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6. Geotextiles

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Abstract:

Geotextiles are technical textiles a newly emerging field in civil engineering and other fields, offer great possibilities in varied areas of applications globally. Geotextiles play a noteworthy part in modern pavement design and maintenance techniques. The growth in their use worldwide for transportation applications, in particular, has been nothing short of phenomenal. Geotextiles are perfect materials for infrastructural works such as roads, harbors, and many others. They have a bright future, thanks to their multifunctional characteristics. The chapter provides an overview of various characteristics, fibers used such as natural and synthetic textile fibers, types of geotextiles, and their applications.

Keywords: *geotextiles, separators, drainage, filtration, reinforcement, woven and non-woven fabrics.*

6.1 Introduction:

Technical textiles are considered an amazing field in the range of textile science and engineering which have diverse applications in all sectors of science and engineering. The modern age is led by the versatile products of technical textiles. The technical textile can be defined, according to the Textile Terms & Definitions, published by the Textile Institute as, "textile materials and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics." Technical textiles are reported to be the fastest-growing sector of the textile industrial sector and the global technical textiles market is expected to reach USD 193.16 billion by 2022, according to a new report by Grand View Research, Inc. Global technical textile market demand was 26.58 million tons in 2014 and is expected to reach 35.47 million tons by 2022, growing at a CAGR of 3.7% from 2015 to 2022 [Horrocks, 2000 and Anonymous[1]. 2022].

The leading international trade exhibition for technical textiles, Techtextil (organized biennially since the late 1980s by Messe Frankfurt in Germany and also in Osaka, Japan), defines 12 main application areas such:

a. Agrotech (agriculture, aquaculture, horticulture, and forestry)
b. Build tech (building and construction)
c. Cloth tech (technical components of footwear and clothing)
d. Geotech (geotextiles and civil engineering)
e. Home tech (technical components of furniture, household textiles, and floor coverings)
f. Indutech (filtration, conveying, cleaning, and other industrial uses)

g. Medtech (hygiene and medical)
h. Mobitech (automobiles, shipping, railways, and aerospace)
i. Oekotech (environmental protection)
j. Packtech (packaging)
k. Protech (personal and property protection)
l. Sport-tech (sport and leisure).

Among these Geotech or geotextiles has widely used all over the world and are one the essential products for the civil and construction engineering sector.

Geosynthetics are products made of synthetic or natural polymeric materials, which are used in contact with soil or rock, and/or other geotechnical materials. Geosynthetics mainly include geotextile, geogrid, geocell, geonet, geomembrane, erosion control mat, geosynthetic clay liner, and geo-composite. Geotextiles are the most widely used geosynthetics. The word Geotextile comes from two words. The Greek word “Geo” means “Earth”, so it can be said that any textile materials used in the earth or soil for technical purposes are called geotextiles. The Textile Institute defined geotextiles in Textile Terms and Definitions as “any permeable material used in filtration, drainage, separation, reinforcement and stabilization purposes as an integral part of civil engineering structures of earth, rock, and other construction materials (Denton, M. J. & Daniels, P. N., 2002). In the last 60 years, geotextiles were widely used in geotechnical engineering. Geotextiles can be used for at least one of the following functions in geotechnical engineering: Separation, filtration, drainage, reinforcement, stabilization, barrier, and erosion protection.

6.2 Important Characteristics of Geotextiles:

The characteristics of geotextiles are broadly classified as:

A. Physical properties:

a. specific gravity
b. weight
c. thickness
d. stiffness
e. density

B. Mechanical properties:

a. tenacity
b. tensile strength
c. bursting strength
d. drapability
e. compatibility
f. flexibility
g. tearing strength
h. frictional resistance

C. Hydraulic properties:

a. porosity
b. permeability
c. permittivity
d. transitivity
e. turbidity /soil retention
f. filtration length etc.

D. Degradation properties:

a. biodegradation
b. hydrolytic degradation
c. photodegradation
d. chemical degradation
e. mechanical degradation
f. other degradation occurring due to attack of rodent, termite, etc.

E. Endurance properties:

a. elongation
b. abrasion resistance
c. clogging length and flow etc.

6.3 Selection of Fibres for Geotextiles:

Different fibers from both natural as well as a synthetic category can be used as geotextiles for various applications.

- **Natural fibers:** Natural fibers in the form of paper strips, jute nets, wood shavings, or wood mulch are being used as geotextiles. In certain soil reinforcement applications, geotextiles have to serve for more than 100 years. But bio-degradable natural geotextiles are deliberately manufactured to have a relatively short period of life. They are generally used for the prevention of soil erosion until vegetation can become properly established on the ground surface. The commonly used natural fibers are –
- **Ramie:** These are subtropical bast fibers, which are obtained from their plants 5 to 6 times a year. The fibers have a silky luster and have a white appearance even in unbleached conditions. They constitute pure cellulose and possess the highest tenacity among all plant fibers.
- **Jute:** This is a versatile vegetable fiber that is biodegradable and can mix with the soil and serve as a nutrient for vegetation. Their quick biodegradability becomes a weakness for their use as a geotextile. However, their life span can be extended even up to 20 years through different treatments and blending. Thus, it is possible to manufacture designed biodegradable jute geotextile, that has specific tenacity, porosity, permeability, and transmissibility according to need and location specificity. Soil composition, water, water quality, water flow, landscape, etc. physical situation determines the application and choice of what kind of jute geotextiles should be used.

In contrast to synthetic geotextiles, though jute geotextiles are less durable they also have some advantages in a certain area to be used particularly in agro-mulching and similar area where quick consolidation are to take place. For erosion control and rural road considerations, soil protection from natural and seasonal degradation caused by rain, water, monsoon, wind, and cold weather are very important parameters. Jute geotextiles, as the separator, reinforcing, and drainage activities, along with topsoil erosion in shoulder and cracking are used quite satisfactorily. Furthermore, after degradation of jute geotextiles, increases the soil's organic content, fertility, and texture and also enhances vegetative growth with further consolidation and stability of the soil.

- **Synthetic Fibres:** The four main synthetic polymers most widely used as the raw material for geotextiles are – polyester, polyamide, polyethylene, and polypropylene. The oldest of these is polyethylene which was discovered in 1931 by ICI. Another group of polymers with a long production history is the polyamide family, the first of which was discovered in 1935. The next oldest of the four main polymer families relevant to geotextile manufacture is polyester, which was announced in 1941. The most recent polymer family relevant to geotextiles to be developed was polypropylene, which was discovered in 1954.
- **Polyamides (PA):** There are two most important types of polyamides, namely Nylon 6 and Nylon 6,6 but they are used very little in geotextiles. The first one is an aliphatic polyamide obtained by the polymerization of petroleum derivative ε-caprolactam. The second type is also an aliphatic polyamide obtained by the polymerization of salt of adipic acid and hexamethylene diamine. These are manufactured in the form of threads which are cut into granules. They have more strength but fewer moduli than polypropylene and polyester They are also readily prone to hydrolysis.
- **Polyesters (PET):** Polyester is synthesized by polymerizing ethylene glycol with dimethyl terephthalate or with terephthalic acid. The fiber has high strength modulus, creep resistance, and general chemical inertness due to which it is more suitable for geotextiles. It is attacked by polar solvents like benzyl alcohol, phenol, and meta-cresol. At pH range of 7 to 10, its life span is about 50 years. It possesses high resistance to ultraviolet radiations. However, the installation should be undertaken with care to avoid unnecessary exposure to light.
- **Polyethylene (PE):** Polyethylene can be produced in a highly crystalline form, which is an extremely important characteristic of fiber-forming polymer. Three main groups of polyethylene are – Low-density polyethylene (LDPE, density 9.2-9.3 g/cc), Linear low-density polyethylene (LLDPE, density 9.20-9.45 g/cc), and High-density polyethylene (HDPE, density 9.40- 9.6 g/cc).
- **Polypropylene (PP):** Polypropylene is a crystalline thermoplastic produced by polymerizing propylene monomers in the presence of a stereo-specific Zeigler Natta catalytic system. Homo-polymers and copolymers are two types of polypropylenes. Homo polymers are used for fiber and yarn applications whereas copolymers are used for varied industrial applications. Propylene is mainly available in granular form. Both polyethylene and polypropylene fibers are creep-prone due to their low glass transition temperature. These polymers are purely hydrocarbons and are chemically inert. They swell by organic solvent and have excellent resistance to diesel and lubricating oils. Soil burial studies have shown that except for low molecular weight components present, neither HDPE nor polyethylene is attacked by micro-organisms.

- **Polyvinyl chloride (PVC):** Polyvinyl chloride is mainly used in geo membranes and as a thermoplastic coating material. The basic raw material utilized for the production of PVC is vinyl chloride. PVC is available in free-flowing powder form.
- **Ethylene copolymer Bitumen (ECB):** Ethylene copolymer bitumen membrane has been used in civil engineering works as sealing materials. For ECB production, the raw materials used are ethylene and butyl acrylate (together forming 50-60%) and special bitumen (40-50%).
- **Chlorinated Polyethylene (CPE):** Sealing membranes based on chlorinated polyethylene are generally manufactured from CPE mixed with PVC or sometimes PE. The properties of CPE depend on the quality of PE and the degree of chlorination.

6.4 Types of Geotextiles:

Geotextiles are permeable synthetic materials made of textile materials. They are usually made from polymers such as polyester or polypropylene. The geotextiles are further prepared in three major categories – woven fabrics, non-woven fabrics, and knitted fabrics.

- **Woven fabrics:** Large numbers of geosynthetics are of woven type, which can be sub-divided into several categories based upon their method of manufacture. These were the first to be developed from synthetic fibers. As their name implies, they are manufactured by adopting techniques that are similar to weaving usual clothing textiles. This type has the characteristic appearance of two sets of parallel threads or yarns -.the yarn running along the length is called the warp and the one perpendicular is called the weft. Most low to medium-strength woven geosynthetics are manufactured from polypropylene which can be in the form of extruded tape, silt film, monofilament, or multifilament. Often a combination of yarn types is used in the warp and weft directions to optimize the performance/cost. Higher permeability is obtained with monofilament and multifilament than with flat construction only.

Figure 6.1: Woven Geotextile

Figure 6.2: Non-woven Geotextile

Figure 6.3: Knitted Geotextile

Figure 6.1: Source: http://www.geosynthetic-fabric.com

Figure 6.2: Source: https://www.erosioncontrol-products.com/geotextiles.html
Figure 6.3: Source: https://www.okorder.com/p/warp-knitted-polyester-geogrid-with-pvc-coating_349277.html

- **Non-woven:** Non-woven geosynthetics can be manufactured from either short-staple fiber or continuous filament yarn. The fibers can be bonded together by adopting thermal, chemical, or mechanical techniques or a combination of techniques. The type of fiber (staple or continuous) used has very little effect on the properties of the non–woven geosynthetics. Non-woven geotextiles are manufactured through a process of mechanical interlocking or chemical or thermal bonding of fibers/filaments. Thermally bonded non-wovens contain a wide range of opening sizes and a typical thickness of about 0.5-1 mm while chemically bonded non-wovens are comparatively thick usually in the order of 3 mm. On the other hand, mechanically bonded non-wovens have a typical thickness in the range of 2-5 mm and also tend to be comparatively heavy because a large quantity of polymer filament is required to provide a sufficient number of entangled filament cross wires for adequate bonding.
- **Knitted fabrics:** Knitted geosynthetics are manufactured using another process that is adopted from the clothing textiles industry, namely that of knitting. In this process of interlocking, a series of loops of yarn together is made. An example of a knitted fabric is illustrated in the figure. Only a very few knitted types are produced. All of the knitted geosynthetics are formed by using the knitting technique in conjunction with some other method of geosynthetics manufacture, such as weaving. Fig 3. Knitted Geotextile Apart from these three main types of geotextiles, other geosynthetics used are geonets, geogrids, geo-cells, geo membranes, geo composites, etc. each having its distinct features and used for special applications.

- **Webbings:** These are produced from strips of moderate width and are similar to coarse woven slit film fabrics.

- **Mats:** These are made of coarse and rigid filaments having a tortuous shape similar to that of open nonwoven fabrics.

- **Nets:** Nets comprise two sets of inclined coarse parallel-extruded strands and are bonded at the intersections by partially melting one of the strands. These net structures can furthermore be manufactured employing a melt extrusion method consisting of rotating dies through which the molten polymer is extruded. Besides, composite geotextiles can be formed by combining several of the above products such as a combination of multiple layers of knitted/woven/nonwoven through stitching, needle-punching, thermal bonding, etc. In the same way, mats/nets/plastic sheets can be sandwiched with one or two geotextiles, especially for drainage applications. Fiber-reinforced polymer composites can also be used as geotextiles for different applications

6.5 Functions of Geotextiles:

Every textile product applied under the soil is a geotextile. The products are used for the reinforcement of streets, embankments, ponds, pipelines, and similar applications. Depending on the required function, they are used in open-mesh versions, such as a woven or, rarely, warp-knitted structure, or with a closed fabric surface, such as a non-woven. The mode of operation of a geotextile in any application is defined by six discrete functions: separation, filtration, drainage, reinforcement, sealing, and protection. Depending on the application the geotextile performs one or more of these functions simultaneously.

Separation The separation function of geotextiles refers to a geotextile that can separate two kinds of materials with different properties, avoid mixing, and lose the integrity and structural integrity of various materials. In Figure 6.4, when stone aggregates are placed on fine-grained soil, both mechanisms will occur at the same time over time. One is that the fine soil in the lower layer tries to enter the void of the aggregate, thus destroying its drainage capacity; the other is that the aggregate in the upper layer tries to invade the fine soil, thus destroying the strength of the aggregate. This usually happens without the use of geotextiles.

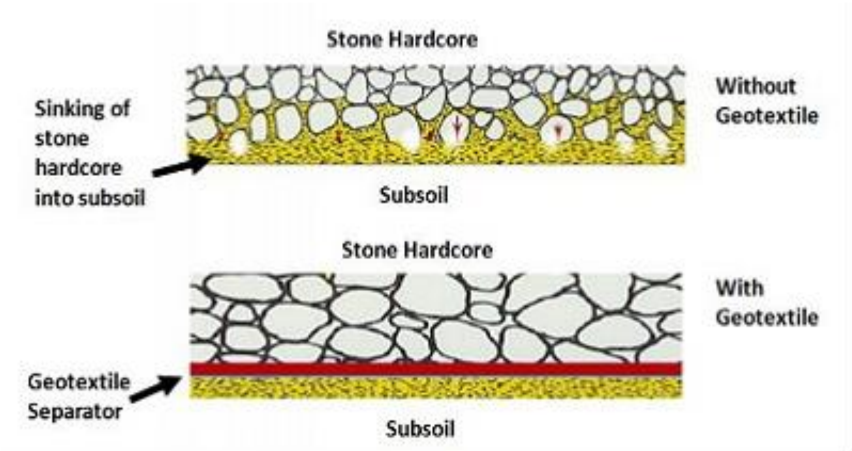

Figure 6.4: Separation Function of Geotextiles (Hao, W. *et al.* 2020)

The separation function of geotextiles can effectively prevent the pumping effect created by dynamics. Some of the applications areas are:

- Between subgrade and stone base in unpaved and paved roads and airfields
- Between subgrade in railroads
- Between landfills and stone base courses
- Between geomembranes and sand drainage layers
- Beneath sidewalks slabs
- Beneath curb areas
- Beneath parking lots
- Beneath sports and athletic fields

Filtration: It is defined as “the equilibrium geotextile-to-soil system that allows for adequate liquid flow with limited soil loss across the plane of the geotextile over a service lifetime compatible with the application under consideration”. Infiltration, fabrics can be either woven or non-woven, to permit the passage of water while retaining soil particles. Porosity and permeability are the major properties of geotextiles that are involved in filtration action. The application helps the replacement of graded aggregate filters by geotextiles warping. These applications are also suitable for both horizontal and vertical drains. A common application illustrating the filtration function is the use of a geotextile in a pavement edge drain, as shown in Figure 6.5.

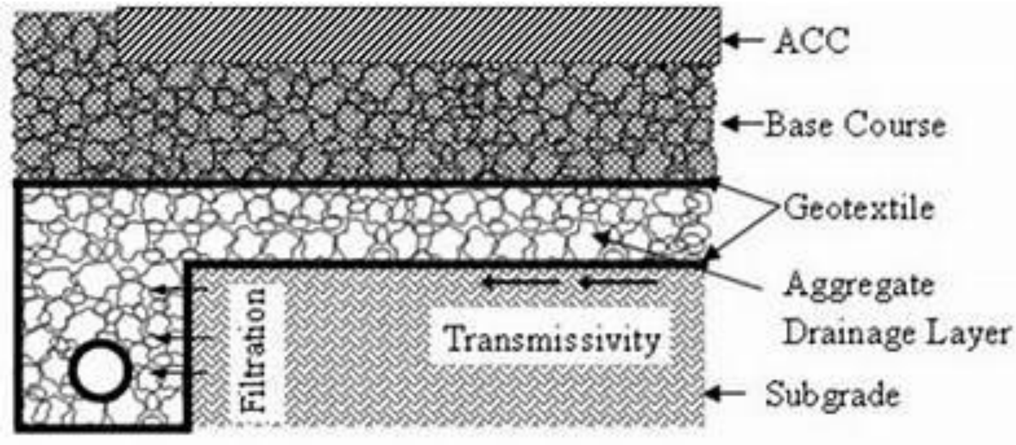

Figure 6.5: Filtration and Transmissivity Functions (Agrawal, B. J. 2011)

In an internally unstable soil, seepage may cause the phenomenon of suffusion; the transport of fine particles by seepage flow is accompanied by a collapse of the soil structure [28–30]. Because geotextiles have positive permeability and air permeability, they can be placed in the soil structure to allow the liquid in the soil to pass through and discharged, and play a role in soil conservation, which can effectively prevent the loss of soil particles, fine sand, and small stones in the upstream, prevent soil damage and effectively avoid the phenomenon of suffusion. The mechanism is demonstrated in Figure 6.6. The filtration function of geotextiles is also widely used in geotechnical engineering. As an example, geotextiles are used to prevent soil particles from migrating and infiltrating drainage aggregates or drainage pipes, while maintaining the normal operation of drainage systems; laying geotextiles under a riprap protective layer and other protective materials on coasts and riverbanks can prevent soil erosion and river bank collapse.

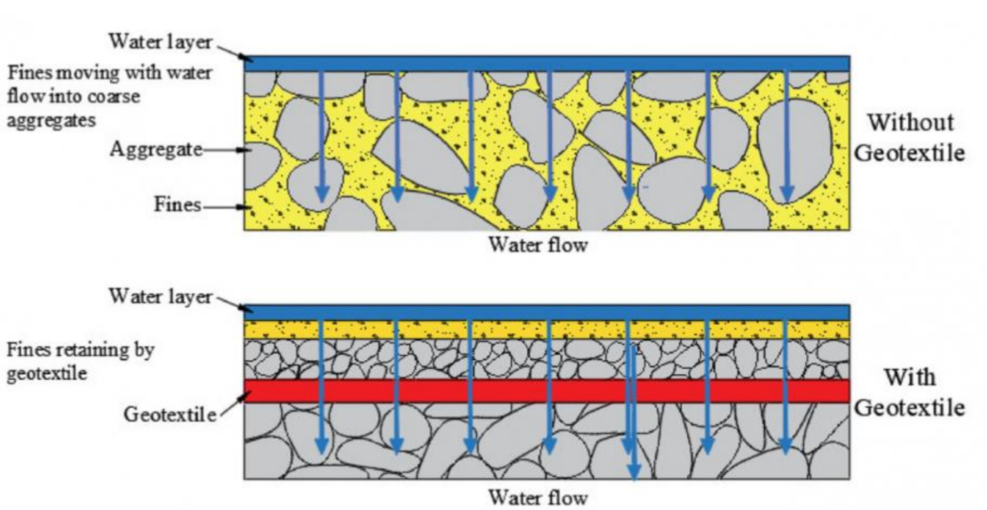

Figure 6.6: Filtration Function of Geo-Textile (Hao, W. *et al.* 2020)

Drainage (Transmissivity): This refers to the ability of a thick nonwoven geotextile whose three-dimensional structure provides an avenue for the flow of water through the plane of the geotextile. Figure 6 also illustrates the transmissivity function of geotextile. Here the geotextile promotes a lateral flow thereby dissipating the kinetic energy of the capillary rise of groundwater. Geotextiles have favorable water conductivity and are used as a drainage channel. The water in the soil structure in the geotextiles can be collected and slowly discharged along the geotextiles. At present, geotextiles have been widely used in underground drainage, subgrade drainage, retaining wall drainage, and other drainage works (Figure 6.7).

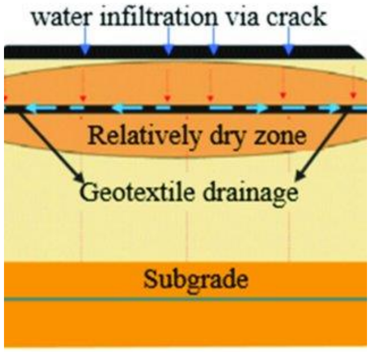

Figure 6.7: Subsurface Drainage Design with the Wicking Geotextiles (Hao, W. *et al.* 2020)

Reinforcement: This is the synergistic improvement in the total system strength created by the introduction of a geotextile into the soil and developed primarily through the following three mechanisms:

- lateral restraint through interfacial friction between geotextile and soil/aggregate
- forcing the potential bearing surface failure plane to develop at alternate higher shear strength surface
- membrane type of support of the wheel loads. In this method, the structural stability of the soil is greatly improved by the tensile strength of the geosynthetic material. This concept is similar to that of reinforced concrete with steel. Since concrete is weak in tension, reinforcing steel is used to strengthen it. Geosynthetic materials function similarly to reinforcing steel by providing strength that helps to hold the soil in place. Reinforcement provided by geotextiles or geogrids allows embankments and roads to be built over very weak soils and allows for steeper embankments to be built.

Geotextiles are placed in the interior of the soil as reinforcing materials, which combine with the soil to form a reinforced composite soil. Compared with the unreinforced soil, the strength and deformation performance of the reinforced composite soils are improved obviously (Figure 6.8). There are three crucial mechanical properties of geotextiles used for reinforcement: Tensile modulus, tensile strength, and surface friction. The reinforcement function of geotextiles is the most commonly used in geotechnical engineering. As shown in Figure 6.8, it has been widely used in reinforcing paved and unpaved roads and railroads, reinforcing walls, berms, and slopes, and reinforcing soft soil foundations.

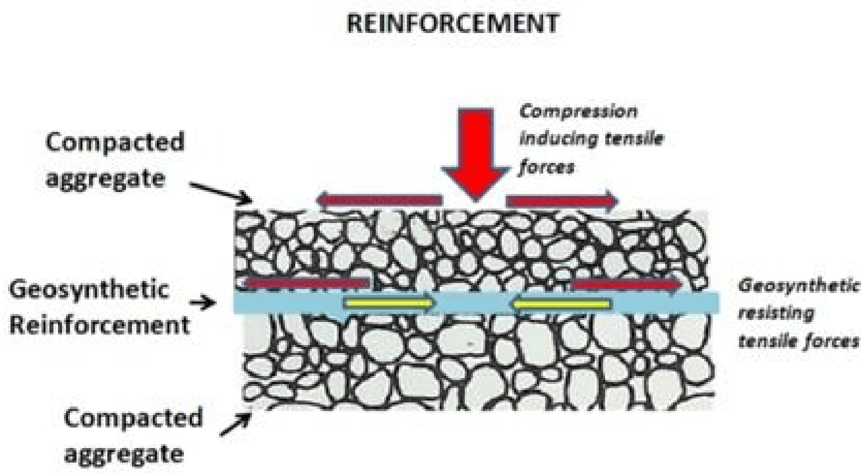

Figure 6.8: Reinforcement Function of Geotextiles (Hao, W. *et al.* 2020)

Sealing Function: A non-woven geotextile performs this function when impregnated with asphalt or other polymeric mixes rendering it relatively impermeable to both cross-plane and in-plane flow. The classic application of a geotextile as a liquid barrier is paved road rehabilitation, as shown in Figure 6.9. Here the non-woven geotextile is placed on the existing pavement surface following the application of an asphalt tack coat. The geotextile absorbs asphalt to become a waterproofing membrane minimizing the vertical flow of water into the pavement structure.

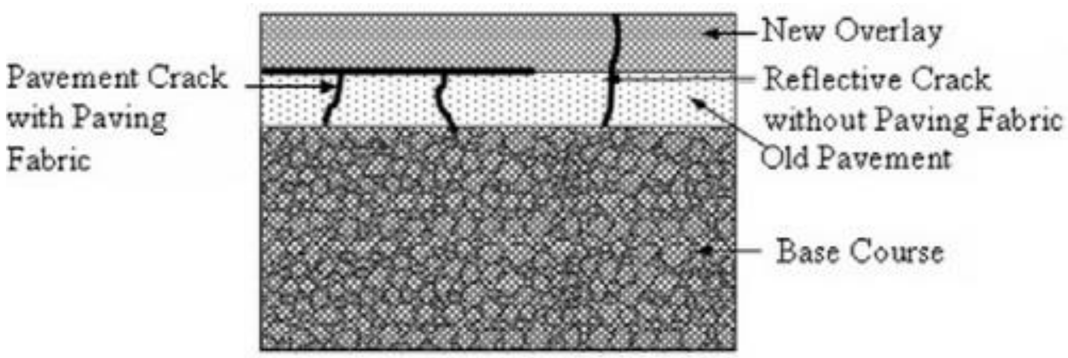

Figure 6.9: Sealing Function of Geotextiles (Agrawal, B. J. 2011)

6.6 Applications of Geotextiles:

Civil engineering works where geotextiles are employed can be classified into the following categories (Figure 6.10):

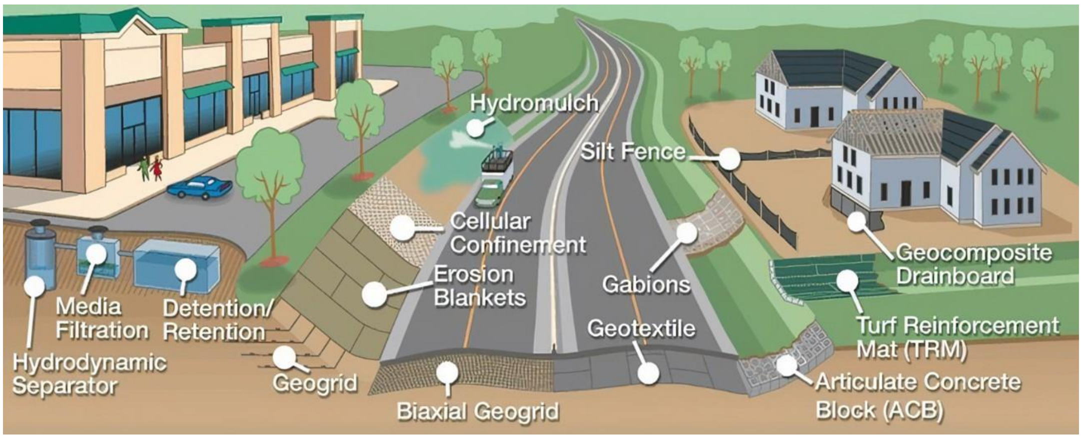

Figure 6.10: Application Areas of Geotextiles (Agrawal, B. J. 2011.)

Road Works: The basic principles of incorporating geotextiles into a soil mass are the same as those utilized in the design of reinforced concrete by incorporating steel bars. The fabrics are used to provide a tensile strength in the earth mass in locations where shear stress would be generated. Moreover, to allow rapid dewatering of the roadbed, the geotextiles need to preserve their permeability without losing their separating functions. Its filtration characteristics must not be significantly altered by the mechanical loading.

Railway Works: The development of the railway networks is being greatly boosted by the present state of the economy because of their profitability because increasing cost of energy and their reliability as a result of the punctuality of trains even in adverse weather conditions.

The woven fabrics or non-wovens are used to separate the soil from the sub-soil without impeding the groundwater circulation where the ground is unstable.

Enveloping individual layers with fabric prevents the material from wandering off sideways due to shocks and vibrations from running trains.

River Canals and Coastal Works: Geotextiles protect river banks from erosion due to currents or lapping. When used in conjunction with natural or artificial enrockments, they act as a filter. For erosion prevention, geotextile used can be either woven or nonwoven. The woven fabrics are recommended in soils of larger particle sizes as they usually have larger pore sizes. Nonwovens are used where soils such as clay silt are formed. Where hydrostatic uplift is expected, these fabrics must be of sufficiently high permeability.

- **Embankments and Retaining Walls**: Geotextile is more effectively used for reinforcesment in the construction of embankments and retaining walls in soft soil. By filling geotextiles horizontally at the base of the embankment it is possible to attain an erect side slope and construction can be cost-efficient. More importantly, in urban areas, the project can be made cost-efficient by reducing the land coverage on both sides of the embankment.

- **Erosion Control:** The application of geotextiles in the erosion control sector is growing fast for attaining short-term effects. In this sector, the materials are applied in a bit different way than they are laid on the surface and bot buried in the soil. The main objective remains to control erosion and for making more efficient vegetation is established which can control erosion naturally. The geotextile is then residue to requirements and can fertilize the soil by degradation. Geotextile can intersect the running off soil particles and protect the unvegetated soil from natural forces like sun, rain, and wind. Weeds and newly planted trees can also be inhibited by them. Erosion control can be applied to riverbanks and coastlines to prevent undermining by the ebb and flow of the tide or just by wave motion.

Drainage: In civil engineering, the need for drainage has long been recognized and has created the need for filters to prevent in-situ soil from being washed into the drainage system. Such wash in the soil causes clogging of the drains and potential surface instability of land adjacent to the drains. The use of geotextiles to filter the soil and a more or less single-size granular material to transport water is increasingly seen as a technically and commercially viable alternative to conventional systems. Geotextiles perform the filtering mechanism for drainages in earth dams, on roads and highways, in reservoirs, behind retaining walls, in deep drainage trenches, and agriculture.

Sports field construction: Geotextiles are widely used in the construction of Caslon playing fields and Astroturf. Caslon playing fields are synthetic grass surfaces constructed of light resistance polypropylene material with porous or nonporous carboxylated latex backing pile as high as 2.0 to 2.5 cm. Astro Turf is a synthetic turf sport surface made of nylon 6,6 pile fiber knitted into a backing of polyester yarn which provides high strength and dimensional stability. The nylon ribbon used for this is 55 Tex. It is claimed that the surface can be used for 10 hr/day for about 10 years or more. Modern Astro Turf contains polypropylene as the base material.

Agriculture: It is used for mud control. To improve muddy paths and trails used by cattle or light traffic, nonwoven fabrics are used and are folded by overlapping to include the pipe or a mass of grit.

6.7 Conclusion:

Technical textile products are now going indispensable for every sector of engineering as well as our practical life. Geotextiles have already been extensively used in various fields of construction and civil engineering all over the world. The market demand for geotextiles is also increasing tremendously.

Currently, the product serves some functions such as separation, filtration, drainage, reinforcement, and so on. But the range of functions of geotextiles can be enhanced and the product can be made more potential and versatile for applications. In this regard, more research has been required to enhance the performance of these valuable technical textile products. Nanotechnology can be applied for this purpose and modification of natural and synthetic fibers as well as novel finishing processes can be performed to attain the best-desired properties for the diverse and viable practical application of geotextiles.

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