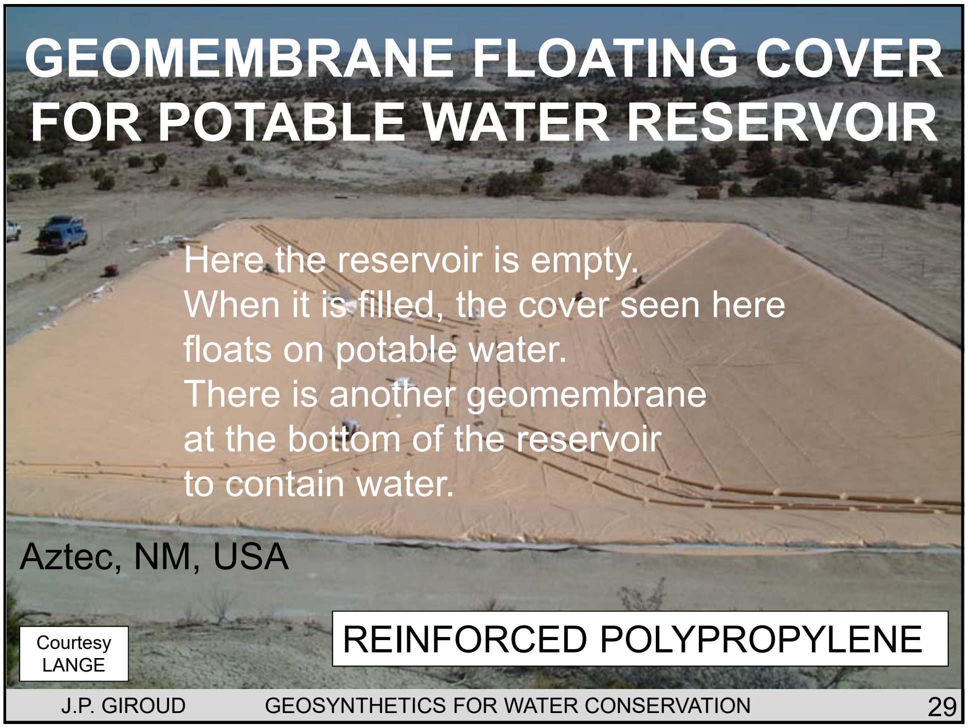
GEOMEMBRANE FLOATING COVER FOR POTABLE WATER RESERVOIR
Here the reservoir is empty.
When it is filled, the cover seen here floats on potable water.
There is another geomembrane at the bottom of the reservoir to contain water.
Aztec, NM, USA
Courtesy LANGE
REINFORCED POLYPROPYLENE
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At the PANAMA CANAL
PVC-geotextile Composite Geomembrane
Courtesy CARPI
The WATER BASINS FOR THE NEW LOCKS are lined with geomembrane.
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FISH FARMS lined with geomembrane

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HYDROPOWER CANAL LINED WITH GEOMEMBRANE

PVC-geotextile Composite Geomembrane

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SMALL IRRIGATION CANAL

YAKIMA CANAL, USA, 2002

Courtesy Coletanche

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This is the TOSHKA CANAL in Egypt,
the largest geomembrane project in the world
Courtesy A.M. Yazdani
HDPE GEOMEMBRANE
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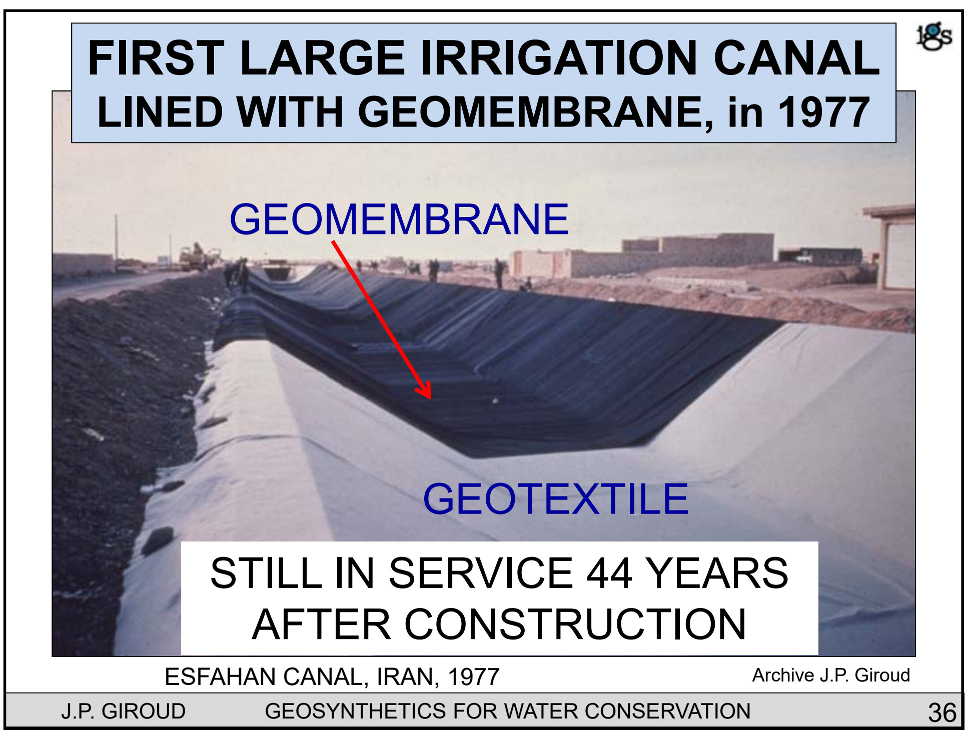
FIRST LARGE IRRIGATION CANAL
LINED WITH GEOMEMBRANE, in 1977
GEOMEMBRANE
GEOTEXTILE
STILL IN SERVICE 44 YEARS
AFTER CONSTRUCTION
ESFAHAN CANAL, IRAN, 1977
Archive J.P. Giroud
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EMBANKMENT DAM WITH GEOMEMBRANE UPSTREAM FACING

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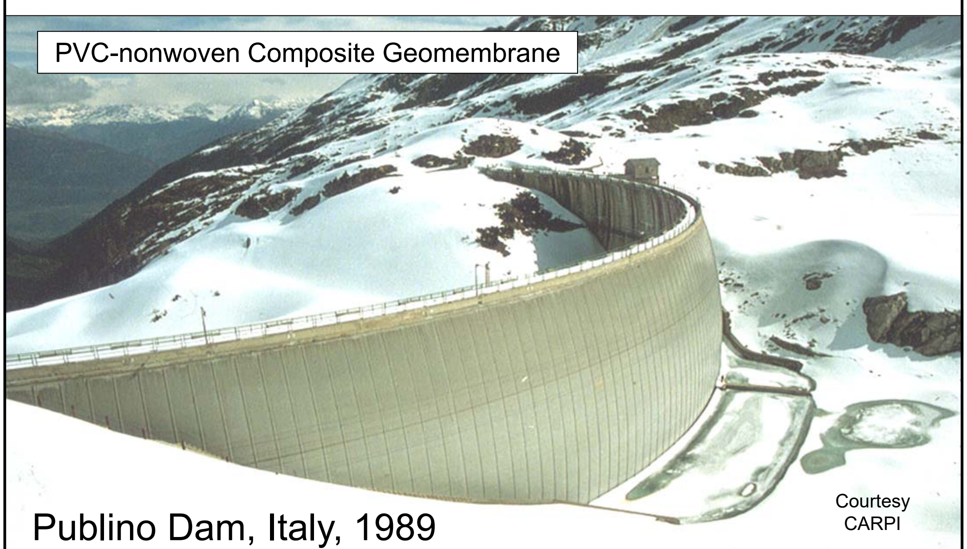
CONCRETE DAM WITH GEOMEMBRANE UPSTREAM FACING



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ROCKFILL DAM REHABILITATED
WITH GEOMEMBRANE FACING
SALT SPRINGS DAM, USA, 2005
Courtesy
CARPI
PVC-GEOTEXTILE COMPOSITE GEOMEMBRANE
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ROLLER COMPACTED
CONCRETE DAM
with geomembrane
upstream facing
188 m high
PVC-nonwoven
Composite
Geomembrane
MIEL DAM
Colombia, 2002
Courtesy
CARPI
J.P. GIROUD
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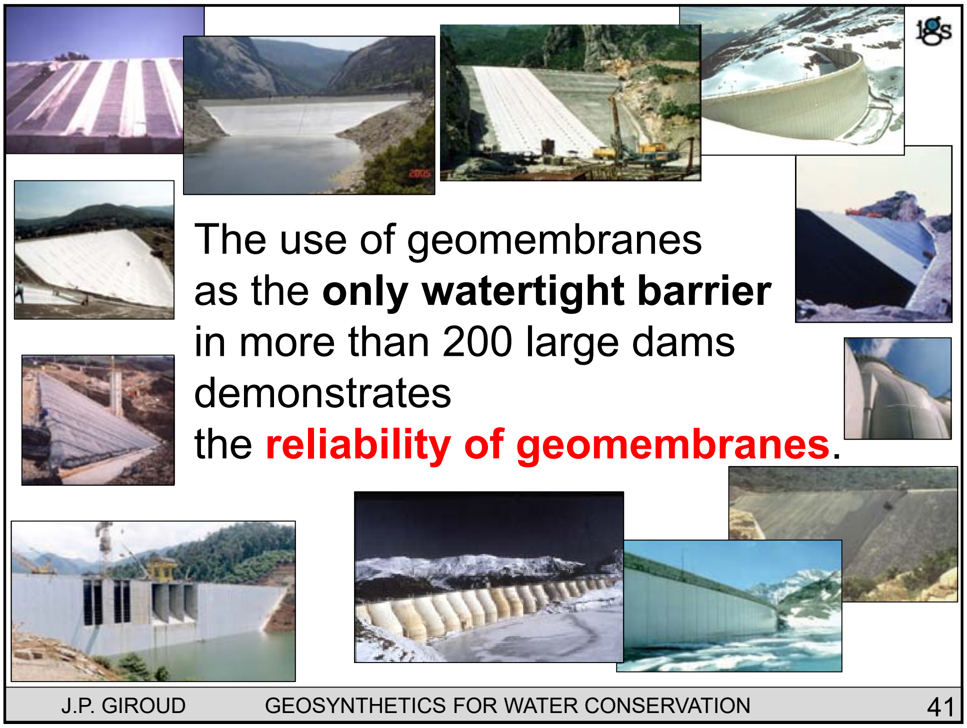
The use of geomembranes
as the **only watertight barrier**
in more than 200 large dams
demonstrates
the **reliability of geomembranes**.
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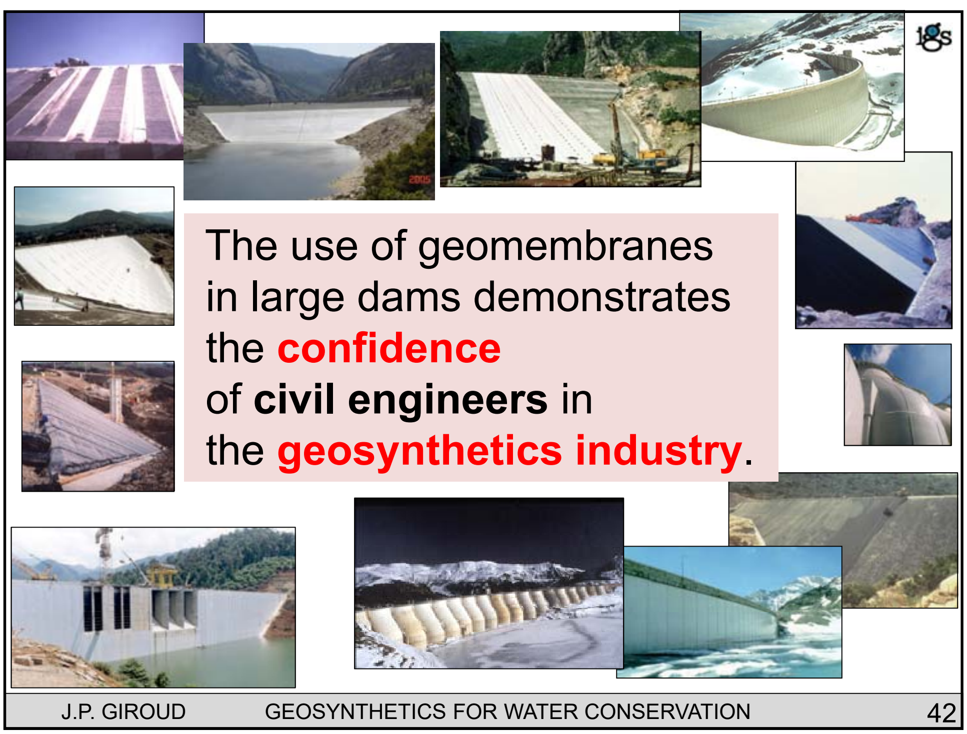
The use of geomembranes
in large dams demonstrates
the **confidence**
of **civil engineers** in
the **geosynthetics industry**.
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Now, let's discuss the watertightness of geomembranes.

The **polymeric compounds** used in geomembranes can be considered **quasi-impermeable**.

For example, **standard tests** used to determine geomembrane acceptance correspond to a **coefficient of permeability** of **less than 10^{-14} m/s**.

In comparison, **other liner materials** are **more permeable**.

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PERMEABILITY OF LINER MATERIALS

COMPARED TO THE LESS THAN 10^{-14} m/s so-called "PERMEABILITY" OF GEOMEMBRANES

Cement concrete, ideal	10^{-12} m/s
Cement concrete in field	10^{-10} m/s to 10^{-8} m/s
Roller compacted concrete	10^{-8} m/s to 10^{-6} m/s
Bituminous concrete, ideal	10^{-9} m/s
Bituminous concrete in field	10^{-8} m/s
Clay layer, ideal	10^{-9} m/s
Clay layer in field	10^{-8} m/s
Bentonite	10^{-11} m/s

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These "permeability" values show that geomembranes are **orders of magnitude** **more watertight** than other lining materials.

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However, it should not be concluded that
there is **no leakage**
with geomembrane liners.

*Impermeability on a **small scale***
*(such as a geomembrane **sample**)*
does not guarantee
*impermeability on a **large scale***
*(such as a geomembrane liner in the **field**).*

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In the field, **leakage is always possible**, including with geomembrane liners when they have holes.

Leakage can be reduced
by a variety of measures
at the design stage and
at the construction stage
in particular by
construction quality assurance
and
electrical leak location survey.

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For a **10 m deep** reservoir,
in the case of
excellent design,
excellent soil preparation, and
excellent installation
(*with construction quality assurance and electrical leak location*),
a rate of leakage of 5000 liters/hectare/day
(a water level drop of **0.5 mm/day**)
can be expected,
as demonstrated in a study
combining **field data** and **theoretical analyses**.

[Peggs & Giroud, 2014]

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If the conditions are not as good
as described in the preceding slide,
a rate of drop in water level as high as
10 mm/day may happen,
or even higher
in case of large holes in the geomembrane.

This water level drop of 10 mm/day
is, however, significantly lower than
a typical water level drop of **250 mm/day**
on an **unlined silty soil**.

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The water level drop values for **reservoirs**,
given in the preceding slides,
are consistent with values of
water level drop in **canals**
presented in the book:

Geomembranes for Lining Canals

by J.P. Giroud & H. Plusquellec

To be published in 2022
Taylor and Francis, Publishers

Values of **water level drop in canals**
are summarized in the next slide.

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Typical **water level drop** in canals,
for a depth of water of 3 m:

- Unlined canal on silty to sandy soil: 100 to 1000 mm/day
  A value of 250 mm/day is often mentioned.
- **Concrete lining in good condition**: 25 to 50 mm/day
- Concrete lining in poor condition: > 100 mm/day
- **Geomembrane well installed**: 0.1 to 1 mm/day
- Geomembrane poorly installed: 1 to 10 mm/day
- Geomembrane with large holes: > 100 mm/day

The water level drop is **100 times lower** with **geomembrane** than with concrete.

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After noting that data on leakage
from **reservoirs** and from **canals**,
are consistent,
one may ask the question:

How effective are geomembranes
for controlling leakage in the case of **dams** ?

To answer this question
it is essential to understand
that the situation of **dams**
is different from the situation
of **reservoirs** and **canals**.

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In the case of dams,
water is in contact with the ground.

Seepage into the ground
cannot be controlled,
unless the entire reservoir
is lined with a geomembrane.

Also, **leakage at the periphery** of
the face of the dam is difficult to control.

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A **tentative answer** regarding the
effectiveness of geomembranes
in controlling leakage in the case of dams
can be obtained
by reviewing data from dam rehabilitation,
and **comparing leakage rates**
before and after
rehabilitation of the dam
with a geomembrane.

*This is only a **tentative answer***
because some of the water,
flowing around the geomembrane periphery,
reaches the monitoring system.

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Data from 8 dams rehabilitated using a geomembrane, show that:

- The leakage rate ratio before and after rehabilitation ranges between 4 and 1200.
- Most typical ratios are between 10 and 100.

The wide range is probably due to different conditions at the geomembrane periphery.

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The preceding slide shows that there is a significant **reduction of leakage** when a geomembrane is used at the upstream face of a dam.

In conclusion, the use of a **geomembrane liner** is a very effective way to **control leakage** and **contain water** in the case of reservoirs, canals and dams.

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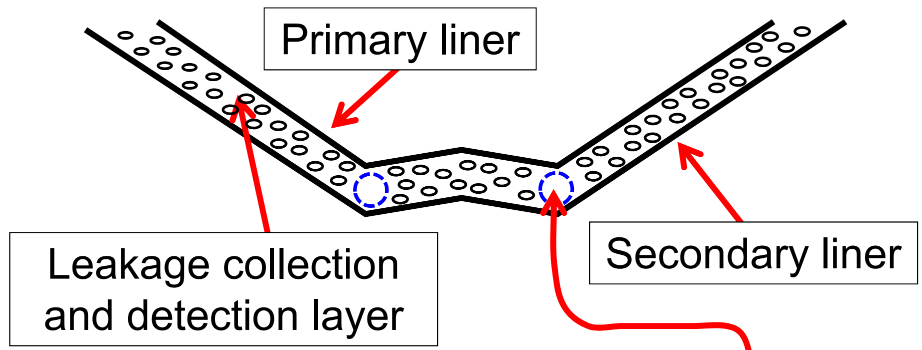
Since there is always
a risk of leakage through a liner,
even a geomembrane,
there is a solution for cases where
quasi-zero leakage
is required:
The solution is
a **double liner system**.

A double liner system
consists of two liners
(*primary liner* and *secondary liner*)
separated by
a drainage layer
acting as
leakage collection
***and detection layer*.**

SCHEMATIC REPRESENTATION
OF A
DOUBLE LINER SYSTEM



The leakage collection and detection layer includes **pipes** to **evacuate the water leaking** through the primary liner.

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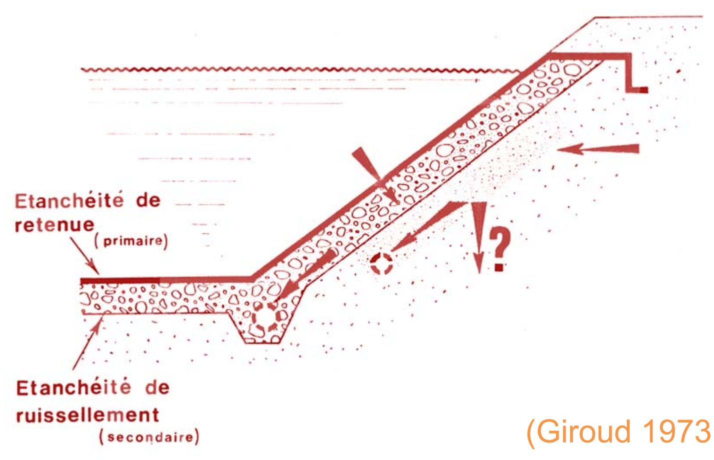
Here is the original drawing published in 1973 presenting the **double liner concept**.



(Giroud 1973)

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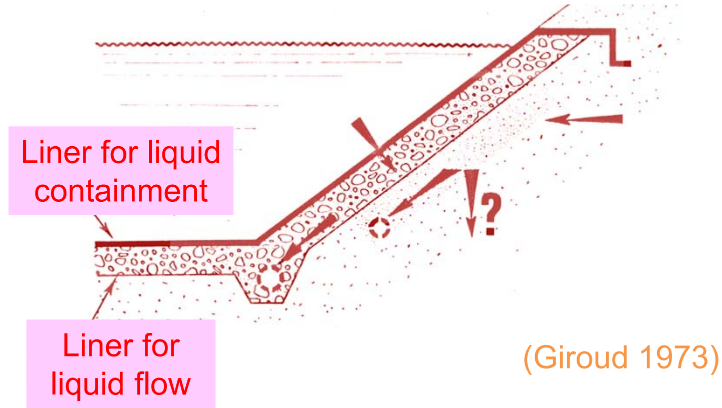
In this original drawing, the terminology was



This terminology clearly indicates that,
while the primary liner is subjected to high head,
the secondary liner is exposed to very low head.

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The essential feature of a double liner is the **very small hydraulic head on the secondary liner**, which ensures that there is very little leakage into the ground.

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CASE HISTORY

THE FIRST DOUBLE LINER

PONT DE CLAIX RESERVOIR
GRENOBLE, FRANCE

CONSTRUCTED IN 1974

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The water **reservoir** was located on a **steep slope**.

The **steep slope**

The **reservoir**

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The slope

The geotechnical study showed that **leakage** from the reservoir could impair the **stability** of the slope.

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Here is the **chemical plant**

Slope stability was essential because there was a large **chemical plant** at the toe of the **steep slope**, 50 meters lower than the reservoir.

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To minimize leakage into the ground, thereby preventing instability of the slope, a **double liner system** was selected.

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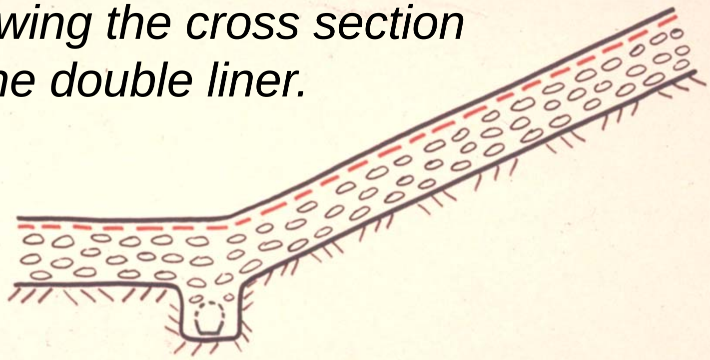
Here is the original drawing showing the cross section of the double liner.



Original drawing by J.P. Giroud

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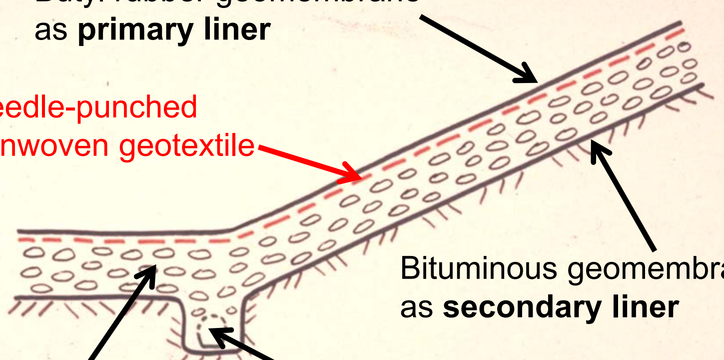
CROSS SECTION OF THE DOUBLE LINER



Original drawing by J.P. Giroud

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Placement of the secondary liner, a bituminous geomembrane

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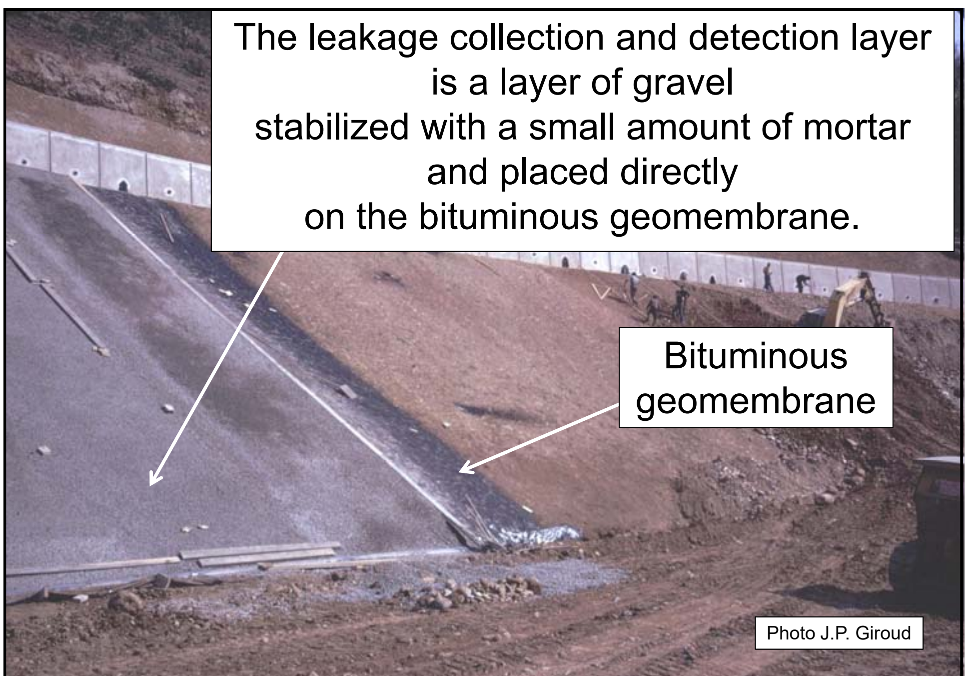

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Completed leakage collection and detection layer

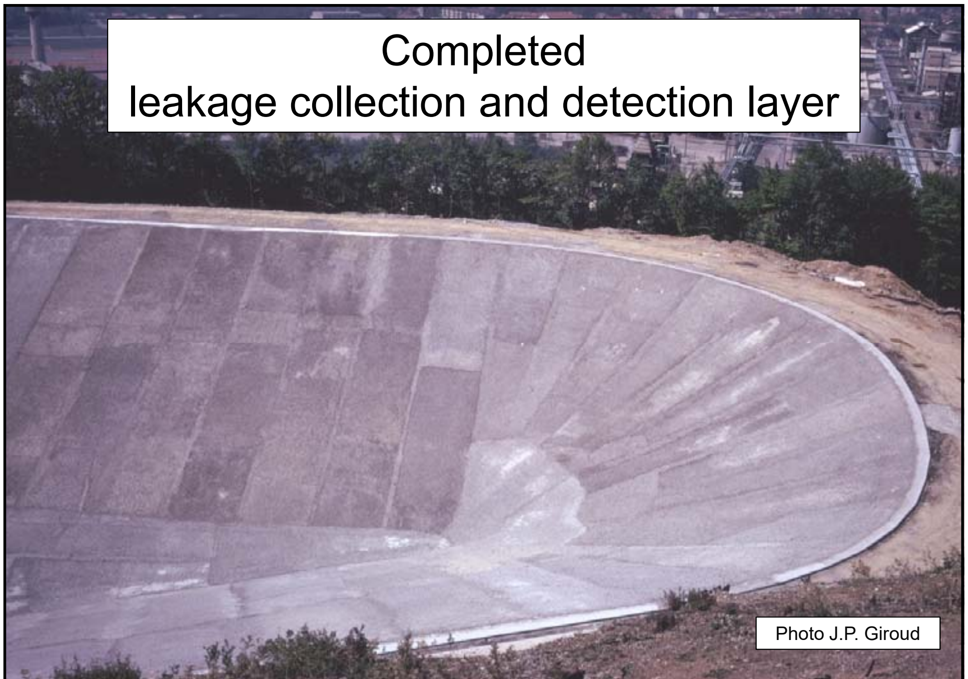

Photo J.P. Giroud

The selection of the mass per unit area of the geotextile protecting the geomembrane resulted from **pressure vessel tests** where the geomembrane/geotextile system was tested on a sample of the mortar-stabilized gravel.

Such tests were not common at the time (1973).

Courtesy D. Fayoux


Butyl rubber geomembrane
Nonwoven geotextile
Leakage collection and detection layer
Photo J.P. Giroud
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COMPLETED RESERVOIR
Photo J.P. Giroud
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The performance during 47 years has been excellent:

- Only one incident happened: **leakage** was detected by the leakage collection and detection system 30 years after construction.
- The leak was **near the water intake structure**.

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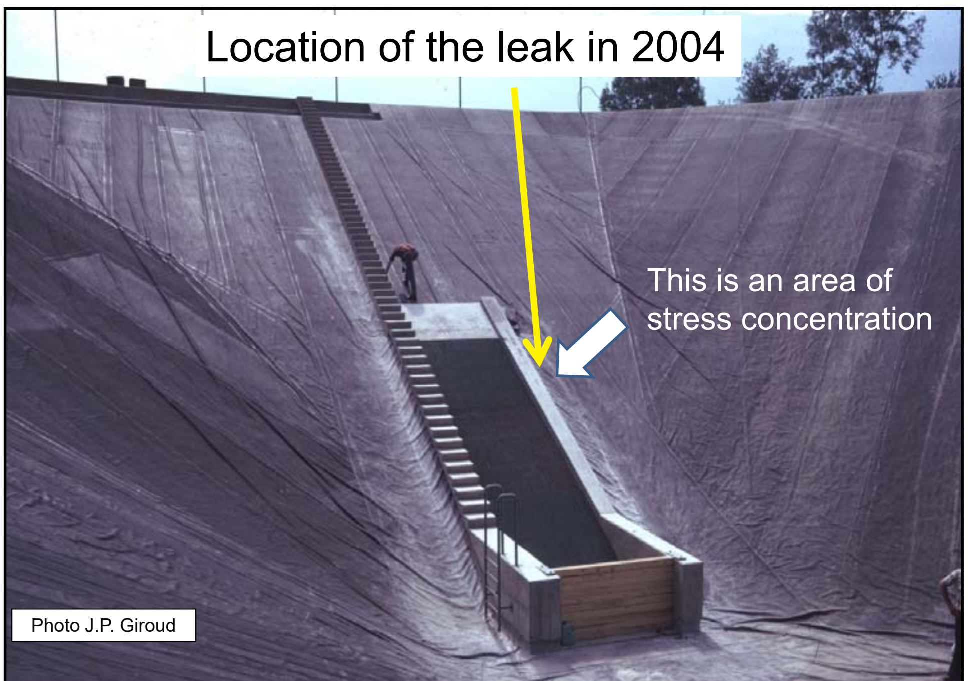
Location of the leak in 2004



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Regardless of the type of geomembrane liner,
single liner (which is the majority of cases) or
double liner,
the **number and size of holes**
in geomembranes **should be minimized**.

The **largest number of holes**
and the **largest size of holes**
in geomembranes
occur **during the placement of materials**
on top of the geomembrane.

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To minimize holes,
it is necessary to properly select
the geomembrane
and
the geotextile protection.

A proper selection
can be done **experimentally**.

It is easy to perform **full-scale tests**
in both the **laboratory** and in **the field.**

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Tests (in laboratory and/or in the field)
can be conducted
with the geomembrane **alone**
or with the geomembrane **protected**
using different geotextiles.

Therefore, **selection**
of the **geomembrane**
and its **geotextile protection**
can be done objectively.

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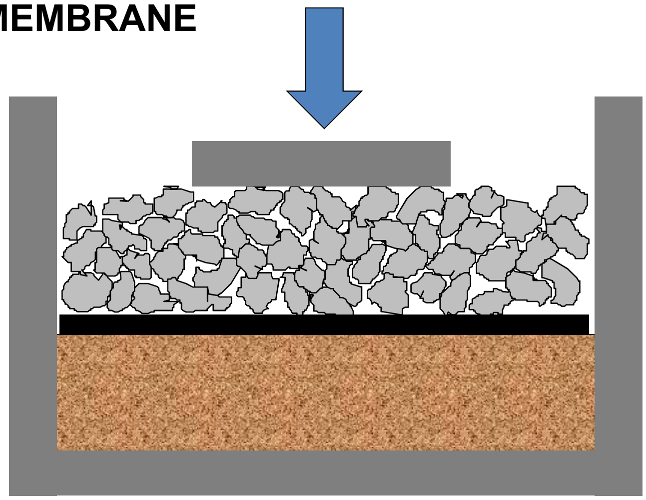
FULL-SCALE LABORATORY TEST WITH MECHANICAL LOAD

WITH GEOMEMBRANE ONLY



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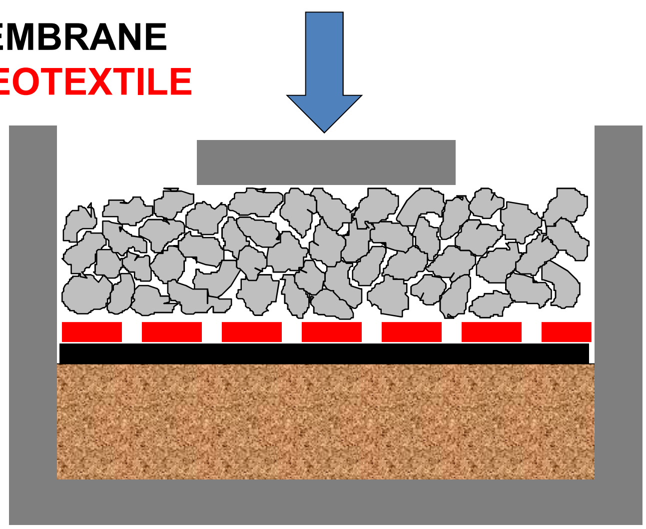
FULL-SCALE LABORATORY TEST WITH MECHANICAL LOAD

WITH GEOMEMBRANE AND GEOTEXTILE



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Here is another type of laboratory test.

This vessel is used to apply a water pressure.

Courtesy COLETANCHE

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GEOMEMBRANE SPECIMEN AFTER THE TEST

Courtesy COLETANCHE

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It is important to note that standard puncture tests, which measure puncture strength under unrealistic conditions, are **irrelevant**.

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EXAMPLE OF FIELD TESTS TO EVALUATE GEOMEMBRANE RESISTANCE TO PUNCTURING AND PROTECTION BY GEOTEXTILE

DONE AT AFOURER RESERVOIRS IN MOROCCO

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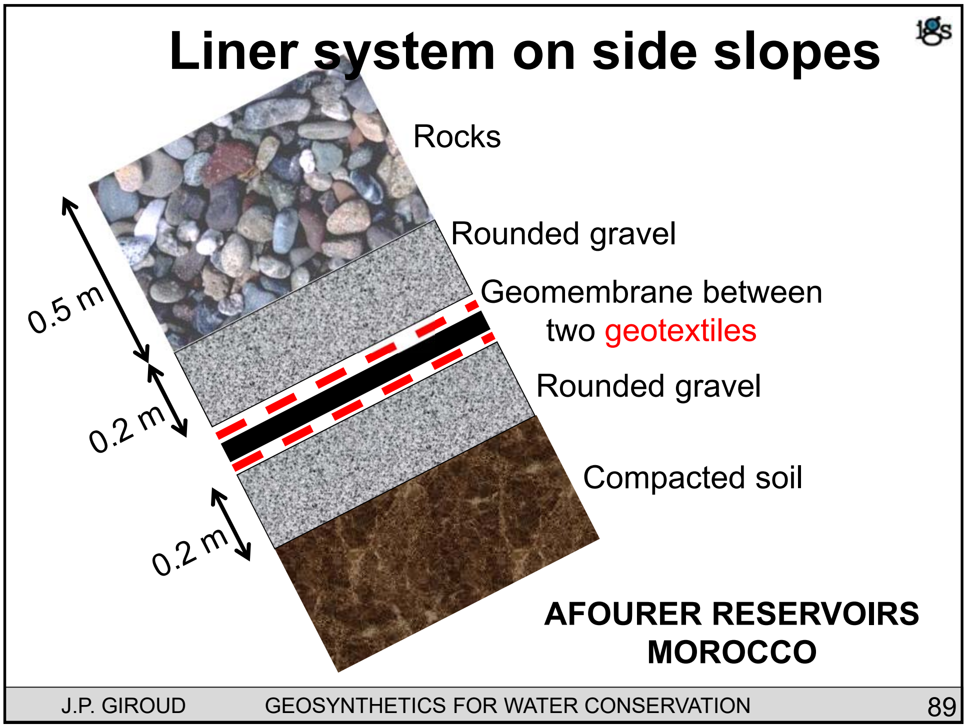
Liner system on side slopes
Rocks
Rounded gravel
Geomembrane between two geotextiles
Rounded gravel
Compacted soil
0.5 m
0.2 m
0.2 m
AFOURER RESERVOIRS MOROCCO
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AFOURER RESERVOIRS, MOROCCO
PVC GEOMEMBRANE
PLACEMENT OF GEOMEMBRANE BETWEEN TWO GEOTEXTILES
Courtesy D. Fayoux
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Covering the geomembrane was necessary:

- Protection against **exposure** to sunlight and weather
- Protection against **wind** uplift and **wave** action
- Protection against **animals**

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Here we see one of the field tests.

Courtesy
D. Fayoux

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ACCEPTANCE CRITERION

Several **configurations**
with different loads and different geotextiles
were tested.

A tested configuration is rejected
if it induces a puncturing mark
reducing the thickness
of the 1.5 mm PVC geomembrane
by more than 0.1 mm.

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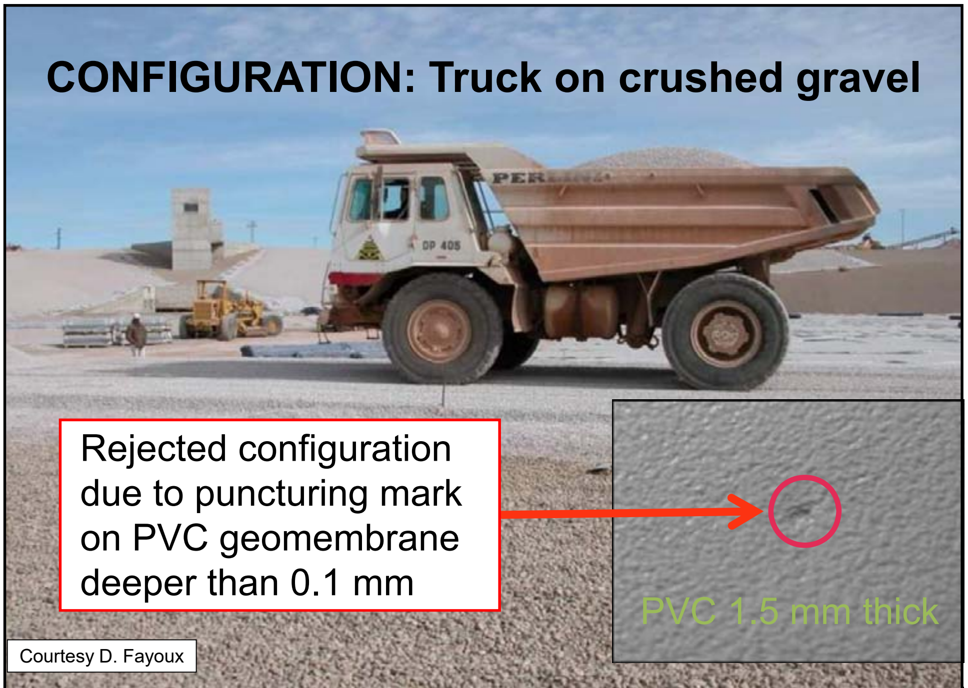

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In many projects, tests are not done.

The design engineer has to choose from a wide range of nonwoven geotextiles with different thicknesses (thickness is related to mass per unit area).

In those cases, the geotextile is selected based on experience and **local practice**.

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For the selection of the nonwoven geotextile, there is wide **discrepancy** between **practices in different countries**.

For example, here are values of mass per unit area of the geotextile:

- USA: 500 g/m^2 is considered heavy
- Europe: 1000 g/m^2 is often used
- In technically advanced cases: 2000 g/m^2

The next slide shows the use of a very heavy nonwoven geotextile.

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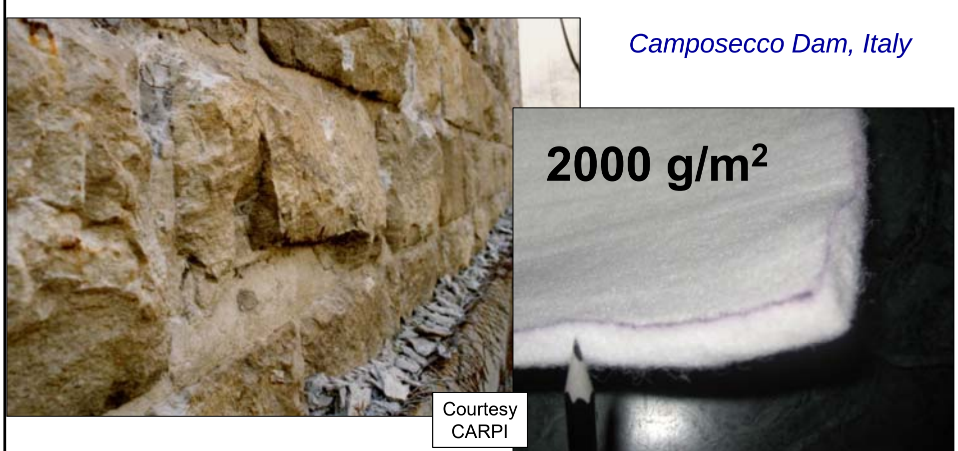
On the face of a **masonry dam**, a **very heavy nonwoven geotextile** was used between masonry and the geomembrane used for the rehabilitation of the dam.

Camposecco Dam, Italy



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TYPES OF GEOMEMBRANE PROTECTION

With the Afourer Reservoirs, we have seen a geomembrane protection by gravel and rocks.

There are other types of geomembrane protection for example:

- **Concrete slab** (rare in reservoirs, but frequent in canals and dams)
- **Geosynthetic system** such as geocell (filled with soil or concrete)

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CONSTRUCTION OF CONCRETE SLAB TO PROTECT THE GEOMEMBRANE FACING OF A DAM

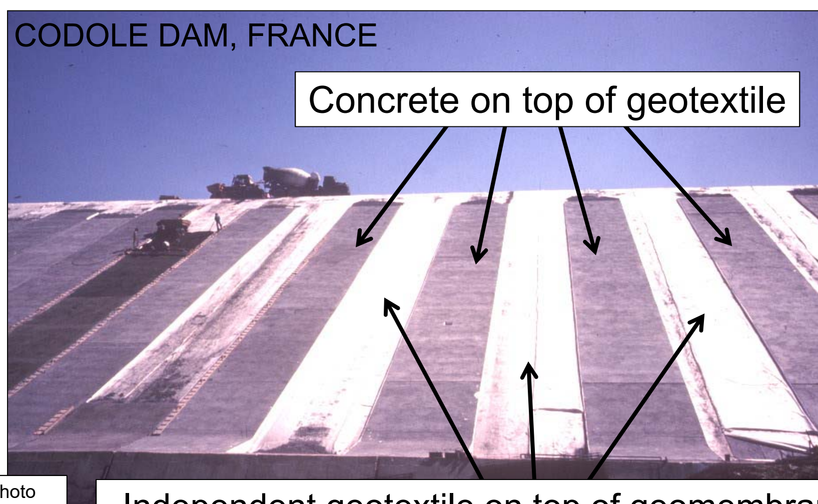

Photo J.P. Giroud

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CONSTRUCTION OF CONCRETE SLAB

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Reinforced concrete, 14 cm thick

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GEOCELL FILLED WITH SOIL

FOR GEOMEMBRANE PROTECTION AND VEGETATION

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GEOCELL FILLED WITH CONCRETE

FOR GEOMEMBRANE PROTECTION

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As mentioned earlier in this presentation, the **quality of geomembrane installation** is essential to minimize the number and size of holes in geomembranes.

To ensure the quality of geomembrane installation **construction quality assurance** and **electrical leak location** are essential.

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Construction quality assurance consists of **inspections and measures**, by a team independent from the geomembrane installer, during **installation of geomembrane** and during **placement of overlying materials**.

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Among the many
construction quality assurance activities
two activities are aimed at
finding holes in the geomembrane:

- **Nondestructive tests on seams**
  to find gaps in seams.
- **Visual inspection** of the entire geomembrane liner
  to find:
  - punctures and tears in the geomembrane
    and
  - gaps in attachments of geomembrane to structures.

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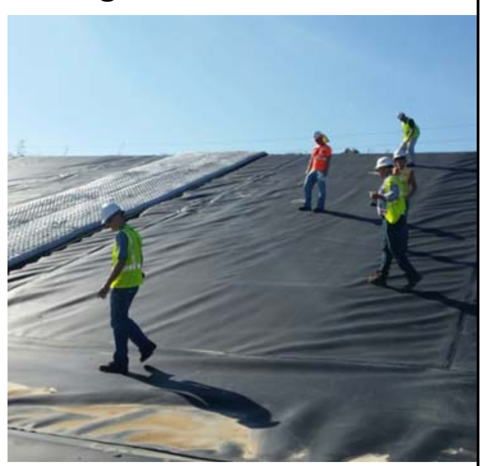
Nondestructive
testing of seam

Visual inspection
of geomembrane



Photos J.P. Giroud

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But, experience shows that
seam testing and visual inspection
are generally **not sufficient**
because they miss a number of holes.

Furthermore, these methods **do not find** geomembrane **holes caused by** the **placement of materials** on the geomembrane.

To find most geomembrane holes,
it is recommended to perform
electrical leak location surveys
in addition to construction quality assurance.

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The **principle** of
electrical leak location surveys is simple.

Most geomembranes are electrical insulators.

Therefore, **electric current will pass**
if there is a **hole** in the geomembrane
or a **gap** in an attachment to
an appurtenant structure.

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In the past two decades,
the **electrical leak location technology** has made **significant progress**.

Today, electrical leak location can be performed:

- on a **bare** geomembrane, (i.e. geomembrane not covered)
- on a geomembrane **under water**,
- or on top of a **layer of soil** placed on a geomembrane.

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Electrical leak location on a **bare** geomembrane

Electrical leak location on top of a **layer of soil** overlying a geomembrane

Courtesy A. Beck

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When a geomembrane is designed to be **covered by a layer of soil**, it is important to perform an electrical leak location survey, *not only after geomembrane installation*, but also **after placement of the soil layer** because holes in the geomembrane are often caused by soil placement.

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Example of construction damage found using electrical survey done on top of soil layer.

Courtesy I. Peggs

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Finding such **large holes** is easy with electrical leak location survey performed on top of a soil layer overlying a geomembrane .

It is **more difficult to find small holes**.

The electrical leak location technology has made great progress,
and, now,
millimetric holes can be found,
even under half a meter of soil.

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CONCLUSION

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This presentation shows that geomembranes are **far superior** to all other materials for **watertightness**.

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Thus,
by using geomembranes
and other **geosynthetics**
to contain water,
we act in a way that is
beneficial to society at large,
because **water** is
one of the great challenges
of the 21st century.

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However, there is more.

The reason for the extraordinary success of geomembranes is

absolutely fundamental.

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To **contain water**
in reservoirs, dams and canals,
it is necessary to use a **liner**,
which is
a **two-dimensional material**.

But, nature does not provide two-dimensional materials.

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Natural materials are essentially three-dimensional . . .

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. . . or three-directional.

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Since nature
does not provide
two-dimensional materials,
synthetic materials
must be used:

the geosynthetics

For this fundamental reason,
because they are
the only two-dimensional
construction materials,
geosynthetics,
in particular geomembranes,
are
the obvious solution
for water containment
and water conservation.


RESERVOIRS
Thank You
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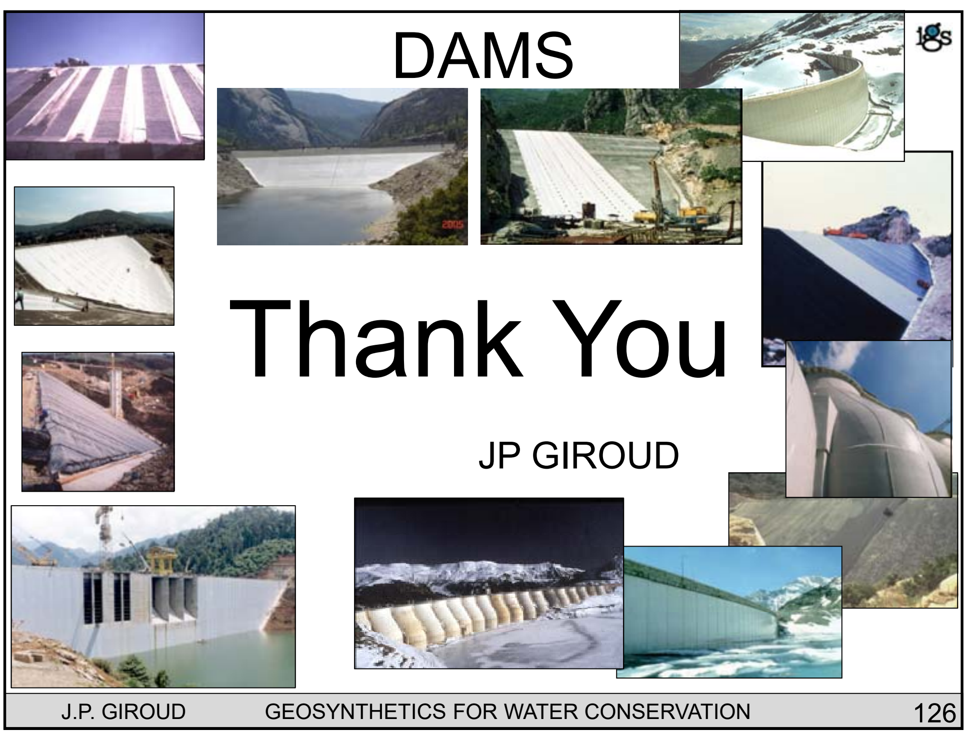
DAMS
Thank You
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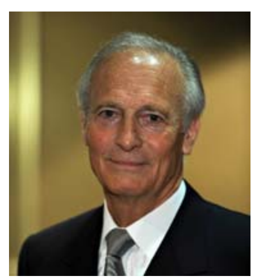
ABOUT THE LECTURER



Dr. J.P. Giroud, civil engineer Ecole Centrale Paris and PhD University of Grenoble, is a consulting engineer, a former professor of geotechnical engineering, founder and Chairman Emeritus of Geosyntec Consultants, past president of the International Geosynthetics Society (the IGS), former chairman of the Editorial Boards of *Geotextile and Geomembranes* and *Geosynthetics International*, and a member of the U.S. National Academy of Engineering.

Dr. Giroud has been involved with geosynthetics since 1970.
He coined the terms “geotextile” and “geomembrane” in 1977.
He has developed numerous design methods used in geosynthetics engineering, for lining systems, leakage control, drainage, geotextile filters, and geosynthetic-stabilized roads.

Dr. Giroud is author of more than 400 publications, and he has presented several prestigious lectures, such as: the Vienna Terzaghi Lecture, the ASCE Terzaghi Lecture (the highest honor for a geotechnical engineer in the United States), the Victor de Mello Lecture, the Szechy Lecture, the Mercer Lecture, the Jack Hilf Lecture, the Raoul Dutron Lecture, the Kersten Lecture.

Dr. Giroud is Doctor *Honoris Causa* of the Technical University of Bucharest, he has been named Hero of the Geo-Institute of the American Society of Civil Engineers, he received the Felix Leader Award of Ecole Centrale Paris for 2013, and he is Chevalier in the Order of the Legion d’Honneur.
The IGS has named his highest honor “the Giroud Lecture” and he became Honorary Member of the IGS in 2002 with the citation “Dr. Giroud is truly the father of the IGS and the geosynthetic discipline”.

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