Geosynthetic Materials and its Properties for Reinforced Earth Structures

Vashi, Jigisha M.[1]
[1]*Research Scholar, AMD, SVNIT, Surat-395007, Email: vashi.jigisha@gmail.com*
Desai, M.D.[2]
[2] *Visiting Professor, SMFE, AMD, SVNIT, Surat-395007, Email:* earthmdd@yahoo.co.in
Desai, A.K.[3]
[3]*Associate Professor, AMD, SVNIT, Surat-395007, Email: akd@amd.svnit.ac.in*
Solanki, C.H.[4]
[4] *Associate Professor, AMD, SVNIT, Surat-395007, Email: chandresh1968@yahoo.co.in*

Abstract: The national planners have put infrastructures development on priority. This has resulted in transport planning widening of National Highway and new roads in country. Thus work of Retaining Earth (RE) structures/ slopes will be going to design in very large numbers over different areas. The availability of backfill material compatible with geosynthetics reinforcements and economy in both has been topic for R & D. The conventional reinforcement with facial block element based on BS 8006:1995 was reviewed in brief. Then the options for alternative fill materials such as wastes soil and Ash with modern woven geofabrics of different raw materials are explained in general. The work in progress, primafaci suggest studies to adopt polyester woven fabric with better strength with creep consideration, UV stability, permeability control, economy and easy of construction. Overall effect is to evolve appropriate code of practice for design and construction in areas having CH (high plastic clay) soil, waste material for site where land is economically easily available.

Introduction:

Because of the good engineering performances, a large number of reinforced earth retaining walls have been constructed throughout the world. Compared with the traditional gravity earth retaining walls, geosynthetics reinforced earth retaining walls have the better engineering characteristics of light deadweight, beautiful shape, construction convenience etc. Especially on the soft ground, the better performances would be embodied in virtue of their light deadweight. Filling material's performances and interface friction properties with the geosynthetics directly influenced the application performances of the geosynthetics reinforced earth retaining walls. As the filling material of geosynthetics reinforced earth retaining walls, it should have the following engineering properties: good mechanical properties which include the strength and rigidity; better interface friction property with the geosynthetics; & the material had better be lightweight.

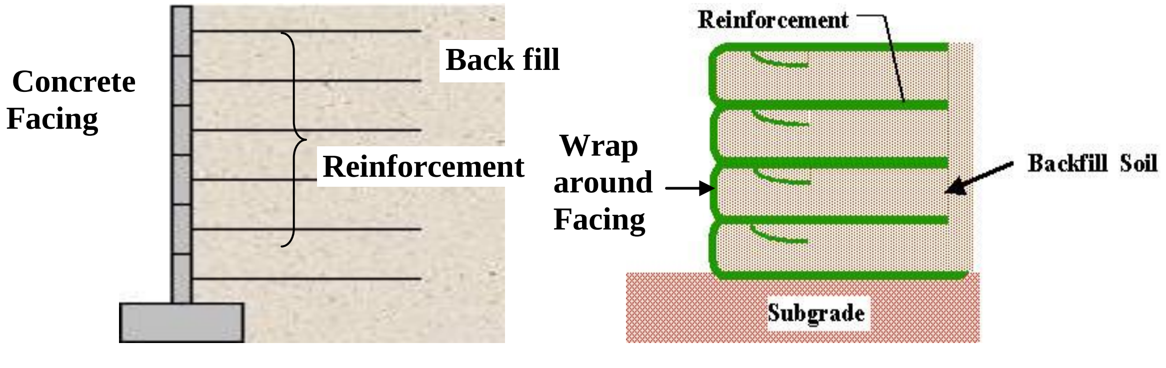

Fig: 1. Concept of Reinforced Retaining walls

Road map to 2022, estimates Rs 3 lakh cr, targets 44 express highways (18,637 Km) across variable soil sub-grade over country. For Rs 20 cr per Km, approximately 2 cr will be spent for flyover/underpass involving Earth Structures (RE Wall etc). Thus there is a huge possibility of RE wall being constructed for every 2 Km of 6-4 lane road of NH, State Highway where there is a need of large fill/backfill quantity of sand is required, as standards specification of sand as backfill specified by BS 8006:1995. But in future sand is not likely to be a source forever, so there is a need for use of local waste/fill materials as backfill that to compatible with modern and novel geofabrics. The detail study of effect of properties of geoynthetics material with alternative backfill materials, ease of construction with economy evolved is needed. The field instrumented observations for such structures to derive code of practice is recommended.

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. It can be thought of as relating to changes over time of both the polymer microstructure and the geosynthetic macrostructure. The former involves molecular polymer changes and the later assesses geosynthetic bulk property changes. The durability of a geosynthetic is dependent to a great extent upon the composition of the polymers from which it is made. To quantify the properties of polymers, knowledge of their structures at the chemical, molecular and supermolecular level is necessary, which was described by Cassidy et al. (1992). The durability of geosynthetics can be assessed by visual examination or microscopic examination with a specified magnification factor to give a qualitative prediction of differences between the exposed and unexposed specimens, for example, dis-colourations, damage to the individual fibres (due to chemical or microbiological attack, surface degradation, or environmental stress cracking), etc. It is traditionally assessed on the basis of mechanical property test results and not on the micro-structural changes that cause the changes in the mechanical properties.

The effects of a given application environment on the durability of a geosynthetic must be determined through appropriate testing. Selection of appropriate tests for durability assessment requires consideration of design parameters and determination of the primary function(s) and/or performance characteristics of the geosynthetic in the specific field application and the associated degradation processes caused by the application environment. Note that the physical structure of the geosynthetic, the type of the polymer used, the manufacturing process, the application environment, the conditions of storage and installation and the different loads supported by the geosynthetic are all parameters that govern the durability of the geosynthetic.

Review of Practice of RE Structures:

Normal practice for the preliminary design of Reinforced Earth structures are explained by Hausmann, M.R., 1990, BS: 8006-1995, Holtz, R. D et al., 1997, & Swami Saran, 2005. The percentage of fines (< 0.08mm) in the backfill is < 15%. Backfill compacted to 95 % of Maximum dry density and OMC. Free-draining backfill & Soil reinforcement friction factor tan δ not < 0.3 (say $\delta = 17°$). The soils with appreciable fines (silt and clays) are not recommended for geosynthetic reinforced walls. For temporary walls, the only backfill chemical requirements specified are as follows: soil pH shall be between 3 and 11, and soil resistivity shall be >1,000 ohm-cm. For some soil environment posing potential concern when using geosynthetics. Soil with pH $\geq$ 12 or pH $\leq$ 3 should not be used in reinforced wall.

Geosynthetic selection:

Several hundred varieties of geosynthetic products are available in the market and many new types are developed each year. In addition to the five types identified as geotextile, geogrids, geomembranes, geonets, and geocomposites, there are specialty products, such as geomettresses, geocells, geotubes and many more that have been developed for specific applications. Even within each group of geosynthetics, a designer will find a wide variety of materials. This enormous choice can often be quite bewildering for the designer. To help in decision making, regulatory authorities in most countries have laid down minimum specification with respect to the properties that have to be satisfied by the products for different applications. General ranges of some specific properties of commercially available geosynthetics are shown in Table: 1.

Table: 1. Range of Value for Some Properties of Geosynthetics (Lawson And Kempton (1995))

Types	Thickness (mm)	Mass per unit area (gsm)	Ultimate max. Tensile strength (kN/m)	Extension at max. load (%)	Apparent opening size (mm)
Non woven-Geotextiles	0.25 – 0.75	100 - 2000	5 – 100	20 – 100	0.02 – 0.6
Woven - Geotextiles	0.25 – 3	100 – 1500	20 – 400	10 – 50	0.05 – 2
Geomembranes	0.25 – 3	250 – 3000	10 – 50	50 – 200 +	≈ 0
Geogrids	5 – 15	200 – 1500	10 – 200	5 – 25	10 - 100
Geonets	3 – 10	100 - 1000	-	-	5 – 15

Good geosynthetic specifications are essential for the success of any project. Due to a wide range of applications and the tremendous variety of geosynthetics available, the selection for a particular geosynthetic with specific properties is a critical decision. The selection of a geosynthetic is generally done keeping in view the general objective of its use. For example, if the selected geosynthetic is being used to function as reinforcement, it will have to increase the stability of soil (bearing capacity, slope stability and resistance to erosion) and to reduce its deformation (settlement and lateral deformation). In order to provide stability, the geosynthetic has to have adequate strength; and to control deformation; it has to have suitable force-elongation characteristics, measured in terms of modulus (the slope of the stress versus elongation curve). Woven geotextiles and geogrids are preferred in most reinforcement applications in practice.

Raw Materials:

Almost exclusively, the raw materials from which geosynthetics are produced are polymeric. Polymers are materials of very high molecular weight and are found to have multifarious applications in the present society. The polymers used to manufacture geosynthetics are generally thermoplastics, which may be amorphous or semi-crystalline. Such materials melt on heating and solidify on cooling. The heating and cooling cycles can be applied several times without affecting the properties.

Molecular weight can affect physical and mechanical properties, heat resistance and durability (resistance to chemical and biological attack) properties of geosynthetics. The physical and

mechanical properties of the polymers are also influenced by the bonds within and between chains, the chain branching and the degree of crystallinity. An increase in the degree of crystallinity leads directly to an increase in rigidity, tensile strength, hardness, and softening point and to a decrease in chemical permeability.
If the polymer is stretched in the melt, or in solid form above its final operating temperature, the molecular chains become aligned in the direction of stretch. This alignment, or molecular orientation, can be permanent if, still under stress, the material is cooled to its operating temperature. The more commonly used types are polypropylene (PP), high density polyethylene (HDPE) and polyester (polyethylene terephthalate (PET)), Polyamide (PA) etc. Most of the geotextiles are manufactured from PP or PET.

The primary reason for PP usage in geotextile manufacturing is its low cost. For non-critical structures, PP provides an excellent, cost-effective raw material. It exhibits a second advantage in that it has excellent chemical and pH range resistance because of its semi crystalline structure. Additives and stabilizers (such as carbon black) must be added to give PP ultraviolet (UV) light resistance during processing. As the critical nature of the structure increases, or the long-term anticipated loads go up, PP tends to lose its effectiveness. This is because of relatively poor creep deformation characteristics under long-term sustained load. Polyester is increasingly being used to manufacture reinforcing geosynthetics such as geogrids because of high strength and resistance to creep. Chemical resistance of polyester is generally excellent, with the exception of very high pH environments. It is inherently stable to UV light.

There are several environmental factors that affect the durability of polymers. Ultraviolet component of solar radiation, heat and oxygen, and humidity are the factors above ground that may lead to degradation. Below ground the main factors affecting the durability of polymers are soil particle size and angularity, acidity/alkalinity, heavy metal ions, presence of oxygen, moisture content, organic content and temperature.

The formulation of a polymeric material is a complex task. No geosynthetic material is 100% of the polymer resin associated with its name, because pure polymers are not suitable for production of geosynthetics. The primary resins are always formulated with additives, fillers, and/or other agents as UV light absorbers, antioxidants, thermal stabilizers, etc. To produce a plastic with the required properties. For example, PE, PET and PA have 97% resin, 2–3% carbon black (or pigment), and 0.5–1.0% other additives.

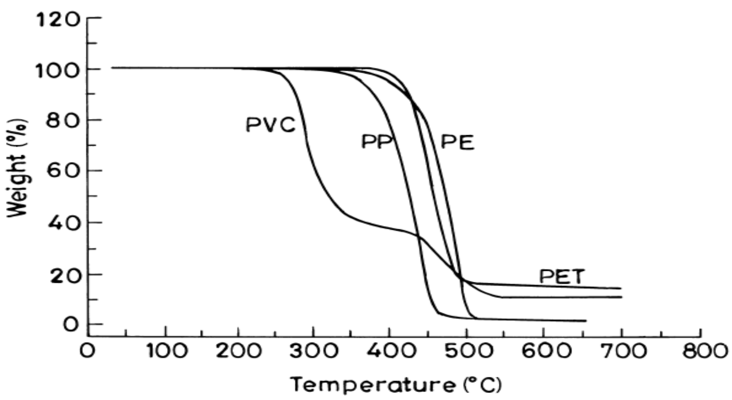

Fig.2: Effect of Temperature on Some Geosynthetic Polymers (After Thomas & verschoor, 1998)

Table: 2. Properties of Polymers Used for the Manufacture of Geosynthetics

Polymer	Specific gravity	Melting Temperature (°C)	Tensile Strength at 20°C (MN/m^2)	Modulus of Elasticity (MN/m^2)	Strain at Break (%)
PP	0.90–0.91	165	400–600	2000–5000	10–40
PET	1.22–1.38	260	800–1200	12,000–18,000	8–15
PE	0.91–0.96	130	80–600	200–6000	10–80

The Basic Properties of Geotextile:

The performance of soil under a given set of conditions is determined by first evaluating the properties of soil-both physical and engineering-and then by analysis for the imposed conditions. Similarly, we also have to determine the properties of geosynthetics before we can assess their suitability to perform a set of functions. However, for geosynthetics the numbers of relevant properties that have to be determined are much larger. These properties can broadly be grouped under six types as listed in Table 3. The table also lists the parameters that have to be evaluated for each of six types:

Physical and chemical properties help us understand the nature and type of geosynthetics. Mechanical properties quantify the strength and deformation behaviour of geosynthetic and are used to assess whether the geosynthetic will perform satisfactorily under the imposed load without yielding, tearing, puncturing and without slipping at the geosynthetic-soil interface. Hydraulic properties help in identifying the quantity of water that can flow through the geosynthetic in the cross plane and in plane directions. Endurance properties relate to construction survivability and the creep behaviour of geosynthetics. The latter is important to study to avoid long term movement of the soil-geosynthetics system. The former is important because during installation the geosynthetics suffers stresses that are peculiar to the installation process and arise from the passage of construction labour or equipment over the geosynthetics due to object falling on it. These stresses often call for greater strength than that required for performance of its primary function. Degradation properties focus on change in properties with time. For example, exposure to ultra-violate rays in sunlight or oxidation with time and this would affect its performance.

Table: 3. Parameters that Indicate the Properties of Geosynthetics

Type of property	**Parameters**
Physical	Thickness, specific gravity, mass per unit area, porosity, apparent opening size.
Chemical	Polymer type, filler material, carbon black percentage, plasticizer and additive details, manufacturing process for fiber and geosynthetics.
Mechanical	Tensile strength, compressibility, elongation, tear/impact/ puncture resistance, burst strength, seam strength, fatigue resistance, interface friction with soil, anchorage in soil.
Hydraulic	Permittivity (cross-plane permeability), transmissivity (in-plane permeability), clogging potential.
Endurance	Installation damage potential - tear/impact/puncture resistance, abrasion resistance, creep
Degradation	Resistance to ultra-violet radiation, temperature, oxidation, aging, chemical and biological reactions.

From the engineering point of view, the durability of geosynthetics is studied as construction survivability and longevity. Construction survivability addresses the geosynthetics survival during installation. Geosynthetics may suffer mechanical damage (e.g. abrasion, cuts or holes) during installation due to placement and compaction of the overlying fill. In some cases, the installation stresses might be more severe than the actual design stresses for which the geosynthetic is intended. The susceptibility of some geosynthetics to mechanical damage during installation can increase under frost conditions. The severity of the damage increases with the coarseness and angularity of the fill in contact with the geosynthetic and with the applied compactive effort, and it generally decreases with the increasing thickness of the geosynthetic. This damage may reduce the mechanical strength of the geosynthetic, and when holes are present it will affect the hydraulic properties as well.

For the design of reinforced earth retaining structures, the most important properties emphasize are tensile strength of geosynthetics, Soil–geosynthetic interface characteristics, creep of geosynthetics, UV stability and permeability criteria and this are discussed here in brief.

The **tensile strength** is the maximum resistance to deformation developed for a geosynthetic when it is subjected to tension by an external force. Tensile strength is usually determined by the wide-width strip tensile test on a 200-mm wide geosynthetic strip with a gauge length of 100 mm (Fig. 3). The 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). During the extension process, both load and deformations are measured. The width of the specimen is kept greater than its length, as some geosynthetics have a tendency to contract (‘neck down’) under load in the gauge length area. The tensile properties depend on the geosynthetic polymer and manufacturing process leading to the structure of the finished product.

The measured strength and the rupture strain are a function of many test variables, including sample geometry, gripping method, strain rate, temperature, initial preload, conditioning and the amount of any normal confinement applied to the geosynthetic. Fig. 4 shows the influence of the geotextile specimen width on the tensile strength (After Myles and Carswell, 1986).

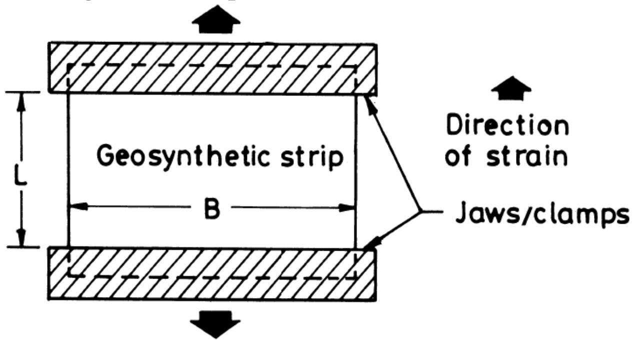

Fig. 3: Wide-Width Strip Tensile Tests

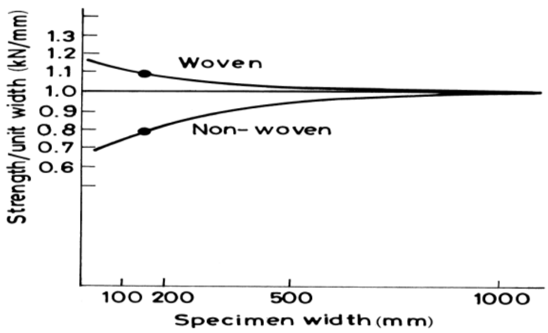

Fig. 4: Influence of geotextile Specimen Width on Its Tensile Strength

The actual temperature has a great influence on the strength properties of many polymers (Fig. 5). For a given geosynthetic, the tensile strength is also a function of the rate of strain at which the specimen is tested. At a low strain rate, the measured strength tends to be lower and occurs at a higher failure strain. Conversely, at a high strain rate, the measured strength tends to be higher and occurs at a lower failure strain.

Soil–geosynthetic Interface Characteristics:

When a geosynthetic is used in reinforcing a soil mass, 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. 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. It is mainly responsible for the transference of stresses from the soil to the geosynthetic. In many applications, it is used to determine the bond length of the geosynthetic needed beyond the critical zone. Two test procedures, currently used to evaluate soil–geosynthetic interaction, are the direct shear test, using a shear box, and the pullout (anchorage) test. The basic principle of these tests is that to move a solid object, of weight W, along a horizontal plane, requires the application of a horizontal force of µW, where µ is the coefficient of friction between the material of the object and the material of the plane.

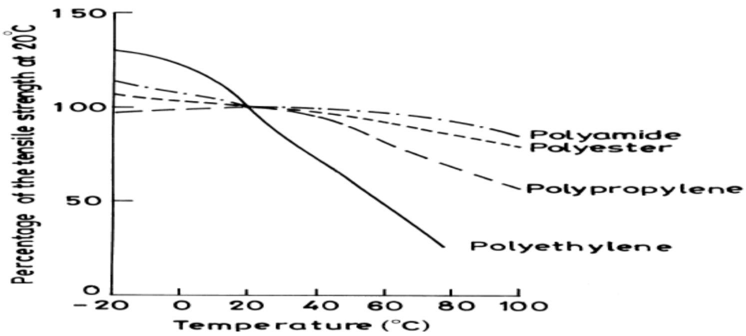

Fig.5: Influence of temperature on the tensile strength of some polymers (After Van Santvoort, 1995).

In direct shear test, the shear resistance between a geosynthetic and a soil is determined by placing the geosynthetic and soil within a direct shear box, about 300 mm square in plan, divided into upper and lower halves. The geosynthetic specimen is anchored along the edge of the box where the shear force is applied. A constant normal force representative of design stresses is applied to the box, and keeping the lower half of the box fixed, the upper half is subjected to a shear force, under a constant rate of deformation. The shear force is recorded as a function of the horizontal displacement of the upper half of the shear box. The test is performed at a minimum of three different normal compressive stresses, selected to model appropriate field conditions. 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. (Fig.6)

It should be noted that 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. 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. Note that the direct shear test can also be conducted to study the geosynthetic–geosynthetic interface frictional behaviour by placing the lower geosynthetic specimen flat over a rigid medium in the lower half of the direct shear box and the upper geosynthetic specimen over the previously placed lower specimen.

In the pullout test, a geosynthetic specimen, embedded between two layers of soil in a rigid box, is subjected to a horizontal force, keeping the normal stress applied to the upper layer of soil constant and uniform. Fig. 7 depicts the general test arrangement of the pullout test. The force required to pull the geosynthetic out of the soil is recorded. Pullout resistance is calculated by dividing the maximum load by the test specimen width. The ultimate pullout resistance, P, of the geosynthetic reinforcement is given by,

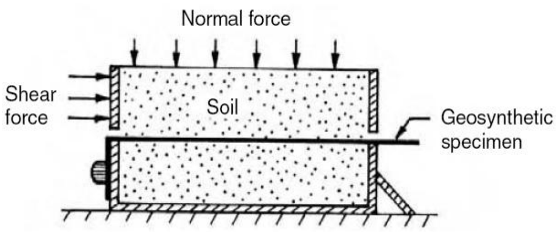

Fig.6: Details of Direct Shear Test

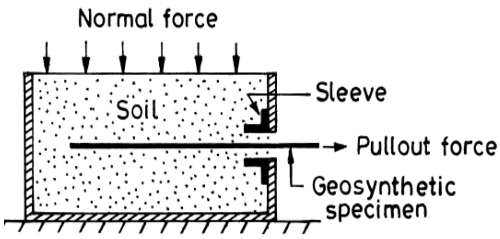

Fig.7: Details of Pullout Test

$P = 2 \times L_e \times W \times \sigma'_n \times C_i \times F$ ....Eq.(1)

This equation is known as pullout capacity formula. Where, L_e is the embedment length of the test specimen; W is the width of the test specimen, σ'_n is the effective normal stress at the soil–test specimen interfaces; C_i is the coefficient of interaction (a scale effect correction factor) depending on the geosynthetic type, soil type and normal load applied; and F is the pullout resistance (or friction bearing interaction) factor. For preliminary design or in the absence of specific geosynthetic test data, F may be conservatively taken as $F = (2/3) \tan\phi$ for geotextiles and $F = 0.8 \tan\phi$ for geogrids.

Porosity, permittivity and transmissivity are the most important **hydraulic properties** of geosynthetics, mainly of geotextiles, geonets and many drainage geocomposites, which are commonly used in filtration and drainage applications. Geosynthetic porosity is related to the ability of the geosynthetic to allow fluid to flow through it and is defined as the ratio of the void volume (volume of void spaces) to the total volume of the geosynthetic, usually expressed as a percentage.

Permittivity of a geosynthetic (generally geotextile) is simply the coefficient of permeability for water flow normal to its plane divided by its thickness. This property is the preferred measure of water flow capacity across the geosynthetic plane and quite useful in filter applications. **Transmissivity** of a geosynthetic (thick nonwoven geotextile, geonet, or geocomposite) is simply the product of the coefficient of permeability for in-plane water flow and its thickness. This property is the preferred measure of the in-plane water flow capacity of a geosynthetic and widely used in drainage applications.

Creep is the time-dependent increase in accumulative strain or elongation in a geosynthetic resulting from an applied constant load. Depending on the type of polymer and ambient temperature, creep may be significant at stress levels as low as 20% of the ultimate tensile strength. In the test for determining the creep behaviour of a geosynthetic, the specimen of wide-width variety (say, 200 mm wide) is subjected to a sustained load using weights, or mechanical, hydraulic or pneumatic systems, in one step while maintaining constant ambient conditions of temperature and humidity. The longitudinal extensions/ strains are recorded continuously or are measured at specified time intervals. Unless otherwise specified, the duration of testing is generally not less than 10,000 h, or to failure if this occurs in a shorter time. A test duration of 100 h is useful for monitoring of products, but for a full analysis of creep properties, durations of up to 10,000 h will be necessary. The percent strain versus log of time is plotted for each stress increment to calculate the creep rate, defined as the slope of the creep–time curve at a given time. Fig.8 compares strain versus time behaviour of various yarns of different polymers. As shown, both the total strain and the rate of strain differ markedly. Creep is an important factor in the design and performance of some geosynthetic reinforced structures, such as retaining walls, steep-sided slopes, embankments over weak foundations, etc. In all these applications, geosynthetic reinforcements may be required to endure exposure to high tensile stresses for long periods of time – typically 75-plus years.

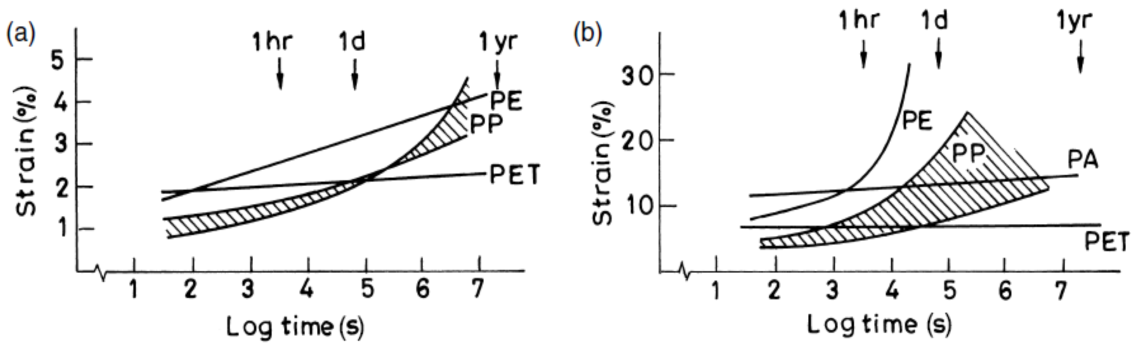

Fig: 8. Results of Creep Tests on Various yarns of Different Polymers: (a) Creep at 20% Load; (b) Creep at 60% Load (After den Hoedt, 1986)

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. Thus the design load will itself limit the lifetime of the geosynthetic. It is required to reduce the geosynthetic strength by a factor of safety corresponding to the specific polymer type to obtain the allowable load. Values of factor of safety are given in Table: 4. Although not as technically accurate as the previous method, this approach is sometimes the only one available to the designer.

Table: 4. Factors of Safety (After den Hoedt, 1986)

Polymers	Factor of Safety
Polypropylene	4.0
Polyester	2.0

It must be noted that creep is more pronounced in PE and PP than it is in polyester (Polyethylene terephthalate (PET)).

Since polymers are visco-elastic materials, strain rate and temperature are important while testing geosynthetics (Andrawes et al., 1986). When a low strain is applied in a wide-width tensile test, the geosynthetic sample takes longer to come to failure and, therefore, the creep strain is greater. High rates of strain (which can be as much as 100% per minute) tend to produce lower failure strains and sometimes yield higher strengths than the strengths caused by low rates of strain. Creep rate of geosynthetics depends on temperature. Higher creep rates are associated with higher temperatures resulting in larger strains of geosynthetics to rupture. The rate of creep is also related to the level of load to which the polymer is subjected (Greenwood and Myles, 1986; Mikki et al., 1990). Chang et al. (1996) reported that under the same confining pressure on geotextiles, the amount of creep increases as the creep load rises; and where the creep load is the same, the increases in confining pressure decrease the amount of creep, which may even be reduced to nil. The results from the creep tests under unconfined environment are conservative with regard to the behaviour of the material in service.

Conclusions:

Looking at the present scenario of rapid infrastructural development, availability and usage of purely cohesionless backfill is rarely possible at all site conditions. The economy & feasibility in usage of property specified soil, by-products of industry including fly ash, and other for backfill, being still at a growing stage, & requires through R & D for better understanding and its optimum utilization for the massive infrastructural projects in India.

The material specification laid down in terms of grading is secondary for mixed and cohesive soils used as fills, with proper compaction at 2% < OMC. By-product of industry available abundantly in major part of our country can be blended, compacted and stabilized with cohesive expansive soils. This can satisfy the requirements of fill material in reinforced walls, slopes with specified compaction, work as a filter material and bring about economy in construction practices.

The properties of polymer material are affected by its average molecular weight (MW) and its statistical distribution. Increasing the average MW results in increasing: tensile strength, elongation, impact strength, stress crack resistance, and heat resistance. Narrowing the molecular weight distribution results in: increased impact strength, decreased stress crack resistance, and decreased processability. Increasing crystallinity results in: increasing stiffness or hardness, increasing heat resistance, increasing tensile strength, increasing modulus, increasing chemical resistance, decreasing diffusive permeability, decreasing elongation or strain at failure, decreasing flexibility, decreasing impact strength, and decreasing stress crack resistance.

Creep is more pronounced in PE and PP than it is in polyester (Polyethylene terephthalate (PET)). So it is better to used geotextile made with PET rather than PP or PE. For the economy point of view especially for earth retaining structures, woven geotextile is performed better than geogrids with cohesive backfill.

More research is required to use of high tensile geotextile with respect to swelling and shrinkage stresses and geotextile strength over years (creep). Mere usage of Geosynthetics will not ensure good performance. Proper selection of Geosynthetics, correct design and quality assurance are essential. Hence, geotextile testing and control lab with integrity is need of time. This will enable better specifications than practice to use a reliable brand.

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Introduction to Author:

Miss. Vashi Jigisha, is right now associated with SV National Institute of Technology, Surat, as Ph.D Research Scholar since 2009. She received her M.tech degree in Soil Mechanics & Foundation Engineering from the Deemed University of Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India, in 2008, & Bachelor of Civil Engineering from the Sardar Patel University, Gujarat in 2005she has 1 year of teaching and 0.5 year of Industrial experience. She is Life time member of IGS and ISTE. Her primary areas of research include earth retaining structures, pavements, grouting technology and geosynthetics. She had published 3 National conference papers.