Geosynthetics : materials, design, durability and applications

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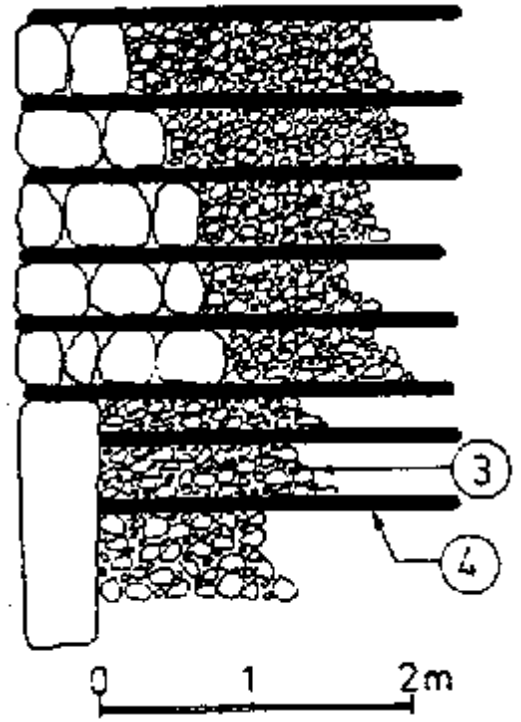
20 octobre 2015

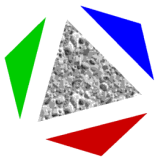
Génie Minéral
Matériaux & Environnement

Historically speaking

The Ziggurat of Agar-Quf, 5km north of Baghdad, is believed to be some 3000 years old and is constructed of clay bricks reinforced with woven mats of reeds.

The Great Wall of China is also constructed of a mixture of clay and gravel reinforced with tamarisk branches (Jones 1996).





Historically speaking

Cairn of Newgrange: Ø=85m and H=12m (Ireland) in 3200 AC (O'KELLY, by J. KERISEL (1993))

Originally speaking

Geo + textiles (synthetics): combination of soil and polymeric textile products

Water Permeable product (*except geomembrane*)

Development in the Netherlands ('60): Oosterschelde

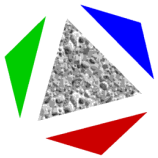
- dams: reinforcement
- filtration and drainage

Geocomposite: geotextile + natural protection with reeds

Scope of the lecture

1. Characteristics and properties of the raw materials
2. Properties of geotextiles
3. Description of « geosynthetics »
4. Roles and functions
5. Durability
6. Design
    1. *Retaining wall: internal stability*
    2. *Filtration system: permeability and retention (filtration) criteria*
    3. Environmental engineering: waste storage

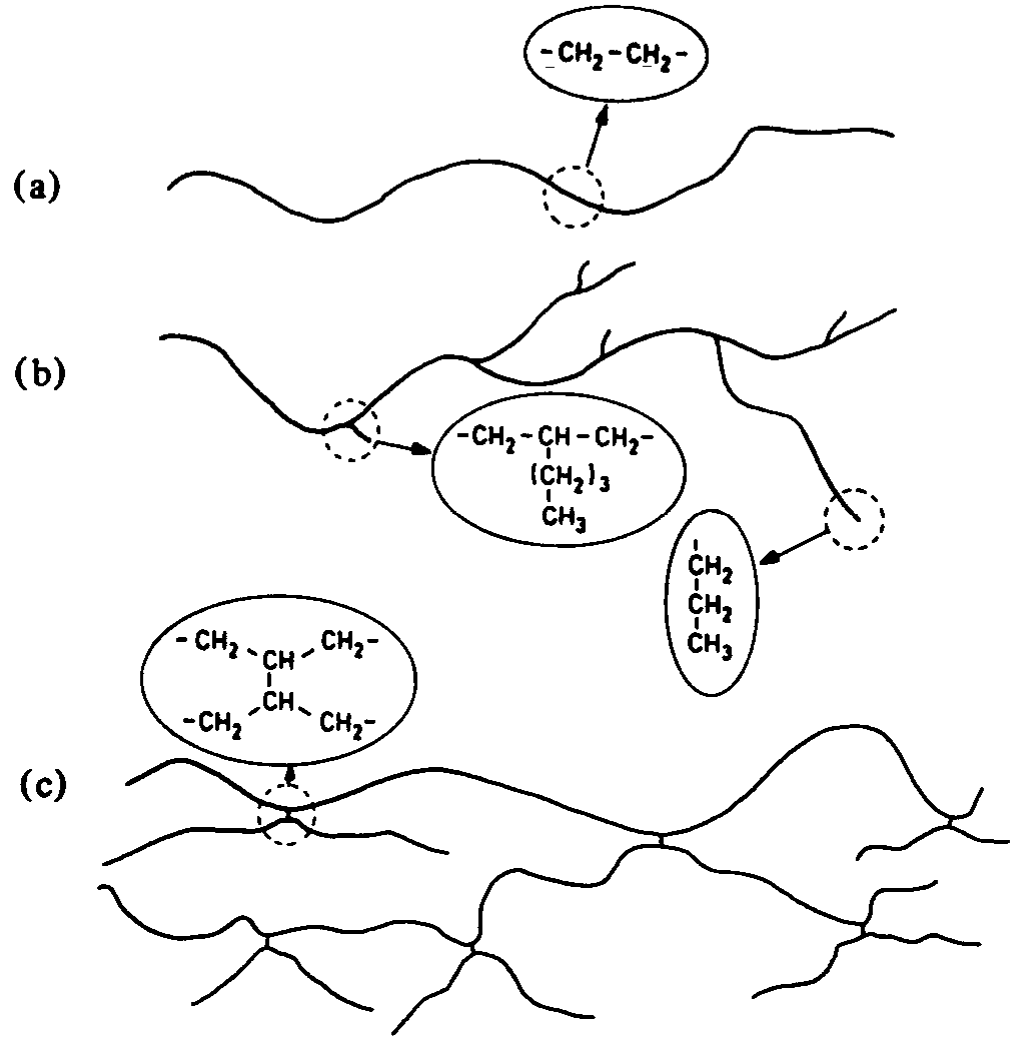
Support: *Utilisation des géosynthétiques en génie civil* (L. Courard– Code AEES 55.061)



Characteristics and properties of the raw materials

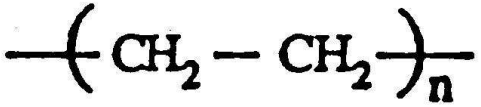
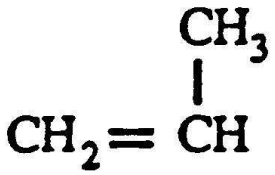
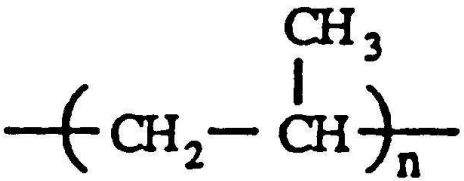
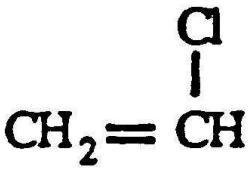
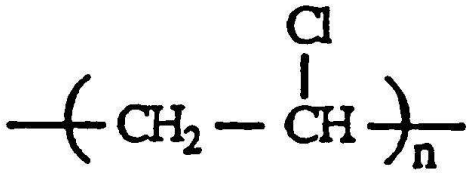
Polymer structure: solids with covalent bonds

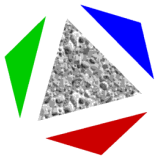
(a) linear polymer (fusible, easy to recycle)



~~(a) tridimensional polymer (non-fusible)~~

Raw materials

éthylène	$CH_2 = CH_2$	polyéthylène (PE) 
propylène		polypropylène (PP) 
chlorure de vinyle		polychlorure de vinyle (PVC) 



Raw materials

Polyamid (NH-(CH_2)y-NH-CO-(CH_2)x-CO

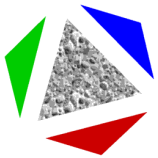
- good mechanical properties, resistance to abrasion
- sensitivity to water

Polyethylen and polypropylen

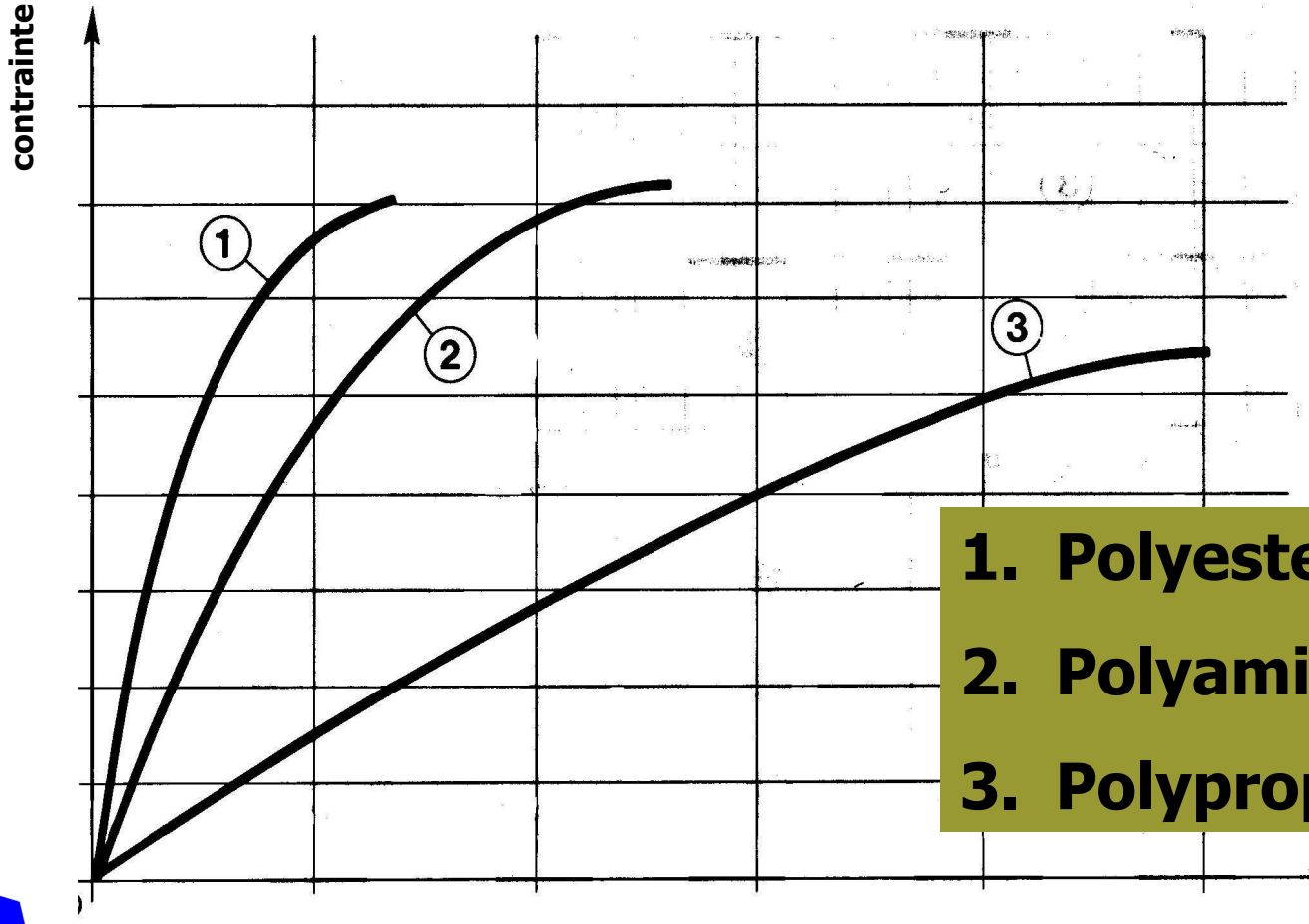
- no sensitivity to acid and bases
- creep (threshold: 10% - speed: high because T_g = -10°C)

Polyesters (PET) COOH-R_1-COOH + OH-R_2-OH

- high E modulus, low thermal susceptibility
- sensitivity to high alkaline materials
- creep (threshold: 40% - speed: low because T_g = 70°C)



Qualitative stress-strain curves for various filaments



1. **Polyester**
2. **Polyamide**
3. **Polypropylene**

Characteristics of the polymers

Property	POLYESTER	POLYAMIDE	POLYPROPYLENE
Specific mass (kg/m³)	1380	1140	900
Modulus (N/mm²)	20000	4000	1750
Tensile strength (N/mm²)	1100	900	190
Elongation (%)	15	15	380
Melting point (°C)	260	250	165
Resistance to micro-organims	X	X	X
Resistance to acids	X	O	X
Resistance to alkali	O	X	X
Resistance to oxidation	X	O	X
Resistance to U.V.	X	O	O

x	GOOD
o	QUITE GOOD

Properties of geotextiles

Fabrication technique: woven (*tissés*)

- tapes: extruded films of PE-PP

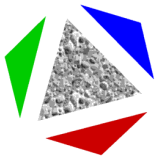
good tensile strength, low water permeability, low puncture resistance

- mono filaments: usual woven textile

excellent filter (constant opening size), high mechanical properties

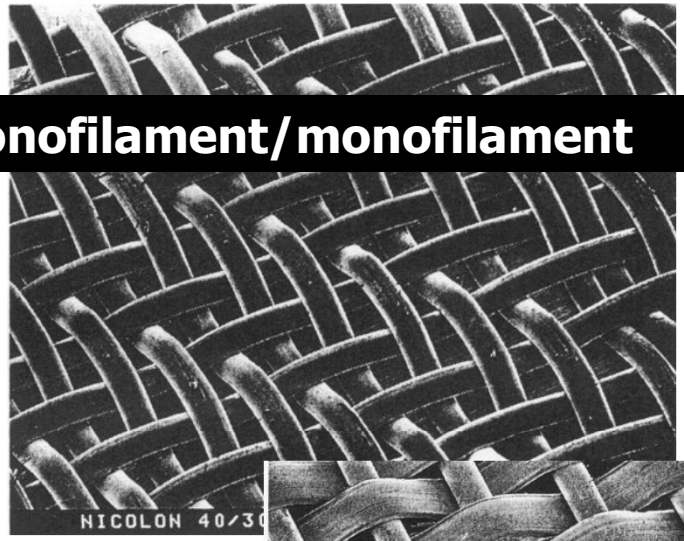
- multi filaments: many filaments of some daµm diameter

high mechanical properties

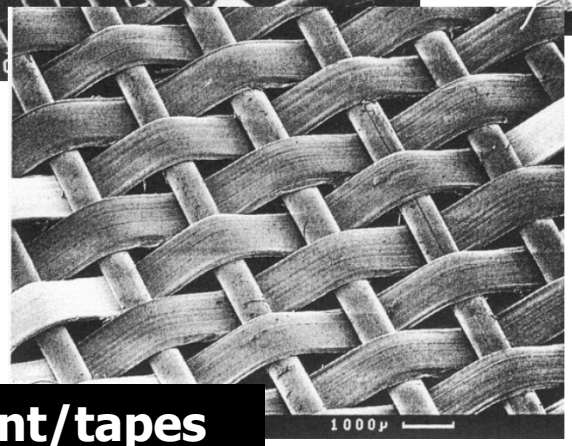


Fabrication technique: woven

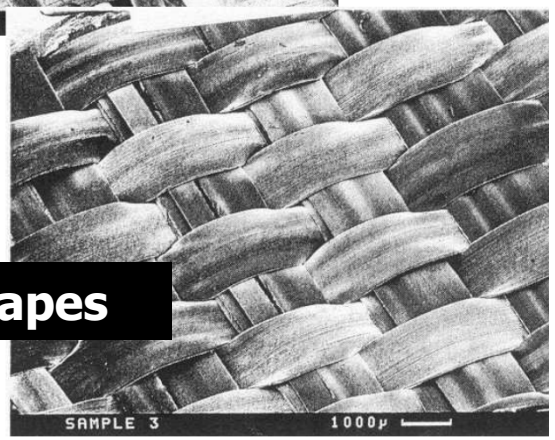
monofilament/monofilament



monofilament/multifilaments

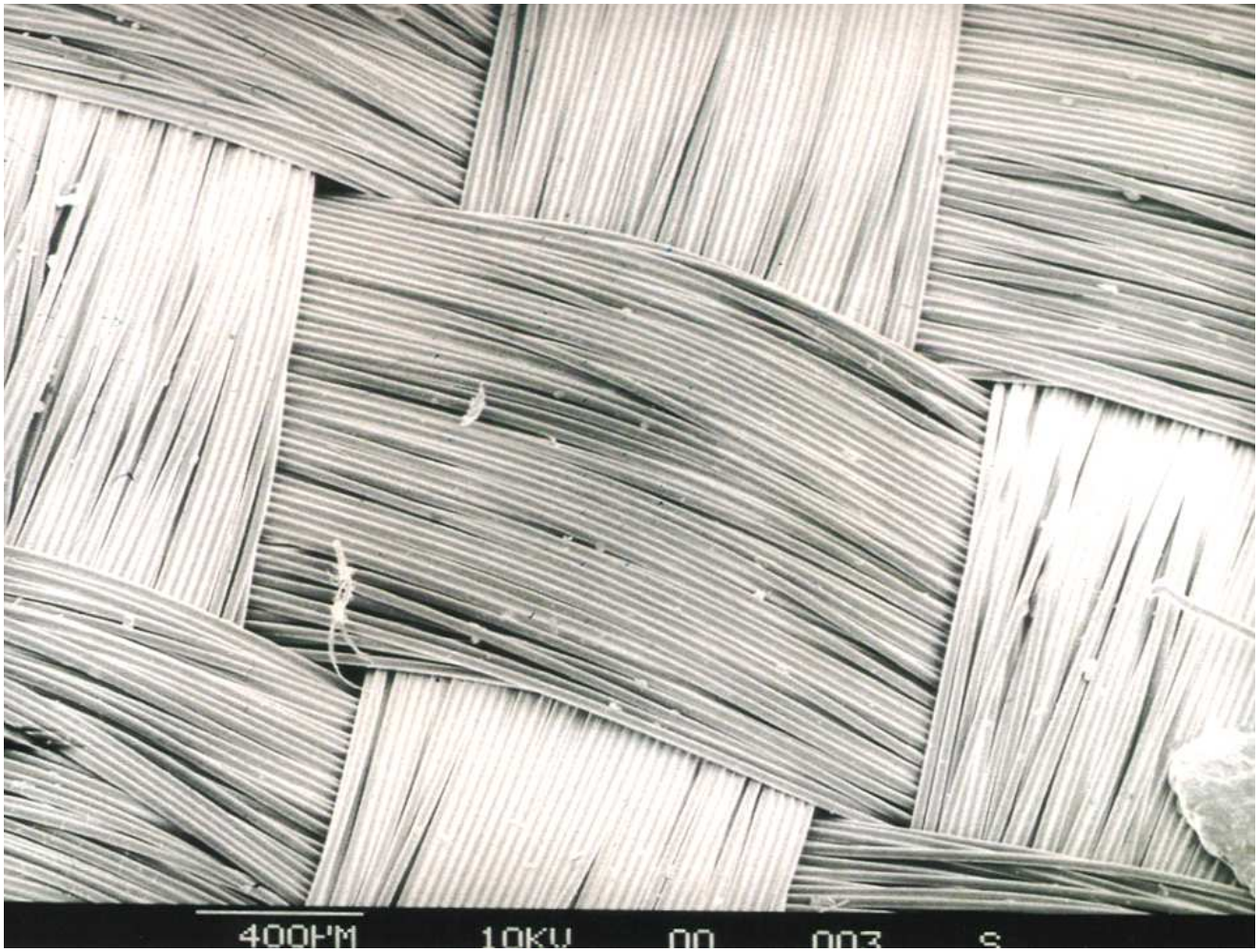


monofilament/tapes

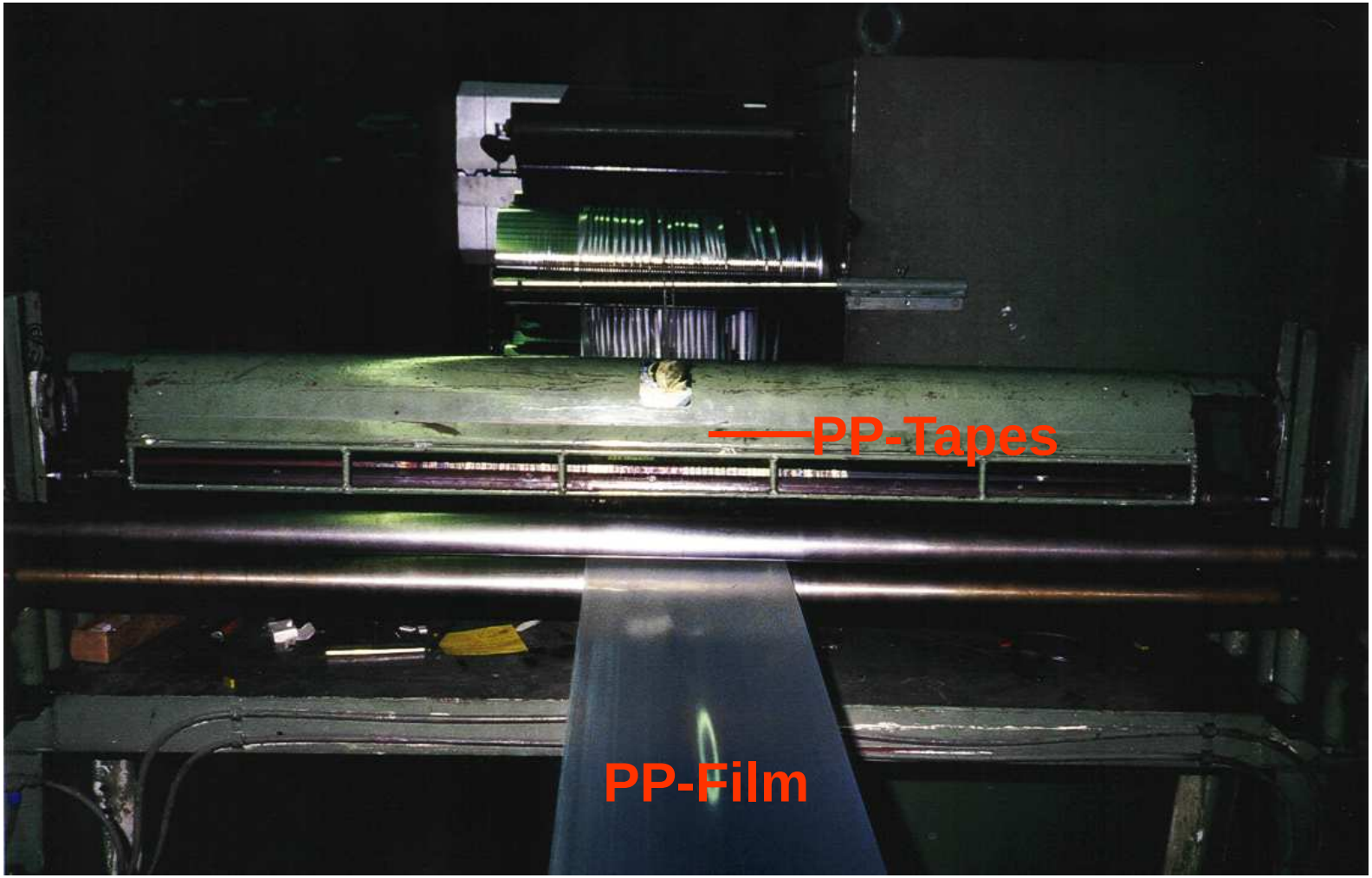


tapes/tapes

PET multifilament woven fabric



PP tape production



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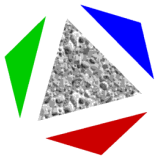
Fabrication technique: non woven (non *tissés*)

- thermobonded : bonding by calendering (thermo fusion)

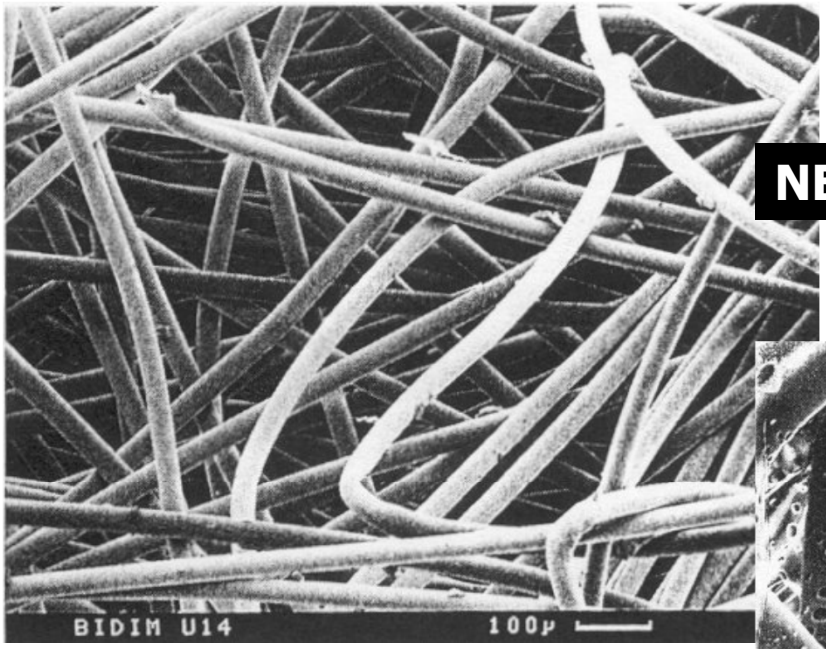
⇒ high initial modulus, low tear resistance (rigid connections), lower porosity

- spunbonded: connections with needles

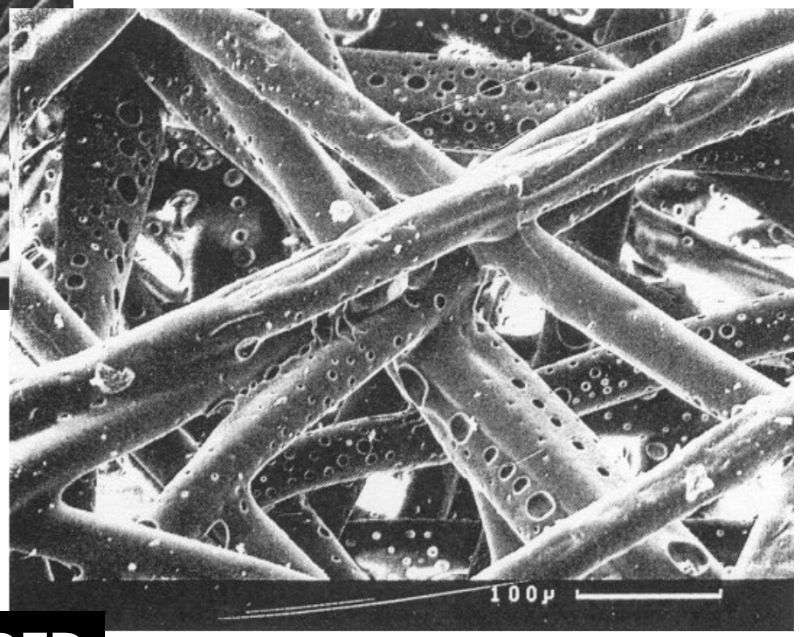
⇒ better transmission of stress, conservation of polymer integrity, higher elongation, higher permeability



Fabrication technique: non woven



NEEDLEPUNCHBONDED



THERMOBONDED

Non woven thermo-bonded

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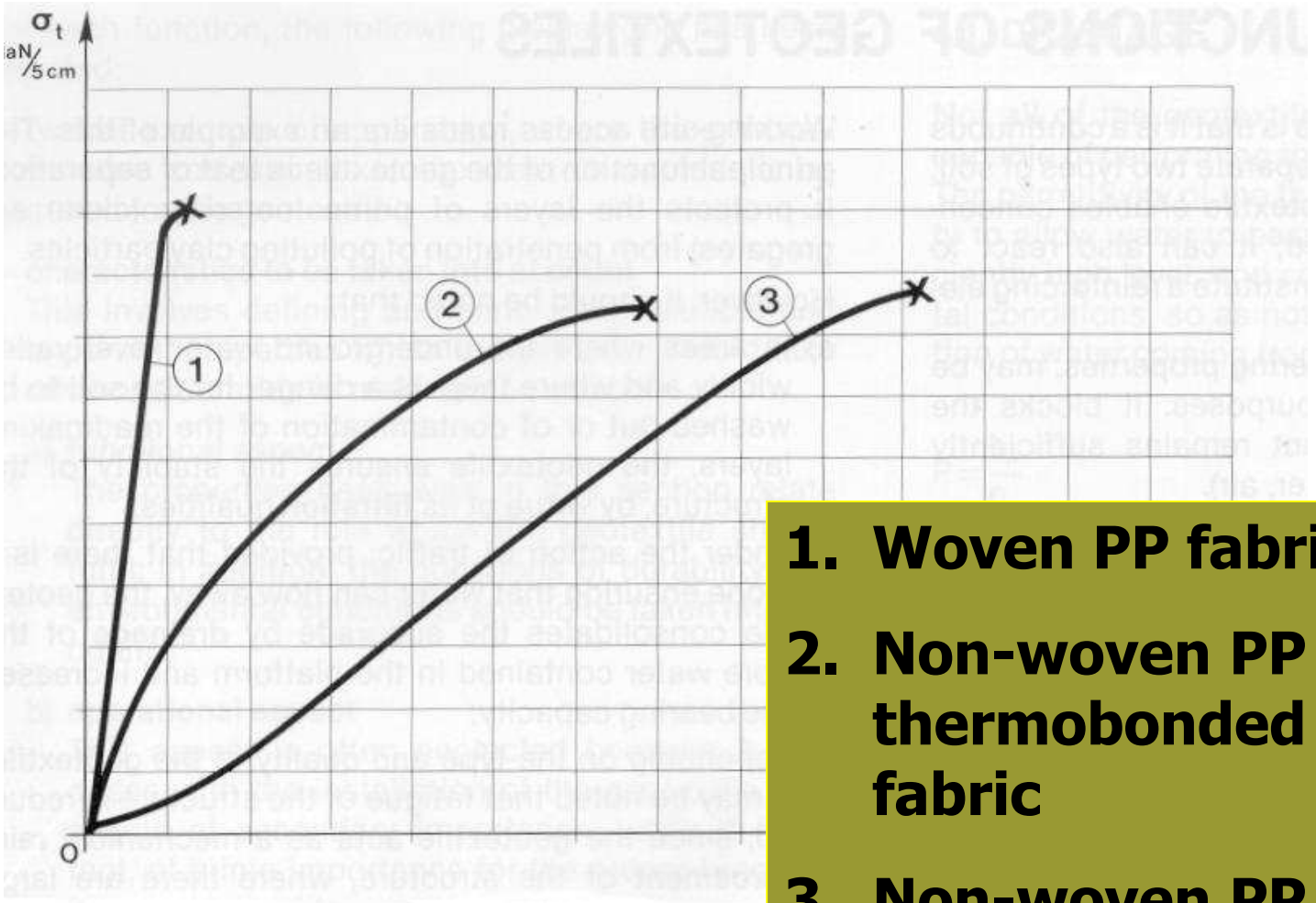
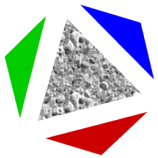
Tensile stength on narrow strip



1. **Woven PP fabric**
2. **Non-woven PP thermobonded fabric**
3. **Non-woven PP needled fabric**

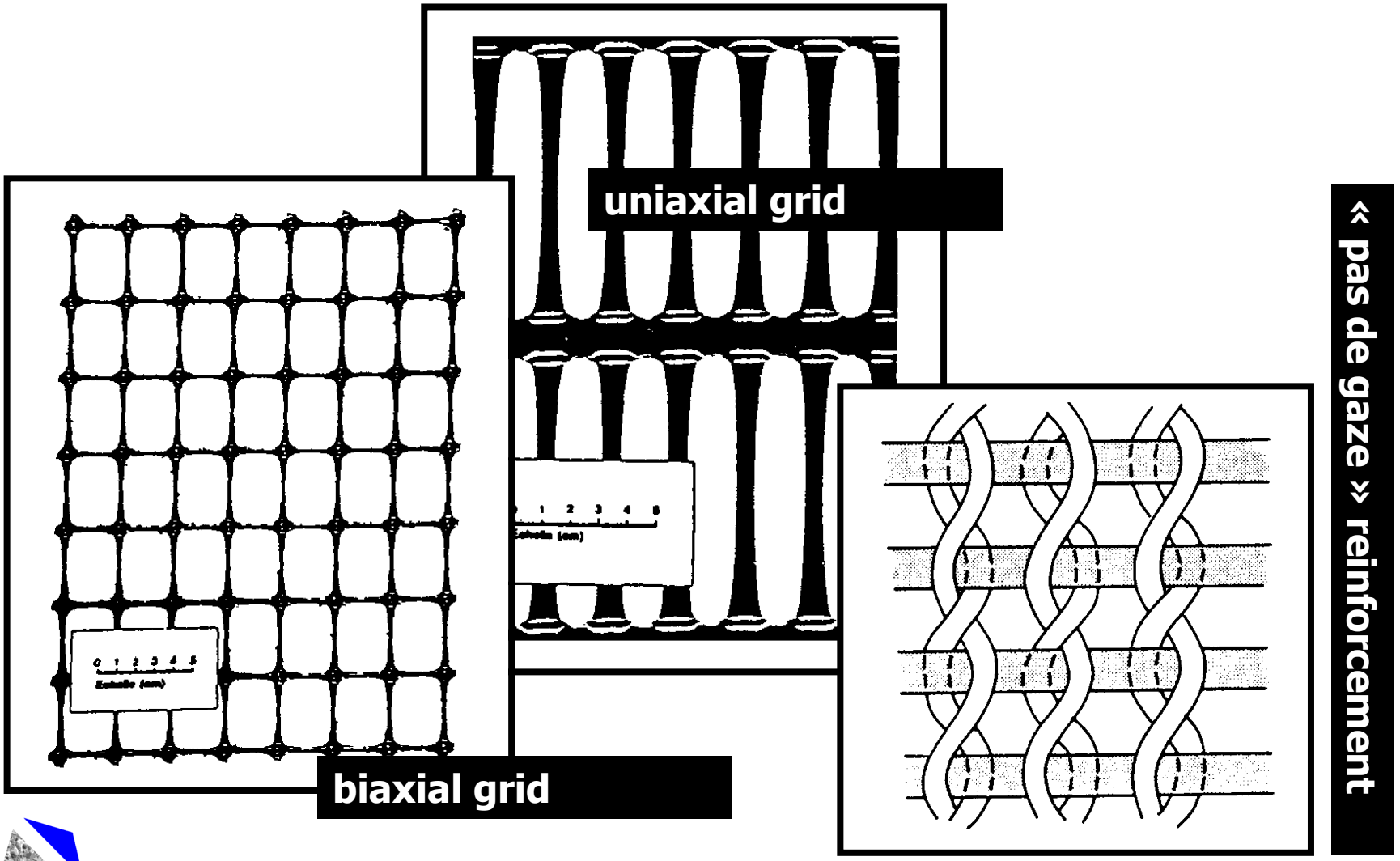
Water permeability of geotextiles

Geotextile	Permeability (cm/s)
Monofilament woven	10 to 10^{-2}
Tape woven	10^{-2} to 10^{-3}
Non woven thermobonded	1 to 10^{-2}
Non woven chemically bonded	10^{-2} to 10^{-3}
Non woven needlepunched	1 to 10^{-2}

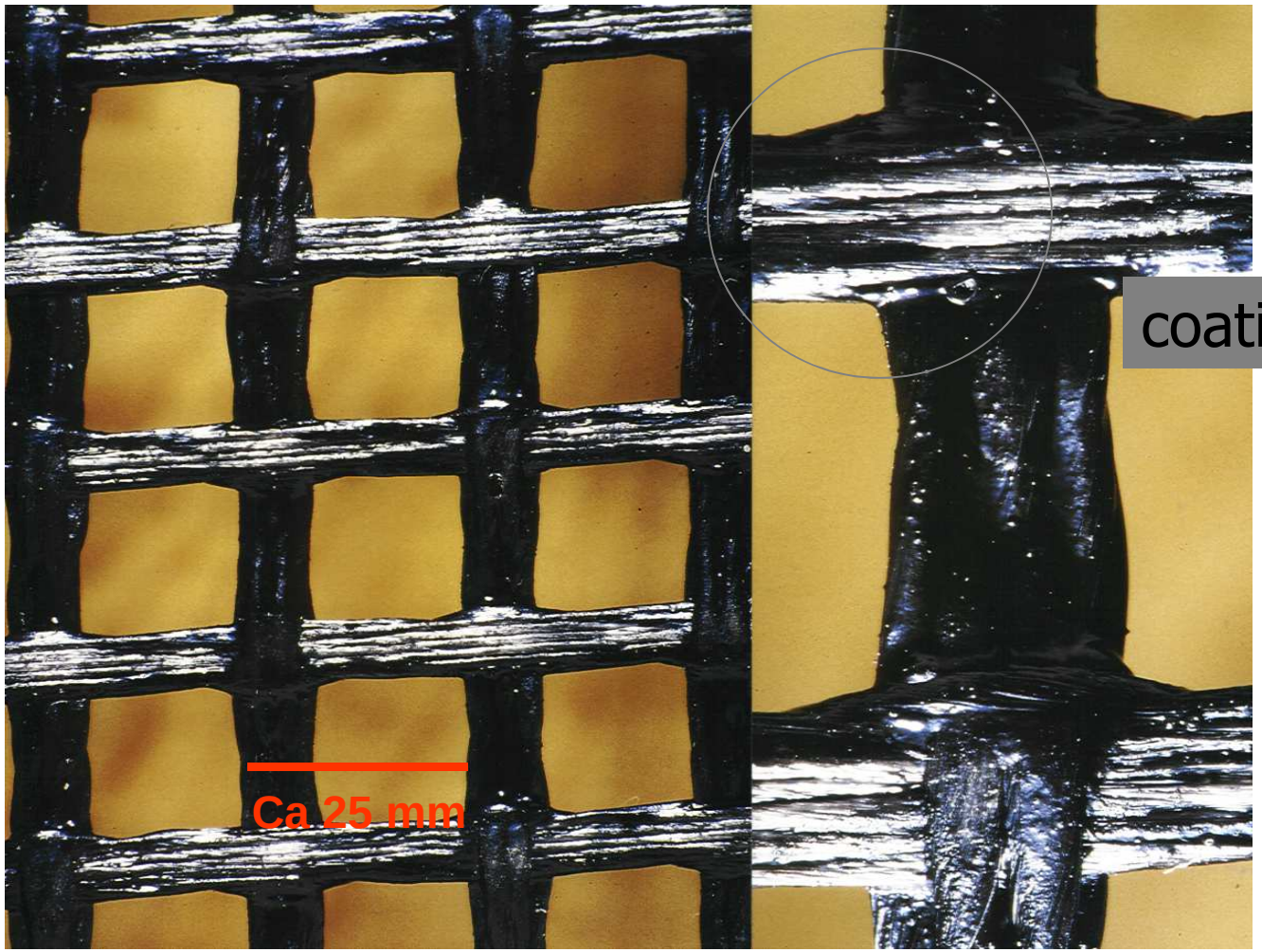


Description of « geosynthetics »

Fabrication technique: geogrids



Coated PET-geogrid



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Welded PET-geogrids

Laserwelded

X-welded

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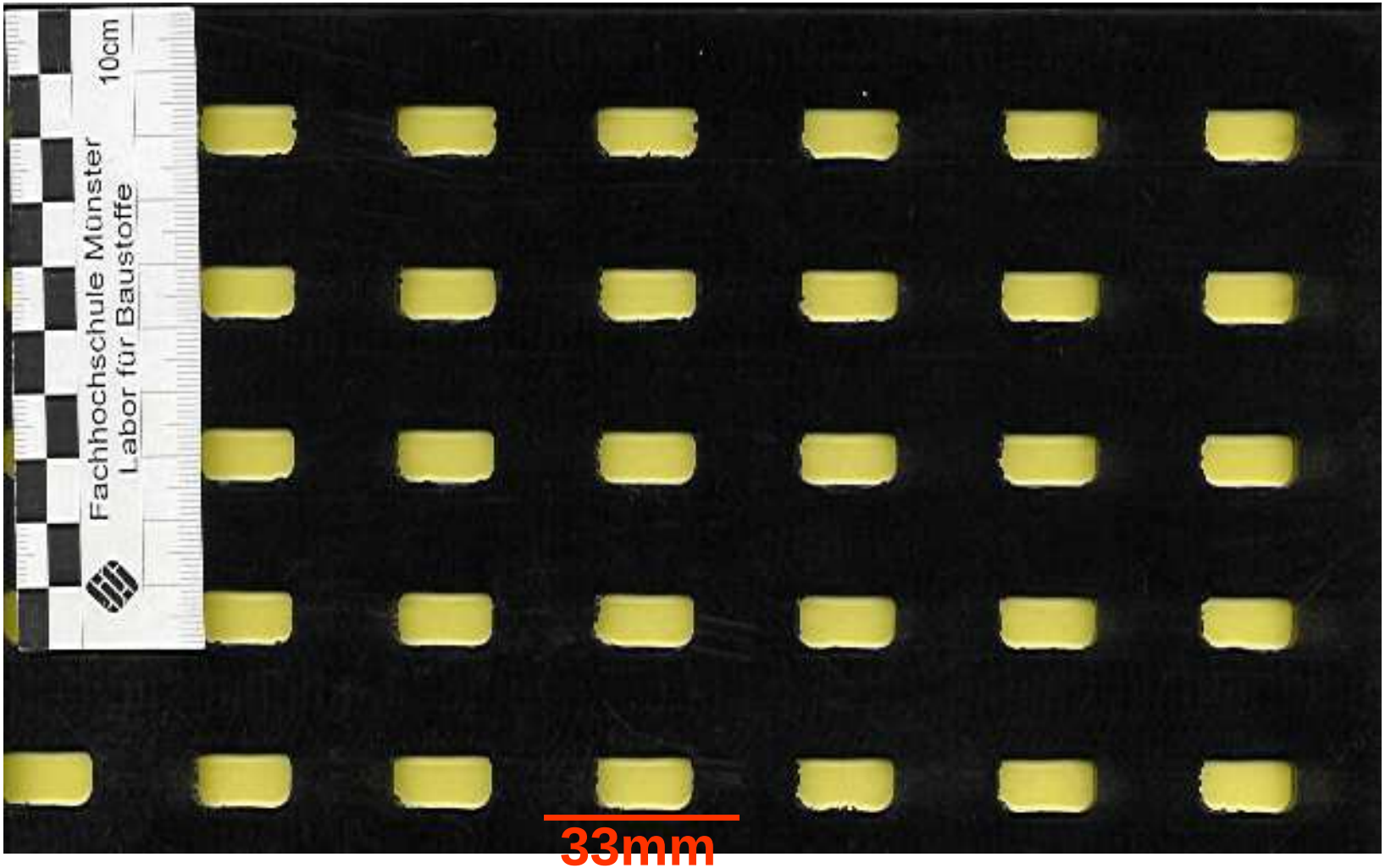
Punched holes in a PE liner



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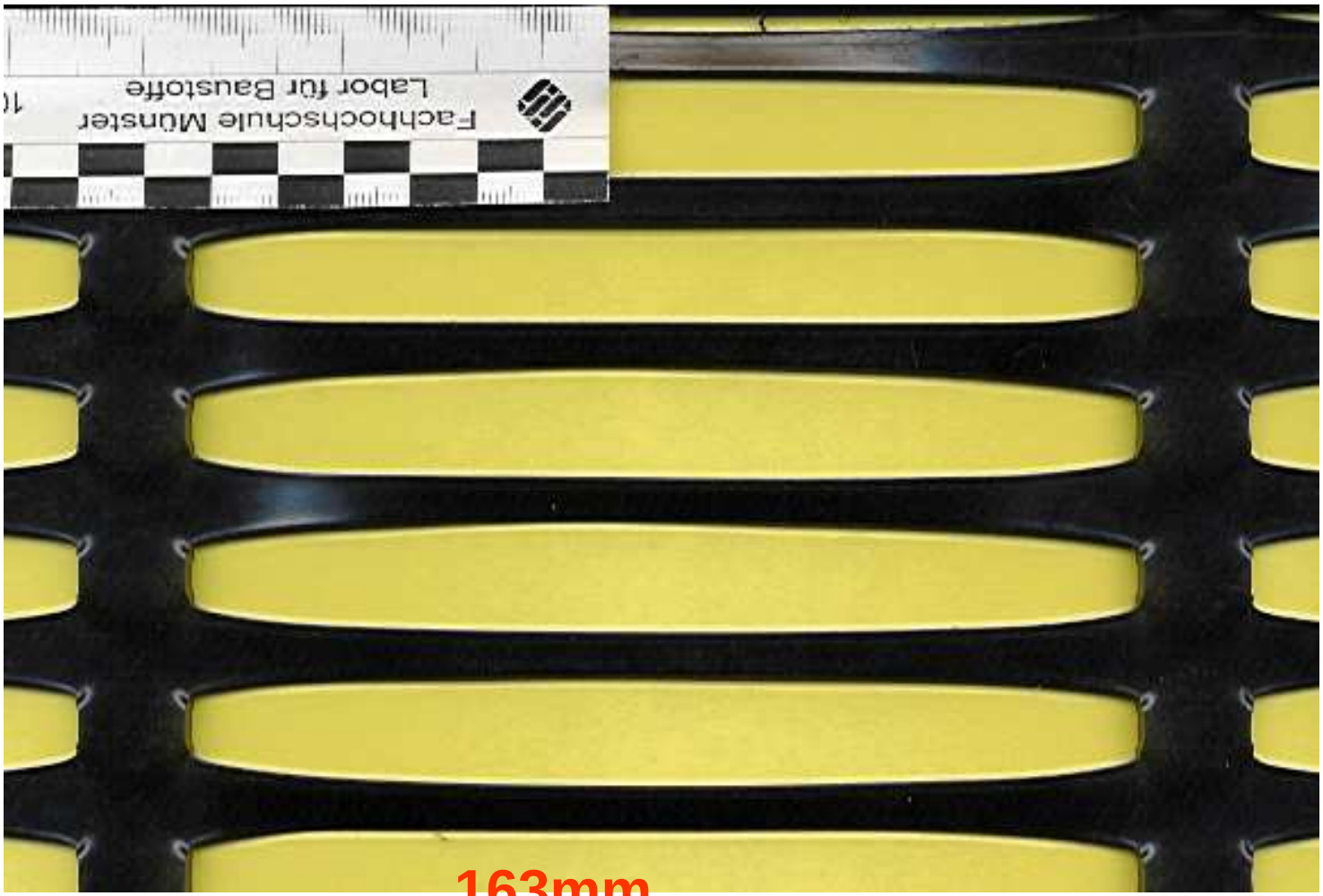
Uniaxial stretched PE-geogrid



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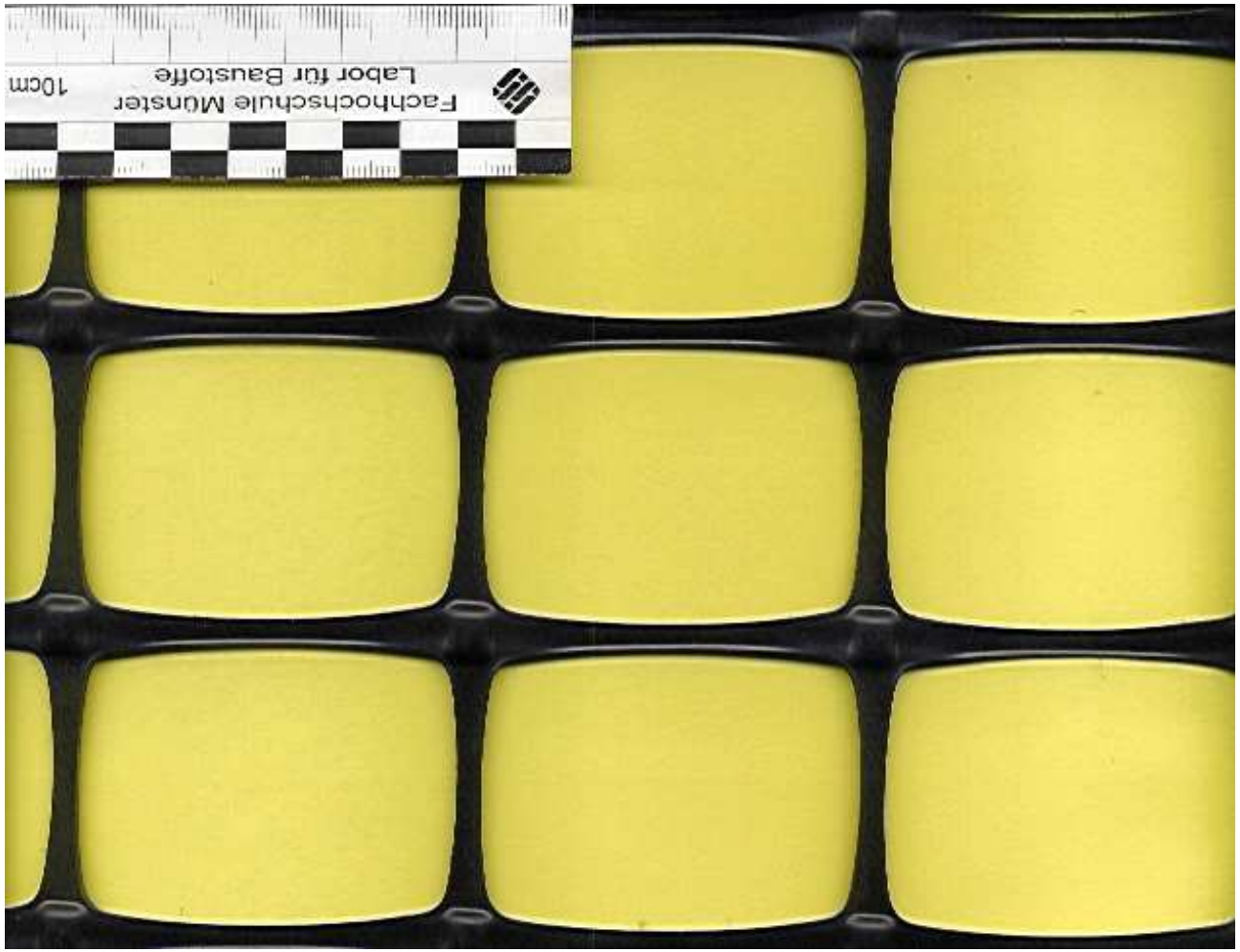
Biaxial stretched PP-geogrids



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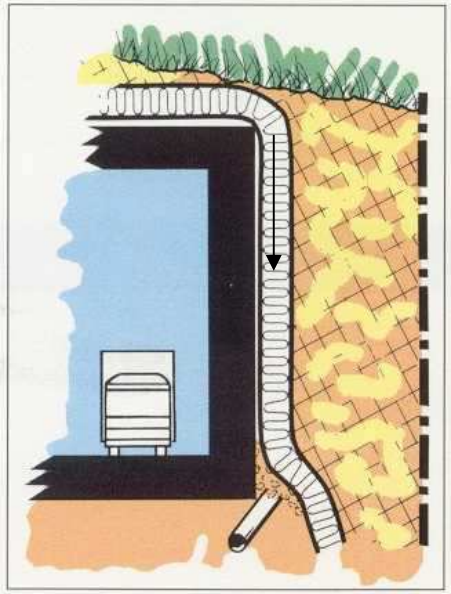
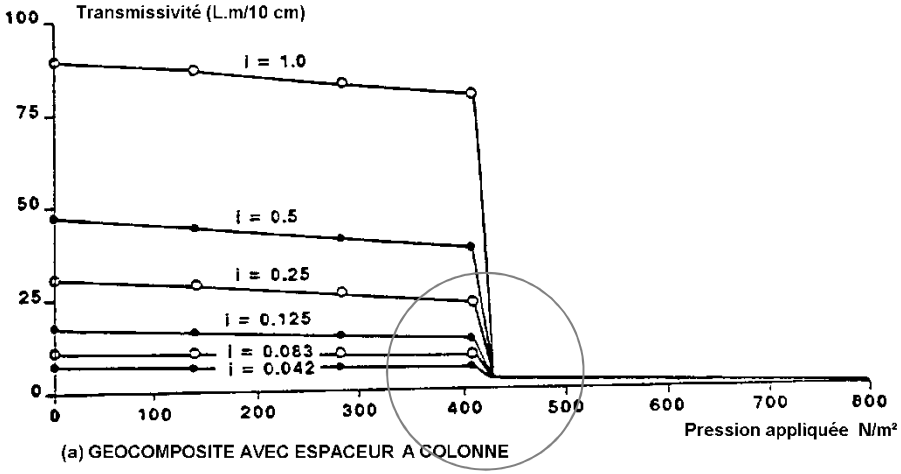
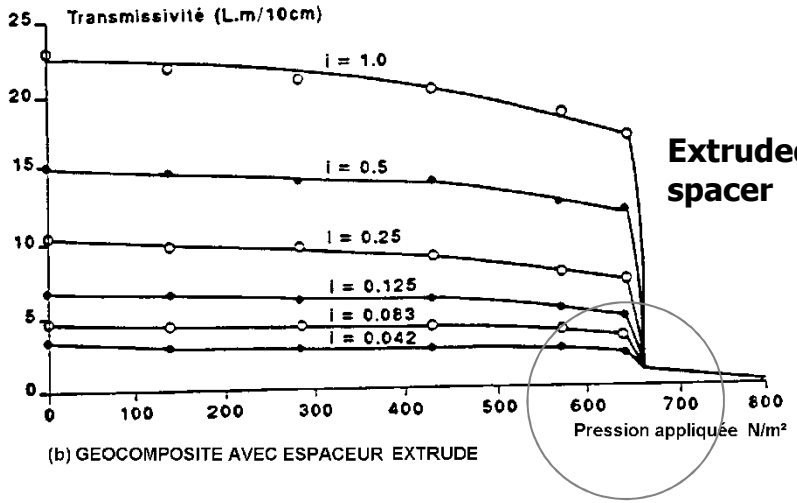
Geocomposits for drainage

Water drainage





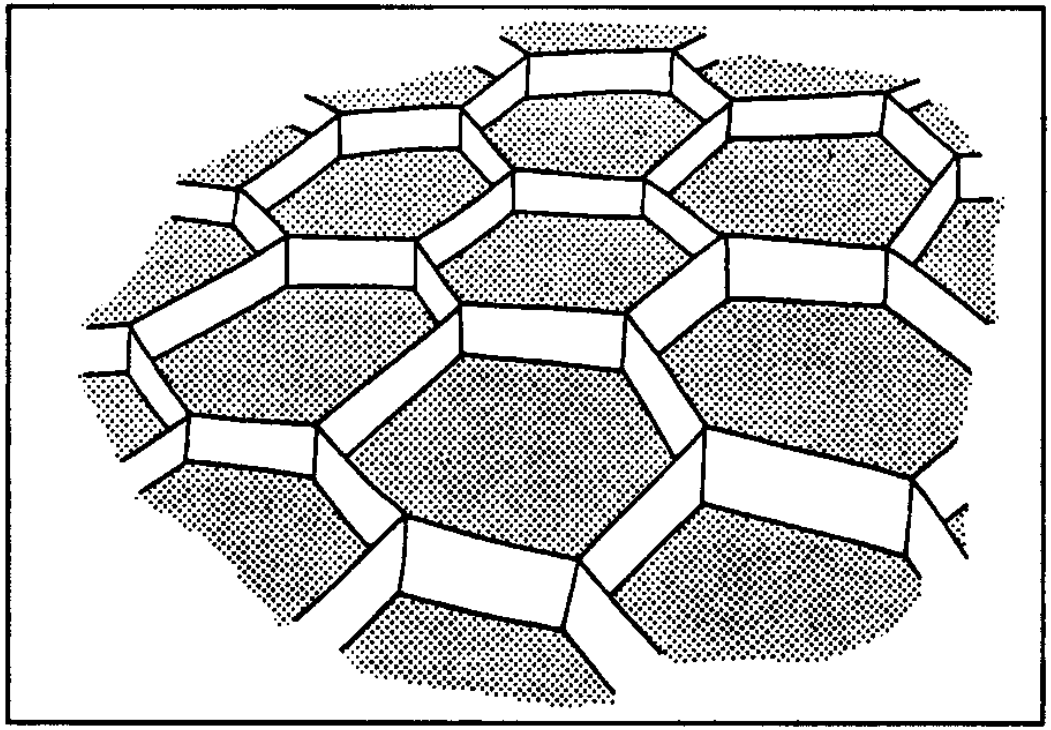
(a) GEOCOMPOSITE AVEC ESPACEUR A COLONNE



(b) GEOCOMPOSITE AVEC ESPACEUR EXTRUDE

Extruded spacer

Fabrication technique: geocells



HDPE strips 200mm wide and 1.2mm thick

Ultrasony welded with 33cm intervals

Placed directly on the sub-soil surface and opened in an accordian-like fashion

Filled with sand and compacted

To improve granular soil shear strength

Natural products

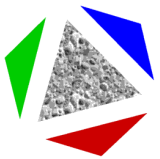
Effective until plants grow

Biodegradable

- jute (Corchorus) from India, Bangladesh or Thaïland;
- coco (coco filaments) from India or Sri Lanka

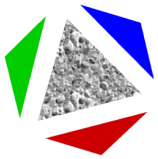
Properties of geosynthetics

Properties	Non woven (thermobonded)	Non woven (needlepunched)	Woven	Grid	Composite grid/geotextile
Surfacic mass (g/m^2)	70 - 400	100 - 2000	100 - 300	200 - 1000	20 - 2000
Thickness (mm)	0.2 - 2	0.2 - 5	0.2 - 1.5	2 - 6	2 - 40
Tensile strength (kN/m)	4 - 30	4 - 50	20 - 1500	2 - 150	20 - 400
Elongation at break (%)	20 - 70	50 - 150	10 - 35	10 - 40	-
Apparent opening size (mm)	0.06 - 0.15	0.06 - 15	0.05 - 1.5	30 - 110	-
Permittivity (1/s)	0.2 - 2	0.2 - 2.5	0.05 - 0.5	-	0.05 - 10



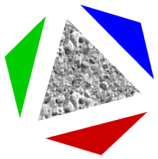
Geomembranes

- Waterproofing (≠ geotextile)
  - PVC: polar polymer
  - PE: *apolar* polymer
- Mechanical resistance (tensile, puncture): *protection with geotextile*
- Resistant to chemical products

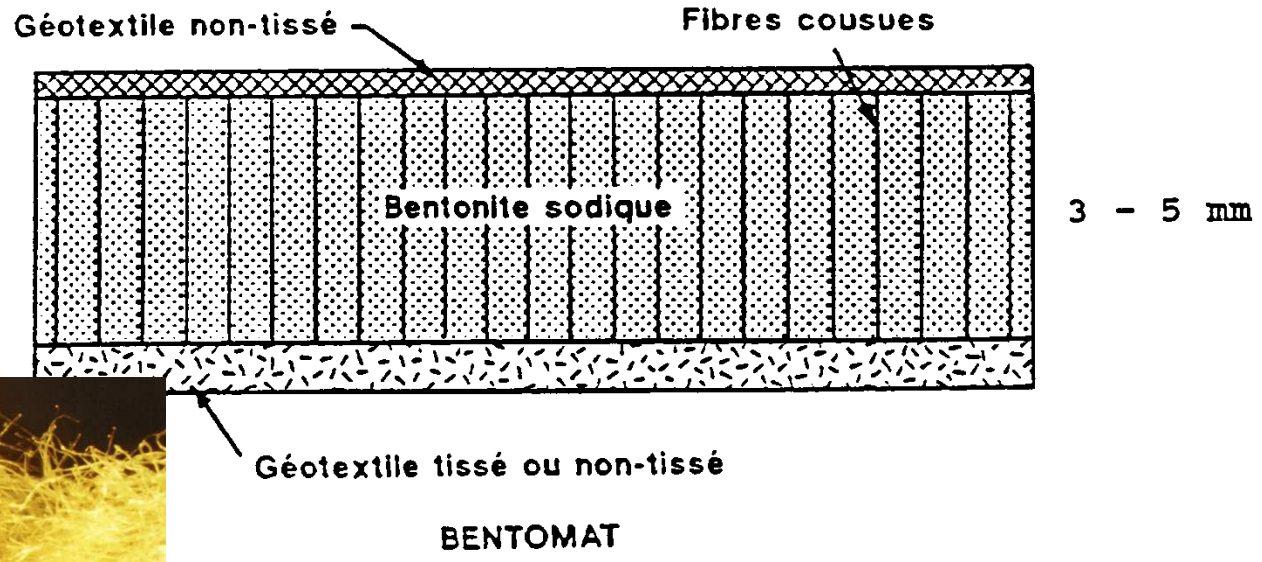


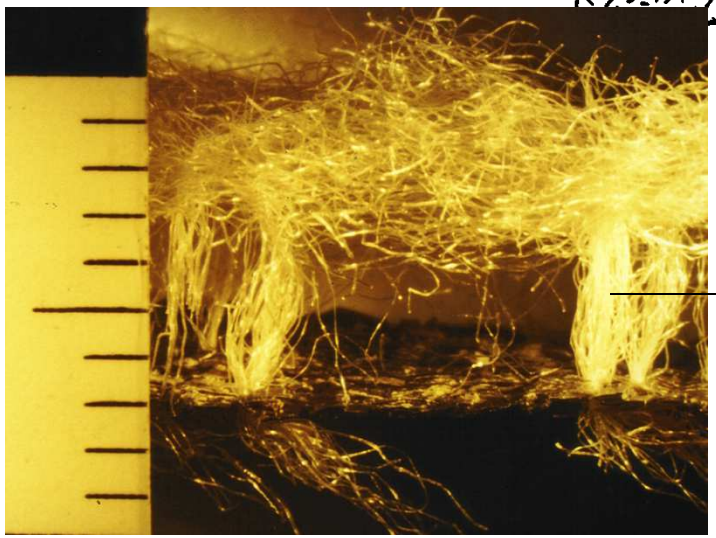
Geomembranes

	HDPE et MDPE	ECB/PE	ECB	CPE	PVC plasti-fié 2)	Bitume
Résistance à la perméance aux :						
- métaux lourds et liaisons inorganiques	+	+	+	+	+	+
- liaisons organiques	?	?	?	?	?	?
- ions métalliques et produits organiques complexes	?	?	?	?	?	?
Résistance aux produits chimiques :						
- essence et huile	+	+	-	+?	+/-	-
- eau de percolation d'ordures ménagères 1)	+	+	+	+	+	+
- hydrocarbures	-	-	-	-	-	-
- hydrocarbures aromatisés	o	o	-	-	-	-
- acides dilués	+	+	+	+	+/-	+
- acides concentrés	o	o	o	-?	-	o?
- milieu fortement oxydant	-	-	-	-	-	-
Résistance au stress-cracking	+	+	+	+	+	+
Caractéristiques mécaniques :						
- résistance à la rupture à court terme	+	+	-	+	+	+
- résistance à la déchirure à court terme	+	+	-	o	o/-	+
- résistance au poinçonnement	+	+	-	o	o	+
Résistance à l'allongement biaxial de longue durée :						
- avec un allongement autorisé de 5 %	+	+	+	+	+	+
- avec un allongement autorisé de 5 à 10 %	o/-	o	+	+	+	+ 3)
- avec un allongement autorisé de 10 à 20 %	-	-	o	o	o	o 3)
Durabilité :						
- résistance à la lumière solaire	+	+	+	+	+/o	+?
- résistance au vieillissement intrinsèque	+	+	+	+	o	o?



Geo-clay-liner





fibers

As waterproofing layer

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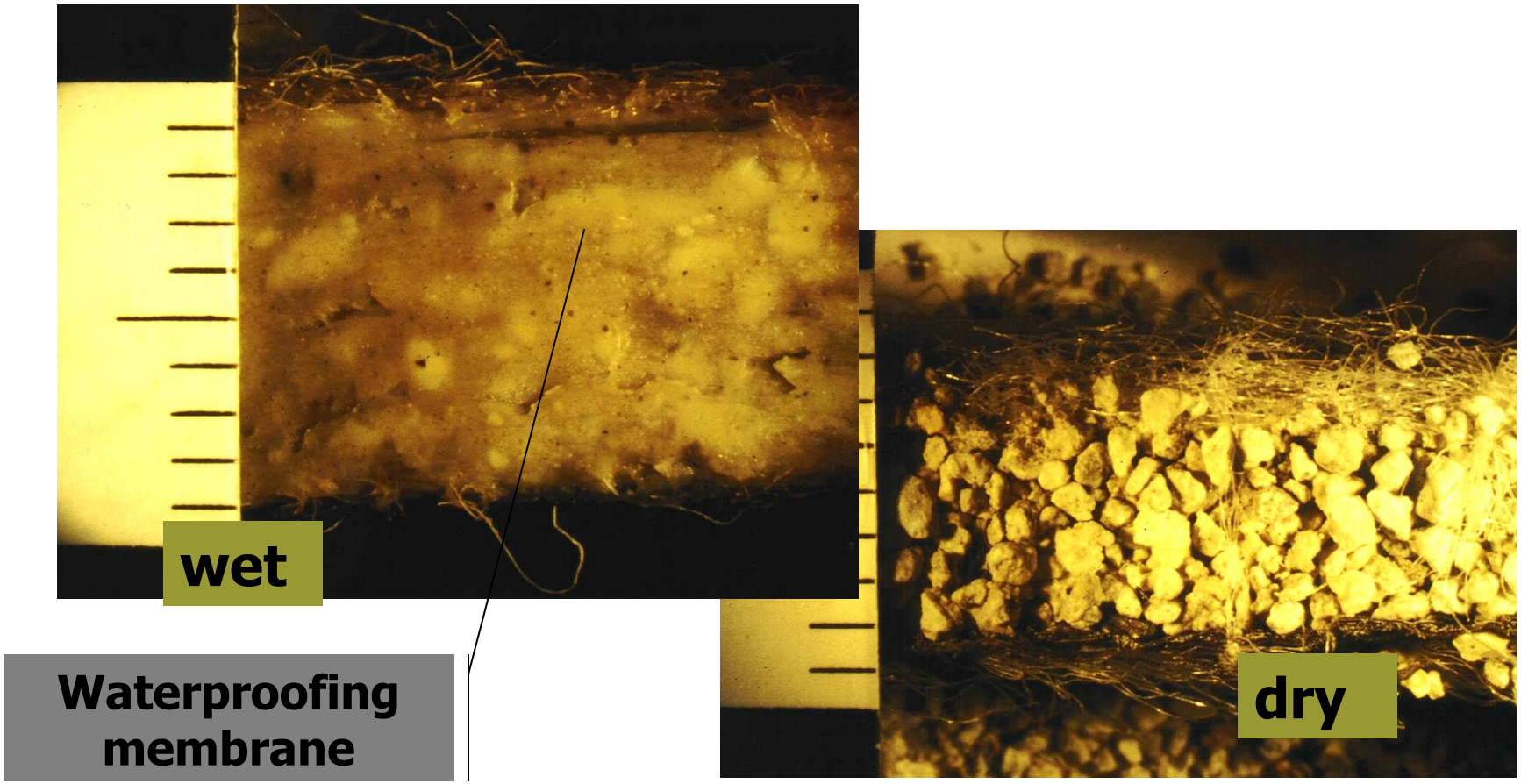
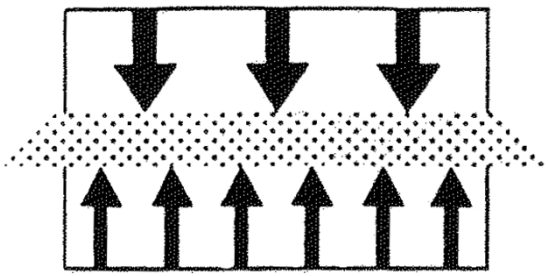
Geo-clay liner

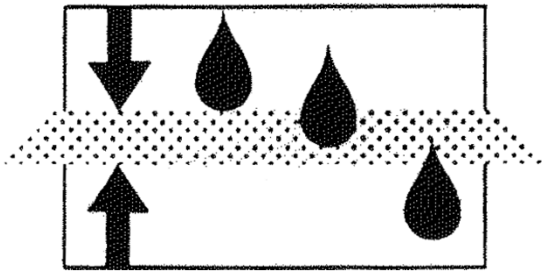


Roles and functions

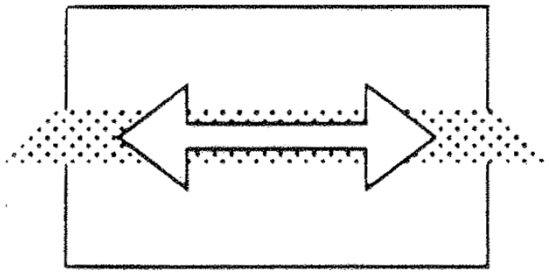
Functions of geosynthetics



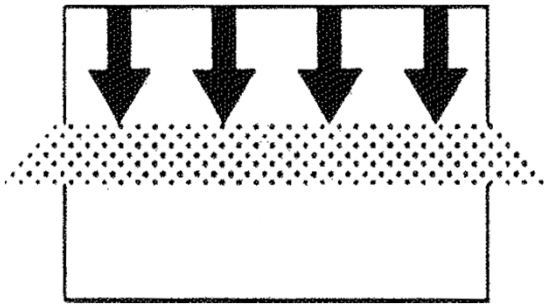
Separation



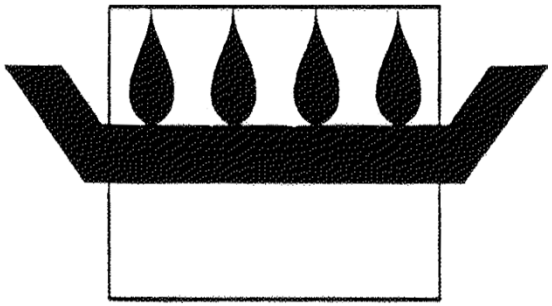
Filtration



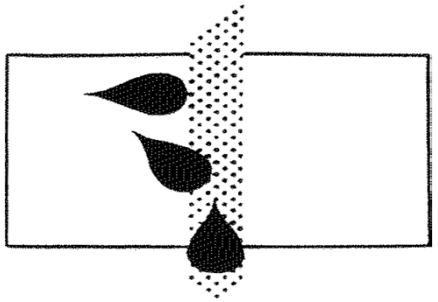
Reinforcement



Protection

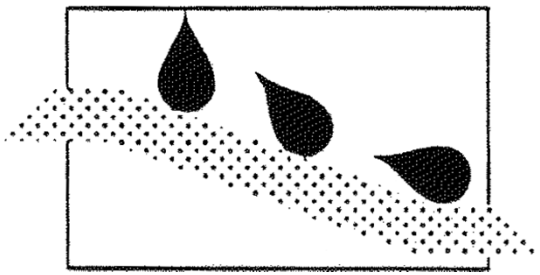


Waterproofing

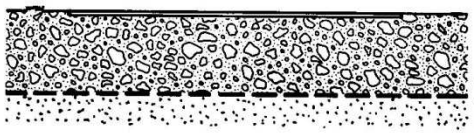


Drainage

Erosioncontrol



SEPARATION (S)



SEPARATION

A) Geometrical separation
Example: anti-contaminant layer

COMMENTS

Prevents intermingling of two layers and thus the mixing of two types of soil possessing different characteristics and properties

Characteristics to be taken into account

Functional aspect
- permeability — permittivity
- filtration diameter

Water must flow freely in the structure without build up of pore pressures.

The choice of filtration diameter should be a compromise, to allow both the free flow of water and good retention of soil particles.

Operational aspect
- mechanical resistance
  - tearing
    - static
    - dynamic
  - piercing
  - tension

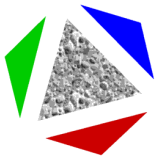
Resistance to stresses and concentrated forces.

Membrane effect
Localized deformation.

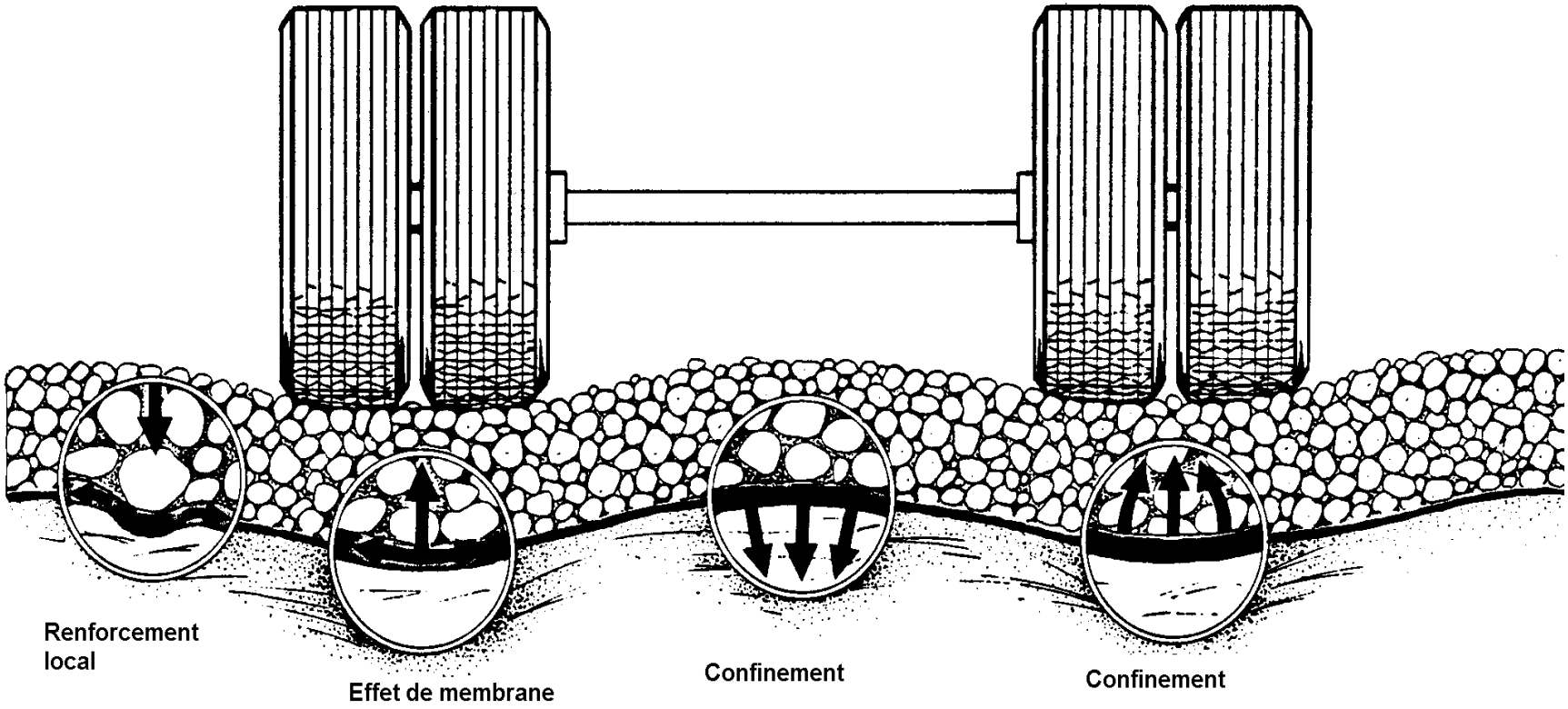
Stitching is recommended, even imperative on highly compressible soils.

Assembling method
- stitching
- eventually overlapping, depending on soil

The overlap should be adapted according to the technical (deformability of geotextile, bearing capacity of soil) and economical (size of overlap, surface lost) parameters.



Separation


Renforcement
local
Effet de membrane
Confinement
Confinement

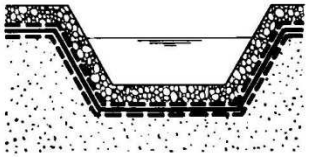
Separation

With geotextile

Without geotextile

AGI

PROTECTION (P)



SEPARATION

COMMENTS

B) Mechanical separation
Example: protection of an impermeable liner

Transition layer, performing damping function.

Characteristics to be taken into account

Functional aspect

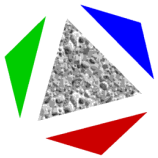
- tension, modulus — *Capacity to withstand concentrated forces at, for example, point of fissure of a rigid structure.*
- piercing — bursting, perforation, puncturing — *Capacity to resist localized mechanical pressures (stone, boulder, rock) appearing, for example, at the surface of a badly graded or badly compacted layer.*
- friction, anchoring — *Capacity to propagate or distribute localized stresses over a large area.*

Operational aspect

- tearing — *Same as above, but applying during installation of geotextile.*
- perforation — *This ensures uniformity of fabric and thus, an homogeneous behaviour of the whole.*

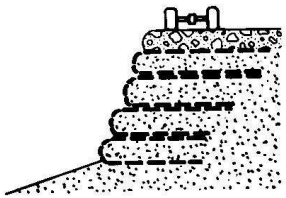
Assembling method

- stitching — *Acceptable in special working conditions (homogeneous and not very deformable subgrade).*
- overlapping



PROTECTION (P)

REINFORCEMENT (R)



REINFORCEMENT

Example: reinforcement of a soil mass

Characteristics to be taken into account

Functional aspect
- tensile strength, modulus, deformability
- flexibility
- friction
- anchoring
- creep, fatigue

Operational aspect
- tearing

Assembling method stitching

COMMENTS

Involves providing the soil with cohesion by incorporating an additional element to take over a part of the tensile forces.

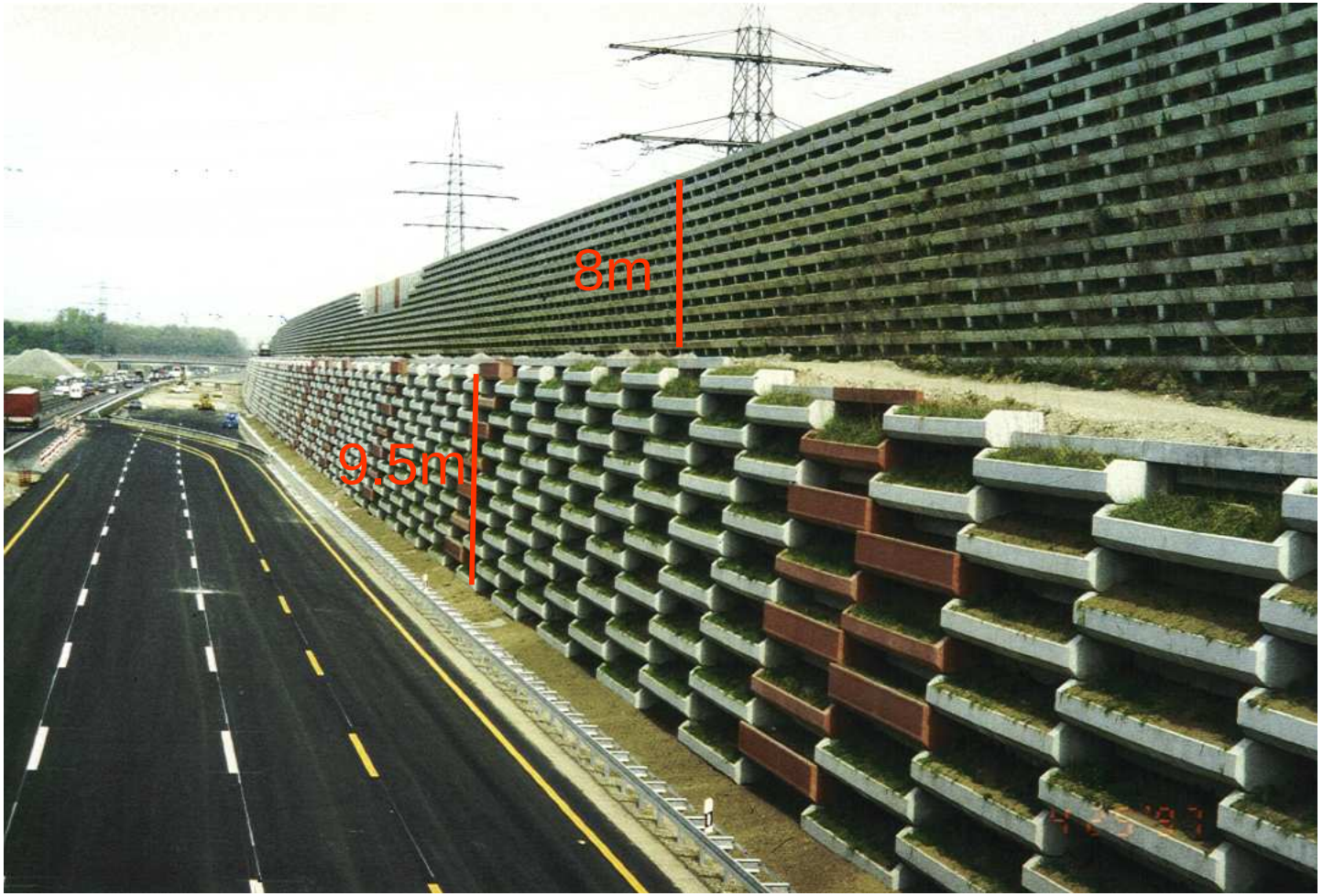
Capacity, depending on the type of reinforcement, to take over a part of the tensile stresses.

In order that a geotextile can take over tensile forces, it must be anchored in the soil, otherwise it may lead to slippage and resulting failure of the structure.

If the geotextile is subjected to continuous or repetitive forces, this must be taken into account, so that the structure can be designed correctly.

Essential.

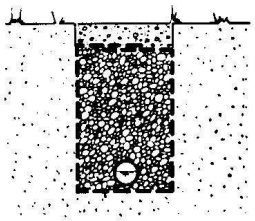
Reinforcement



Reinforcement

Reinforcement

FILTRATION (F)



FILTER

Example: drainage trench

COMMENTS

Lowering of the water table:
— system simple to realize
— effective over a large area
— possibility of deformation

Characteristics to be taken into account

Functional aspect
- permeability normal to plane → permittivity
- thickness
- filtration diameter
- flexibility

High permittivity causes small losses of pressure head and thus large flowing capacity through fabric.

A carefully selected filtration diameter provides good retention of particles without giving rise to high losses of pressure head.

A flexible geotextile:
— provides a better soil/geotextile interface
— prevents soil particles from washing out
— stabilises and checks migration of moving particles.

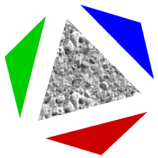
Operational aspect — mechanical resistance — piercing, tension → tearing

Any alteration in the continuity of the fabric will give rise to unstable areas, with internal erosion of the soil mass.

Assembling method
- overlapping 0,2 to 0,3 m
- stitching

Sufficient overlapping in normal applications, otherwise increase to 1 m, if necessary.

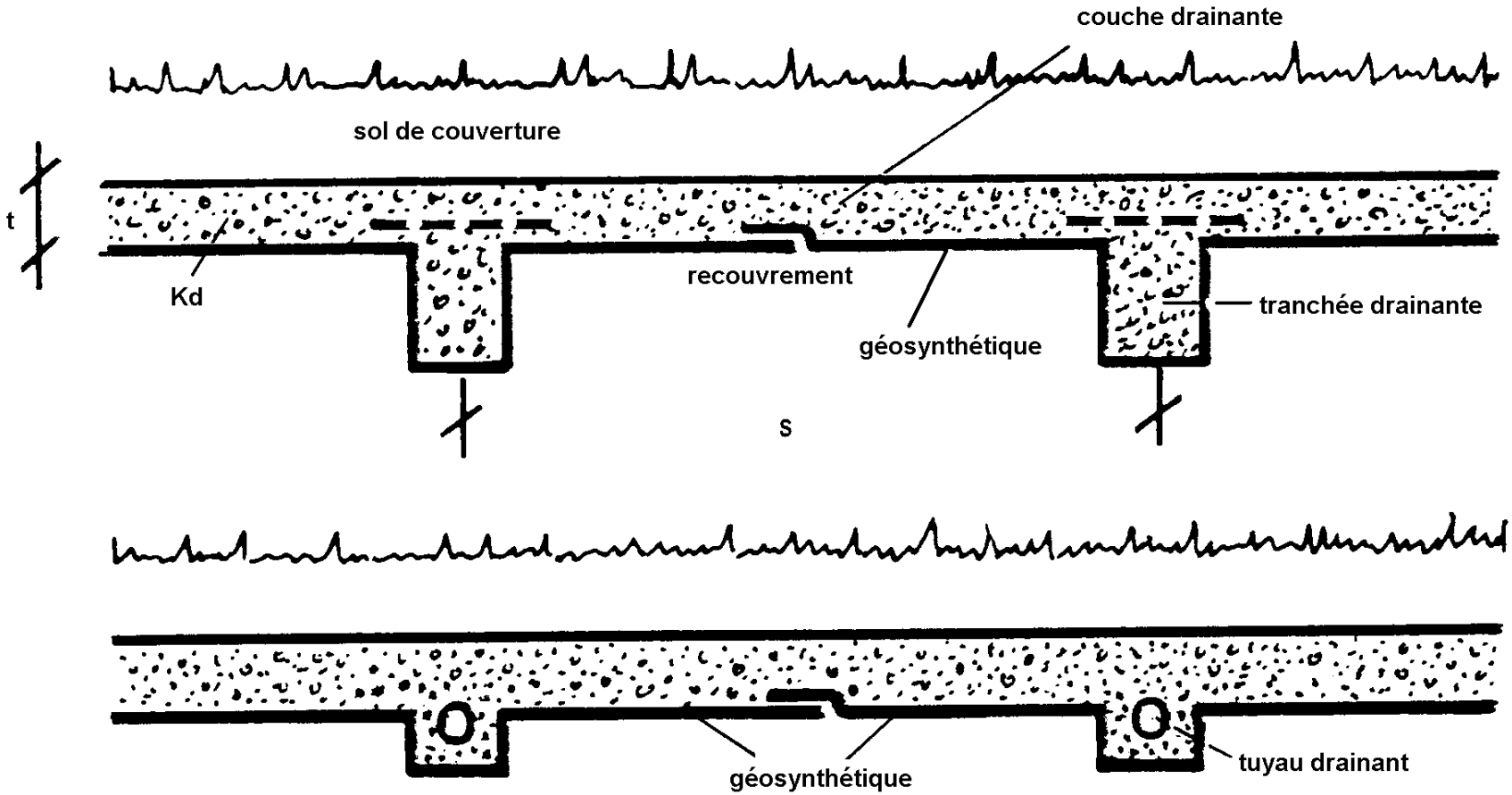
Best method, but may appear too expensive and therefore unwarranted for a structure of this type.



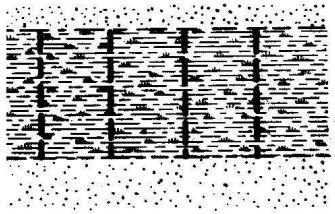
FILTRATION (F)

Drainage trench

Football and sportive area



DRAINAGE (D)



DRAIN

COMMENTS

Example: vertical drains → *Consolidation of a highly compressible soil, with a high water content.*

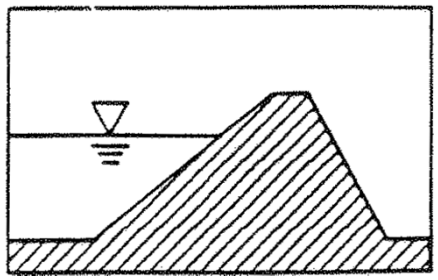
Characteristics to be taken into account

- **Functional aspect**
  - permeability along plane of geotextile
    - transmissivity → *Capacity to quickly dissipate pore water pressure in a soil mass.*
    - permittivity → *Capacity of geotextile to offer low resistance to water penetration through fabric.*
  - thickness, compressibility
  - filtration diameter
- **Operational aspect**
  - tensile strength
  - tearing
  - limited deformability

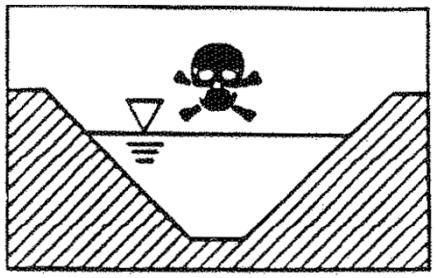
  → *Capacity of geotextile to withstand stresses during installation; should be compatible with surrounding medium.*

Assembling method
- stapling
- stitching

Application of geosynthetics

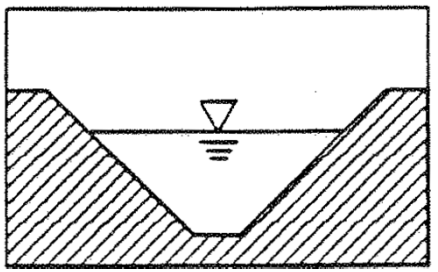


Resevoirs, dams

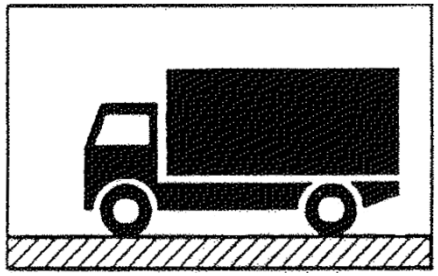


Liquid waste

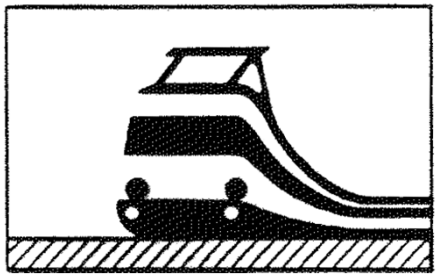
Solid waste



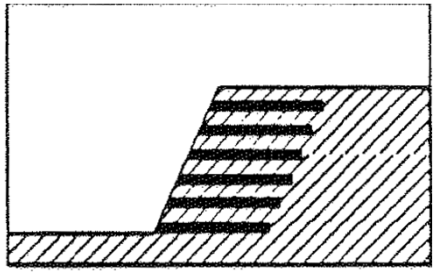
Canals



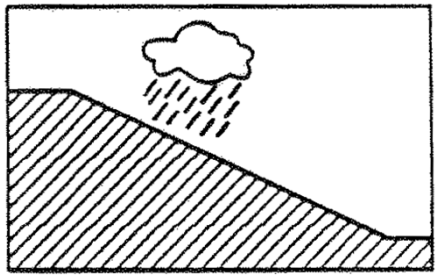
Roads



Railroads

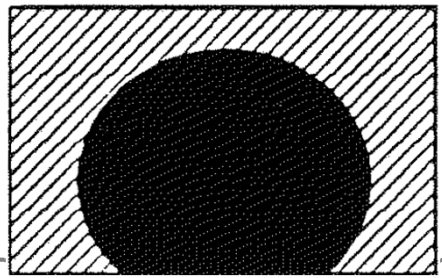


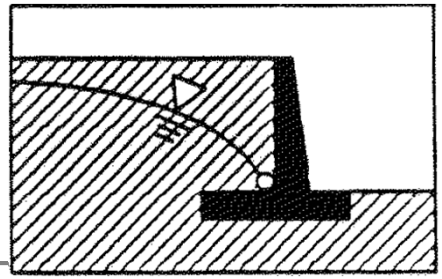
Retaining walls



Erosion protection

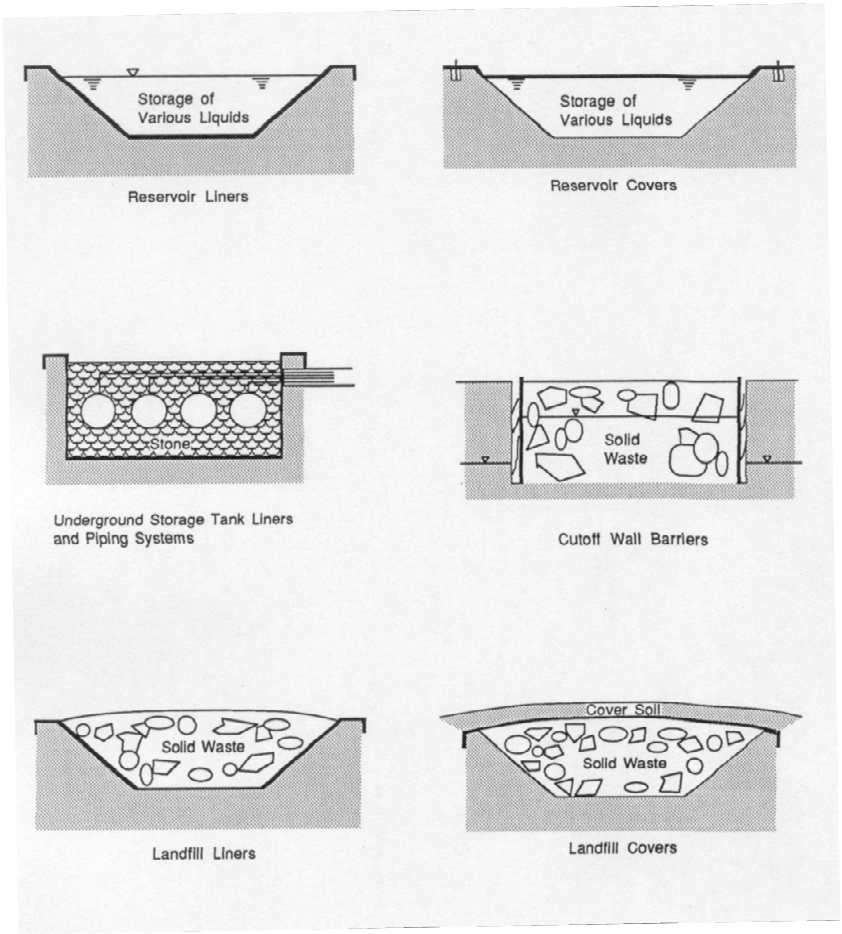
Tunnels

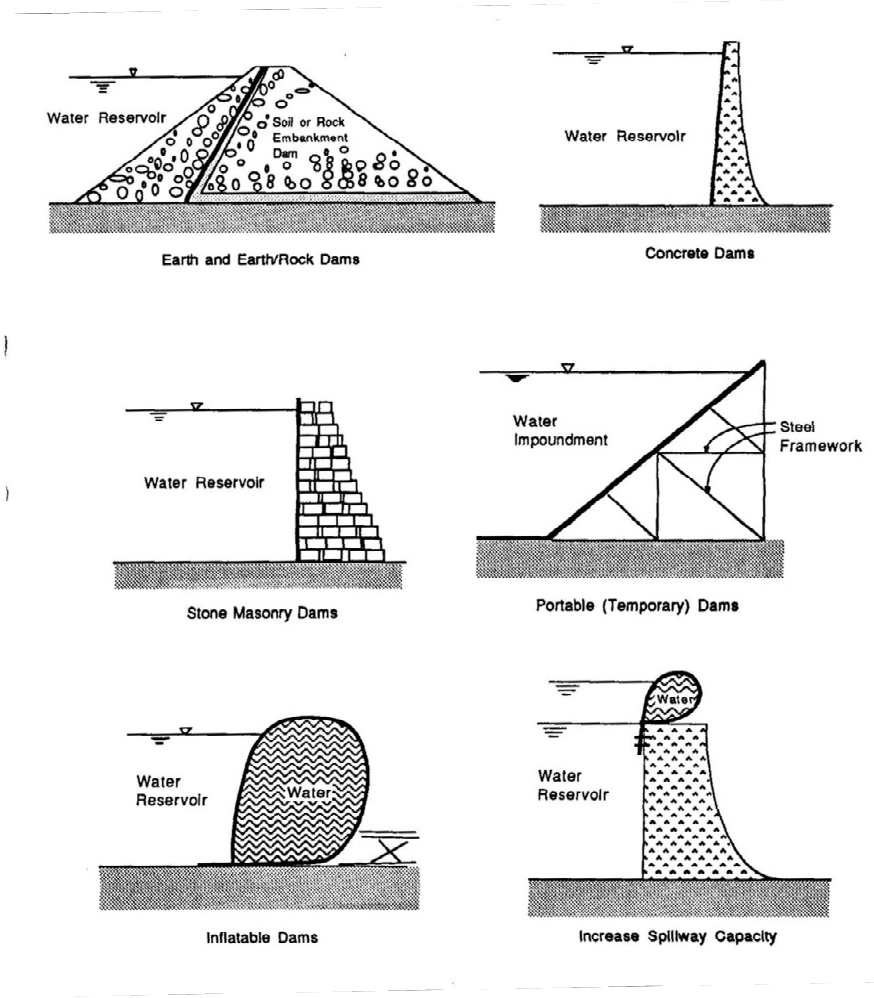




Drainage systems

Geomembranes: applications

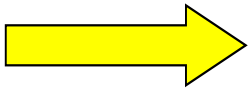




Durability

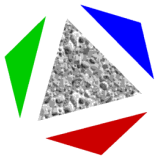
Properties and durability

- interaction soil-geosynthetics
- physico-chemical environment
- degradations during on site works
- creep of the material and the fabric



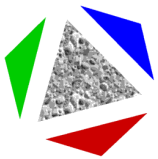
safety coefficients on products

$$T_{permis} = \frac{T_{ultime}}{SF_x . SF_y .... SF_n}$$



Installation damage reduction factors *(AASHTO, 1997)*

Geosynthetic	**Max. Size 102mm D50/30mm**	**Max. Size 20mm D50/0.7mm**
HDPE uniaxial grid	1.20 – 1.45	1.10 – 1.20
PP biaxial geogrid	1.20 – 1.45	1.10 – 1.20
PVC coated PET geogrid	1.30 – 1.85	1.10 – 1.30
Acrylic coated PET geogrid	1.30 – 2.05	1.20 – 1.40
Woven gtx (PP&PET)	1.40 – 2.20	1.10 – 1.40
Non woven gtx (PP&PET)	1.40 – 2.50	1.10 – 1.40
Slit film woven PP gtx	1.60 – 3.00	1.10 – 1.20



Durability reduction factors *(AASHTO, 1997)*

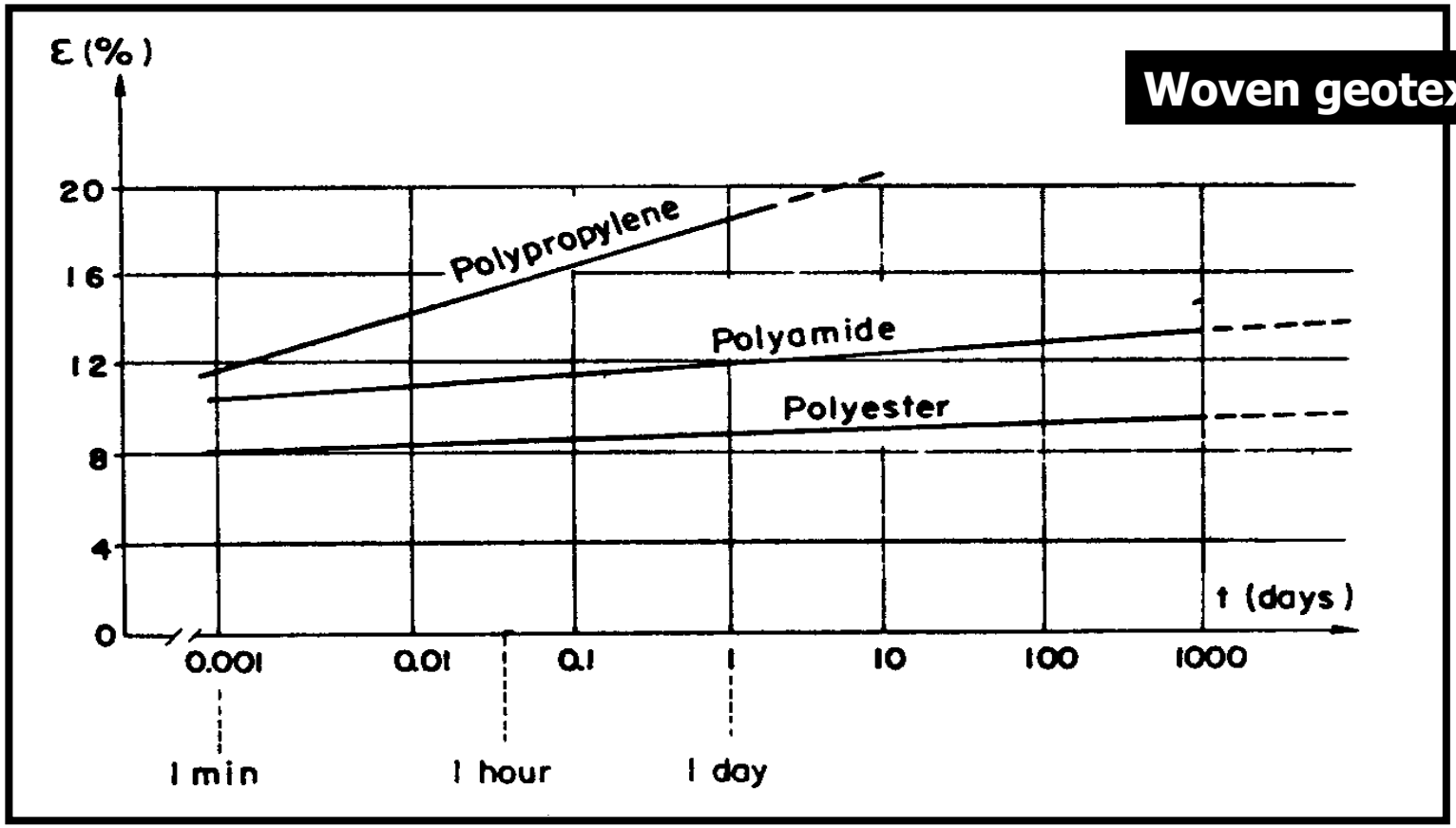
Product	3<pH<5	5<pH<8	8<pH<9
PET gtx	2	1.6	2
PVC coated PET geogrid	1.3	1.15	1.3
PE&PP gtx	1.1	1.1	1.1
PE&PP geogrid	<1.1	<1.1	<1.1

⇨ **polyethylen and polypropylen : oxidation, heat, UV rays, leachates**

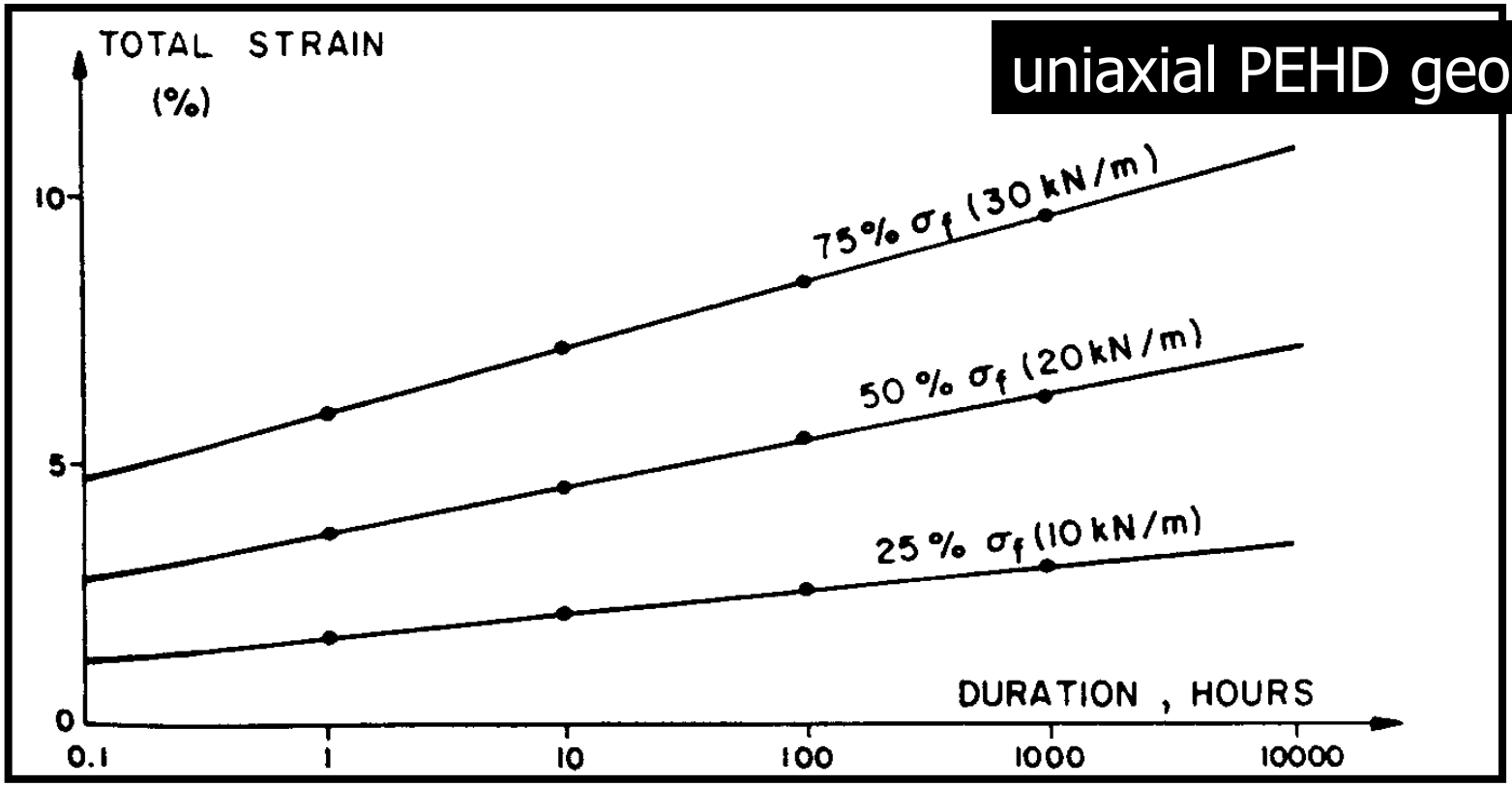
⇨ **polyesters (PET) : hydrolysis, surface abrasion due to high alkalinity levels**

⇨ ***EFFECT OF TEMPERATURE***

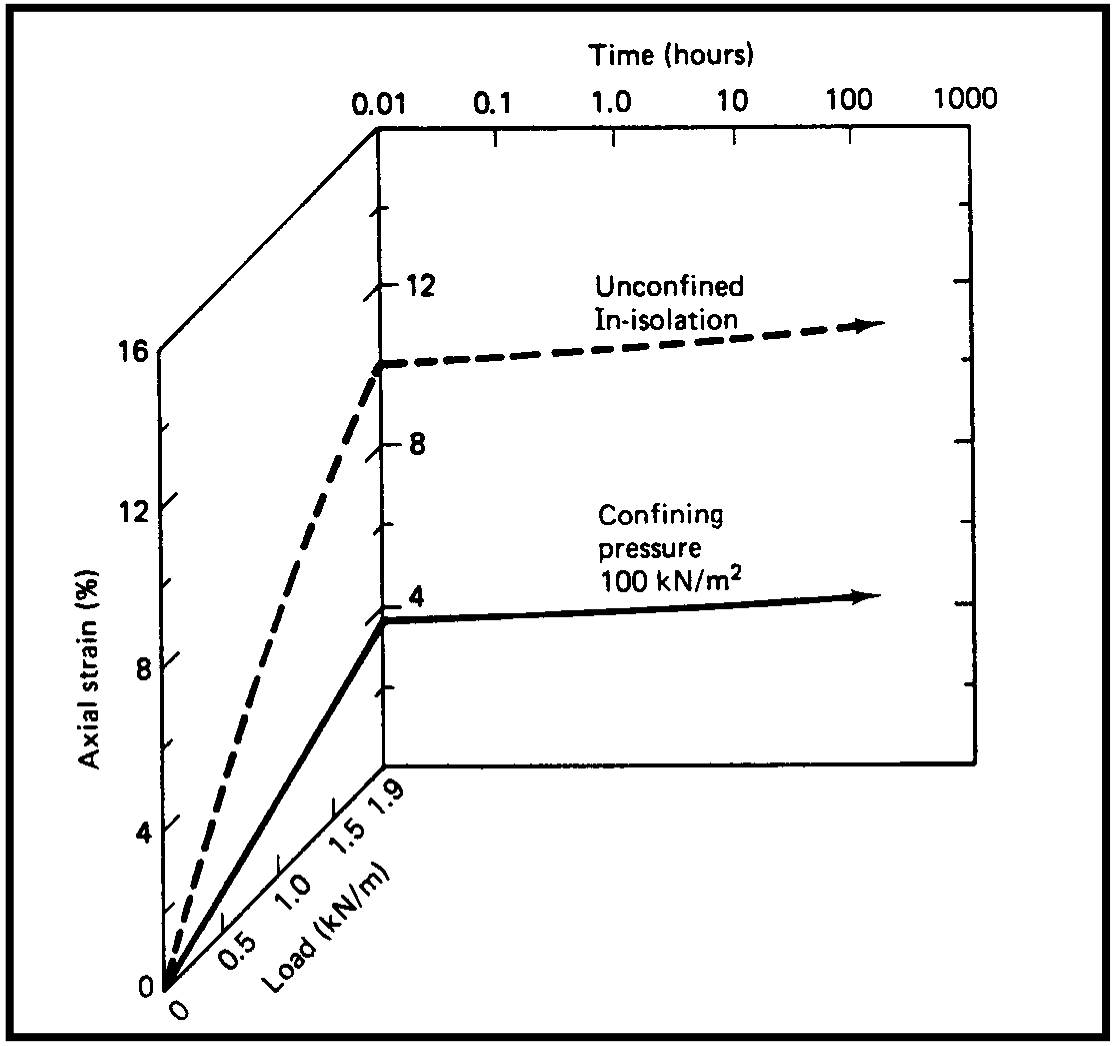
Influence of polymer and product type *(Van Leeuwen, 1977)*



Effect of loading rate *(Mc Gown and all, 1982)*

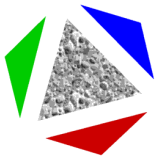


Confining effect *(MacGown, 1982)*



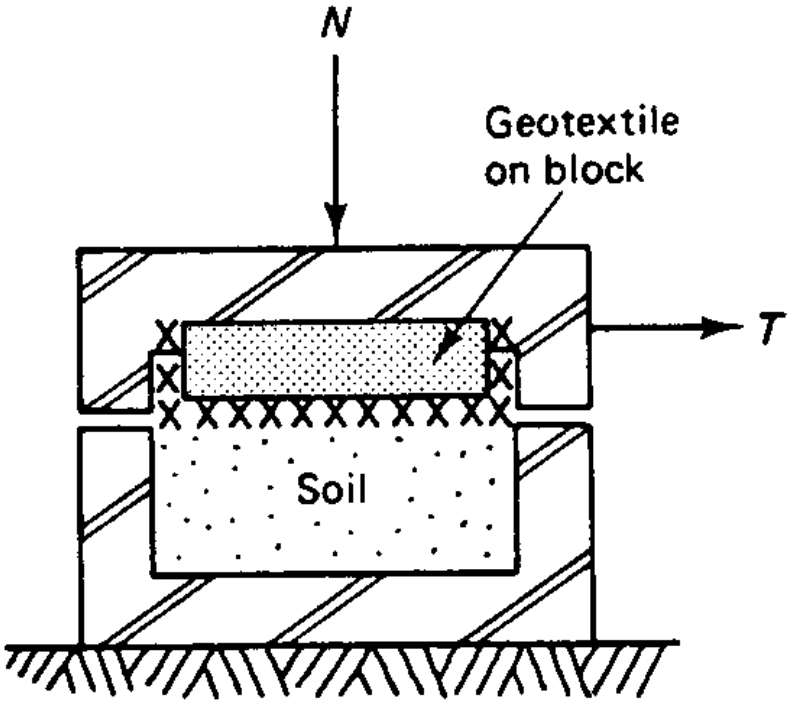
Safety coefficient for creep

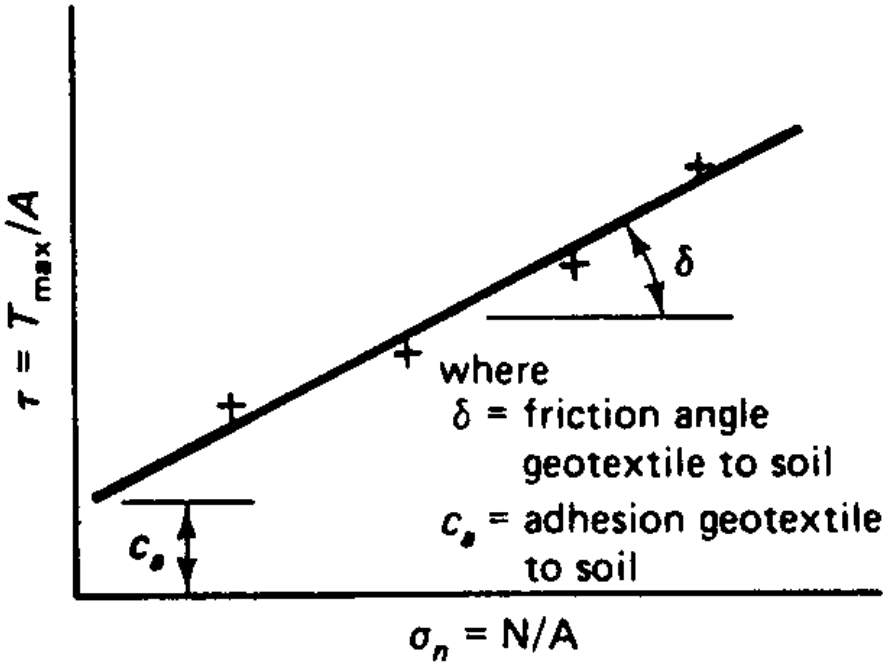
- **polypropylene geosynthetics en : SF = 4**
- **polyethylene geosynthetics en : SF = 4**
- **polyamide geosynthetics en : SF = 2.5**
- **polyester geosynthetics en : SF = 2**

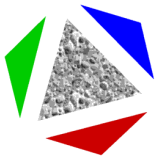


Efficiency in contact angle

$$E = \frac{tg\,\delta}{tg\,\varphi} \times 100$$

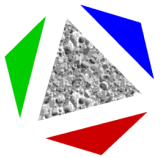


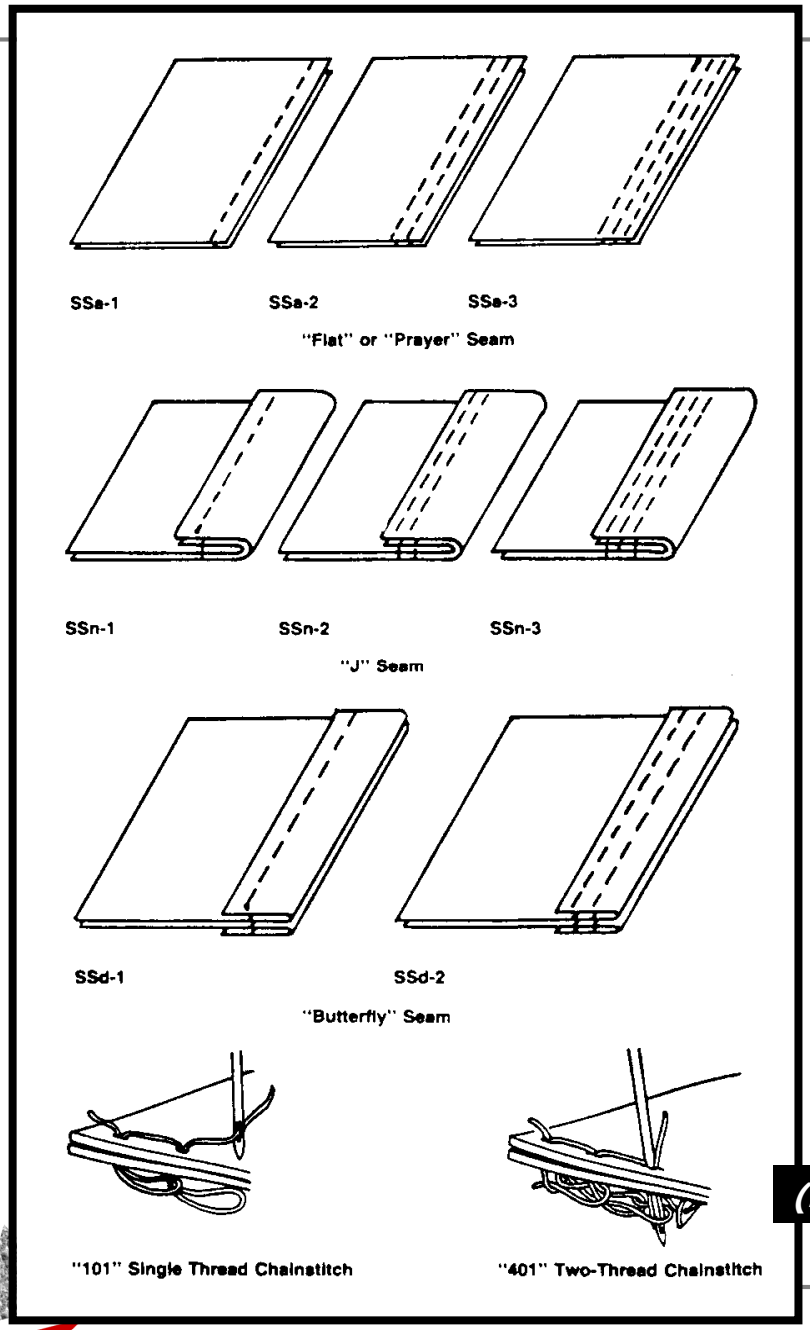




Soil-to-fabric friction angles and efficiencies in cohesionless soil *(Martin and all, 1984)*

Geotextile type	**Concrete sand Ø=30°**	**Rounded sand Ø=28°**	**Silty sand Ø=26°**
Woven, monofilament	26° (84%)	-	-
Woven, silt film	24° (77%)	24°(84%)	23°(87%)
Non woven, melt-bonded	26° (84%)	-	-
Non woven, needle-punched	30° (100%)	26°(92%)	25°(96%)



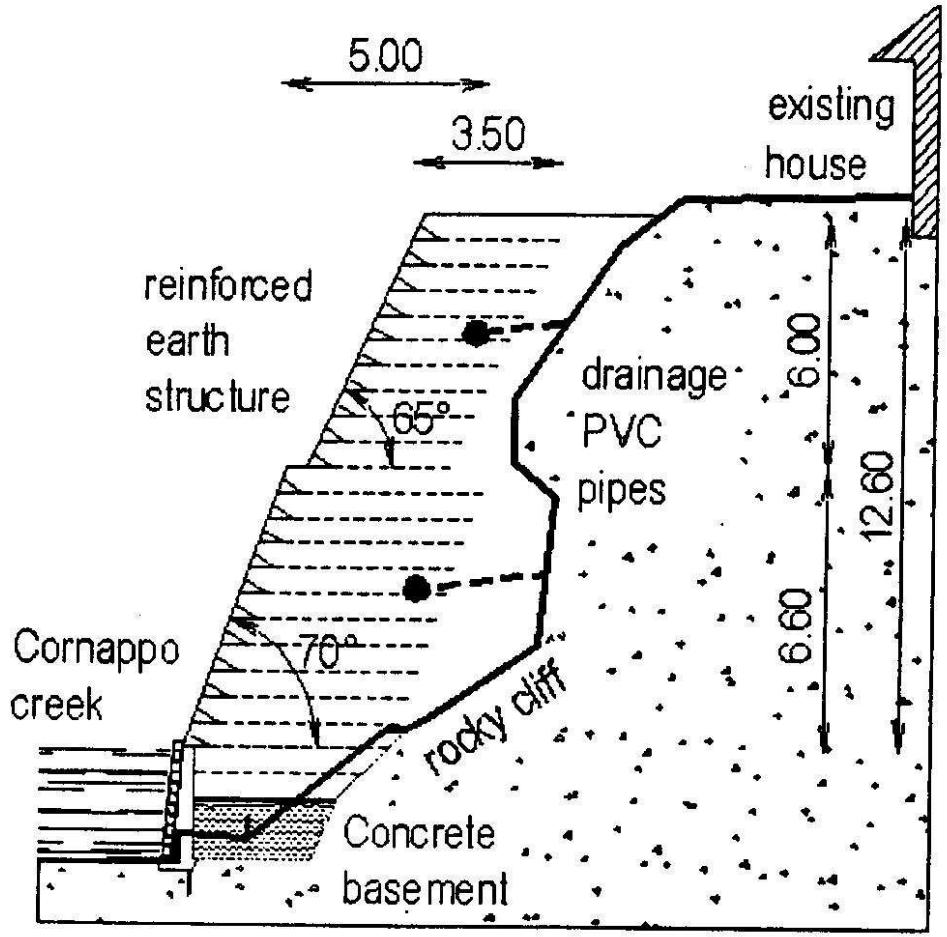


- type of filament
- tension strenght of the filament
- density of knitted points
- type of knitting
- number of knitted lines

(Diaz, 1985)

Design: retaining wall

Retaining wall



ADVANTAGES

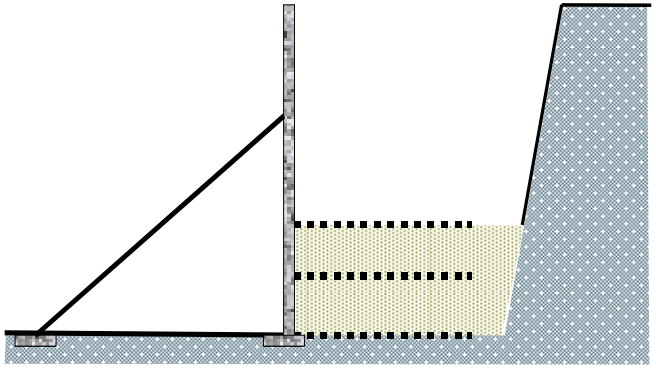
- **Flexible wall system**
- **Minimum excavation behind face of wall**
- **No corrosion**
- **Backfill can contain fines**
- **Drainage with geotextiles**
- **Unskilled labor used**
- **No heavy equipment**

DISADVANTAGES

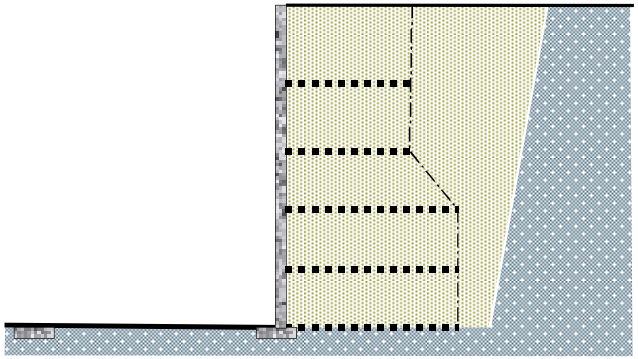
- **Design method quite conservatives**
- **Fabric interaction not often considered**
- **Creep**
- **Wall face must be covered (UV, vandalism)**

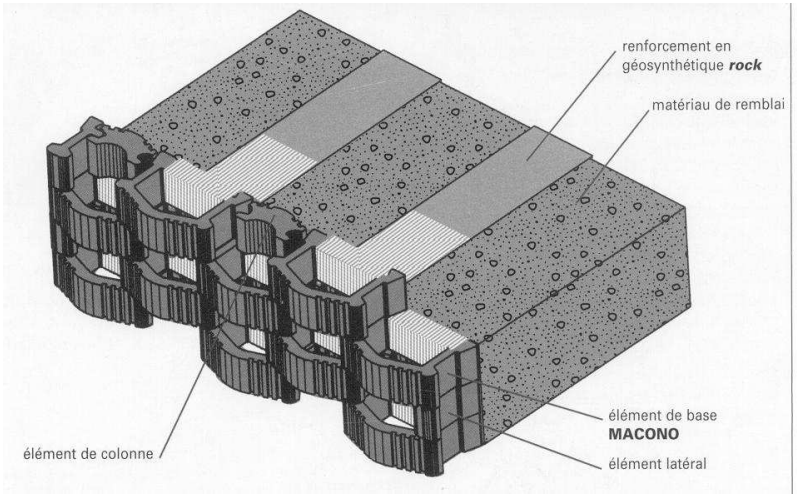
Retaining wall: systems

Without face anchoring system



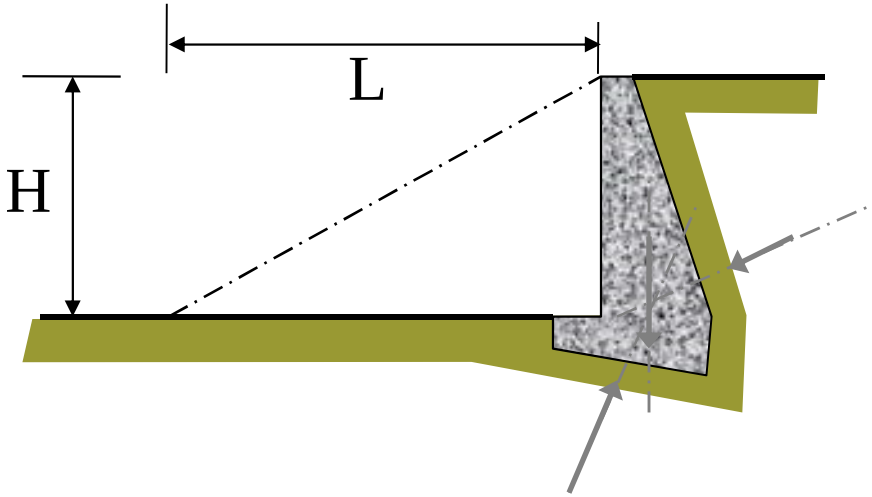
With face anchoring system

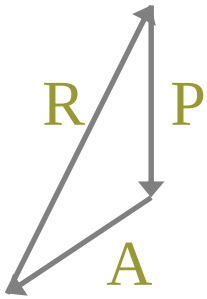




Retaining wall *(Bolle, 2002)*

Global design





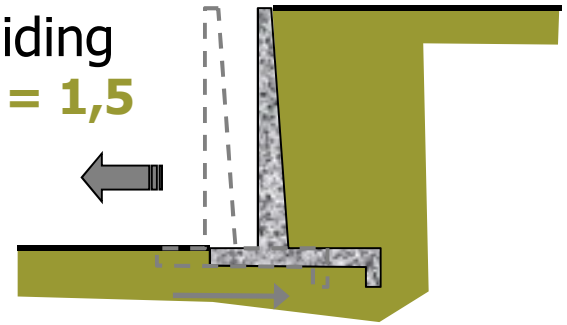
The weight of the wall P is combined with earth pressure A to produce a resultant R transfered to the soil by the foundation slab.

A high quantity of concrete is necessary to give the weight

Retaining wall *(Bolle, 2002)*

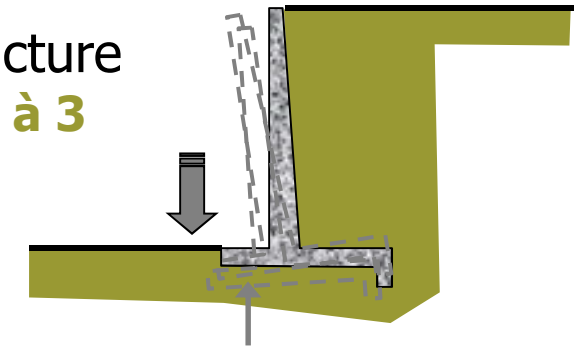
Sliding

S_F = 1,5



Soil puncture

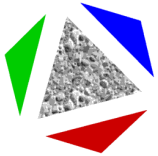
S_F = 2 à 3



soil bearing capacity

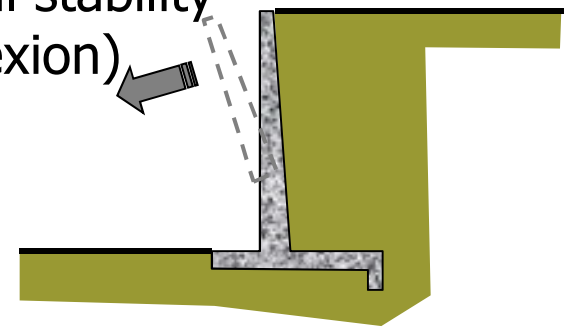
Rupture types

- Sliding
- Soil puncture
- Internal stability
- Settlement (rotation)

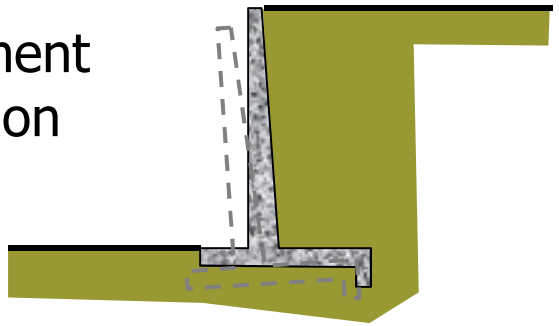


Retaining wall *(Bolle, 2002)*

Internal stability
(flexion)



Settlement
Rotation



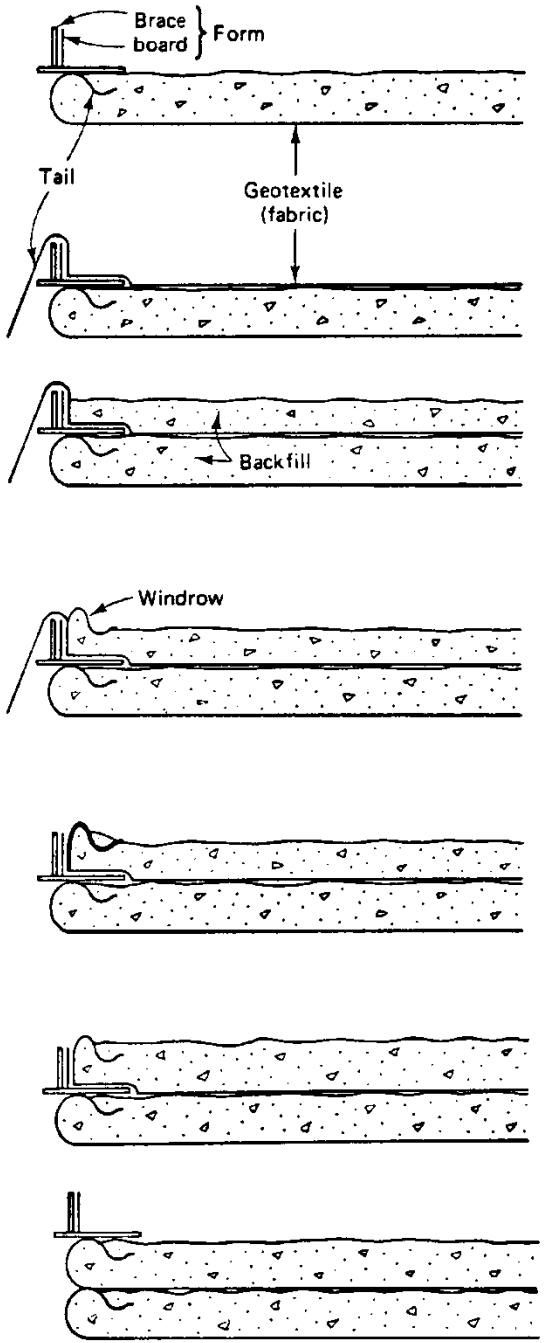
When WATER :

- additional sollicitations

- decreasing of strength

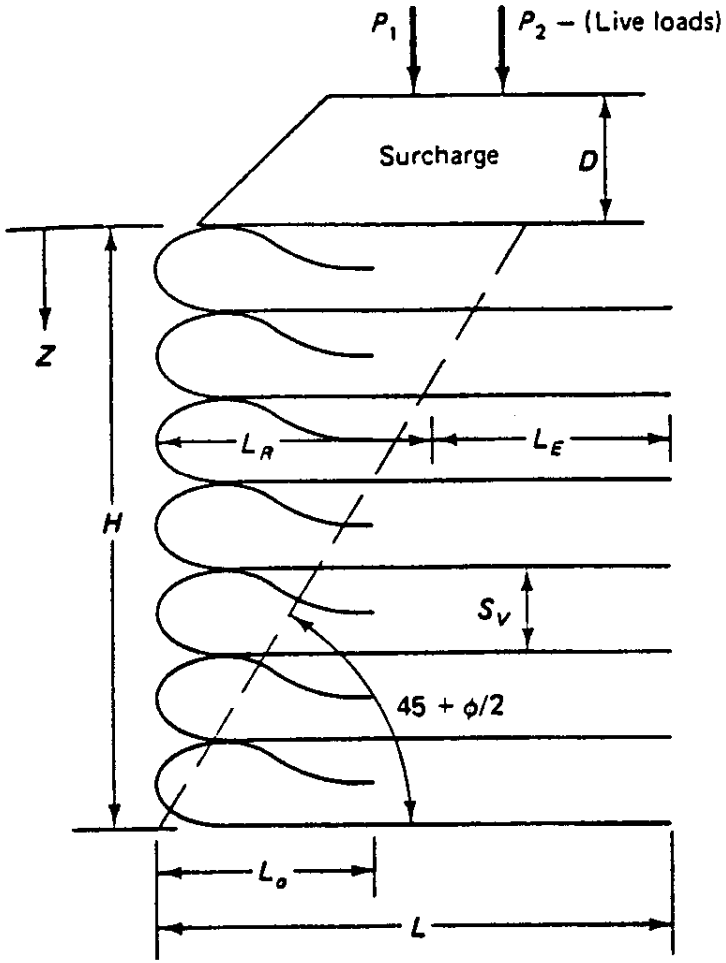
➡ Necessity of a good drainage system !

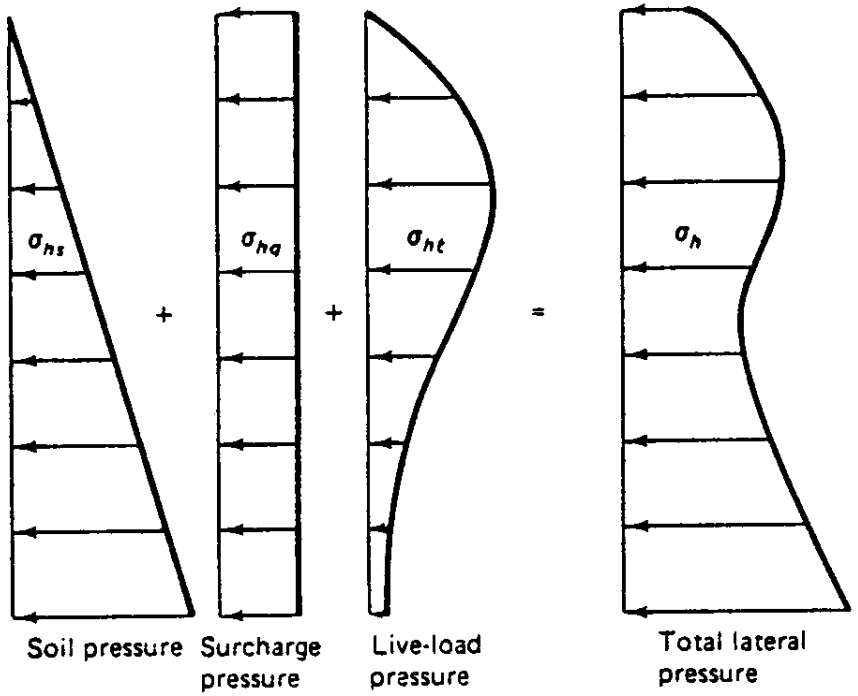
Retaining wall *(Bolle, 2002)*

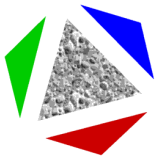


1. Set form on completed lift
2. Unrool the fabric and position it
3. Place backfill to about half of the total lift height
4. Make a windrow to slightly greater than full lift height against the form
5. Place the fabric « tail » over the windrow and lock into place with backfill
6. Complete backfilling for planned lift thickness
7. Reset the form and repeat the sequence

Retaining wall: internal stability







Retaining wall: internal stability

$$\sigma_h = \sigma_{hs} + \sigma_{hq} + \sigma_{hl}$$

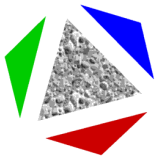
where

σ_h = total horizontal pressure

$\sigma_{hs} = K_a.\gamma.z$ = pressure due to soil

$\sigma_{hq} = K_a.q$ = pressure due to surcharge load

$\sigma_{hl} = P.\ x^2.z/R^5$ = pressure due to live load



Retaining wall: internal stability

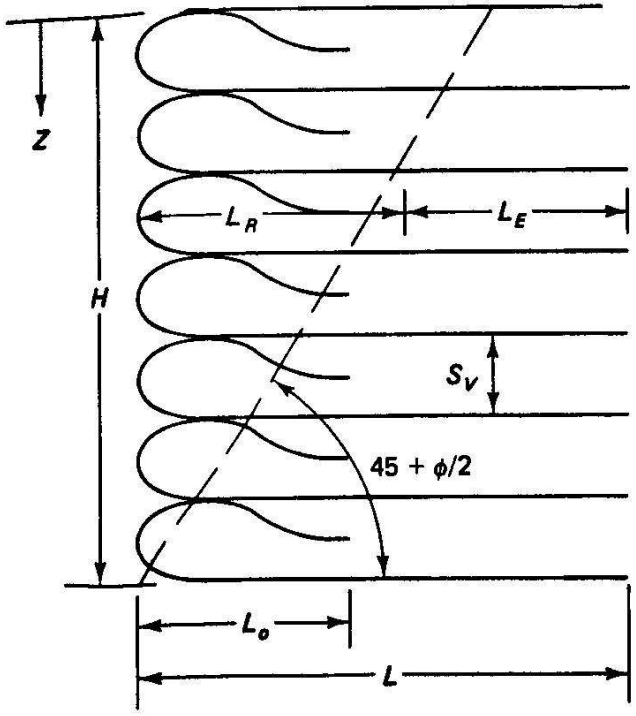
1 $$\sigma_h S_v = \frac{T_{allow}}{FS} \quad \Leftarrow \quad T_{allow} = T_{ult}\left[\frac{1}{FS_{ID} \times FS_{CR} \times FS_{CD} \times FS_{BD}}\right]$$

$$S_v = \frac{T_{allow}}{\sigma_h FS}$$

2 $$L_R = (H - z)\tan\left(45 - \frac{\phi}{2}\right)$$

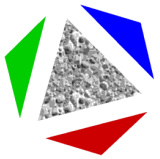
3 $$L_e = \frac{S_v \sigma_h FS}{2(c + \gamma z \tan\delta)}$$

4 $$L_o = \frac{S_v \sigma_h FS}{4(c + \gamma z \tan\delta)}$$



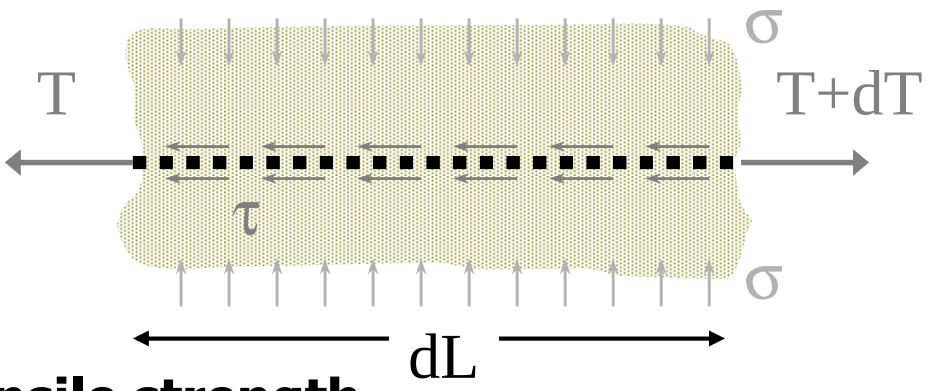
Retaining wall: safety coefficients on the products

	Installation damage	Creep	Chemical degradation	Biological degradation
Retaining walls	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5	1.0 to 1.3
Slope stabilization	1.1 to 1.5	1.5 to 2.0	1.0 to 1.5	1.0 to 1.3
Railways	1.5 to 3.0	1.0 to 1.5	1.5 to 2.0	1.0 to 1.2



Retaining wall: internal stability *(Bolle, 2002)*

Internal stability



Geosynthetics have a **high tensile strength**.
Tensile strnegth is transferred to soil by shear stresses (friction) :

$$dT = \int_0^{dL} 2.\tau.dx = 2.\tau.dL$$

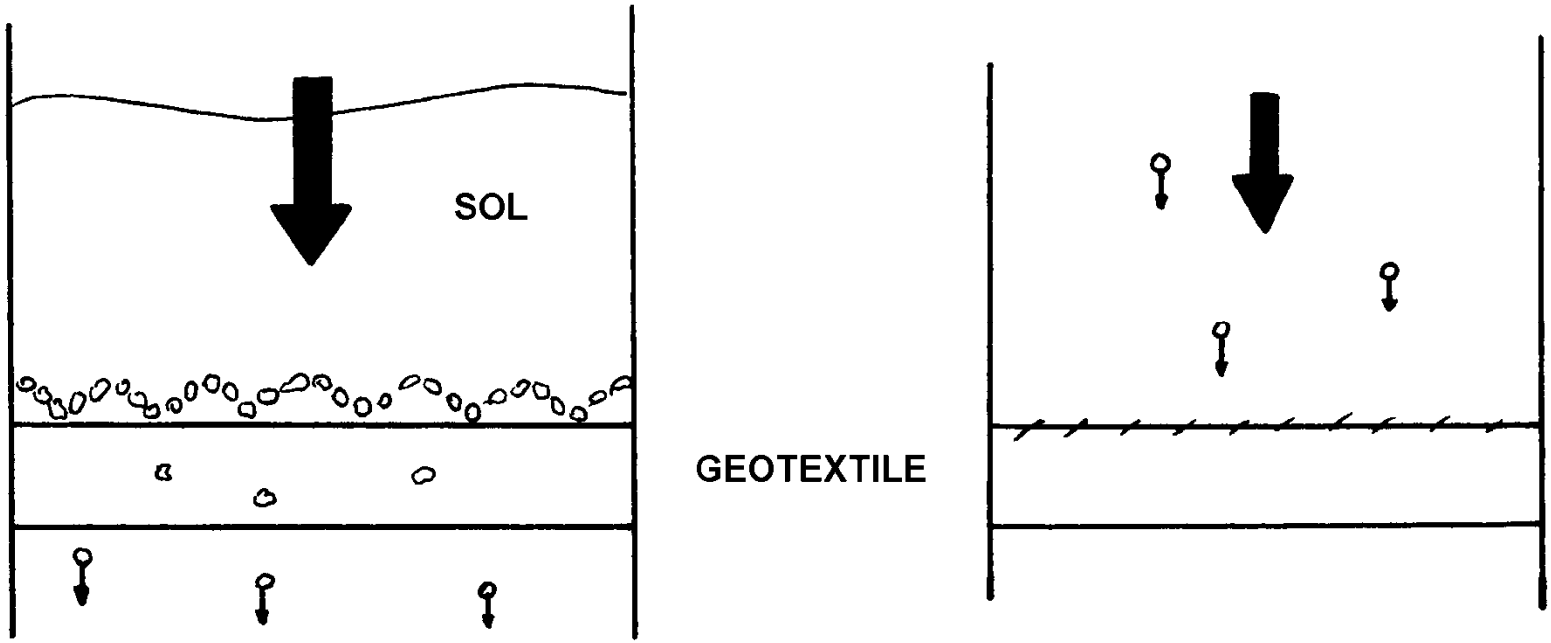
τ *is limited by sliding soil-reinforcement :* $\tau \leq \sigma.\tan\Psi$, *with* $\Psi \leq \phi$

Verifications of internal stability:

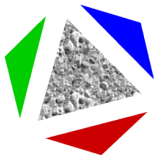
- rupture par excess of **traction** in the geosynthetics,
- rupture par **sliding** soil - reinforcement.

Design: drainage system

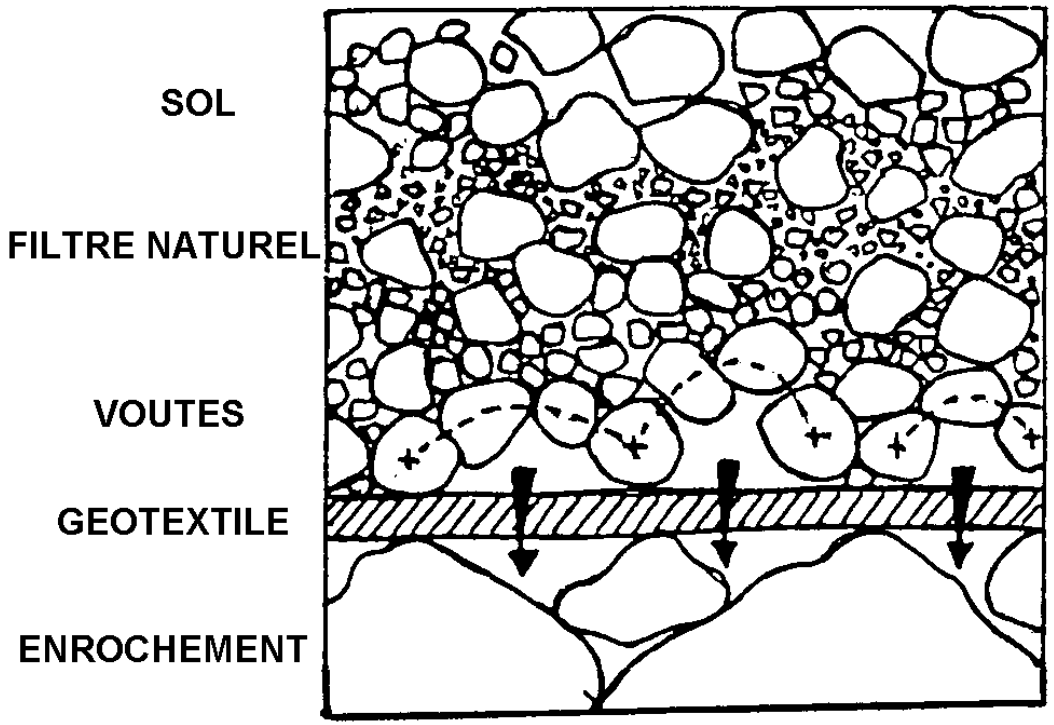
Filtration



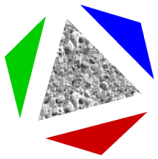
Principe : permettre l'écoulement de l'eau en retenant la plupart des particules de sol



Filtration



Comme l'eau s'infiltre dans un sol, des particules migrent vers le filtre mais un état stabilisé apparaît au bout d'un certain temps. Les particules plus grosses que les ouvertures du géosynthétique sont retenues en amont alors que les particules plus petites pénètrent partiellement le géosynthétique et sont partiellement retenues en amont de celui-ci.



Filtration: critère de perméabilité

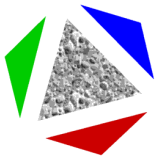
Interaction sol - géotextiles

• le sol : granulométrie, coefficient d'uniformité, compactage, plasticité, cohésion;
• les caractéristiques de la nappe : porométrie (Omax), épaisseur, perméabilité à l'eau, compressibilité, structure;
• les conditions hydrauliques : écoulement unidirectionnel ou réversible, gradient, précipitations chimiques, attaque bactériologique;
• les conditions d'installation : endommagement de la nappe lors de son installation.

Ψ permittivité = k_n/e

$= Q/\Delta h. A$ (loi de Darcy)

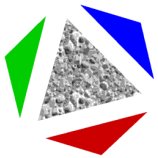
CRITERE: $\Psi > C.k_s$



Filtration: critère de perméabilité

$$\psi_{permis} = \psi_{ult} \left(\frac{1}{FS_{CS} \times FS_{CR} \times FS_{IV} \times FS_{CC} \times FS_{BC}} \right)$$

Application	Colmatage du sol	Fluage	Remplissage des vides	Colmatage chimique	Colmatage biologique
Ouvrages de retenue	2.0 à 4.0	1.5 à 2.0	1.0 à 1.2	1.0 à 1.2	1.0 à 1.3
Drains enterrés	2.0 à 4.0	1.0 à 1.5	1.0 à 1.2	1.2 à 1.3	1.2 à 1.3
Contrôle de l'érosion	2.0 à 4.0	1.0 à 1.5	1.0 à 1.2	1.0 à 1.2	1.2 à 1.5
Centres d'enfouissement	2.0 à 4.0	1.5 à 2.0	1.0 à 1.2	1.2 à 1.5	1.5 à 3.0
Drainage gravitaire	2.0 à 4.0	2.0 à 3.0	1.0 à 1.2	1.2 à 1.5	1.2 à 1.5
Drainage sous pression	2.0 à 3.0	2.0 à 3.0	1.0 à 1.2	1.1 à 1.3	1.1 à 1.3

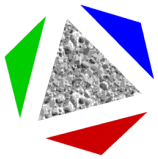


Filtration: critère de filtration (rétention)

d_x : dimension des particules de sol dont x% sont inférieures à d

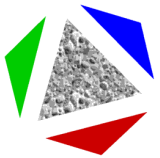
O_y : dimension des ouvertures du géotextile dont y% sont inférieures à O

CRITERE: $O_f < \lambda_r . d_{85}$



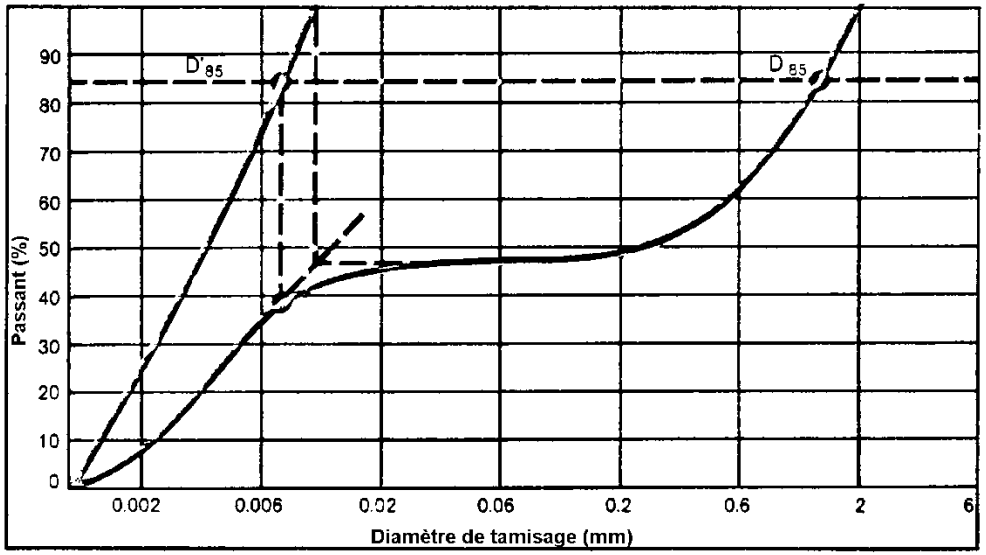
Filtration: critère de filtration (rétention)

PAYS	AUTEUR	λr	CONDITIONS ET VALEURS DE r					
U.S.A.	GIROUD (1982) Sol lâche	$\frac{A.O.S.}{d_{85}}$	$1 < Cu < 3$ $Cu^{0,3}$			$Cu > 3$ $9\ Cu^{-1,7}$		
	Sol dense		$2\ Cu^{0,3}$			$18\ Cu^{-1,7}$		
SUISSE	FHWA (1985)	$\frac{A.O.S.}{d_{85}}$	$1<Cu<2$	$2<Cu<4$		$4<Cu<8$	$Cu > 8$	
			1,0	0,5 Cu		8/Cu	1.0	
FRANCE	CFGG	$\frac{A.O.S.}{d_{85}}$	$1 < Cu < 4$			$Cu > 4$		
			$i < 5$	$5< i< 20$	$20<i<40$	$i < 5$	$5< i< 20$	$20<i<40$
	Sol lâche ou non confiné		0,64	0,51	0,38	0,8	0,64	0,48
	Sol dense et confiné	$\frac{0_f}{d_{85}}$	1,00	0,8	0,6	1,25	1,00	0,75
BELGIQUE	NBN S 29001	$\frac{0_{90}}{d_{90}}$	2					



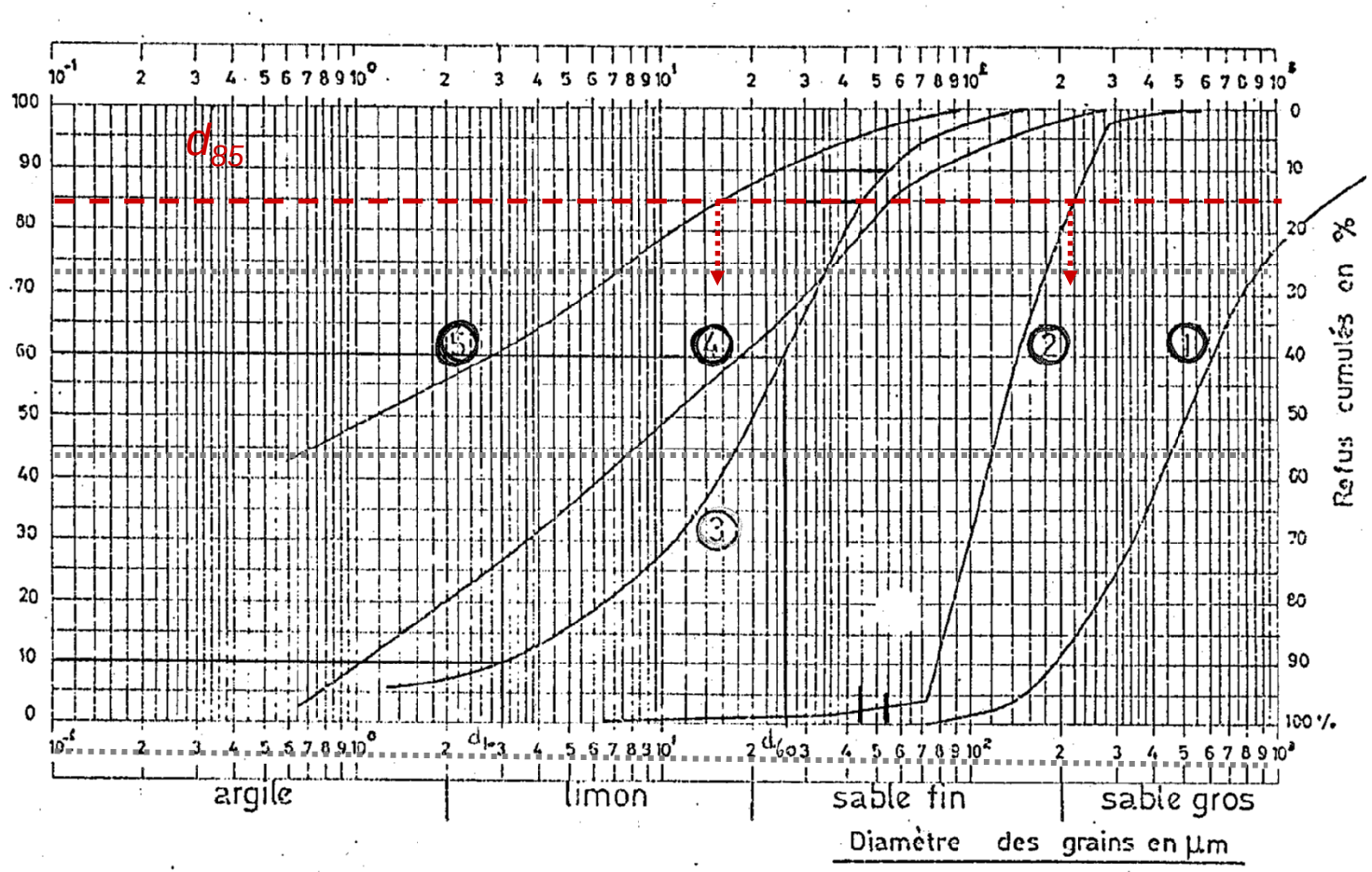
Filtration: critère de filtration (rétention)

$C_u = \frac{d_{60}}{d_{10}}$	**Type de granulométrie**
< 2	très uniforme
2 à 5	uniforme
5 à 20	peu uniforme
> 20	très peu uniforme ou étendue



Filtration: critère de filtration (rétention)

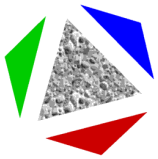
1. Sable de Rhin
2. Sable de Zandvliet
3. Limon d'Ans
4. Terre plastique
5. Bentonite



Filtration: critères

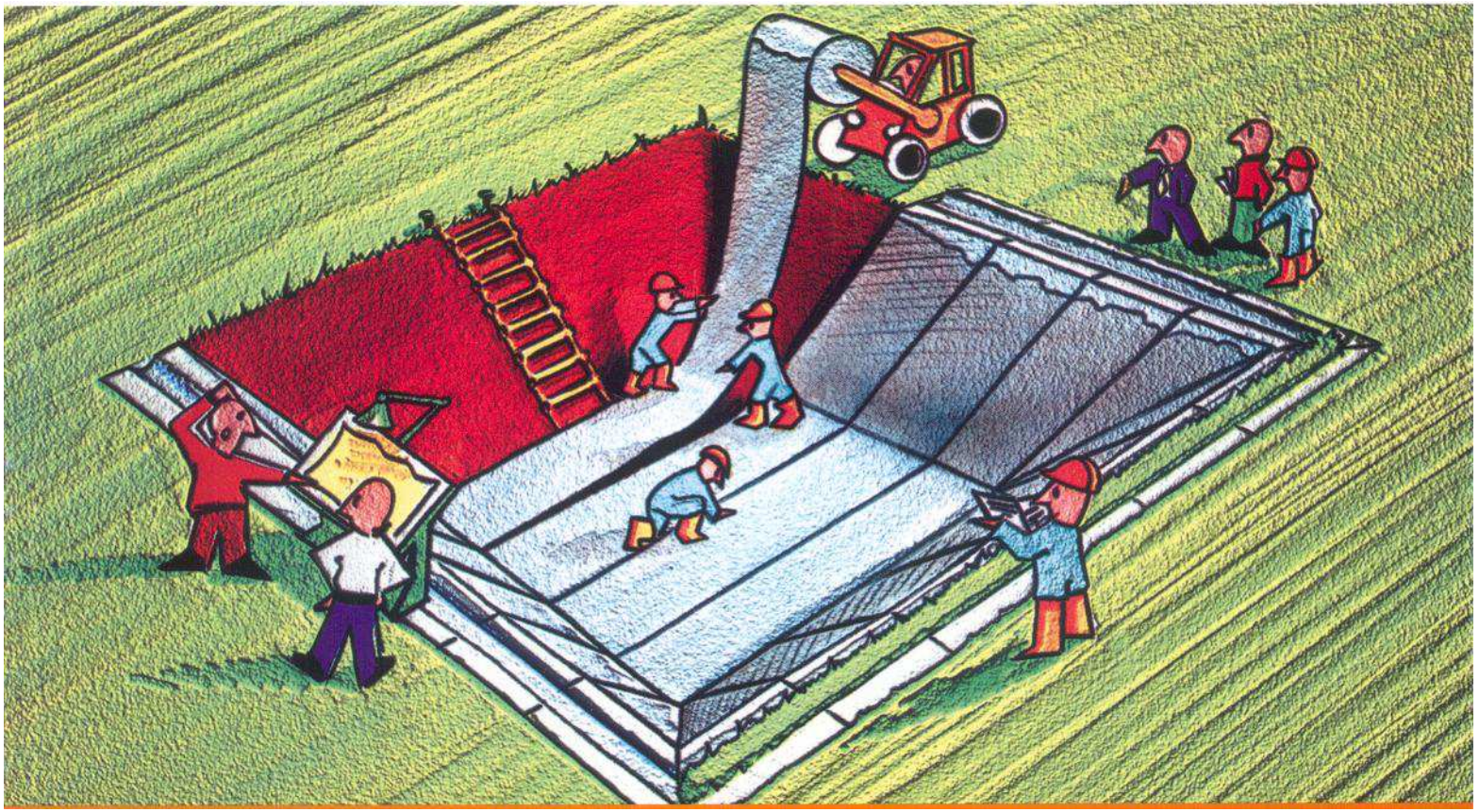
Critère de perméabilité: $\Psi > C.k_s$

Critère de filtration : $O_f < \lambda_r.d_{85}$



Design: waste storage

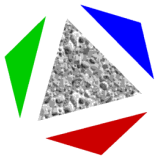
Environmental engineering

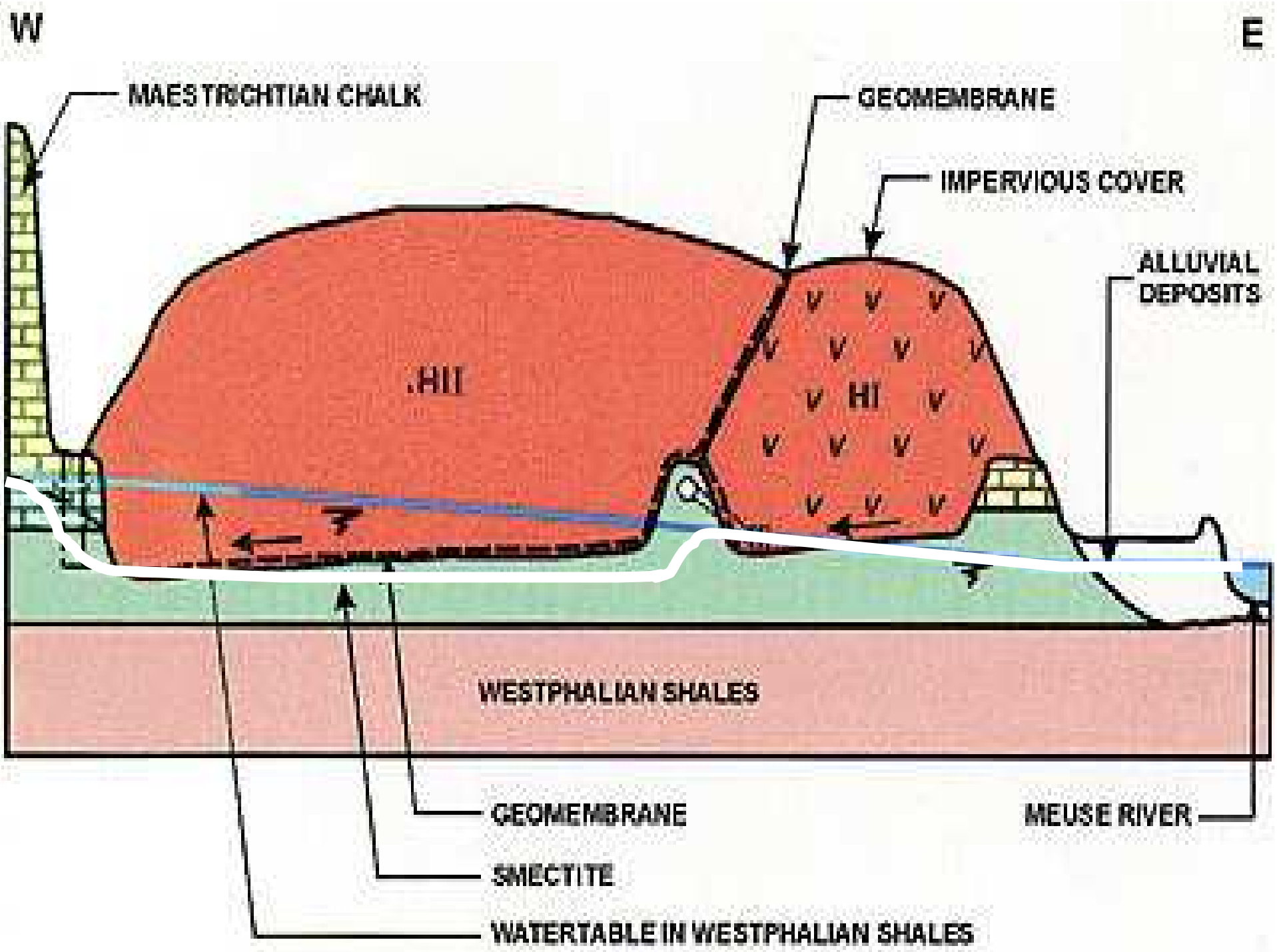


Environmental engineering: waste storage

MAIN PRINCIPLES

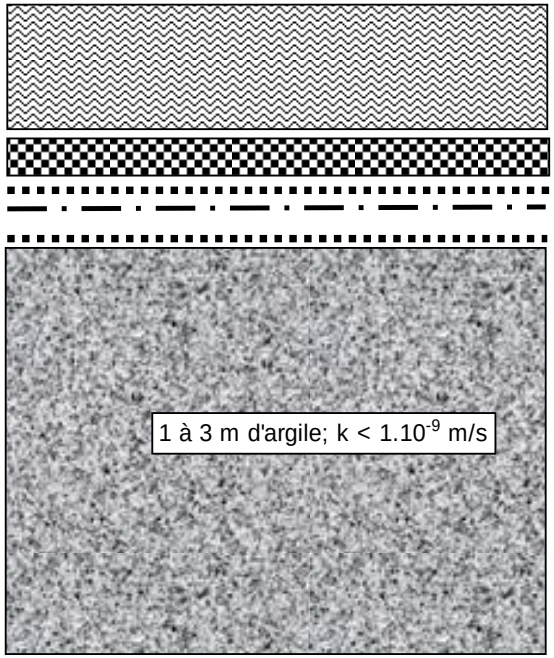
- **Waterproofing must be maximum**
- **Hydraulic gradient must be minimum**
- **Waterproofing must be aeternal**
- **Capping must protect against pollution (water, odors)**
- **Natural waterproofing (geology) as high as possible**




W
E
MAESTRICHTIAN CHALK
GEOMEMBRANE
IMPERVIOUS COVER
ALLUVIAL DEPOSITS
.HII
HI
WESTPHALIAN SHALES
GEOMEMBRANE
MEUSE RIVER
SMECTITE
WATERTABLE IN WESTPHALIAN SHALES

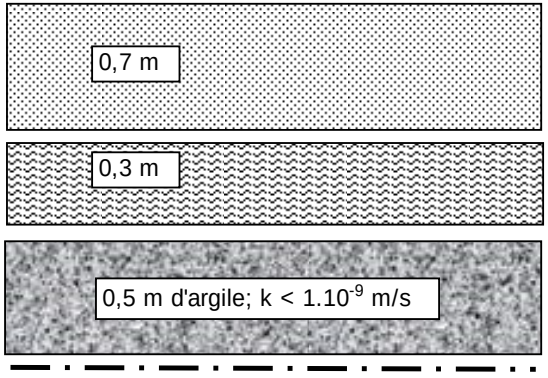
Flandre

Fond



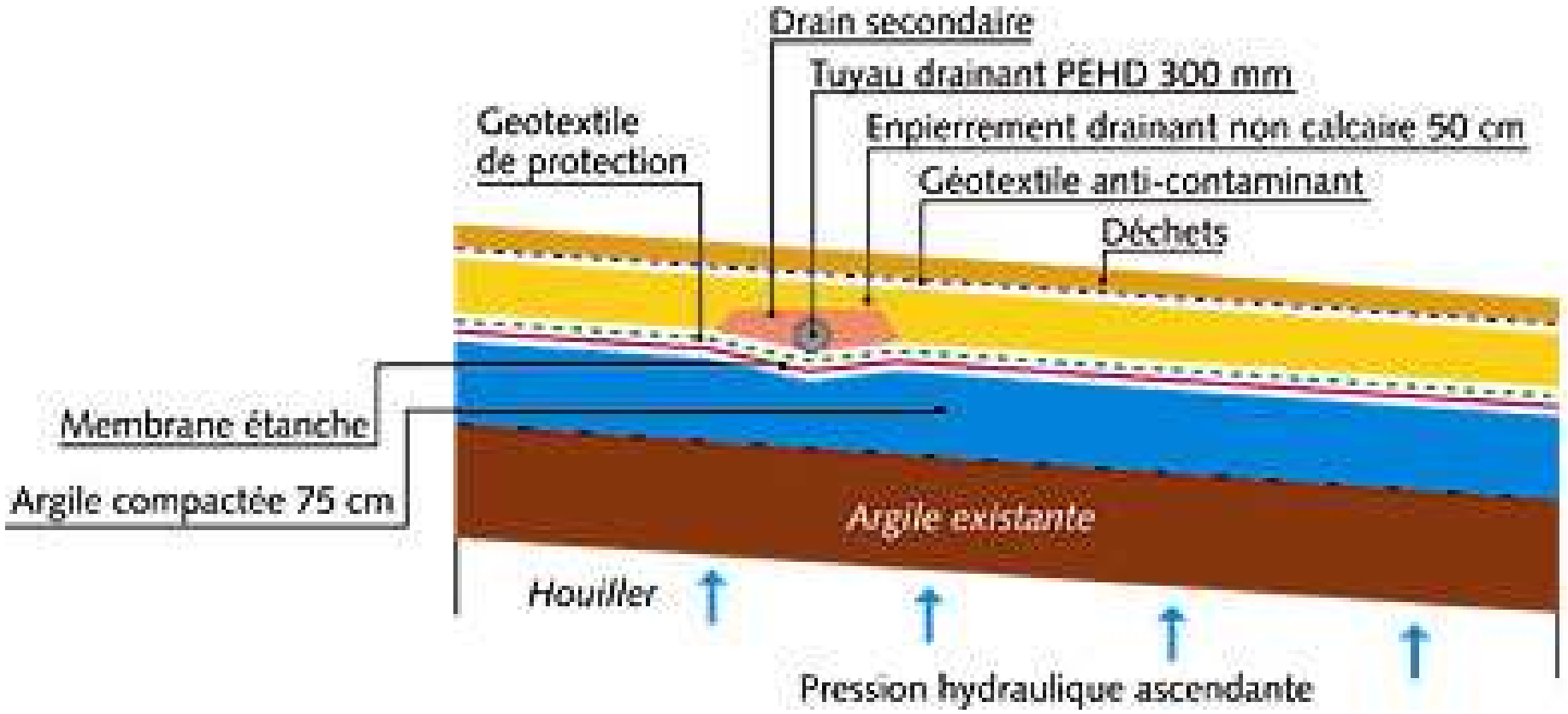
ou système équivalent agréé par l'autorité compétente

Capping

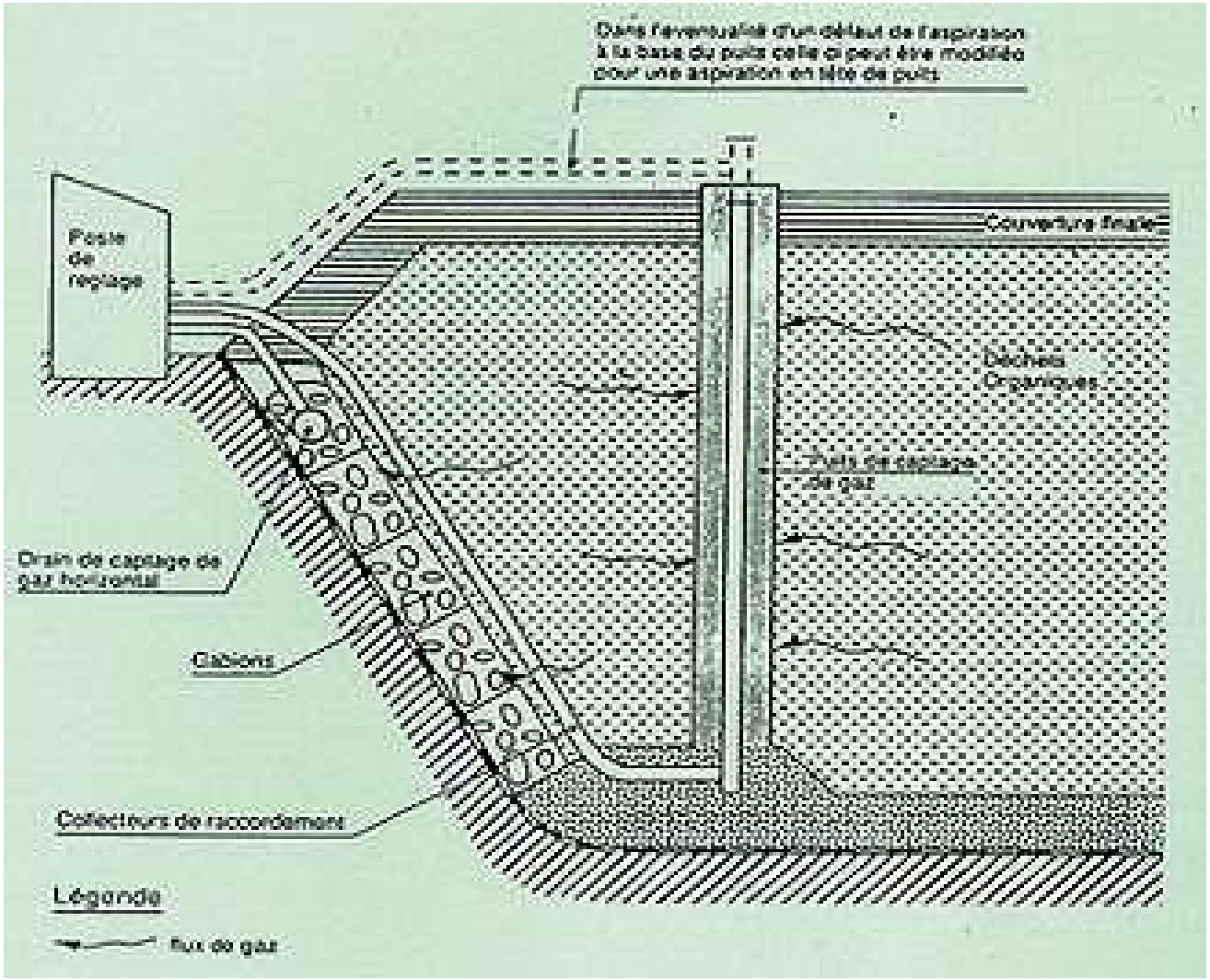


Environmental engineering: regulation

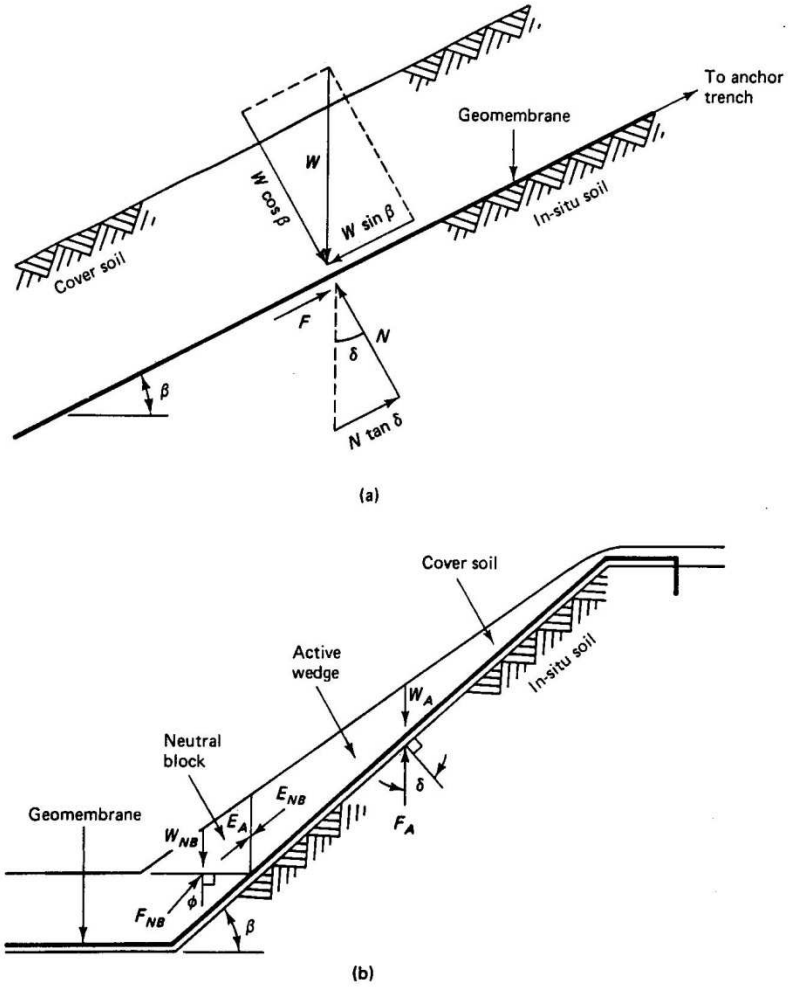
Waterproofing-drainage system in Hallembaye



Pumping system for gas collection



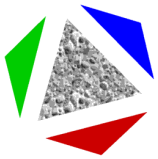
Environmental engineering: waste storage



Schematic diagrams for forces involved with cover soils on geomembrane-lined slopes

a) Uniform (constant) depth of soil

b) Non uniform (tapered) depth cover soil

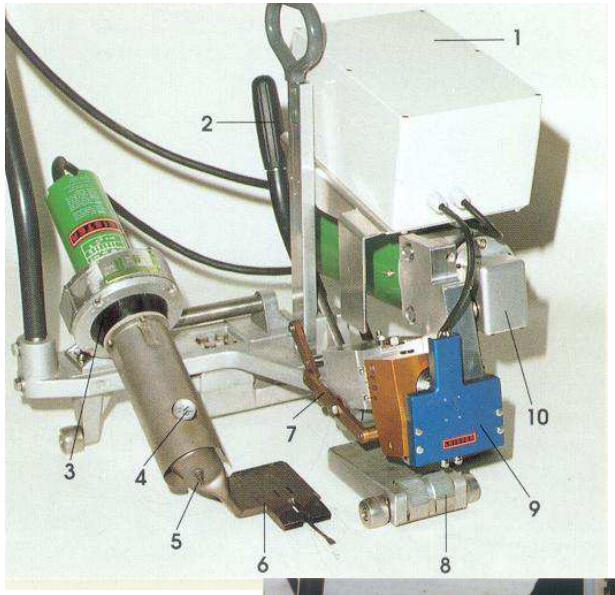


Environmental engineering

Environmental engineering


Pierdop

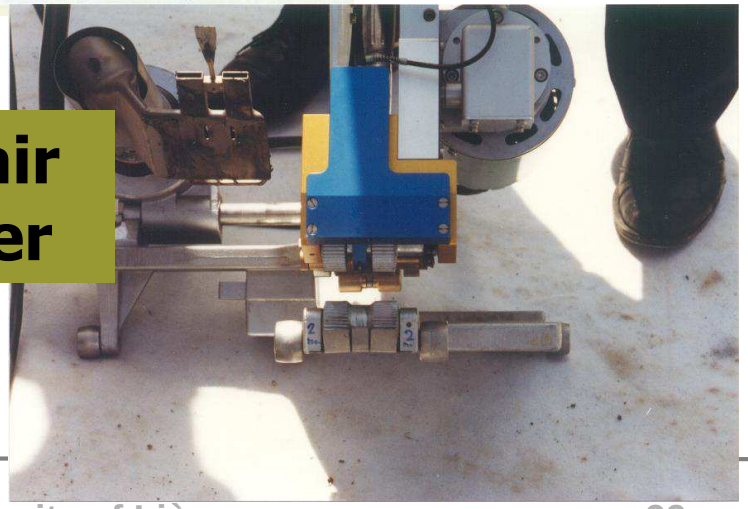
Environmental engineering: gmb welding



Hot-wedge

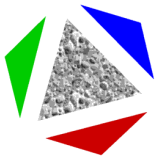
Extrusion welder

Hot-air welder



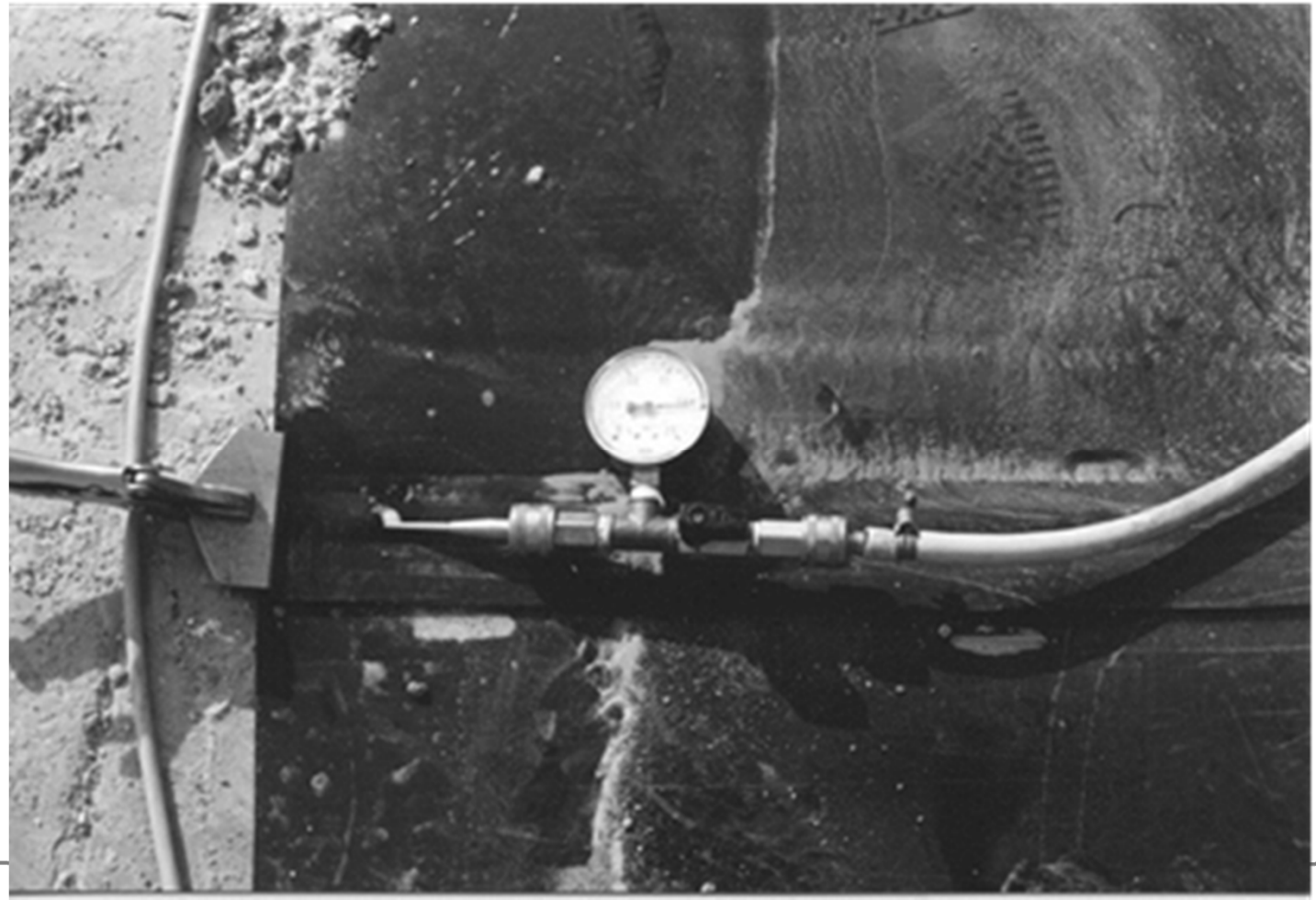
Geomembranes

- Dual Seam Test
- Le dispositif de mise en pression comprend :
  - une aiguille creuse ;
  - un manomètre de 0 à 250 kPa;
  - un obturateur ;
  - un compresseur d’air.



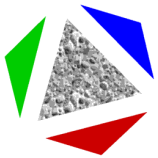
Geomembranes

- Dual Seam Test



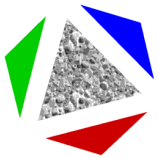
Geomembranes

- La séquence de mise en pression du joint est la suivante :
  - mise en pression à 200 kPa ;
  - maintien pendant 2 minutes pour permettre la relaxation et la mise en place du matériau ;
  - mise en pression définitive à 200 kPa ;
  - maintien pendant 5 minutes.
- Critère d'acceptation du joint: la chute de pression enregistrée pendant la période des 5 minutes doit être inférieure à 30 kPa



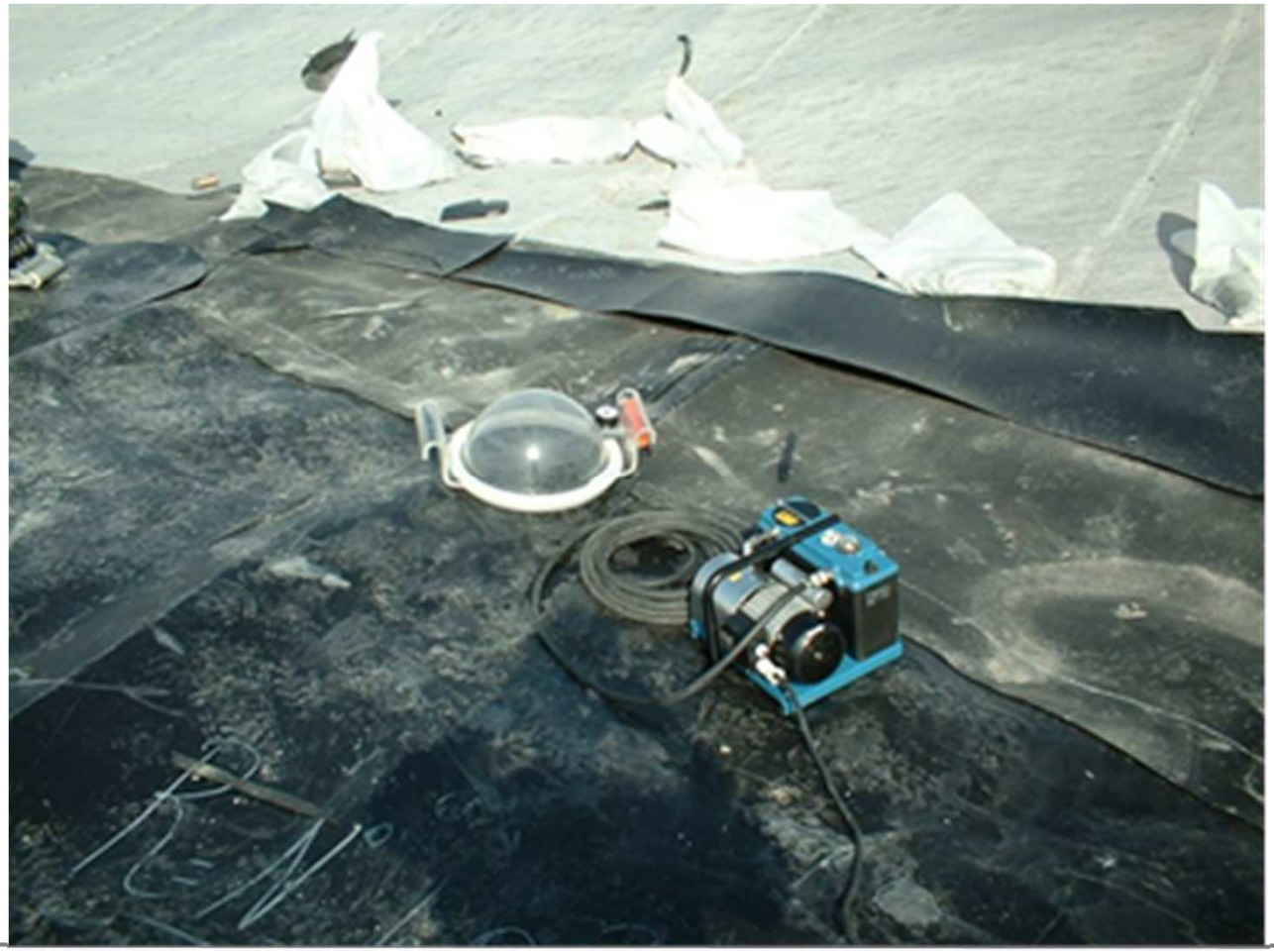
Geomembranes

- Cloche à vide
- Le dispositif de mise en dépression comprend :
  - une cloche à vide (60 cm x 20 cm) (photo 2) ;
  - un joint d'étanchéité ;
  - une pompe à vide ;
  - un dispositif de limitation de dépression.
- Ce contrôle s'applique :
  - aux points triples ;
  - aux réparations ;
  - aux soudures réalisées par air chaud (4-5 tests par soudure) et aux zones soudées à la main ;



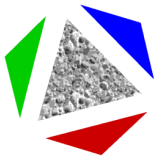
Geomembranes

- Cloche à vide



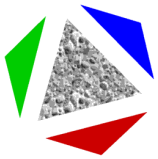
Geomembranes

- La séquence de mise en pression du joint est la suivante :
  - identification de la zone à contrôler ;
  - badigeonnage de la zone à contrôler à l'aide d'une eau savonneuse ;
  - mise en place de la cloche à vide ;
  - application de la dépression de 30 kPa pendant 20 secondes ;
  - observation de la présence éventuelle de fuites.
- Critère d'acceptation: aucune fuite



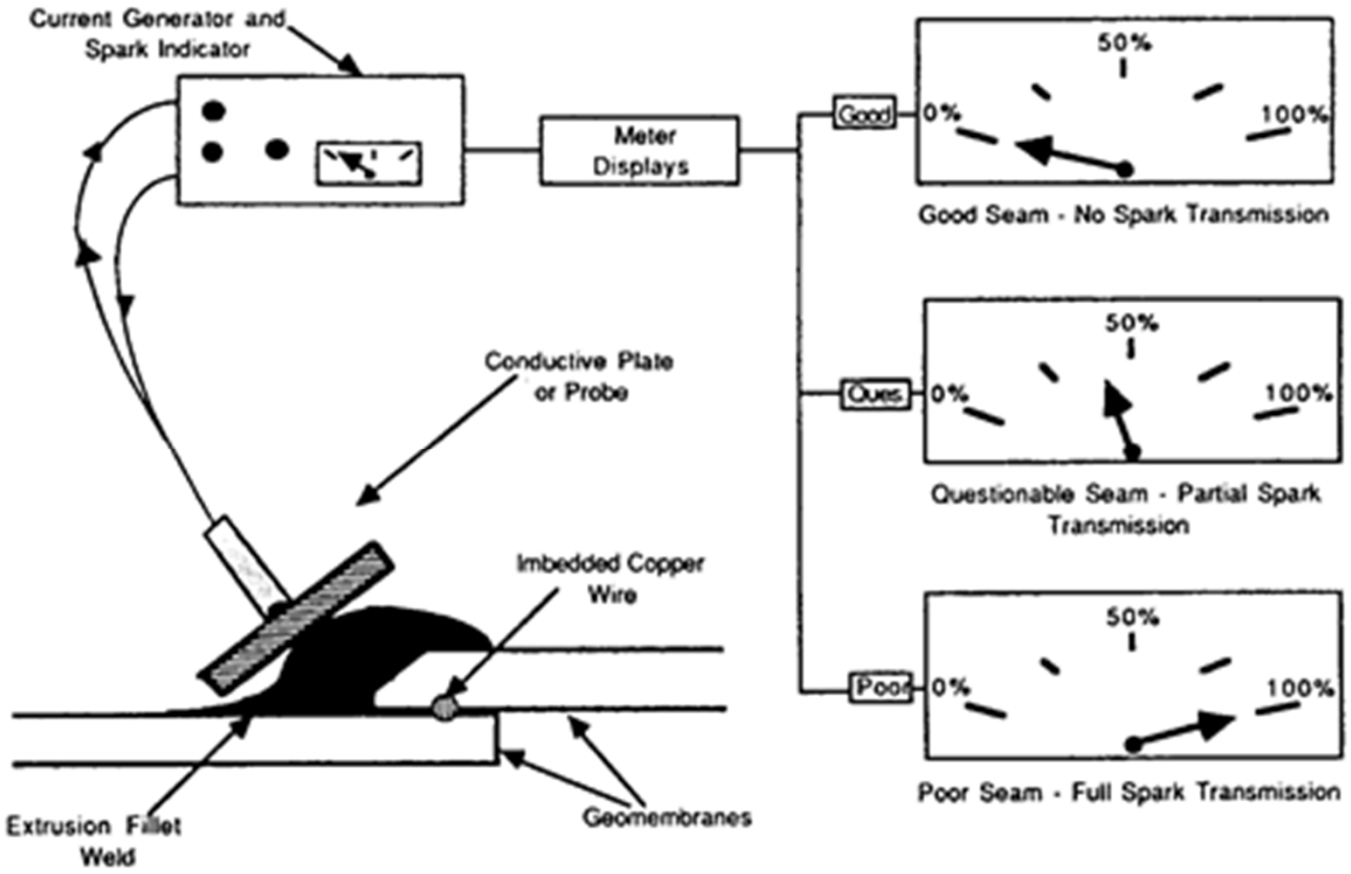
Geomembranes

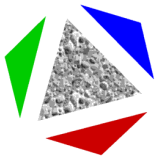
- Fil électrique
- Etablir une différence de potentiel importante (9 kV) entre un palpeur que l'on déplace le long d'un joint soudé et un fil de cuivre noyé dans la masse de la soudure
- En cas de non-continuité de la soudure, un arc électrique se produit, ce qui permet de détecter un défaut de soudure.



Geomembranes

- Fil électrique

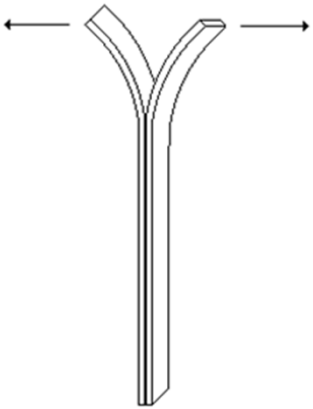


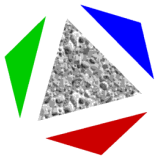


Geomembranes

- Epaisseur
- Essais destructifs
  - Cisaillement

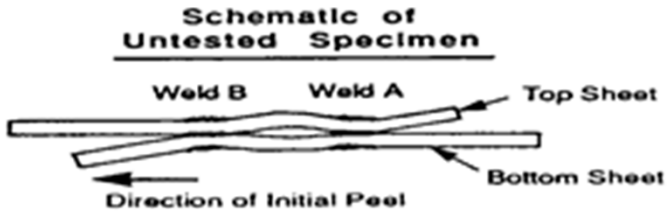
  - Pelage



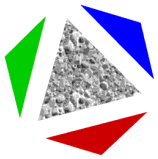


Geomembranes

- Essais destructifs: soudures doubles



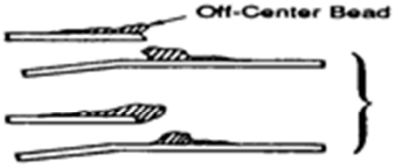
Types of Break	Locus-of-Break Code	Break Description	Classification[a]
	AD	Adhesion failure.	Non-FTB
	BRK	Break in sheeting. Break can be in either top or bottom sheet.	FTB
	SE1	Break at outer edge of seam. Break can be in either top or bottom sheet.	FTB
	SE2	Break at inner edge of seam through both sheets.	FTB
	AD-BRK	Break in first seam after some adhesion failure. Break can be in either the top or bottom sheet.	FTB



Geomembranes

- Essais destructifs: soudures extrudées

Schematic of Untested Specimen

Types of Breaks	Locus-of-Break Code	Break Description	Classification[a]
	AD1	Failure in adhesion. Specimens may also delaminate under the bead and break through the thin extruded material in the outer area.	Non-FTB
	AD2	Failure in adhesion.	Non-FTB
	AD-WLD	Break through the fillet. Breaks through the fillet range from breaks starting at the edge of the top sheet to breaks through the fillet after some adhesion failure between the fillet and the bottom sheet.	Non-FTB[b]
	SE	Break at seam edge. Indicate location by 1, 2, or 3.	FTB
	BRK	Break in the sheet. Use 1 to indicate bottom sheet and 2 to indicate top sheet. If break is in buffed area, indicate with "(B)".	FTB
	AD-BRK	Break in the bottom sheeting after some adhesion failure between the fillet and the bottom sheet. (Applicable to peel only).	FTB
	HT	Break at the edge of the hot tack for specimens which could not be delaminated in the hot tack.	No Test