trolleys to transport to the construction site. Compaction of cold mix with 8-10 tone roller shall be carried out to get the finished premix carpet surface.

Properly designed uniformly cold mix shall be discharged to the tippers for transportation to site. The spreading of cold mix will be done preferably by means of a self propelled mechanical paver at a suitable speed capable of spreading, tamping and finishing to the proper grade, line and cross-section. The mix shall be spread in such a manner that, after compaction, the required thickness of surfacing layer is achieved. The paver laid cold mix, after becoming black from original brown colour due to breaking of emulsion on surface of aggregate, shall be thoroughly and uniformly compacted by a set of rollers at a speed not more than 5 km per hour. The break down rolling shall be done with 8-12 tonne three wheel steel roller. Rolling operation is to be done for 5 to 6 times. During rolling operation, wheels of the roller should be cleaned by wet cloth or gunny bag to avoid falling of dirt on the surface. Compacted thickness of the finished road should be 20 mm. Rolling shall commence longitudinally from edges and progress towards the centre except on super elevated portions, where it shall progress from lower to the upper edge. Rolling shall be continued till the specified density is achieved and all roller marks are eliminated. Traffic shall be allowed after 2-3 hours, when the cold mix is well set and is not picked up by the vehicles.

Advantages

- 2-3 times faster progress using existing facilities at site without any extra investment in capacity building or equipments.
- Green Technology: Non polluting process, no heating, saves fuel and 90% energy efficient.
- Highly durable - contains anti-stripping properties, performing better than Hot Mix roads.
- All weather construction- during monsoons and cold winters on dry days.
- Cold mix technology is environment friendly
- Cold mix technology helps in saving of fuel but about 5 % costlier
- The use of cold mix technology is worker friendly and is good for health of construction workers as it prevents burns, occurrence of diseases like asthma, cancer and frequent vomiting

Comparison between Cold and Hot mixes

Cold Mix	Hot Mix
No heating required- Saves fuel and its cost.	Requires about 1,800 litres of fuel per km
Pollution free green road concept	Polluting and energy intensive it affects the health of public and construction workers
Heating cost is completely saved and is also environment friendly	High energy requirement
No temperature control requirement	Requires temperature control
Faster progress- Completes 1km in 3-4 days with proper manpower and support (by using concrete mixer)	Low output for mix production and laying work in rain/ cold climate.
Local ,unskilled and women workers can execute the work	Skilled and experienced workers required
All weather construction	Limited working season- No work during rains and cold winters. Loss of adhesion at high attitude due to sudden drop of temperature.
No chance of accident of labour	Maximum chance of accident of labour during work execution

Following precautions should be taken to ensure successful laying of cold mixes and to achieve good performance

• Cold mixes generally have good resistance to detrimental effects of water damage during construction. However, if rain occurs before the mixture is cured, traffic should be kept off, until the mix is cured and the necessary compaction is accomplished.

• The mixing water content should be just sufficient required to adequately disperse the emulsion and achieve good workability

• Mixtures should be mixed only enough to properly disperse the emulsion. Excessive mixing may cause the emulsion to break prematurely or strip from the mineral aggregates

• For faster curing, place the cold mix in several thin layers rather than in a single thick layer.

• If case ravelling observed due to traffic, the loose material should be broomed off as soon as possible to prevent further damage to the surface. If the ravelling continues, the surface should be fog sealed with a light application of a slow-setting emulsion diluted with soft water in 1 :1 ratio.

Refer IRC:SP:100-2014, Use of Cold Mix Technology in construction and maintenance of roads using bitumen emulsion.

9.4.5 PERVIOUS CONCRETE

Pervious concrete (also called porous concrete, permeable concrete, no fines concrete and porous pavement) is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge. Pervious concrete has performed successfully in pedestrian walkways, sidewalks, driveways, parking lots and low volume roadways. Pervious concrete has the ability to capture the runoff of rainwater and remove trace pollutants. Pervious concrete pavement is a unique and effective means to meet growing environmental demands.

The subgrade should be properly compacted to provide a uniform and stable surface. Moistening the subgrade prior to concrete placement prevents pervious concrete from setting and drying too quickly. Typically pervious concrete has a water to cementitious materials ratio of 0.35 to 0.45 with a void content of 15 to 25%. The mixture is composed of cementitious materials, coarse aggregate and water with little to no fine aggregates. Addition of a small amount of fine aggregate will generally reduce the void content and increase the strength, which may be desirable in certain situations. This material is sensitive to changes in water content, so field adjustment of the fresh mixture is usually necessary. The correct quantity of water in the concrete is critical.

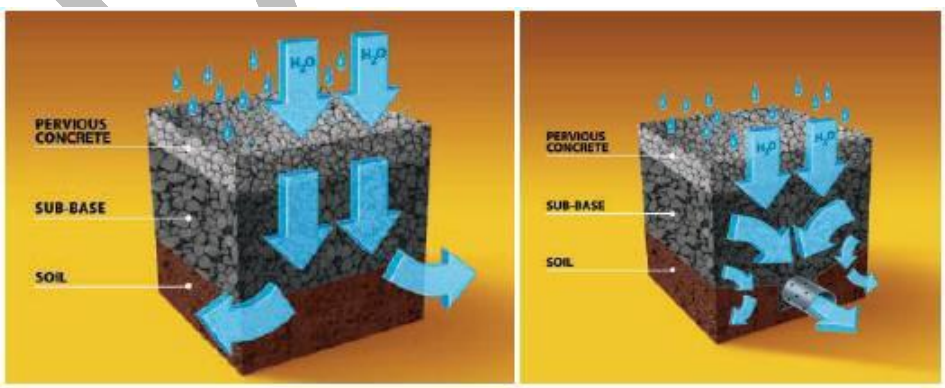
A low water to cement ratio will increase the strength of the concrete, but too little water may cause surface failure. A proper water content gives the mixture a wet-metallic appearance. As this concrete is sensitive to water content, the mixture should be field checked. A small amount of sand can be used for compressive strength improvement but air void content will be reduced and permeability lowered. It is important to maintain the proper volume of paste/ mortar in the mix design so that the aggregate is equally coated but the excess of paste/ mortar does not fill the void space within coarse aggregate. Voids within the Pervious concrete should be interconnected so they create channels through which water can freely flow.

The concrete is compacted to improve the bond and smooth the surface. Excessive compaction of pervious concrete results in higher compressive strength, but lower porosity (and thus lower permeability).

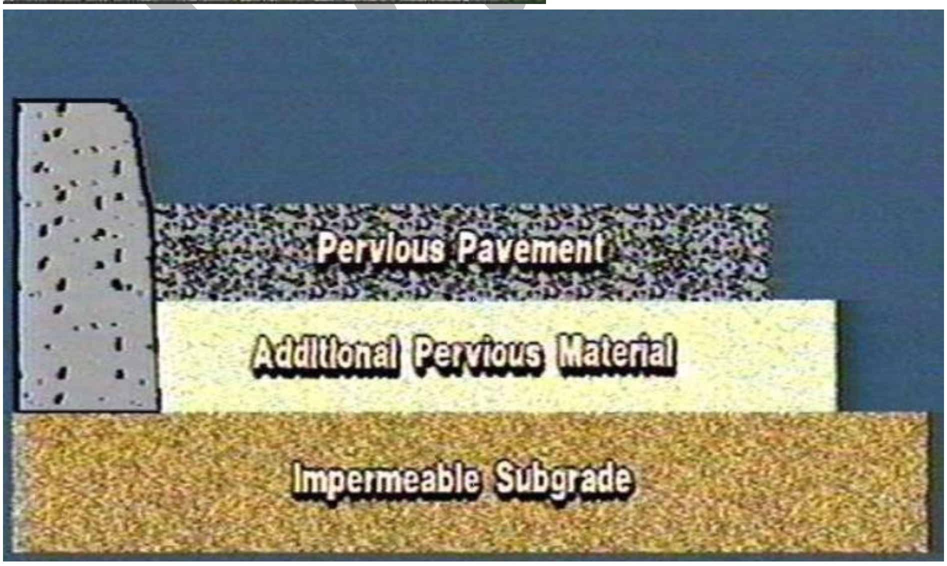
Jointing pervious concrete pavement follows the same rules as for concrete slabs on grade.

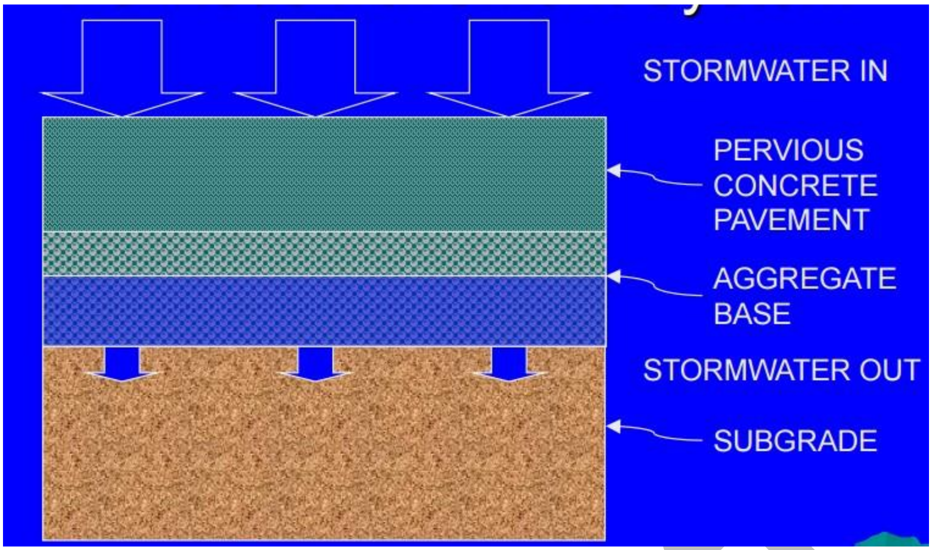
Proper curing is essential to the structural integrity of a pervious concrete pavement. Pervious concrete pavement shall be cleaned regularly to prevent clogging.

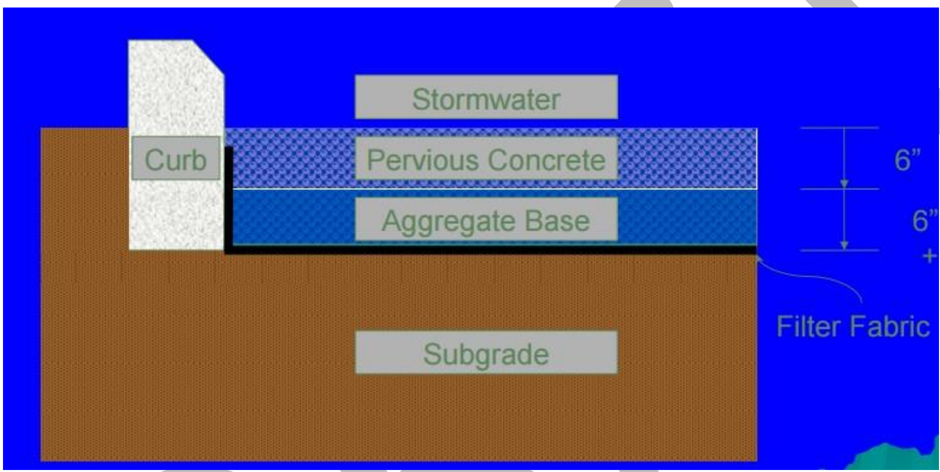
Pervious concrete



Typical cross sections of PC pavements


Pervious Pavement
Additional Pervious Material
Impermeable Subgrade





9.4.5.1 Advantages

The environmental benefits from PC allow it to be incorporated into municipal green infrastructure and low impact development programs. In addition to providing stormwater volume and quality management, the light colour of concrete is cooler than conventional asphalt and helps to reduce urban temperatures and improve air quality. Unlike the smoothed surface of conventional concrete, the surface texture of pervious concrete is slightly rougher, providing more traction to vehicles and pedestrians.

Pervious concrete reduces the runoff from paved areas, which reduces the need for separate storm water retention ponds and allows the use of smaller capacity storm sewers. Pervious concrete also naturally filters storm water and can reduce pollutant loads entering into streams, ponds and rivers. A pervious concrete pavement allows the transfer of both water and air to root systems allowing trees to flourish even in highly developed areas.

9.4.6 GEOSYNTHETICS

Geosynthetics can be defined as planar products manufactured from polymeric material, which are used with soil, rock, or other geotechnical engineering-related material as an integral part of a manmade project, structure, or system (ASTM, 1995). Geosynthetics could be either a natural product or an artificial product, that is used along with soil in geotechnical constructions. Some of the natural materials are coir, jute, hemp and other similar products. Jute and coir products are employed extensively in several parts of India especially for erosion control applications, and for low volume road reinforcements and so on. Geo-textiles are the permeable fabrics which, when used in association with soil have the ability to separate, filter, reinforce, protect or drain. Geosynthetics are typically made from polypropylene or polyester. Geo-textile fabrics come in three basic forms: woven, needle punched or heat bonded.

Geo-textiles have many applications and currently support many civil engineering applications including roads, airfields, embankments, retaining structures, reservoirs and construction site. Geo-textiles have a major role in construction of paved roads over areas having high ground water table. There are several key applications, construction of pavements, in asphalt concrete overlays and for drainage systems, which helps in enhancing the performance and extending the service life of roads. Drainage of water from pavements has always been an important consideration in road design. When functioning as a drain, geo-textiles acts as a conduit for the movement of liquid or gases in the plane of geo-textile.

The major issues related to the rural roads are, most of them are constructed in weak subgrade. Even though the traffic flow is low, the proximity of these roads to the agricultural field, poor drainage system and infiltration of rain water through comparatively porous surface finish, softens the subgrade which causes large deformation/ rutting along the wheel paths. The loss of macadam into the soft subgrade through mud pumping will reduces the necessary minimum thickness of sub base/ base course layer accelerating the rutting phenomenon.

The pavement performance of both paved and unpaved roads can be improved with the inclusion of geosynthetics. It is a quicker and easier solutions compared to traditional alternatives due to the ease of installation. Unavailability, high cost of geosynthetics, and stringent environmental protection requirement make it important to explore alternative natural products to make the constructions cost efficient and eco-friendly. Many efforts are done to utilize the geotextile made from natural fibers readily available in Indian sub-continent for reinforcing the unpaved roads. India and Srilanka shares the 90% of the world’s production of coir and India is the largest jute producing country in the world. The usage of these materials can bring down the cost.

Coir

Jute

The classification of geotextile for the usage in the field can be obtained from AASHTO M288-10. The reinforcement function of the geosynthetics has been attributed to three mechanisms in helping to accomplish the improvement in the performance of the unpaved roads. They are (a) lateral restraint, (2) increased bearing capacity and (3) tensioned membrane effect. The geosynthetic reinforcement is often placed between the base and sub-base layers or at the interface between the sub-base and subgrade layers or within the base course layer of the flexible pavement. The placement position of reinforcement is the main factor affecting the bearing capacity of reinforced granular soil and higher bearing capacity is observed when the depth of placement of reinforcement is decreased. Thus geotextile helps reduces the vertical stress acting on the subgrade than in unreinforced pavements

The presence of the reinforcement layer increases lateral restraint or passive resistance of the fill material, increasing the rigidity of the system and reducing the vertical and lateral pavement deformation

Reinforcing mechanism of geosynthics capabilities can also provide the tensile resistance to lateral aggregate movement. Reinforcement placed high up in the granular layer hinders lateral movement of the aggregate due to frictional interaction and interlocking between the fill material and the reinforcement which raises the apparent load-spreading ability of the aggregate and reduces the necessary fill thickness.

9.4.6.1 Geosynthetic Types

Geosynthetics are widely used in many geotechnical, environmental, and hydraulic applications related to groundwater quality and control. Geosynthetics applications are very diverse. To fulfill different functions in the design of geotechnical-, environmental-, and hydraulic-related systems, the geosynthetic industry has developed a number of products to meet engineers' needs.

Categories of geosynthetics:

1. Geotextiles
2. Geomembranes
3. Geogrids
4. Geosynthetic Clay Liners
5. Geocells
6. Geocomposites

Geotextiles - flexible, textile-like fabrics of controlled permeability used to provide filtration, separation or reinforcement in soil, rock and waste materials

Geomembranes - essentially impermeable polymeric sheets used as barriers for liquid or solid waste containment

Geogrids - stiff or flexible polymer grid-like sheets with large apertures used primarily as reinforcement of unstable soil and waste masses

Geosynthetic clay liners - prefabricated bentonite clay layers incorporated between geotextiles and/or geomembranes and used as a barrier for liquid or solid waste containment

Geocells- interconnected strips of three-dimensional cellular structure into which specified infill materials are placed and compacted which prevents mass movements by providing tensile reinforcement.

Geocomposites - hybrid systems of any, or all, of the above geosynthetic types which can function as specifically designed for use in soil, rock, waste and liquid related problems

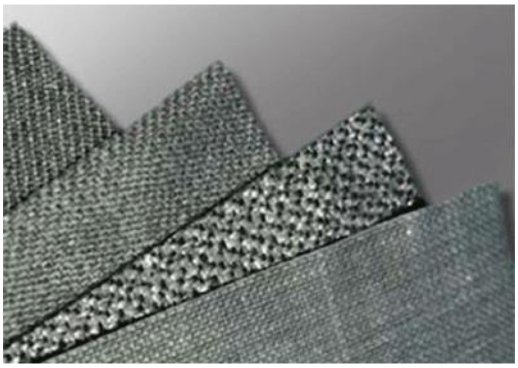
The growth of these geosynthetic materials in Transportation, Geotechnical and Environmental related applications has been sustained for the past 20 years. Total use and sales of these materials are regularly increasing at rates of 10% to 20% per year in each of the above categories. The main applications of geosynthetics are use of geotextiles as filters in trench drains, geomembranes in landfill liner systems, HDPE vertical panels in groundwater control projects, geotextiles as filtration elements in dams and waste containment systems, geocomposites as erosion control elements in channels and slopes and geogrids as reinforcement elements in soil embankments.

Geosynthetics are manufactured in sheet form in a factory-controlled environment. They are most often packaged in rolls for transporting to the site. They may also be folded or cut and stacked and placed in cartons. At the project site the geosynthetic sheets are unrolled on the prepared subgrade surface, overlapped to form a continuous geosynthetic blanket, and often physically joined to each other, for example, by melting (geomembranes) or sewing (geotextiles).

9.4.6.1.1 Geotextiles

Among the different geosynthetic products, geotextiles are the ones that has the widest range of properties. They can be used to fulfill the different functions for many different geotechnical, environmental, and hydraulic applications. For example , if a reinforced slope is constructed in which geotextiles were selected as multipurpose inclusions within the fill, then they can provide not only the required tensile strength (reinforcement function), but also the required transmissivity (drainage function) needed for that particular project.

NonWoven Geotextiles



Woven Geotextile

Based on their structure and the manufacturing technique, geotextiles may be broadly classified into woven and nonwoven. Woven geotextiles are manufactured by the interlacement of warp and weft yarns, which may be of spun, multifilament, fibrillated or of slit film. Nonwoven geotextiles are manufactured through a process of mechanical interlocking or thermal bonding of fibers/filaments.
Mechanical interlocking of the fibers/filaments is achieved through a process called “needle punching”. Needle-punched nonwoven geotextiles are best suited for a wide variety of civil engineering applications and are the most widely used type of geotextile in the world. Interlocking of the fibers/filaments could also be achieved through “thermal bonding”. Heat-bonded geotextiles should be used with caution, as they are not suitable for filtration applications or road stabilization applications over soft soils Nonwovens are used in Filtration, Drainage, Separation, Protection and/or Erosion Control applications.

Woven geotextiles are manufactured using traditional weaving methods and a variety of weave types. Nonwoven geotextiles are manufactured by placing and orienting the filaments or fibers onto a conveyor belt, which are subsequently bonded by needle punching or by melt bonding. The needle-punching process consists of pushing numerous barbed needles through the fiber web. The fibers are thus mechanically interlocked into a stable configuration. As the name implies, the heat (or melt) bonding process consists of melting and pressurizing the fibers together.

Geotextiles form one of the two largest group of geosynthetics, and have been steadily growing in use during the past 20 years. They are textiles in the traditional sense, but consist of synthetic fibers rather than natural ones such as cotton, wool, or silk. Thus biodegradation is not a problem. These synthetic fibers are made into a flexible, porous fabric by standard weaving machinery or are matted together in a random, or nonwoven, manner. The major point is that they are pervious to water flow across their manufactured plane and also within their plane, but to a widely varying degree.

Geotextiles are manufactured from polymer fibers or filaments that are later formed to develop the final product. Approximately 85% of the geotextiles used today are based on polypropylene resin. An additional 10% are polyester and the remaining 5% is a range of polymers including polyethylene, nylon, and other resins used for speciality purposes. As with all geosynthetics, however, the base resin has various additives, such as for ultraviolet light protection and long-term oxidative stability The filaments, fibers, or yarns are formed into geotextiles using either woven or nonwoven methods.

Natural geotextiles: Natural geotextiles such as coir and jute absorb moisture and are suitable in areas of low rainfall and situations where the establishment of vegetation takes a long time, leaving slopes susceptible to erosion. When they degrade they form organic mulch and this in turn helps in hastening the establishment of vegetation.

Different geotextiles have different rates of degradation and this rate depends on site conditions.The effectiveness of natural geotextiles in erosion control is temporary as with time these materials either bio-degrade or photo-degrade as they are made from natural vegetative materials. In other words, natural geotextiles mainly provide temporary erosion control pending the development of full vegetation cover. However, they are more effective in controlling erosion than their synthetic counterparts because of their higher % cover and greater absorption of water.

Synthetic geotextiles: Synthetic geotextiles on the other hand are manufactured from synthetic polymers (e.g. high density polyethylene).They can be used to provide permanent protection against erosion because they do not bio-degrade or photo-degrade (especially when degradation effects of sunlight are mitigated through the addition of carbon black in the process of manufacture). The commercial market is dominated by synthetic geotextiles and due to their composition, they can last more than 25 years in the site, compared to the 2-5 years life span of natural geotextiles.

9.4.6.1.2 Geomembranes

Geomembranes are flexible, polymeric sheets that have very low hydraulic conductivity (typically less than 10−11 cm/sec) and, consequently, are used as liquid or vapour barriers. The most common types of geomembranes are high density polyethylene (HDPE), very flexible polyethylene (VFPE), polyvinyl chloride (PVC), flexible polypropylene (fPP) and reinforced chlorosulfonated polyethylene (CSPE). Geomembrane. It is a planar relatively impermeable, polymeric (synthetic or natural) sheet used in contact with soil/rock and/or any other geotechnical material in civil engineering applications.

Geomembranes represent the other largest group of geosynthetics. Their growth has been stimulated by governmental regulations originally enacted in 1982. The materials themselves are "impervious" thin sheets of rubber or plastic material used primarily for linings and covers of liquid- or solid-storage or disposal facilities. Thus the primary function is always as a liquid or vapor barrier. The range of applications, however, is very great, and at least 30 individual applications in civil engineering have been developed.

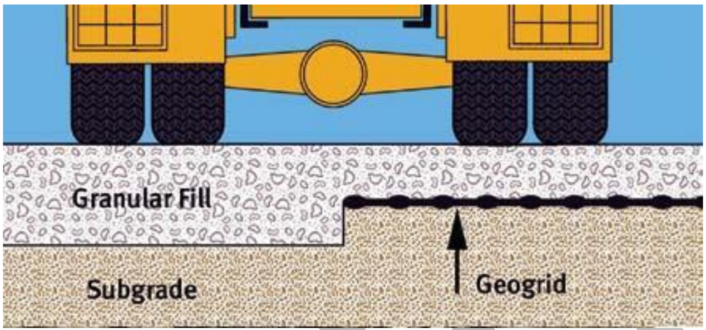
Polyethylene is the type of geomembrane most commonly used in landfill applications for base and cover liner systems. This is primarily because of its high chemical resistance and durability. Specifically, high-density polyethylene (HDPE) is typically used in base liner systems. This material is somewhat rigid but generally has good physical properties and can withstand large stresses often imposed on the geomembrane during construction.

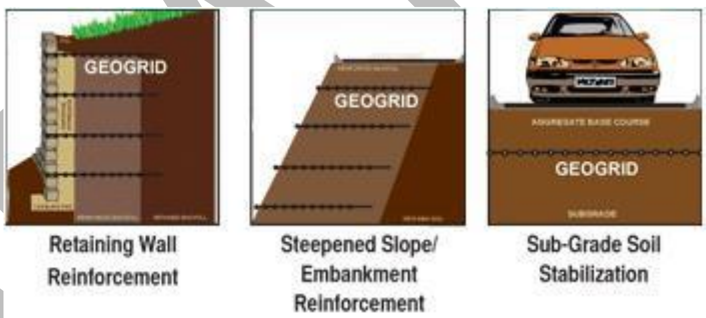
PVC geomembranes are used in liners for many waste containment applications, such as contaminated soils containment and liquid storage ponds. While PVC may not be as durable as polyethylene geomembranes, the merits of PVC geomembranes are that they are generally less expensive than polyethylene geomembrane and can be factory manufactured in relatively large panels. The large panel sizes allow easier installation as there are fewer field fabricated seams.

In landfill applications, geomembranes are typically used as a base or a cover liner in place of or in addition to low-hydraulic conductivity soils. Geomembrane thickness ranges from 0.75 to 2.5mm. A properly designed geomembrane has the potential of hundreds of years of service lifetime, but installation must follow high quality management principles.

9.4.6.1.3 Geogrids

It is a planar, polymeric structure consisting of a regular open network of integrally connected tensile elements, which may be linked by extrusion, bonding or interlacing, whose openings are larger than the constituents, used in contact with soil/rock and/or any other geotechnical material in civil engineering applications.





Geogrids represent a rapidly growing segment within the geosynthetics area. Rather than being a woven, nonwoven or knit textile or textile-like fabric, geogrids are plastics formed into a very open, gridlike configuration, i.e., they have large apertures. Geogrids are either stretched in one or two directions for improved physical properties or made on weaving machinery by unique methods. By themselves, there are at least 25 application areas, however, their function is exclusively as reinforcement materials.

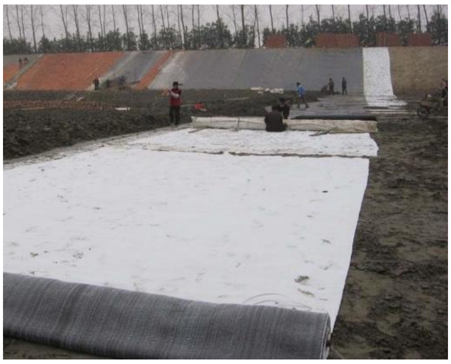
Geogrids constitute a category of geosynthetics designed preliminary to fulfill a reinforcement function. Geogrids have a uniformly distributed array of apertures between their longitudinal and transverse elements. The apertures allow direct contact between soil particles on either side of the installed sheet, thereby increasing the interaction between the geogrid and the backfill soil.

Geogrids are composed of polypropylene, polyethylene, polyester, or coated polyester. They are formed by several different methods. The coated polyester geogrids are typically woven or knitted. Coating is generally performed using PVC or acrylics to protect the filaments from construction damage and to maintain the grid structure. The polypropylene geogrids are either extruded or punched sheet drawn, and polyethylene geogrids are exclusively punched sheet drawn. In the past several years, geogrids have also been manufactured by interlacing polypropylene or polyester strips together and welding them at their cross-over points (i.e., junctions).

Although geogrids are used primarily for reinforcement, some products are used for asphalt overlay and some are combined with other geosynthetics to be used in water proofing or in separation and stabilization applications. In waste containment systems, geogrids may be used to support a lining system over a weak subgrade or to support final landfill cover soils on steep refuse slopes. Geogrids are also used for support of liners in the design of landfills, which are landfills built vertically over older, usually unlined landfills. Regulatory agencies often require that a liner system be installed between the old and new landfill. As the old refuse is highly compressible, it provides a poor base for the new lining system. A geogrid may be used to support the lining system and bridge over voids that may occur beneath the liner as the underlying refuse components decompose.

9.4.6.1.4 Geosynthetic Clay Liners

Geosynthetic clay liners (or GCLs) are the newest subset within geosynthetic materials. They are rolls of factory fabricated thin layers of bentonite clay sandwiched between two geotextiles or bonded to a geomembrane. Structural integrity is maintained by needle punching, stitching or physical bonding. They are seeing use as a composite component beneath a geomembrane or by themselves as primary or secondary liners.



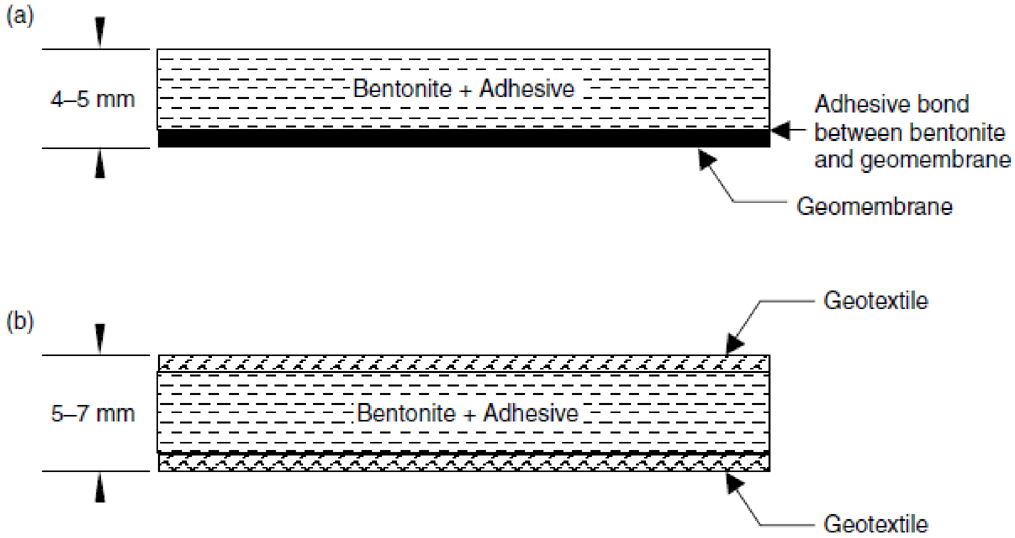
Geosynthetic clay liners are rapidly expanding products in the geosynthetics market. They are infiltration barriers consisting of a layer of unhydrated, loose granular or powdered bentonite placed between two or on top of one geosynthetic layer (geotextile or geomembrane). GCLs are produced in panels that are joined in the field by overlapping. They are generally used as an alternative to compacted clay liners.

Due to the inherent low shear strength of hydrated bentonite, GCL usage had initially been limited to applications where stability of the overlying materials was not a concern. In the late 1980s, however, methods were developed to reinforce the GCLs, producing a composite material with higher shear strength properties. This allowed the use of GCLs in landfill applications

Some advantages of GCLs over compacted clay liner are that they occupy significantly less space to achieve equivalent performance, plus they are flexible, self-healing, and easy to install. In locations where low hydraulic conductivity clays are not readily available, they may offer significant construction cost savings. In addition, as they are factory manufactured with good quality control, field construction quality assurance costs are typically less than with compacted clay liners.

Geosynthetic clay liners are manufactured by laying down a layer of dry bentonite, approximately 5mm thick, on a geosynthetic material and attaching the bentonite to the geosynthetic. Two general configurations are currently employed in commercial processes ; bentonite sandwiched between two geotextiles or bentonite glued to a geomembrane. The primary purpose of the geosynthetic components is to hold the bentonite together in a uniform layer and to permit transportation and installation of the GCL without loss of bentonite.

The outer geosynthetic layer of GCLs can be mechanically bonded using stitching or needle punching (resulting in reinforced GCLs). A different process consists in using an adhesive bond to glue the bentonite to the geosynthetic (resulting in unreinforced GCLs). The mechanical bonding of reinforced GCLs increases their internal shear strength.



GCL configurations: (a) bentonite glued to a geomembrane; (b) bentonite sandwiched between two geotextiles.

9.4.6.1.5 Geocells

Geocells (or cellular confinement systems) are three-dimensional, expandable panels made from strips, typically 50 to 100 mm wide. When expanded during installation, the interconnected strips form the walls of a flexible, three-dimensional cellular structure into which specified infill materials are placed and compacted. This creates a system that holds the infill material in place and prevents mass movements by providing tensile reinforcement. Cellular confinement systems improve the structural and functional behavior of soil infill materials.

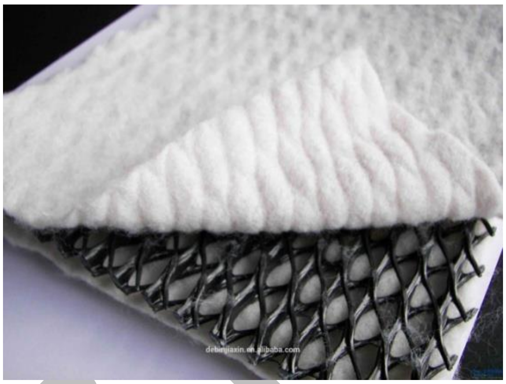
Geocells were developed in the late 1970s and early 1980s for support of military vehicles on weak subgrade soils. The original type of geocell consists of HDPE strips 200 mm wide and approximately 1.2mm thick. They are ultrasonically welded along their 200mm width at approximately 330mm intervals and are shipped to the job site in a collapsed configuration. At the job site they are placed directly onto the subgrade surface and propped open in an accordion-like fashion with an external stretcher assembly. They are then filled generally with gravel or sand (although other infill materials such as concrete, can be used) and compacted using a vibratory hand-operated plate compactor. Geocell applications include protection and stabilization of steep slope surfaces, protective linings of channels and hydraulic structures, static and dynamic load support on weak subgrade soils, and multilayered earth-retaining and water-retaining gravity structures.

Geocells have proven very effective in providing a stable foundation over soft soils. The cellular confinement system improves the load-deformation performance of infill materials because cohesionless materials gain considerable shear strength and stiffness under confined conditions. Confining stresses are effectively induced in a geocell by means of the hoop strength developed by the HDPE cell walls. The overall increase in the load carrying performance of the system is provided through a combination of the cell wall strength, the passive resistance of the infill material in adjacent cells, and the frictional interaction between the infill soil and the cell walls. The cellular structure distributes concentrated loads to surrounding cells thus reducing the stress on the subgrade directly beneath the geocell.

Infill selection is primarily governed by the nature and intensity of anticipated working stresses, availability and cost of materials, and aesthetic requirements for a fully vegetated appearance. Aggregates, vegetated topsoil, and concrete constitute typical geocell infill types. A complete cellular confinement system may also include geotextiles, geomembranes, geonets, geogrids, integral polymeric tendons, erosion-control blankets, and a variety of earth anchors.

9.4.6.1.6 Geocomposites

Geocomposites are multi-layered combinations of geosynthetics. These combinations provide benefits over individual layers by enhancing functions, increasing interface friction angles and increasing the speed of installation. With careful design they can provide drainage, protection, reinforcement, and filtration and barrier functions and replace expensive and scarce mineral resources.



Almost any two or more geosynthetics may be bonded together in multiple layers in widths of up to 6m. Materials are bonded together using heat or adhesives to form composites with two or more components which are often project specific to solve installation and service life objectives.

The basic philosophy behind geocomposite materials is to combine the best features of different materials in such a way that specific applications are addressed in the optimal manner and at minimum cost. Thus, the benefit/cost ratio is maximized. Such geocomposites will generally be geosynthetic materials, but not always. In some cases it may be more advantageous to use a nonsynthetic material with a geosynthetic one for optimum performance and/or least cost. As seen in the following, the number of possibilities is huge — the only limits being one's ingenuity and imagination.

A geocomposite consists of a combination of geotextile and geogrid; or geogrid and gromembrane; or geotextile, geogrid, and geomembrane; or any one of these three materials with another material (e.g., deformed plastic sheets, steel cables, or steel anchors). The application areas are numerous and growing steadily. The major functions encompass the entire range of functions listed for geosynthetics discussed previously : separation, reinforcement, filtration, drainage, and liquid barrier.

Geotextile - Geomembrane Composites : Geotextiles are laminated on one or both sides of a geomembrane for a number of puposes. In the reinforcement area, the geotextiles provids increased resistance to puncture, tear propagation, and friction related to sliding, as well as providing tensile strength in and of themselves. Quite often, however, the geotextiles are of the nonwoven, needle-punched variety and are of relatively heavy weight. In such cases they act as drainage media, since their in-plane transmissivity feature can conduct water or leachate away from direct contact with the geomembrane.

Geomembrane - Geogrid Composites: Since some types of gemembrances and geogrids can be made from the same material (e.g., high-density polyethylene), they can be joined together (actually welded) to form an impervious barrier with enhanced strength and friction capabilities.

Geotextile - Geogrid Composites: Those geotextiles with low modulus, low strength and / or high elongation at failure can be greatly improved by forming a composite material with a geogrid, or even with a woven fabric scrim. The synergistic properties of each component usually enhances the final product.

Other Geocomposites : By weaving steel strands within a geotextile matrix, incredible composite material strength can result. Used as a substrate, extrmely large loads can be sustained. A measurable increase in bearing capacity for the support of buildings is alos possible.

Open-graded styrofoam beads have been sandwiched between geotextile (as filters) and geomembranes (as vapour barriers) for drainage materials behind basement walls and earth-sheltered homes. Here the styrofoam acts as the drain but has the added advantage of acting as a heat insulator.

Geotextiles with prefabricated holes for the insertion of steel rod anchors have been used to stabilize slopes and as in-situ compaction and consolidation systems. The rods act as anchors, stressing the geotextile against the soil, which is put into compression. The geotextile thus acts dually as a tensile stressing mechansim and as a filter allowing the pore water to escape while retaining the individual soil particles.

Added to this list are short fibers, grids, and nets to be placed in concrete or bitumen to form a high impact composite material, etc.

9.4.6.2 Functions of Geosynthetics

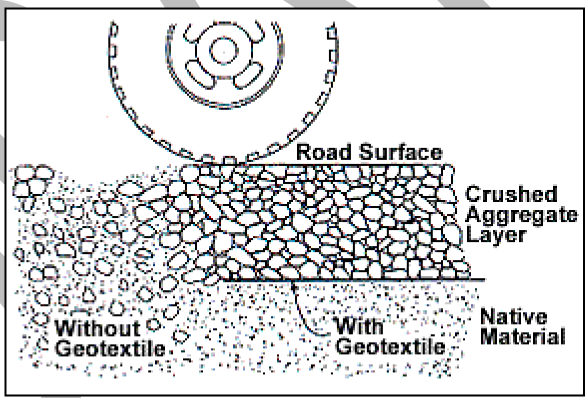
The different functions performed by geosynthetics are as follows:

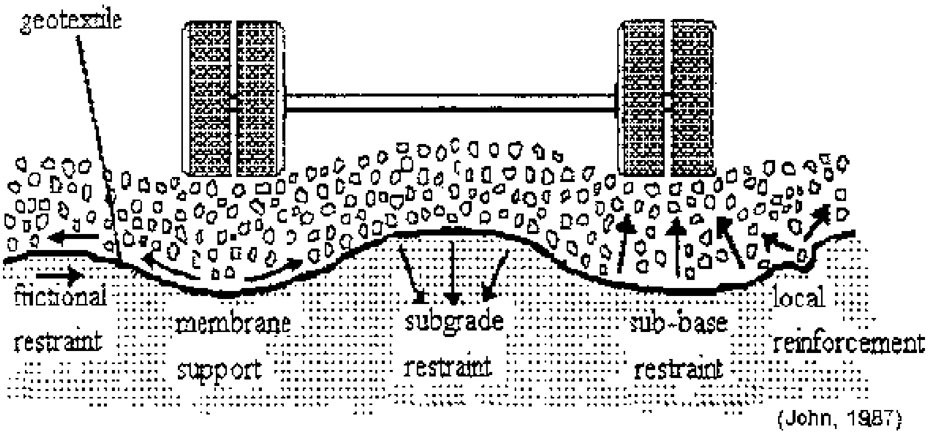
- Separation
- Drainage
- Filtration
- Reinforcement
- Moisture barrier
- Protection

The primary function(s) of geosynthetics can be separation, reinforcement, filtration, drainage, infiltration barrier, or protection. However, a certain geosynthetic product can perform different functions and, similarly, the same function can often be performed by different types of geosynthetics. Geosynthetic applications are usually defined by the primary or principal function. In addition, geosynthetics can perform one or more secondary functions, which must also be considered when selecting the geosynthetic characteristics for optimum performance. For example, a geotextile can provide separation of two dissimilar soils (e.g., gravel from clay in a road), but the geosynthetic may also be required to provide the secondary function of filtration to minimize the build up of excess pore water pressure in the soil beneath the separator.

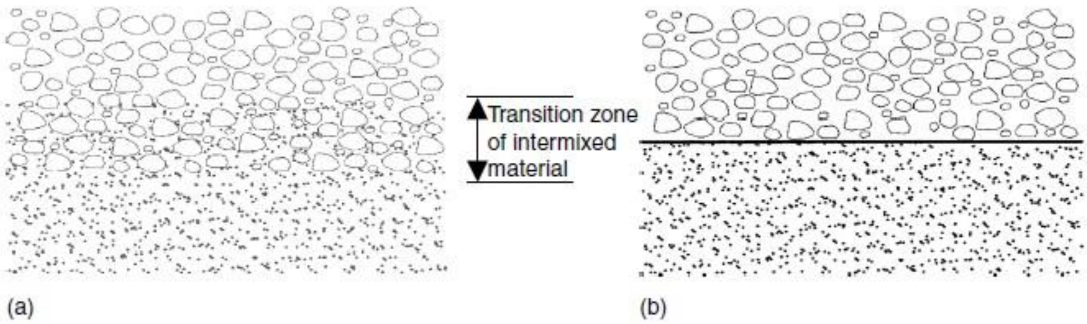
9.4.6.2.1 Separation

Separation is the introduction of a flexible, porous geosynthetic product between dissimilar materials so that the integrity and functioning of both materials can remain intact or be improved. For example, a major cause of failure of roadways constructed over soft foundations is contamination of the aggregate base course with the underlying soft subgrade soils. Contamination occurs both due to: (1) penetration of the aggregate into the weak subgrade due to localized bearing capacity failure under stresses induced by wheel loads, and (2) intrusion of fine-grained soils into the aggregate because of pumping or subgrade weakening due to excess pore water pressure. Subgrade contamination results in inadequate structural support that often leads to premature failure of the system. A geotextile can be placed between the aggregate and the subgrade to act as a separator and prevent the subgrade and aggregate base course from mixing





Among the different geosynthetics, geotextiles have been the products generally used in the function of separation. Examples of separation applications are the use of geotextiles between subgrade and stone base in roads and airfields, and between geomembranes and drainage layers in landfills. In addition to these applications, in which separation is the primary function of the geotextile, it could be said that most other geosynthetic applications generally include separation as a secondary function.



Separation function of a geotextile placed between road aggregate and soft saturated subgrade. (a)Without geotextile and (b)With geotextile.

9.4.6.2.2 Reinforcement Function

Geosynthetic inclusions within a soil mass can provide a reinforcement function by developing tensile forces that contribute to the stability of the geosynthetic-soil composite (a reinforced soil structure). Design and construction of stable slopes and retaining structures within space constrains are major economical considerations in geotechnical engineering projects. For example, when geometry requirements dictate changes of elevation for a retaining wall, or dam project, the engineer faces a variety of distinct alternatives for designing the required earth structures. Traditional solutions have been either a near vertical concrete structure or a conventional, relatively flat, unreinforced slope. Although simple to design, concrete wall alternatives have generally led to elevated construction and material costs. On the other hand, the construction of unreinforced embankments with flat slope angles dictated by stability considerations is an alternative often precluded in projects where design is controlled by space constraints. an alternative would be to place horizontal, geosynthetic reinforcing elements in the soil to allow