

NPTEL Course

GROUND IMPROVEMENT

MATERIAL PROPERTIES OF GEOSYNTHETICS

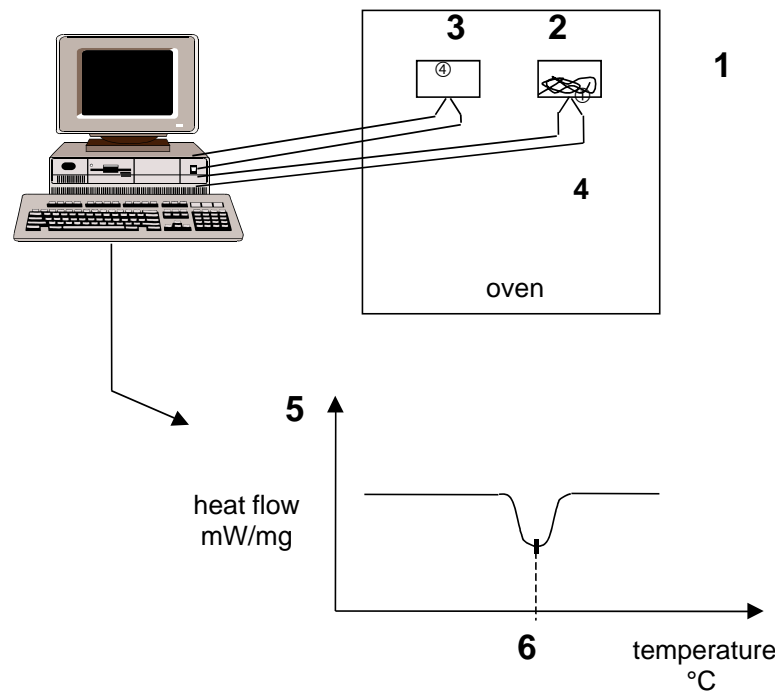
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Thanks to International Geosynthetics Society and Helmut Zanzinger,
SKZ - TeConA GmbH, Germany

General Product Identification

- **Polymer identification**
- **Geometrical information**
 - ↳ **Thickness**
 - ↳ **Grid opening size / pitch dimensions**
- **Mass per unit area**

Polymer Identification



1. controlled heating of oven specimen in pan
2. inert dummy in pan
3. heat flow sensors
4. monitor and control-PC
5. result graph
6. crystal melting point

Differential Scanning Calorimetry gives the percent crystallinity and melting temperature

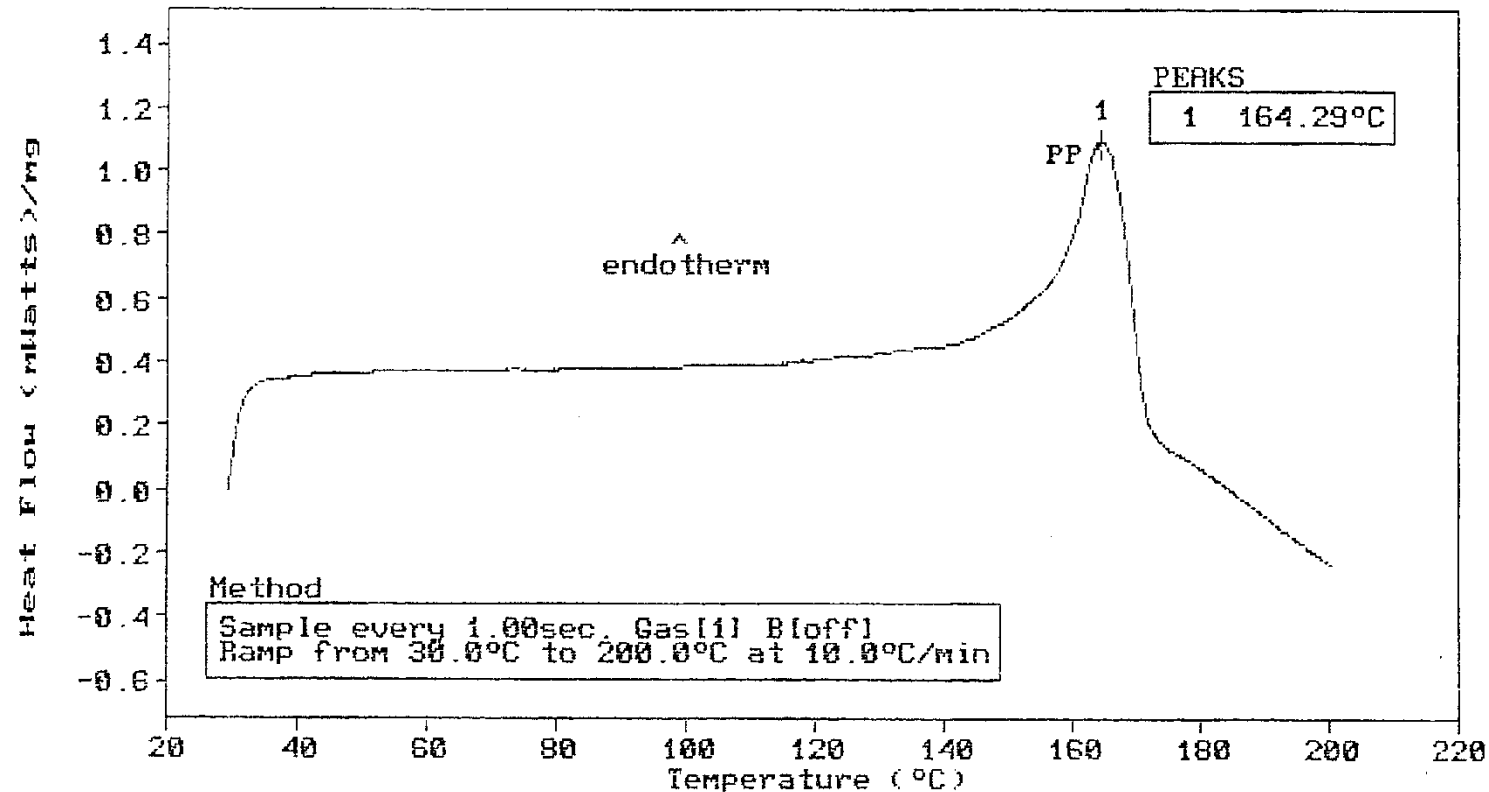
DSC- Curve of a Polypropylene Sample

DSC (PL)

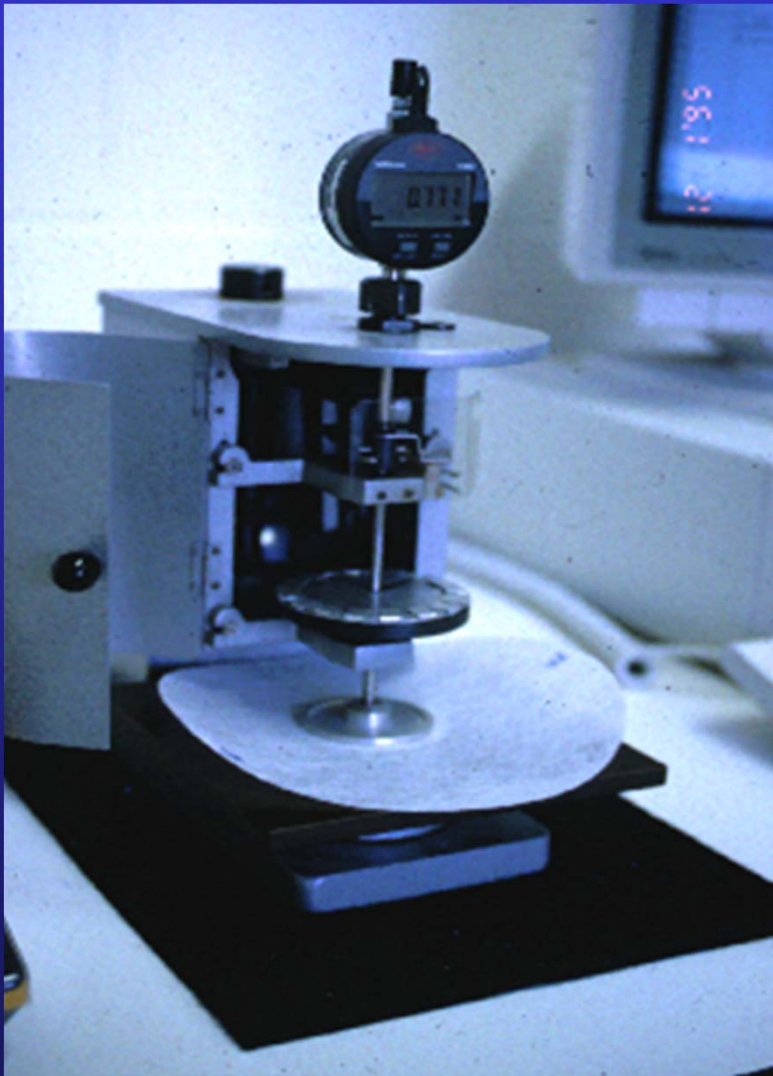
SMPL ID : 1fb13-99
RUN ID : 2.Lauf
SIZE : 5.840 MG
OPERATOR: tb

DATE RUN: Jun/29/1999
GAS 1 : Luft
GAS 2 :
COMMENT : PP-Ulies/F32M

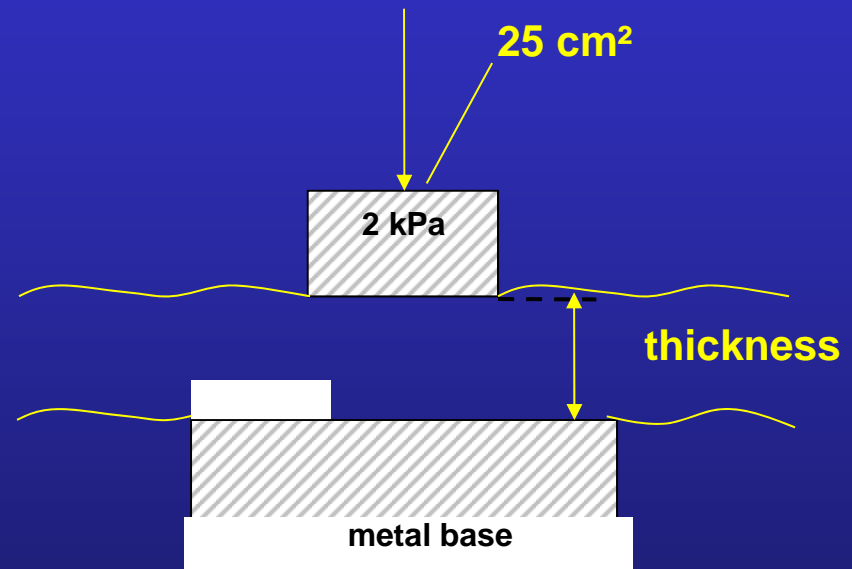
Polymer Laboratories



Geometric Information



Schematic

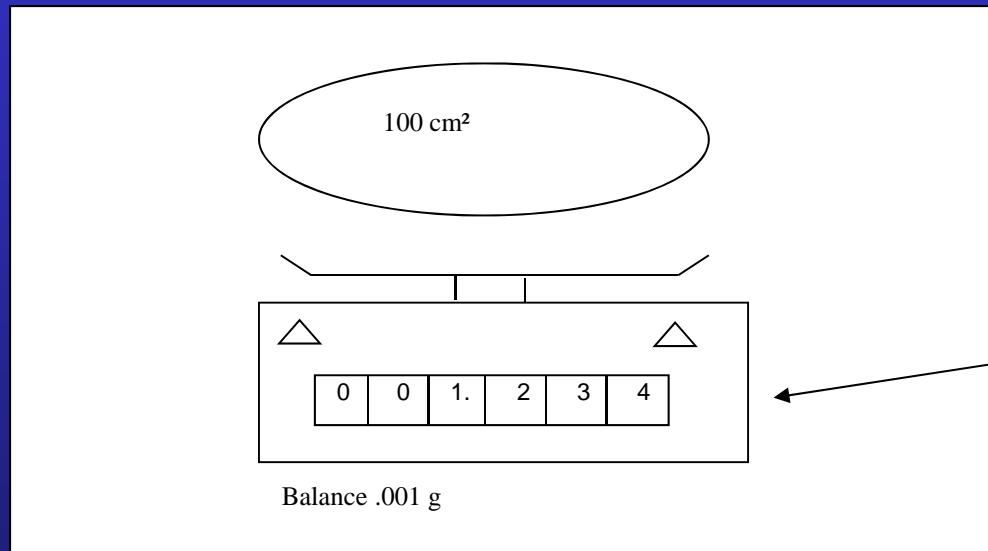


Measuring thickness at 2 kPa

The test is performed to EN964 part 1 for a single layer products and to EN964 part 2 for multi-layer

Mass / Unit Area (mua)

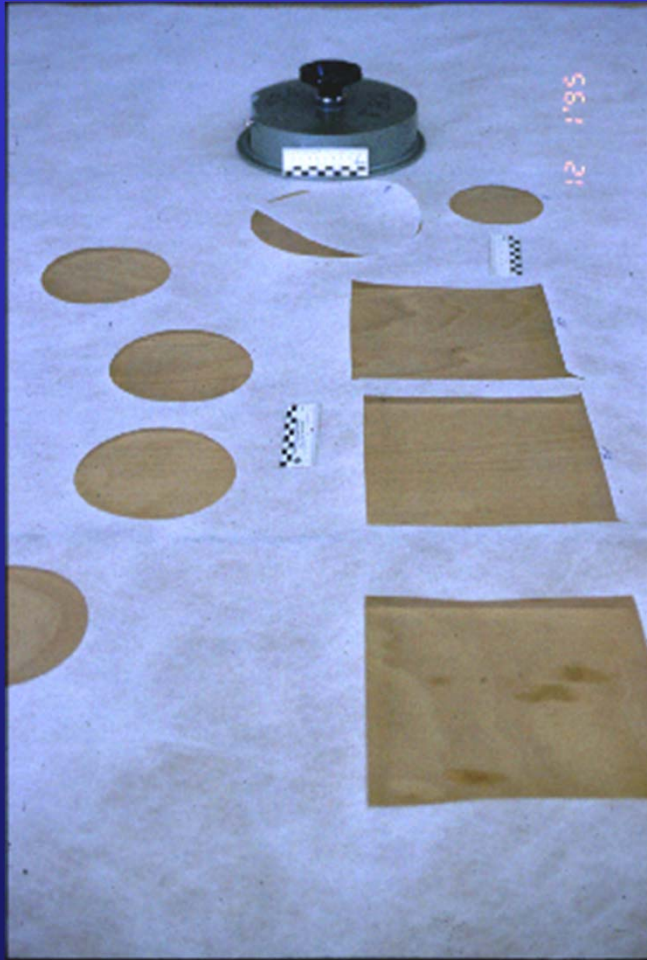
- **Mass per unit area (mua) (ISO 9864; EN 965 : 1995 ASTM)**
the mass per unit area is one of the most often used characteristic values, giving the price creating mass of the raw material



$$\text{mua} = 123.4 \text{ g/m}^2$$

- Specimens are cut preferably with a circular cutter, the number depends on the specimen size; Minimum 3, each 100 cm² to a maximum of 10 specimen, and then weighed to accuracy of + 0.001g and calculate the mua.

Sampling



Measuring (mua)



Mechanical Properties

- Short-term tensile strength and dependent deformation
- Long-term tensile behaviour (creep/creep rupture)
- Long-term compressive creep behaviour (with/without
 - Shear stress)
- Resistance against impact or punching
 - Static puncture test, rapid puncture
- Resistance against abrasion
- Friction properties
 - Direct shear, inclined plane test, pullout resistance
- Protection efficiency
- Damage during installation
- Geosynthetics or composites internal strength
- Geosynthetic reinforcement segmental retaining wall unit connection testing

Mechanical Properties

- Short-term tensile strength and dependent deformation (standards see table below)

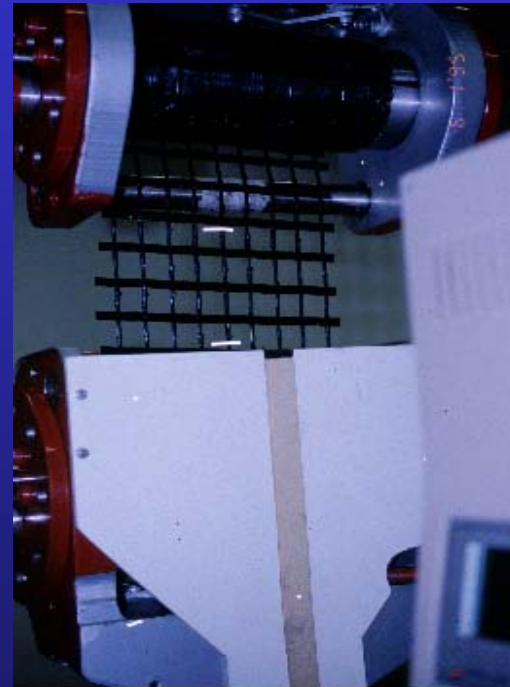
Standard	Specimen ¹⁾	strainrate/X -head
EN ISO 10319 : 1996	200 x 200	20 %/min
ISO 5081	50 x 300	variable f (ϵ_u)
ASTM D 4 595	200 x 200	10 %/min

¹⁾ in mm

Mechanical Properties

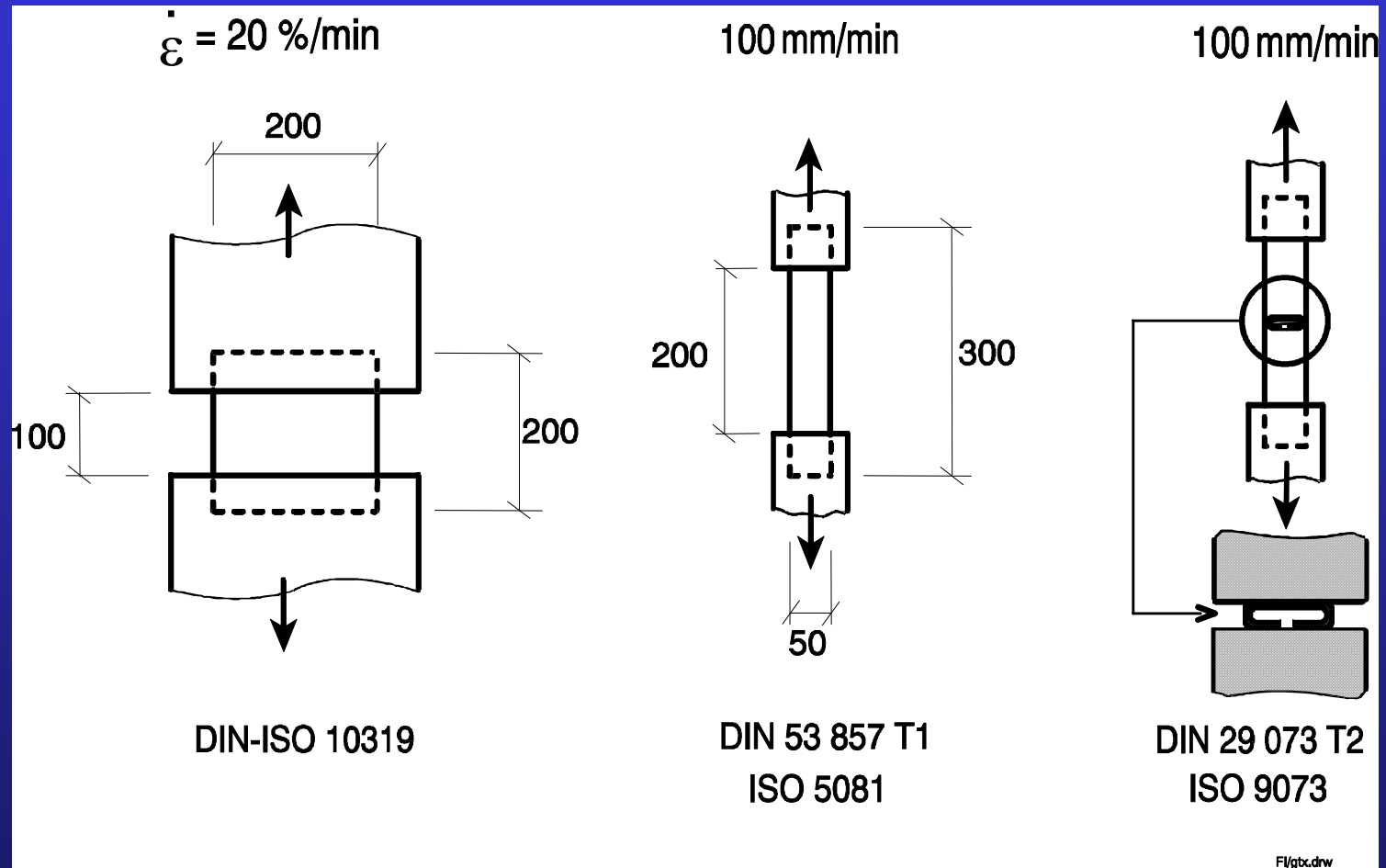


**Testing machine with
video-extensometer**

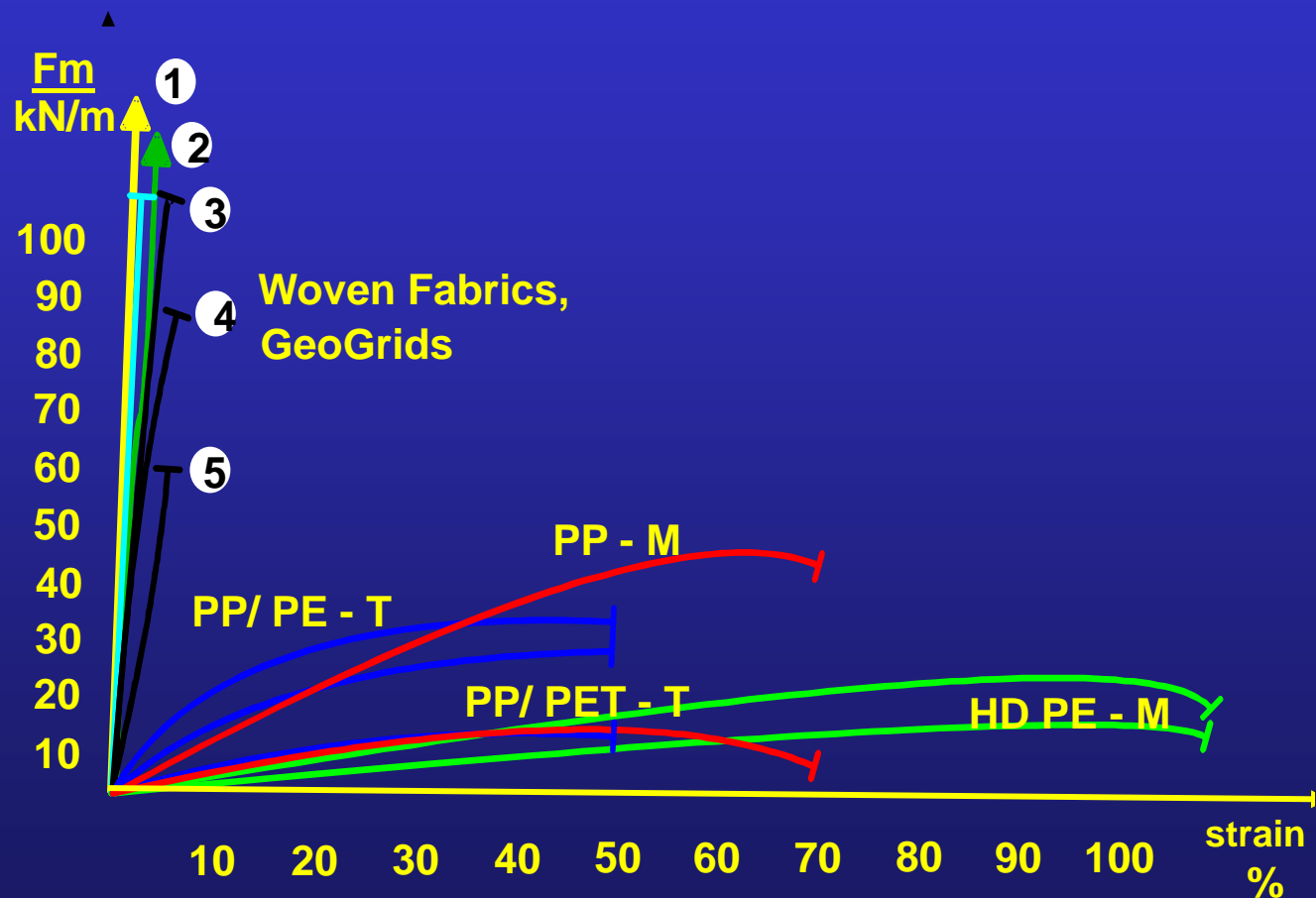


**Capstain clamp for
geogrid with laser-
extensometer**

Tensile Tests



Force - Strain Behaviour of Geosynthetics



Tensile Creep and Creep Rupture

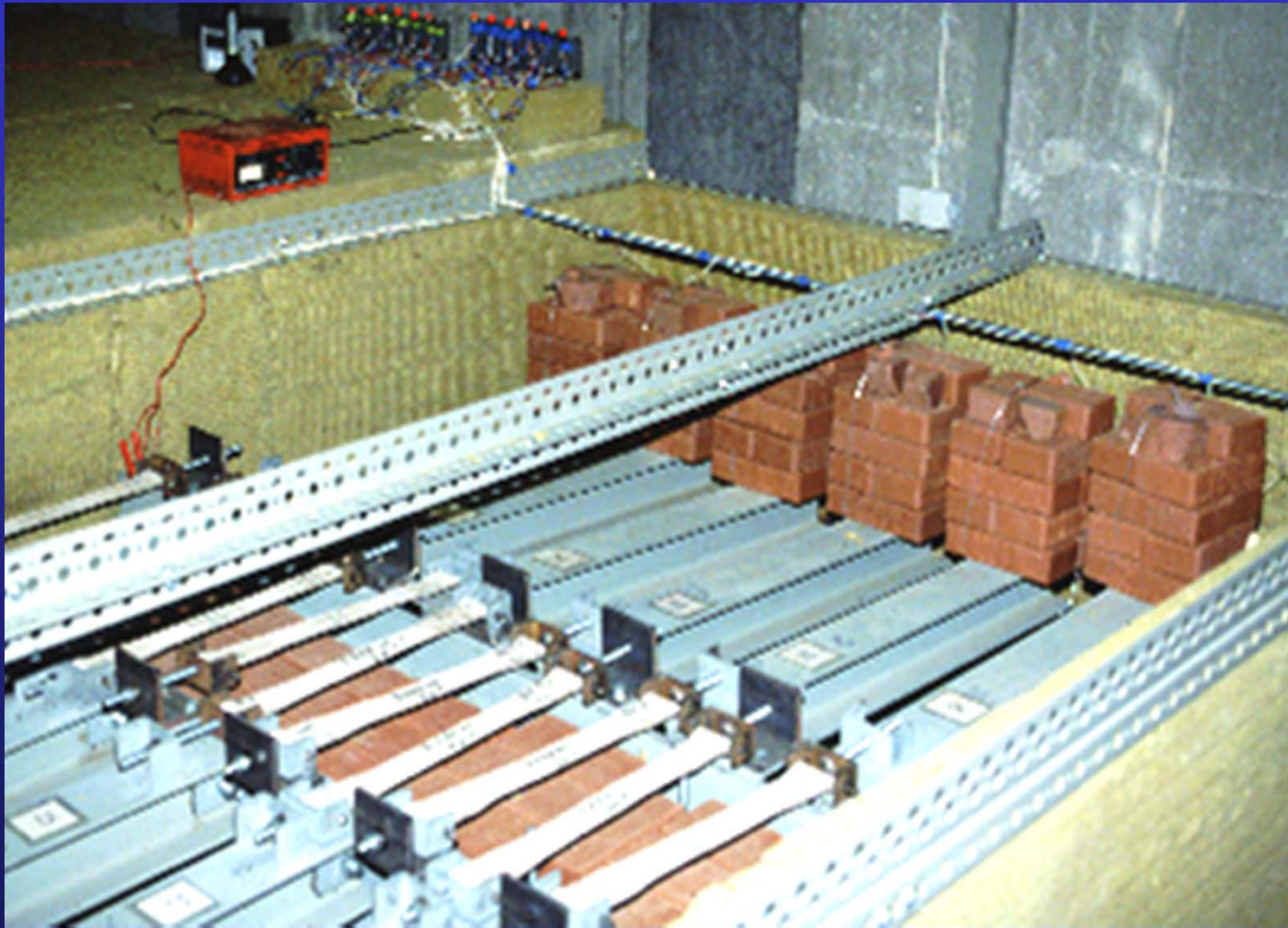
EN ISO 13431 : 1996 ASTM)

- Tensile creep tests give information on time-dependent deformation at constant load.
- Creep rupture tests give time until failure at constant load.
- A deformation measurement is not necessary for creep rupture curves.
- Loads for creep testing are most often dead weights, often enlarged by lever arms.

Creep Test Rigs
– set up in a
controlled
environment,
free from
vibrations



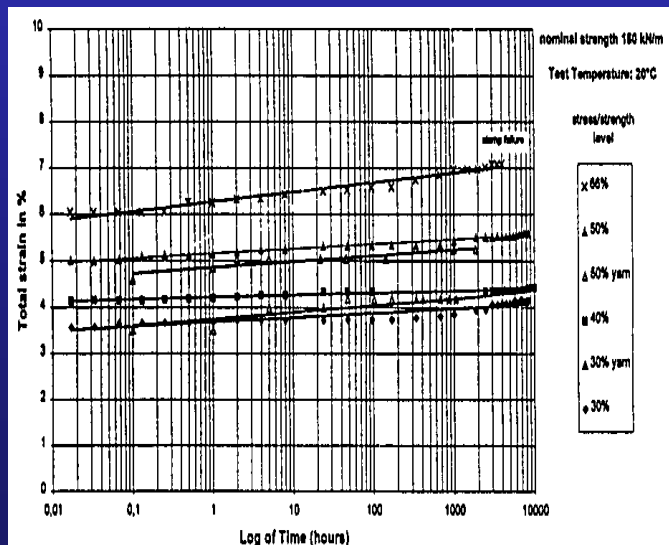
Multiple Creep Rupture Rigs in a Temperature Controlled Chamber



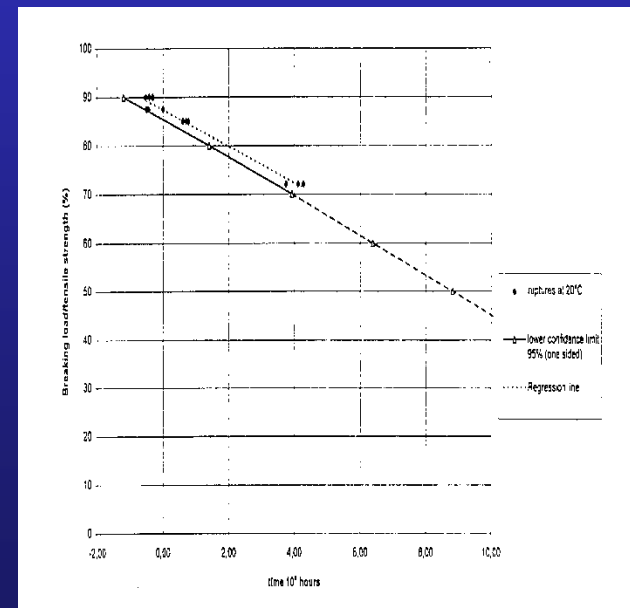
Creep Test Results.

Results are plotted for creep as linear deformation vs log time

For creep rupture linear or log load vs log time.
Typical curves are shown



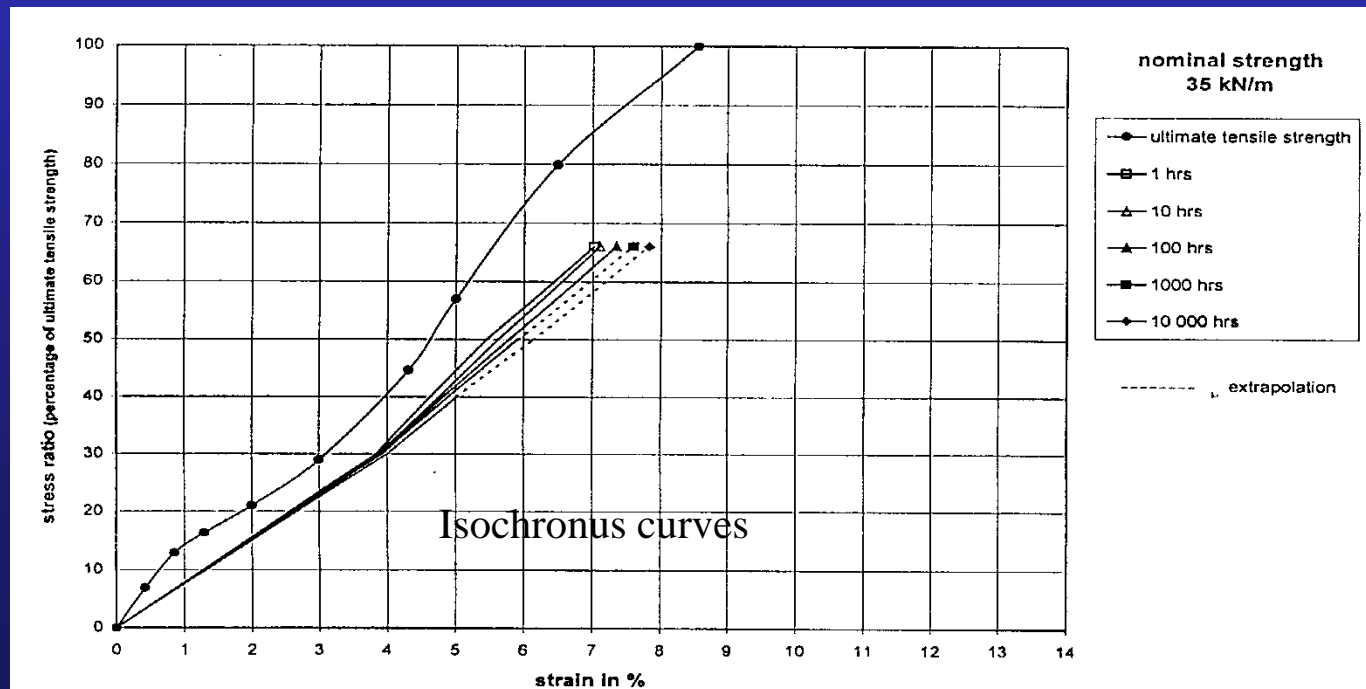
Creep Curves



Creep Rupture

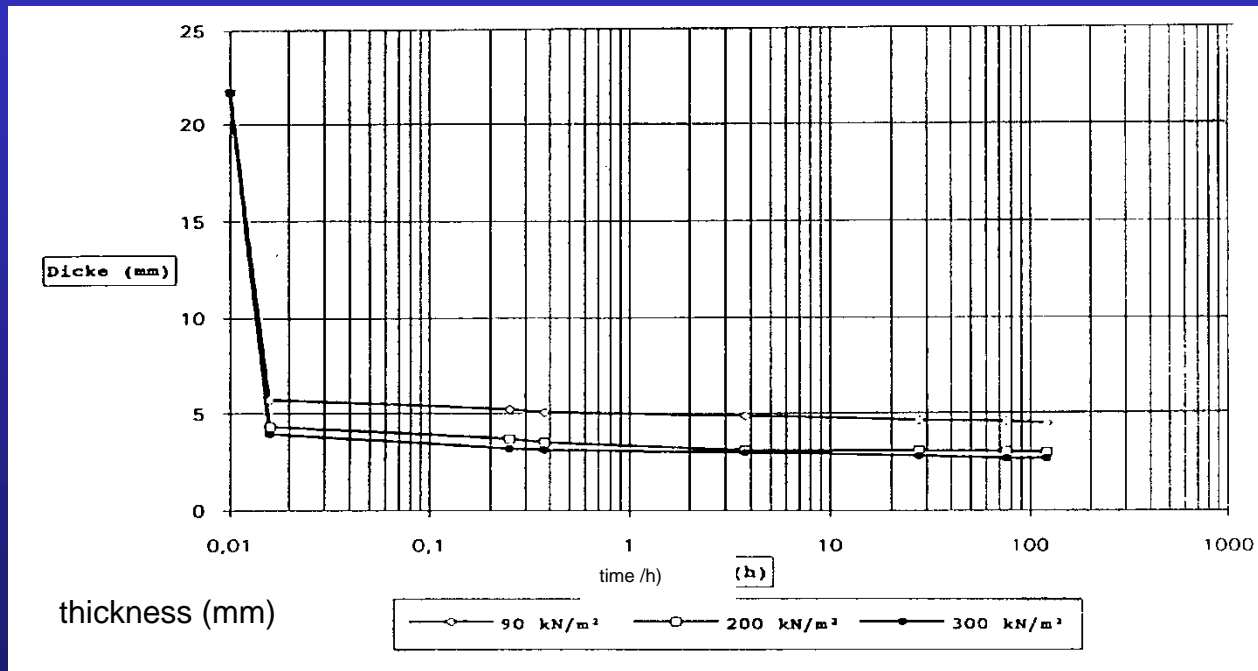
Isochronous Curves

From creep curves at different stress grades isochronous stress strain curves may be derived or extrapolated for calculation of structure's deformation at a given time.



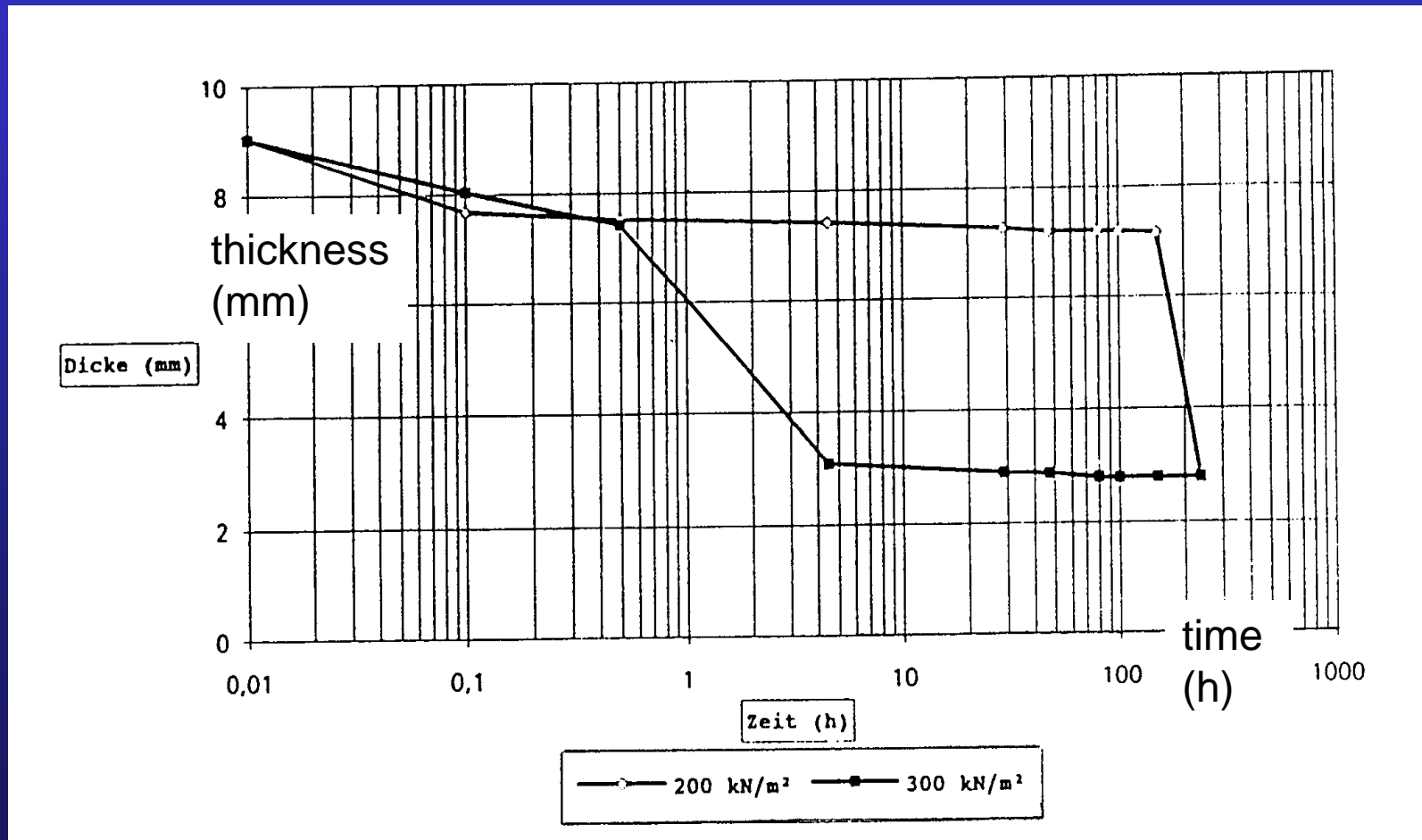
Compressive Behaviour

(EN ISO 13432)

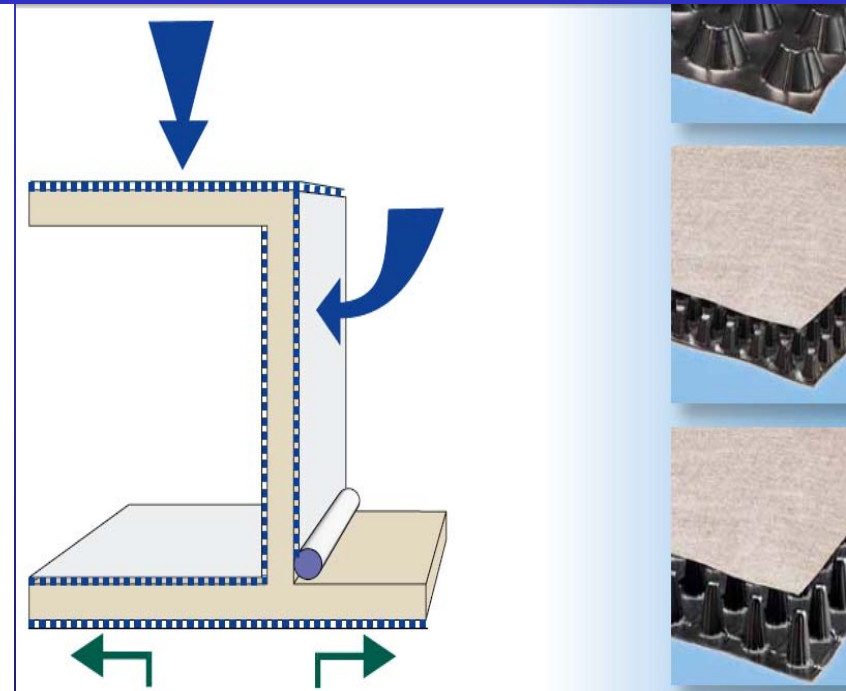
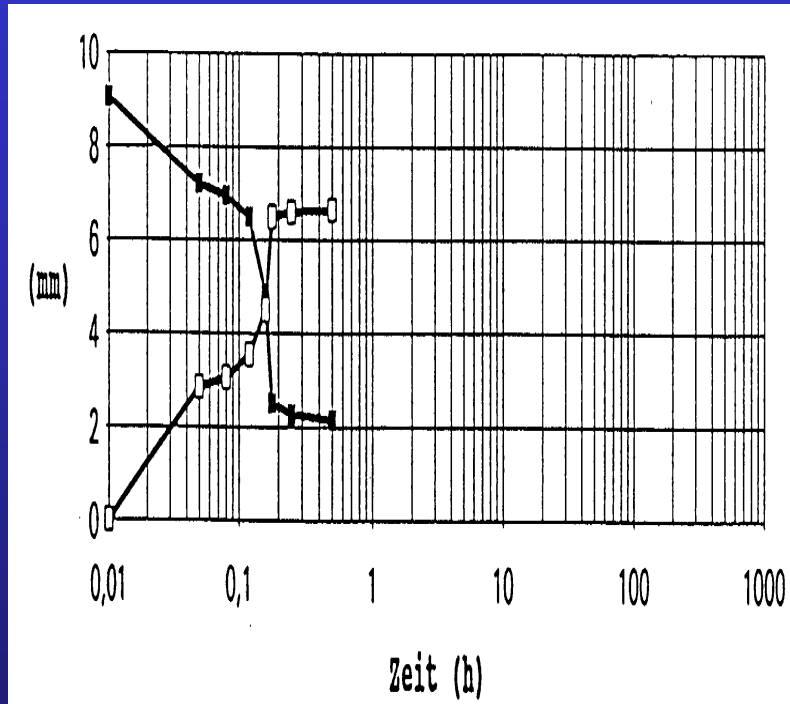


Compressive creep random wire drainage product

Compressive Creep Cusped Fin Drainage Product



Creep Under Normal and Shear Stress - Cuspated Fin Drainage Product



—□— Horizontal Displacement —■— Thickness

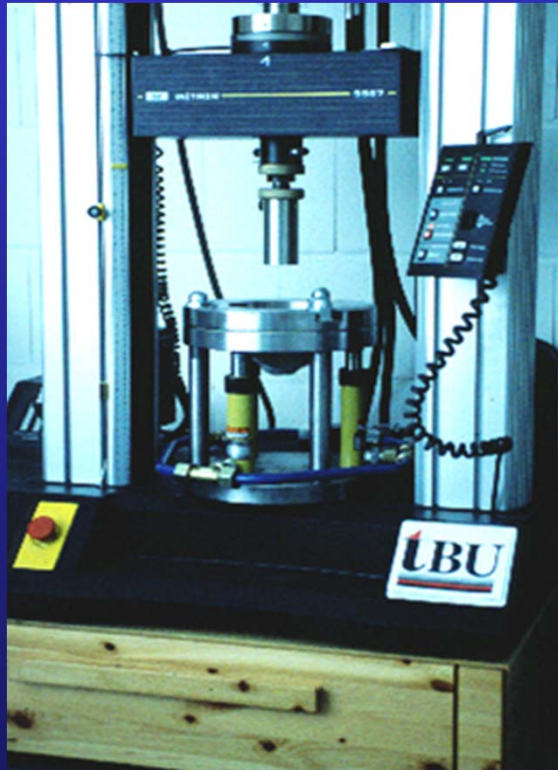
Resistance To Static Puncture

- **Static Puncture Test:**
The Test CBR (EN ISO 12236 : 1996)

The use of soil mechanics California Bearing Ratio (CBR) apparatus for this static puncture test, has resulted in the unusual name for this test.

- **A plunger of 50mm diameter is pushed at a speed of 50 +/- 10mm min onto and through the specimen clamped in the circular jaws. Measurement of force and displacement are taken. The test is widely used for geotextiles, it is not applicable to grids, and the test provides useful data for geomembranes.**

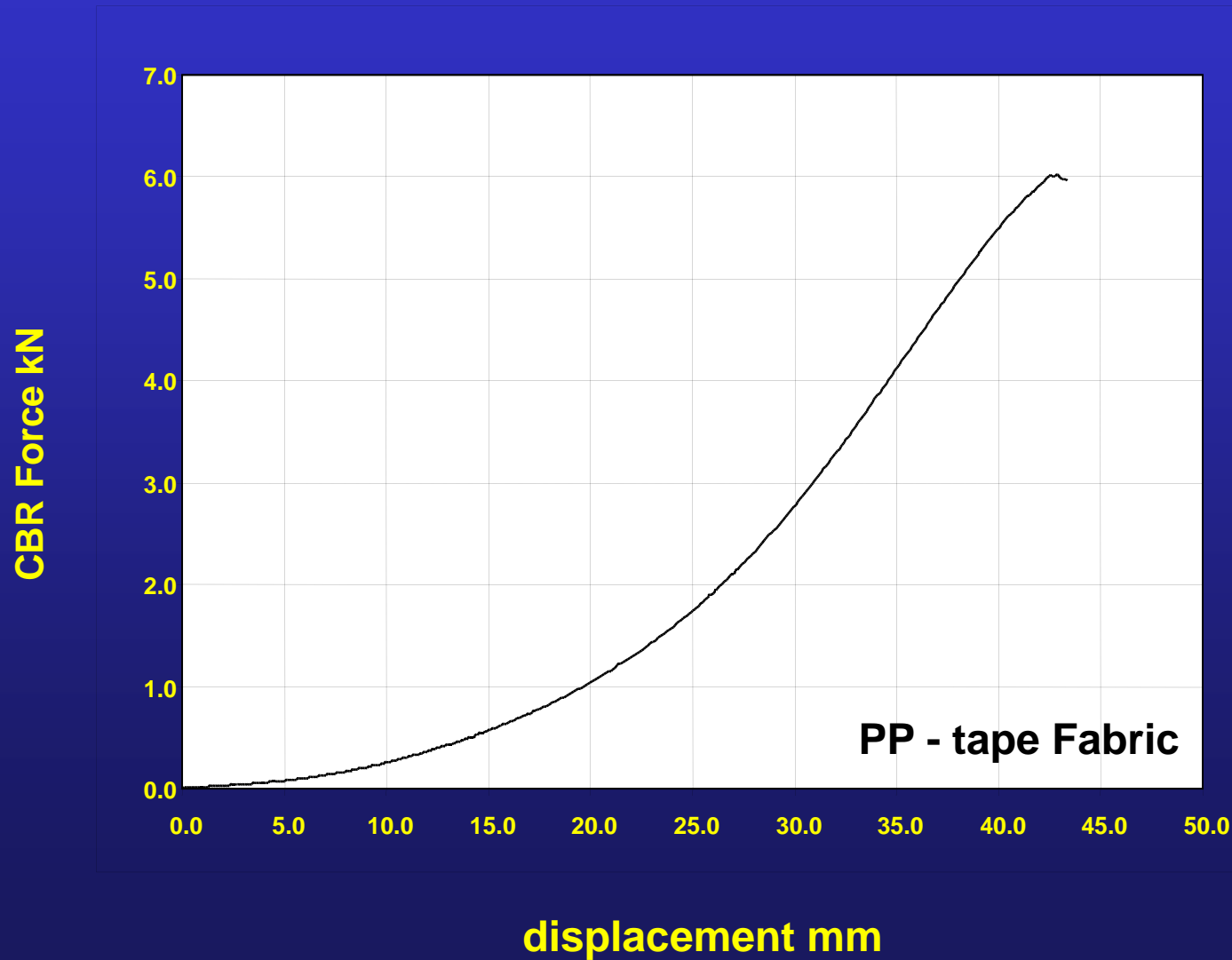
CBR - device in testing machine



Inserting specimen in hydraulic CBR- clamps

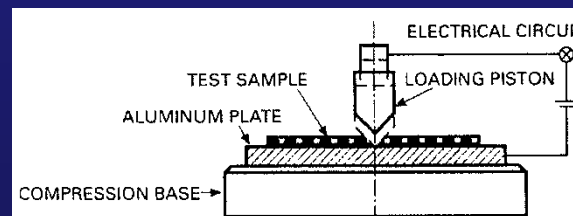
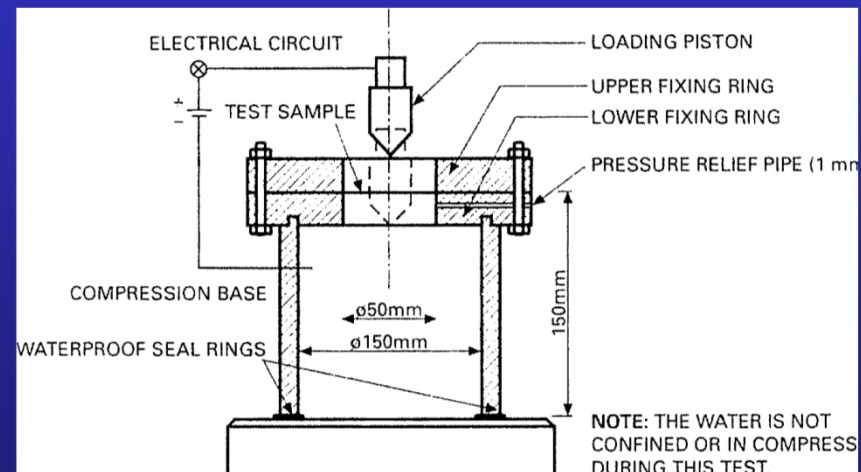


Typical CBR-curve force vs displacement



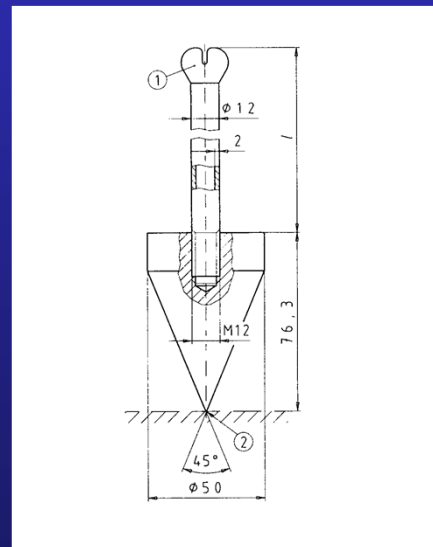
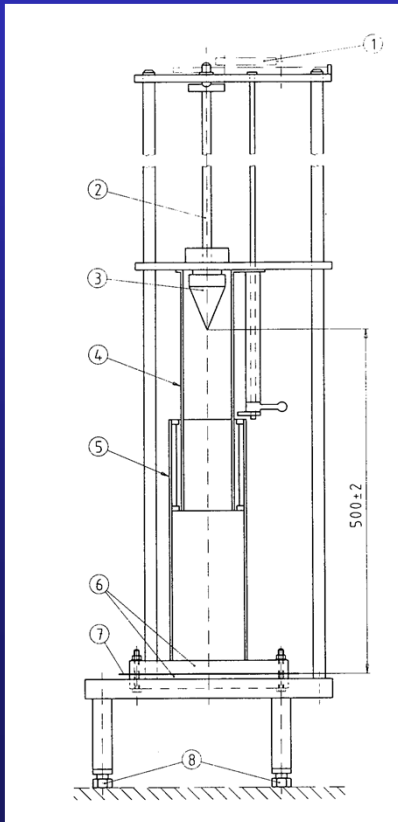
PYRAMID PUNCTURE (ASTM 5494-93)

Details of Apparatus



Dynamic Puncture Test : Cone Drop Test (ISO 13433, EN 918 : 1995)

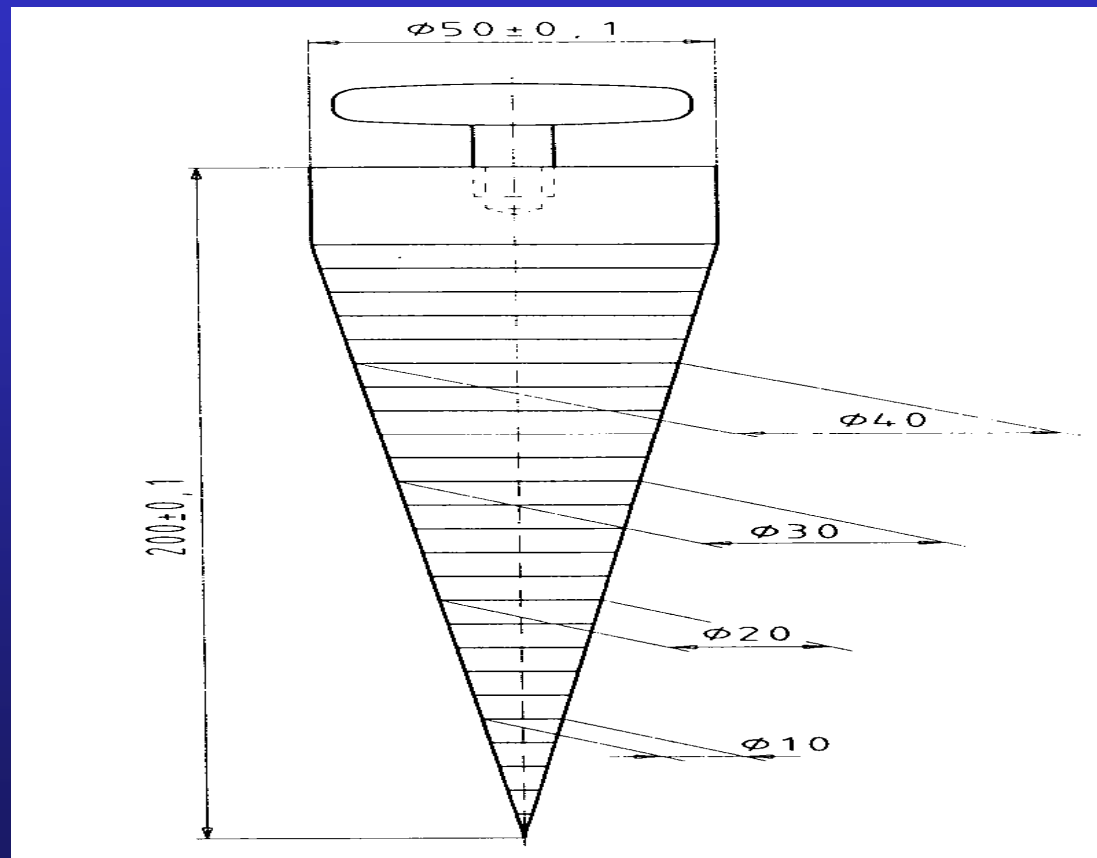
- A 1kg pointed cone is dropped from a height of 1m onto a specimen, held tight in a circular clamp
 - The diameter of a hole created is measured by means of a graduated aluminium cone scale.



1. Head, release mechanism to suit laboratory requirements
2. Guide rod
3. Cone
4. Metal screen
5. Screen
6. Clamping plates
7. Test specimen
8. Levelling screws

Note: This diagram is not to scale

Measuring Cone for Cone Drop Test



Impact Resistance Test

(CEN TC 189 WI 14; ISO 13428 draft)

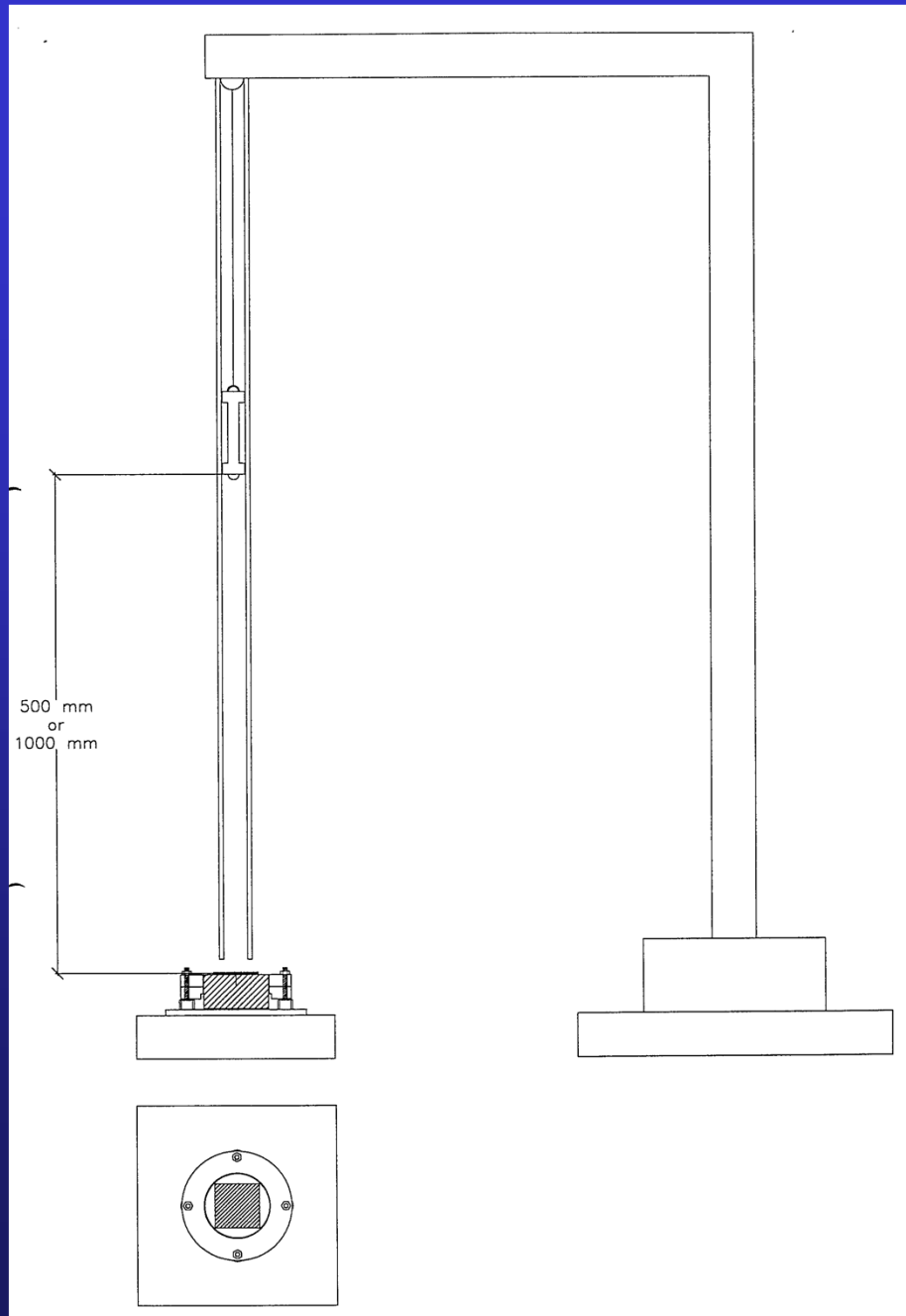
- Efficiency of protection materials can be tested by dropping a hemispherical shaped weight onto a specimen placed on a lead plate on a resilient base.
- The impression in the lead and the condition of the specimen are recorded.

Lighter round shaped drop weights are used for other geosynthetics. The deformation of a metal sheet under the tested material gives quantitative results.

Impact Resistance Test

- Drop weight, lead platen, specimen under ring



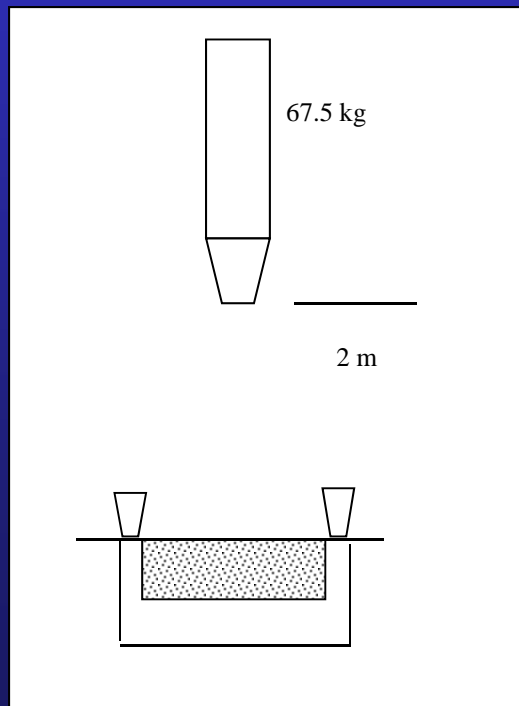


Layout of the Impact Test Apparatus

Impact Resistance Test

(performance test : BAW)

- A heavy drop weight (67.5 kg) is dropped from 2 m height on the geosynthetic placed on sand and fixed in a ring. The result is a “penetration yes or no” decision.



The Test

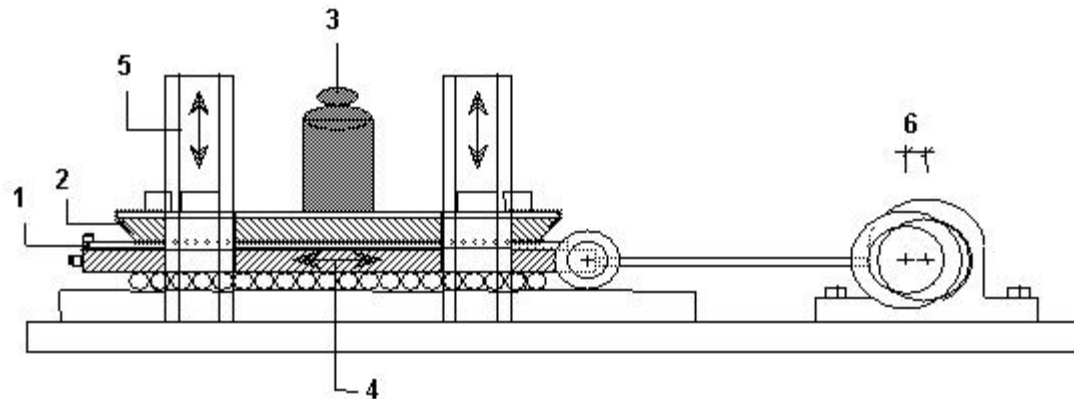


**Result of drop tests -
no penetration**

Abrasion Resistance

(EN ISO 13427 : 1995)

- Emery cloth of a specific grade is moved linearly along the specimen. After 750 cycles the abraded specimen is tested to measure the residual tensile strength or hydraulic properties



- 1 Sliding block with emery cloth P 100
- 2 Geotextile specimen (50 x 300 mm)
- 3 Total weight 6 kg
- 4 25 mm linear motion
- 5 Vertical guidance
- 6 Excentricity 12.5 mm

**Example of Apparatus
with Sliding Block**

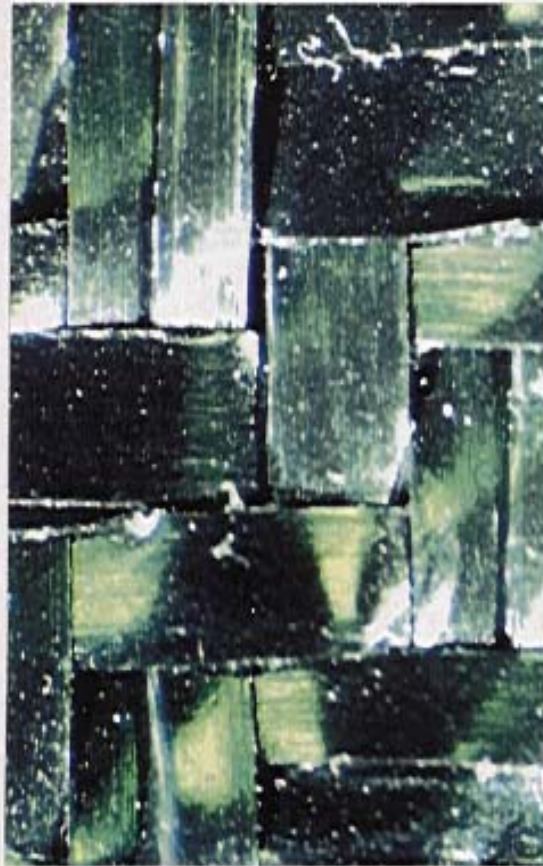
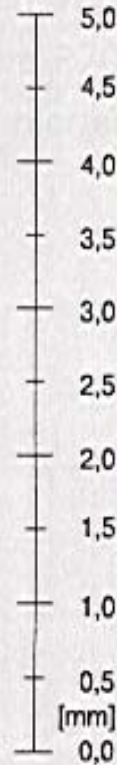


Bild 7.2a unbehandelte Probe

**Specimen
before test**



Maßstab

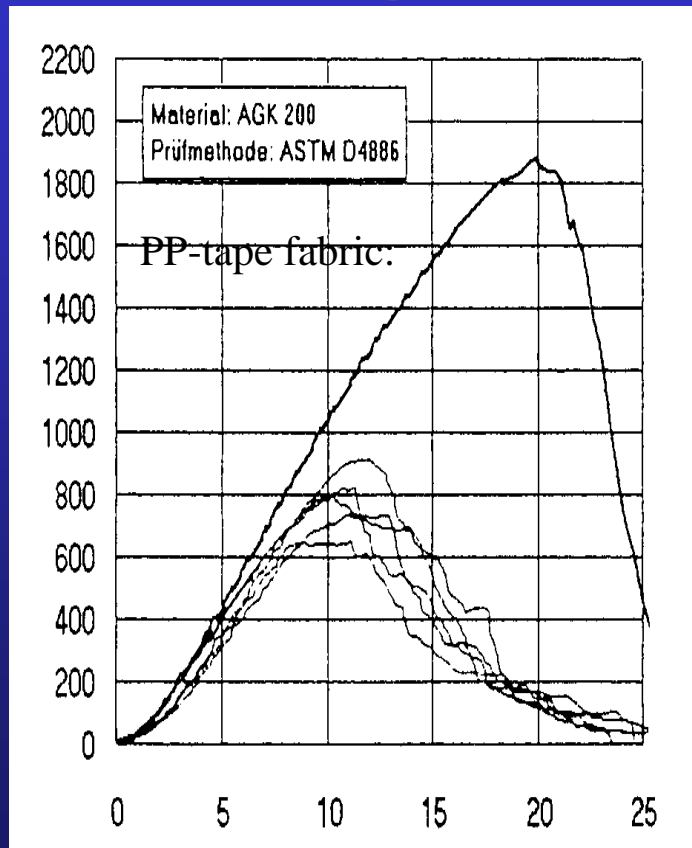


Bild 7.2b beanspruchte Probe

**Specimen after
abrasion test**

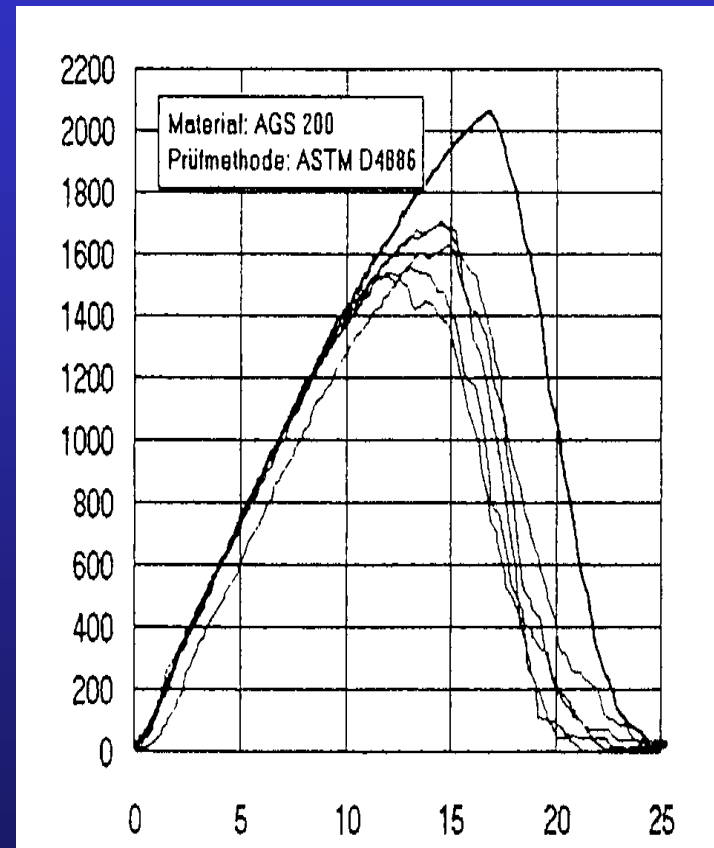
Force vs displacement of abraded specimen (lower lines) to undamaged specimen (upper line)

Force in N



Strain in %
warp

Force in N



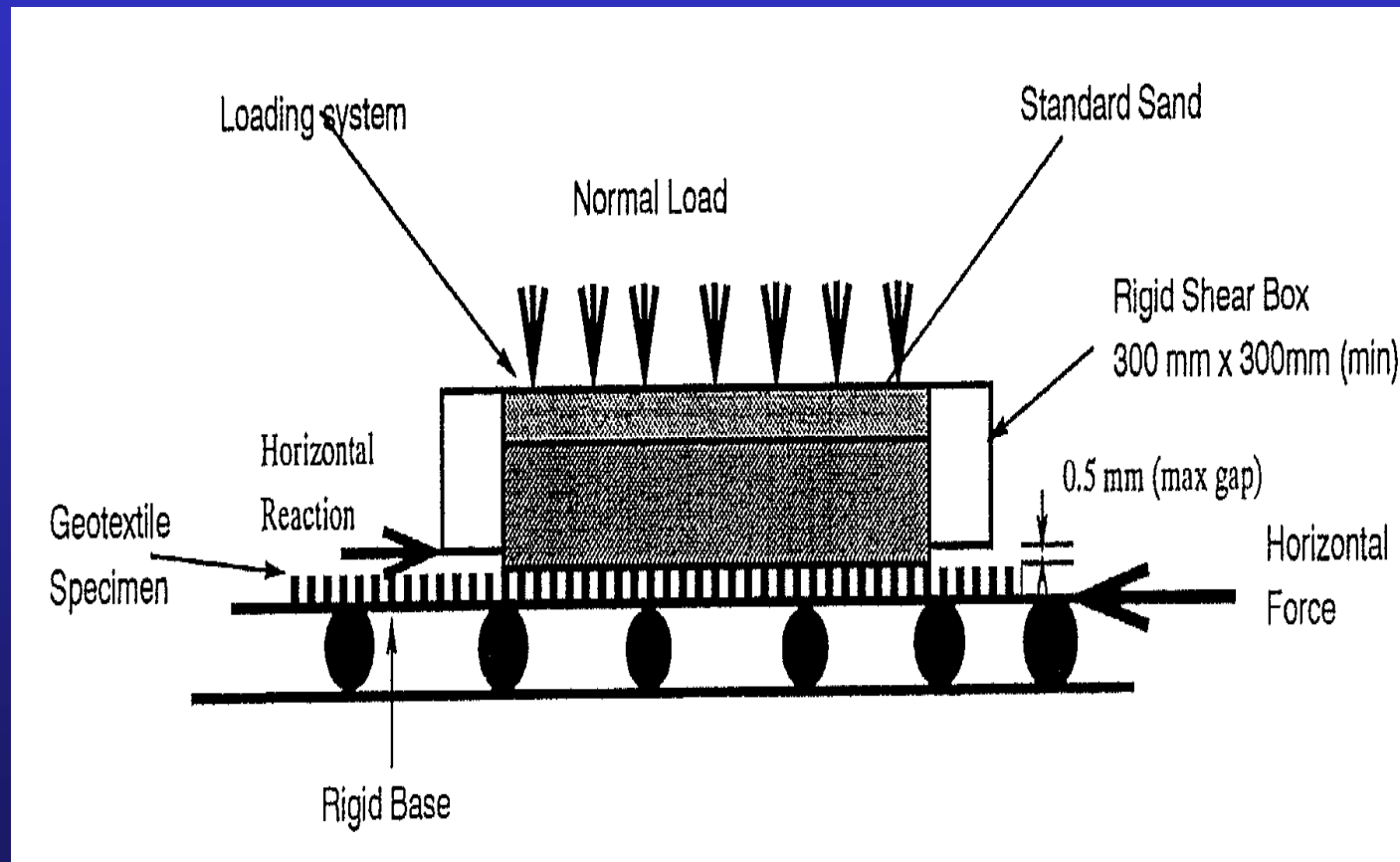
Strain in %
weft

Direct Shear Friction

(EN ISO 12957 : 1998)

- Reinforcing geosynthetics develop their tensile resistance by the transfer of stresses from the soil to the fabric through friction. The friction ratio is defined as the angle of friction, the ratio of the normal stress to the shear stress. Low normal stresses may be tested by an inclined plane test and higher normal stresses by direct shear or by pull out test.
- Direct shear (EN ISO 12957-1)
The friction partners are placed one in an upper box, the other in the lower box. The lower box is moved at a concentrate of displacement (index testing: 1 mm/min) while recording force and displacement. The results for three normal stresses (50, 100, 150 kPa) are plotted, the value of friction angle is calculated

Section Through Shearbox Test

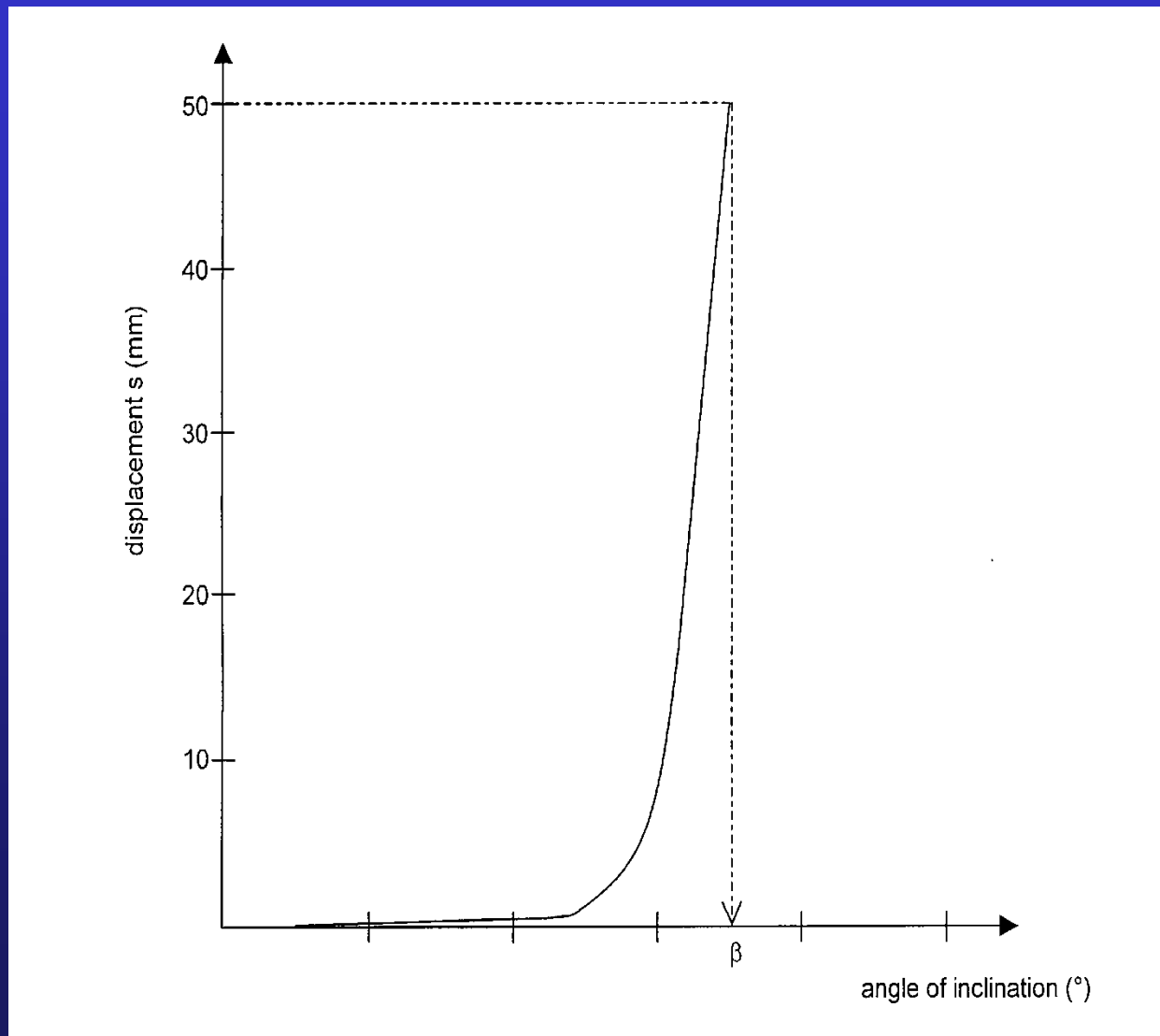


Inclined Plane Test

(EN ISO 12957-2)

- The friction partners to be tested (geomembrane/geosynthetic; geomembrane/soil; geosynthetic/soil) are set up on an inclinable steel table.
- Movement of the upper box and inclination are measured while lifting the table by 3 degrees/min.
- When the upper box moves 50mm the test is stopped and the angle of the table is taken as the angle of friction for the chosen materials combination.
- The normal stress must be recalculated for the resulting angle at the end of the test.

Inclined Plane Test: Typical Graph



Pullout Resistance (1)

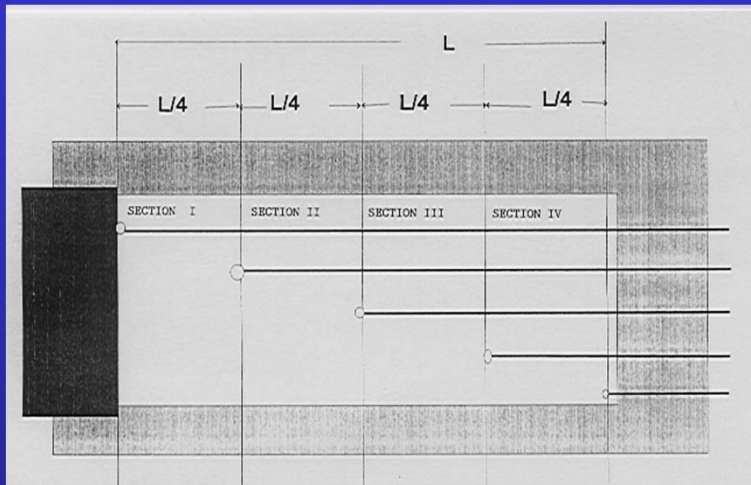
- A strip of the geosynthetic, just narrower than the width of the box, is pulled out of a soil filled box. A load is applied to the soil geosynthetic by pneumatic, hydraulic system or deadweight system.

Force and deformation are recorded for several points of the material inside the box.

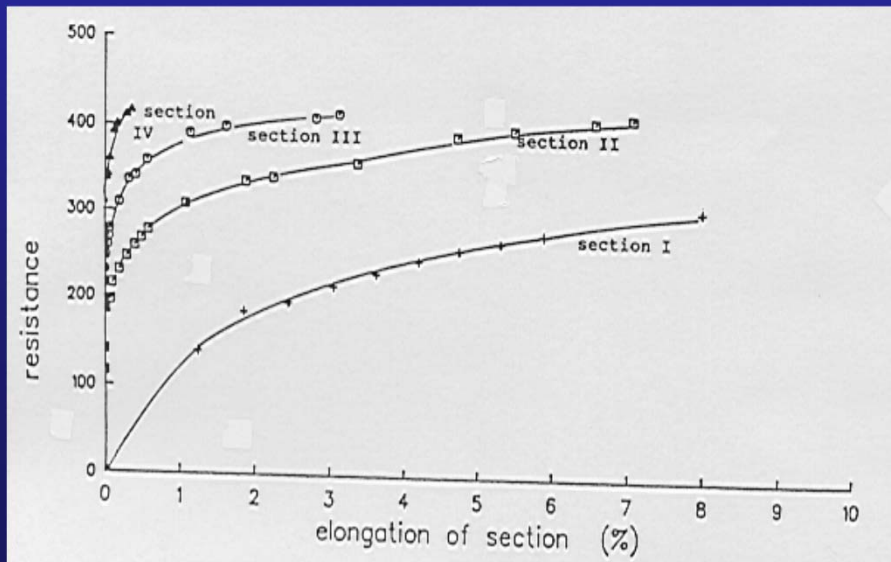
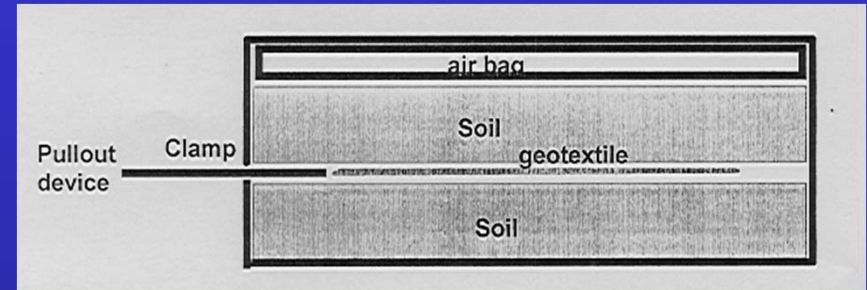
- Force transfer at the point where the geosynthetic leaves the apparatus must be avoided. It is important to design a system at the front of the pullout box which avoids transferring load to the box.

Results may be max force at rupture or slippage or plots of force v deformation.

Plan view and typical gauge placement



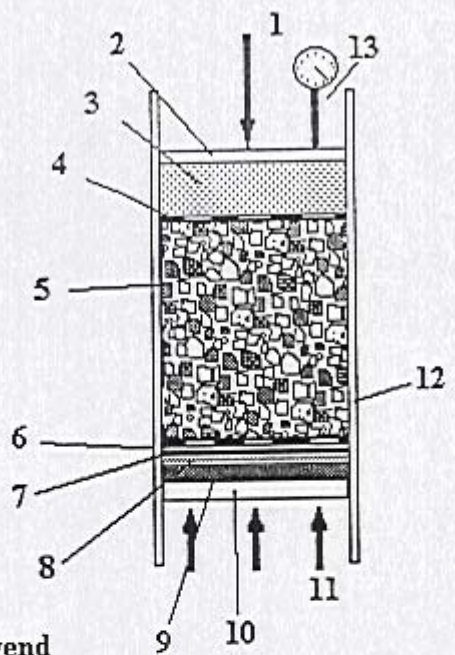
Pullout Box



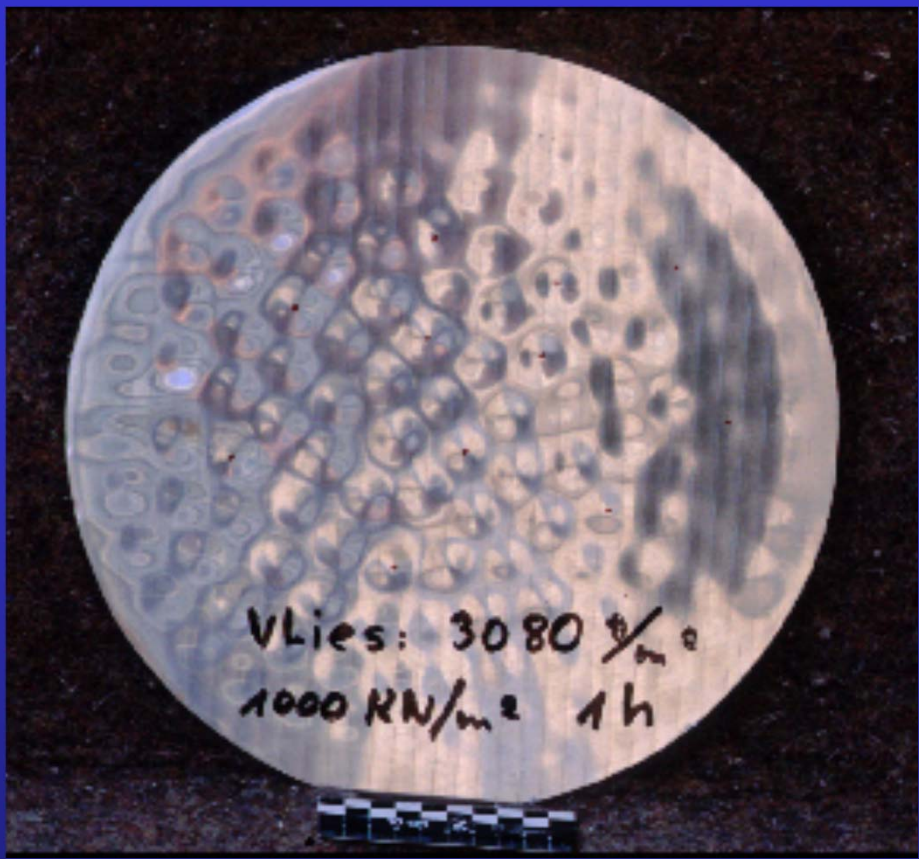
Pullout resistance versus percent strain of sections of pullout specimen during test

Protection Efficiency

- **The ability of a geotextile to protect a geomembrane is quantified by a test based on a German procedure.**
- **The deformation of a lead plate, loaded with standard M10 nuts, used as a consistently reproducible granular material. The efficiency of the geotextile to protect a geomembrane is calculated from the depth and width of the indentations.**



- Legend
- 1 applied load
 - 2 upper steel plate
 - 3 sand
 - 4 separator geotextile
 - 5 drainage aggregate
 - 6 geotextile specimen
 - 7 geomembrane
 - 8 metal sheet
 - 9 dense rubber pad
 - 10 lower steel plate
 - 11 load cells
 - 12 cylinder
 - 13 settlement gauge



Protection Efficiency Arrangement of Test Apparatus

Damage During Installation

- The CEN-ISO standard applies a cyclic load to a platen (100 x 200) pressing via a layer of Corundum aggregate placed on top of the geosynthetic being tested. (Corundum is a trade name for a sintered aluminium oxide.
- After 200 cycles between 5 kPa and 900 kPa maximum stress the specimen is exhumed and may be subject to a tensile test for the residual strength for reinforcement applications, or for filtration the hydraulic properties for filtration applications.
- A performance test requires the soil and fill to be used on the site and the equipment to spread and compact the material.
- Typical results of an index-test are shown

Damage During Installation

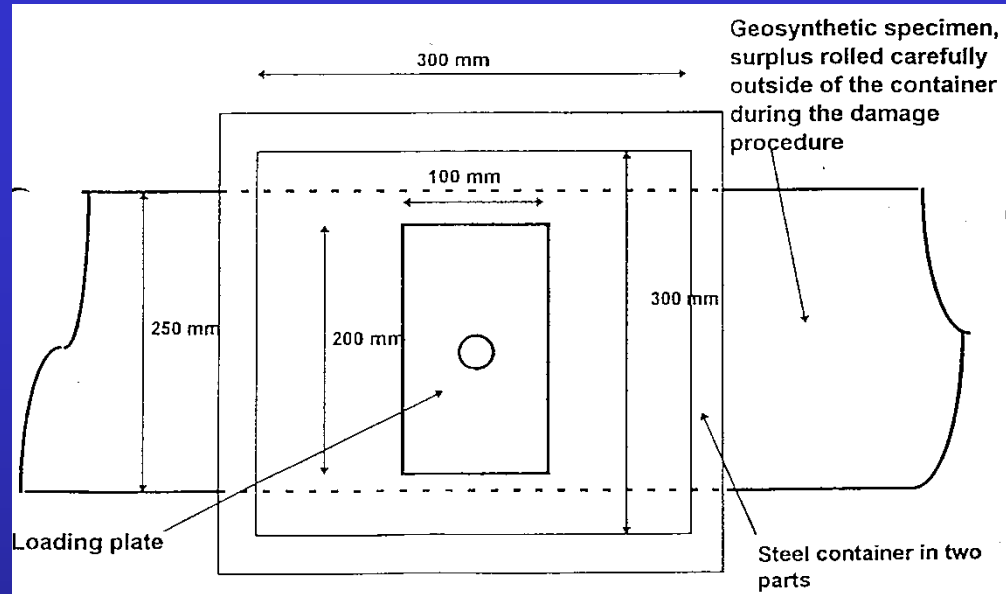
(ENV ISO 10722-1 : 1997)

- **The forces applied to a geosynthetic during installation can be the most severe loading that will be applied to the material,**
- **It is therefore necessary to have a test which simulates the installation process.**

Damage During Installation



Filling Corundum into upper box

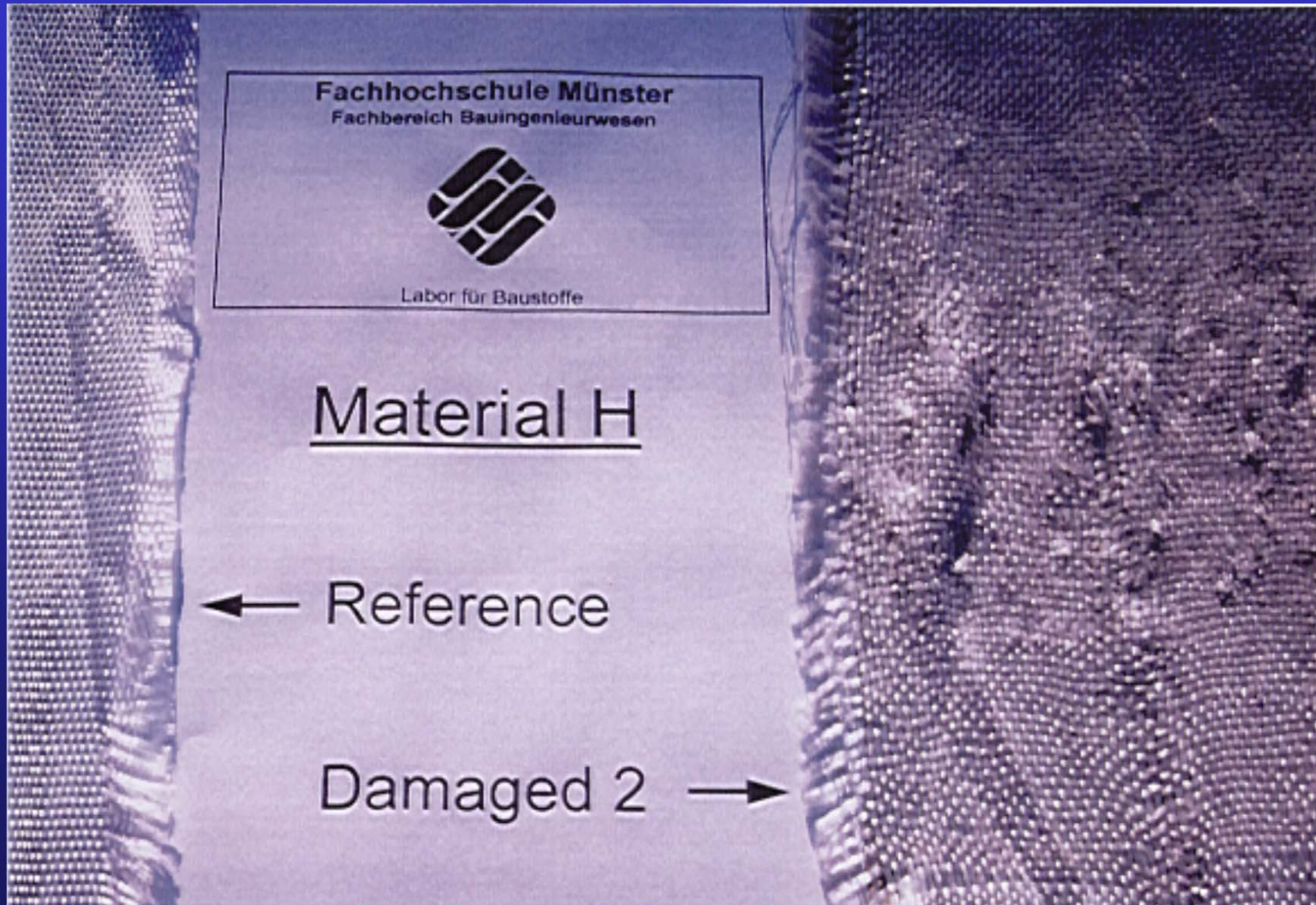


Plan on apparatus



Cyclic loading

Material Before (left) and After (right) Damage Test

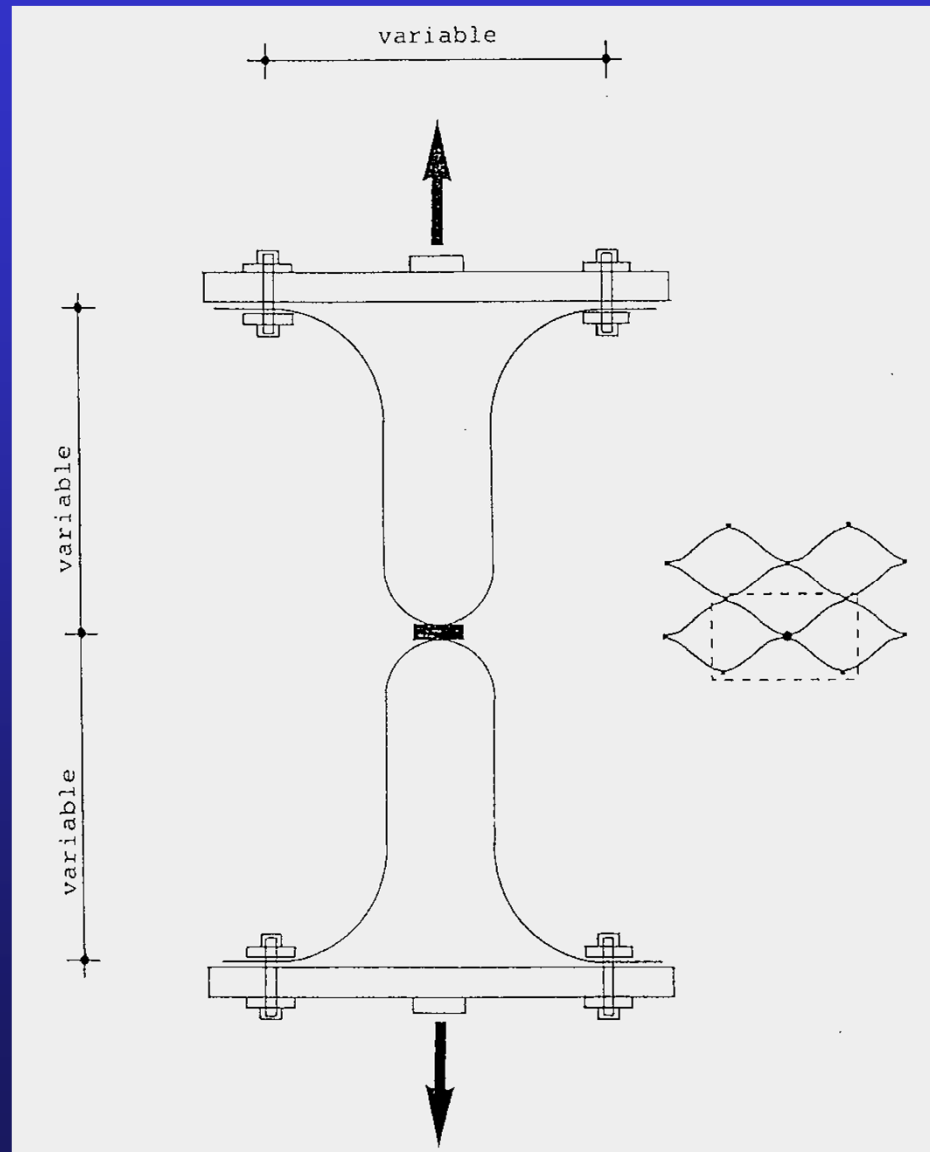


Geosynthetics (composites internal strength)

(EN ISO 13426-1)

- If a failure of internal junctions may cause failure of a structure, the strength of these junctions can be tested. CEN WG 3 is developing a 3 part test.
- Geocells: The loading of a internal geocell-connection may be of:
 - a tensile shear type
 - a peeling type
 - a splitting typeor of combinations.

A Typical Junction Strength Test



Hydraulic Properties

- **Water permeability characteristics normal to plane, without load**
 - **Constant head**
 - **Falling head**
- **Water flow capacity in their plane**
- **Characteristic opening size**

Hydraulic Properties:

Water permeability characteristics normal to the plane, without load (ENISO-11058 : 1999)

When geosynthetics are working as filters, they are required to allow water through freely but soil grains need to be retained. Some very fine soil grains are allowed through such that a stable secondary filter is developed in the contact soil zone.

- The water flow may be determined at stationary (time independent) conditions i.e. constant flow at constant water head or at in stationary conditions, i.e. “falling head”.

Constant Head Test

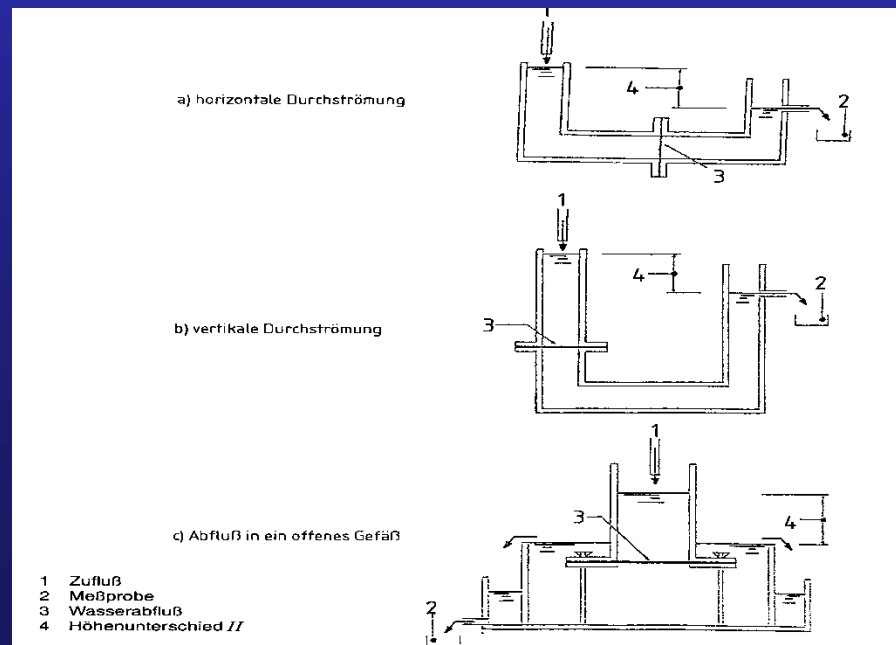
- De-aired water passes the specimen charged with normal stresses from top to bottom (multilayer specimen of 20-40 mm are used), flow vs time is measured and expressed as a k_v (kn)-factor.

Example of apparatus for the constant head method

In Darcy's equation $v = k_v \cdot i$

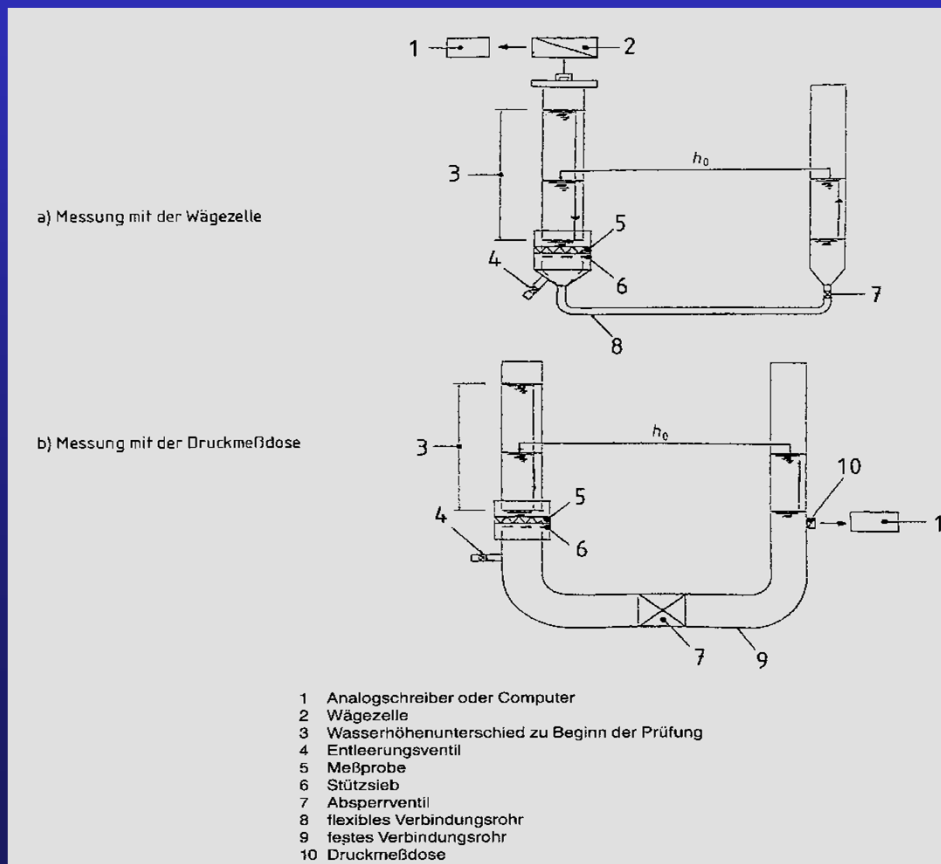
v = speed of flow (m/s)

i = hydraulic gradient = head difference/specimen thickness



Falling Head Method

- De-aired water passes the specimen charged with normal stresses from top to bottom (multilayer specimen of 20 - 40 mm are used), flow vs time is measured and expressed as a kv (kn)-factor.

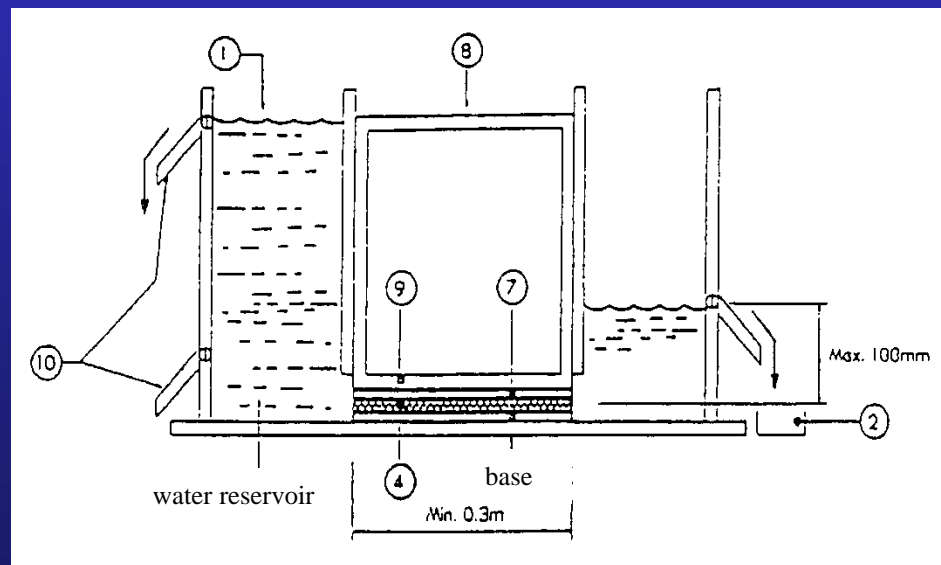


Examples of
apparatus for the
falling head
method

Water Flow Capacity in the Plane

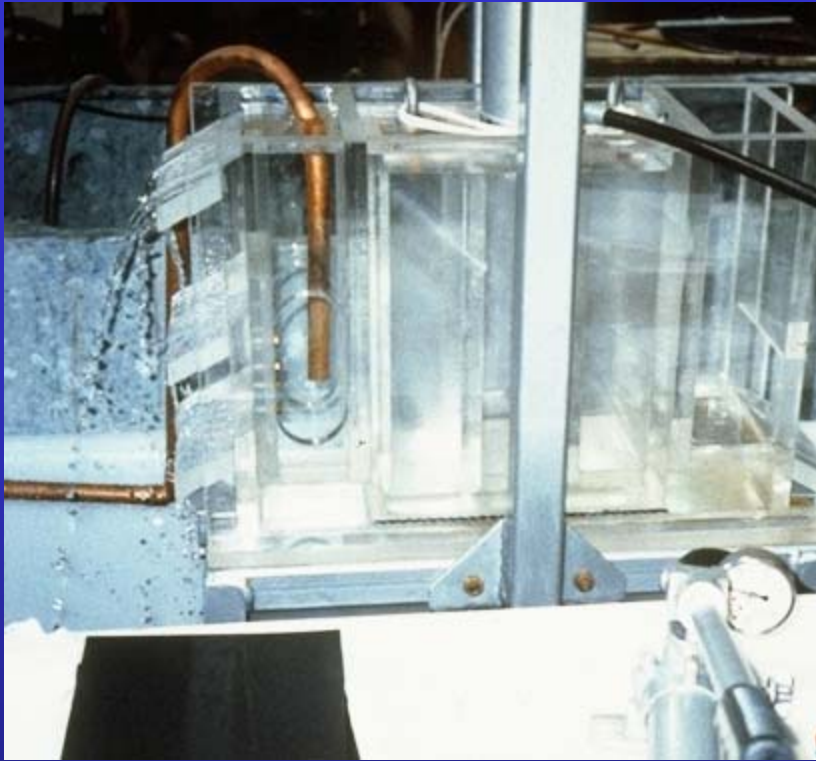
(EN ISO 12958 : 1999)

- In drainage applications water needs to flow in the plane of the geosynthetic. Tests according to EN-ISO or ASTM differ in specimen size, but use the same basic principles.



- 1 water supply
- 2 water collection
- 4 specimen
- 7 foam
- 8 load
- 9 loading platen
- 10 overflow weirs at hydraulic gradients 0,1 and 1,0

Typical Example
of Apparatus

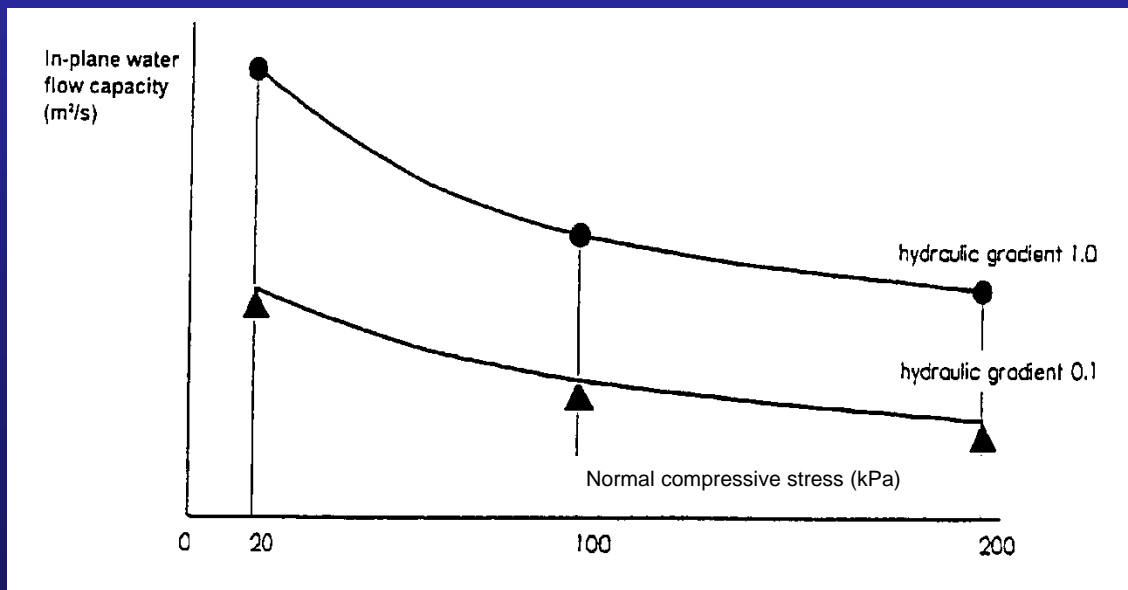


**CEN - apparatus in
plane flow**



**Specimen in
apparatus, net core
with soft contact
faces**

Flow is measured at constant water head and expressed either as k_H (k_p), unit m/s, or as flow capacity, unit l/s per m width of the product at given gradient. The flow value is dependent on the thickness of the product, as some products compress under load the flow values are time dependant. For a long-term design, flow values need to be corrected for the compressive creep of the product..



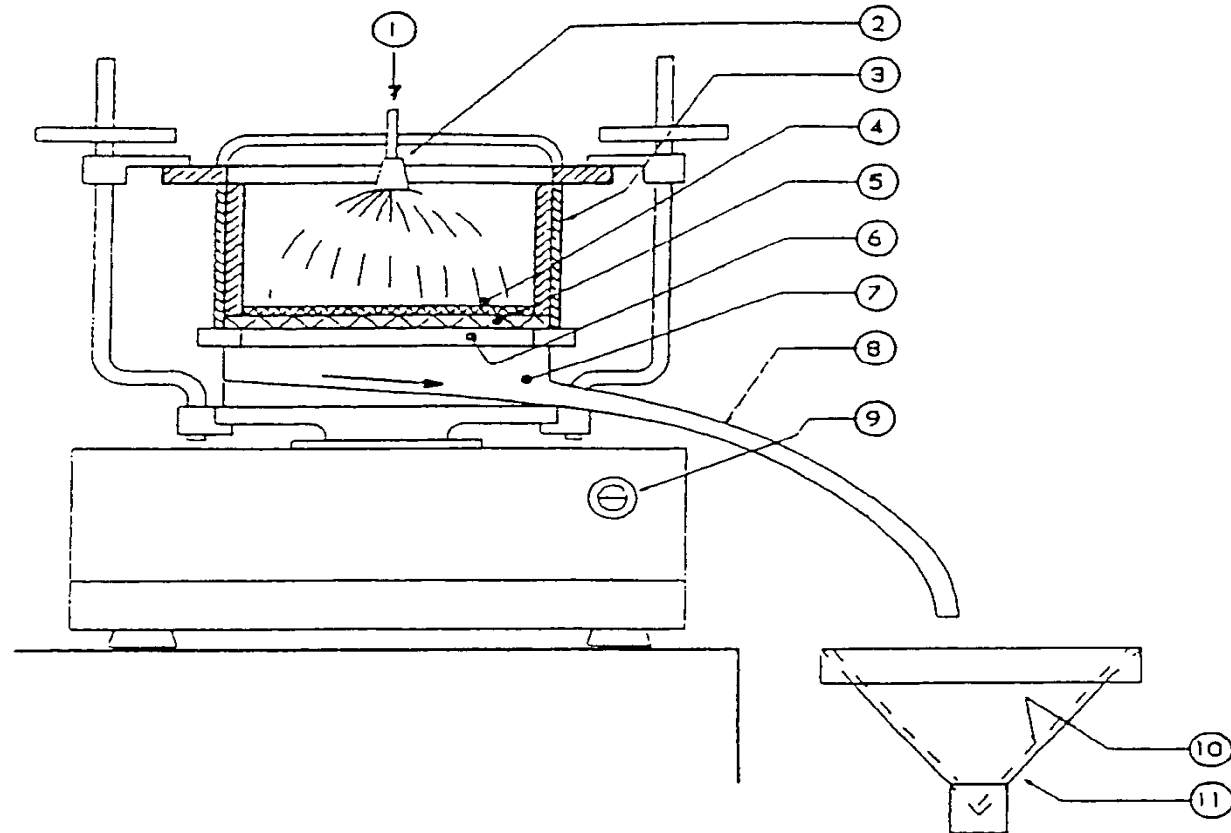
Typical examples of in-plane water flow capacity curves

Characteristic Opening Size

(EN ISO 12956 : 1999)

- To determine, which grain size can passing through a geosynthetic and which is retained, a wet sieving test is used with a standard “soil”.
- The ‘soil’ passing the geotextile is extracted from the water and sieved again.
- A characteristic value O_{90} is calculated according to EN ISO 12956.
- $O_{90} = d_{90}$ of the ‘soil’ passing the geosynthetic

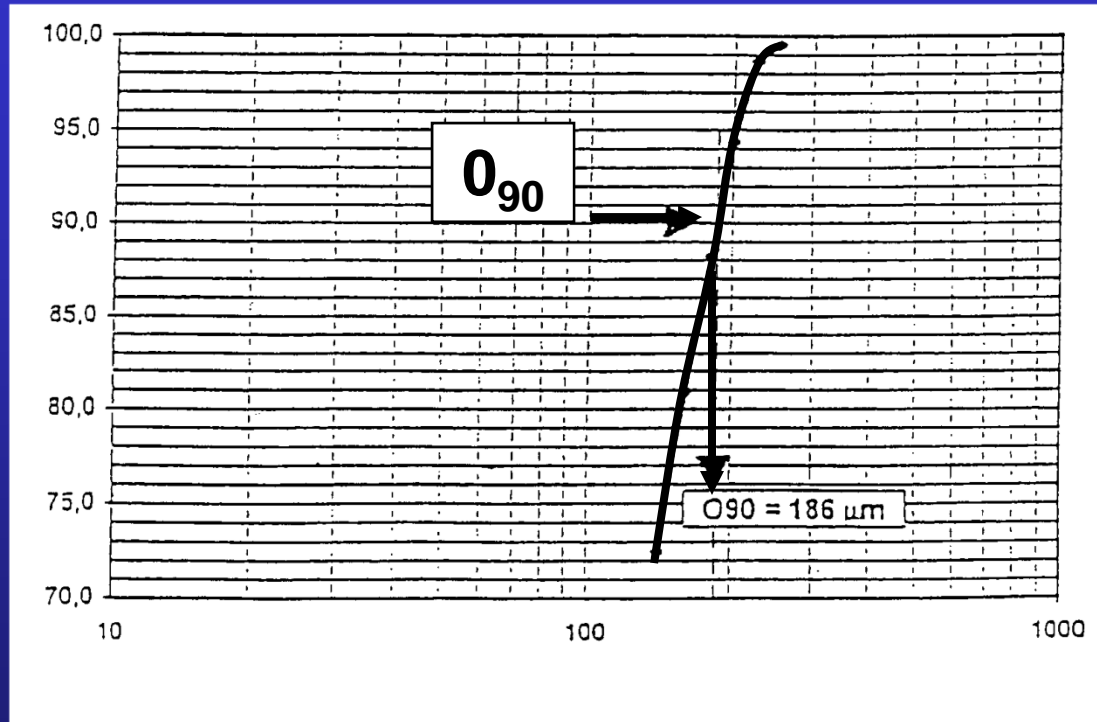
Example of Wet Sieving Apparatus



- | | | | |
|---|------------------|----|---------------------|
| 1 | Wassorzuleitung | 7 | Auffangschale |
| 2 | Sprühdüse(n) | 8 | Verbindungsschlauch |
| 3 | Klemmvorrichtung | 9 | Amplitudenregler |
| 4 | Prüfboden | 10 | Filterpapier |
| 5 | Meßprobe | 11 | Auffangbehälter |
| 6 | Stützsieb | | |

Tests according to other standards use single grade soil sand or glass-spheres to measure similar properties.

cumulative percentage passed (%)



sieve opening size (µm)

Cumulative curve of the granular material passed through the specimen and determination of O_{90}

Durability Properties

- Resistance to weathering
- Resistance to microbiological degradation (soil burial)
- Resistance to liquids
- Resistance to hydrolysis
- Resistance to thermal oxidation

Durability Properties

- **Geosynthetics may be used for temporary structures such as access roads for construction sites or may be required for medium term applications until consolidation of soils makes them redundant. Long-term applications are the main use (30 to 60 years for some in UK application or ; more than 120 years for landfills in most countries). Therefore durability is an important requirement.**

Resistance to Weathering

(prEN 12224 : 1996)

- **Products exposed uncovered to light and products placed without cover-soil for service are tested by artificial weathering.**
- **Exposure to UV-light of defined emission spectrum and rain at elevated temperature accelerates the test.**

Exposure to Natural Weathering



Tensile tests after exposure and reference to fresh specimen tensile strength loss in %. Tensile tests on exposed and fresh specimens can be used to determine the loss of tensile strength, normally expressed as a percentage of strength retained after exposure.

Resistance to Microbiological Degradation

(ENV 12225 : 1996)

- Fungi and bacteria living in soils may attack the polymeric materials used as geosynthetics. (There are no recorded failures of geosynthetics due to microbiological attack).
- To check the resistance the product to be tested they are buried in biologically active soil and after the “soil burial” test residual strength is measured. ENV 12224 gives types of bacteria and environments be used.

Resistance to Liquids

(ENV ISO 12960)

- **The chemical tests developed to date are:**
 - **the resistance to hydrolysis for Polyester based geosynthetics**
 - **and the resistance to thermal oxidation for geosynthetics made from Polyolefines.**

Immersion of geosynthetics in liquid agents



Resistance to Thermal Oxidation

(prEN ISO 13430)

- To the polyolefine molecules of PE, PP oxygen may be connected creating increased brittleness of the polymers.
- Stabilizing additives delay this oxidation.
- For the test the products are exposed to high temperature in an oven.

Resistance to Hydrolysis

(pr EN 12447)

- **Hydrolysis of Polyester is the reverse action of the evolution by polycondensation and means connecting water molecules or parts to the PET molecules, thus increasing the Carboxyl end group (CEG)-content and decreasing the average molecular weight often expressed as solution viscosity.**
- **External hydrolysis by alkaline attack occurs also at low temperatures, internal hydrolysis in neutral environments is relevant at elevated temperatures.**
- **Products are immersed in liquids for times up to 90 days and residual strength and deformation are tested.**

Concluding remarks

- **Geosynthetic testing, property assessment, durability for different applications is vital in all projects to ensure safety, stability in ground improvement projects.**