Applications of geosynthetics in dams and tunnels

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SUMMARY

1. Introduction
2. Dams and reservoirs
3. Tunnels and underground structures
4. Conclusions

1. Introduction

Over the last 60 years, the use of geosynthetics has increased in civil, geotechnical, and geo-environmental projects around the world for a variety of functions.

In more recent decades, **their use instead of, or in partial combination with, natural materials** – such as gravel, sand, clay, and so forth – emphasized their crucial role in terms of **sustainability, circular economy**, and in light of the dramatic **climatic change** issues.

2. Dams and reservoirs

Geotextiles as filters in dams

Geotextiles and geomembranes as protection and barrier in dams

Geotextiles and geomembranes as protection and barrier in reservoirs for artificial snow systems

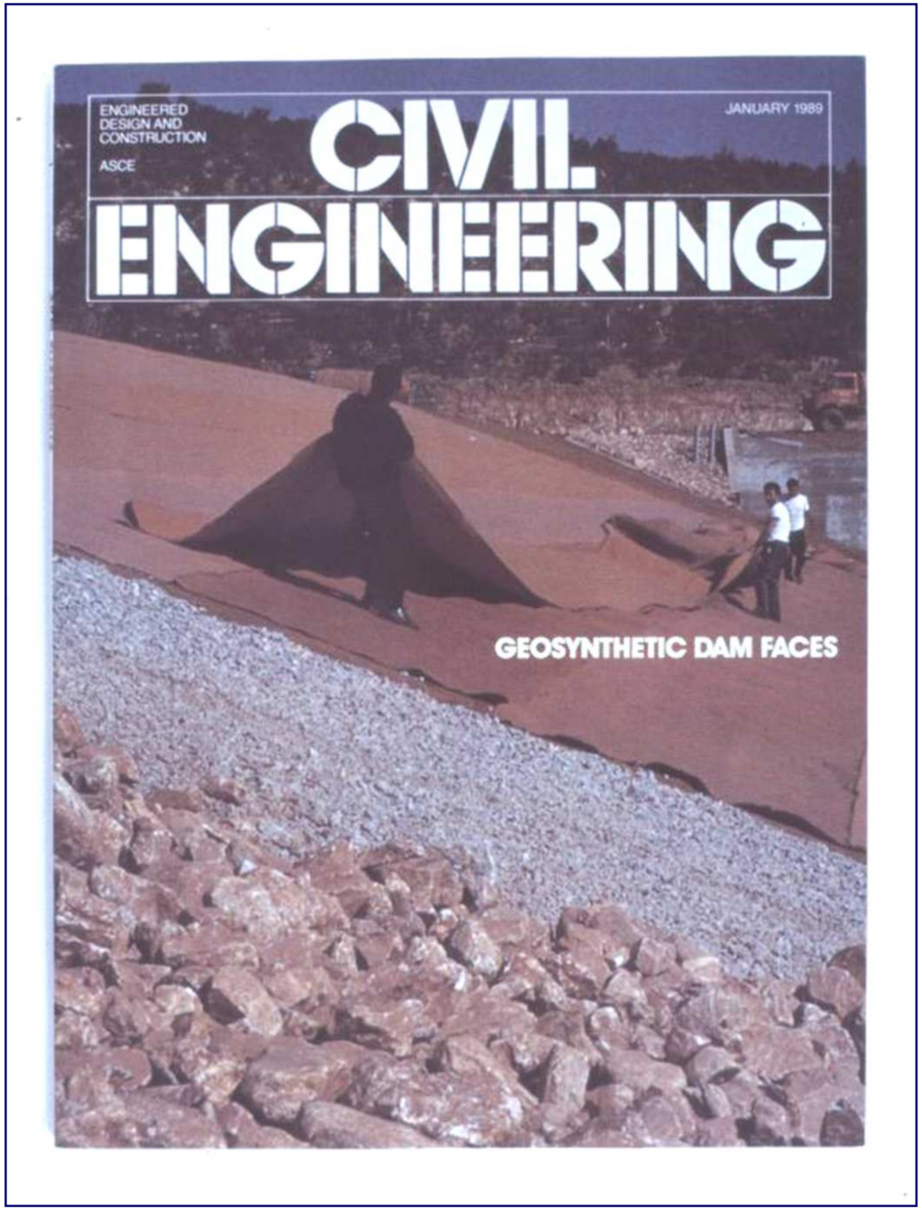
2.1 Geotextiles as filters in dams

FIRST USE OF A GEOTEXTILE IN A DAM

VALCROS DAM

FRANCE, 1970

VALCROS DAM, FRANCE (1970)



shown here
on the cover of
CIVIL ENGINEERING.

is
the **first dam**
constructed
using **geotextiles**:

on the upstream slope,
as we see here,
but, more importantly . . .

. . . as a geotextile filter for the downstream drain.

Photo J.P. Giroud


Photo J.P. Giroud

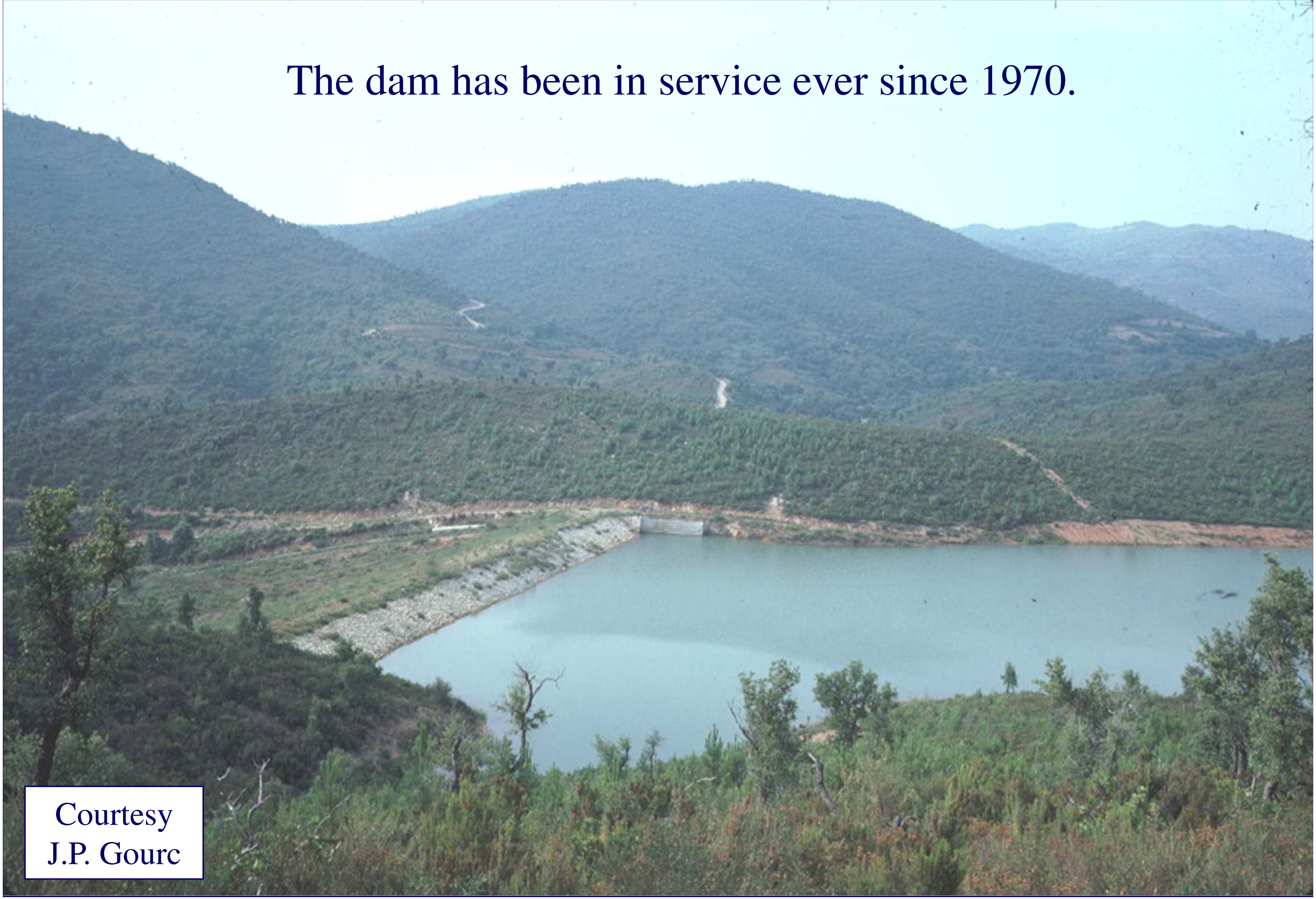

Photo J.P. Giroud


Photo J.P. Giroud

VALCROS DAM

- SOIL: Silty sand 30% < 0.075 mm
- FILTER: nonwoven geotextile
  (never used before as a filter in a dam)

The dam has been in service ever since 1970.



Courtesy
J.P. Gourc

The performance has been satisfactory:

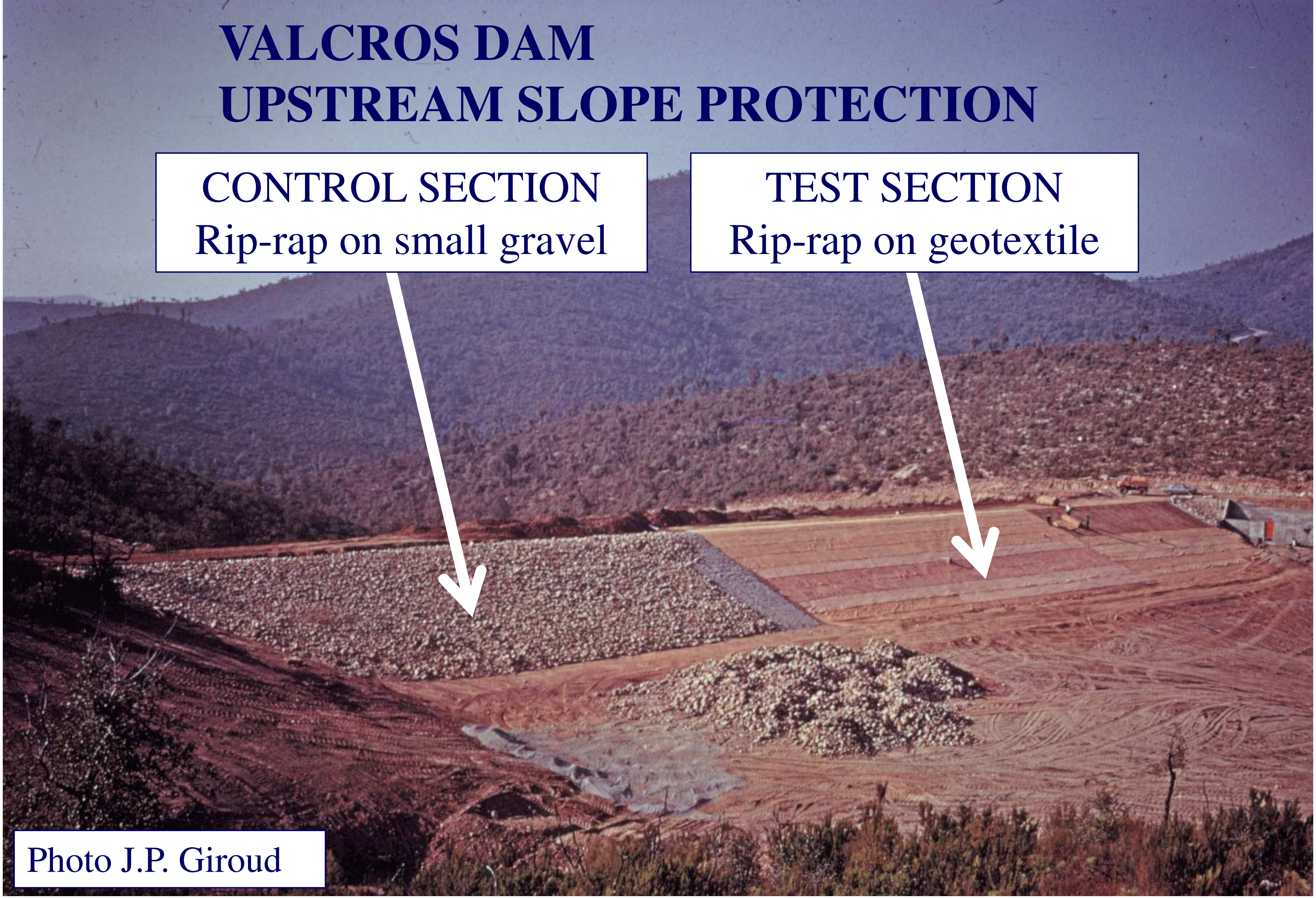
- Constant trickle of clean water.
- Flow rate consistent with the hydraulic conductivity of the embankment soil.
- No seepage of water ever observed through the downstream slope.
- Geotextile filter in good condition and clogging absolutely negligible (0.2% of the pore volume of the geotextile).

as demonstrated by tests on samples of geotextile removed from the actual filter, 6 years and 22 years after construction.

VALCROS DAM DOWNSTREAM SLOPE

The outstanding performance
of the geotextile filter
of Valcros Dam
can be explained by the fact that
the four filter criteria are met:

- permeability and porosity
- retention and thickness

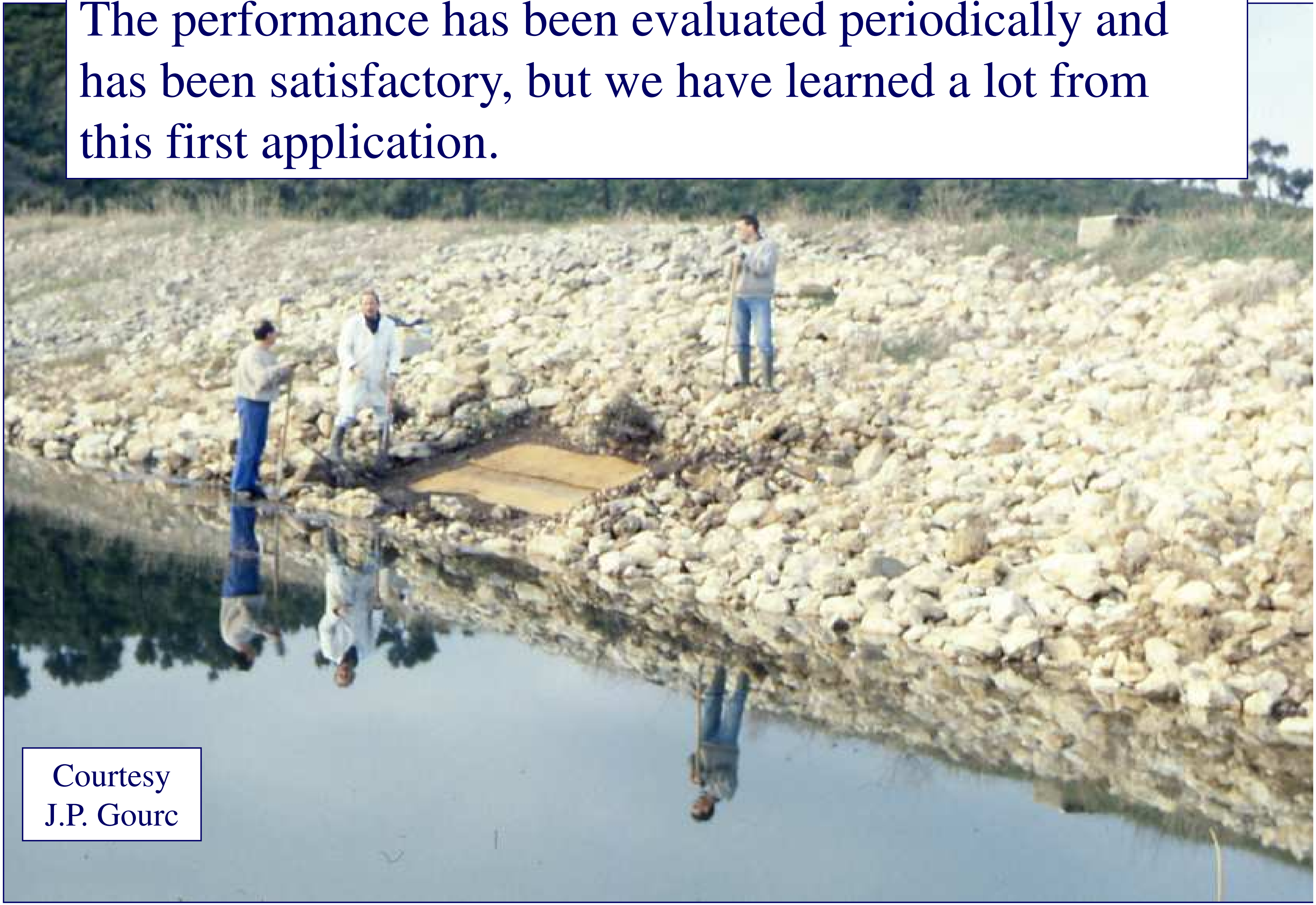

VALCROS DAM
UPSTREAM SLOPE PROTECTION
CONTROL SECTION
Rip-rap on small gravel
TEST SECTION
Rip-rap on geotextile
Photo J.P. Giroud

VALCROS DAM DURING CONSTRUCTION

Photo J.P. Giroud

Photo J.P. Giroud

The performance has been evaluated periodically and has been satisfactory, but we have learned a lot from this first application.



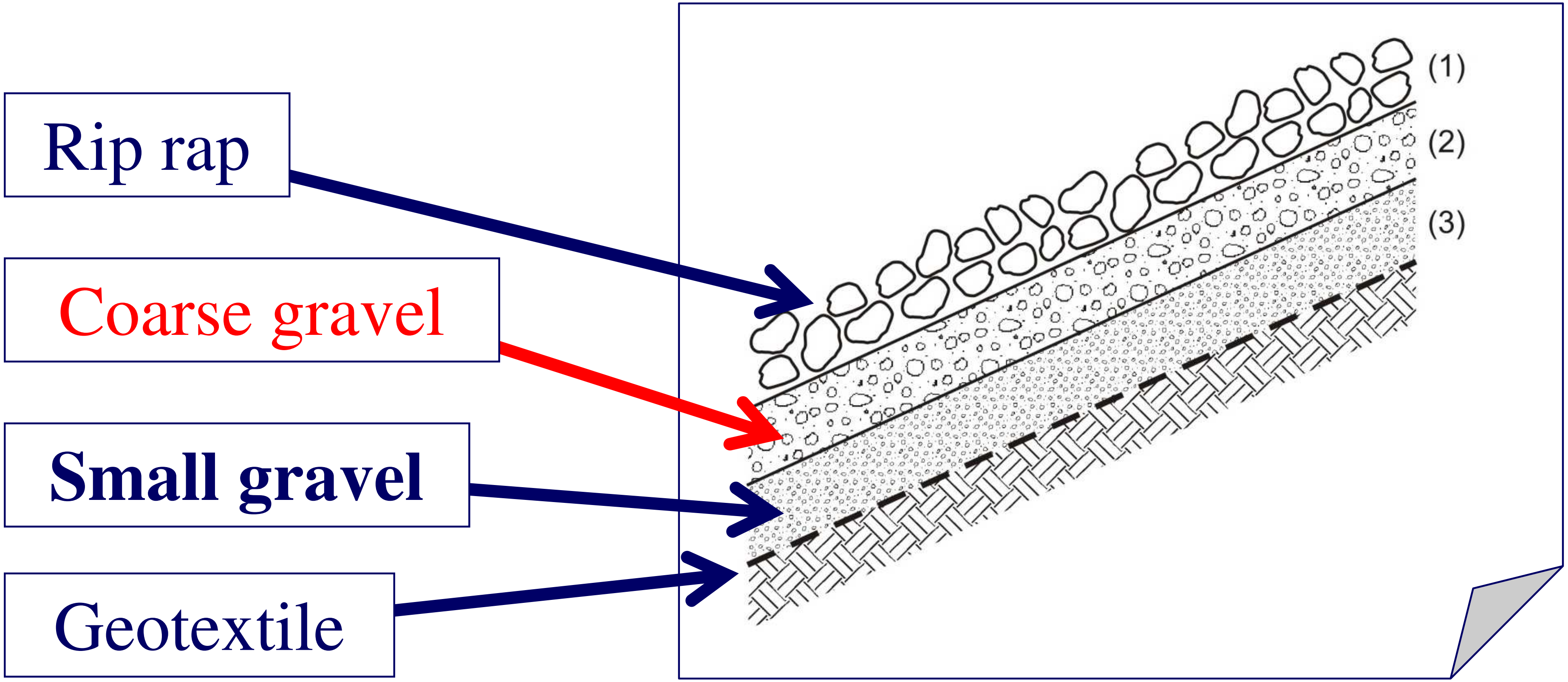
Courtesy J.P. Gourc

In fact, if strong wave action is expected
(large reservoir, windy area),
the geotextile filter should be kept in **intimate contact with the embankment soil**.

If not, soil particles will be displaced and the geotextile filter will risk to become clogged.

To that end, **small gravel should be placed against the geotextile to ensure that uniform stress is applied on the geotextile**.

A layer of **coarse gravel** may be needed to ensure transition between small gravel and rip rap.



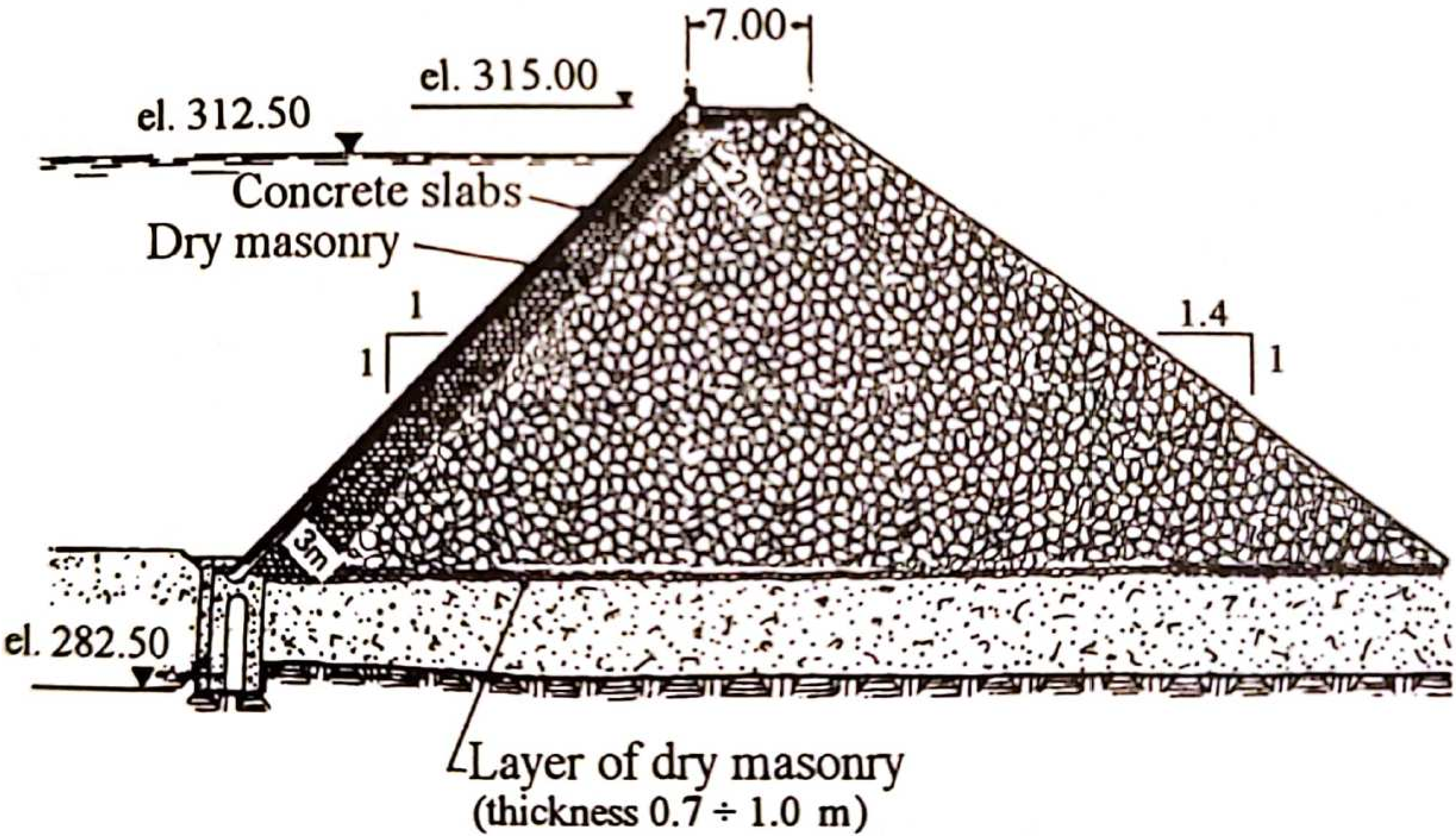
2.2 Geotextiles and geomembranes as protection and barrier in dams

FIRST USE OF A GEOMEMBRANE IN A DAM

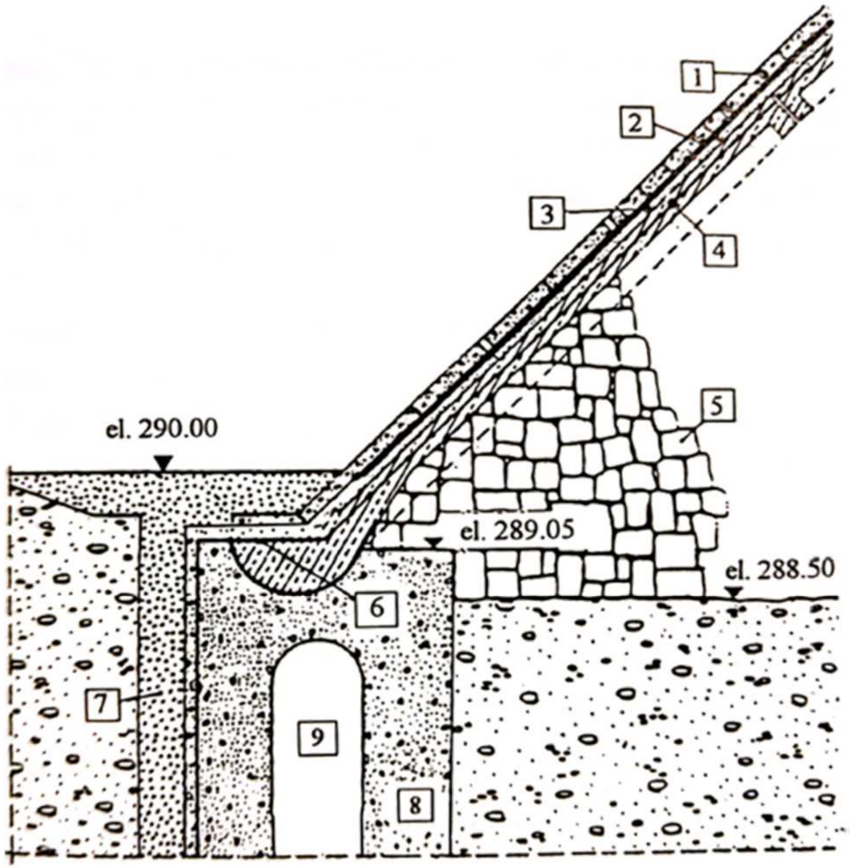
CONTRADA SABETTA DAM

ITALY, 1959

Contrada Sabetta Dam



Contrada Sabetta Dam



1) 0.20 m thick concrete slabs
2) one sheet of bituminous paper-felt + two sheets of polyisobutylene geomembrane (2.0 mm thick) + bituminous adhesive
3) porous concrete (0.10 m thick)
4) reinforced concrete slabs (0.25 m thick)
5) dry masonry (thickness ranging from 2.00 to 3.00 m)
6) joint be-tween plinth and upstream facing
7) plastic concrete diaphragm wall
8) concrete plinth
9) inspection and drainage gallery

For protection function of the geomembrane, no geotextile was used but porous concrete layer under and concrete slab over

Contrada Sabetta Dam

- 32.5 m high, 1V:1H
- Dry masonry
- **First dam** constructed using **geomembrane**
- Elastomeric geomembrane **PIB Polyisobutylene**
- 2.0 mm thick for each layer (two layers)
- Underlain by drainage layer (porous concrete)
- Geomembrane protected by concrete slabs, 2 m x 2 m x 0.2 m with 1 mm **open joints**

Contrada Sabetta Dam

The dam has been in service ever since 1959

Photo 38 years after construction (1997)

2.2 Geotextiles and geomembranes as protection and barrier in dams

New construction

L'OSPEDALE DAM, FRANCE (1978)

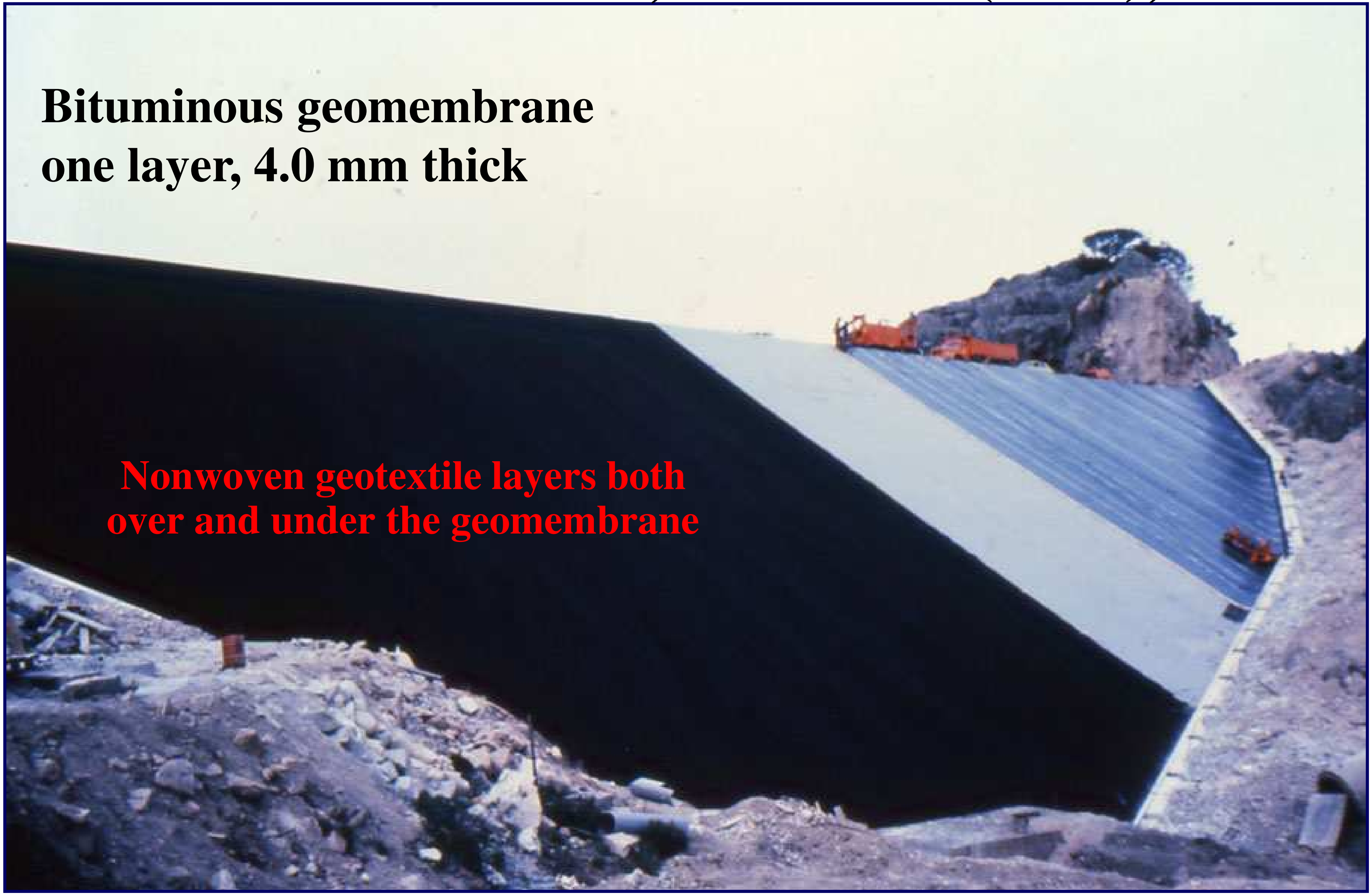
BOVILLA DAM, ALBANIA (1996)

Rehabilitation

KADAMPARAI DAM, INDIA (2005)

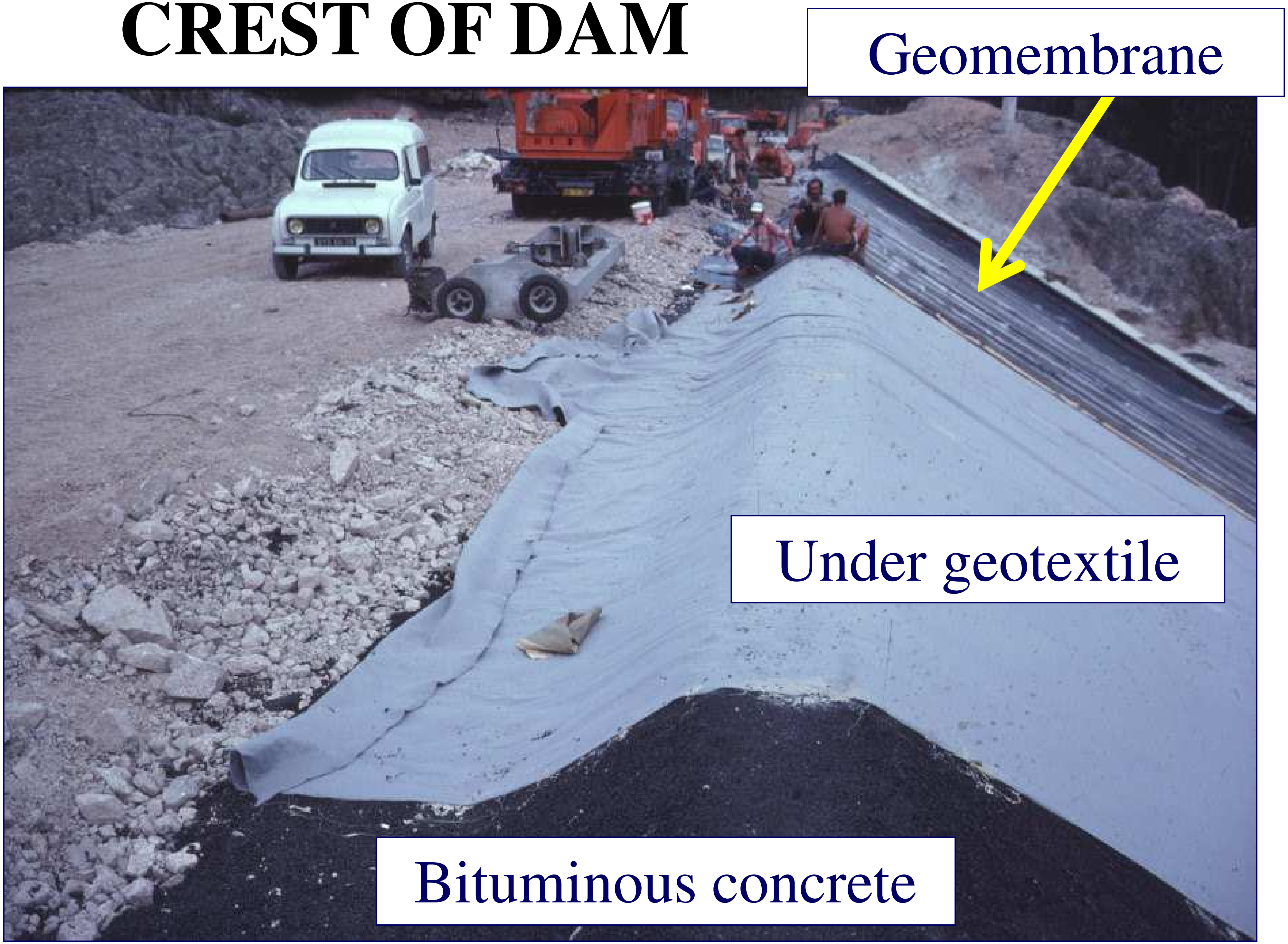
First example of bituminous geomembrane fully covered

L'OSPEDALE DAM, FRANCE (1978), 26 m

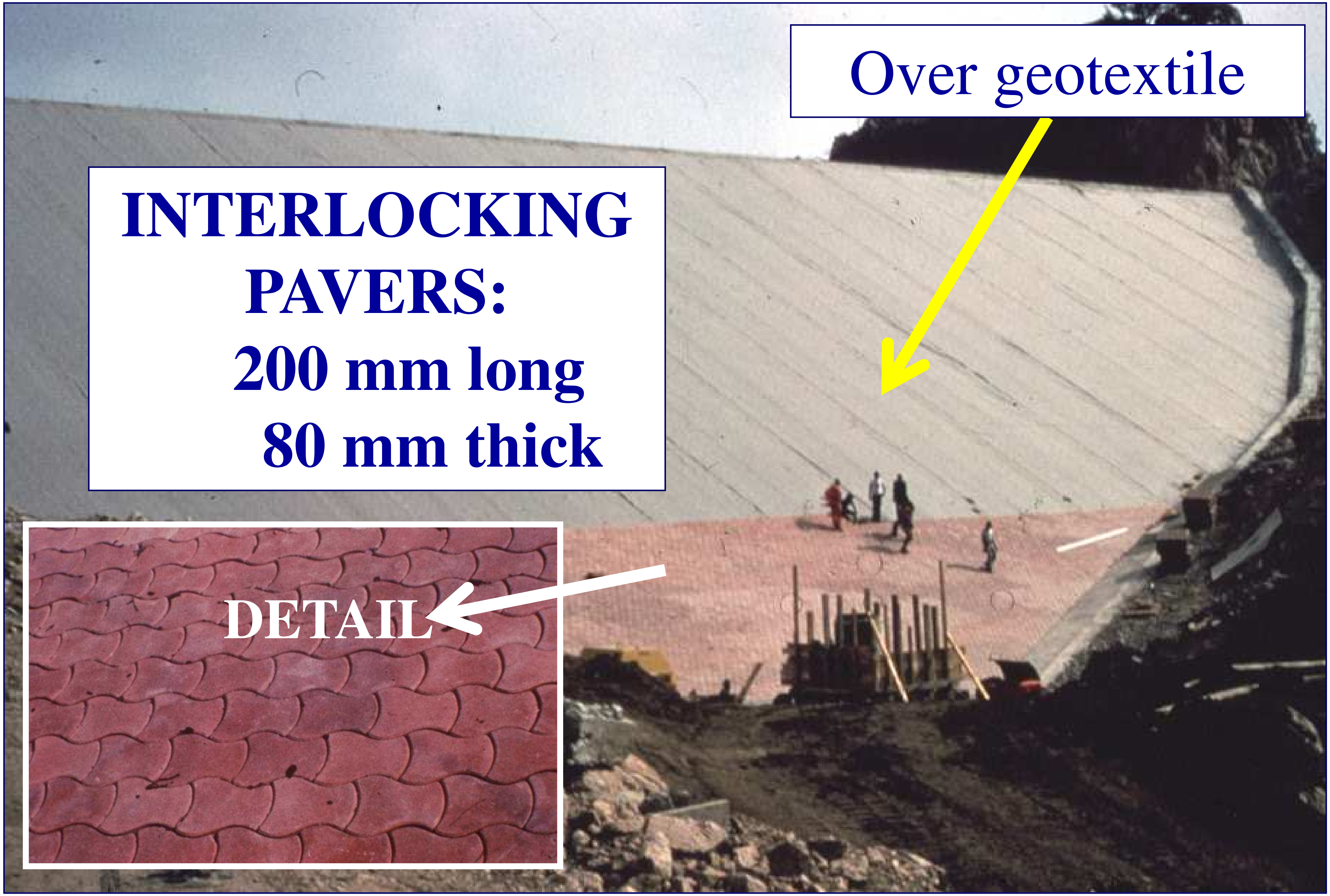


GEOSYNTHETIC INSTALLATION

CREST OF DAM



GEOMEMBRANE COVERED WITH OVER GEOTEXTILE AND CONCRETE PAVER BLOCKS



Composite PVC geomembrane fully covered

BOVILLA, ALBANIA (1996)
Height 91.0 m
Cover layer: unreinforced concrete slabs

Composite geomembrane formed by:

PVC geomembrane, 3.0 mm thick

PET nonwoven geotextile, 700 g/m^2

Composite geomembrane does not require heavy surface preparation

An extra layer of PP nonwoven geotextile (800 g/m^2) was placed over the composite geomembrane before the casting of unreinforced concrete slabs

Casting of unreinforced concrete slabs, by alternate method


All barrier system installation: 30 days

KADAMPARAI DAM, INDIA (2005)

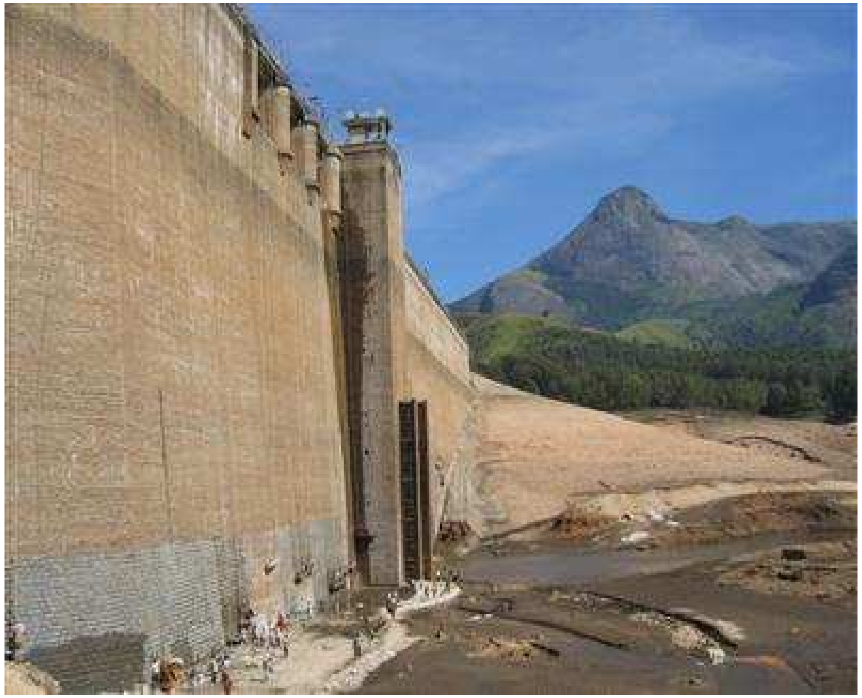
Dam height: 67 m - (pumped storage, 400 MW)

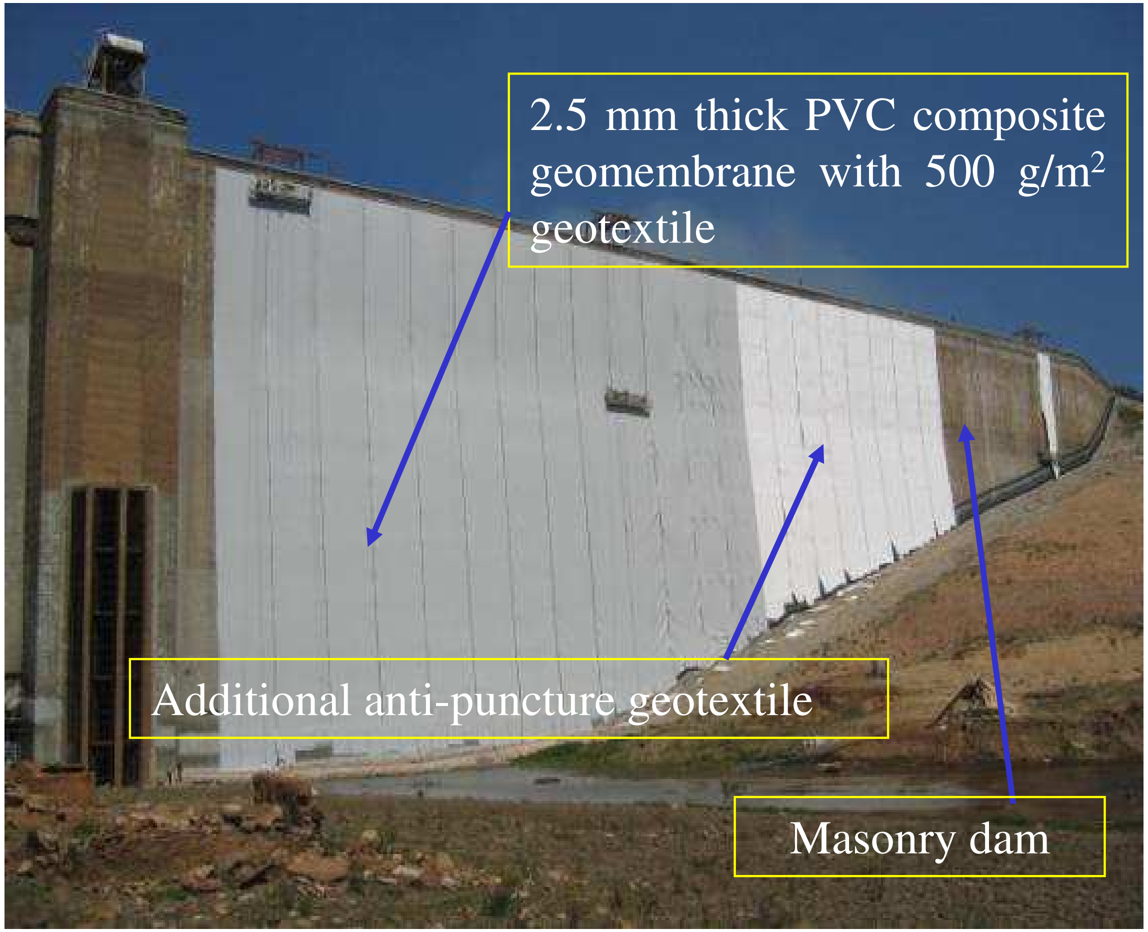
EXPOSED PVC COMPOSITE GEOMEMBRANES USED FOR REHABILITATION OF MASONRY DAMS

Dam masonry surface on which installation
of composite geomembrane was required

Surface preparation consisted only of a very thick nonwoven geotextile as anti-puncturing

Kadamparai dam, India





Kadamparai dam, India

After repair with exposed composite geomembrane, leakage reduced from 38,000 l/m → 30 l/m

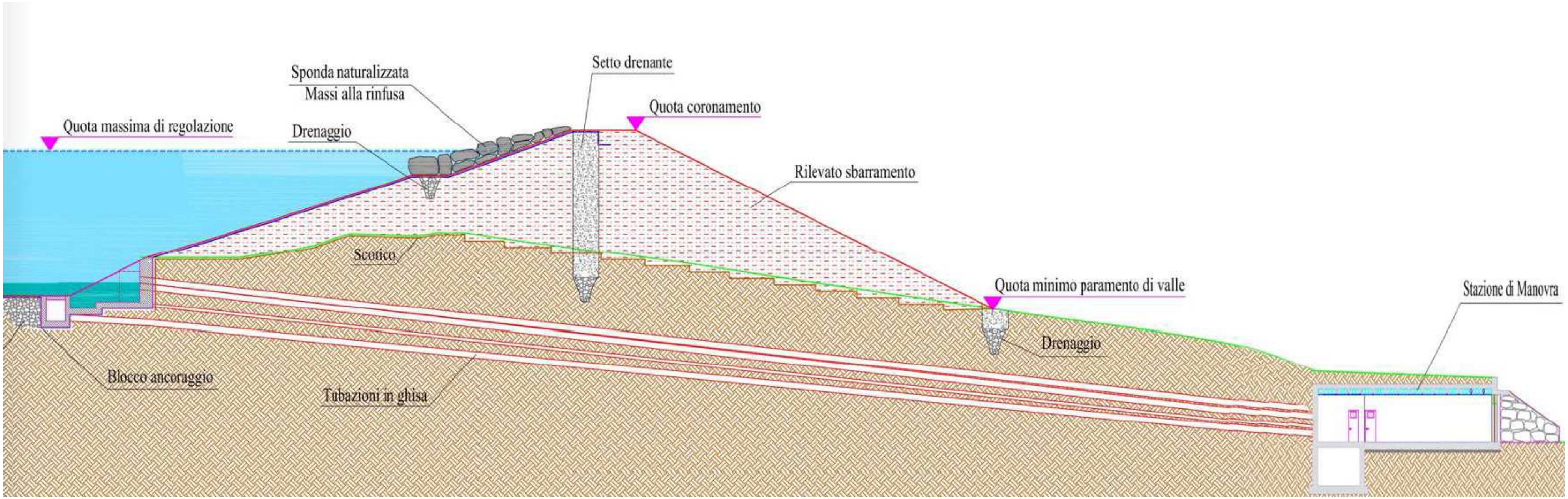
EXPOSED COMPOSITE GEOMEMBRANES FOR REHABILITATION OF MASONRY DAMS

Before repair

After repair

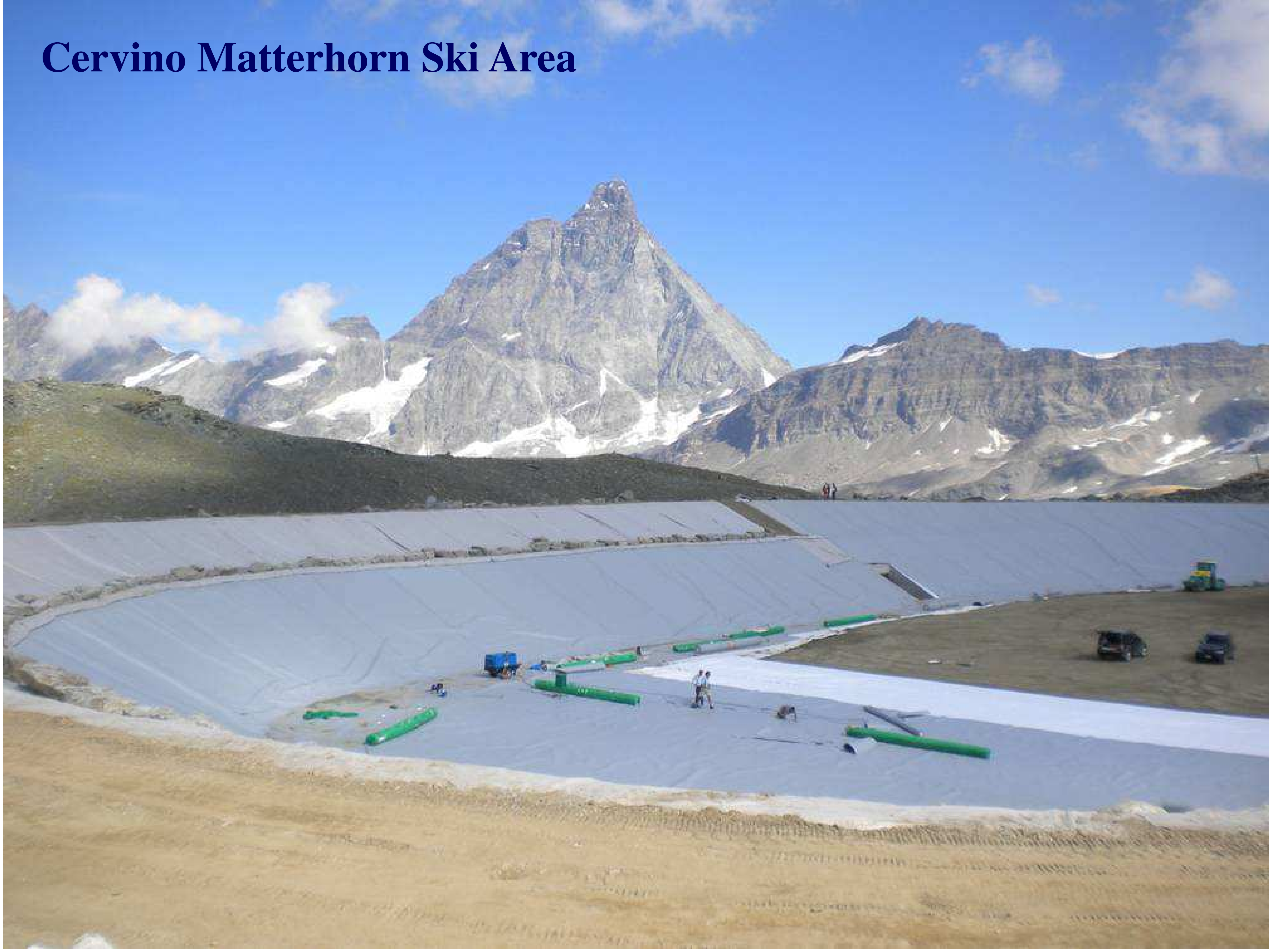
Barrier system works executed in 3 months (>17.000 m^2)

2.3 Geotextiles and geomembranes as protection and barrier in reservoirs for artificial snow systems



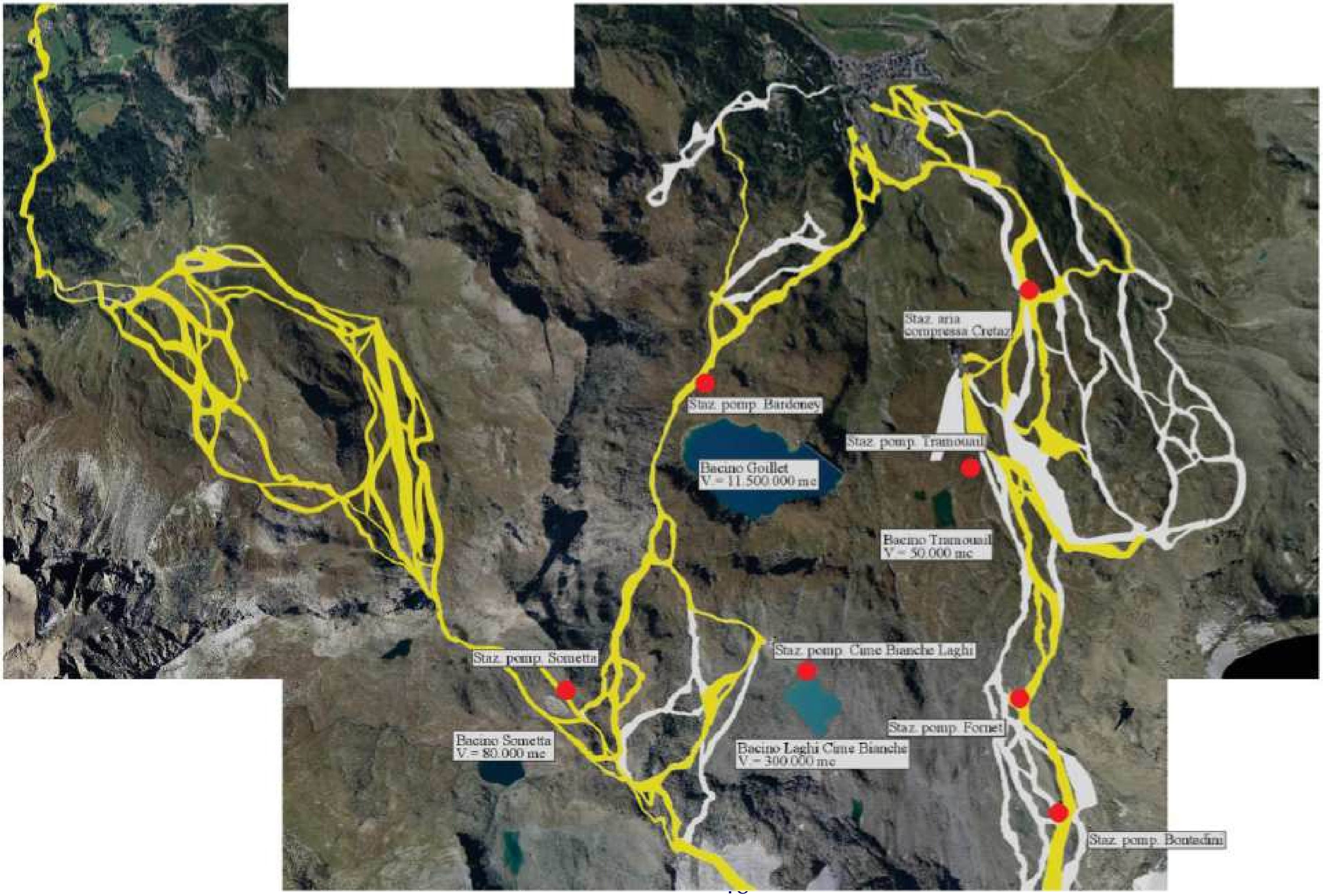
Influence of **climate change**

Cervino Matterhorn Ski Area

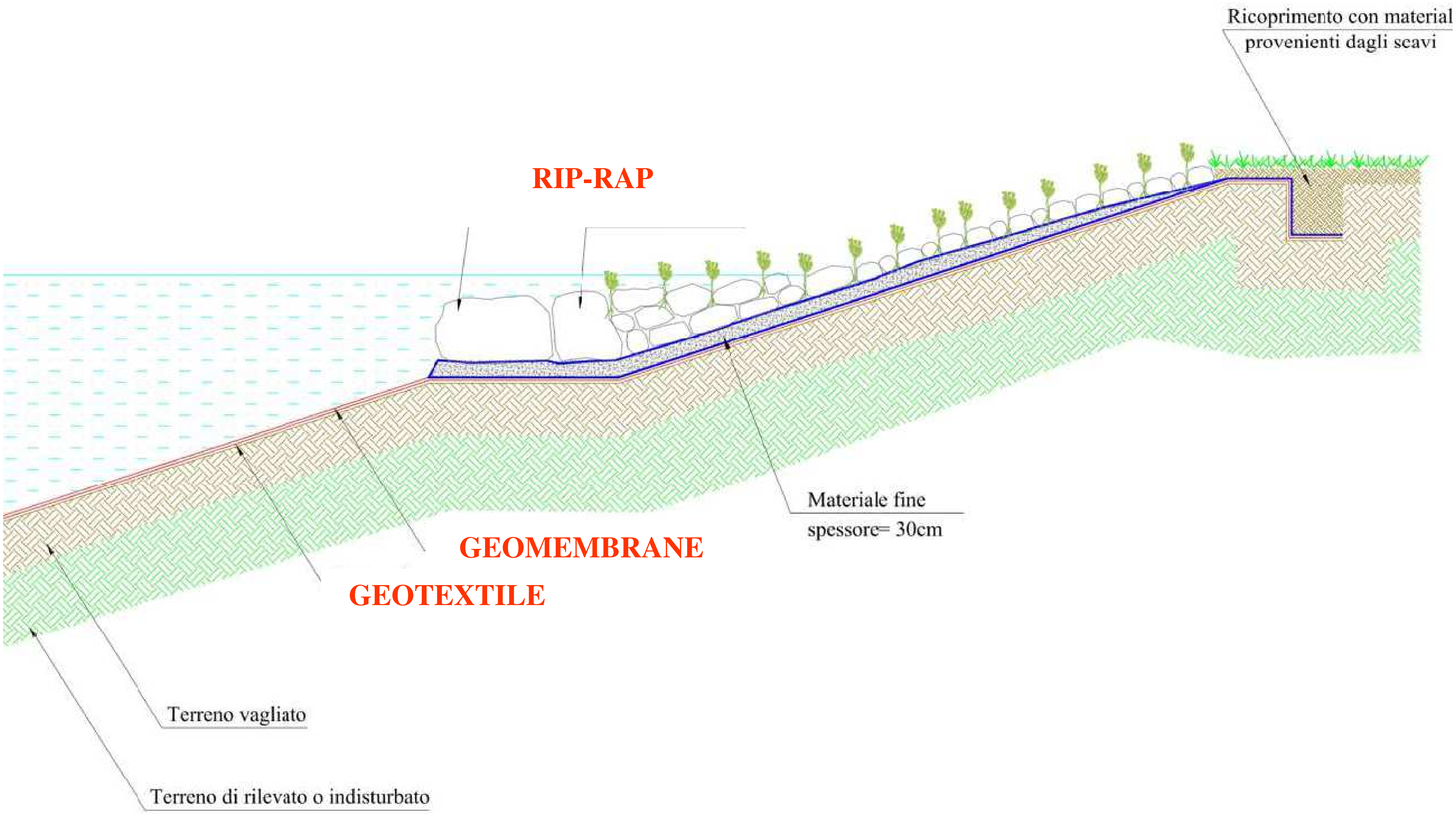


Cervino Matterhorn Ski Area

Cervino Matterhorn Ski Area



Monte Rosa Ski Area



Monte Rosa Ski Area

Monte Rosa Ski Area

Piani di Bobbio Ski Area

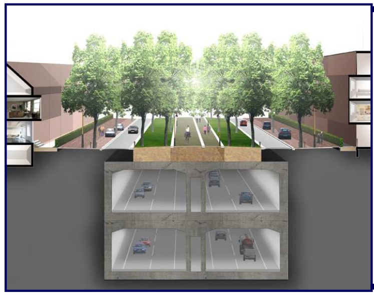
Piani di Bobbio Ski Area

Piani di Bobbio Ski Area

Piani di Bobbio Ski Area

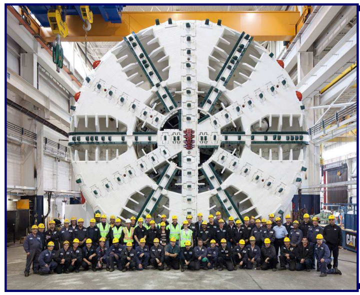
3. Tunnels and underground structures

Types of construction methods



Cut and cover tunnelling

Drill and blast tunnelling
(conventional tunnelling NATM)

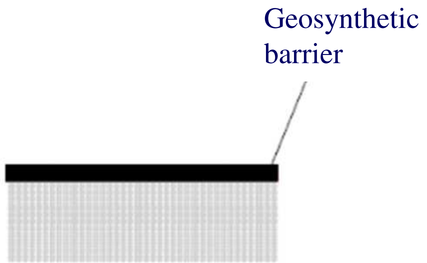


Mechanized tunnelling using
Tunnel Boring Machine (TBM)

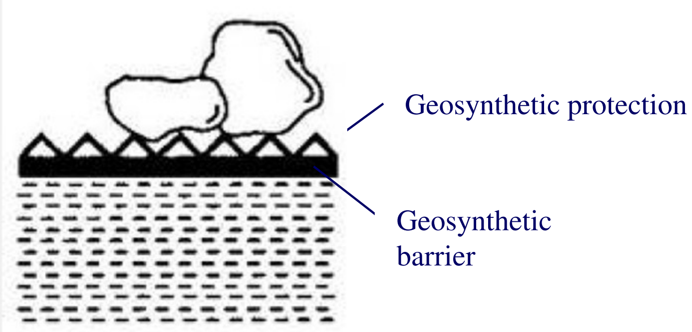
Geosynthetics in tunnels and underground structures: functions and types

Barrier (mainly waterproofing) ⇒ Geomembranes

Composite geomembranes

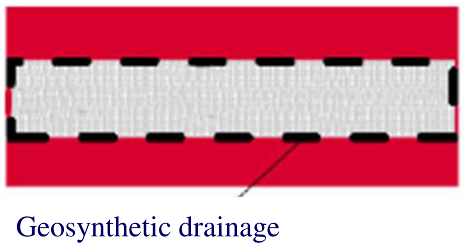


Protection ⇒ Nonwoven Geotextiles



Drainage ⇒ Geonets

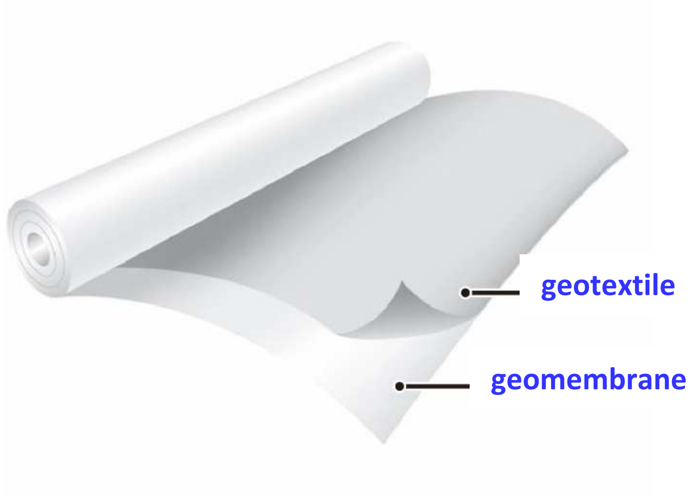
Drainage geocomposites



Geosynthetics for barrier (waterproofing)

Geomembranes

Composite Geomembranes



Tunnel of Marão - Portugal

Spalov Tunnel - Czech Republic

Geosynthetics for protection

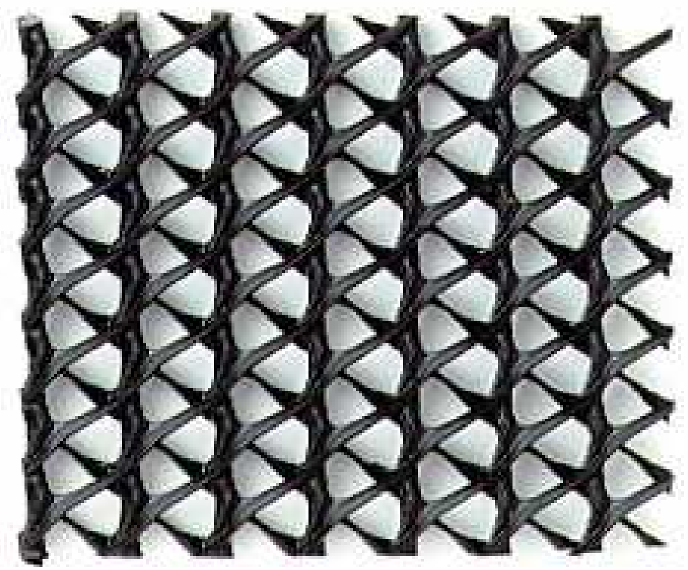
Nonwoven Geotextiles

Chojlla Tunnel – Bolivia

Gleitalm Tunnel – Austria

Geosynthetics for drainage

Geonets	Drainage geocomposites

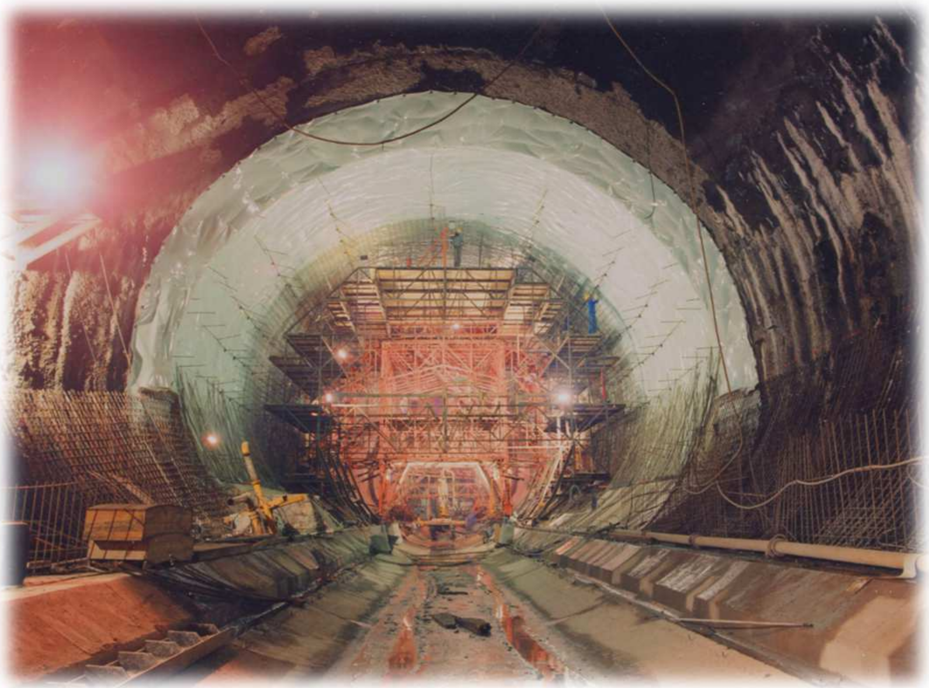


Belden Tunnel – United States

Driskos Tunnel – Greece

Transportation tunnels and hydraulic tunnels

TRANSPORTATION TUNNELS



Baixa-Chiado Station Lisbon subway
Portugal

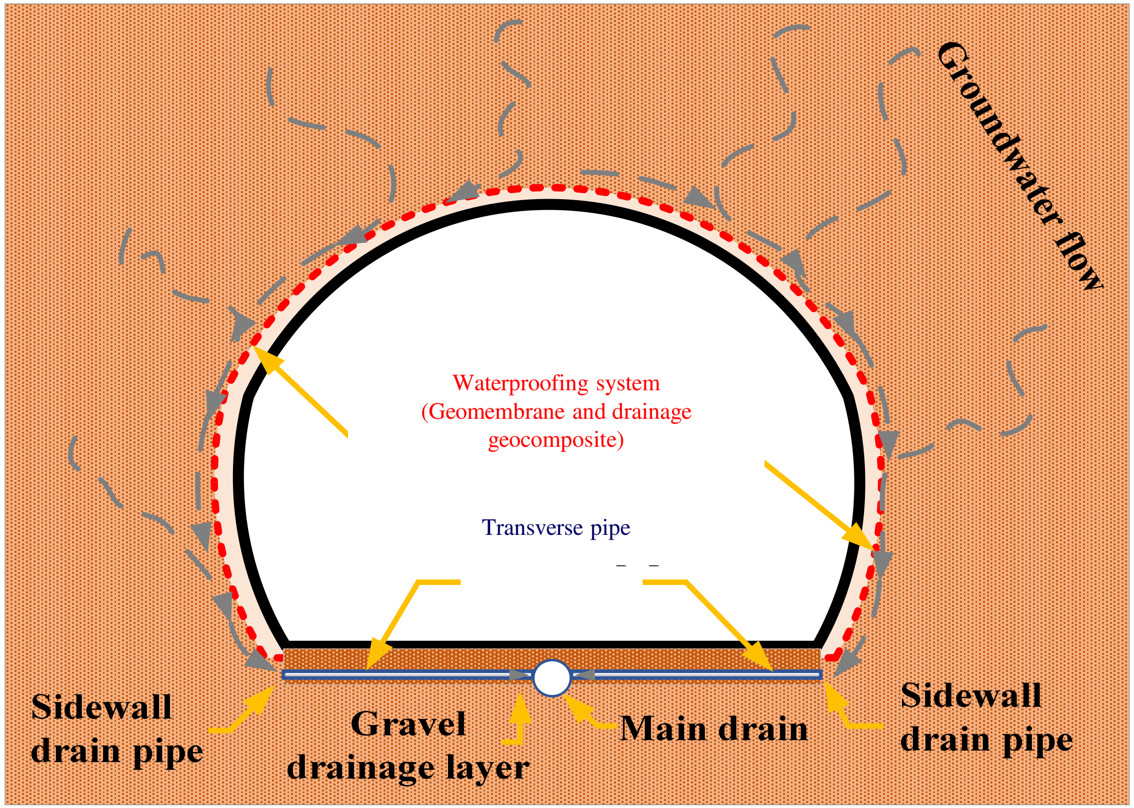
HYDRAULIC TUNNELS

Belden Tunnel (near Albany)
New York state
United States

Waterproofing and drainage in transportation tunnels

Drained Waterproofing System

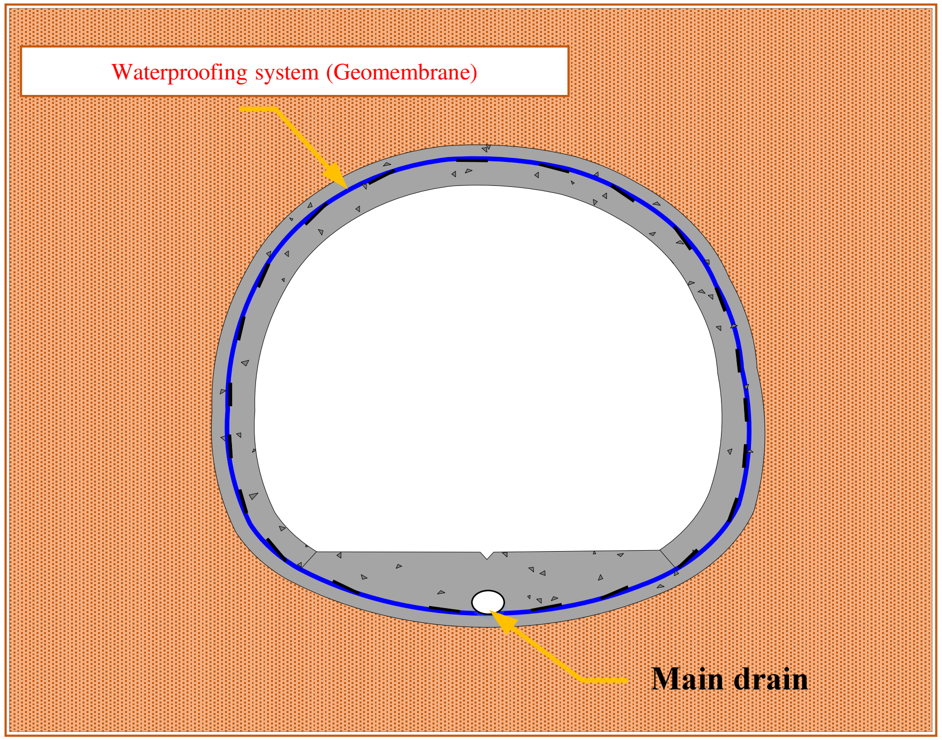
- The groundwater is collected and conducted to perforated sidewall drainage pipes
- Therefore, no hydrostatic pressure is acting from outside on the final concrete lining



Waterproofing and drainage in transportation tunnels

Undrained Waterproofing System

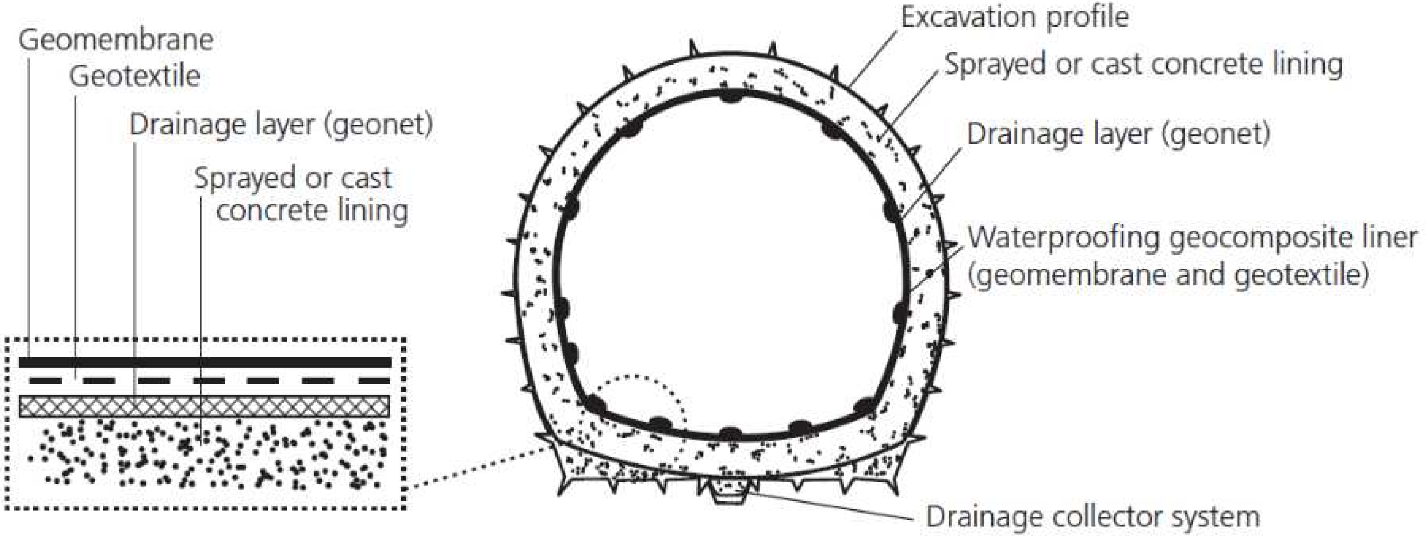
- Geomembrane is installed around the entire tunnel envelope without any drainage layer
- Full hydrostatic pressure is acting on the final concrete lining, therefore the tunnel invert should be designed to have proper structural capacity



Comparison

	Drained tunnel	Undrained tunnel
Construction	• drainage geosynthetics such as geocomposite drains are placed in the interface between shotcrete and concrete lining to provide a stable interface for water discharge	• geomembranes are placed in the interface between shotcrete and concrete lining as unique layer of complete waterproofing
Advantages	• can reduce hydrostatic pressure acting on the final concrete lining → reduction in concrete lining thickness	• lower construction cost
Disadvantages	• higher construction cost	• requires thicker final concrete lining due to higher hydraulic head

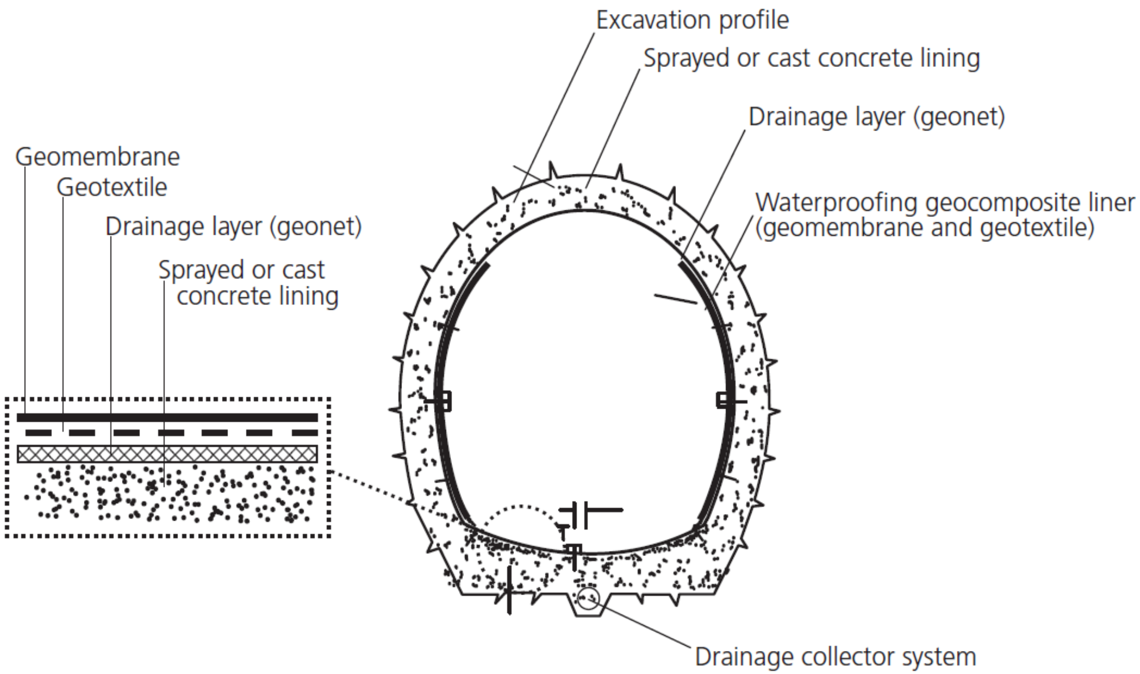
Waterproofing and drainage in hydraulic tunnels



A typical hydraulic pressure tunnel cross-section, where the geomembrane (or the composite geomembrane) is exposed

Spalov Tunnel - Czech Republic

Waterproofing and drainage in hydraulic tunnels

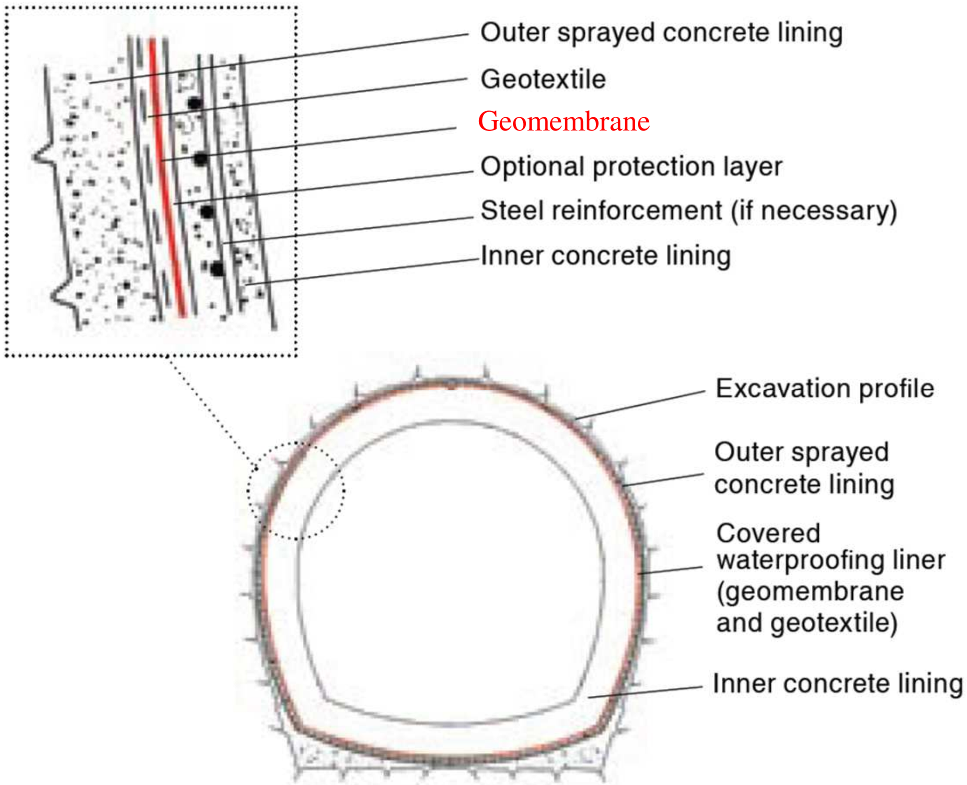


A typical hydraulic free-flow tunnel cross-section, where the geomembrane (or the composite geomembrane) is placed over the walls & invert and left exposed

Chavonne Tunnel - Italy

Frailino Tunnel - Italy

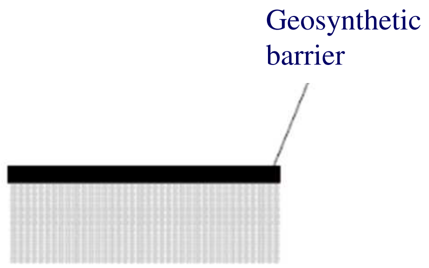
Waterproofing and drainage in hydraulic tunnels



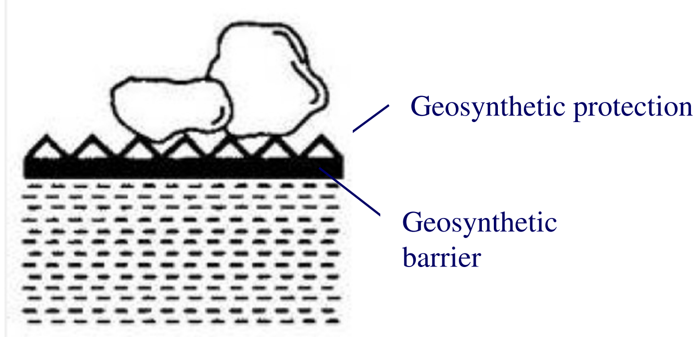
A typical hydraulic free-flow tunnel cross-section, where the geomembrane (or the composite geomembrane) is covered with an inner concrete lining

Geosynthetics in tunnels and underground structures: functions and main required properties

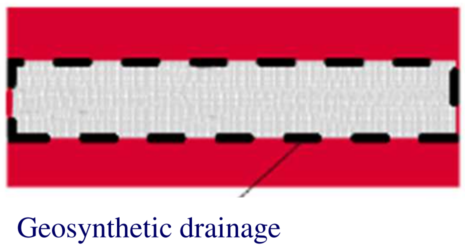
Barrier (mainly waterproofing) → water (or gas) permeability, tensile strength and elongation at maximum load, puncture resistance, durability



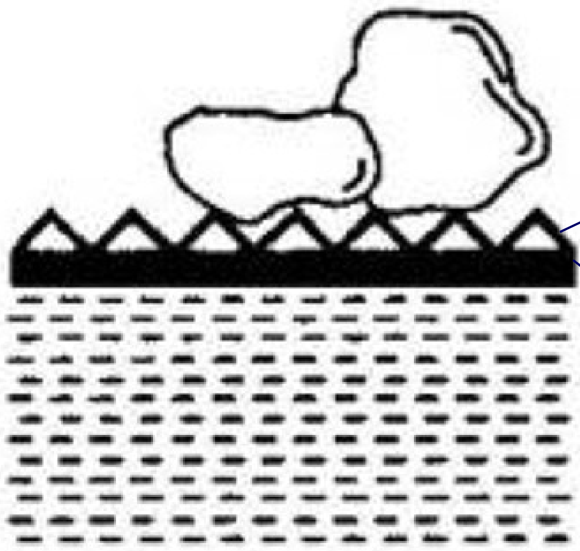
Protection → tensile strength and elongation at maximum load, dynamic perforation resistance, protection characteristics, durability



Drainage → tensile strength and elongation at maximum load, water flow capacity in the plane, compressive creep, durability, filter properties



Protection properties



Harmonised standard EN 13256

“Geotextiles and geotextile-related products — Required characteristics for use in the construction of tunnels and underground structures”

- ✓ This harmonised European Standard specifies the relevant characteristics of geotextiles and geotextile-related products used for **protection function** in the construction of tunnels and underground structures, and the appropriate test methods to determine these characteristics.
- ✓ The intended use of these geotextiles or geotextile-related products is to protect the geosynthetic barrier layers used in tunnels and underground structures.

Harmonised standard EN 13256

Geotextiles and geotextile-related products used in the construction of tunnels and underground structures
Functions, related characteristics and test methods to be used

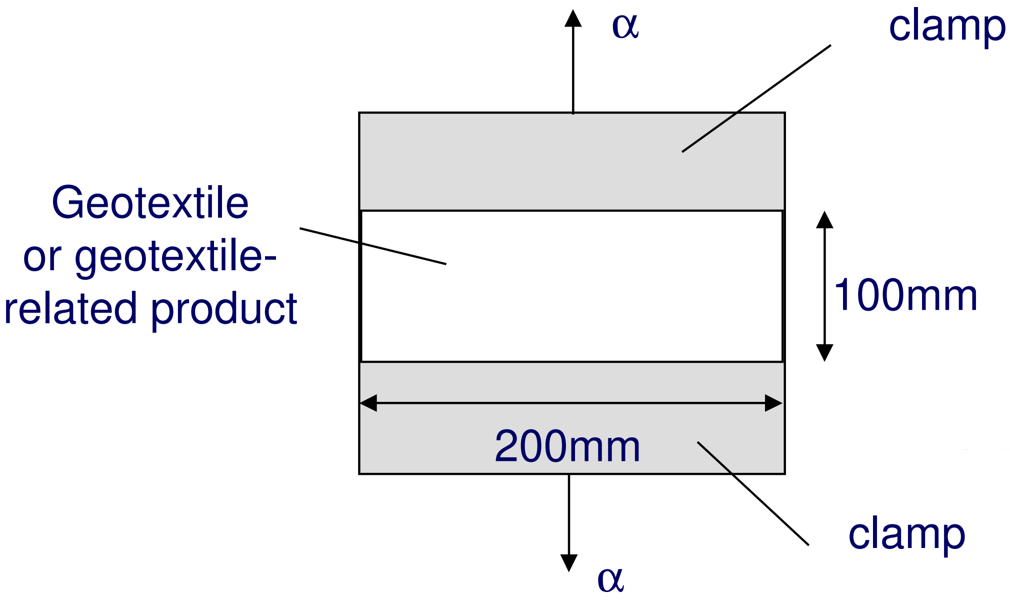
Characteristic	Test Method	Function Protection
(1) Tensile strength	**EN ISO 10139**	**A**
(2) Elongation at maximum load		**A**
(3) Tensile strength of seams and joints	EN ISO 10321	S
(4) Static puncture resistance (CBR test)	EN ISO 12236	S
(5) Dynamic perforation resistance (cone drop test)	**EN ISO 13433**	**A**
(6) Friction characteristics	EN ISO 12957-1 EN ISO 12597-2	S
(7) Damage during installation	EN ISO 10722	S
(8) Protection charateristics	**EN 13719**	**A**
(9) Durability	According to Annex B	A

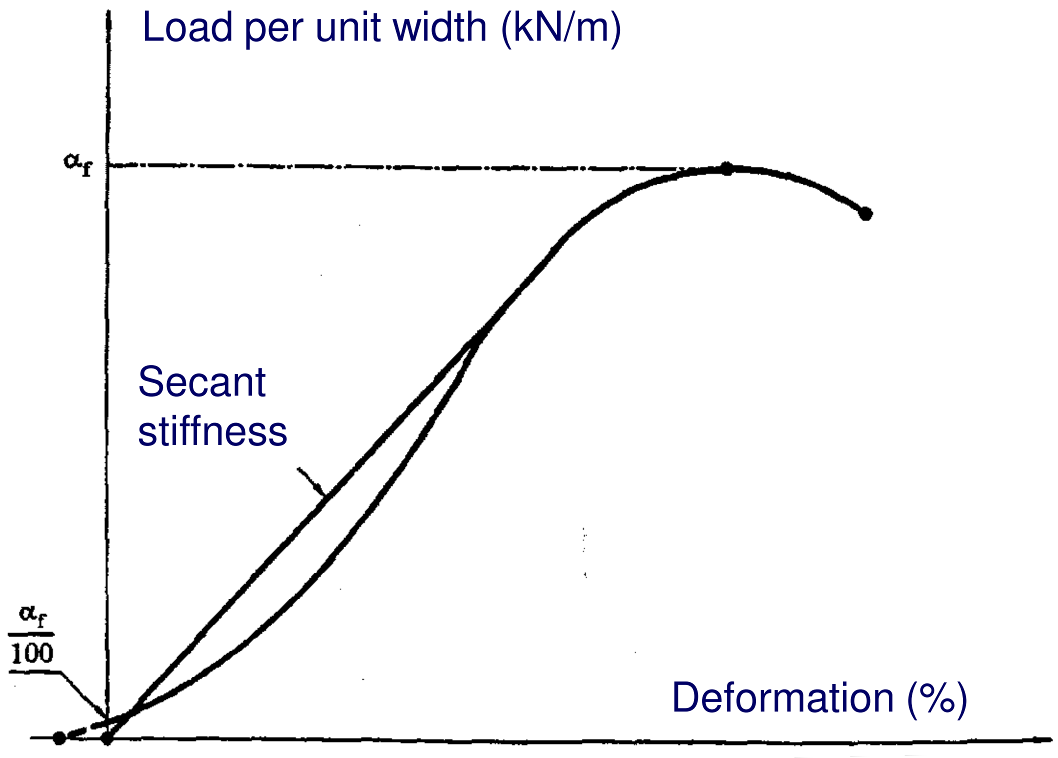
A: relevant to all conditions of use – See following test method descriptions

S: relevant to specific conditions of use

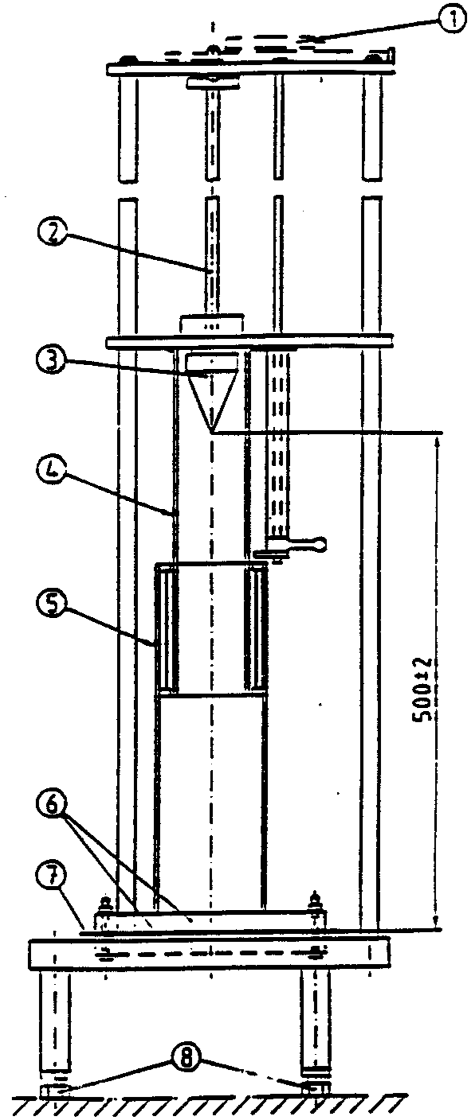
Tensile strength and elongation at maximum load

(EN ISO 10319)

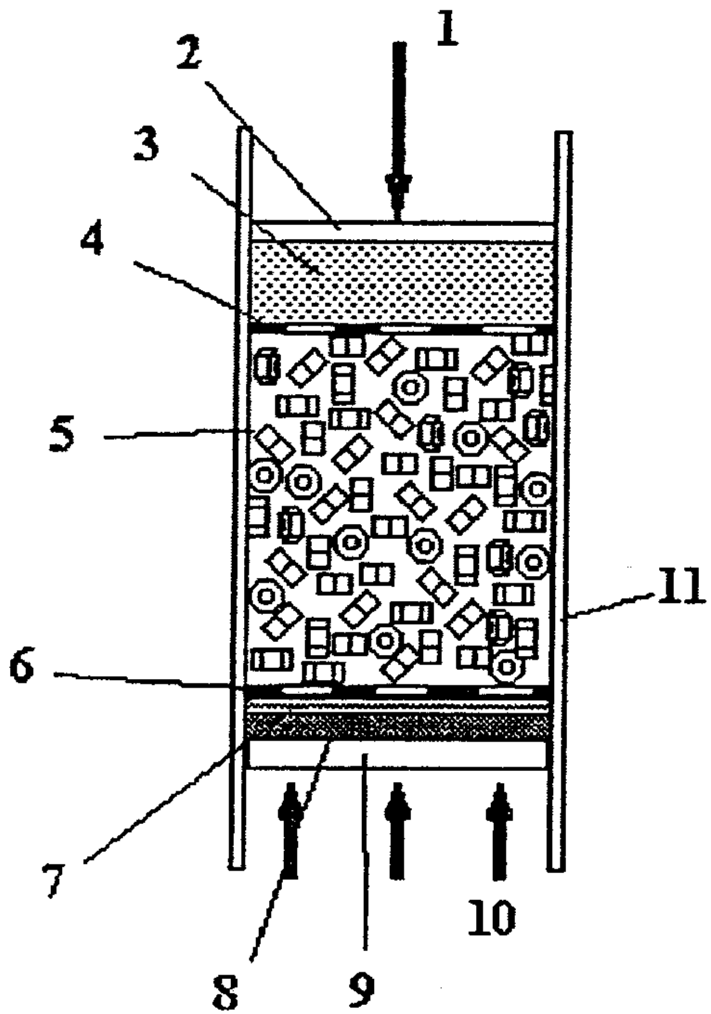




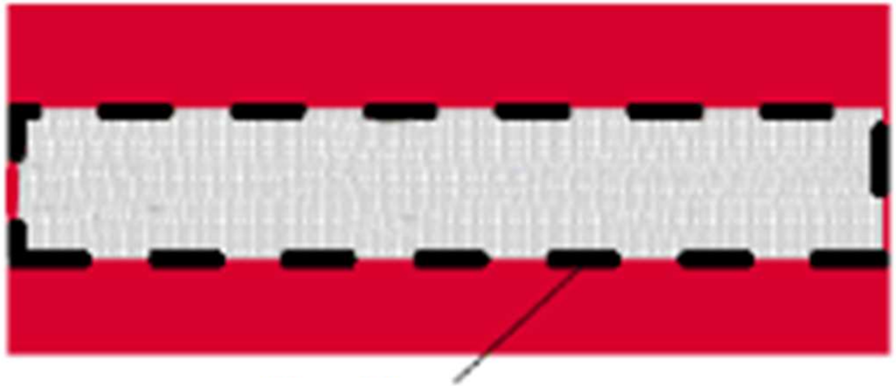
Dynamic perforation resistance – cone drop test (EN ISO 13433)



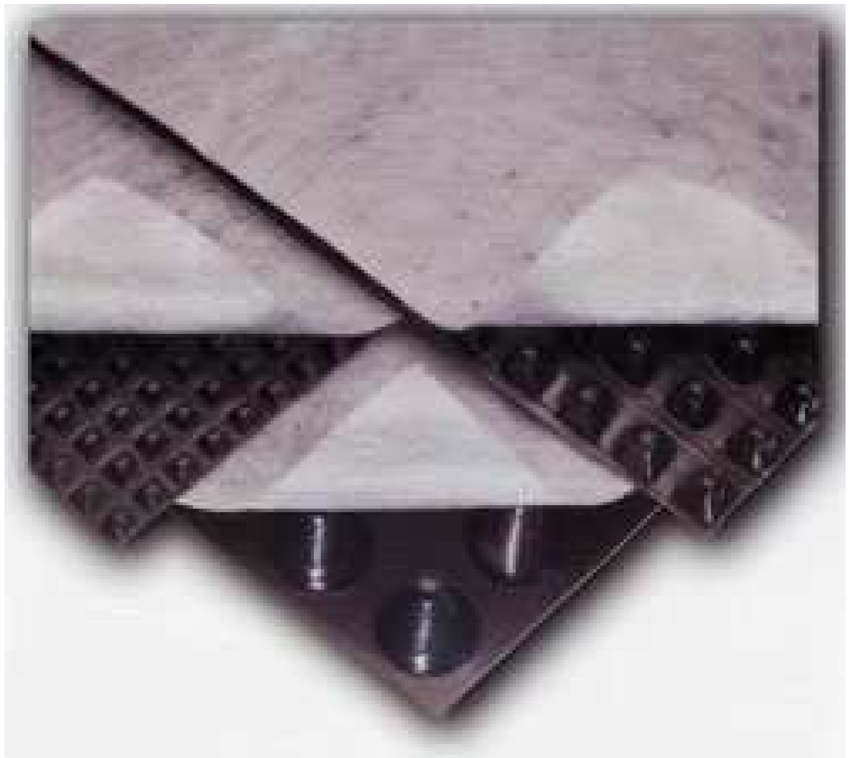
Protection charateristics (EN 13719)



Drainage properties



Geosynthetic drainage



Harmonised standard EN 13252

"Geotextiles and geotextile-related products — Required characteristics for use in drainage systems"

- ✓ This European Standard specifies the relevant characteristics of geotextiles and geotextile-related products (mainly **drainage geocomposites**) used in drainage systems and the appropriate test methods to determine these characteristics.
- ✓ The intended use of these geotextiles or geotextile-related products is to fulfil one or more of the following functions: filtration, separation and drainage.

Harmonised standard EN 13252

Geotextiles and geotextile-related products used in the construction of drainage systems
Functions, related characteristics and test methods to be used

Characteristic	Test Method	Functions Drainage
(1) Tensile strength	EN ISO 10139	A
(2) Elongation at maximum load		A
(3) Compression strength under load	EN ISO 25619-2	S
(4) Tensile Strength of seams and joints	EN ISO 10321	S
(5) Tensile strength of internal junction (of GCO)	EN ISO 13426-2	S
(6) Static puncture resistance (CBR test)	EN ISO 12236	-
(7) Dynamic perforation resistance (cone drop test)	En ISO 13433	-
(8) Friction characteristics	EN ISO 12957-1 EN ISO 12597-2	S
(9) Compressive creep characteristics	EN ISO 25619-1	A
(10) Damage during installation	EN ISO 10722	S
(11) Characteristic opening size	EN ISO 12956	-
(12) Water permeability normal to the plane	EN ISO 11058	-
(13) Water flow capacity in the plane (soft/soft)	EN ISO 12958	A
(14) Water flow capacity in the plane (soft/rigid or rigid/rigid)	EN ISO 12958	S
(9) Durability	According to Annex B	A

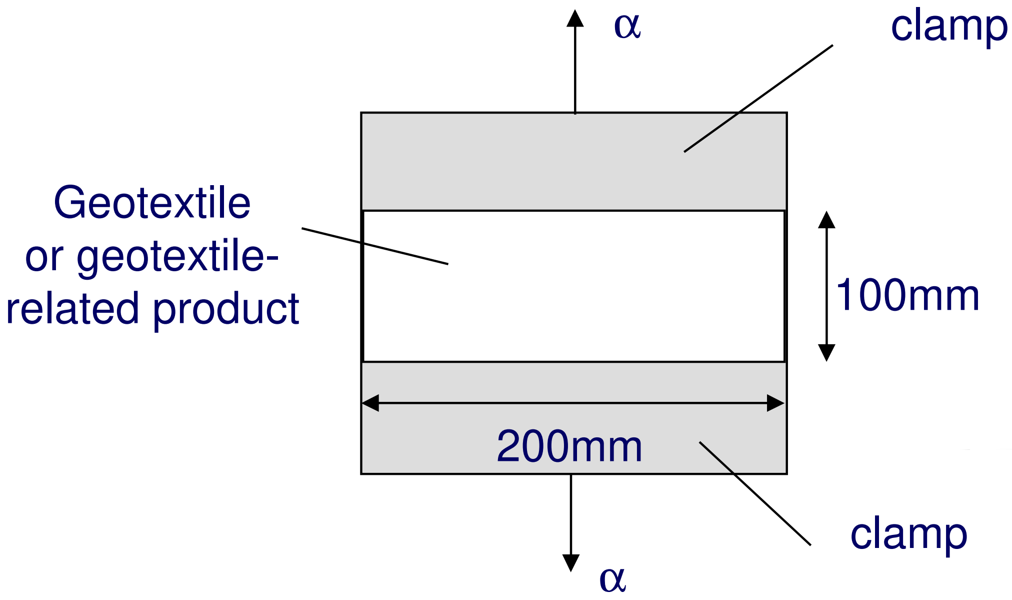
A: relevant to all conditions of use

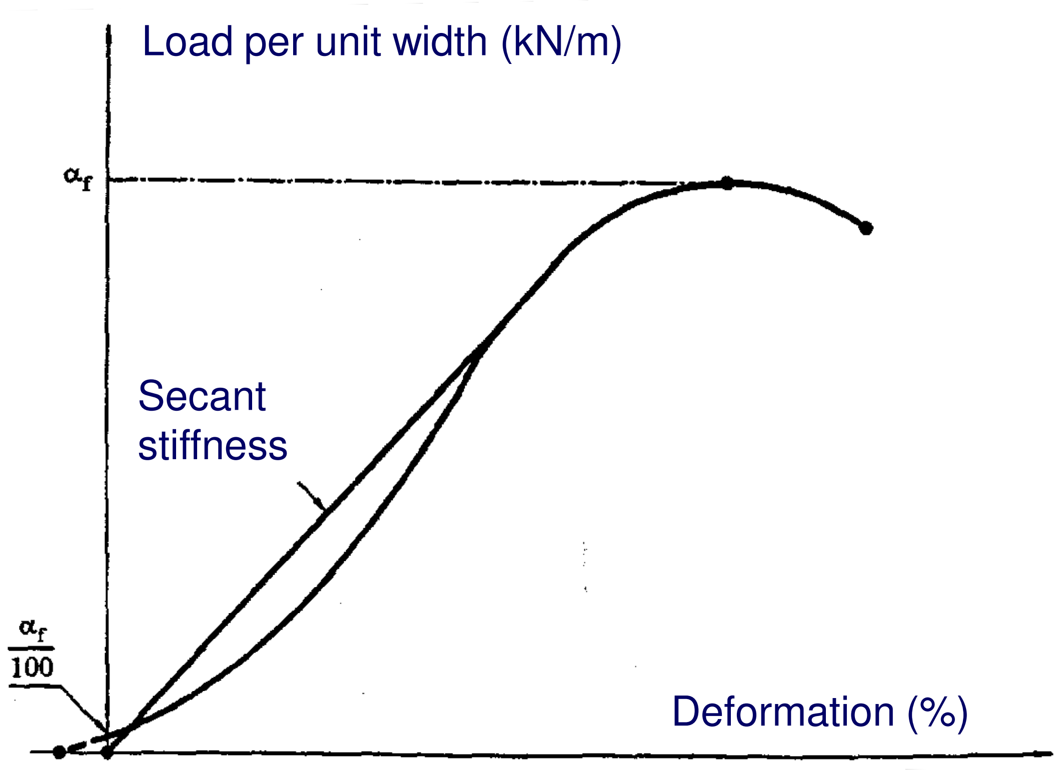
S: relevant to specific conditions of use

"-" : indicates that the characteristic is not relevant for that function

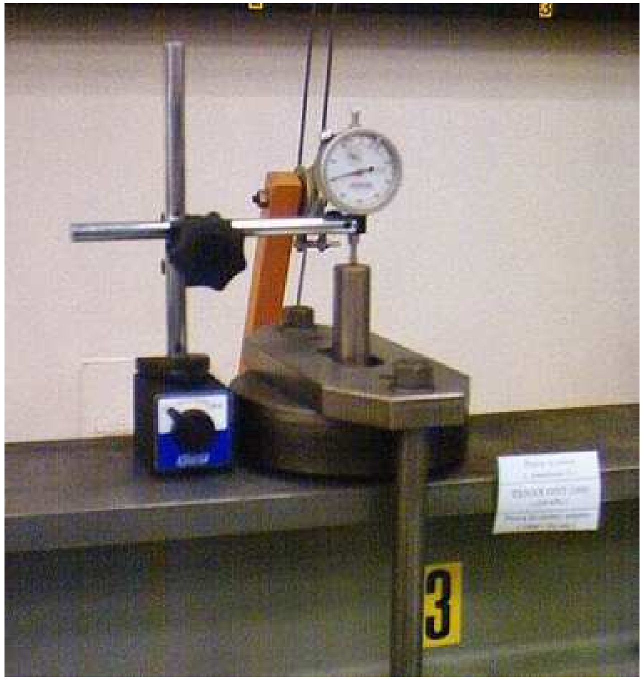
Tensile strength and elongation at maximum load

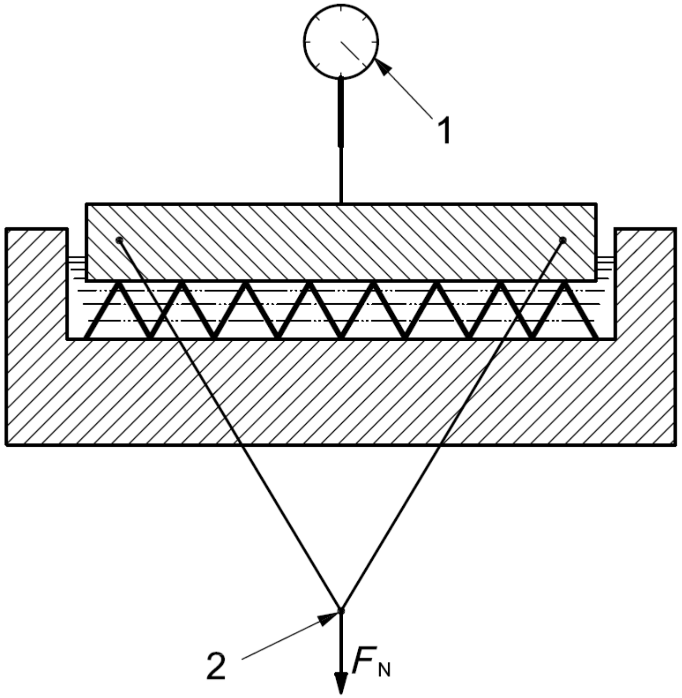
(EN ISO 10319)

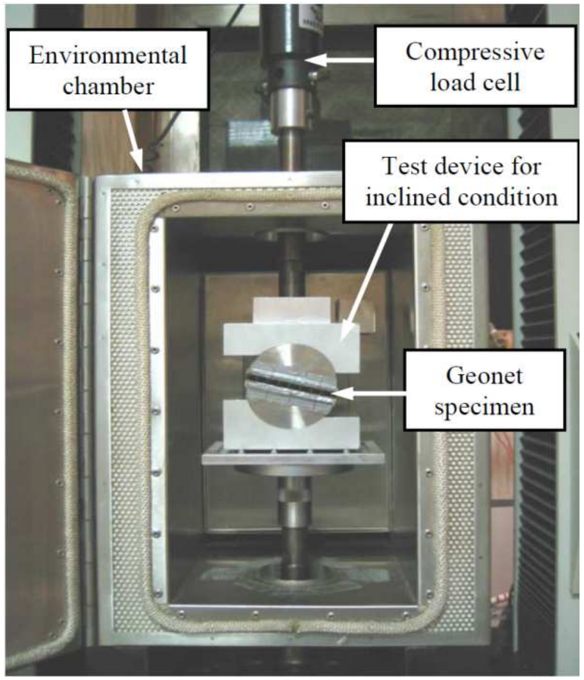


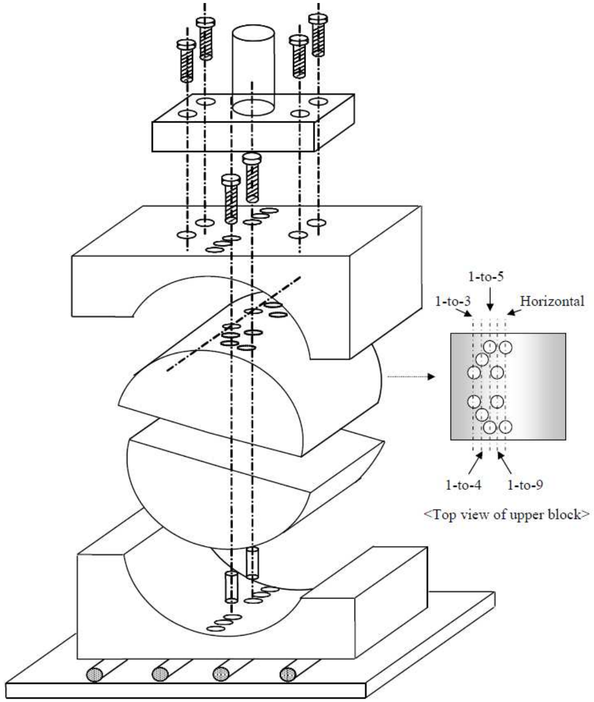


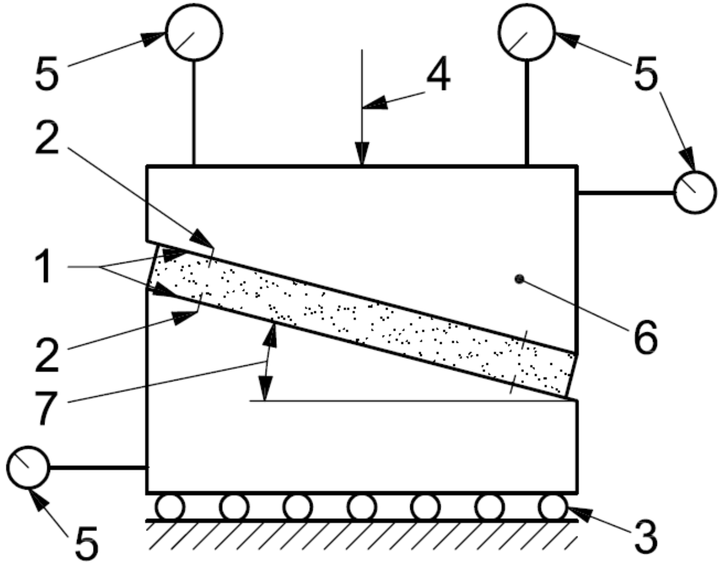
Compressive Creep (EN ISO 25619-1)







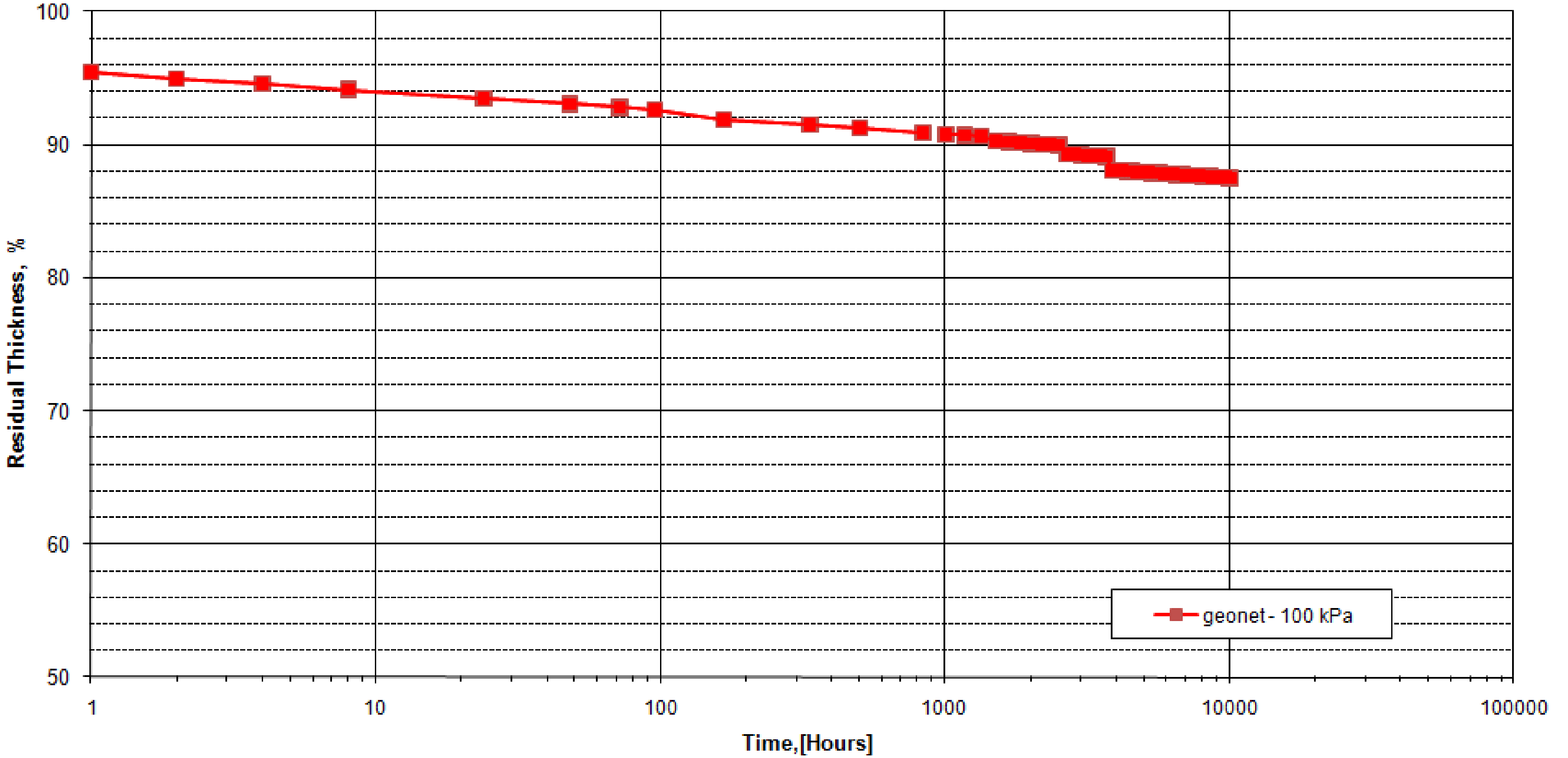




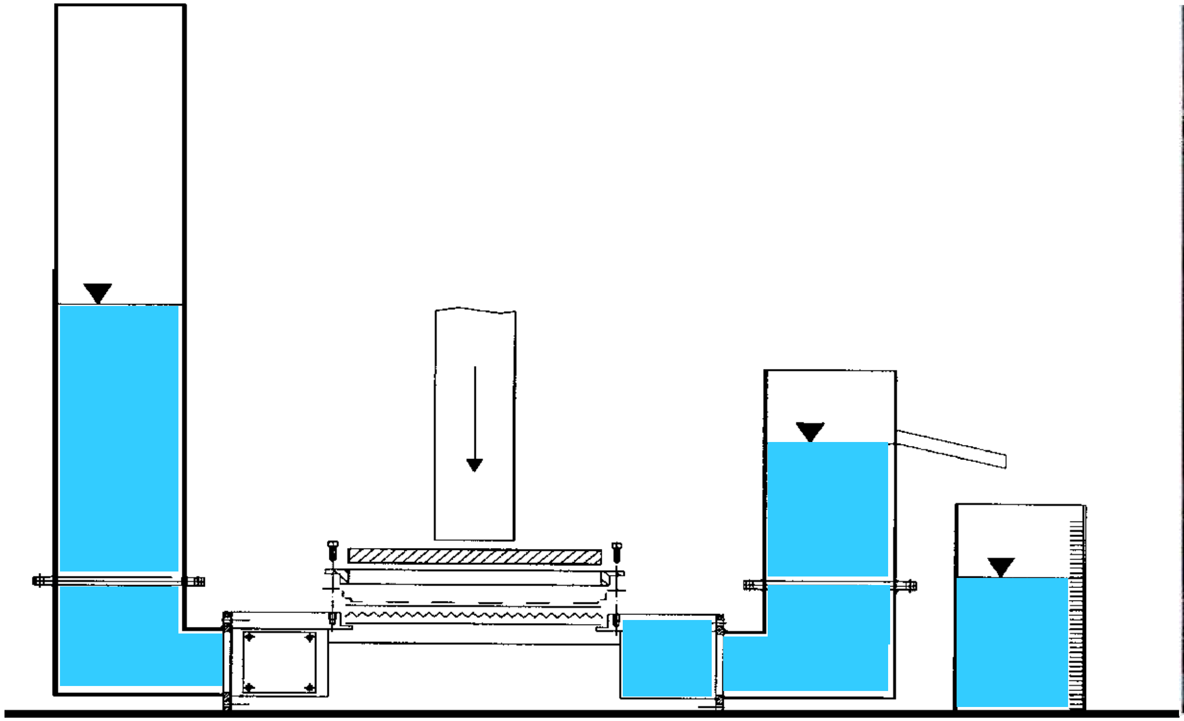
Compressive Creep (EN ISO 25619-1)

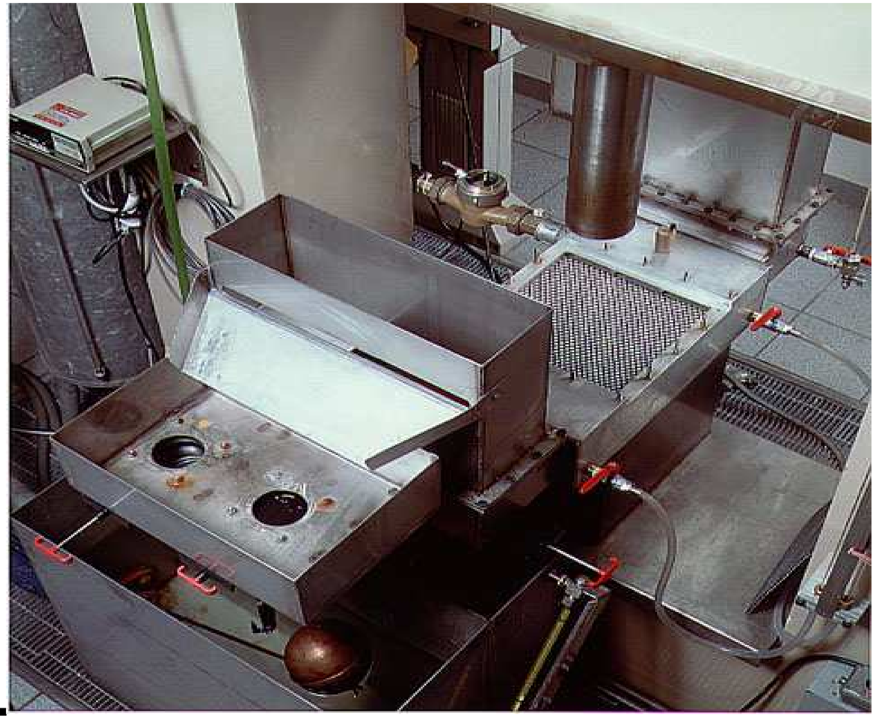
The thickness variation vs time due to the compressive creep of the **drainage geocomposite** produces a variation of porosity and, as a consequence, also the water flow capacity in plane changes during the service life of the underground structure

$$\Theta(t) = K_p(t)\, t_G(t) = q(t)/i$$



Water flow capacity in the plane (EN ISO 12958)





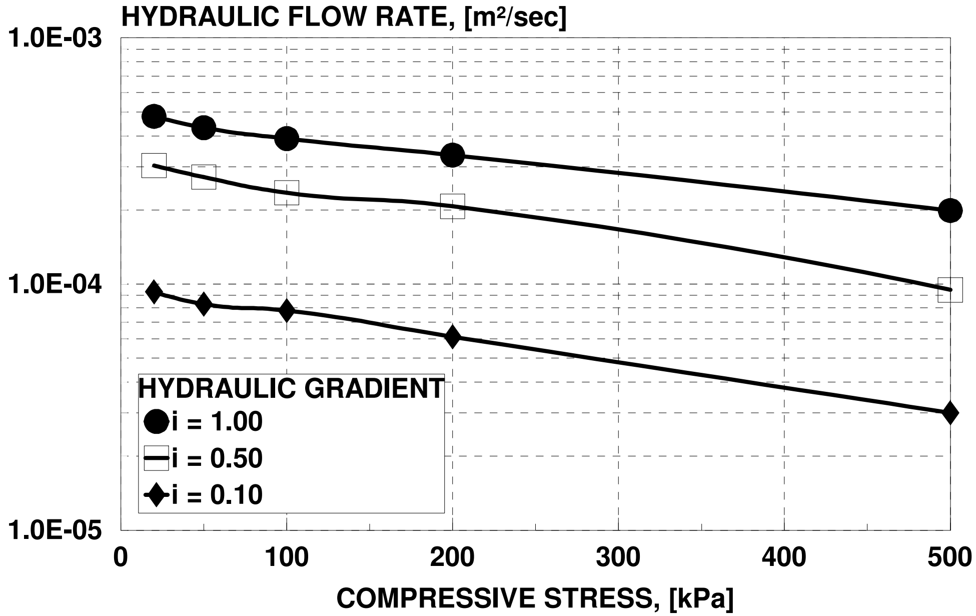
$$Q = vA = k_p\, i\, A = k_p\, i\, t_G\, W$$

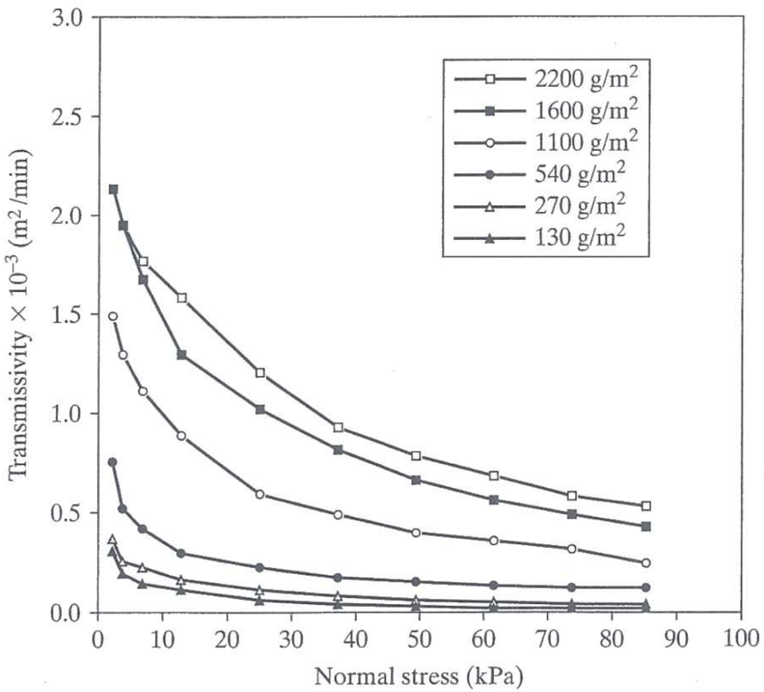
$$\vartheta = k_p\, t_G = Q / iW = q / i$$

Q = Flow rate
q = Q/W = Specific flow rate
θ = Transmissivity
K_p= In plane permeability
t_G = Drainage geocomposite thickness
i = Hydraulic gradient
W = Specimen width

Water flow capacity in the plane (EN ISO 12958)

$$\vartheta = k_p \, t_G = Q / iW$$





Protection and drainage properties requirements

		OBV [14]		**SIA [17]**	**DB [18]**	**RFI**	**BBT**	
Properties	Unit	PP (max 10% internal reworked)		-	PP or HDPE	-	PP (max 5% internal reworked)	
Mass per unit area	(g/m^2)	≥500 (crown and springs)	≥900 (invert and cut &cover)	500-1500	500-1200	≥500	≥500	≥900
Thickness at 200 kPa	(mm)	≥1.7	≥3.4	-	≥4	≥1.9	≥1.7	≥3.4
Tensile strength	(kN/m)	≥30	≥50	≥15	≥25-30	≥30	≥30	≥50
Elongation at maximum load	(%)	≥50		≥20	≥50 (nonwoven) ≤30 (woven)	-	≥50	-
CBR puncture resistance	(kN)	≥3	≥7	≥2.5	≥5.5 and < 20	≥5	≥3	≥7
Dynamic perforation (cone drop test)	(mm)	≤13	≤7	≤10	-	-	≤13	≤7
In plane permeability	(m^2/s)	$\geq 2\ 10^{-6}$ (@200 kPa)		$\geq 10^{-5}$ (@200 kPa)	$\geq 10^{-3}$ (@20 kPa)	$\geq 1.5\ 10^{-6}$ (@100 kPa)	$\geq 2\ 10^{-6}$ (@200 kPa)	
Fire resistance	(-)	Class E		-	B2	-	Class E	

*__OBV:__ Österreichische Bautechnik Vereinigung (Austrian Tunnelling Association); **SIA**: Schweizerischer Ingenieur- und Architektenverein (Swiss Society of Engineers and Architects); **DB:** Deutsche Bahn AG (German Railways); **RFI:** Rete Ferroviaria Italiana (Italian Railways Infrastructures); **BBT:** Brenner Basistunnel (Brenner Base Tunnel).

Required properties for geotextiles and geotextile-related products for the different authorities in Europe

4. Conclusions

Geosynthetics (geotextiles, geomembranes, related products and associated technologies) really represent sustainable solutions for a variety of applications :

- dams, reservoirs and hydraulic tunnels for **better storage and conveying of water** (one of the most important natural resources)
- transportation tunnels for **improving mobility** (crucial item in all continents)
- other applications, as in reservoirs for artificial snow, to try to **partially solve the problems induced by the climate change**

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Thank you very much for your kind attention !