Properties of Geosynthetics and their evaluation

Properties of Geotextiles

- Physical Properties
- Mechanical Properties
- Hydraulic Properties
- Endurance and degradation properties

GEOSYNTHETIC

- Polymer based product
- Plastic to visco-elastic behaviour
- Level of performance depends on several factors:
  - Ambient temperature
  - Stress under working condition
  - Duration of stress and rate of application of stress.

Testing of Geo-synthetics

- It brings to Hygroscopic and Thermal equilibrium or standard atmospheric temperature.
- This process is called “ Conditioning” .
- The factors mentioned in previous slide should be considered for testing.

PHYSICAL PROPERTIES

1. Specific gravity
2. Unit mass (weight)
3. Thickness
4. Stiffness

In order to achieve consistent results in the laboratory, a good environmental control during the testing is therefore important.

Considered as INDEX Properties of Geosynthetic

- Some more physical properties which **geogrids** and **geonets**

  Type of structure

  Junction type

  Aperture size and shape

  Rib dimensions

  Planar angles made by intersecting ribs and vertical angles made at the junction point.

The physical properties are more dependent on temperature and humidity

SPECIFIC GRAVITY

- Specific Gravity = Unit weight of Geosynthetic (without any voids)

$$\text{Specific Gravity} = \frac{\text{Unit weight of Geosynthetic (without any voids)}}{\text{Unit volume weight of water (at 4°C)}}$$

- It can be determined by the displacement method.

Values of Specific Gravity

Sr.No.	Material	Specific Gravity
1	Polypropylene	0.91
2	Polyester	1.22- 1.38
3	Nylon	1.05-1.14
4	Polyethylene	0.91-0.95
5	Polyvinyl Chloride	1.69
6	Cotton	1.55
7	Glass	2.54
8	Steel	7.87

Through which Geotextile manufactured (rows 1–5)

Added for comparison (rows 6–8)

Specific Gravity of some of the polymers is less then 1, Which is drawback when working with geo-textiles under water. (i.e. Some of them will float)

MASS PER UNIT AREA (UNIT WEIGHT)

- Usually given in units of gram per square metre (g/m^2)
- It is determined by weighing square or circular test specimens of known dimensions (generally area not less than 100 cm^2).
- Linear dimensions should be measured *without any tension in the specimen*.
- For commonly used geo-synthetics, it varies in order of 100 to 1000 g/m^2.
- Unit weight of geo-textiles< Unit weight of geo-membranes may have substantially larger values of mass per unit area, even up to several thousands of grams per square metre.

MASS PER UNIT AREA (UNIT WEIGHT)

CONT…

- It should be measured to the accuracy nearest to 0.01 % of total specimen weight.
- Fabric cost is directly related to mass per unit area (Unit weight).
- Important for Economy of a project.

Thickness of Geotextiles

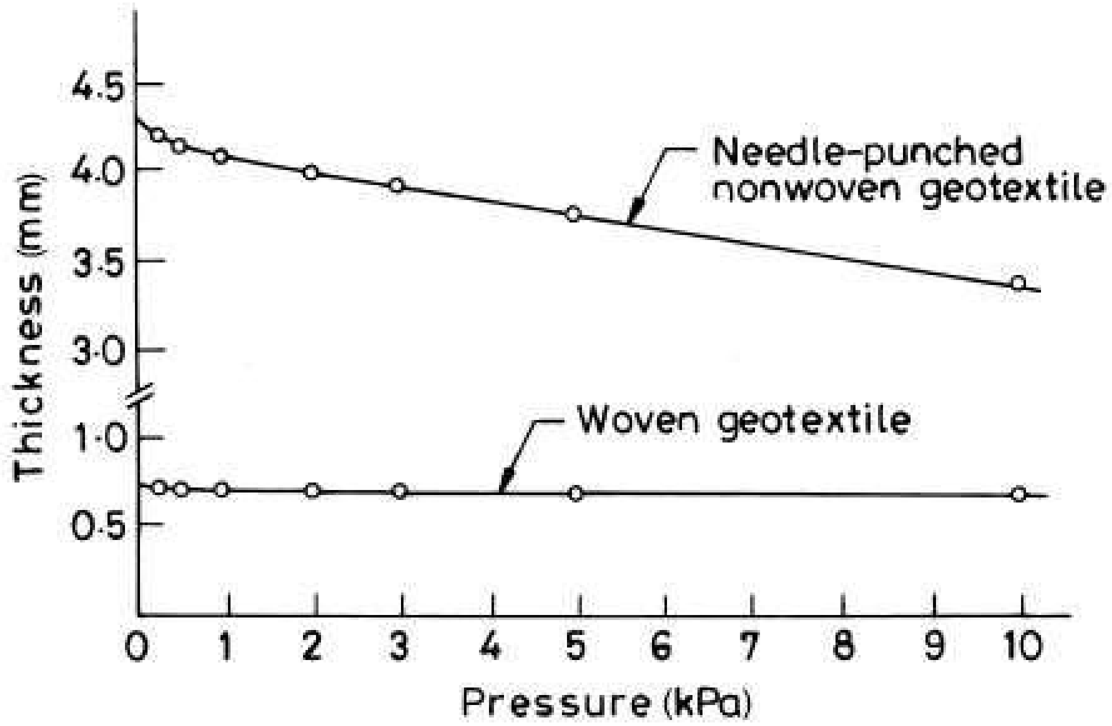
- The *thickness of a geosynthetic is the distance between its upper and* lower surfaces, measured normal to the surfaces at a specified normal compressive stress.
- Generally *2.0 kPa for geotextiles* and 20 kPa for geogrids and geomembranes.
- Measured to the accuracy of o.o2mm
- Thickness varies in between 0.25mm to 7.5mm
- Thickness is important for permittivity (c/s plane)and Transmissivity (in-plane) .

ASTM Guide for pressure to measure fabric

Sr.No.	Type of Material	Examples	Pressure range (gm/cm²)
1	Soft	Blankets, Fleeces, knits, lofty, nonwovens, woowans	0.035- 35
2	Moderate	Worsted, sheeting, carpets	1.4 – 144
3	Firm	Ducks, asbestos fabric, felts	7-700

- The thickness-testing instrument is basically a thickness gauge that consists of a base and a free-moving pressure foot-plate with parallel planar faces having an area of more than 2000 mm^2.

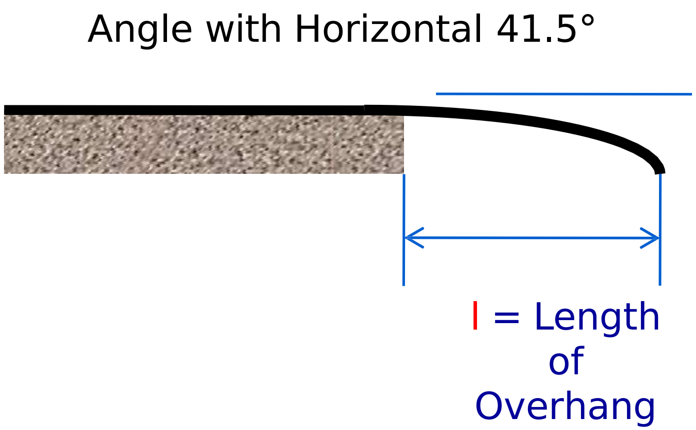
VARIATION OF THICKNESS OF GEOTEXTILES WITH APPLIED NORMAL PRESSURE (AFTER SHAMSHER, 1992).



- The thickness of geosynthetics decreases when applied normal compressive stress is increased

STIFFNESS (FLEXURAL RIGIDITY)

- It is ability to resist flexure (bending) under its own weight



- It can be measured by its capacity to form a cantilever beam without exceeding a certain amount of downward bending under its own weight.

$l/2$ = Bending length $= B_L$

Flexural Rigidity $= B_L{}^3 \times \gamma$

- The stiffness of a geosynthetic indicates the feasibility of providing a *suitable working surface for installation*.

- In the commonly used test, known as the *single cantilever test*, the geosynthetic specimen is placed on a horizontal platform with a weight placed on it.

- Holding the weight, the specimen along with the weight is slid slowly and steadily in a direction parallel to its long dimension until the leading edge projects beyond the edge of the platform.

- The length of overhang is measured when the tip of the test specimen is depressed under its own weight to the point where the line joining the tip to the edge of the platform makes an angle of 41.5 with the horizontal.

- One half of this length is the bending length. The cube of this quantity multiplied by the weight per unit area of the geosynthetic is the flexural rigidity.

Mechanical properties

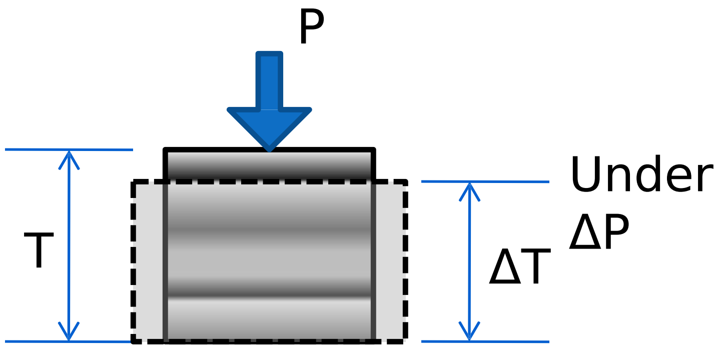
- *Compressibility*
- *Tensile strength*

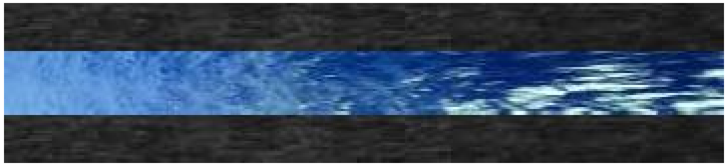
Mechanical properties are important in those applications where a geosynthetic is required to perform a structural role under applied loads or where it is required to survive installation damage and localized stresses.

SURVIVABILITY PROPERTIES

- *Tearing strength*
- *Static puncture strength*
- *Impact strength (dynamic puncture strength)*
- *Bursting strength*
- *Fatigue strength*
- *Friction Behaviour*

COMPRESSIBILITY





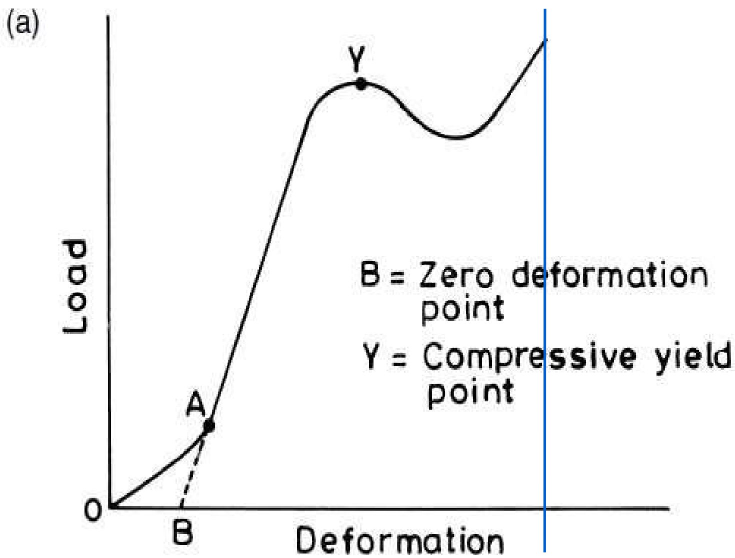
- The compressibility of a geosynthetic is measured by the decrease in its thickness at increasing applied normal pressures.

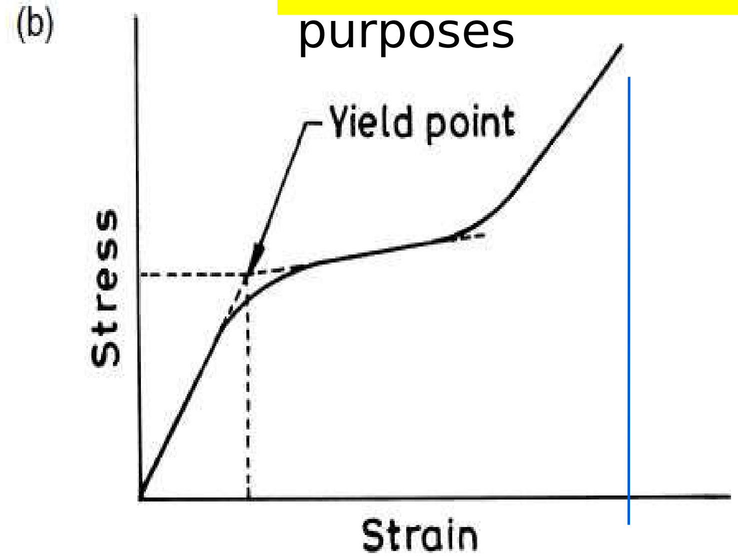
- This mechanical property is very important for nonwoven geotextiles, because they are often used to convey liquid within the plane of their structure.

- Compressibility can be studied by applying compressive stress, by placing the geosynthetic between two plates and constant stress applied.

COMPRESSIBILITY CONT…

stress–strain curve can be used to determine yield point for comparative purposes





(a) typical load–deformation curve

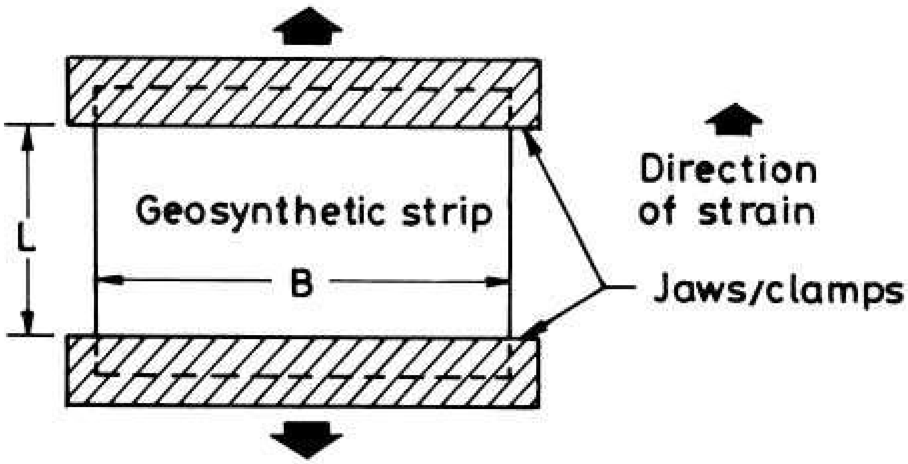
(b) typical stress–strain curve

- The compression behaviour of geosynthetics, particularly geocomposites, can be studied by applying compressive loads at a constant rate of deformation to specimens mounted between parallel plates in a loading frame.
- The deformations are recorded as a function of load and plotted as shown in Figure (a).

TENSILE STRENGTH

- The *tensile strength* is the maximum resistance to deformation developed for a geosynthetics when it is subjected to tension by an external force.

TENSILE STRENGTH



Wide-width strip tensile test.

Note: B= 200 mm; L=100 mm.

Tensile strength determination:

- Tensile test on a 200-mm wide geosynthetic strip with a gauge length of 100 mm.
- Entire width of a 200-mm wide geosynthetic specimen is gripped in the jaws of a tensile strength testing machine and it is stretched in one direction at a prescribed constant rate of extension until the specimen ruptures (breaks).

Tensile properties depends on...

- Geosynthetic polymer.
- manufacturing process

Measured Strength and rupture strain is a function of.....

- Sample geometry,
- Gripping method,
- Strain rate,
- Temperature,
- Initial preload,
- Conditioning and the amount of any normal confinement applied to the geosynthetic.

Tensile Strength Test

- **Note:**
- The width of specimen should be greater then the length to avoid "*necking*" effect.
- Greater width reduces the contraction effect.
- Maintains plain strain condition.
- Test Provides following parameters:

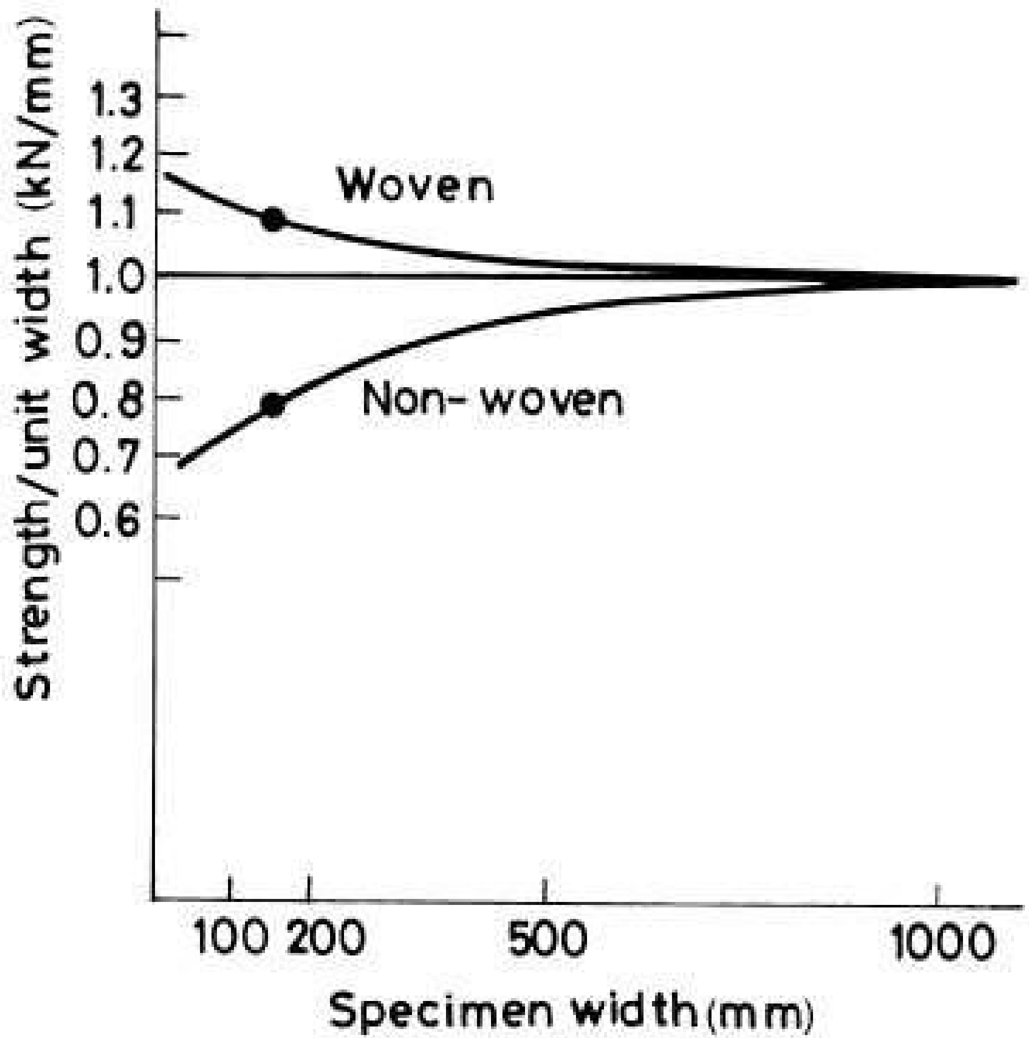
1. Peak strength
2. Elongation
3. Tensile modulus

- Due to specific geometry and irregular cross-sectional area that cannot be easily defined, the tensile strength of geosynthetics cannot be expressed conveniently in terms of stress.

- It is, therefore, defined as the peak (or maximum) load that can be applied per unit length along the edge of the geosynthetic in its plane.

- Tensile properties of a geosynthetic are studied using a tensile strength test in which the geosynthetic specimen is loaded and the corresponding force–elongation curve is obtained.

INFLUENCE OF GEOTEXTILE SPECIMEN WIDTH ON ITS TENSILE STRENGTH (AFTER MYLES AND CARSWELL, 1986).



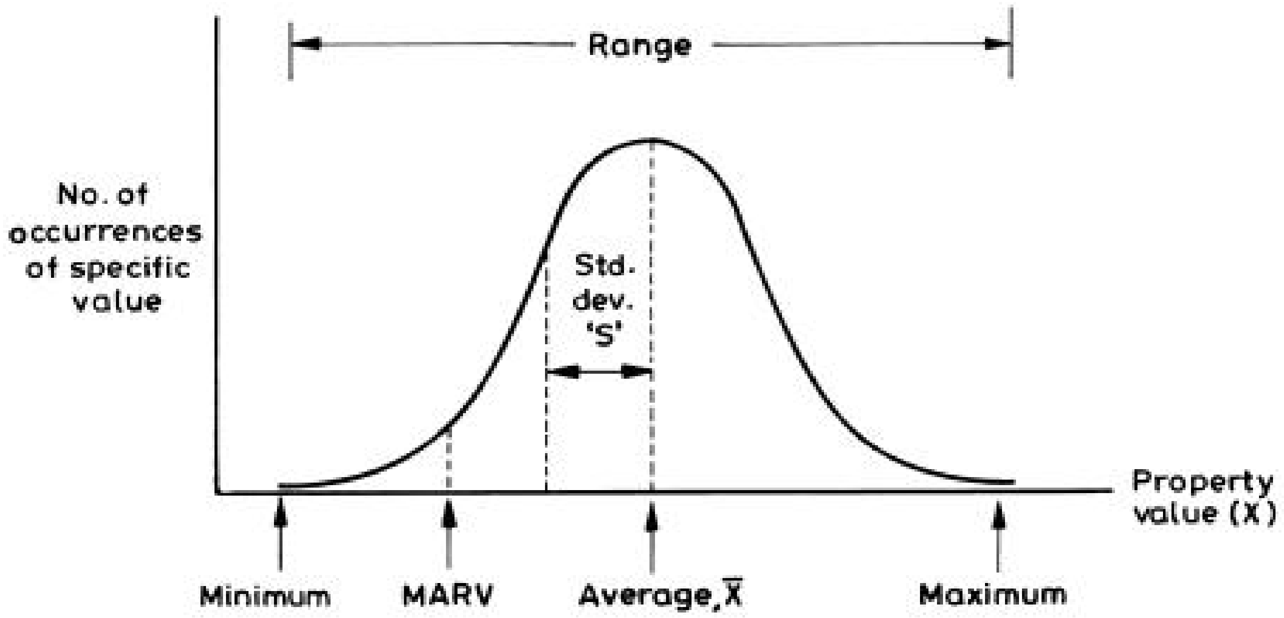


Fig: Statistical distribution of geotextile properties.

- During manufacturing process, the variability in geosynthetic properties may occur as happens with other civil engineering construction materials.

- Based on quality control tests, a manufacturer of geosynthetics can represent properties statistically in normal distribution curve as shown in above fig.

- Project specifications tend to include several qualifiers such as Minimum, Average (Mean/Typical), Maximum and Minimum Average Roll Value (MARV).
- If $X_1, X_2, X_3, \ldots, X_N$ are individual property values in a sample of size N, then these qualifiers as well as standard deviation can be determined using the following expressions

$$\text{Average, } \overline{X} = \frac{X_1 + X_2 + X_3 + \cdots\cdots + X_N}{N}$$

$$\text{Standard deviation, } S = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \cdots\cdots + (X_N - \overline{X})^2}{N - 1}}$$

$$\text{MARV} = \overline{X} - 2 \times S$$

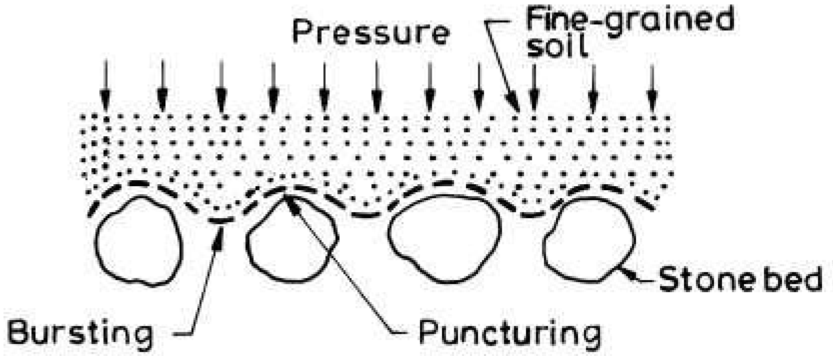
$$\text{Minimum} = \overline{X} - 3 \times S$$

$$\text{Maximum} = \overline{X} + 3 \times S$$

$$\text{Range} = \text{Maximum} - \text{Minimum}$$

- The significance of standard deviation lies in the variation in material properties and testing values of the particular property under investigation. The current trend is to report the strength value as a MARV in the weakest direction.
- A specification based on the MARV means that 97.5% of the geosynthetic samples from each tested roll are required to meet or exceed the designer's specified value for the geosynthetic product to be acceptable.
- MARV has now become a manufacturing quality control tool used to allow manufacturers to establish published values such that the user/purchaser will have a 97.5% confidence that the property in question will meet or exceed the published values.
- MARV is applicable to a geosynthetic's intrinsic physical properties such as weight, thickness and strength, but it may not be appropriate for some hydraulic, degradation or endurance properties.
- It has been observed that for design engineers, the use of MARV results in better communication with manufacturers, lower number of change requests and simpler and economical designs, thus resulting in cost savings for everyone involved in the process.

PUNCTURE AND BURST STRENGTH



Field situations showing puncturing and
bursting of the geosynthetic

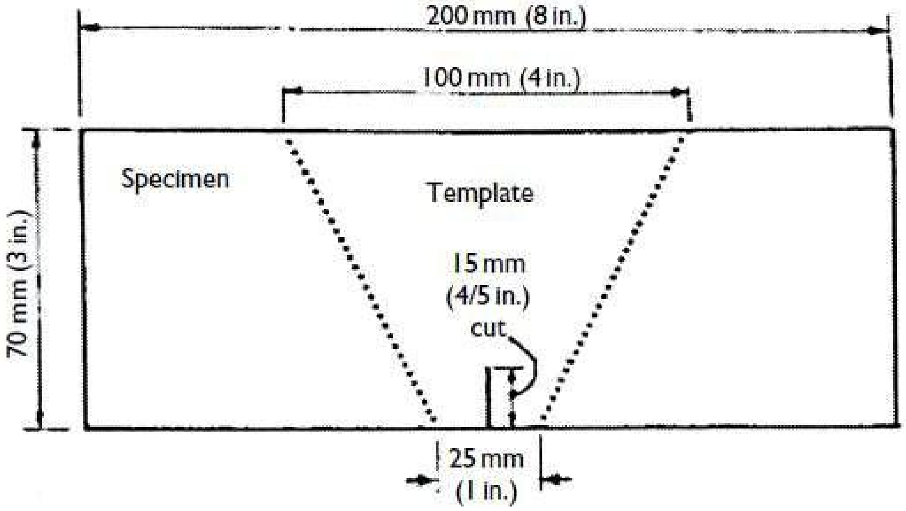
Survivability properties

- *Tearing strength*
- *Static puncture strength*
- *Impact strength (dynamic puncture strength)*
- *Bursting strength*
- *Fatigue strength*

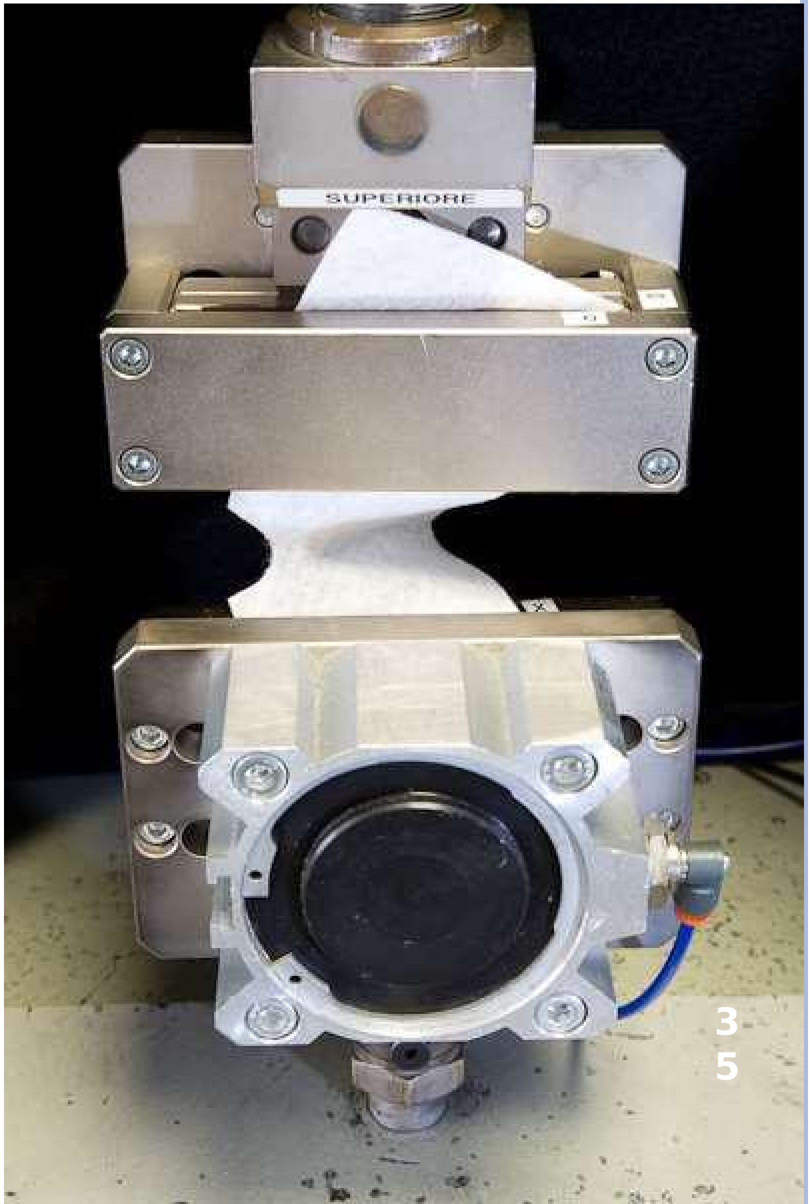
TEARING STRENGTH

- Definition: The ability of a geosynthetic to withstand stresses causing to continue or propagate a tear in it, often generated during their installation.

- The tearing strength of geotextiles under in-plane loading is determined by *trapezoid tearing strength test.*



Trapezoidal template for trapezoid tearing strength test

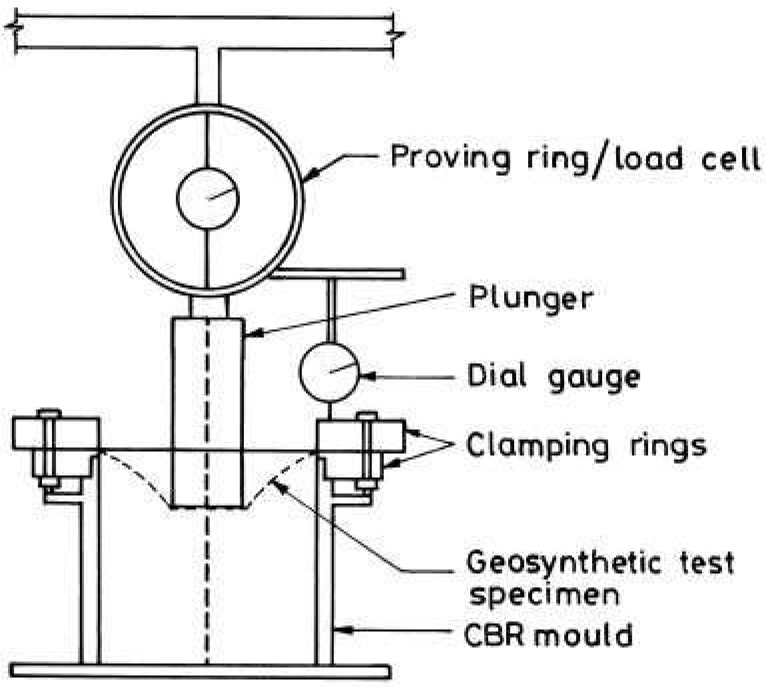


- In this test, a trapezoidal outline is marked centrally on a rectangular test specimen Fig. Note that an initial 15-mm cut is made to start the tearing process.
- The specimen is gripped along the two non-parallel sides of the trapezoid in the jaws of a tensile testing machine. A continuously increasing force is applied in such a way that the tear propagates across the width of the specimen.
- The load actually stresses the individual fibres gripped in the clamps rather than stressing the geosynthetic structure.
- The value of tearing strength of the specimen is obtained from the force–extension curve and is taken as the maximum force thus recorded.

Static puncture strength

- The ability of a geosynthetic to withstand localized stresses generated by penetrating or puncturing objects such as aggregates or roots, under quasistatic conditions

STATIC PUNCTURE STRENGTH



A typical test arrangement for static puncture test (CBR plunger test)

- In the *static puncture strength test*, a circular geosynthetic specimen is gripped without tension around its entire circumference between two steel clamping rings in a loading frame.

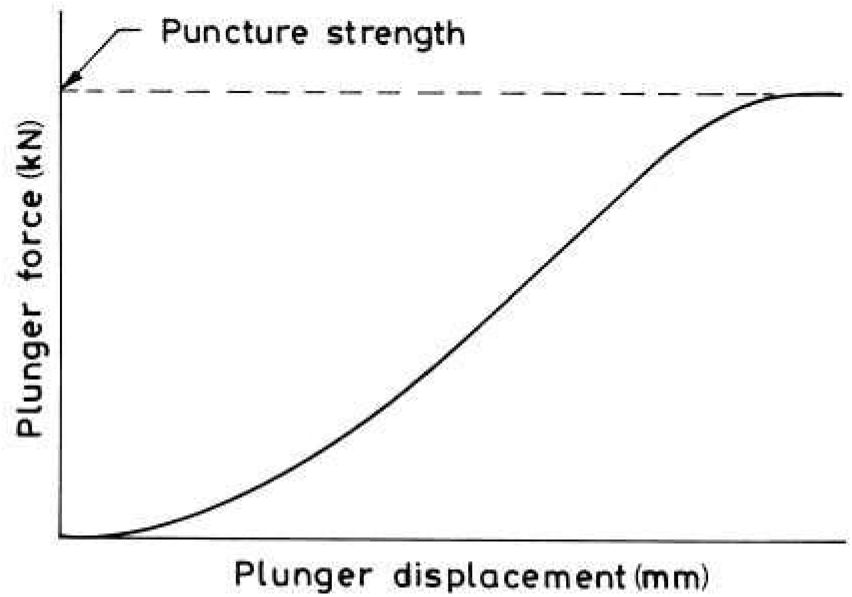
- A flat-ended cylindrical steel plunger attached to the load indicator is forced through the centre of the test specimen and perpendicular to it at a constant rate of displacement (generally 50 mm/min.) until rupture of the specimen occurs.

- The diameter of the plunger is generally 50 mm and the internal diameter of the ring is 150 mm. The relatively large size of the plunger provides a multidirectional force on the geosynthetic.

- The clamping system should prevent pre-tensioning of the specimen before and slippage during the test.

- Since this test utilizes the California Bearing Ratio (CBR) principle of the method to determine the puncture resistance and an approximate indication of the resulting strain, it is known as *CBR plunger test*. The force applied by the plunger and the corresponding displacement are measured

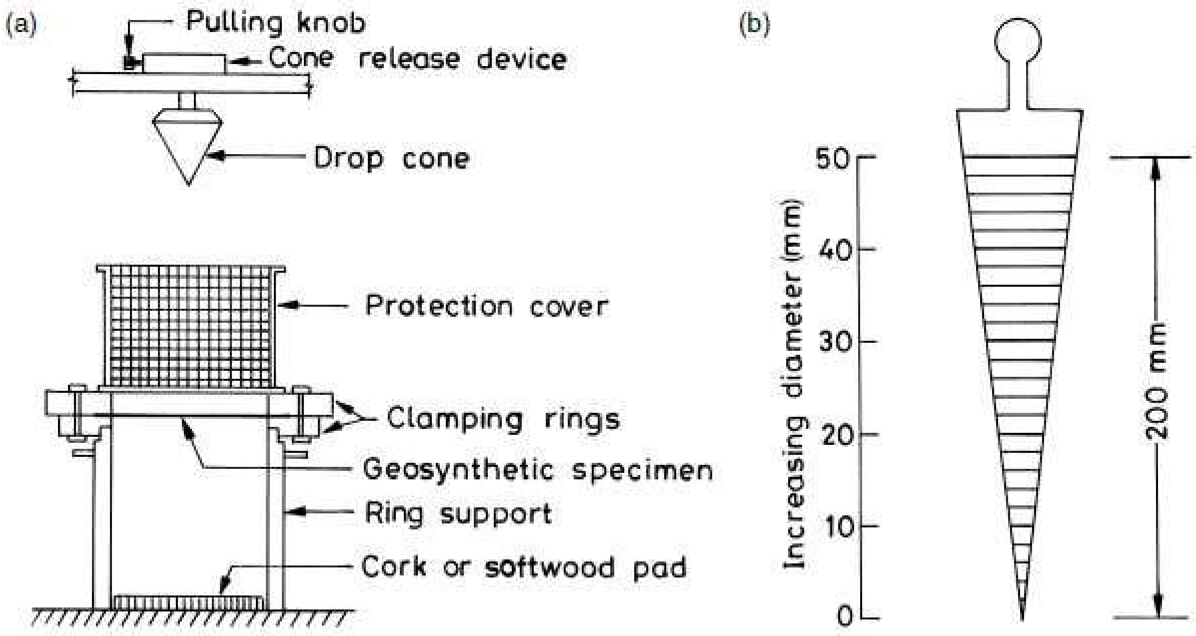
A TYPICAL PLUNGER FORCE–DISPLACEMENT CURVE



DYNAMIC PUNCTURE TEST SETUP

- The ability of a geosynthetic to withstand stresses generated by the sudden impact and penetration of falling objects such as coarse aggregates, tools, and other construction items during installation process.

IMPACT STRENGTH (DYNAMIC PUNCTURE STRENGTH)



Impact strength (dynamic puncture strength) test: (a) typical test arrangement; (b) penetration measuring cone.

- The *impact strength* of the geosynthetics can be evaluated by cone drop test method. This test involves the determination of the diameter of the punctured hole made by dropping a standard brass or stainless steel cone weighing 1 kg from a specified height onto the surface of a circular geosynthetic specimen gripped between clamping rings.

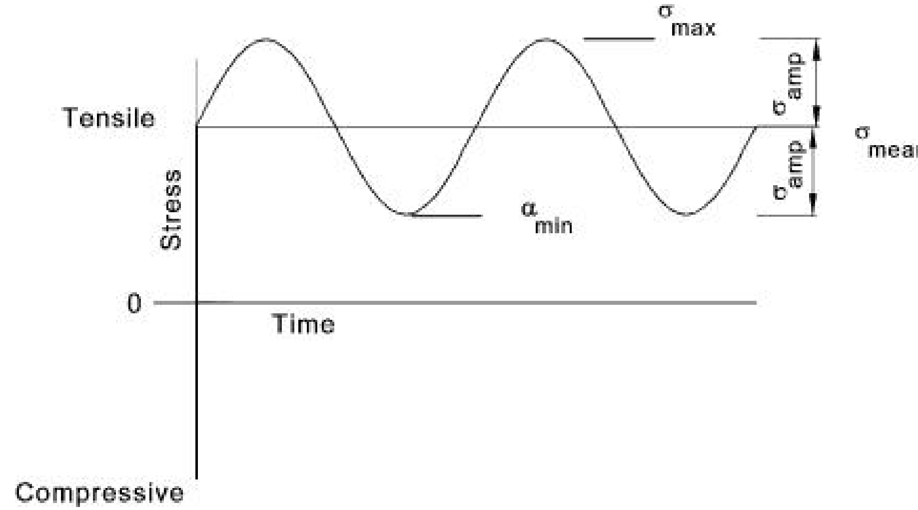
- The geosynthetic may be supported by water or soil to simulate the field conditions. The diameter of the punctured hole, measured using a penetration measuring cone in combination with the drop height, gives a measure of impact resistance (strength).

- The smaller the diameter of the hole, the greater the impact resistance of the geosynthetic to damage during installation.

BURSTING STRENGTH

- The ability of a geosynthetic to withstand a pressure applied normal to its plane while constrained in all directions in that plane
- This test is performed by applying a normal pressure, usually by air pressure against a geosynthetic specimen clamped in a ring. The normal stress against the geosynthetic at failure gives the value of the bursting strength. A typical range of bursting strength of geotextiles is 350–5200 kPa.

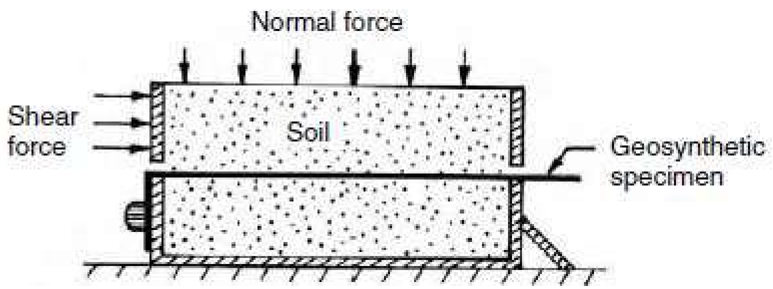
FATIGUE STRENGTH



- Specimen is stressed longitudinally at constant rate of extension to a predetermined load (less then failure load) and then back to lower zero load.
- This cycling is repeated until failure occurs.
- Lower stress failure --- Larger number of cycles required.
- Examples: seismic load, rail road loadings, wave and tidal action.

- The ability of a geosynthetic to withstand repetitive loading before undergoing failure.

SOIL–GEOSYNTHETIC INTERFACE CHARACTERISTICS



- It is important that the bond developed between the soil and the geosynthetic is sufficient to stop the soil from sliding over the geosynthetic or the geosynthetic from pulling out of the soil when the tensile load is mobilized in the geosynthetic.

Soil–geosynthetic interface characteristics Cont…

- The bond between the geosynthetic and the soil depends on the interaction of their contact surfaces.
- The *soil–geosynthetic interaction (interface friction and/or interlocking characteristics) is thus the* key element in the performance of the geosynthetic-reinforced soil structures such as retaining walls, slopes and embankments and other applications where resistance of a geosynthetic to sliding or pullout under simulated field conditions is important.

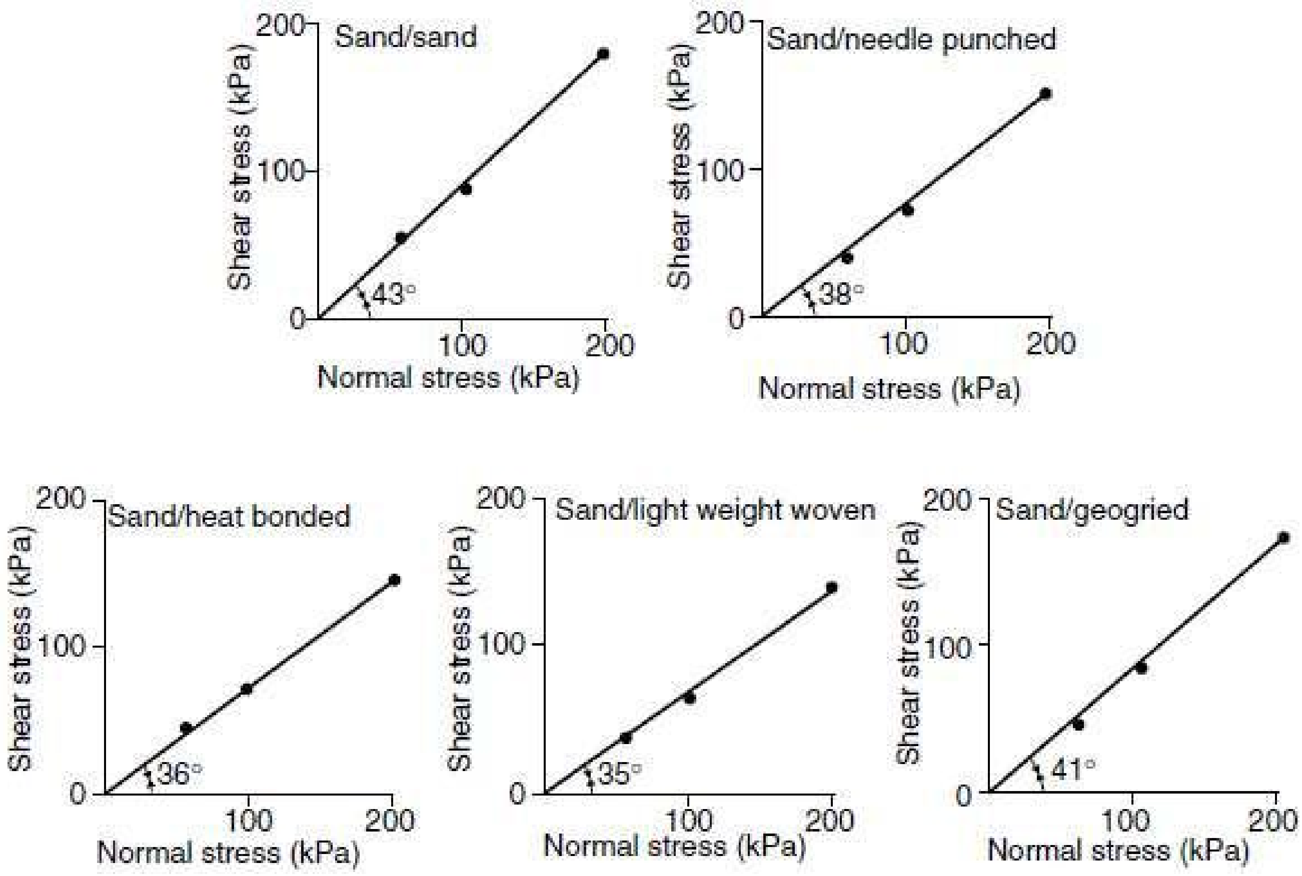
Soil–geosynthetic interface characteristics Cont...

- In many applications, it is used to determine the bond length of the geosynthetic needed beyond the critical zone.
- The limiting values of shear stresses, typically of the peak and residual shear stresses, are plotted against their corresponding values of the applied normal stress.
- The test value may be a function of the applied normal stress, geosynthetic material characteristics, soil gradation, soil plasticity, density, moisture content, size of specimen, drainage conditions, displacement rate, magnitude of displacement and other parameters.

SOIL–GEOSYNTHETIC INTERFACE CHARACTERISTICS *CONT…*

- The direct shear test data can be used in the design of geosynthetic applications in which sliding may occur between the soil and the geosynthetic.
- the direct shear test can also be conducted to study the geosynthetic–geosynthetic interface frictional behaviour.

Typical Results of Direct Shear Test

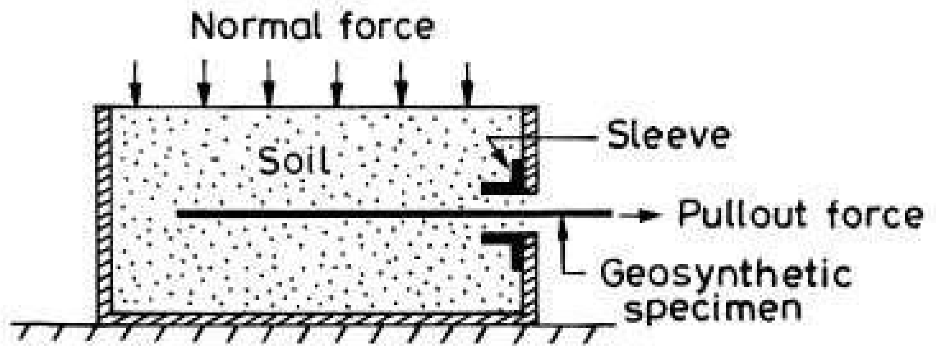


Typical results from direct shear test [Reprinted, with permission, from BS 6906: Part 8 (1991), *Determination of sand–geotextile frictional behaviour by direct*

PULL OUT TEST

- The direct shear test is not suited for the development of exact stress–strain relationships for the test specimen due to the non-uniform distribution of shearing forces and displacement.
- Total resistance may be a combination of sliding, rolling, interlocking of soil particles and geosynthetic surfaces, and shear strain within the geosynthetic specimen.
- Shearing resistance may be different on the two faces of a geosynthetic and may vary with direction of shearing relative to orientation of the geosynthetic

PULL OUT TEST



Details of pullout test.

- *Pullout test:*
- *a geosynthetic specimen, embedded between two layers of soil in a* rigid box.
- Subjected to a horizontal force.
- The normal stress applied to the upper layer of soil constant and uniform.

PULLOUT RESISTANCE

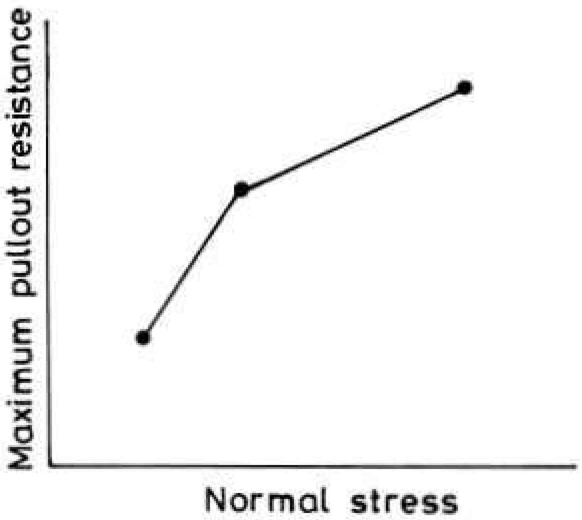
pullout capacity formula

- The ultimate pullout resistance, *P, of the geosynthetic reinforcement* =

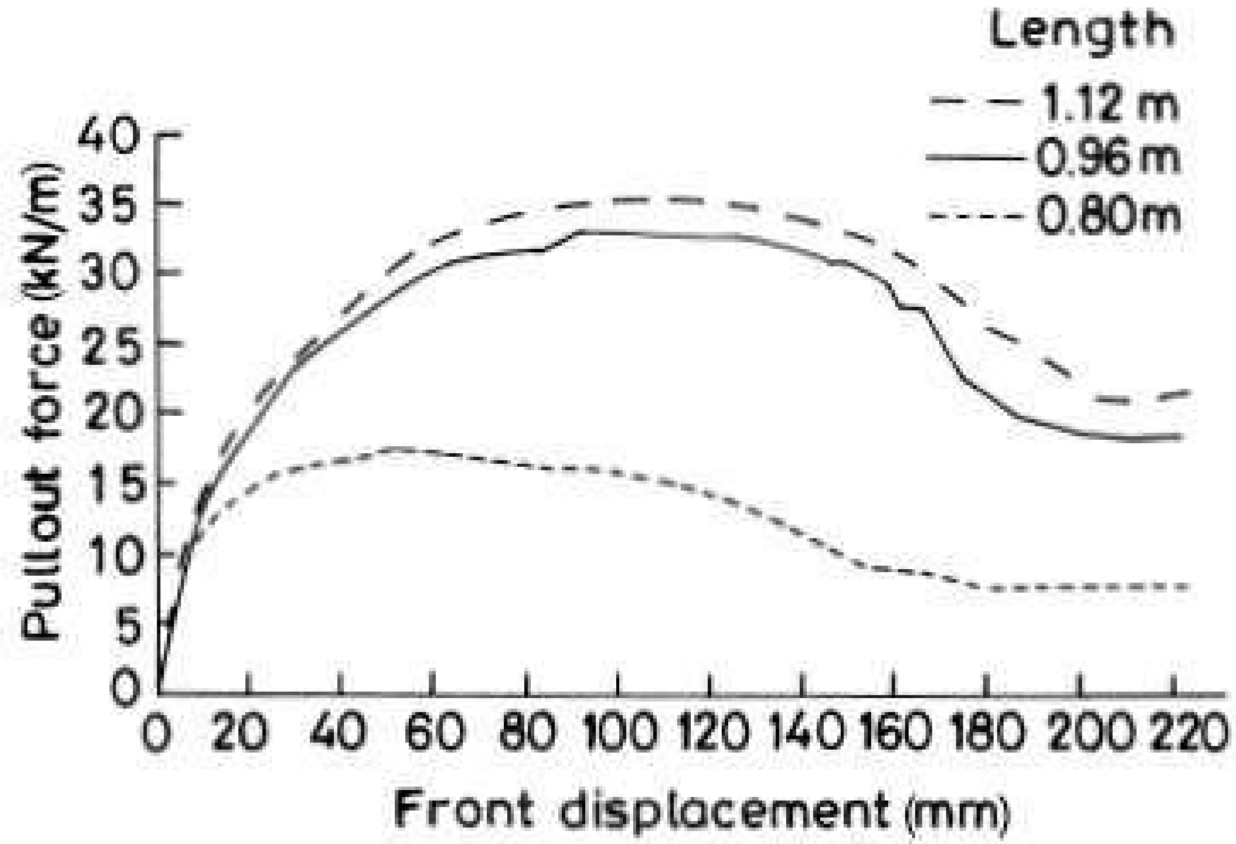
$$P = 2 \times L_e \times W \times \sigma'_n \times C_i \times F$$

- *Le* = embedment length of the test specimen.
- *W* = width of the test specimen.
- σ_n' = effective normal stress at the soil–test specimen interfaces
- C_i = coefficient of interaction (a scale effect correction factor) depending on the geosynthetic type, soil type and normal load applied
- *F* = pullout resistance (or friction bearing interaction) factor.

- The pullout resistance versus normal stress plot is a function of :
- Soil gradation.
- Plasticity, as-placed dry unit weight,
- Moisture content.
- Embedment length and surface characteristics of the geosynthetic.
- Displacement rate.
- Normal stress and other test parameters.



INFLUENCE OF THE SPECIMEN EMBEDMENT LENGTH ON THE PULLOUT BEHAVIOUR OF A GEOGRID (AFTER LOPES AND LADEIRA, 1996).



HYDRAULIC PROPERTIES OF GEOTEXTILES

Porosity, permittivity and transmissivity

Geosynthetic pore (or opening) characteristics

- The voids (or holes) in a geosynthetic are called pores or openings.
- The measurement of sizes of pores and the study of their distribution is known as *porometry.*

GEOSYNTHETIC POROSITY

- It is related to the ability of the geosynthetic to allow fluid to flow through it.
- GT Porosity = $\frac{\text{Void volume (volume of void spaces)}}{\text{Total volume of the geosynthetic}}$
- expressed as a percentage.

$$\eta = \frac{V_v}{V} = \frac{V - V_s}{V} = 1 - \frac{V_s}{V} = 1 - \frac{\frac{mA}{\rho_s}}{A\Delta x} = 1 - \frac{m}{\rho_s \Delta x}$$

- η= porosity
- m= Mass per unit area, k*g/m*^{2}
- ρ_{s}= Density of polymer solid, kg/m^3.
- Δx= Thickness (mm)
- A= Surface area of geotextile

Percent Open Area

- Applicable only for woven monofilament Geotextiles.
- POA Ranges between: 0% to 36%.

PERMEABILITY CHARACTERISTICS

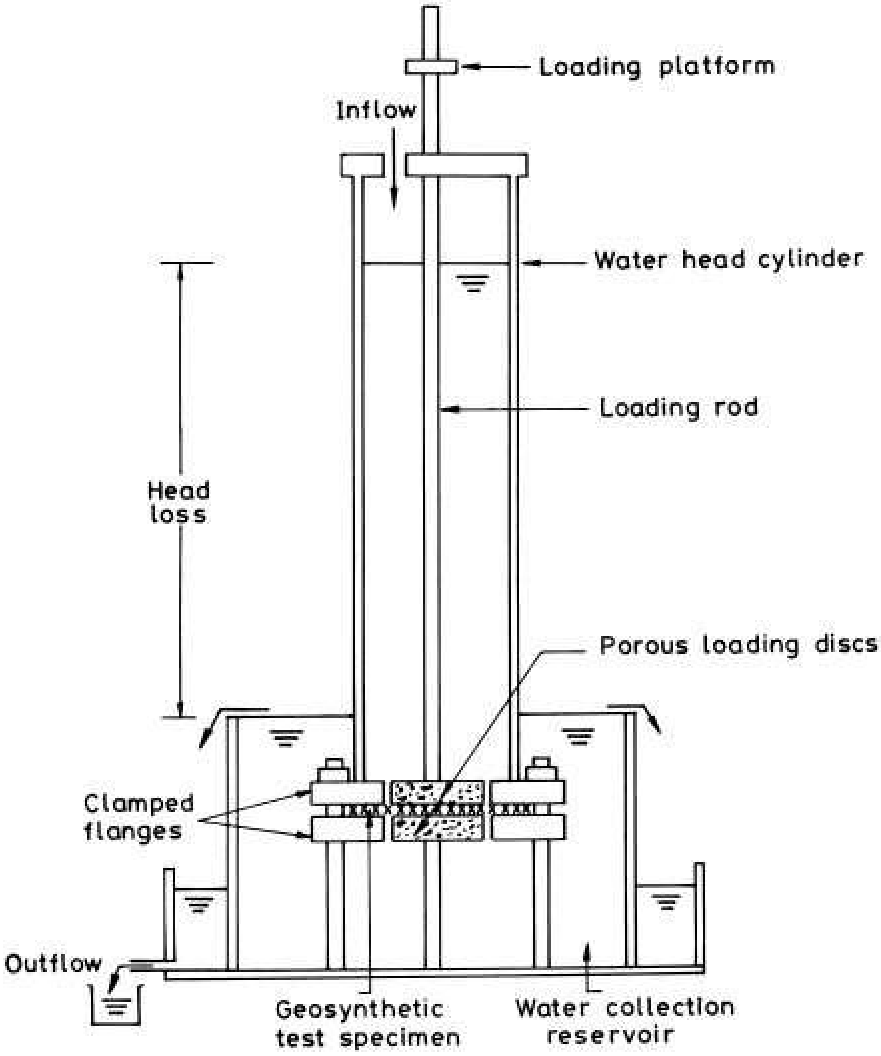
- The ability of a geosynthetic to transmit a fluid is called *permeability*..

- The simplest method of describing the permeability characteristics of geosynthetics is in terms of volume flow rate at a specific constant water head (generally 10 cm).

- The advantage of this method is that it is the simplest test to carry out, it does not rely on Darcy's law for its authenticity, and

- It can easily be used to compare different geosynthetics used for drainage and filtration applications.

A TYPICAL TEST ARRANGEMENT OF CONSTANT HEAD CROSS-PLANE WATER FLOW APPARATUS



PERMITTIVITY MEASUREMENT

- Permittivity may be defined as the volumetric flow rate of water per unit cross-sectional area of the geosynthetic per unit head, under laminar conditions of flow in a direction normal to the plane of the geosynthetic

- This property is the preferred measure of water flow capacity across the geosynthetic plane and quite useful in filter applications.

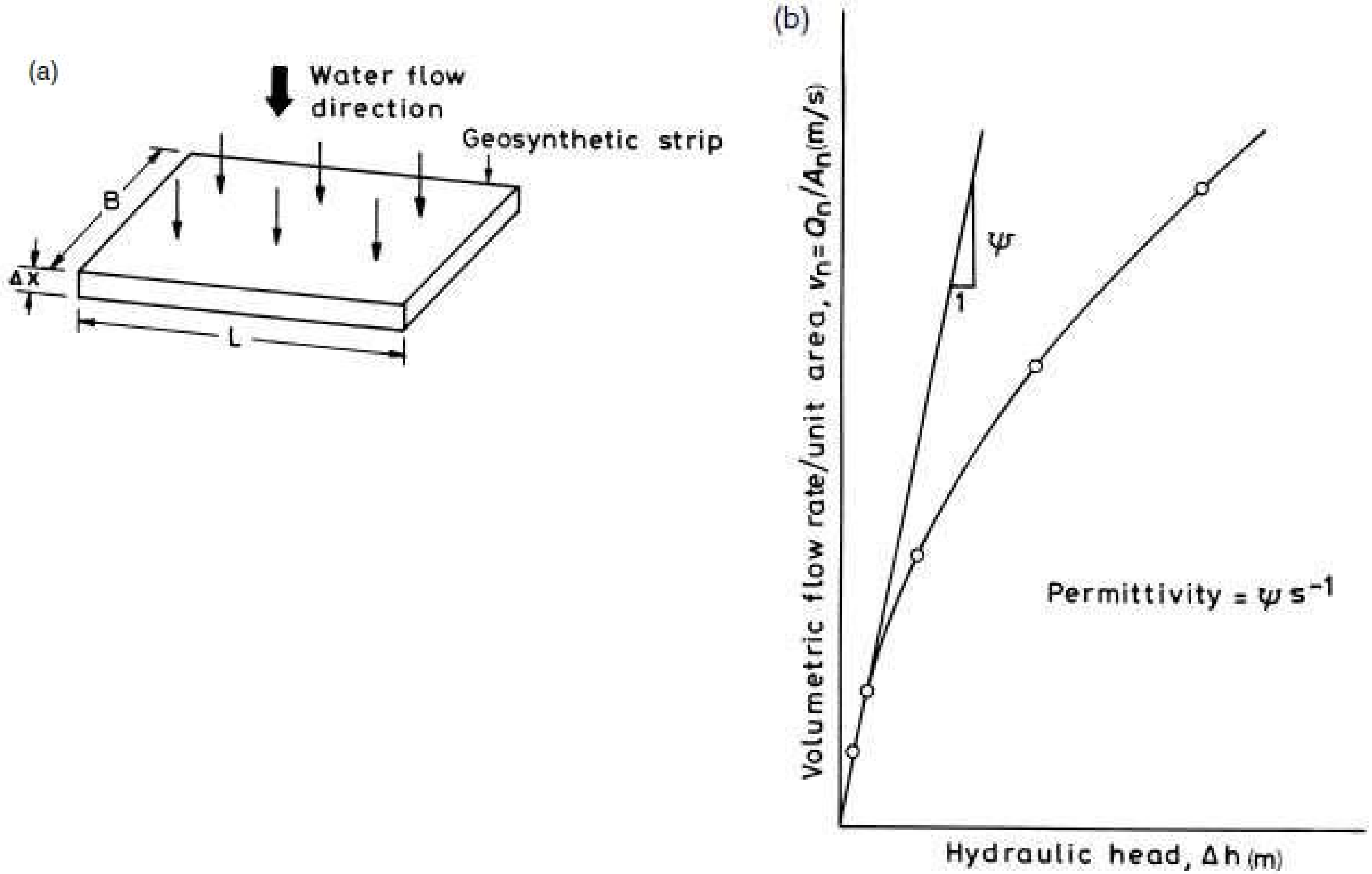
PERMITTIVITY : CROSS-PLANE PERMEABILITY

$$Q_n = k_n \frac{\Delta h}{\Delta x}(LB) = \psi \, \Delta h \, A_n$$

- Where:
- *Q_n is the cross-plane volumetric flow rate of water, in m^3/s; that is, the volumetric* flow rate of water for flow across the plane of the geosynthetic;
- k_n *is the coefficient* of cross-plane permeability, in m/s;
- *Δh is the hydraulic head causing flow, in m;*
- Δx is the thickness of the strip of geosynthetic measured along the flow direction under a specified normal stress, in m;
- *L is the length of the strip of geosynthetic, in m;*
- *B is the width of the strip of geosynthetic, in m;*

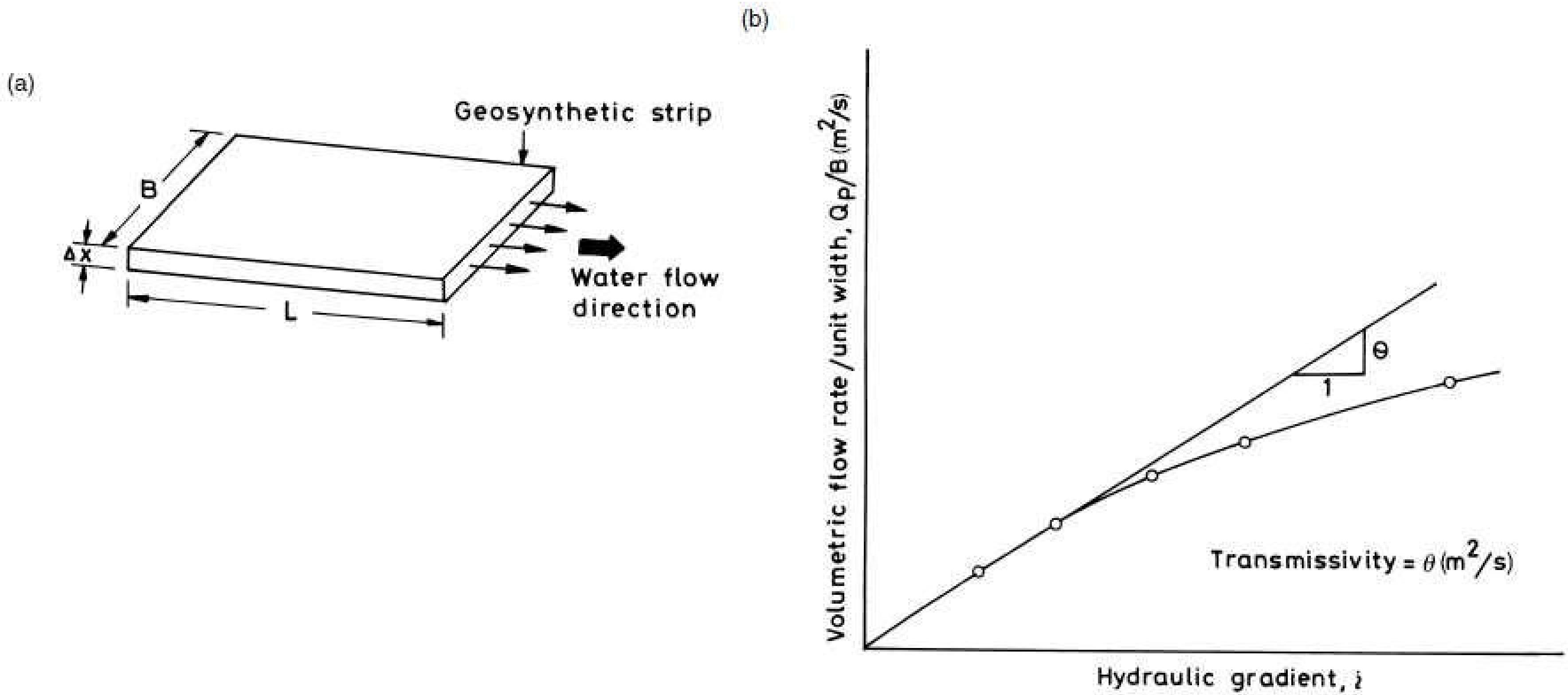
- $\Psi = k_n/\Delta x$, *which is the permittivity* of the geosynthetic, in
- *LB is the area of cross-section of geosynthetic* for cross-plane flow, in m^2.

PERMITTIVITY



Geosynthetic permittivity: (a) normal flow of water through a geosynthetic strip; (b) definition

TRANSMISSIVITY: IN PLANE PERMEABILITY



Geosynthetic transmissivity: (a) in-plane flow of water through a geosynthetic

- Transmissivity may thus be defined as the volumetric flow rate of water per unit width of the geosynthetic per unit hydraulic gradient, under laminar conditions of flow within the plane of the geosynthetic.
- This property is the preferred measure of the in-plane water flow capacity of a geosynthetic and widely used in drainage applications.

Endurance and degradation properties

CREEP

- *Creep is the time-dependent increase in accumulative strain or elongation in a* geosynthetic resulting from an applied constant load.
- test for determining the creep behaviour of a geosynthetic.
- 200 mm wide specimen.
- load applied using weights, or mechanical, hydraulic or pneumatic systems.
- test duration : 100 h.
- for a full analysis of creep properties, durations of 10,000 h will be necessary.

Creep for Design Considerations:

- Drainage applications.
- Containment applications.
- At higher loads, creep leads ultimately to *stress rupture, also known as creep rupture or static fatigue.*
- The higher the applied load, the shorter the time to rupture.
- creep data should not be extrapolated beyond one order of magnitude

Abrasion

- *Abrasion of a geosynthetic is defined as the wearing away of any part of it* by rubbing against a stationary platform by an abradant with specified surface characteristics.

- The ability of a geosynthetic to resist wear due to friction or rubbing is called *abrasion resistance.*

Long-term flow characteristics or Long-term flow capability

- The compatibility between the pore size openings of a geotextile and retained soil particles in filtration and/or drainage applications can be assessed by the ***gradient ratio test***.
- This test is basically used to evaluate the clogging resistance of geotextiles with **cohesionless soils** (having a hydraulic conductivity/permeability greater than 5 x10^{-4} m/s) under unidirectional flow conditions.

$$HCR = \frac{K_{sg}}{K_{sgo}}$$

- where
- k_{sg} *is the hydraulic conductivity of the soil–geotextile system at any time during the* test, and
- k_{sgo} *is the initial hydraulic conductivity of the soil–geotextile system measured at* the beginning of the test

- **HCR** value indicates the performance of geotextile as a filter when used with a particular **cohesive soil.**

DURABILITY

- The *durability of a geosynthetic may be regarded as its ability to maintain* requisite properties against environmental or other influences over the selected design life.

Thank You