IRC:SP:59-2019

GUIDELINES FOR USE OF GEOSYNTHETICS IN ROAD PAVEMENTS AND ASSOCIATED WORKS

(First Revision)

INDIAN ROADS CONGRESS

2019

CONTENTS

CHAPTER - 1
INTRODUCTION

Geosynthetic is defined as a planar product manufactured from a polymeric material which are used with soil, rock, or other geotechnical-related material as an integral part of a road project, to improve its performance. Synthetic materials in the form of strong flexible sheets either woven or nonwoven, permeable or water tight, 2-dimensional or 3-dimensional have been used for several years to improve soil quality and performance in different pavement related facets of geotechnical engineering, e.g. base and sub base stabilization, reinforcement, drainage, protection of slopes and embankments. Specific products such as, geotextiles, geogrids, geocell, geomembranes, geocomposite etc., have been progressively developed for various applications. A common generic name 'Geosynthetics' is being used to refer the different materials mentioned above.

Several detrimental factors affect the service life of roads and pavements including environmental factors, subgrade conditions, traffic loading, utility cuts, and ageing. Pavement distresses such as surface cracks, joints, and subgrade failures cause the rapid reflection/propagation of cracks up through the pavement layers and increase the maintenance cost. Therefore, the preferred strategy for long term road and pavement performance is to build in safeguards during initial construction. These performance safeguards include stabilizing the subgrade against moisture intrusion and associated weakening, strengthening the road base and sub-base by allowing the efficient drainage of infiltrated water, and enhancing the stress absorption and moisture proofing capabilities.

1.1 Scope

This publication contains information on Geosynthetics made from polymeric materials and their use in road pavements and other associated works. This document provides detailed design methodology, specifications, construction guidelines, standard test methods, handling and storage of all the geosynthetics for road pavement applications. The applications addressed in the document include:

- Stabilization and reinforcing of pavement layers
- Separation and filtration
- Subsurface and surface drainage
- Erosion control of road embankments

The document however excludes other possible applications of geosynthetics such as reinforced soil walls & slopes, containment of landslides and geosynthetics made from natural fibres.

These guidelines may require revision from time-to-time based on future developments and experience in the field. Towards this end, it is suggested to all the organizations using the guidelines to keep a detailed record of the year of construction, subgrade CBR, soil characteristics including resilient modulus, pavement composition and specifications, reinforcement details, traffic, pavement performance, type and thickness of overlay performance, climatic condition, periodical measurements (both before and after strengthening) etc. and provide feedback to the Indian Roads Congress for further revision.

Chapters in this publication are organized in a way that followed sequence gives a better understanding of the objective of the publication.

Chapter-1 “Introduction” provides details of different geosynthetic materials, their composition, functions and applications in road pavement works.

Chapter-2 “Properties and Test methods” addresses all the required tests to be performed to evaluate the Geosynthetic function and applications. It gives detailed testing procedures and the properties required as per the available ISO, IRC, BIS, ASTM and BS.

Chapter-3 “Design methodology” explains the mechanism, design methodology using different geosynthetic materials and analysis for different applications.

Chapter-4 “Geosynthetic Selection Criteria” provides guidance and helps design engineers and specification writers with the selection of geosynthetics based on the required function, application, site conditions, and other economical technical feasibilities.

Chapter-5 “Construction guidelines” brings out the installation aspects and methodologies to be practiced while executing and installing geosynthetics.

Chapter-6 “Handling, storage and Installation” gives information on safe handling and transportation of geosynthetics without any damage before installation.

This document also includes the solved numerical example in Annexure IV for easy understanding of the design methodologies explained in Chapter-3.

1.2 Raw Materials and Classification of Geosynthetics

1.2.1 *Raw materials*

Polymers are the major raw materials for manufacturing geosynthetics. The polymers used are polypropylene, polyester, polyethylene, polyamides, polystyrene, polyvinyl chloride. Some types of geosynthetics are made from carbon fibre, glass fibre and natural fibres also.

1.2.2 *Classification of geosynthetics*

Geosynthetics can be classified in many ways based on manufacturing process, materials used or function. General classification of geosynthetics for the applications in pavements is given in **Fig. 1.1**. The classification is based on the spatial aspects of the geosynthetic material. For example, one dimensional material will have only one spatial character as length compared to other dimensions (ropes, straps and cables). Two dimensional materials will have only two spatial characteristics either length or width or height (Geogrids, Geotextiles, Geocomposites and Geomembranes), whereas three dimensional materials will possess the spatial characteristics in all three dimensions i.e. length, width and height (geocell, geomats, geonets, geospacers and three dimensional geogrids).

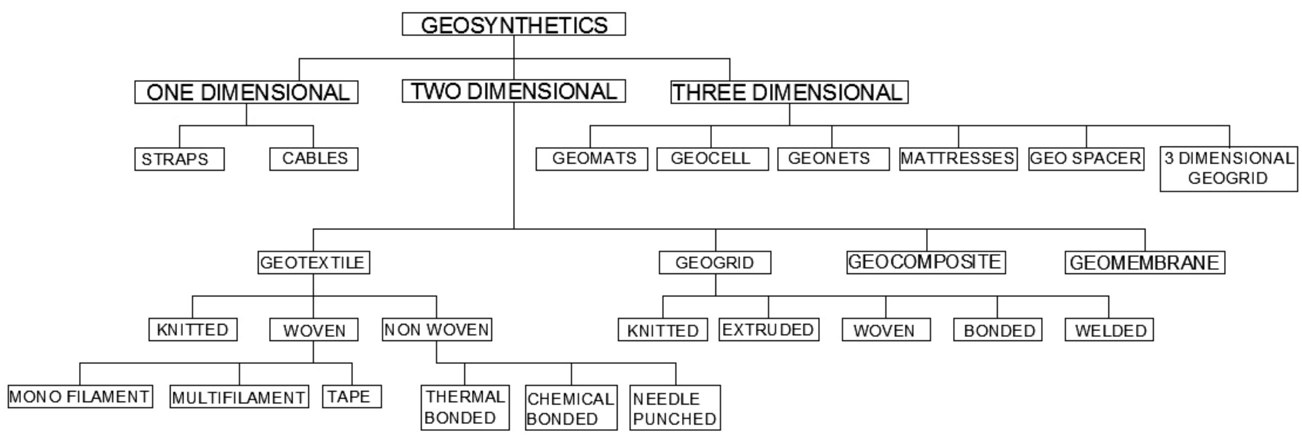


Fig. 1.1 Classification of Geosynthetics

1.2.3 *Types of geosynthetics for pavement applications*

1.2.3.1 Geotextile: Geotextiles can be defined as any permeable synthetic textile used with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of an infrastructure project, structure, or system. The geotextiles are generally classified by the manufacturing process and are often separated into two sub-categories, namely, woven and non-woven. Another type of geotextile includes (i) Knitted geotextiles and (ii) Composite geotextiles (**Fig. 1.2**).

Woven geotextiles are manufactured by weaving weft threads through warp threads. Strength of geotextile in machine direction is usually larger than cross machine direction.

Non-woven geotextiles are produced from randomly distributed continuous filaments or staple fibres, which are bonded together chemically, thermally or mechanically.

Knitted geotextiles consists of a single strand systematically intertwined with itself and is manufactured with a knitting machine, instead of a weaving loom.

Composite geotextiles (Multi-layered geotextiles) are manufactured by combining layers of different types of geotextiles. The components can be combined by needling, stitching, chemical bonding or heat bonding. (IRC HRB Special Report No. 12, 'State-of-the-Art: Application of Geotextiles in Highway Engineering').

Fig. 1.2 Geotextile

1.2.3.2 Geogrid: Geogrids are polymers formed into a very open, grid like configuration, i.e., they have apertures between individual ribs in the transverse and longitudinal directions. Geogrids are mainly made from polymeric materials, typically polypropylene (PP), high density polyethylene (HDPE) and polyester (PET). Geogrids can be classified according to (a) manufacturing process(woven, knitted, bonded, welded, extruded), (b) directional behaviour (uniaxial, biaxial, etc.), (c) bonding between ribs and (d) Polymer (polypropylene, polyester, PVC etc). Biaxial geogrids have significant strength in both the machine and cross machine directions.

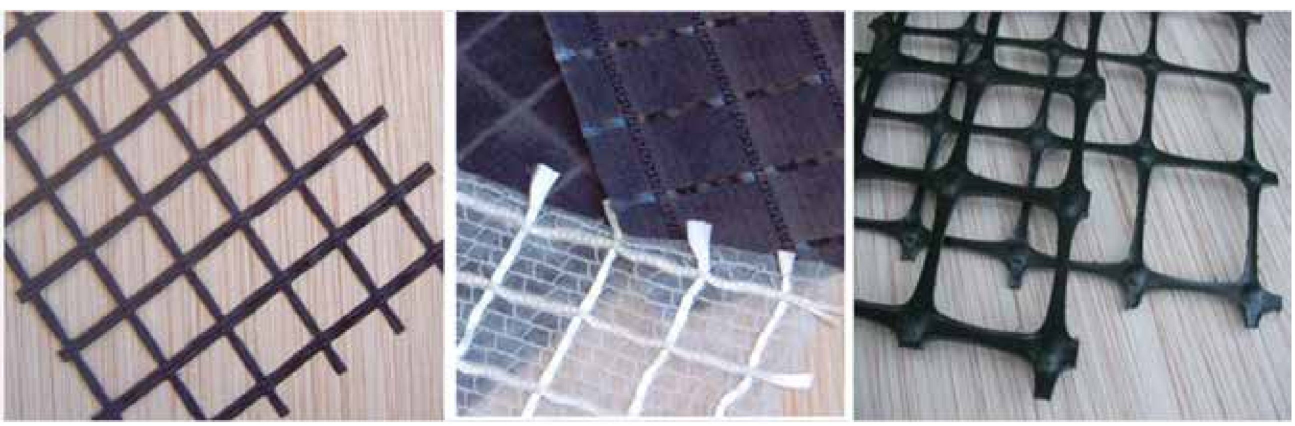


Fig. 1.3 Geogrids

1.2.3.3 Geomembranes: Geomembrane is a very low permeability/impervious synthetic membrane liner or barrier used to control fluid migration across the plane. These are made from relatively thin continuous polymeric sheets, but they can also be made from the impregnation of geotextiles with bitumen, polymer sprays or as multilayered bitumen geocomposites. Continuous polymer sheet geomembranes are by far the most common.

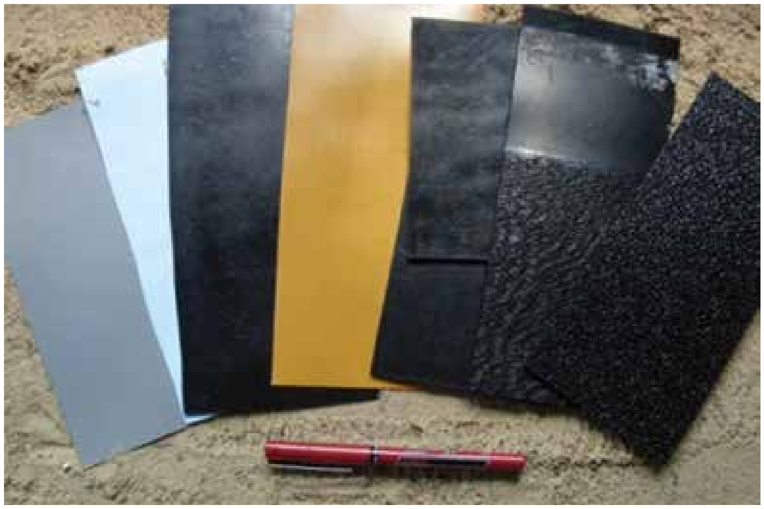


Fig. 1.4 Geomembranes

1.2.3.4 Geonets: Geosynthetic material consisting of integrally connected parallel sets of ribs overlying similar sets at various angles formed by a continuous extrusion into a net like configuration for in plane drainage of liquids. Geonets are often laminated with geotextiles on one or both surfaces and are referred to as drainage composites. There are three categories of geonets.

- Bi-planar geonets: These are the original and most common types and consist of two sets of intersecting ribs at different angles and spacing's. The ribs themselves are of different sizes and shapes for different styles.
- Tri-planar geonets: These have parallel central ribs with smaller sets of ribs above and beneath mainly for geometric stability.
- Other geonets: These newer geonet structures have either box shaped channels or protruding columns from an underlying support network.

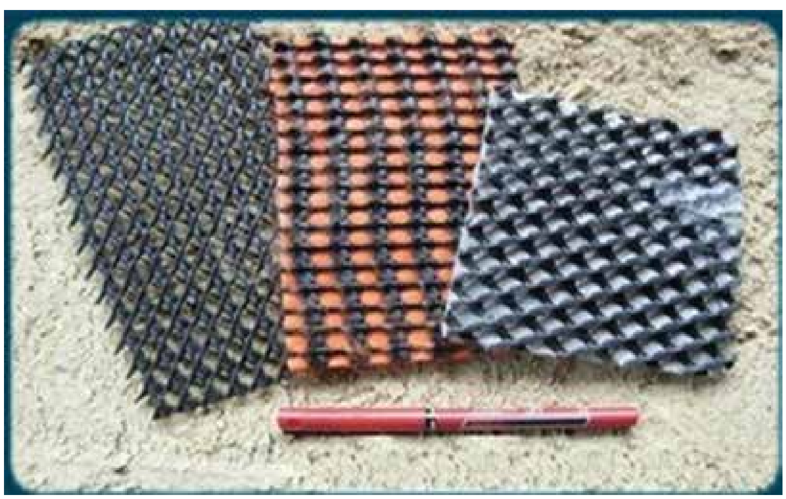


Fig. 1.5 Geonet

1.2.3.5 Geospacer: Geospacer is a three-dimensional geosynthetic extruded from polymeric materials such as HDPE. It provides separation and a void between layers to provide in-plane drainage. Typical geospacers are formed in continuous sheets which can be used as an impermeable layer or perforated to allow water migration. The material is UV stabilised with carbon black. Geospacer are often laminated with geotextiles on one or both sides and are referred to as drainage geocomposites increasingly being used to replace traditional gravel drainage layers.

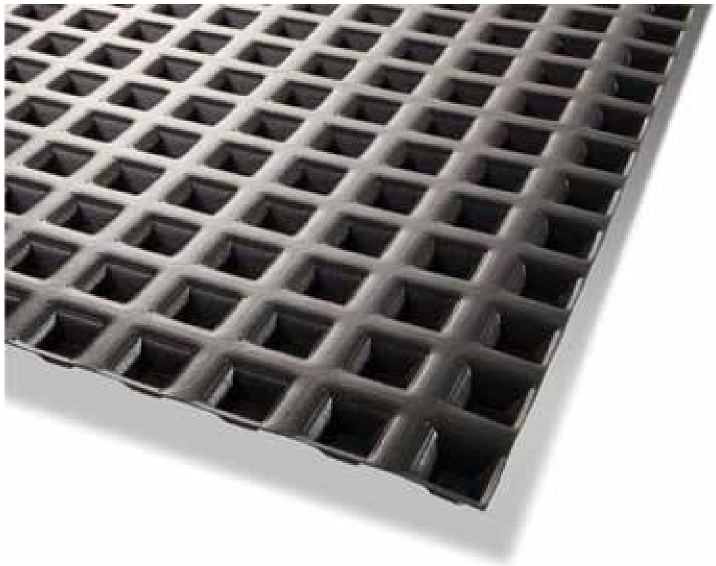


Fig. 1.6 Geospacers

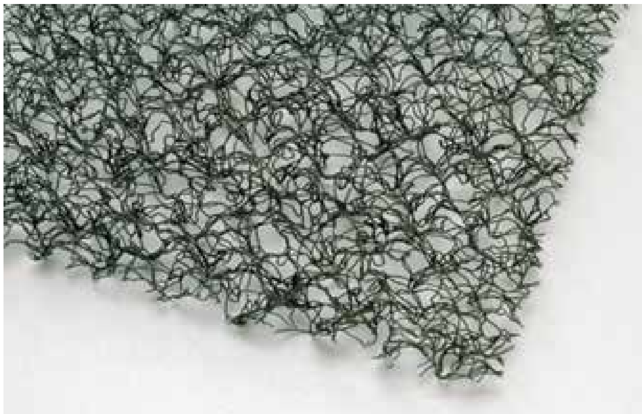
1.2.3.6 Geocell: Geocells (also known as Cellular Confinement Systems) are three-dimensional honeycombed cellular structures that form a confinement system when in-filled with compacted soil or aggregate. Extruded from polymeric materials such as HDPE, into strips welded together ultrasonically in series or in continuous process capable to create the cells without any subsequent welding, the geocell structures, the strips are expanded to form the stiff (and typically textured and perforated) walls of a flexible 3D cellular mattress. The material is UV stabilised with carbon black.

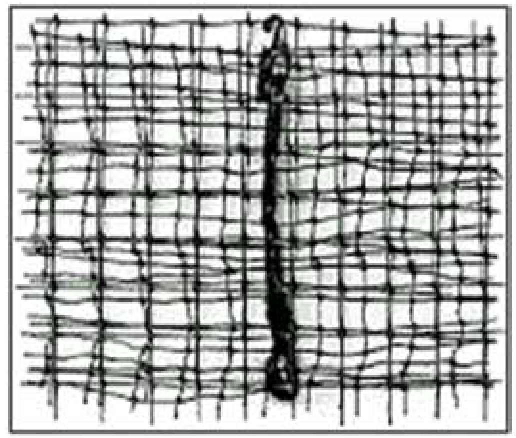
(a) closed form

(b) open form

Fig. 1.7 Geocell

1.2.3.7 Geomats: These are two dimensional or three dimensional mats with specified thickness, made of multi-filaments, layers of geogrids folded and knitted or bonded together with apertures to allow vegetation growth for erosion control application. IRC:56-2011 (Clause 5.8 & 5.9) provides detailed information on types, test method and property requirements of geomats.





(a) Unreinforced Geomats **(b) Reinforced Geomats**

Fig. 1.8 Geomat

1.2.3.8 Asphalt Reinforcement: There are three products for strengthening of asphaltic layer for pavement, which are described below:

1. *Paving Fabric:* Paving Fabric is made from the fibres with non-weaving process (needle punch and heat bonded) and applied by providing tack coat with asphaltic layer.
2. *Paving Grids/Glass-Fibre Grid:* The paving grid used with this specification shall be manufactured from a glass fibre roving or polymeric grid pattern; resistant to chemical attack (from flux oils, paraffin's or any other solvents used in bituminous binders), mildew and rot, and shall meet the physical requirements listed in Chapter 4 of this guidelines.
3. *Asphalt Interlayer Composites (AIC)/Composite Paving gird:* A Grid combined with a Paving Fabric it is called a Composite. AIC is made from Nonwoven Geotextile knitted with Fibre Glass rovings, will provide dual functions.

(a) **(b)**

Fig. 1.9 (a) Paving Fabric (b) Paving Grid

1.2.3.9 Geocomposite: Geocomposites are formed by combining geotextiles or geomembranes with a core of geonet.

(a) Drainage Composite

(b) Reinforced Geocomposite

Fig. 1.10 Geocomposite

1.3 Functions of Geosynthetics

In a given application, a geosynthetic can perform one or several functions to improve the mechanical and/or hydraulic behaviour of the structure in which it is incorporated. The basic functions performed by a geosynthetic are as follows:

1. Separation/Filtration
2. Reinforcement
3. Drainage
4. Moisture Barrier
5. Erosion Control

Each of these functions can be defined in terms of the role they fulfil in the installation. Definitions and description of each of these functions are explained below.

Properties, testing methods and the selection guidelines for each geosynthetic material for various functions listed above are given in Chapters 2 and 4 respectively.

1.4 Separation/Filtration

The separation function refers prevention of intermixing of the two layers of dissimilar materials throughout the design life of the material. Normally, geotextiles provide for separation between layers in pavement. It prevents intrusion/pumping of soil particles into the base/sub-base course. Simultaneously, it performs the function of filtration by dissipating the pore water pressure and allowing the passage of fluids into or across the plane of the geotextiles while preventing the uncontrolled passage of soil particles.

1.5 Reinforcement

Reinforcement function of geosynthetics is defined as use of the stress-strain behaviour of a geosynthetic material to improve the mechanical properties of soil or other construction materials. Different types of geogrids and woven geotextiles have high tensile strength can be used as reinforcing materials in pavements. The combined use of soil (good in compression and poor in tension) and geotextiles/geogrids (good in tension and poor in compression) suggests a number of situations in which they have made existing design work better or developed entirely new applications. In base reinforcement applications, geogrids are placed within or at the bottom of unbound layers of a flexible pavement system and improve the load-carrying capacity of the pavement under repeated traffic.

Asphalt reinforcement reduces the reflective cracking and improves moisture retention by impregnating with bitumen in tack coat. In general paving fabric, paving grids and Asphalt Interlayer Composite (AIC) or composite paving grids are used for asphalt reinforcement in pavements.

With moisture barrier function of paving fabric, it will not allow moisture to reach granular layers and which also prevents propagation of crack and also acts as (Stress Absorbing Membrane Interlayer) SAMI layer.

Paving grids are with square apertures and laid with minimum cover of bituminous layers. Paving Grid strengths are decided, considering the stresses to be absorbed.

Considering above two generic products, for combined benefit of moisture barrier and stress absorbing functions, composites are needed. A Grid combined with a Paving Fabric it is called a Composite (Geocomposite). Composites provide the membrane and also high strength reinforcement. Asphalt Interlayer composite is made from Nonwoven Geotextile knitted with Fibre Glass yarn, will provide dual functions. Composites are stiffer materials with less or minimal elongation and require slower installation speeds.

Table 1.1 Comparison between Paving Fabric, Fibre-Glass Grid and AIC

Sr. No.	Property	Paving Fabric	Fibre-Glass Grid	AIC
1.	Tensile Strength	Low	High	High
2.	Moisture Barrier	High	Low	High
3.	Stress Absorbing Member Interlayer (SAMI)	High	Low	High
4.	Bitumen Retention	High	Low	High

1.6 Drainage

Drainage is collecting and transporting of precipitation, ground water, and/or other fluids in the plane of a geosynthetic material. A suitable permeable geosynthetic material provides a filtration function which serves the same role in soil structures as the various gradation of granular material.

1.7 Moisture Barrier

The barrier function refers to the prevention or limits the migration of fluid across the plane of the geosynthetic material. This geosynthetic function has wide application in asphalt pavement overlays and encapsulation of swelling soils. A nonwoven geotextile provides a barrier function when saturated with an impermeable material like, bitumen. In this application, the geotextile is saturated with a bitumen-based material (tack coat) and the new overlay is placed directly onto the geotextile. The geotextile-tack coat combination prevents the movement of water from the surface of the overlay into the pavement layers and vice-versa.

1.8 Erosion Control

Use of a geosynthetic material is to prevent or limit soil or other particle movements at the surface of a slope due to water run-off and/or wind forces.

In addition to the primary function, Geosynthetics usually perform one or more secondary functions. The primary and secondary functions of geosynthetic make up the total contribution material in better way to a particular application. It is important to consider both the primary and secondary functions in the design computations and specifications.

Table 1.2 Primary Functions of Geosynthetics

Type of Geosynthetic	Primary Functions of Geosynthetics					
	Separation	Reinforcement	Filtration	Drainage	Impermeable Barrier	Erosion Control
Geotextile	✓	✓	✓	✓		✓
Geogrid		✓				✓
Geo Membrane	✓				✓	
Geonets				✓		✓
Geospacer	✓			✓	✓	
Geocell		✓				✓
Geomat				✓		✓
Paving Fabric					✓	
Paving Grid		✓				
Geo Composite	✓	✓	✓	✓	✓	✓

Note: The given matrix of primary functions is indicative only; each product can have multiple functions as per site conditions.

Use and selection of geosynthetics in pavements has to be analysed based on site conditions, applicability and project specific requirements with judgement of Engineer in Charge. However, before actually begin with design, a designer must give due consideration to “Engineering” and “Economic” factors involved in design.

1.9 Applicability and Benefits of Geosynthetics in Roadways

1.9.1 *Areas of Application of Geosynthetics in Roads and Pavements*

The four main applications for geosynthetics in roads are subgrade separation, stabilization, base or subbase reinforcement, and overlay stabilization. Subgrade stabilization and base or subbase reinforcement involve improving the road structure as it is constructed by inserting an appropriate geosynthetic material.

Conventional construction material like aggregates is becoming progressively scarce on account of environmental concerns as well as legal restrictions on quarrying while the construction activity has expanded phenomenally. This has shifted focus from large scale use of conventional aggregates to use of local, recycled and engineered marginal aggregates in construction. Geosynthetics can enhance the properties of such recycled and engineered marginal aggregates in construction.

Geosynthetics are also helpful in rehabilitating the distressed road surfaces. The application of a layer of bituminous concrete called an overlay is often the solution for damaged pavement. Geosynthetics can be used as inter-layers by placing them below or within the overlay. Some geosynthetics relieve stress and others are able to reinforce the overlay. The products may also provide a moisture barrier. The following are the applications of geosynthetics in roadways and pavements in brief:

- Subgrade separation and stabilization
- Base or subbase stabilization by reinforcement
- Overlay stress absorption and reinforcement

➢ In Subsurface Drainage

- Subgrade dewatering
- Base or subbase drainage

➢ In Erosion and Sediment Control

- Beneath the hard armor systems, revetments

➢ In Seepage Control Systems

- Structure water proofing
- Environmental protection

Table 1.3 Application Areas of Geosynthetics

S. No.	Application	Description
1	Pavement stabilization and reinforcement	Pavement stabilization and reinforcement involves stabilizing and reinforcing different layers of the pavement to provide subgrade restraint, to stabilize the base and/or sub base, to reinforce the bound layers i.e. surface course to increase the service life of the pavement by preventing fatigue and reflective cracks.
2	Drainage	Draining out of water ingressed through the pavement structure and prevention of capillary action and moisture control need to be taken care
3	Moisture Control	It is related to enhance and lengthen pavement performance by reducing the influence of moisture on pavement materials
4	Erosion control	It refers to the protection of the top surface of the exposed slopes, surfaces.

1.9.2 *Temporary roads, diversions and working platforms in roadway and pavement systems*

Geosynthetics are used in temporary roads to reduce rutting of the gravel surface and/or to decrease the amount of gravel required to support the anticipated traffic. Furthermore, the geosynthetic helps to maintain the aggregate thickness over the life of the temporary road. Where the soils are normally too weak to support the initial construction work, geosynthetics in combination with gravel provide a working platform to allow construction equipments access to sites. This is one of the most important uses of geosynthetics. Even if the finished roadway can be supported by the subgrade, it may be virtually impossible to begin construction of the embankment or roadway. Such sites require stabilization by dewatering, de-mucking, excavation and replacement with selected granular materials, utilization of stabilization aggregate, chemical stabilization, etc. Geosynthetics can often be a cost effective alternate to these expensive foundation treatment procedures.

1.9.3 *Permanent paved and unpaved roads*

For permanent road construction, a temporary working platform can be constructed to provide an improved roadbed using geogrid reinforcements with an aggregate layer to provide a form of mechanical stabilization. This mechanically stabilized aggregate layer enables contractors to meet minimum compaction specifications for the first two or three aggregate lifts. This is especially true on very soft, wet subgrade, where the use of ordinary compaction equipment is very difficult or even impossible. Long term, a geogrid or, in some cases, a geocomposite acts to maintain the roadway design section and the base course material integrity. Thus, the geosynthetic will ultimately increase the life of the roadway.

Another geogrid application in roadways is to place the geogrid or geocomposite at the bottom or within the base course to provide reinforcement through lateral confinement of the aggregate layer. Lateral confinement arises from the development of interface shear stresses between the aggregate and the reinforcement and occurs during placement, compaction, and traffic loading. A small residual restraint remains after each load application, thus increasing the lateral confinement of the aggregate with increasing load applications. Base reinforcement thus improves the long-term structural support for the base materials and reduces permanent deformation in the roadway section and has been found under certain conditions to provide significant improvement in pavement performance.

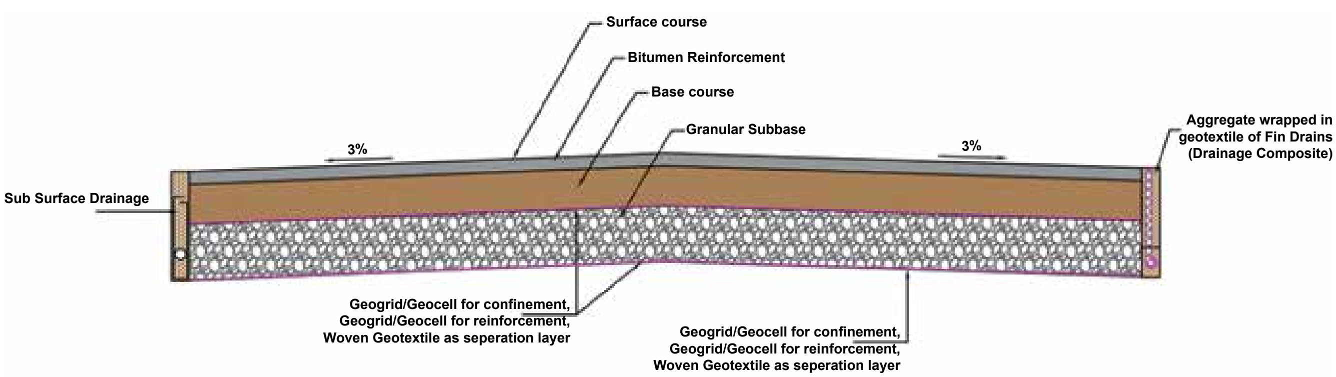


Fig 1.11 Potential Applications and Typical Location of Geosynthetics in Layered Pavement System

Note: The location of Geosynthetics would depend on other factors such as terrain, its application and type of geotextile material.

CHAPTER - 2
PROPERTIES AND TEST METHODS FOR DIFFERENT GEOSYNTHETIC MATERIALS

Geosynthetic Materials shall be Tested and Certified in the following manner:

- The manufacturer shall have ISO or CE certification for manufacturing process and quality control.
- The manufacturer shall provide manufacturer's test certificate for every lot supplied from the factory.
- The supplier shall provide third party test reports from an independent laboratory with valid accreditation for all the test values in Manufacturer's test certificate.

Geosynthetics shall be tested in accordance with tests prescribed by relevant BIS, ISO, ASTM, EN or BS shall be conducted.

2.1 Typical and Minimum Average Roll Values of the Geosynthetics

2.1.1 The term 'Typical Value' and Minimum Average Roll Value; both relate to the variability inherent in geosynthetic material properties. This variability stems from the manufacturing process and is similar to that which occurs with all construction materials, including concrete and steel. Geosynthetics manufacturers continuously perform Quality Control (QC) testing to monitor the physical properties of their products. Using the result of this testing, manufacturer can represent physical properties statistically in normal distribution curves as shown in **Fig. 2.1**.

2.1.2 The "typical" value refers to the average or mean value and is valid for any geosynthetic material. As shown in **Fig. 2.1 (a)** 50 per cent of the test results can be expected to exceed this value and 50 per cent can be expected to fall below this value. The 'minimum average roll value" (MARV) is 97.7 per cent as per clause no. 3.1 IS 16362 as shown in **Fig. 2.1 (b)**. The MARV is derived statistically as the average value minus two standard deviations.

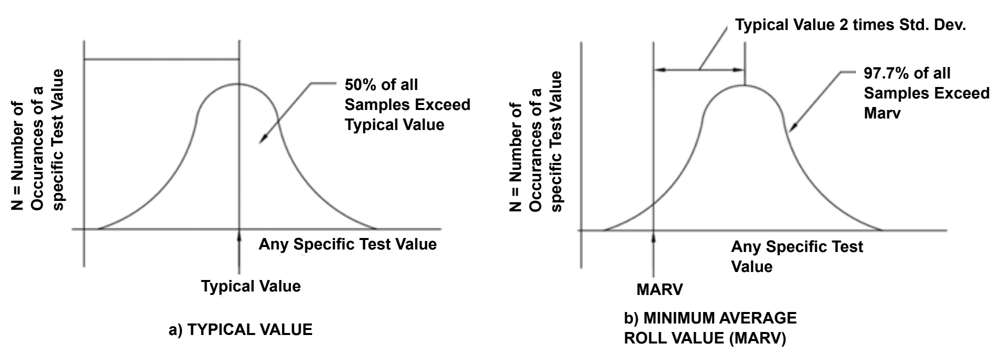


Fig. 2.1 Statistical Distribution of the Geosynthetic Material Properties

2.1.3 Specification sheet of a geosynthetic material should list the physical properties required to serve its intended function. The civil engineering community has adopted standards for verifying the physical properties of geosynthetic material in accordance with the MARV. A specification based on the MARV means that 97.7 per cent of the product is required to meet or exceed the specified values. In contrast, if a manufacturer certifies to higher "typical" values only lesser percentage of the product would meet the specified values.

2.1.4 Designers must rely on a statistical basis for assuring that the geosynthetic materials delivered to the job meet the specifications. On any given project, the minimum average roll value must meet or exceed the designer's specified value for the product to be acceptable.

2.2 Geotextile

This section gives an insight into various properties of geotextiles and test methods in use or currently favoured for testing of geotextiles as per existing worldwide standards. This section has been subdivided into following three major categories:

- Physical properties
- Mechanical properties
- Hydraulic properties

2.2.1 *Physical properties:* The properties, discussed in the subsection, refer to fabric in its manufactured or as received condition. Physical properties are considered to be index properties of geotextiles.

2.2.1.1 *Specific gravity:* Specific gravity is defined as the ratio of material's unit volume weight (without any voids) to that of distilled, de-aired water at 27°C. The specific gravity of fibres from which geotextiles are made is actually the specific gravity of the polymer raw material (ISO 1183, ASTM D792 or ASTM D1505). Some typical values of specific gravity of commonly used polymeric materials made into geotextiles are as follows:

Polypropylene	:	0.91
Polyester	:	1.22 to 1.38
Nylon	:	1.05 to 1.14
Polyethylene	:	0.90 to 0.96
Polyvinyl chloride	:	1.69

2.2.1.2 *Mass per unit area (weight):* Mass per unit area governs the fabric cost and normally mechanical properties are directly related to it. Test wise, the mass (weight) should be measured to the nearest 0.01 per cent of the total specimen mass. Length and width should be measured under zero tension induced in geotextile. Methods for this test are based on ISO 9864, IS 14716 and ASTM D5261. The geotextiles mass per unit area is given in grams per square meter. The range of typical values for most geotextiles is from 100 to 1000 gm/m^2.

2.2.1.3 *Thickness:* Thickness is measured as the distance between the upper and the lower surface of the fabric, measured at a specified pressure. ISO 9863-1, IS 13162 (Part 3) and ASTM D5199 stipulates that thickness is to be measured to an accuracy of at least 0.01 mm under a pressure of 2 kPa. According to ISO the thickness should be measured after 30 seconds of application of full force, where, as per ASTM the duration is 5 seconds only. The thickness of the commonly used geotextiles ranges from 0.25 to 7.5 mm.

2.2.2 *Mechanical properties:* The mechanical properties to be discussed here indicate the geotextiles resistance to tensile stresses mobilized under applied loads and/or installation conditions. The index tests such as wide width tensile strength, grab strength, puncture strength and sewn seam strength are used for determining the mechanical properties of the geotextiles.

2.2.2.1 Tensile strength: ISO 10319 or IS 13325 or ASTM D4595 gives test method for the determination of the tensile properties of geotextile and related products, using a wide-width strip. This test is applicable to most of the geotextile families including woven, non-woven, geo composites, knitted fabrics and felts. The reason wide-width specimens are necessary that geotextiles when tensioned tend to have a severe necking effect under increasing stress and they rope up, giving artificially high values. Thus, the tendency for design-related tests is to use wide-width specimens.

Grab strength test will also be applicable for the determination of tensile properties of geotextiles. ISO 13934 or IS 16342 or ASTM D4632 shall be used to evaluate the grab strength of geotextiles. Narrow Strip Test as per ASTM D751 is another tensile test method.

2.2.2.2 Puncture strength: This test is conducted to make an assessment of geotextile resistance to objects, such as, rocks or pieces of wood under quasi-static conditions and reported as N or kN. Such a test described under ISO 12236, IS:13162 (Part 4) and ASTM D6241, IS 16078 shall be used to evaluate the CBR puncture strength of geotextiles.

2.2.2.3 Sewn seam strength: Seam strength is typically evaluated in the laboratory using ISO 10321 “Geosynthetics- Tensile test for joints/seams by wide-width strip method” or IS 15060 or ASTM D4884, “Test Method for Seam Strength of Sewn or Thermally Bonded Seams of Geotextiles”. This method tests 200 mm wide specimen and the results have been shown to correlate accurately to anticipated field seam strength.

2.2.3 *Hydraulic properties*

Filter system flow capacity or flow rate, q is the quantity of water, which will pass through the system in a given period of time. Flow capacity is usually expressed in cm^3/sec or cm^3/sec/m^2. Properties of both the soil and geotextile influence the hydraulic characteristics of the soil/geotextile system. Two important properties are soil permeability and geotextile permittivity. Other properties are listed in **Table 2.1**.

Table 2.1 Soil/Geotextile Filter System Properties

Soil	Geotextile
Permeability	Permittivity
Grain size distribution	Apparent opening size
Plasticity	Per cent open area
Dispersivity	Structure
Compaction and confinement	Durability

2.2.3.1 Apparent opening size (AOS): The Apparent Opening Size (AOS) or the Equivalent Opening Size (EOS) is a measure of the largest effective opening in a geotextile. It can be measured using the procedure described below:

Standard Test Methods for Determining Apparent Opening Size of a Geotextile are ISO 12956 (using the wet sieving principle), IS:14294 and ASTM D4751 (using the dry sieving principle). This test method covers the determination the Apparent Opening Size (AOS) of a geotextile by sieving glass beads through a geotextile.

Table 2.2 Geotextile Properties and Testing Methods

Property	**Test Method**
Specific gravity	ASTM D792 or ASTM D1505
Mass per unit area	IS:14716, ISO 9864, ASTM D5261
Thickness	IS:13162 (Part 3), ISO 9863, ASTM D5199
Tensile strength i. Grab strength test ii. Narrow strip test	IS:13325, ISO 10319, ASTM D4595 IS:16342, ISO 13934, ASTM D4632, ASTM D751
Puncture strength	IS:13162 (Part 4), IS:16078 (For CBR Puncture strength), ISO 12236, ASTM D6241
Sewn seam strength	ASTM D4884
Apparent Opening Size (AOS)/Characteristic Opening Size (COS)	IS:14294, ISO 12956, ASTM D4751
Permittivity	IS:14324, ISO 11058, ASTM D4491
Clogging potential i. Gradient ratio test ii. Hydraulic conductivity ratio test	IS:16389 ASTM D5101 ASTM D5567

2.2.3.2 Geotextile permittivity: Permittivity ψ is laboratory measured characteristic of the geotextile. Permittivity is measured using the index test method ISO 11058, IS:14324 and ASTM D4491.

2.2.3.3 Determination of clogging potential of geotextile: IS:16389 "Geosynthetics - Method of Test for Biological Clogging of Geotextile or Soil/Geotextile Filters" shall be used to determine clogging potential of geotextiles. There are two test methods available to evaluate flow capacity of a soil/geotextile system: first one by ASTM D5101, the "Gradient Ratio" and the other by "Hydraulic Conductivity Ratio (HCR) Test". In this test, the soil is compacted and is placed under a confining pressure to simulate field conditions. The HCR testing of soil/geotextile systems can be conducted using ASTM D5567 method.

2.3 Geogrid

The primary function of geogrid is improving the geotechnical material property by reinforcing and stabilizing. Based on the function and applications of geogrid, its properties are classified generally into three categories like, physical, mechanical and endurance properties.

2.3.1 *Physical properties:* Many of the physical properties of geogrids-including the type of structure, rib dimensions, junction type, aperture size and thickness can be measured directly and are relatively straightforward.

2.3.2 *Mechanical properties:* As reinforcing is the main function of geogrid, the tensile strength of single rib or at junction of geogrid is considered as mechanical properties of geogrid. The tensile strength is the maximum resistance to tensile stresses mobilized under applied loads and/or installation conditions. Nodal strength test and wide width strength tests are general tests to be conducted to determine the tensile strength of geogrids.

2.3.2.1 Single rib and junction (nodal strength): The initial tendency when assessing a geogrid's tensile strength is to pull a single rib in tension until failure and then to note its behaviour. A single rib tension strength test merely uses a constant rate-of-extension testing machine to pull a single rib to failure, as described in ASTM D6637. For unidirectional geogrids, this would most likely be a longitudinal rib. For bidirectional geogrids, both longitudinal and transverse ribs require evaluation. By knowing the repeat pattern of the ribs, equivalent wide-width strength can be calculated. Alternatively, a number of ribs can be tested simultaneously to obtain a more statistically accurate value for the wide-width strength. Geogrid for use as reinforcement of base and sub-base layers of flexible pavements shall be tested according to the references mentioned in **Table 2.3**.

Table 2.3 Test Methods of Geogrid for Base and Subbase Stabilization of Flexible Pavement

Property	Test Method
Tensile strength and/or stiffness @ 0.5 % strain	ISO 10319
Tensile strength @ 2% strain	ISO 10319
Tensile strength @ 5% strain	ISO 10319
Junction strength	ASTM D7737
Geogrid aperture MD/CMD	Direct scale measurement by using scale or ruler

2.3.2.2 Wide-width tensile strength: Clearly the wide-width tensile strength of a geogrid, in its machine direction for unidirectional geogrids and in both machine and cross-machine directions for bidirectional geogrids, is of prime importance. ISO 10319 or IS 13325 or ASTM D6637 wide-width strength testing of geogrids can be referred to determine the tensile strength of geogrids.

2.3.3 *Endurance properties:* As geogrids are used in critical reinforcement applications, some of which require long service lifetime; it is generally necessary to evaluate selected endurance properties. Installation damage, creep and accelerated test methods will be addressed in this section.

2.3.3.1 Installation damage: As with all geosynthetic, the placement of geogrids in the field requires a considerable degree of planning and care. As happens all too often with careless field construction crews and heavy machinery, installation damage of the geogrid can occur. Other uncertainties in this same area are coarse soil impingement, falling objects and other accidents that may occur before the geogrid is covered. There is a formalized procedure available to assess installation damage as per ISO 10722. ASTM D5818-06 may be referred for exposure and retrieval of sample to evaluate installation damage of geosynthetics.

Generally, the higher strength-loss values come about where large, poorly graded, quarried aggregate is used and heavy construction equipment performs the placement and compaction. If it is necessary to use such materials and methods; it is prudent to first place a cushioning layer of sand above and sometimes below the geogrid.

2.3.3.2 Tensile creep behaviour: Sustained-load deformation or tensioned creep is one of the major endurance properties of geogrid. Since geogrids are manufactured from polymers consisting of long-molecules arranged in crystalline regions with interspersed amorphous regions, the creep response reflects upon the per cent crystallinity.

Creep is predominantly a function of stress level, time, temperature and a number of environmental factors. The tensile creep test has been adopted from ISO 13431, ASTM D6992 and ASTM D5262. Consideration of creep reduction factor for reinforcement application of geosynthetics in reinforced soil systems reference may be made to IRC:SP:102, MoRTH Section 3100.

2.3.4 *Degradation issues:* For all types of geogrids being used in permanent reinforcement applications, it is generally necessary to evaluate selected degradation considerations. This section briefly discusses some of these issues.

2.3.4.1 *Temperature effects:* Given the temperature ranges of typical environments, temperature extremes (hot or cold) should have no serious adverse effects on geogrids. The one caution is that high temperature can exhibit strains arising from tension creep, creep rupture, and/or stress relaxation.

2.3.4.2 *Oxidation effects:* EN ISO 13438 test method can be used for determining the resistance to oxidation (ISO 13438).This method for screening the resistance to oxidation, in particular applicable to polypropylene and polyethylene based products.

2.4 Geomembrane

2.4.1 *Physical properties:* Physical properties have to do with the geomembranes in an as-manufactured and/or as-received state. They are important for quality control, quality assurance and proper identification.

2.4.1.1 *Thickness:* Depending on the type of geomembranes, there are three types of thickness to be considered: (1) Thickness of smooth sheet, (2) The core thickness of textured sheet, and (3) Thickness (or height) of the asperities of textured sheet.

Smooth Sheet: The determination of the thickness of a smooth geomembranes is performed by a straightforward measurement. The test uses an enlarged-area micrometer under a specified pressure, resulting in the desired value. ISO 09863 and ASTM D5199 is the test methods generally used for measuring geomembranes thickness.

Textured Sheet: The roughened surface of a textured geomembranes results in a significant increase in its interface friction with adjacent materials versus the same geomembranes with a smooth surface. The thickness of such textured sheets is measured as the minimum core thickness between the roughened peaks or asperities. To measure the core thickness, a tapered-point micrometer for measuring machine screw threads is recommended. The tapered point dimensions as per ASTM D5994 are a 60° angle with the extreme tip at 0.08 mm diameter. The normal load on tapered point is 0.56N.

Asperity Height: For textured geomembranes, the height of the asperity is of interest inso far as it relates to mobilizing the desired amount of interface shear strength with the opposing surface. Less involved, but still useful as a quality control and quality assurance method, is to merely measure the height of the asperities per ASTM D7466.

2.4.1.2 *Melt (flow) index:* The melt-flow index or melt index (MI) test should be used by geomembranes manufacturers as a method of controlling polymer uniformity and process ability. The test method often used for geomembranes polymers is ASTM D1238.

2.4.1.3 *Mass per unit area (weight):* This test is straightforward to perform and usually follows ISO 9864 or ASTM D3776 procedures.

2.4.2 *Mechanical properties*

2.4.2.1 *Tensile behaviour:* The test procedures generally used are covered in ISO 527-3, ASTM D6693 or as well as ASTM D6392, D882, D751, and D413.

2.4.2.2 *Tear resistance:* The measurement of tear resistance of a geomembrane can be done using ASTM D1004. ASTM D1004 uses a template to form a test specimen shaped such as to have a 90˚ angle where tear can begin to propagate.

2.4.2.3 *Puncture resistance:* To measure puncture resistance ASTM D4833 is often used since it is the test method used by manufacturers for quality control purposes.

2.4.3 *Endurance properties*

2.4.3.1 *Oxidation:* There are two related test methods that are used to track the amount and/or depletion of antioxidants. They are called Oxidative Induction Time (OIT) tests.

Standard OIT (ISO 11357 or ASTM D3895): The oxidation is conducted at 35 kPa and 200°C. This test appears to misrepresent antioxidant packages containing thiosynergists and/or hindered amines due to the relatively high test temperature.

High Pressure OIT (ASTM D5885): The oxidation is conducted at 3500 kPa and 150°C. This test can be used for all types of antioxidant packages and is the preferred test.

A summary of properties of geomembranes and testing procedure is listed in **Table 2.4** below:

Table 2.4 Properties and Test Method Standards for Geomembranes

Test	Test Method
Density	ASTM D792
Melt flow index	ASTM D1238
Carbon black content	ASTM D1603
Carbon black dispersion	ASTM D5596
Oxidative Induction Time (OIT) Standard OIT High Pressure OIT	ISO 11357, ASTM D3895, ASTM D5855
Low temperature brittleness	UNE 104302
Water absorption	EN ISO 62
Asperity height	GRI GM 12
Thickness	ISO 9863, ASTM D5199
Puncture resistance	ASTM D4833/ASTM D5494
Tear Resistance	ASTM D1004

Test	Test Method
Dimensional stability	ASTM D1204
Tensile strength and elongation	ISO 527-3, ASTM D6693/ ASTM D638
Tensile strength (Wide Width Strip Method)	ASTM D4885
Integrity	ASTM D4437/ASTM D6392

2.5 Geonet/Geospacer

The primary function of a geonet/geospacer is to convey liquid within the plane of its structure. The inplane flow rate or Transmissivity is an important design parameter. However, other features, which may influence this value over the service lifetime of the geonet, are also of importance. Thus a number of physical, mechanical, endurance, and environmental properties will also be presented in this section.

2.5.1 *Physical properties*

2.5.1.1 Density: The density or specific gravity of the polymer is an important property and it can be evaluated either by ASTM D1505 or D792.

2.5.1.2 Thickness: Thickness can be determined using ISO 9863/IS 13162 Part-3, ASTM D5199.

2.5.1.3 Mass per unit area: This can be determined using ISO 9864/ASTM D3776. Other physical properties such as rib dimensions, planar angles made by the intersecting ribs, cross-planar angles made at the juncture locations, aperture size and shape can be measured directly.

2.5.2 *Mechanical properties*

2.5.2.1 Tensile strength and elongation: ISO 10319 or IS 13325 or ASTM D4595 gives index test method for the determination of the tensile properties of geonet/geospacer, using a wide-width strip.

2.5.2.2 Compressive strength and deformation: ASTM D6364, "Standard method for determining the short-term compressive strength of geosynthetic" is used to evaluate the short-term compressive strength parameters of geonet.

2.5.2.3 Shear strength: The appropriate interface shear test method is ISO 12957-1 or ASTM D5321, and it is obviously a product-specific and site-specific test that must be performed for each set of conditions that arise.

2.5.3 *Hydraulic properties*

The in-plane hydraulic test to determine planar flow rate, or transmissivity, of geonets should be performed using ISO 12958 and ASTM D4716. Both test methods use a planar transmissivity device and not the radial transmissivity device this is necessary because the flow regime in a geonet is surely turbulent (consisting of irregular flow paths and eddies).

2.5.4 *Endurance properties:* The major endurance properties of concern when using geonets have to do with the long-term sustained deformation of the material and its ability to continue to transmit the required in-plane flow rate.

Type of polyethylene resin: Depending upon the type of polyethylene resin, primarily characterized by its density, the geonet will have different mechanical and endurance properties. The high density resins (e.g., greater than 0.950 mg/l), will result in relatively high modulus, high strength and high creep resistance. Conversely, lower density resins (e.g., less than 0.945 mg/l) will be more flexible and can deform under high compressive stresses more easily.

Intrusion of adjacent materials into the geonet's apertures: All geospacers or geonets will necessarily be covered on their upper and lower surfaces with geotextiles, geomembranes, concrete wall surface, or some other material. If the geonet's surfaces are not covered, the adjacent soil will invade its apertures, rendering flow impossible. For this reason all flow tests should be conducted with soft foam rubber platens on both sides to simulate soil intrusion, unless the designer can demonstrate that hard platens on one or both sides are representative of the conditions that the drainage core will encounter during operations. Intrusion refers to the deformation of the flexible covering materials, primarily geotextiles, occupying some of the geonet's void space.

Table 2.5 Geonet Properties and Test Methods

Test	Test Method
Density (g/cm^3)	ASTM D792
Mass per Unit Area	ASTM D3776
Wide width Tensile Strength (MD)	ISO 10319/ASTM D4595
Flow capacity	ISO 12958/ASTM D4716
Thickness at 20kPa	EN ISO 9863-1

2.6 Geocell

Geocell is the three dimensional structure element with interconnected cells made of polyester/ polypropylene/high density polyethylene stabilized with carbon black. Stabilization by providing lateral confinement is the main function of Geocell. It has various properties classified as physical, mechanical and chemical properties. **Table 2.6** represents the different properties and test methods for the Geocell.

Table 2.6 Material Test Methods for Geocell

Test Properties	Test Method
Wall Thickness Nominal	ASTM D5199
Seam Efficiency (min. avg)	GRI-GS13
Density (min. avg.)	ASTM D1505/D792

Test Properties	Test Method
Tensile Properties (min. avg.) (1) yield strength break strength yield elongation break elongation	ASTM D6693
Seam Peel Strength i. Method A ii. Method B	US – ACE GL -86 – 19 ISO 13426-1 (Method B)
Seam Hang Strength (Pass on temperature variation from 23°C-54°C with dead weight of 72.5 kg for 7 days)	ASTM D751
Tear Resistance (min. avg.)	ASTM D1004
Puncture Resistance (min. avg.)	ASTM D4833
Carbon Black Content (range) (2)	ASTM D4218
Carbon Black Dispersion (3)	ASTM D5596
Direct Shear Friction Angle (4)	ASTM D5321
Oxidative Induction Time (OIT) (min. avg.) (5) (a) Standard OIT — or — (b) High Pressure OIT	ASTM D3895 or ASTM D5885
Oven Aging at 85°C (5) (a) Standard OIT (min. avg.) - % retained after 90 days (b) High Pressure OIT (min. avg.) - % retained after 90 days	ASTM D5721 ASTM D3895 ASTM D5885
UV Resistance (6) (a) Standard OIT (min. avg.) — or — (b) High Pressure OIT (min. avg.) - % retained after 1600 hrs (8)	ASTM D7238 ASTM D3895 ASTM D5885
Environmental Stress Crack Resistance	ASTM D1693
NCTL stress crack resistance	ASTM D5397
Resistance to weathering (Min. 95% retained strength)	EN ISO 12224
Resistance to oxidation (min. 28 days)	EN ISO 13438

Note:

(1) Machine Direction (MD) and Cross Machine Direction (CMD) average values should be on the basis of five test specimens each direction. Yield elongation is calculated using a gauge length of 33 mm. Break elongation is calculated using a gauge length of 50 mm.

(2) Other methods such as D1603 (tube furnace) or D6370 (TGA) are acceptable if an appropriate correlation to D4218 (muffle furnace) can be established.

(3) Carbon black dispersion (only near spherical agglomerates) for 10 different views: 9 in Categories 1 or 2 and 1 in Category 3

(4) Actual geocell strip against well graded sand

(5) The manufacturer has the option to select either one of the OIT (oxidative induction time) methods listed to evaluate the antioxidant content in the geomembranes.

(6) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. Condensation at 60°C.

(7) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(8) UV resistance is based on per cent retained value regardless of the original HP-OIT value.

2.7 Geomat

Geomats are permeable material made of bonded filaments, layers of geogrids (folded and knitted or bonded together). They can be used for permanent erosion control problems. The roots of grass and small plants act as reinforcement for vegetation. These are two-dimensional or three-dimensional mats with specified thickness, made of multi-filaments, layers of geogrids (folded and knitted or bonded together), with apertures to allow vegetation growth for erosion control application.

2.7.1 *Physical properties*

2.7.1.1 Thickness: The thickness of geosynthetic mats can be determined using ISO 9863 or ASTM D5261, “Standard method for measuring nominal thickness of permanent rolled erosion control products”.

2.7.1.2 Mass per unit area: This can be determined using ISO 9864/ASTM D3776.

2.7.2 *Mechanical properties*

2.7.2.1 Tensile strength: Tensile strength of geosynthetic mats can be determined using ISO 10319 or ASTM D4595, for wide width tensile test. In this method, a test specimen is clamped in a tensile testing machine and a force applied to the specimen until it breaks.

2.8 Asphalt Reinforcement

2.8.1 *Physical properties*

2.8.1.1 Thickness: The thickness of paving fabric can be determined using ISO 09863, ASTM D5199.

2.8.1.2 Weight: Methods for the determination of weight are ISO 9864 and ASTM D5261. The paving fabric’s mass per unit area is given in grams per square meter.

2.8.2 *Mechanical properties*

2.8.2.1 Tensile strength: Wide width tensile tests as per EN ISO 10319 or ASTM D4595 or are used to determine the tensile strength of paving fabric. Other properties of paving fabric are represented in **Table 2.7**.

Table 2.7 Different Properties and Test Methods of Paving Fabric

Property	Test Standard	Unit
Static Puncture (CBR-test)	EN ISO 12236/ASTM D6241	N
Dynamic Perforation (Cone Drop)	EN ISO 13433	mm
Bitumen Retention	ASTM D6140	kg/m^2
Melting point	EN ISO 3146/ASTM D276	°C

2.8.2.2 Tensile properties: The tensile properties of asphalt reinforcing geogrid's shall be determined as per ISO 10319 or ASTM D4595, "Standard test method for determining tensile properties of geogrids by the single or multi-rib tensile method".

2.8.2.3 Melting point: Melting point can be determined as per ASTM D276, "Standard Test Methods for Identification of Fibres in Textiles".

Table 2.8 Different Properties and Test Methods of Asphalt Reinforcing Geogrid

Property	Units	Code
Tensile strength	kN/m	ISO 10319/ASTM D6637
% Elongation at break	%	ISO 10319/ASTM D6637
Mesh Opening Size	mm	
Melting Point	°C	ISO 3146/ASTM D276
Tensile Resistance @ 2% Strain	kN/m	ASTM D6637/ISO 10319
Secant Stiffness EA @1% strain	N/mm	ASTM D6637/EN ISO 10319
Young Modulus E (MPa) (For Glass Fibre)	MPa	

2.9 Geocomposite

As geocomposite is a combination of two or more different geosynthetic materials, the properties confirming to the individual geosynthetic constituting a geocomposite will be valid for geocomposite also. **Table 2.9** presents the different properties and corresponding test methods of Geocomposites.

Table 2.9 Different Properties and Test Methods of Geocomposite for Drainage

Properties	Reference Standard	Unit of Measurement
Geotextile Properties		
Pore Size O_{90}/AOS	EN ISO 12956/ASTM D4751/IS 14294	mm

Properties	Reference Standard	Unit of Measurement
Permeability/Permittivity	EN ISO 11058/ASTM D4491/IS 14324	l/m^2.sec
Tensile Strength	EN ISO 10319/ASTM D4595	kN/m
Thickness at 2kPa	EN ISO 9863-1	mm
CBR puncture resistance	EN IS0 12236	N
Dynamic perforation cone drop	EN ISO 13433	mm
Property of Drainage Core		
Mass per Unit Area	EN ISO 9864/ASTM D3776	g/m^2
Long Term Creep	ASTM D7361	%
Thickness at 20kPa	EN ISO 9863-1	mm
Property of composite material		
Wide width Tensile Strength	EN ISO 10319/ASTM D4595	kN/m
CBR Puncture Resistance	EN ISO 12236/ASTM D6241/IS 13162	kN
Mass per Unit Area	EN ISO 9864/ASTM D3776	g/m^2
Inplane flow capacity (i=1)	EN ISO 12958	
@ 20 kPa		l/m.sec
@ 50 kPa		l/m.sec
@ 100 kPa		l/m.sec
@ 200 kPa		l/m.sec
@ 400 kPa		l/m.sec
Thickness at 20 kPa	EN ISO 9863/ASTM D5199	mm
In-plane flow capacity (i=0.1)	EN ISO 12958	
@ 20 kPa		l/m.sec
@50 kPa		l/m.sec
@ 100 kPa		l/m.sec
@ 200 kPa		l/m.sec
@ 400 kPa		l/m.sec

CHAPTER - 3
DESIGN METHODOLOGIES

General

The performance of reinforced road structures relies heavily on the condition of surrounding materials and on the traffic loads and therefore each design requires specific analysis and calculations.

Proposed design methods for different functions of geosynthetics such as reinforcement, separation, drainage, filtration in pavement section are either based on empirical and analytical considerations or analytical models modified by experimental data. To date, a general analytical design solution has not been found that addresses all of the many variables that impact performance. All empirical design methods are limited by the conditions associated with the experiments of the study. Several methods are based on obtaining a performance level (Traffic Benefit Ratio [TBR] or Base Course Reduction [BCR]) from a laboratory model test. The lab test results must be extrapolated to field conditions for application to design. For a given set of conditions, many of the methods produce reliable results. This chapter provides the currently available and generally used design methodologies for several functions described in these guidelines.

Material properties, specifications and minimum thickness requirements of each pavement layer will remain same as specified in other relevant codes, guidelines for pavement construction (IRC:37 and other relevant codes). The surface and subsurface drainage of the pavement shall comply with provisions of IRC:SP:42.

3.1 Design for Reinforcement of Unbound Pavement Layers

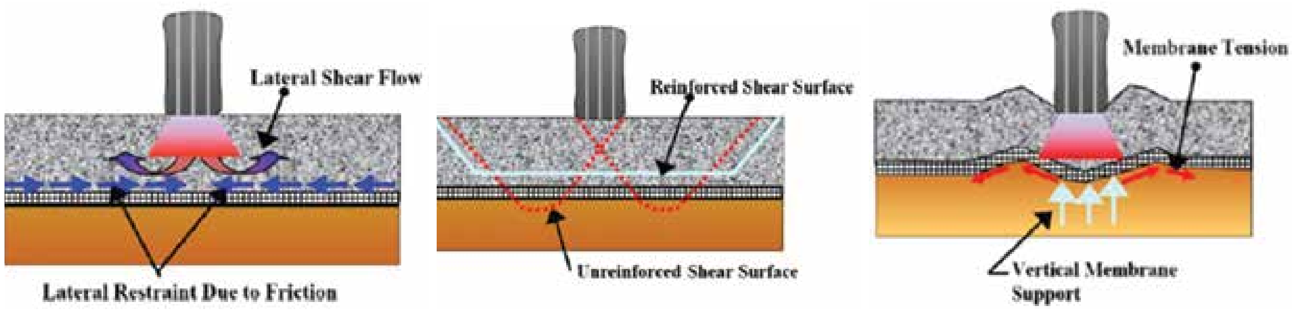
Pavement reinforcement involves reinforcing different layers of the pavement. Geosynthetics are incorporated into base and subbase section for following reasons:

1. To provide subgrade restraint for construction of the road over weak subgrade conditions.
2. To reinforce the base and/or sub base

3.1.1 *Basic mechanism*

Basic mechanism of reinforcement can be identified as (a) lateral restraint, (b) improved bearing capacity, and (c) tensioned membrane effect.

Lateral restraint (**Fig. 3.1(a)**) refers to the confinement of the aggregate material during loading, which restricts lateral flow of the material from beneath the load. Since most aggregates used in pavement systems are stress-dependent materials, improved lateral confinement results in an increase in the modulus of the base course material. The effect of increasing the modulus of the base course is an improved vertical stress distribution applied to the subgrade and a corresponding reduction in the vertical strain on the top of the subgrade. Improved bearing capacity is achieved by shifting the failure envelope of the pavement system from the relatively weak subgrade to the relatively strong base course material (**Fig. 3.1(b)**). The third fundamental reinforcement mechanism has been termed the "tensioned membrane effect." The tensioned membrane effect (**Fig. 3.1(c)**) is based upon the concept of an improved vertical stress distribution resulting from tensile stress in a deformed membrane.



(a) (b) (c)

Fig. 3.1 Mechanism of Reinforcement: (a) Lateral Restrain Effect, (b) Improved Bearing Capacity, (c) Tension Membrane Effect

3.1.2 *Design of geogrid reinforced flexible pavements*

Geogrid reinforced flexible pavement section can be designed based on two design approaches i.e. MEPDG (Mechanistic-Empirical Pavement Design Guide) method following MIF (Modulus Improvement Factor) and Modified AASHTO method following LCR (Layer Coefficient Ratio).

The approach to flexible pavement design according to modified AASHTO method is similar for reinforced and unreinforced pavements and can be divided into two steps:

1. Determination of structural number for a given traffic load, project conditions and arriving unreinforced section thickness for individual pavement layers.
2. Determination of reduced thickness by incorporating the effect of geosynthetic in the form of improvement factor in the obtained SN.

3.1.2.1 AASHTO design method

The basic design equation for flexible pavements according to AASHTO 1993 design guide has the following form:

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07 \quad (1)$$

where:

W_{18}	=	predicted number of 80 kN ESALs
Z_R	=	standard normal deviate (example: Z_R = -1.645 for 95 % reliability)
S_o	=	combined standard error of the traffic prediction and performance prediction
SN	=	Structural Number (an index that is indicative of the total pavement thickness required) [inches]
ΔPSI	=	difference between the initial design serviceability index, p_o, and the design terminal serviceability index, p_t
M_R	=	subgrade resilient modulus (in psi)

The AASHTO method utilizes the term Structural Number (SN) to quantify the structural strength of a pavement required for a given combination of soil support, total traffic, reliability, and serviceability level. The required SN is converted to actual thickness of surfacing, base and sub base, by means of appropriate layer coefficients representing the relative strength of the construction materials. The design equation used is as follows:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + ... \quad (2)$$

Where: a_i= i^{th} layer coefficient

D_i=i^{th} layer thickness (inches), and

m_i= i^{th} layer drainage coefficient (drainage effect on the asphalt layer is not considered in the AASHTO 93 guide)

The subscripts 1, 2 and 3 refer to the bituminous concrete course, aggregate base course and sub base course (if applicable) respectively. For detailed design methodologies refer AASHTO 1993.

3.1.2.2 Modified AASHTO method with geogrids for base/sub base stabilization

The structural contribution of a geogrid on a flexible pavement system can be quantified by an empirical term defined as layer coefficient ratio (LCR). Hence the equation 2 is modified as below.

$$SN = a_1 \times D_1 + LCR_2 \times a_2 \times D_2 \times m_2 + LCR_3 \times a_3\, D_3\, m_3 + ... \quad (3)$$

Where: LCR is the Layer Coefficient Ratio, with a value higher than one

Layer coefficient ratio represents the improvement/enhancement provided by a specific geogrid to the layer coefficient of the layer in which the geogrid is placed (most commonly a base course and subbase course or both).

This value is back-calculated, based upon the number of load cycles on a reinforced section to the number of load cycles on an unreinforced section, with the same geometry to reach the defined failure state. Appropriate empirical value of LCR may be used. Such values are normally provided by the manufacturer based on their field and laboratory testing for various materials. These factors may differ from product to product. Agency-Specific evaluation to select appropriate empirical ratio is recommended. Such evaluation shall be tailored to local materials, practice, costs. Furthermore, agency specific evaluation should provide the designers with guidance on value of reliability for reinforced pavement. A general procedure for the determination of LCR by extensive laboratory and filed testing is provided in **Annexure II**.

According to FHWA NHI-07-092, based on the AASHTO, 1993 design guide, the overall structural contribution of geosynthetic reinforcement is considered in the design through either of the following factors that are derived from empirical product specific data:

− Traffic Benefit Ratio (TBR) - the ratio of the number of load applications necessary to reach a specific failure state in a geosynthetic-reinforced pavement to the number of load applications required to reach the same failure state in an unreinforced section (i.e., the same pavement section but without reinforcement).

− Base Course Reduction Factor (BCR) - the per cent reduction in the thickness of base or subbase material in a reinforced pavement compared to an unreinforced one, given that the traffic capacity for a defined failure state remains the same.

3.1.2.3 Design procedure for geogrid reinforced flexible pavement

IRC:37 provides design procedure for unreinforced section. As many of the parameters used are still empirical, the equation requires modification to include the benefit of reinforcement in the pavement layers. Hence to take the advantage of empirical and mechanistic empirical methodologies, reinforced pavement design shall be done in the following procedure. Design for geogrid reinforced pavement design procedure shall be done in two parts:

a) Determine the conventional unreinforced pavement section as per IRC:37 for given sub grade CBR, design traffic.

b) Determine the improved layer parameters by inclusion of geogrid in different layers. Using these improved parameters, reinforced section shall be designed with same methodology as per IRC:37 and calculation of fatigue and rutting resistance of geogrid reinforced pavement section.

The detailed design procedure for geogrid reinforced pavement section.

1. Determine the sub grade CBR and design traffic load for which the flexible pavement is to be designed. Unreinforced section thickness shall be determined according to the IRC:37 for specified sub grade CBR and Design Traffic.
2. Resilient moduli M_{R_GB} and M_{R_GSB} are evaluated for the base and sub-base.
3. The tensile horizontal and vertical strains are evaluated for the conventional section at Points A and B for the given subgrade CBR and traffic/pavement life.
4. Structural layer coefficients a_2, a_3 for granular base and subbase layer of unreinforced section shall be determined from its resilient modulus using following equations from AASHTO 1993.

   $$a_2 = 0.249\ (log_{10}\ M_{R\_GB}) - 0.977 \quad (4)$$

   $$a_3 = 0.227\ (log_{10}\ M_{R\_GSB}) - 0.839 \quad (5)$$

   Where M_{R_GB} and M_{R_GSB} are resilient modulus of base and subbase layers

5. Benefit of inclusion of geogrid reinforcement in the pavement layers will be represented in improvement of resilient modulus of respective layer. Consider the layer within which the geogrid is placed, base, or sub-base, or both. Accordingly the corresponding structural layer coefficient(s) is/are modified by multiplying by the corresponding linear coefficient ratios.

   $$LCR_2 a_2 = 0.249\ (log_{10}\ M^1_{R\_GB}) - 0.977 \quad (6)$$

   $$LCR_3 a_3 = 0.227\ (log_{10}\ M^1_{R\_GSB}) - 0.839 \quad (7)$$

   Where $M^1_{R\_GB}$ and $M^1_{R\_GSB}$ are modified resilient modulus of base and subbase layers.
6. From equation (6) and/or (7), $M^1_{R\_GB}$ and/or $M^1_{R\_GSB}$ are evaluated.
7. $M^1_{R\_GB}$ and/or $M^1_{R\_GSB}$ are then used to determine the reduced thicknesses of the pavement components.
8. Further, these values are imposed in the IRC recommended IITPAVE software and evaluated for the strain values as shown in below **Fig. 3.2**.

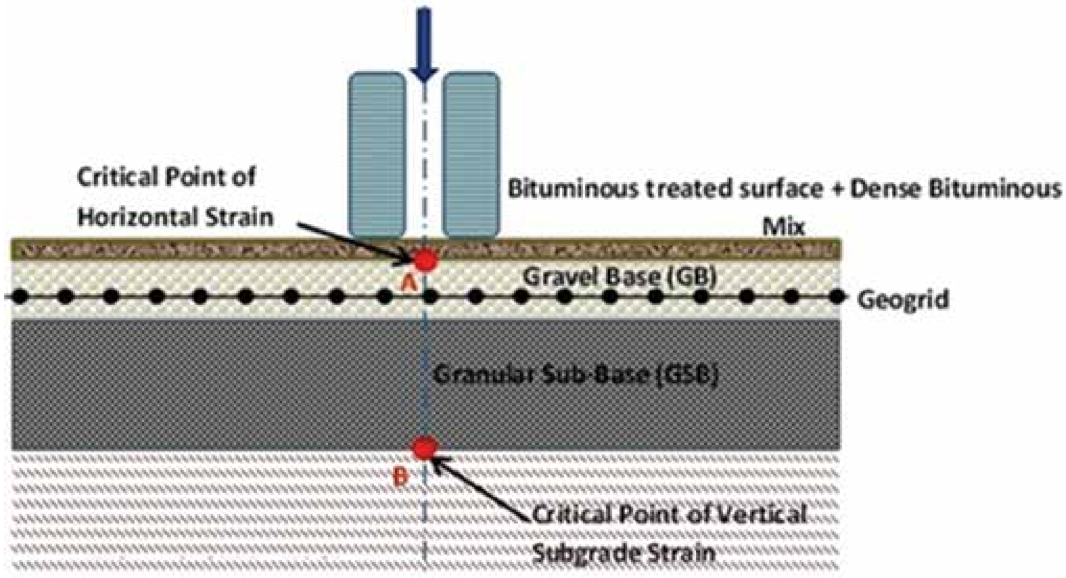


Fig. 3.2 Critical Points for Evaluation of Horizontal and Vertical strains

9. By using critical tensile strain and compressive strain induced at the bottom of the bituminous course and top of the sub grade respectively, the allowable traffic should be determined for fatigue and rutting failures using equations from IRC:37.

10. If obtained strain values are less than the permissible strain values the section is safe for pavement life in rutting and fatigue and may be adopted for the construction.

In this way the advantages of both, Mechanist Empirical method from IRC:37 (for unreinforced road design) and modified AASHTO 1993 method (for reinforced road design) are taken into consideration in designing geogrid reinforced section. This design procedure for geogrid reinforced flexible pavements can be adopted for any subgrade CBR values and any traffic values.

Value of LCR depends on stiffness of geogrid, CBR of subgrade, and depth of placement of reinforcement. **Table 3.1** below gives recommended range of LCR values that may be adopted in design. In the absence of LCR value for a particular geogrid reinforced pavement system, LCR equal to 1.2 may be taken as a default value for design. If the manufacturer/designer intends to use higher LCR values in the design, then such values shall be based on proper testing/ evaluations. **Annexure I** provide procedure for determination of layer coefficients from Falling Weight Deflectometer (FWD) and CBR values. Such higher values obtained through testing shall be verified and certified by an independent third-party agency/institution.

Table 3.1 Indicative Range of LCR Values

S. No.	CBR	Indicative Range of LCR* for geogrid
1	<3%	1.2-1.8
2	>3%	1.2-1.6

Note:* These values are the indicative range of improvement ratios. Recommended LCR is based on extensive review of studies available in the literature. These values may differ from product to product, subgrade and granular layer properties. However actual certified values shall be used in the design subject to the maximum value in the table.

* It may be noted for CBR <3, geogrids of higher strengths and stiffness higher LCR may be considered.

Default minimum values are applicable for the stabilized layer using geogrid i.e. base, subbase and subgrade layers of the pavement section. For properties of geogrid and test methods, Section 4.6.2 and **Table 2.3** shall be referred to.

Haas et al. (1988) after performing laboratory experiments concluded the importance of variables such as geogrid placement position, base course thickness, and subgrade strength. The optimum geogrid location for lower thicknesses (< 150 mm) shall be at the bottom of the layer and for the higher thicknesses (> 150 mm) it shall be at 1/3rd to half of thickness from top. For very soft subgrades (CBR≤3%), optimum performance occurs with two layers of geogrids when geosynthetic shall be used in separate layers of base and sub base.

Drainage coefficients: The drainage characteristics of the pavement are accounted for the use of modified layer coefficients. AASHTO 1993 (Pg. No. II- 22) presents the definitions of suggested drainage levels. The drainage characteristic of the bituminous layer (Layer 1) is not considered in design. For accounting the m_i values in the design of pavement, ASSHTO 1993 (**Table 2.4**, Pg. No. II-25) presents the recommended m_i values as a function of the drainage quality and the percentage of time during the year the pavement structure would normally be exposed to moisture levels approaching saturation.

3.1.3 *Design of geosynthetic (geocell/geogrid) reinforced flexible pavement using Modulus improvement factor (MIF)*

Geocell/Geogrid reinforced/stabilised flexible pavement design is based on Mechanistic Empirical approach as given in IRC:37. This design procedure can be adopted for any subgrade CBR values and any traffic values.

Step wise design procedure for geocell/geogrid reinforced flexible pavement is as follows:

1. Determine the soaked subgrade CBR as per IS 2720-Part 16 design traffic load from traffic survey.
2. Selection of conventional pavement as per IRC:37 for specific subgrade CBR and design traffic.
3. Since geocell/geogrid can be used in base/subbase layer and so the elastic modulus of corresponding layer shall increase due to confinement action of Geocell and confinement, tension membrane action and bearing capacity improvement action of geogrid. This increased modulus of confined base/subbase layers may be computed by applying a Modulus Improvement Factor (MIF) to the unconfined modulus of base material.

$$E_{\text{reinforced base/subbase layer}} = MIF \times E_{\text{unreinforced base/subbase layer}}$$

4. Based on this increased modulus of base layer the strain at the bottom of the asphalt layer shall be again calculated. By trial and error method thickness of surface layer shall be reduced in a manner that the tensile strain at the bottom of surface layer is less or equal to that of conventional section.
5. For this reinforced section with reduced surface layer thickness, determine the compressive strain at the top of subgrade.

6. Based on tensile strain and compressive strain calculate the fatigue and rutting resistance (N_F and N_R respectively) from equations given in IRC:37. The fatigue and rutting resistance must be greater or equal to design traffic load.

This MIF has a very crucial role in design and must be evaluated from field and laboratory testing. MIF depends on geosynthetic material type and their properties and stiffness and shear strength of different fill soil. Precise MIF can be taken from manufacturer based on their field and laboratory testing for specific size and material. However, it is recommended to ensure correct MIF for proper optimized design and MIF must be verified by appropriate testing for some trial patch before full fledge execution of the work. Only third party validated MIF values must be used for the design. The indicative range of MIF values for geogrid to be used in the design shall be 1.2 to 2, and for geocell these ranges shall be as per **Table 3.2**.

Table 3.2 Indicative Range of MIF Values

S. No.	CBR	Indicative Range of MIF* for geocell
1	<3	2 to 2.75
2	>3	1.4 to 2

Note:* These values are the indicative range of improvement ratios. Recommended MIF is based on extensive review of studies available in the literature.

These values may differ from product to product, subgrade and granular layer properties. Higher MIF values may also be considered subjected to actual certified values as per test results subject to the maximum value in the **Table 3.2**.

Design of geosynthetic reinforced flexible pavement can be followed by either LCR approach or MIF approach, based on the availability of coefficient values which represents the benefit of geosynthetic in pavement layers.

3.1.4 *Material properties*

Regardless of the design procedure, it is essential that the material properties are adopted only after conducting relevant tests on the materials. Grade of bitumen and recommended modulus values, poison ratios, minimum thickness requirements, reliability specified in IRC:37 shall also be applicable for geosynthetic reinforced pavement design.

3.2 Designing for Separation

Separation is the major function of geotextile. In the pavement applications, the best use of geotextile as separators illustrates when it is placed between a reasonably firm soil subgrade (beneath) and a stone base course, or aggregate, or ballast above the geotextile. Subgrade shall be “reasonably firm” because it is assumed that the subgrade deformation is not sufficiently large to mobilize uniformly high-tensile stress in the geotextile. Thus, for a separation function to occur, the geotextile has to be placed on the soil subgrade and then have aggregate Base/Subbase course spread over the geotextile and compacted on top of it (as shown in **Fig. 3.3**).

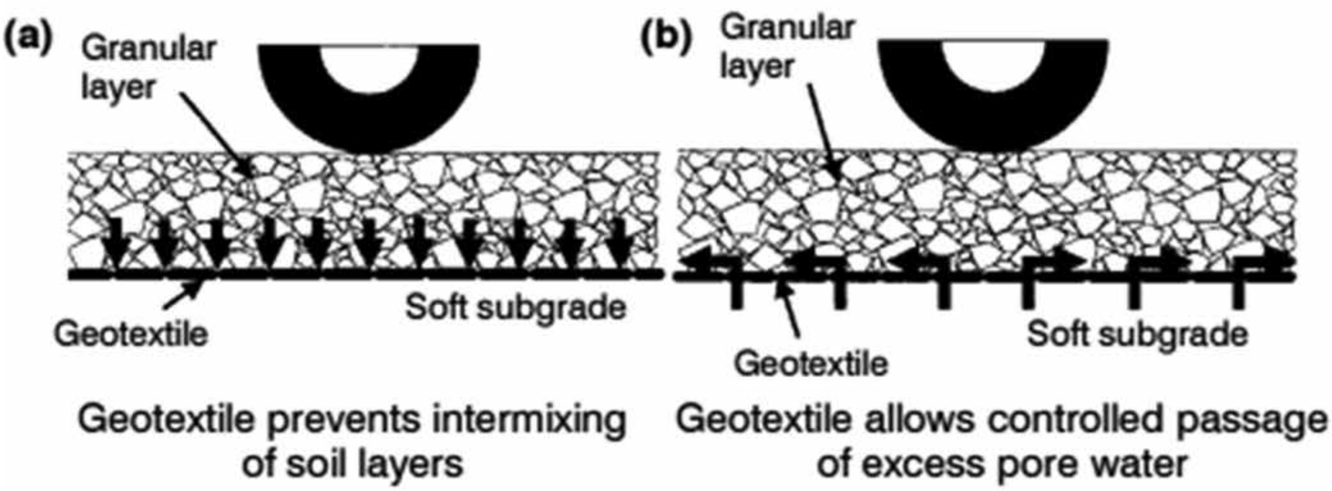


Fig. 3.3 Separation Function of Geotextile

For separation design, the base and subbase course thickness required to adequately carry the design traffic loads for the design life of the pavement and these thickness not reduced due to the use of a geosynthetic. Recall that geotextile separators help prevent pavement failures due to the intrusion of finer subgrade soil fractions into the granular base layer(s). Geotextiles separation layers may also be used between dense and open graded base layers. Mostly any geotextile will work in this application as long as it is strong enough to survive construction. As indicated earlier, filtration is a secondary function in this application. Therefore, the geotextile should have small enough openings to prevent contamination of the base and subbase pavement layers from the subgrade materials and be sufficiently permeable (i.e., more permeable than the subgrade) to prevent the development of pore water pressure in the subgrade. AASHTO M288, **Table 4** explains the degree of survivability of geotextile for different subgrade conditions.

3.3 Design for Filtration

The geotextile must prevent in-situ soil from being washed into the system without clogging over time. FHWANHI-070-092 Section 2.3 presents the basic principles, geotextile filter design and selection.

3.4 Design for Drainage Applications

Water in pavement systems is one of the principal causes of pavement distress. It is well known that improved roadway drainage extends the life of a roadway system. Modern roadways incorporating good drainage are predicted to have a design life of up to two to three times over that of undrained pavement sections. This section provides design guidance for a new alternative drainage method, which incorporates a Geo Composite drainage layer tied directly and continuously into an edge drain system. This Geo Composite drainage layer can be used to directly replace drainable aggregate layers in modern rigid or flexible pavement systems. The layer can also be used to significantly enhance the drainage of dense graded aggregate layers.

3.4.1 *Design requirements*

In order to perform in this application, the geocomposite must have the stiffness required to withstand compaction and support traffic without experiencing significant damage due to compaction and deformation under cyclic traffic loading. At the same time, the geocomposite must have the flow capacity required to rapidly drain the pavement section and prevent saturation of the base. As discussed in the previous section, in order to provide optimum drainage, the outflow capacity of the drainage layer must be sufficient to drain the pavement section within a few hours of a moisture event. The geocomposite must have a high crush resistance to withstand construction loading and compaction stresses. A factor of safety of 5 between the anticipated load and geocomposite crush resistance as determined by quick load tests is recommended by the FHWA to resist creep in geocomposite drains (Christopher et al., 2001). Considering the high cost of pavement replacement, it is prudent to consider only high modulus, high compressive resistance materials such as geonet drainage composites.

The design of a geocomposite drainage system is carried out as follows:

Identify/set all the design conditions, including (but not limited to):

- Types of soil involved (stones, gravel, clay etc.) and their grading curves.
- Environment (aggressive for landfill bottom, medium for landfill capping, ordinary for roof gardens etc.).
- Chemical and physical properties of the materials in contact with the geocomposite (pH, chemical and biological content, hardness, stiffness etc.) and of the liquid to be drained (pH, chemical and biological content, density, viscosity, turbidity etc.).
- Set the boundary conditions (that is the type of materials in contact with the two faces of the geocomposite).
- Calculate the maximum applied pressure, the hydraulic gradient and the design input flow rate for the geocomposite.
- Select one or more geocomposites and for each of them calculate the available flow rate for the design conditions of materials in contact with the two faces, maximum applied pressure, and hydraulic gradient.
- Compare the available flow rate with the design input flow rate and consider only the geocomposites for which the former is larger than the latter.
- Make the final selection of the geocomposite.
- Provide design specifications and details, in particular the method for fixing the geocomposites on the supporting surface and the connections/overlaps between geocomposite rolls and between the geocomposites and other elements of the drainage system (manholes, perforated pipes etc.).

3.4.2 *Calculation of input flow rate*

The calculation of the input flow rate is project specific.

The generalized equation for input flow rate in the geocomposite is:

$$Q_D = FS_Q \bullet [(Q_F / L) + Q_S]$$

Where:

Q_F = Total rainfall flow on the catchment zone (m^3/s or l/s)

A = Horizontal area of the catchment zone (m^2)

L = Running length of the geocomposite drain (m)

Q_S = Input flow rate due to additional surficial flow ($m^3/s/m$ or l/s/m)

FS_Q = Factor of Safety on input flow rate

Q_D = Input flow rate in the geocomposite ($m^3/s/m$ or l/s/m)

3.4.3 *Calculation of available flow rate*

The flow velocity inside a geocomposite is proportional to the hydraulic gradient (i) which is defined as:

$$i = \delta h / L$$

Where: δh = Hydraulic head loss along the distance L for the fluid flow in the geosynthetic (m)

L = Distance between two points along the average direction of flow in the geosynthetic (m)

Since the design of the drainage system ensures that the available flow rate of the geocomposite is always larger than the design input flow rate, pressure flow will never occur and the flow will always occur at atmospheric pressure.

The available flow rate of a geocomposite will depend on the types of material in contact with its two faces.

It is evident that a very rigid material (concrete slabs in case of rigid pavements etc.) will compress and deform the geocomposite evenly, imparting a homogeneous decrease in its thickness, but without pushing the geotextile into the channels of the draining core; rigid materials produce negligible geotextile intrusion into the core. Conversely, a soft material (like a soil, gravel, ballast) in contact with the geocomposite will deform the geotextile, forcing the textile to intrude into the draining core with a resulting reduction in the cross-sectional area of the draining core and commensurate decrease of the draining capacity. Therefore, the available flow rate of a geocomposite with a given structure will be a function of:

- Thickness of the geocomposite (H)
- Distance (L) between the support points of the geotextile filter
- Pressure (P) on the filter
- Strength, modulus and tensile creep of the geotextile filter
- Deformability of the material in contact with the geocomposite
- Roughness of the geotextile filter

For all applications, the available flow rate of the geocomposite shall be obtained by applying a set of reduction factors which take into account all the phenomena that may decrease the flow rate over the entire design life compared to the short term flow rate measured in the tests according to EN ISO 12958 or ASTM D4716 - 08(2013) standard:

$$Q_a = \frac{Q_L}{RF_{in} \cdot RF_{cr} \cdot RF_{cc} \cdot RF_{bc}}$$

Where:

Q_a = available long term flow rate for the geocomposite
Q_L = short term flow rate obtained from laboratory tests
RF_{in} = Reduction Factor for the intrusion of filter geotextiles into the draining core
RF_{cr} = Reduction Factor for the compressive creep of the geocomposite
RF_{cc} = Reduction Factor for chemical clogging of the draining core
RF_{bc} = Reduction Factor for biological clogging of the draining core

Table 3.3 Suggested Range of Values of the Different RFs for Geo Composites

Term	**Description**	**Suggested range for geocomposites**
RF_{in}	Reduction Factor for intrusion of the filter geotextile into the drainage core	1.0 – 1.5
RF_{cr}	Reduction Factor for thickness change due to compressive creep of the core	1.2 – 1.5
RF_{cc}	Reduction Factor for pore/volume reduction due to chemical clogging*	1.0 – 1.3
RF_{bc}	Reduction Factor for pore/volume reduction due to biological clogging**	1.0 – 1.3
Π_{RF}	Product of all Reduction Factors for the site-specific conditions	1.20 – 4.0
* values can change according to the type of the core and also according to the type of filtering geotextile used ** values are related to the type of the liquid/fluid to be drained and to its nature (clean water, polluted water, leachate, etc)		

Once the design input flow Q_D has been calculated, the available input flow Q_a shall be calculated for one or more geocomposite.

The final Factor of Safety of Geocomposite FS_G afforded by the design with each geocomposite is given by:

$$FS_G = Q_a / Q_D$$

The final selection of the geocomposite shall be done among the geocomposite for which:

$FS_G \geq 1.00$ taking into consideration also costs and availability

Once the core is designed to carry the required flow, geotextiles on either side of the core shall be designed for separation and filtration as per the requirements. Geotextile separation design as per section 3.2 and filter design shall be same as explained in section 3.3. This method of drainage is applicable to all types of road construction (whether rigid or flexible) and should be preferred wherever economically feasible based on the site conditions.

3.5 Geosynthetic Capillary Barrier Drain

Water can travel up to 10 m vertically in silty soils because of capillary action. Two forces affect water movement through soils, gravity and capillary action. A capillary barrier forms and restricts water flow when two porous materials with differing hydraulic conductivities are in contact.

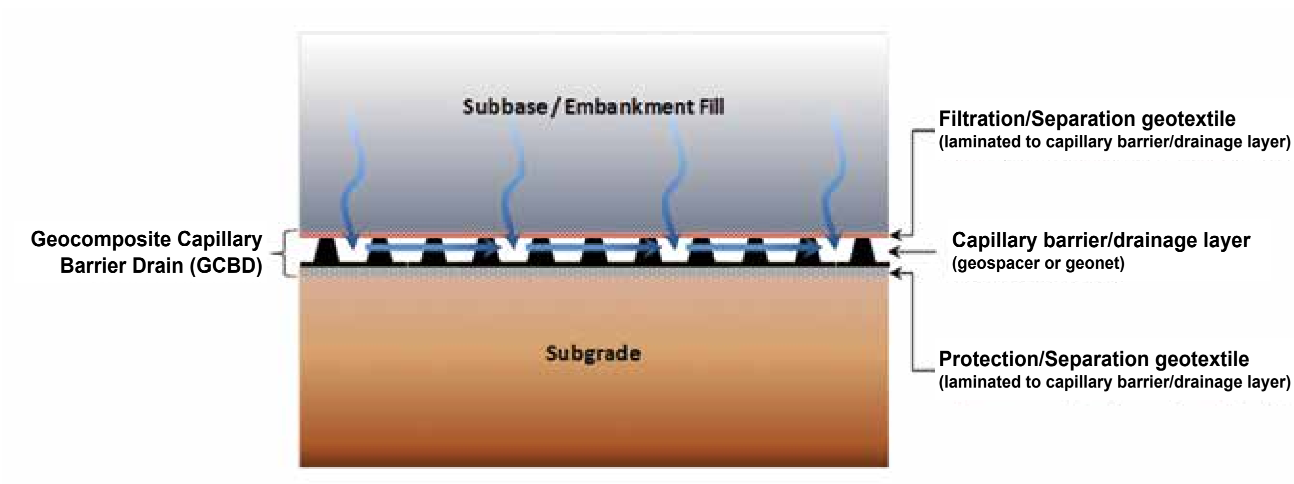


Fig. 3.4 GCBD Between Base Course and Subgrade Illustrating how Water Laterally Drains in Transport Layer

Utilizing a GCBD for pavement drainage explicitly accounts for unsaturated flow, and will result in greater drainage efficiency compared to conventional drainage system. With a GCBD, the base and subgrade will contain less water than a pavement without a GCBD at any point of time. This is important because the strength of both the base course and subgrade degrades with increased moisture content and ultimately reduces pavement structural durability. Thus, a GCBD will result in increased longevity of the pavement. Expected benefits of the GCBD include:

- Reduced equilibrium water content in base
- Prevent positive pressures in base
- Prevent wetting of underlying subgrade due to infiltration
- Prevent capillary rise of water from subgrade into base
- Provide complementary separation and stabilization

Design of geocomposite barrier drain is similar to the design of drainage composite that is outlined in the above section 3.4. IRC:34 and IRC:SP:42 shall be referred for detailed design procedure and specifications/properties of geocomposite for capillary barrier drain.

3.6 Design for Asphalt Reinforcement

Reinforcement in asphalt layers such as fabrics, grids or composites can enhance cracking and rutting resistance of the asphalt layers significantly if properly applied. This has lead to increased use of reinforcement in asphalt layers over the past years throughout the world. Asphalt reinforcement prevents reflective cracking, by acting as a barrier against crack propagation.

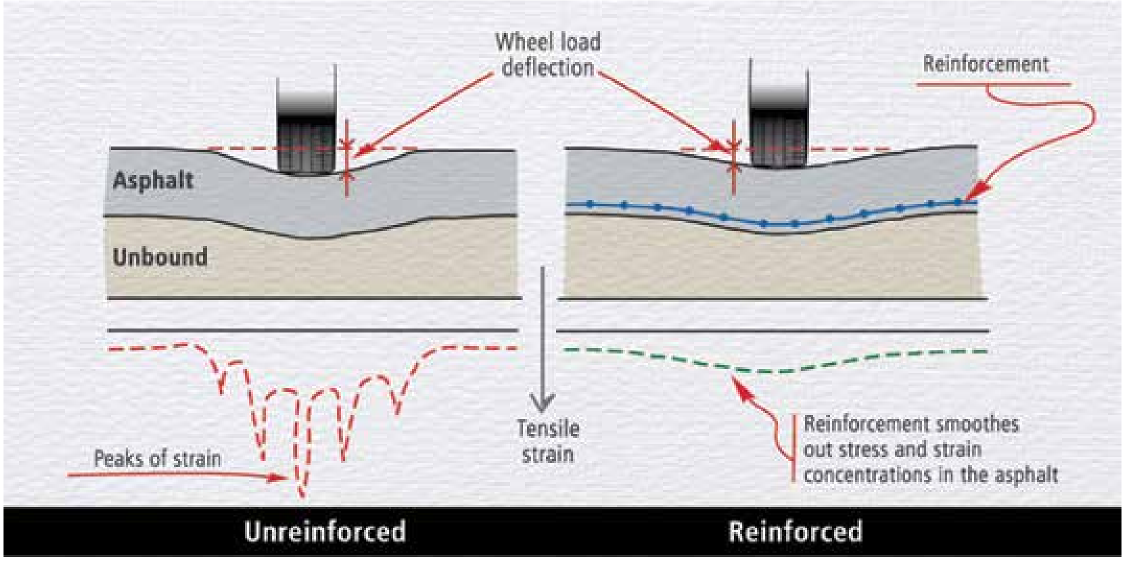


Fig. 3.5 Reinforcement Action

The crack starts to propagate (due to thermal and traffic loading or uneven soil movements) from its original position upward until it reaches the stabilized layer; If the interlayer is stiff enough (stiffer than the surrounding materials), the crack will turn laterally and move along the interface until its energy is exhausted. Based on this mechanism, a stabilized interlayer may contribute to the structural capacity of the pavement.

3.7 Subgrade Stabilization

The purpose of subgrade modification is to enhance the strength of the subgrade, create a working platform for construction equipment. This increased strength is then taken into account in the pavement design process. Soil properties such as strength, compressibility, hydraulic conductivity, workability, swelling potential, and volume change tendencies may be altered by various soil modification or stabilization methods.

The methods of subgrade modification or stabilization include physical processes such as soil densification, blending with granular material, use of reinforcements (geosynthetic inclusions), undercutting and replacement etc.

Chemical processes such as mixing with cement, fly ash, lime, lime by products, and blends of any one of these materials. Details of cement stabilization are covered in IRC:SP:89 “Guidelines for Soil and Granular Material Stabilization Using Cement Lime and Fly Ash”.

For improving the subgrade, several ground improvement methods may also be adopted based on available subgrade CBR and the required CBR to be achieved and as per the site feasibilities and project requirement. Suitable type of ground improvement shall be chosen accordingly. For details regarding several ground improvement methods reference may be made to the documents mentioned therein IRC:75, IRC:113, IRC-HRB: SR-13, SR-14.

State of art reports IRC-HRB: SR-13, SR-14 deal with different ground improvements SR-14 deals with various ground improvement methods including vertical drains (PVDs), lime columns, stone columns, geosynthetics and dynamic consolidation.

The purpose of this section is to assist pavement design engineers in the selection and design of a Subgrade Enhancement Geosynthetic (SEG).

SEG is a geosynthetic placed between the pavement structure and the subgrade (the subgrade is usually untreated). The placement of SEG below the pavement will provide subgrade enhancement by bridging soft areas.

Different types of geosynthetics that are used in subgrade stabilization are geotextiles, geogrids and geocell. Geocell, geotextile, geogrid and geosynthetic composites achieve mechanical stabilization through slightly different mechanisms.

Subgrade Enhancement Geogrid (SEGG): A geogrid's primary stabilization mechanism is lateral restraint of the subbase or base materials through a process of interlocking the aggregate and the apertures of the geogrid. The level of lateral restraint that is achieved is a function of the type of geogrid and the quality and gradation of the base or subbase material placed on the geogrid. To maximize performance of the geogrid, a well-graded granular base or subbase material should be selected that is sized appropriately for the aperture size of the geogrid. When aggregate is placed over geogrid, it quickly becomes confined within the apertures and is restrained from punching into the soft subgrade and shoving laterally. This results in a "stiffened" aggregate platform over the geogrid. Very little deformation of the geogrid is needed to achieve the lateral restraint and reinforcement. For longer life, a separator geotextile should be used. Requirement of geogrids for stabilization applications shall be as per **Table 4.5**.

Subgrade Enhancement Geocell (SEGC): Geocell serves as load spreader when loads are imposed upon the system. This 3D mattress reduces vertical differential settlement into soft subgrades, improves shear strength, and enhances load-bearing capacity, while reducing the amount of aggregate material required extending the service life of roads. As a composite system, cellular confinement strengthens the aggregate in fill, thereby simultaneously enabling the use of poorly graded inferior material (e.g. local native soils, quarry waste or recycled materials) for infill as well as reducing the structural support layer thickness. Requirement of geocells for stabilization applications shall be as per **Table 4.6**.

Subgrade Enhancement Geotextile (SEGT): A geotextile's primary stabilization mechanism is filtration and separation of a soft subgrade and the subbase or base materials. The sheet-like structure provides a physical barrier between these materials to prevent the aggregate and subgrade from mixing. It can also reduce excess pore water pressure through a mechanism of filtration and drainage. Secondary mechanisms of a geotextile are lateral restraint and reinforcement. Lateral restraint is achieved through friction between the surface of the geotextile and the subbase or base materials. Reinforcement mechanism requires deformation of the subgrade and stretching of the geotextile to engage the tensile strength and create a "tensioned membrane". Stabilization function of geotextile is applicable to pavement structures constructed over soils with a CBR between 1 and 3 (IS 16362). Requirement of geotextiles for stabilization applications shall be as per Table 1, IS:16362.

3.8 Performance Evaluation of Reinforced Flexible Pavements

Performance of reinforced flexible pavements can be evaluated by applying loads on the pavements that simulate the traffic loading by measuring the elastic deflection under such loads, and analysing these data duly considering the factors influencing the performance such as subgrade strength, thickness and quality of each of the pavement layers, drainage conditions, pavement surface temperature etc.

Among the equipment's available for structural evaluation of pavements, the Falling Weight Deflectometer (FWD) is extensively used world-wide because it simulates, to a large extent, the actual loading conditions of the pavement. IRC:115 explains the structural evaluation of flexible road pavements using deflection data from Falling Weight Deflectometer.

CHAPTER - 4
PROPERTY REQUIREMENTS & SELECTION CRITERIA OF GEOSYNTHETICS BASED ON FUNCTION

4.1 General

4.1.1 This section of the document covers the criteria for selection of a particular type of geosynthetic material and its property requirement based on its function and application in road works for different project conditions. Specific design and site conditions often require individual geosynthetic properties and construction recommendations to be taken care to ensure that the chosen geosynthetics are consistent with project needs.

4.2 Construction Survivability

This section talks about the necessity of provision of geosynthetic and selection of geosynthetic material according to the site condition and application of intended. AASHTO 1990 (After Taskforce 25) provides different cover thicknesses adopted for different site soil CBR and different ground contact pressures.

4.3 Ultraviolet Stability

4.3.1 Ultraviolet light degradation is a process where a particular property of a geosynthetic is damaged or reduced through its exposure to U-V Rays (sunlight). Typical reductions can be seen in the physical properties of geosynthetic material after exposure for a certain period of time to sunlight. The rate of deterioration varies with the product, the exposure environment and the time of exposure. Atmospheric exposure of geosynthetic material following lay down shall be a maximum of 14 days to minimize the damage potential. **Table 4.1** gives specifications for ultraviolet light degradation.

Table: 4.1 Requirements for Ultra Violet Stability

<table>
<tr><th>S. No</th><th>Properties of Fabric</th><td rowspan="5">UV Stability as per IS 13162 Part 2/ASTM D 4355</td><th>Requirements (Retained Strength)</th></tr>
<tr><td>1</td><td>Grab Strength</td><td rowspan="4">Not less than 70% after 500 hours of exposure</td></tr>
<tr><td>2</td><td>Tear Strength</td></tr>
<tr><td>3</td><td>Puncture Strength</td></tr>
<tr><td>4</td><td>Burst Strength</td></tr>
</table>

4.4 Certificate

4.4.1 The supplier of any geosynthetic material should provide a certificate to the engineer stating the name of the manufacturer, product name, style number, roll number, chemical composition of the filaments or yarns and other pertinent information regarding property values of individual roll to fully describe the specific geosynthetic material.

4.4.2 The manufacturer is responsible for establishing and maintaining a quality control program to assure compliance with the requirements of the specifications. Documentation describing the quality control program shall be made available upon request. The manufacturer's certificate shall state that the furnished geosynthetic material meets MARV requirements of the specifications as evaluated under the Manufacturer's quality control program and are in conformance as per ASTM D4759 or equivalent standards/procedures. The certificate shall be attested by a person having legal authority to bind the manufacturer.

4.4.3 Any misrepresentation or mislabelling of materials shall become a sufficient reason to reject the geosynthetic products.

4.5 Separation/Filtration Requirements

In roads and pavements works geotextile is the most preferred geosynthetic material which satisfies the function of separation/filtration which prevents intermixing of subgrade soil and aggregate cover material (Base/Subbase) with sufficient filtration. **Table 4.2** and **4.3** explains the geotextile property requirements for separation function.

Table 4.2 Geotextile Requirements for Separation (Subgrades Soaked CBR >3)

Sl. No.	Geotextile Property	Requirement
1.	Permittivity as per IS 14324/ASTM D 4491	0.02 sec^{-1} (per sec)
2.	Maximum Apparent Opening Size as per IS 14294/ ASTM D 4751	0.60 mm

Table 4.3 Geotextile Requirements for Separation (Subgrades Soaked CBR ≤3)

Sl. No.	Geotextile Property	Requirement
1.	Permittivity as per IS 14324/ASTM D 4491	0.05 sec^{-1} (per sec)
2.	Maximum Apparent Opening Size as per IS 14294/ ASTM D 4751	0.43 mm

4.6 Base/Subbase Reinforcement Requirements

Geosynthetics have been found to be a cost-effective alternative to improve poor sub-soils in adverse locations, in almost all geotechnical engineering projects such as airport and highway pavements. For pavement application geotextile, geogrids and geocells will perform this function primarily.

4.6.1 *Geotextile requirements:* In some installations, the geotextile can also provide the function of reinforcement along with separation and filtration. The geotextile shall meet the strength property requirements as specified in **Table 4.4a** and **4.4b**.

Table 4.4a Minimum Geotextile Strength Property Requirements

Installation condition	Type	Strength Property Requirement (MARV)					
		Grab Strength in Newton (N) as per IS 16342/ASTM D 4632		Tear Strength in Newton (N) as per IS 14293/ASTM D 4533		Puncture Strength in Newton (N) as per IS 16078/ISO 12236/ ASTM D 6241	
		Elongation at Failure					
		<50%	≥50%	<50%	≥50%	<50%	≥50%
Harsh installation condition	Type I	1400	900	500	350	2800	2000
Moderate Installation condition	Type II	1100	700	400	250	2250	1400
Less Severe Installation condition	Type III	800	500	300	180	1700	1000

Note:

(1) All numeric values in the above table represent Minimum Average Roll Value (MARV) in weaker principal direction. The MARV is derived statistically as the average value minus two standard deviations.

(2) When the geotextiles are joined together by field sewing, the seam strength shall be at least 60 per cent of the material's tensile strength. All field seams shall be sewn with thread as strong as the material in the fabric.

(3) **Table 4.4b** provides required degree of survivability as a function of ground conditions, construction equipment, and lift thickness of Type 1, 2 and 3 as given in **Table 4.4a**.

Table 4.4b Required Degree of Survivability

	Low Ground Pressure Equipment ≤25 kPa (3.6 psi)	Medium Ground Pressure Equipment >25 to ≤50 kPa (>3.6 to ≤7.3 psi)	High Ground Pressure Equipment >50 kPa (>7.3 psi)
Subsoil has been cleared of all obstacles except grass, weeds, leaves, and fine wood debris, surface is smooth, and level so than any shallow depressions and humps do not exceed 450 mm (18 in.) in depth or height. All larger depressions are filled, Alternatively, a smooth working table may be placed.	Low (Type 3)	Moderate (Type 2)	High (Type 1)

	Low Ground Pressure Equipment ≤25 kPa (3.6 psi)	**Medium Ground Pressure Equipment >25 to ≤50 kPa (>3.6 to ≤7.3 psi)**	**High Ground Pressure Equipment >50 kPa (>7.3 psi)**
Subsoil has been cleared of obstacles larger than small to moderate sized tree limbs and rock. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 450 mm (18 in.) in depth or height. Larger depressions should be filled.	Moderate (Type 2)	High (Type 1)	Very high (Type 1+)
Minimal size preparation is required. Trees may be felled, delimbed, and left in place, stumps should he cut to project not more than ±150 mm (±6 in.) above subgrade. Geotextile may be draped directly over the tree trunks, stumps, large depressions and humps, holes, stream channels, and large boulders, items should be removed only if placing the geotextile and cover material over them will distort the finished road surface.	High (Type 1)	Very high (Type 1+)	Not recommended

Recommendations are for 150 to 300 mm (6 to 12 in.) initial lift thickness.

For initial lift thicknesses:

300 to 450 mm (12 to 18 in.): reduce survivability requirement one level;

450 to 600 mm (18 to 24 in.): reduce survivability requirement two level;

>600 mm (24 in.): reduce survivability requirement three level;

For special construction techniques such as prerutting, increase the geotextile survivability requirement one level. Placement of excessive initial cover material thickness may cause bearing failure of the soft subgrade.

4.6.2 *Geogrid requirements:* Reinforcement is the primary function of geogrids. It performs better than geotextiles in base layer reinforcement mainly because of grid interlock with aggregate particles. Poor friction properties of geotextiles do not allow good interlock with aggregate particles. The geogrid for use in both base and sub base, shall meet the requirements of **Table 4.5**.

Table 4.5 Minimum Requirements of Geogrid for Base & Sub-base Stabilization of Flexible Pavement

Property	Test Method	Unit	Requirement
Stiffness at 0.5% strain	IS 13162 Part 5/ISO 10319	kN/m	≥350; both in machine and cross-machine direction
Tensile strength @2% strain	IS 13162 Part 5/ISO 10319/ ASTM D6637	kN/m	≥15 % of T_{ult}; both in machine and cross-machine direction
Tensile strength @5% strain	IS 13162 Part 5/ISO 10319/ ASTM D6637	kN/m	≥20 % of T_{ult}; both in machine and cross-machine direction
Junction efficiency for extruded geogrids	GRI-GG2-87 or ASTM-WK 14256	-	90 % of rib ultimate tensile strength
Ultraviolet stability	IS 13162 Part 2/ASTM D4355	-	70% after 500 hrs exposure

Note:

(1) All numerical values in the Table represent MARV in the specified direction.

(2) All geogrids shall be placed along machine direction parallel to the centre line of roadway alignment.

4.6.3 *Geocell requirement:* Geocell is a honey comb shaped cellular structure made of polymers such as high density polyethylene, polypropylene or alloy material to suit the harsh environmental conditions, especially increased temperate in case of flexible pavements where the asphalt layers are subjected to very elevated temperatures during installation. Geocell property requirements would remain same as given in **Table 4.10**, except for the cell wall thickness. Minimum 1.5 mm cell wall thickness is recommended considering the load bearing application of geocell in base and subbase reinforcement.

4.7 Subsurface Drainage Requirements

4.7.1 *Geotextile property requirements:* Geotextiles will become integral part of any structure, wherever they are being used. So, it is necessary that the geotextile should possess sufficient strength to withstand the construction and other stresses which a fabric is likely to bear during its life span. **Table 4.6** provides the geotextile property requirements for subsurface drainage. The specifications are applicable for placing a geotextile against the soil to allow long term passage of water into a subsurface drain system retaining the in-situ soil. For drainage purpose, woven slit film geotextiles (i.e. geotextiles made from yarns of a flat, tape like character) should not be allowed.

Table 4.6 Geotextile Requirements for Subsurface Drainage

In-situ Passing 0.075 mm Sieve (%)	Permittivity, per sec, as per IS 14324 /ASTM D 4491	Maximum Apparent Opening Size, mm IS 14294/ ASTM D 4751
< 15	0.5	0.43
15 to 50	0.2	0.25
> 50	0.1	0.22

4.7.2 *Geocomposite property requirement:* Geocomposite shall be able to meet the drainage and protection requirements in structurally demanding water draining application. It should be able to effectively eliminate hydrostatic pressure against below grade structures and aid in dewatering saturated soil by collecting and conveying groundwater to a drain pipe for discharge. Geosynthetic drainage composite (drainage composite/Geonet/Geospacer between one or two Geotextile layers) shall also satisfy the requirements of subsurface drainage as per the site requirement.

Geotextile used in drainage composite shall meet the requirements as specified in **Table 4.7**. The properties of the Geocomposite shall meet the requirements as indicated in **Table 4.8**.

Table 4.7 Geotextile Requirements for Fin Drains

In-situ Soil Passing 0.075 mm sieve (%)	Permittivity, per sec IS 14324/ASTM D 4491	Maximum Apparent Opening Size, mm as per IS 14294/ASTM D 4751
< 15	0.5	0.43
15 to 50	0.2	0.25
> 50	0.1	0.22

Table 4.8 Properties of Geocomposite

<table>
<tr><th colspan="2">Property</th><th>Test Method</th><th>Units</th><th>Minimum Average Roll Value</th></tr>
<tr><td colspan="2">Tensile strength</td><td>EN ISO 10319</td><td>kN/m</td><td>16</td></tr>
<tr><td colspan="2">Static puncture test (CBR test)</td><td>EN ISO 12236</td><td>kN</td><td>3</td></tr>
<tr><td colspan="2">Mass per unit area</td><td>EN ISO 9864</td><td>g/m²</td><td>710</td></tr>
<tr><td colspan="2">Thickness of Composite</td><td>EN ISO 9863</td><td>mm</td><td>4.5</td></tr>
<tr><td rowspan="2">In-plane permeability</td><td>Hydraulic Gradient, i=1 at 100 kPa pressure</td><td>EN ISO 12958</td><td>l/m/s</td><td>0.55</td></tr>
<tr><td>Hydraulic Gradient, i=1 at 200 kPa pressure</td><td></td><td></td><td>0.45</td></tr>
</table>

4.8 Erosion Control Requirements

Geotextile, geocell, geogrids and geosynthetic mats are different geosynthetics which will perform erosion control function effectively in different applications in roads and pavement works. Engineer can select any product based on the project requirement and experience.

4.8.1 *Geotextile requirement:* This specification is applicable to the use of a geo-textile between energy absorbing armor systems and the in-situ soil to prevent soil loss resulting in excessive scour and to prevent hydraulic uplift pressures causing instability of the permanent erosion control system. The primary function of the geotextile in erosion control application is filtration. Geotextile filtration properties are a function of site hydraulic conditions, in-situ soil gradation, density and plasticity. The geotextile requirements for the above applications are given in **Table 4.9**.

Table 4.9 Geotextile Requirements for Erosion Control

In-situ Soil Passing 0.075 mm Sieve (%)	Permittivity, per sec IS 14324/ASTM D 4491	Maximum Apparent Opening Size, mm IS 14294/ASTM D 4751
<15	0.7	0.43
15 to 50	0.2	0.25
>50	0.1	0.22

4.8.2 *Geocell requirement:* For the steep slope vegetation may be difficult to establish and it also may not be possible to mitigate potential erosive forces that are likely to overcome the strength of the root system. In that cases geocells are effective solution by preventing soil slippage and thereby encourage vegetation. Geocell forms a 3 dimensional honey comb structure with geocell height of 75 mm to 150 mm when it expanded. Geocells placed on the slope are secured to adjoining cell at suitable intervals by using a clip arrangement and these expanded cells should be secured to the slope using steel staples typically 300 mm long and 9.5 mm diameter. Geocell requirements for erosion control are given in **Table 4.10**.

Table 4.10 Requirements of Geocell for Slope Protection

Property	Test Method	Unit	Min. Required Value
Density	IS 13360-Part 3-1/ ASTM D792	g/cm^3	0.9
Environmental Stress Crack Resistance (ESCR)	ASTM D1693	Hrs	3000
Carbon Black Content	ASTM D 4218	% by Weight	1.5 to 2
Strip/Cell Wall thickness	ASTM D5199	mm	1.20
Seam Peel-Strength Test		N per 25 mm of cell depth	350
Creep Rupture Strength	ASTM D2990		Creep Rupture Load at 10,000 hours shall be 1 kN minimum obtained from the 95% prediction interval at 10,000 hours considering a logarithmic time/creep rupture model.

4.8.3 *Geogrid requirement:* With the provision of polymer geogrid mesh for root reinforcement, extremely high density of grass growth can be achieved. Geogrid reinforcement slope protection has been shown to provide erosion protection equivalent to 250 mm thick revetment and is treated as an attractive cost-effective alternative solution. Geogrid requirements for erosion control shall be in accordance with IRC:56 (Clause No. 5.8).

4.8.4 *Geomat requirement:* Vegetation growth for slope protection is very unpredictable and unreliable as it may be extremely difficult to achieve 100 per cent vegetation coverage. Reinforced vegetation (or reinforced grass) is a better alternative for enhancing slope stability and erosion control. The synthetic materials can be of two dimensional polymeric meshes or three dimensional mats. Three dimensional geosynthetic materials with multi filaments, layers of geogrids folded and knitted or bonded together, with specific thickness are effective in this application which also known as Rolled Erosion Control Products (RECPs). These geomats (3-D mats) are made exclusively from UV stabilized synthetic fibres and filaments processed into permanent, high strength, three dimensional matrices. A tension element, i.e., a reinforcing element like geogrid or steel wire mesh shall be included along with the three dimensional polymeric mats to provide strength against erosive forces, if specified in the contract in case of severe environmental conditions.

Table 4.11 and **4.12** provides the property requirements of geosynthetic mats for erosion control applications.

Table 4.11 Tensile Strength Requirement for Normal (Non-Reinforced) Three Dimensional Geosynthetic Mat for Erosion Control Application (Less Severe Environmental Condition)

Property	Test Method	Units	Minimum Average Roll Value
Tensile strength requirement (For slopes less than 60°)	ISO 10319	kN/m	2
Ultraviolet stability at 500h, Retained strength percentage with respect to original strength	IS 13162 Part 2/ ASTM D4355	%	80
Thickness	ISO 9863 Part-1/ ASTM D 6525	mm	6.5
Mass per unit area	ISO 9864/ASTM D 3776	g/m^2	250

Table 4.12 Tensile Strength Requirement for Reinforced Three Dimensional Geosynthetic Mat for Erosion Control Application (Severe Environmental Conditions)

<table>
<tr><th colspan="2">Property</th><th>Test Method</th><th>Units</th><th>Minimum Average Roll Value</th></tr>
<tr><td rowspan="2">Tensile strength requirement</td><td>For Slopes up to 60°</td><td rowspan="2">ISO 10319</td><td rowspan="2">kN/m</td><td>10</td></tr>
<tr><td>For Slopes up to 80°</td><td>35</td></tr>
<tr><td colspan="2">Ultraviolet stability at 500h, Retained strength percentage with respect to original strength</td><td>IS 13162 Part 2/ASTM D4355</td><td>%</td><td>80</td></tr>
<tr><td colspan="2">Thickness</td><td>ISO 9863 Part-1/ASTM D 6525</td><td>mm</td><td>12</td></tr>
<tr><td colspan="2">Mass per unit area of the composite</td><td>ISO 9864/ASTM D 3776</td><td>g/m²</td><td>500</td></tr>
</table>

4.8.5 *Selection criteria for erosion control*

4.8.5.1 The primary function of geotextile used for permanent erosion control is to protect the soil beneath it from erosion due to water flowing over the protected soil. The need for a permanent erosion control geotextile depends on the type and magnitude of water flow over the soil being considered for protection, the soil type in terms of its erodability, and the type and amount of vegetative cover present.

4.8.5.2 Geocells can be used where heavy runoff or channel scouring is anticipated. Geocells filled with concrete can be used to protect bridge aprons, guide bunds and pier areas, abutting waterfront as revetment as an alternative to conventional stone/boulder pitching. Geocells can be adopted, for the steep slopes where vegetation growth may be difficult and mitigation of potential erosive forces to overcome the strength of root system is not possible.

4.8.5.3 Under erratic weather conditions, successful vegetation growth and its maintenance depends on unseasonal rainfall and hence longer life of reinforcing material would be required for ensuring vegetation growth apart from contribution of the mesh towards reduction in velocity of surface runoff. Use of polymer geogrid mesh provides a permanent protection as it is not biodegradable. Because of its longer life and almost unfailing success rate for vegetation growth rate per year, polymer geogrid mesh is very favourable over other reinforcing concepts by using natural fibres.

4.8.5.4 Vegetation along with reinforcement is a better method for enhancing slope stability and erosion control where unreliable vegetation growth with 100 per cent coverage is extremely difficult. Geosynthetic mats with specific thickness are required to hold the seed mix and polymer mat to last for long time. Steel wire mesh is also included in these mats sometimes optionally when high strength against erosive forces is required such as in steeper slopes and heavy rainfall areas.

4.9 Asphalt Reinforcement Requirement

Geosynthetics such as geotextiles, geogrids and geocomposites provide the widest range of products used for asphalt reinforcement as they are able to withstand high stiffness demand, installation damage and loadings.

4.9.1 *Paving fabric requirements:* The paving fabric shall be specifically designed for asphalt pavement applications and be non-woven, heat bonded on one side. The fabric shall satisfy the requirements given in **Table 4.13**. These specifications are applicable to the use of paving fabric, saturated with bitumen, between two bituminous pavement layers. The function of the paving fabric is to act as a water barrier and stress relieving membrane within the pavement structure.

Table 4.13 Physical Requirements for Paving Fabrics (Minimum Average Roll Value)

Property	Units	Standard Requirements	Test Method
Grab Tensile Strength	N	450	ASTM D 4632
Elongation	%	>50	ASTM D 4632
Mass per unit area	gm/m^2	140	IS 14716/ISO 9864/ASTM D 3776
Asphalt Retention	Kg/10 sq.m	10*	ASTM D6140
Melting Point	°C	160	ASTM D 276
Surface Texture	-	Heat bonded on One side only	Visual Inspection

Notes: *the product asphalt retention property must meet MARV provided by the manufacturer

4.9.2 *Glass fibre geo-grid requirements:* Glass fibre geogrid are a flexible reinforcement made of high modulus glass fibre yarns which are connected to each other by a special knitting process so that an open mesh structure results. These grids are coated with a special PVC material/modified polymer that is compatible with bitumen and should be self-adhesive and these are generally are supplied with a pressure sensitive adhesive backing. These glass fibre geogrid acts as stress relieving interlayer for the purpose of reinforcing asphalt overlay. **Table 4.14** provides the typical specifications of glass fibre geogrid which shall be manufactured from a glass fibre roving, resistant to chemical attack (from flux oils, paraffin's or any other solvents used in bituminous binders), mildew and rot.

Table 4.14 Properties of Glass Fibre Geogrids

Property	**Units**	**Requirement**			
		Tensile Strength in Both Median and Cross-Machine Direction			
Tensile Strength	kN/m	ISO 10319/ ASTM D6637	50	100	200
% Elongation at the ultimate strength	%		<4	<4	<4
Minimum Mesh Size	mm		25 x 25	12.5 x 12.5	12.5 x 12.5
Melting Point	°C		> 250	> 250	> 250

4.9.3 *Composite paving grids:* This composites combine the positive effects of paving grid such as high strength, high modulus, low creep which affects longevity and performance and positive effects of a nonwoven paving fabric. The stabilizing effect of the high strength, low strain component in combination with the sealing, stress relieving and uniform adhesive bonding properties of the nonwoven paving fabric fleece leads to a dramatic reduction of reflective cracking. Specifications for composite paving grid shall meet the requirements given in **Tables 4.15** and **4.16**.

Table 4.15 Properties of Asphalt Fibre Composite

Property	**Units**	**Test Method**	**Requirement**		
			Tensile Strength in Voth MD and CD, not less than		
Tensile strength	kN/m	ISO 10319/ ASTM D4595	25	50	100
% Elongation at break	%		<4	<4	<4
Minimum mesh Size	mm		15 x 15	15 x 15	15 x 15
Melting Point	°C		> 160	> 160	> 160

Table 4.16 Properties of Polyester Yarn Composite

Property	Units	Requirements			
		Tensile Strength in Both Machine and Cross-Machine Direction			
Tensile strength	kN/m	ASTM D 4595 ISO 10319	25	50	100
% Elongation at break	%		12.5	12.5	12.5
Minimum mesh Size	mm		35 x 35 20 x 20	35 x 35 20 x 20	35 x 35 20 x 20
Melting Point	°C		>180	>180	>180

4.9.4 *Selection criteria for asphalt reinforcement:* Three main types of asphalt reinforcements with variations thereof are covered in this section, namely, paving fabrics, paving grids (glass fibre and polymeric) and composites. Their benefit in the use of joint and localized (spot) pavement repairs; full width (curb-to-curb) coverage to provide a moisture barrier for the pavement structure and retard reflective cracking in asphalt overlays. Selection of specific asphalt reinforcement is particular conditions are based on several design considerations given in **Annexure III**.

4.10 Capillary Cut-off

A capillary cut-off could be provided to arrest the capillary rise of water in embankment. Drainage composite can be considered as suitable alternatives for capillary cut-off over conventional sand/ granular material.

The drainage composite for capillary cut-off (plastic spacer encased between impermeable layer of low density polyethylene geomembrane and non-woven geotextile) of adequate thickness over the full width of embankment is recommended as a capillary cut off. By using this drainage composite, use of sand blanket can be avoided as generally provided in any other method of capillary cut off mentioned as per clause 4.1 to 4.6 of IRC:34. The specifications mentioned as in clause 7.2.2.1, IRC:34 are suitable for capillary cut off applications as an alternative for drainage and other conventional measures of capillary cut off.

4.10.1 *Geocomposite requirements:* Geocomposite capillary break is comprised of a tri-planar geonet core/Geospacer consisting of thick supporting ribs with diagonally placed top and bottom ribs and with thermally bonded nonwoven geotextiles on both sides for Geonet and one side for Geospacer. This product is capable of quickly remove surface water infiltrating or ground water seeping into the soil base. The product provides a void-maintaining system under high normal loads to work as a capillary break; it also works as a separation and sub-base reinforcement layer and will have properties conforming to the values and test methods listed in IRC:34 (Section 7.2.2.1).

CHAPTER - 5
CONSTRUCTION GUIDELINES FOR USE OF GEOSYNTHETICS IN ROAD WORKS

5.1 General

The material properties are only one factor in a successful installation using geosynthetics. Proper construction and installation techniques are essential in order to ensure that the intended function of geosynthetics is fulfilled. Though, the installation techniques appear fairly simple, most geosynthetic problems in roadways occur as a result of improper construction techniques. If the geosynthetic is ripped or punctured or tore during construction activities, it will not perform as desired. If the geosynthetic is placed with lot of wrinkles or folds, it will not be in tension and, therefore, cannot provide a reinforcing effect. The following step-by-step procedure should be followed in different construction activities with geosynthetics.

The geosynthetics shall not be placed when weather conditions, in the opinion of the engineer, are not suitable to allow placement or installation. This will normally be at times of wet conditions, heavy rainfall, extreme cold or frost conditions, or extreme heat.

These are general guidelines for the construction and installation; however, manufacturer specific installation guidelines and quality control shall be followed subject to the concurrence of Engineer-in-charge and project specific requirements.

5.2 Construction Guidelines for Subsurface Drainage

5.2.1 Trench excavation shall be done in accordance with details of the project plans. In all instances, excavation shall be done in such a way so as to prevent large voids from occurring in the sides and bottom of the trench. The graded surfaces shall be smooth and free of debris, depression or obstructions.

5.2.2 The geosynthetic material shall be placed loosely with no wrinkles or folds, and with no void spaces between the geosynthetic and the ground surface. Successive sheets of geosynthetics shall be overlapped a minimum of 300 mm with the upstream sheet overlapping the downstream sheet.

5.2.3 In trenches equal to or greater than 300 mm in width, after placing the design filter material, the geosynthetic shall be folded over the top of the backfill material in a manner to produce a minimum overlap of 300 mm. In trenches less than 300 mm but greater than 100 mm wide, the overlap shall be equal to the width of the trench. Where the trench is less than 100 mm, the geosynthetic overlap shall be sewn or otherwise bonded. All seems shall be subject to the approval of the Engineer. In case the geosynthetic gets damaged during installation or drainage aggregate placement, a geosynthetic patch shall be placed over the damaged area with minimum 300 mm overlap all around or the specified seam overlap, whichever is greater.

5.2.4 Placement of design filter material (as per MoRTH 702.2.3) should proceed immediately after placement of the geosynthetic material. The geosynthetic should be covered with a minimum of 300 mm of loosely placed aggregate prior to compaction. If a perforated collector pipe is to be installed in the trench, a bedding layer of drainage aggregate should be placed below the pipe, with the remainder of the aggregate placed to the minimum required construction depth.

5.2.5 The aggregate should be compacted to a minimum of 90 per cent of standard proctor density. **Figs. 5.1** to **5.3** illustrate various geosynthetic drainage application details.

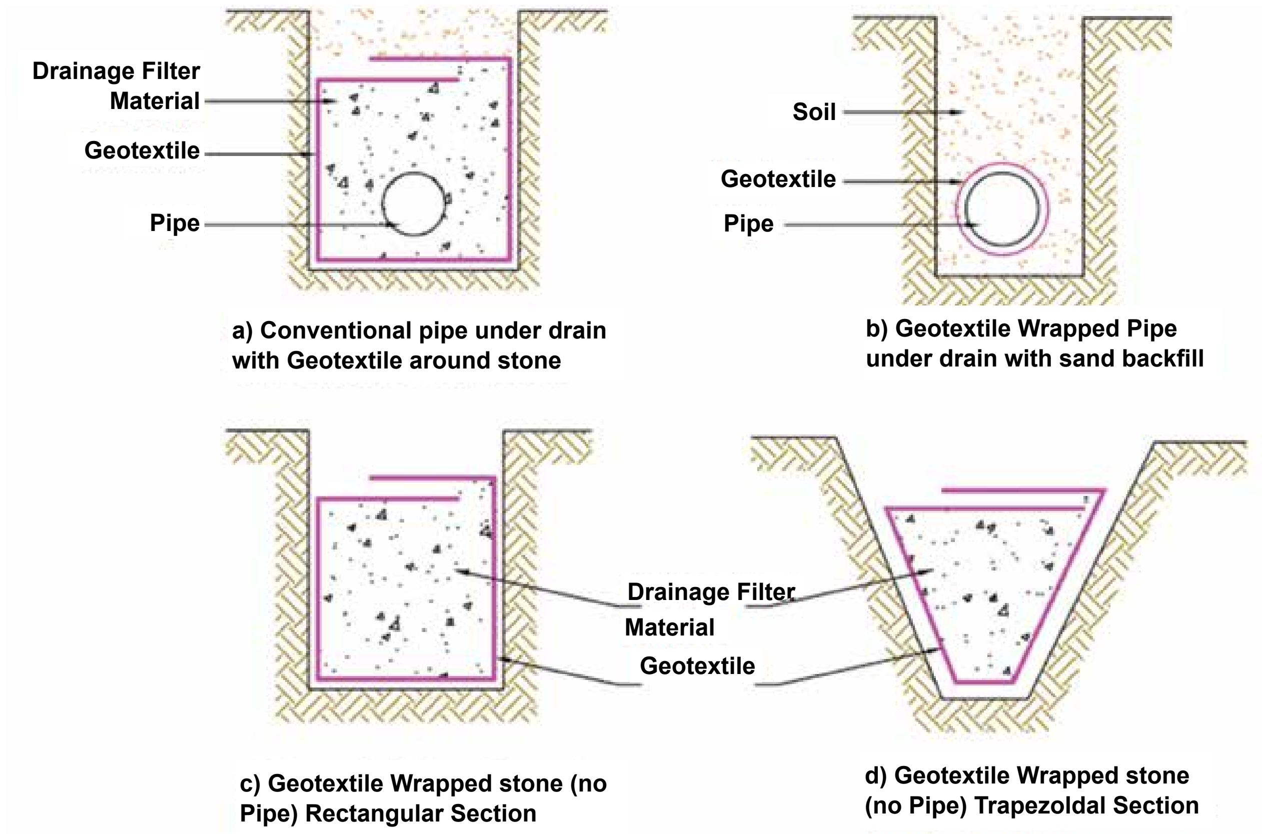


Fig. 5.1 Various Arrangements for Trench Drains

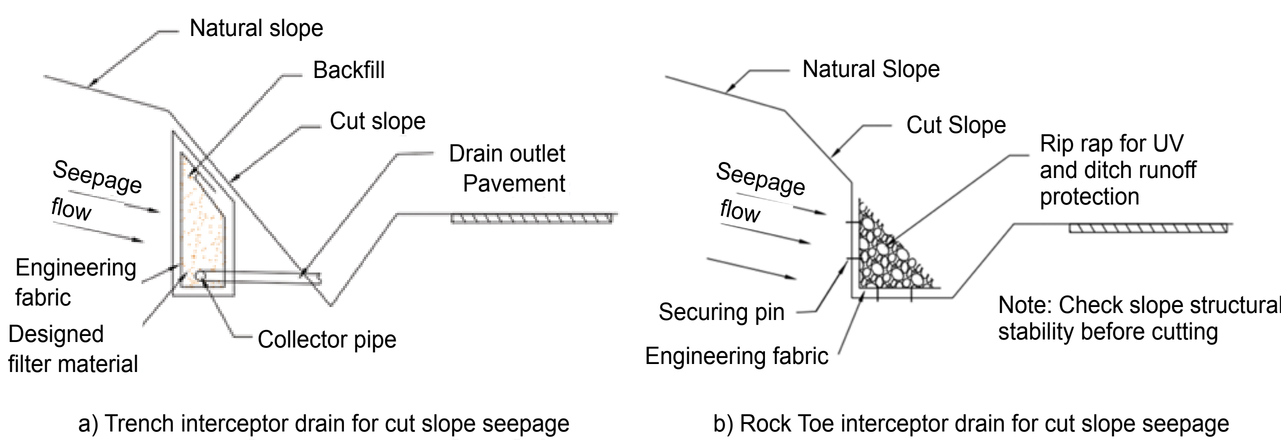


Fig. 5.2 Trench and Toe Interceptor Drain for Cut Slope Seepage

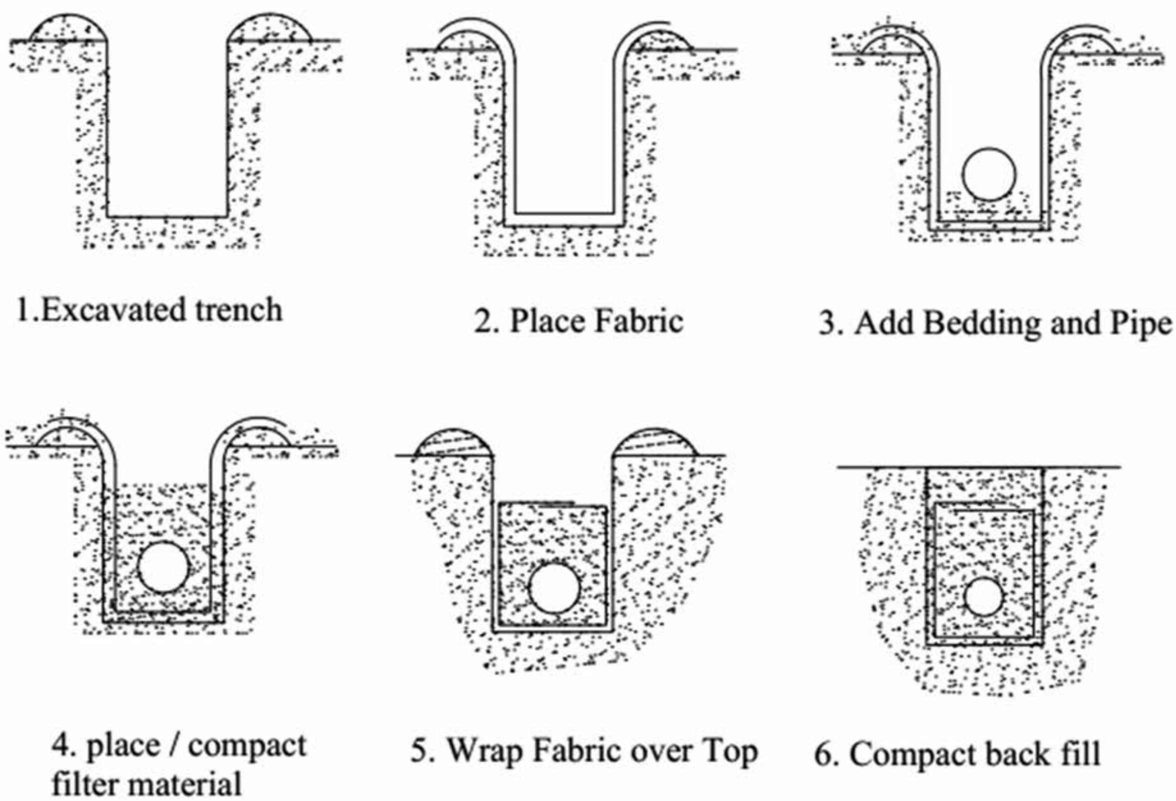


Fig. 5.3 Sequence of Construction Procedure for Drains

5.3 Construction Guidelines for Separation/Filtration/Subgrade/Base/Subbase Reinforcement Function

These construction guidelines are related to placing a geosynthetic material between base or subbase and subgrade for any of the following applications:

- Base or Subbase Separation
- Base or Subbase Stabilization
- Base or Subbase Capillary Barrier
- Base or Subbase Reinforcement

5.3.1 The site should be cleared, grubbed and excavated to design grade, stripping all topsoil, or any other unsuitable materials. If moderate site conditions exist, i.e., CBR greater than 1, lightweight profiling operations should be considered to locate unsuitable materials. Isolated pockets where additional excavation is required should be backfilled.

5.3.2 During stripping operations, care should be taken not to excessively disturb the subgrade. This may require the use of lightweight dozers or graders for low strength, saturated, non-cohesive and low-cohesive soils. In this case, all vegetation should be cut at the ground surface. Sawdust or sand can be placed over stumps or roots that extend above the ground surface to cushion the geosynthetic. The subgrade preparation must correspond to the survivability properties of the geosynthetic.

5.3.3 Once the subgrade along a particular segment of the road alignment has been prepared, the geosynthetic should be rolled in line with the placement of the aggregate. Field operations can be expedited if the geosynthetic is pre-sewn to design widths in the factory or on firm ground so it can be unrolled on site in one continuous sheet. The geosynthetic should not be dragged across the subgrade. The entire roll should be placed and rolled out as smoothly as possible. Wrinkles and folds in the fabric should be removed by stretching and stacking as required.

5.3.4 Adjacent rolls of geosynthetic should be overlapped. For curves, the geosynthetic should be folded or cut and overlapped in the direction of construction. For separation, drainage and capillary barrier applications, geosynthetics shall be sewn or joined as required. Folds in the geosynthetic should be stapled or pinned approximately 0.6 m centre-to-centre as shown in **Fig. 5.4 (a)** and **(b)**.

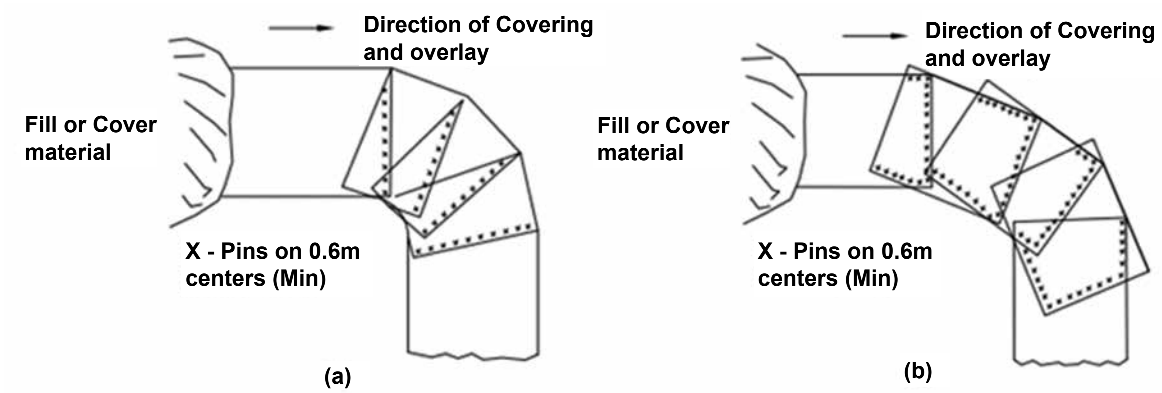


Fig. 5.4 Folding of Geosynthetics

5.3.5 Before covering, the condition of the geosynthetic should be checked for damage (i.e., holes, nips, tears, etc.) by an Engineer experienced in the use of these materials. If excessive defects are observed, the section of the geosynthetic material containing the defect should be repaired by placing a new layer of geosynthetic over the damaged area in case of geotextiles and geomembrane for separation, drainage and capillary barrier applications. The minimum required overlap for adjacent rolls should extend beyond the defect in all directions. Alternatively, the entire defective section can be replaced. In case of geogrids and geocells for reinforcement and stabilization function, if the material is damaged, placing a new layer over damaged portion won't provide membrane effect and intended function may not fulfil. In those cases replacing with a new material for entire design role length of geosynthetic material in transverse direction is advisable.

5.3.6 The first lift of aggregate should be spread and graded to 300 mm, or to design thickness if less than 300 mm prior to compaction. At no time should traffic be allowed on a soft roadway with less than 200 mm of aggregate over the geosynthetic.

5.3.7 Any ruts that form during construction should be filled to maintain adequate cover over the geosynthetic. In no case should ruts be bladed down, as this would decrease the amount of aggregate cover over the geosynthetic.

5.3.8 All remaining base aggregates should be placed in lifts not exceeding 250 mm in loose thickness and compacted to the specified density. Different operation sequences for construction are shown in **Fig. 5.5**.

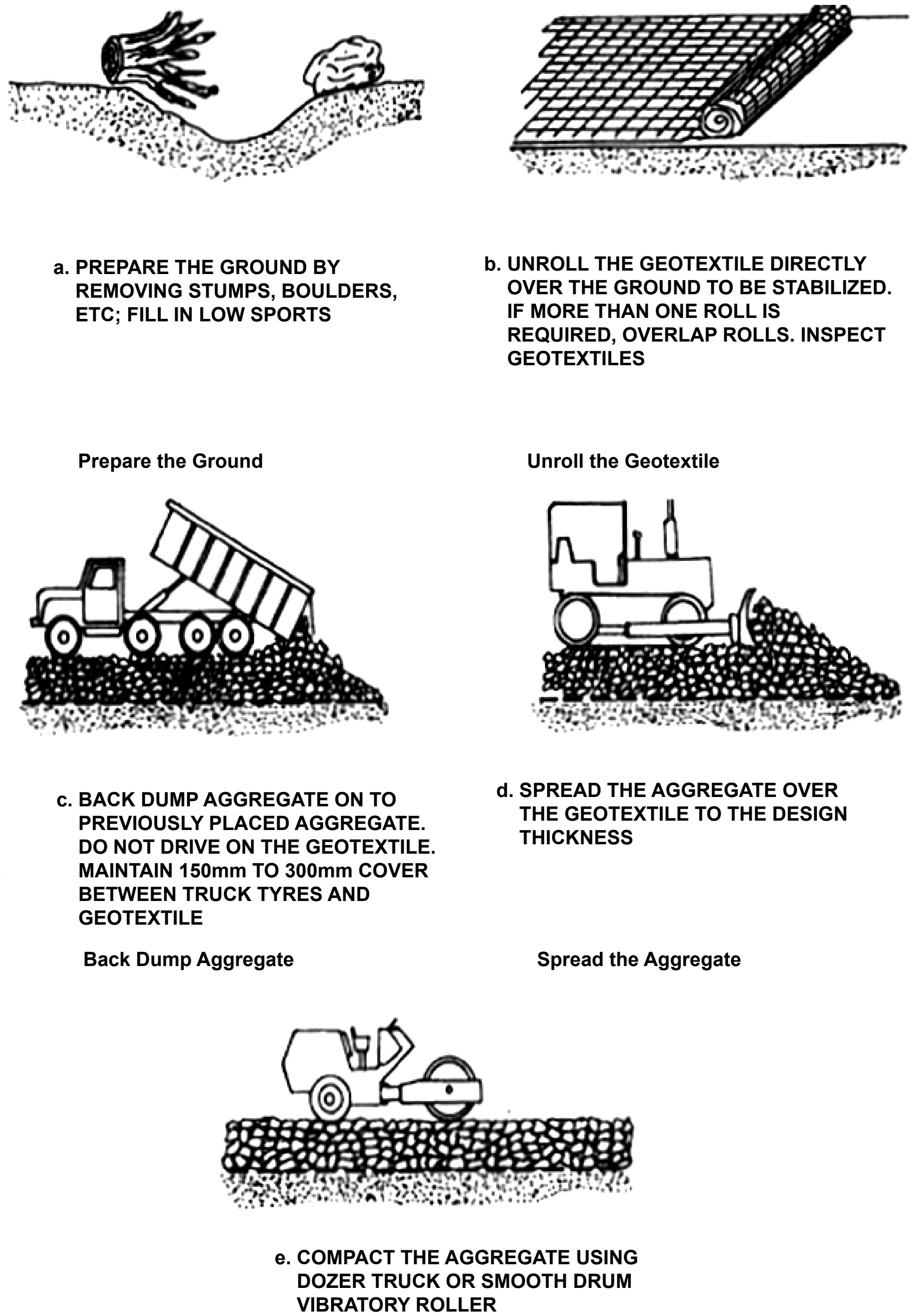


Fig. 5.5 Construction Sequence

5.4 Geosynthetic Overlaps

5.4.1 When geosynthetic material is used the overlaps can be used to provide continuity between adjacent geosynthetic rolls through frictional resistance between the overlaps. Also, a sufficient overlap is required to prevent soil from squeezing into the aggregate at the joint. The amount and type of overlap depends primarily on the soil conditions, type of geosynthetics their function and application. If the subgrade does not rut under construction activities, only a minimum overlap is required to provide some pull-out resistance. As the potential for rutting and squeezing of soil increases, the required overlap increases. Since rutting potential can be related to CBR, it can be used as a guideline for the minimum overlap required.

Table 5.1 Overlap Requirement of Geotextile for Different CBR Values (IS 16345)

Soil Strength (CBR)	Overlap Unsewn, cm	Overlap Sewn, cm
Greater than 3 and above	60	-
2-3	76	8
1-2	97	20
Less than 1	-	23
All Roll Ends	100	25

Table 5.2 Overlap Requirement of Geogrid for Different CBR Values (IS 16349)

Soil Strength (CBR)	Method of Joining (mm)
Greater than 3	300-450
1-3	600-1000
0.5-1	1000 or sewn
Less than 0.5	sewn
All Roll Ends	1000 or sewn

5.4.2 The geosynthetic can be stapled or pinned at the overlaps to maintain their positions during construction activities. For the separation and filtration applications using geotextiles the overlap requirements are given in **Fig. 5.6**. For underwater applications, 5 mm dia and 450 mm long steel pins should be placed at a maximum of 1.0 m centre-to-centre.

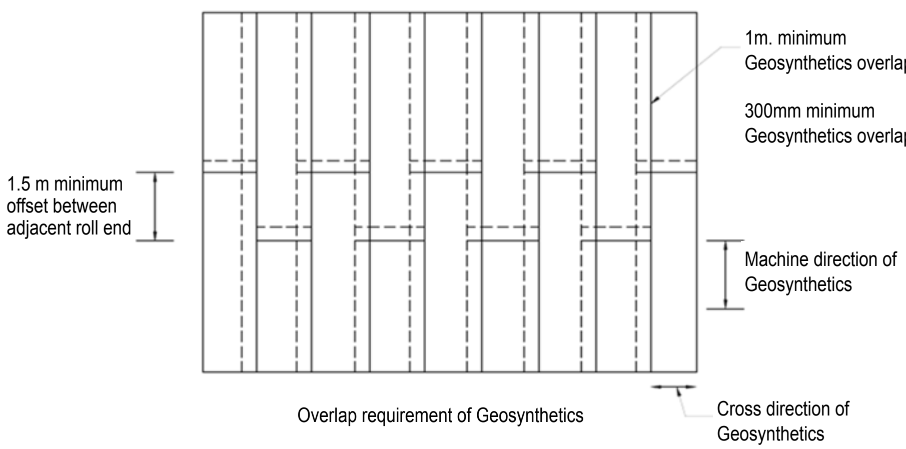


Fig 5.6 Overlap Requirement of Geosynthetics

5.4.3 Since manufactured rolls of geocomposite drainage materials must cover large areas, field constructed connections along their sides and ends are necessary. This guide addresses such connections. Even further, the ends of the geocomposite must eventually terminate by attachment to pipes, sumps or swales. These are also made in the field by construction personnel. The following situations are presented in this section illustrating various connections.

Connection of Overlapping Geocomposite on their ends and sides: **Fig. 5.7** shows an overlapped geocomposite with the up-gradient end overlapping the down gradient end. For the sides of the rolls which is placed, upper or lower, is not important. The recommended lengths of overlap ("L") are 300-450 mm for ends and 100-150 mm for sides. One other consideration has to do with the roll ends being factory supplied or cut in the field. The manufacturers of geocomposite usually leave an excess of 300 mm of un-bonded geotextile for complete coverage purposes. Field cut geocomposite have no such excess geotextile.

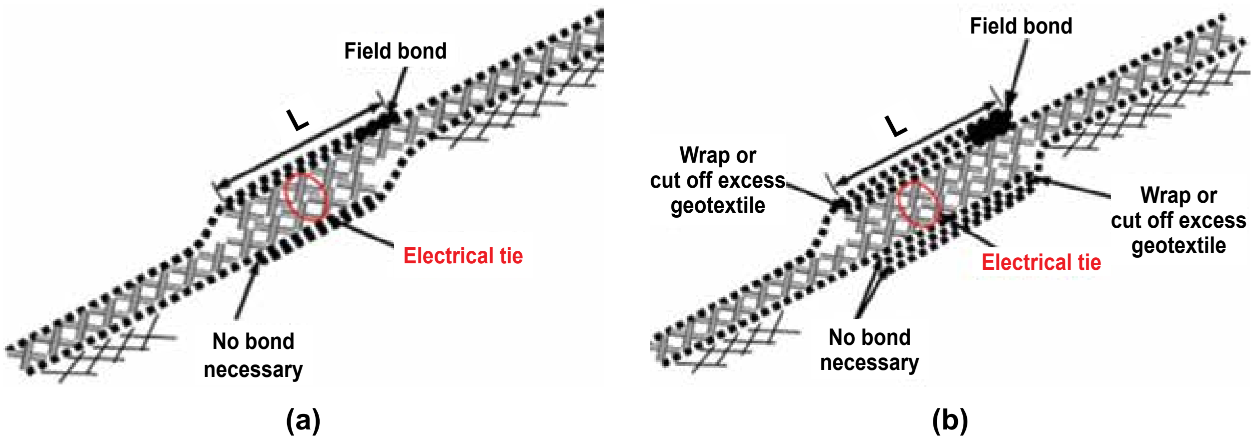


Fig. 5.7 (a) Field Cut Geocomposite, (b) Factory Ends with Excess Geotextile

Geocomposite to Horizontal Pipe Connection: Geocomposite drainage core should wrap around the entire pipe with no intervening geotextile in the flow transfer area (**Fig. 5.8a**) The geocomposites upper geotextile must be stripped off the drainage core, greatly trimmed, and then bonded to the reverse side of the geocomposite with its geotextile intact after wrapping around the pipe. The overlap distance “L” should be approximately three times the encapsulated drainage pipe diameter. Also note that plastic electrical ties are necessary to hold the geonet together particularly for thick bi-planar and all tri-planar geonet composites. Generally, two ties are necessary to minimize the air space around the encapsulated pipe. This same detail can also be followed if the drainage pipe is located in a trench at a lower elevation than the exiting geocomposite drain; see **Fig. 5.8b**.

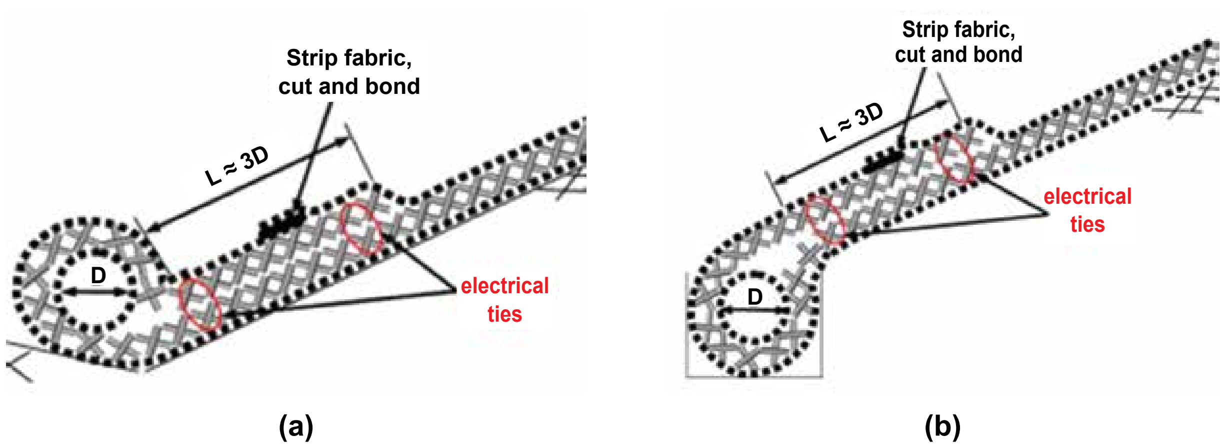


Fig. 5.8 (a) Drainage Pipe on a Slope, (b) Drainage Pipe in a Trench

5.5 Seams

5.5.1 When seams are required for separation applications using geotextile, there should be minimum of 90 per cent of the material’s tensile strength requirements of survivability (**Table 5.1**). All factory or field seams should be sewn with thread as strong and durable as the material in the fabric.

5.5.2 When field-sewing geotextiles, a number of details must be addressed. They are:

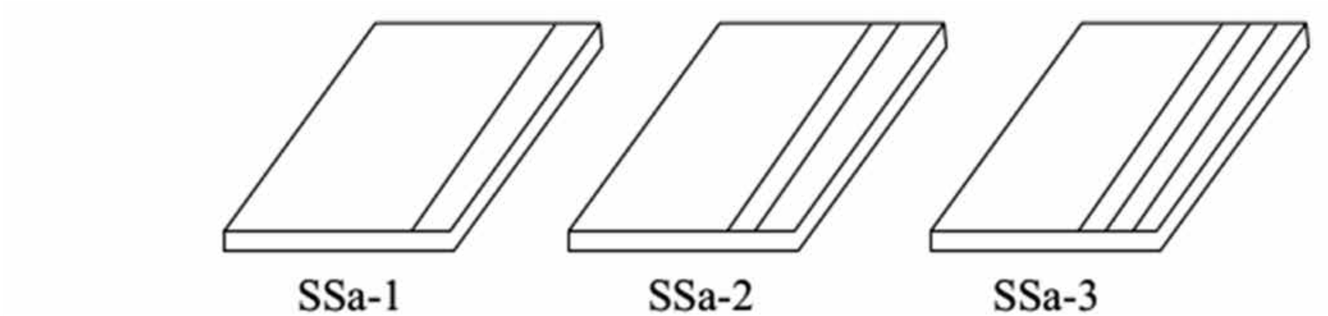
Thread type: The choices are polyester, polypropylene and polyamides. Consideration should be given to using the same thread type as geotextile fibre.

Thread tension: This is usually adjusted in the field so as to be sufficiently tight without cutting the geotextiles.

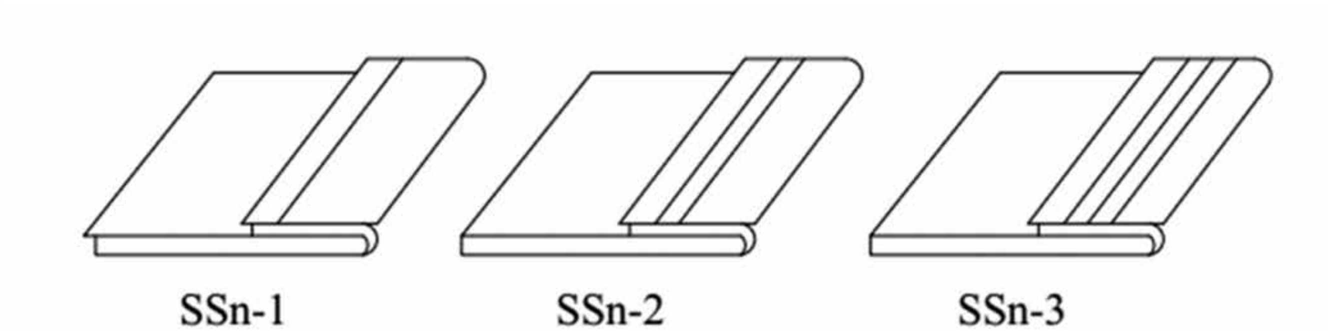
Stitch density: Two, three or four stitches per 25 mm are customary.

Stitch type: The choices are prayer, J-type, or butterfly. **Fig. 5.9** shows typical seams for geotextiles. The strongest being the butterfly type.

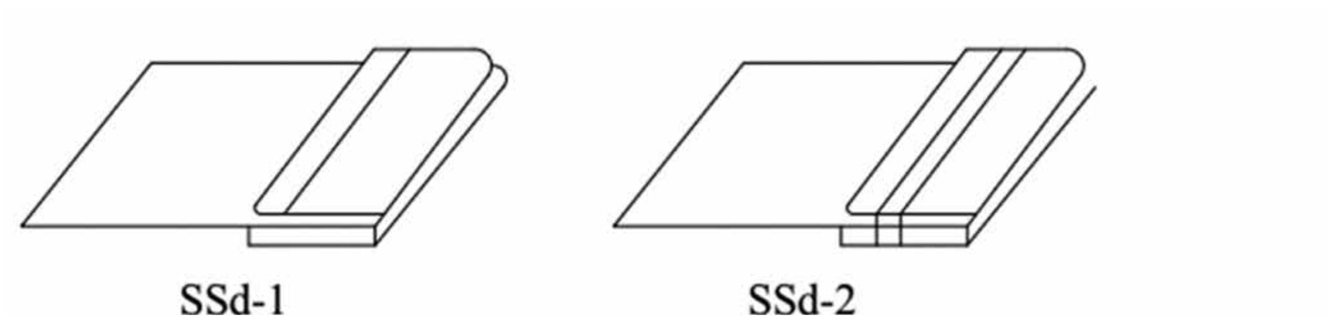
Number of rows: One, two or three are customary; generally two are recommended.



"Flat" or "Prayer" Seam



"J" Seam



"Butterfly" Seam

Fig. 5.9 Typical Seams for Geotextiles

5.6 Construction Guidelines for Erosion Control

5.6.1 The geosynthetic shall be placed in intimate contact with the soils under slight tension, without wrinkles or folds and anchored on a smooth graded surface approved by the Engineer. The geosynthetic shall be placed in such a manner that placement of the overlying materials will not excessively stretch so as to tear the geosynthetic. Using geotextiles, geomats, biodegradable mats anchoring of the terminal ends shall be accomplished through the use of key trenches or aprons at the crest and toe of slope.

The following anchoring recommendations are provided as a guide and needs to be adjusted based on specific site conditions and manufacturer's instructions.

Anchoring the edges of the erosion control mat in a trench approximately 150-200 mm deep by 150 mm wide prevents water flowing under the mat and provides maximum erosion protection. When installing mat down a slope, it is recommended, the upstream edge is anchored in a trench to provide better protection from stream flow. Mat should have good contact with the soil surface and be secured with an appropriate number of pins for degree of slope. As a general rule, mat should be secured with pins at 0.5-1 m intervals along the length of the mat and staggering pins 400-600 mm across the mat. Pins should be driven flush with the soil surface and be long enough to ensure sufficient ground penetration to resist pullout. If the degree of slope is greater than 1V:3H it is recommended the anchor trench be installed at least 1 m from the crest of the slope.

Type of Slope	Gradient	Minimum Pins/sq.m
Steep slopes	1:1 – 1:2 or greater	6 to 8
Moderate slopes	1:2 – 1:3	4 to 6
Gentle slopes	1:4 or less	

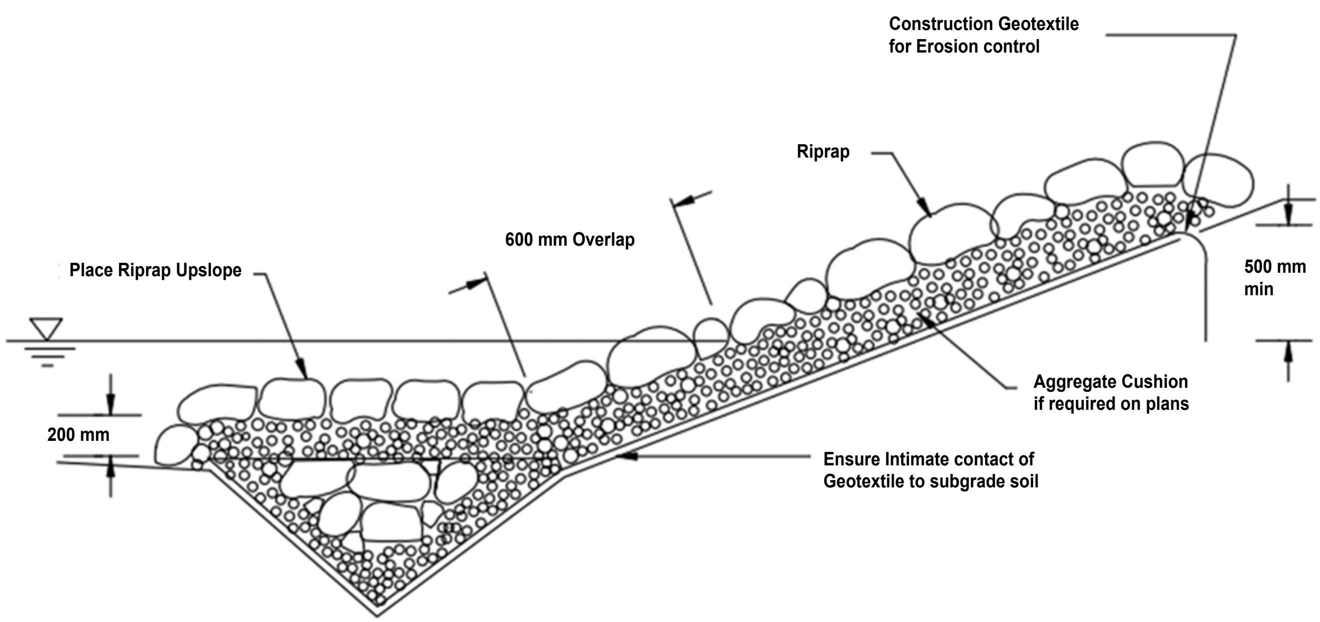


Fig. 5.10 (a) Erosion Control using Geotextiles

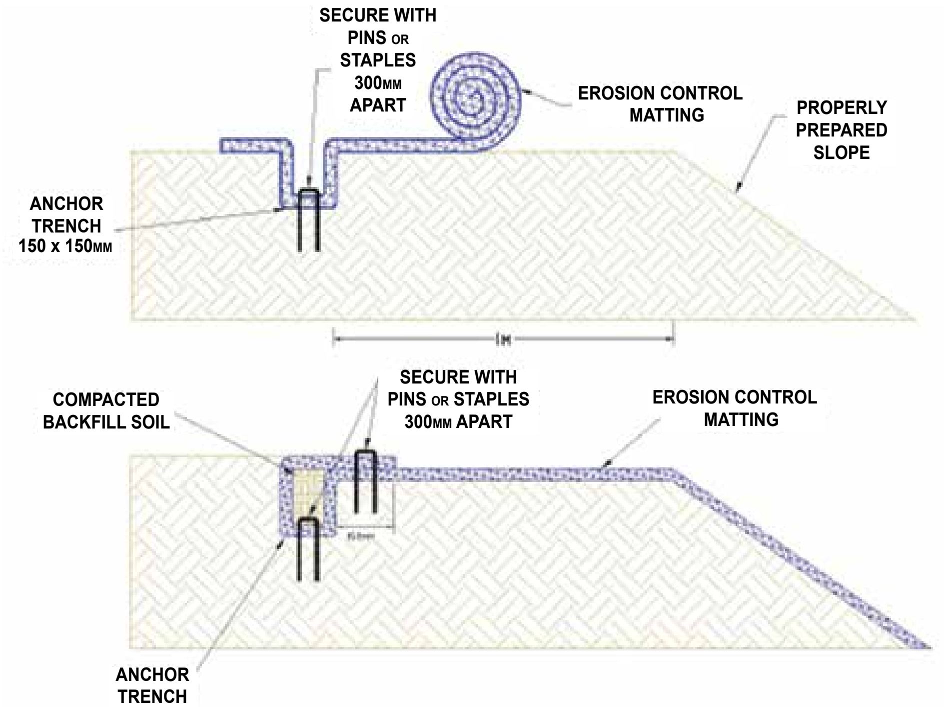


Fig. 5.10 (b) Anchoring Details of Erosion Control Mats

5.6.2 The geosynthetic shall be placed with the machine direction parallel to the direction of water flow which is normally parallel to the slope for erosion control runoff and wave action and parallel to the stream or channel in the case of stream bank and channel protection. Adjacent geosynthetic sheets shall be joined by either sewing or overlapping or joining. Overlap at roll ends and at adjacent sheets shall be minimum of 300 mm, except when placed under water. In such instances, the overlap shall be minimum of 1 m.

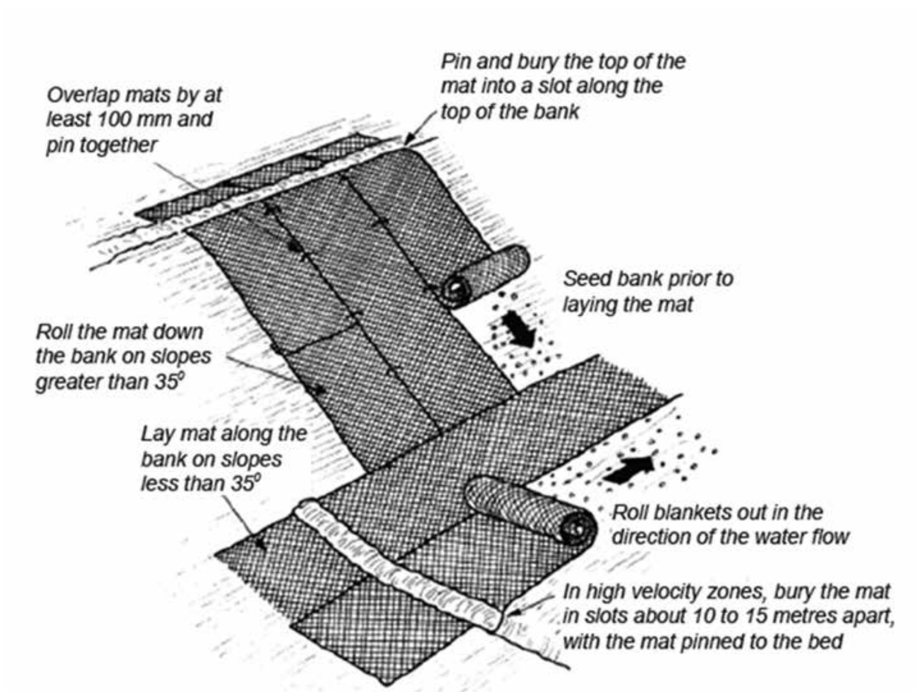


Fig. 5.10 (c) Orientation of Matting on Slopes and Channels

5.6.3 In cases where wave action or multi-directional flow is anticipated, all seams perpendicular to the direction of flow shall be sewn.

5.6.4 Care shall be taken during installation so as to avoid damage occurring to the geosynthetics as a result of the installation process. Should the geosynthetic be damaged during installation, a geosynthetic patch shall be placed over the damaged area extending 1 m beyond the perimeter of the damage.

5.6.5 The armour system placement shall begin at the toe and proceed up the slope. Placement shall take place so as to avoid stretching and subsequent tearing of the geosynthetic. Riprap and heavy stone filling shall not be dropped from a height of more than 300 mm. Stone with a mass of more than 100 kg shall not be allowed to roll down the slope.

5.6.6 Slope protection and smaller sizes of stone filling shall not be dropped from a height exceeding 1 m, or a field trial should be undertaken to verify that the placement procedures will not damage the geosynthetic. In underwater applications, the geosynthetic and backfill material shall be placed the same day. All void spaces in the armour stone shall be backfilled with small stone to ensure full coverage.

5.6.7 Following placement of the armour stone, grading of the slope shall not be permitted if the grading results in movement of the stone directly above the geosynthetic.

5.6.8 Field monitoring shall be performed to verify that the armour system placement does not damage the geosynthetic. Any geotextile damaged during backfill placement shall be replaced as directed by the Engineer-in-charge.

5.7 Construction Guidelines for Use of Asphalt Reinforcement

5.7.1 *General preparation work prior to paving:* The existing pavement must show no significant signs of pumping, movement or structural instability. All patches, pothole repairs and crack sealing should be done prior to paving. Bituminous reinforcement adheres best to a smooth, flat bituminous surface.

5.7.2 *Therefore a bituminous levelling layer may be necessary:*

- On a coarsely milled or very rough surface
- On a very uneven (rutted) surface

A levelling layer is not normally necessary:

- For an overlay on an old surface that is smooth and flat
- On a finely milled surface

5.7.3 *The surface must be clean and dry before placing the asphalt reinforcement*

- Clean for good adhesion
- Dry (of moisture) also for adhesion
- Dry bitumen (tack or fresh bituminous) to avoid pick-up on construction vehicle tyres that may in turn lift the asphalt reinforcement.

Fig. 5.11 Glass Fibre Grid placed on Levelling Layer Prior Paving

5.7.4 *Repair of defects prior to paving:* The degree and extent of surfacing defects and failures necessitate certain methods of repair to render the road surface serviceable again. Bituminous Reinforcement is an alternative to the reworking of pavement layers and usually applied before a road surface is resealed or overlaid with bituminous.

5.7.4.1 *Pothole patching:* All loose materials of the damaged surfacing and base layers must be removed to the full depth and backfilled with approved bituminous mixtures as described in various handbooks or as specified. The shape of the repair area should be square or rectangular and the surfacing cut 75 to 100 mm wider than the cleaned - out area.

5.7.4.2 *Seal cracks:* The repair of seal cracks shall follow the provisions of MoRTH section 3000.

5.7.5 Certain types of bituminous reinforcement do not require cracks to be sealed beforehand.

5.7.5.1 *Levelling course:* When required to remove unacceptable irregularities, bumps or slacks, a screed of densely graded bituminous should be placed. It is also possible to remove high spots and ridges by planning, in which case it is recommended that the milled surface be left rough.

5.7.5.2 *Rut filling:* Rut depths of up to 15 mm, or as specified, can be filled with coarse slurry. It is recommended that rapid setting slurry be used. Rut depths up to 25 mm can be filled with hot, densely graded bituminous. Ruts deeper than 25 mm should be removed by surface patching methods.

5.7.6 This work shall consist of lying of geotextile (paving fabric) between two bituminous layers as part of pavement strengthening to provide a water resistant membrane and crack retarding layer. **Fig. 5.9** shows layer arrangement for using paving fabric. It is recommended that paving fabric should be used over the entire pavement area affected by cracking and not in the form of strips over the pavement cracks.

5.7.7 On existing cement concrete pavements, a layer of DBM/Bituminous Concrete should be provided before laying the paving fabric.

5.7.8 The tack coat used to impregnate the fabric and bond the fabric to the pavement shall be as per the provisions of Section 503 of MoRTH.

5.7.9 Minimum air and pavement temperature shall be at least 10°C or more for placement of tack coat. Neither tack coat nor paving fabric shall be placed when weather conditions, in the opinion of the Engineer, are not suitable.

5.7.10 The pavement surface shall be thoroughly cleaned of all dirt, water and oil to the satisfaction of the Engineer. Cracks wider than 3 mm shall be cleaned and filled with suitable bituminous material by a method approved by the Engineer. Crack filling material shall be allowed to cure prior to application of tack coat. Potholes and other pavement distress shall be repaired. Repairs shall be performed as directed by the Engineer. A profile correction course shall be laid, wherever required, before placing the paving fabric.

5.7.11 The tack coat shall be sprayed preferably by means of a calibrated distributor spray bar. Hand spraying and brush application may be used in locations of fabric overlap. Every effort shall be made to keep hand spraying to a minimum. The tack coat shall be applied uniformly to the prepared dry pavement surface at the rate governed by the following equation:

$$Q_d = 0.36 + Q_s + Q_c$$

Where,

Q_d = Design tack coat quantity

Q_s = Saturation content of the geotextile being used (kg/m^2) to be provided by the manufacturer

Q_c = Correction based on tack coat demand of the existing pavement surface (kg/m^2)

Table 5.2 gives typical values of tack coat demand of existing bituminous pavement surfaces. Within street intersections, on steep grades or in other zones where vehicle speed changes, the normal application rate shall be reduced by about 20 per cent or as directed by the Engineer.

Table 5.2 Tack Coat Demand of Existing Bituminous Pavement Surfaces

Type of Surface	Quantity of Liquid Bituminous Material in kg/sq.m area
Normal bituminous surface	0.20 to 0.25
Dry and hungry bituminous surface	0.25 to 0.30

5.7.12 The temperature of the tack coat shall be sufficiently high (140°C) to permit a uniform spray pattern. To avoid damage to the fabric, distributor tank temperature shall not exceed 160°C.

5.7.13 The target width of tack coat application shall be equal to the paving fabric width application plus 150 mm. The tack coat shall be applied only as far in advance of paving fabric installation as is appropriate to ensure a tacky surface at the time of paving fabric placement. Traffic shall not be allowed on the tack coat. Any spillage or excess tack coat should either be removed or sand be sprayed over it.

5.7.14 Paving fabric shall be placed on a dry surface. In case it rains after installing the paving fabric, but before placing the overlay over it, all excess water should be removed and the fabric should be allowed to dry up sufficiently before placing the overlay.

5.7.15 The paving fabric shall be placed with heat set side facing up, onto the tack coat using mechanical or manual lay down equipment capable of providing a smooth installation with a minimum amount of wrinkling or folding. The paving fabric shall be placed prior to the tack coat cooling and losing tackiness. Paving fabric shall not be installed in areas where the overlay bituminous layer tapers to a thickness of less than 40 mm. Excess paving fabric, which extends beyond the edge of existing pavement or areas of tack coat applications shall be trimmed and removed. Wrinkles or folds in excess of 25 mm shall be slit and laid flat. Brooming and/or pneumatic rolling will be required to maximize paving fabric contact with the pavement surface. All areas with paving fabrics placed will be paved the same day. No traffic except necessary construction equipment will be allowed to drive on the paving fabric. Additional tack coat shall be placed between the overlap to satisfy saturation requirements of the fabric. Overlap shall be sufficient to ensure full closure of the joint but not exceed 150 mm. Overlaps of adjacent rolls shall be staggered by a minimum of one meter.

5.7.16 After laying the paving fabric, some loose bituminous concrete should be sprinkled on it in the wheel path of the paver and the tipper to ensure that the fabric is not picked up between the wheels.

5.7.17 Turning of the paver and other vehicles shall be done gradually and kept to a minimum to avoid movement and damage to the paving fabric. Abrupt starts and stops shall also be avoided. Damaged fabric shall be removed and replaced with the same type of fabric.

5.7.18 Bituminous overlay construction shall closely follow fabric placement. All areas in which paving fabric has been placed will be paved the same day. Excess bitumen, which bleeds through the paving fabric, shall be removed by spreading hot mix or sand on the paving fabric. The hot mix should be placed between a temperature range of 130°C to 145°C so as to given enough heat to the bitumen in the tack coat to rise up into the fabric.

5.7.19 The introduction of paving fabrics have been reported to reduce the required design overlay thickness. However, these guidelines do not recommend any reduction in design overlay thickness; rather its introduction is to enhance the performance of the pavement.

In general, installation of geotextiles as pavement fabric shall follow IS 16343.

CHAPTER - 6
HANDLING AND STORAGE OF GEOSYNTHETICS

6.1 General

6.1.1 Geosynthetics are durable products, which provide cost-effective solutions to a variety of civil engineering design/construction related problems. As with any construction material, geosynthetics must be handled and stored properly to ensure that the specified physical properties are retained to serve project needs. The damages caused on this account can significantly reduce the geosynthetic ability to perform its intended function in some applications.

The objective of geosynthetic handling and storage is to safely transport and store the geosynthetic rolls or panels at the project site without damaging the geosynthetic or unduly exposing it to sunlight (ultraviolet light), moisture or other contamination. The following are some of the general recommendations to be followed while working with geosynthetic materials at site. Handling and storage of geosynthetics can be as per product manufacturer's suggestions and instructions.

6.2 Site Unloading

6.2.1 A fork-lift or front-end loader fitted with a long, tapered pole is recommended for unloading of geosynthetic rolls. The pole, shown in **Fig. 6.1**, is often referred to as a 'carpet pole' or 'stinger'. The carpet pole is inserted into the geosynthetic roll core and the roll is lifted off the truck bed. The pole should be long enough to extend at least two third of the way into the geosynthetic roll core to avoid the possibility of breaking or damaging the roll core.

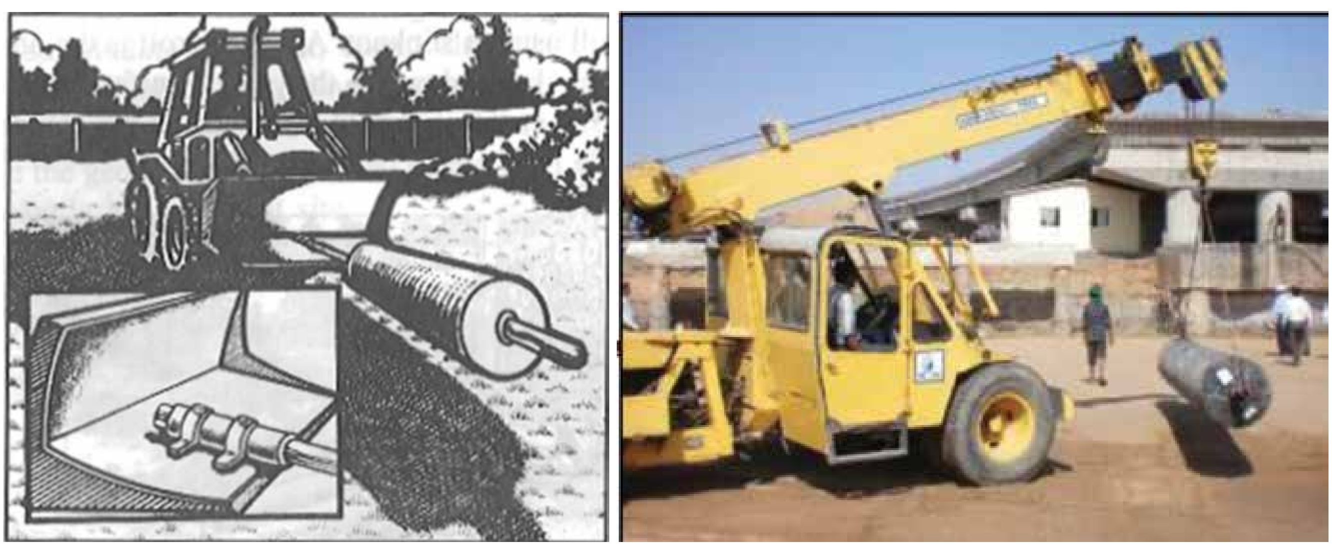


Fig. 6.1 Hydro Crane Shifting the Geosynthetic Roll to the Location

6.2.2 Geosynthetic rolls may also be lifted from flatbed trailers using nylon straps or rope and a crane, backhoe, or bulldozer. Not more than three geosynthetic rolls should be lifted at a time. Exceeding this number may cause damage to the roll core and hamper while geosynthetic deployment. Chains and cables should not be used to lift geosynthetic rolls. The equipment recommended to unload geosynthetic rolls may not be always available at construction sites. In such cases, unloading and handling is invariably done by other locally available methods or with labours. If unloaded with care, the geosynthetic will remain suitable for easy laying. A roll puller, nylon strap, or rope can be used to unload geosynthetic rolls from an enclosed trailer if a carpet pole is not available. Roll pullers are devices, which are inserted into the roll core and attached via a chain or strap to a loader, bulldozer, or other vehicle as shown in **Fig. 6.2**. As the vehicle pulls, the roll puller expands against the inside of the roll core and drags the roll to the edge of the truck bed and down to the ground surface. Nylon straps or ropes may also be wrapped around the geosynthetic roll using a slip knot. Again the roll is dragged to the edge of the truck and down to the ground surface. A tarpaulin, sheet of plastic or fabric should be placed on the ground where the geosynthetic rolls are to be unloaded.

Fig. 6.2 Unrolling of Geosynthetic Roll

Fig. 6.3a Geocell Panels at Site

Fig. 6.3b Geogrid Rolls at Site

Fig. 6.3a & b Geocell Panels and Geogrid Rolls Readied for Placement

6.3 Site Handling

Rolls of geosynthetic should always be lifted off the ground surface prior to moving. Dragging the geosynthetic and operating equipment on the geosynthetic, which results in physical damage, should be avoided at all times. Geocell panels are packed in a collapsed form [**Fig. 6.4**].

(a) (b)

Fig. 6.4 (a) Folded Geocell Panels on Fork Lift Pallet,
(b) Packaged Geocell Panels in the factory on Fork Lift Pallet

6.4 Site Storage

6.4.1 The geosynthetic rolls should be adequately protected from ultraviolet light exposure during storage at site. A protective wrapping should be kept on rolls until the geosynthetics are installed. If stored outside, the geosynthetic should be elevated from the ground surface and adequately covered to protect them from the following; site construction damage, precipitation, ultraviolet radiation including sun light, chemicals that are strong acid/bases, flames including welding sparks, temperature in excess of 71°C and any other environmental condition that may damage the geosynthetic. **Fig. 6.5** illustrates the mode of covering of geotextile before use at site.

Fig. 6.5 Covering of Geosynthetic Rolls before Use at Site

To the extent possible, geocells shall be stored with the packaging intact. This is essential for the following reasons:

a) Easy identification of the material type, batch no. and other details;

b) Protection against any damage during storage;

c) Protection against damage during onward handling

Heavy equipment may be moved on the panels only after in filling as may be seen in the **Fig. 6.6**.

(a) **(b)**

Fig. 6.6 (a) In Filling from Side, (b) Equipment Run on Geocell Filled with Soil

6.4.2 *Steps to be taken if geosynthetic roll or protective wrapping is damaged*

6.4.2.1 In most cases, damage to a roll of geosynthetics is limited to the protective wrapping. If the wrapping is damaged, proper storage of the geosynthetic is particularly critical. The rolls must be elevated off the ground surface and securely covered with a tarpaulin or opaque plastic sheet. If the outer layer of the geosynthetic itself is damaged, it is necessary during installations to remove the outermost wraps of the roll and discard the damaged material. The remaining undamaged material is suitable for use. Removing the outermost wrap of geosynthetic is called for when a roll is exposed to sunlight for a period beyond that permitted by the project specifications. The remaining unexposed material is suitable for construction.

6.4.2.2 Exposing geosynthetic rolls to moisture or water prior to installation can lead to serious handling problems. Non-woven geosynthetics in particular can absorb water up to three times their weight. In addition, the cores on which the geosynthetic rolls are wound are manufactured from laminated paper. When wet, the strength of these cores is seriously diminished to the point where the core will not support the weight of the geosynthetic. Consequently, it can be extremely difficult to install wet rolls of geosynthetic. In addition, it is nearly impossible to unroll wet, frozen geosynthetic without first allowing it to thaw.

6.4.3 *Steps to be taken if geosynthetic rolls become wet*

If geosynthetic rolls become wet, it is permissible to remove the waterproof cover to allow for a few days of exposure to wind in order to dry the geosynthetic material. It is essential that the rolls be elevated during the process. It is also permissible to remove the protective wrapping from one end of the roll and elevate the opposite end of the roll. Then the majority of excess water will flow out of the geosynthetic. In most cases, these procedures will not allow the geosynthetic material to dry completely. Once unrolled during installation, the geosynthetic will dry very quickly in the sun and wind. However, it should be noted that non-woven geosynthetics used in conjunction with asphalt overlays of existing pavements must be completely dry prior to installation.

6.4.4 *Protection from sunlight (ultraviolet light) degradation*

6.4.4.1 Geosynthetic materials slowly degrade in the presence of ultraviolet light. Though some geosynthetics contain ultraviolet stabilizing chemicals to keep this degradation to a minimum, it is advisable to limit geosynthetic exposure to sunlight until just before installation. Acceptable limits of exposure to ultraviolet light depend upon site environmental conditions (temperature, latitude, time of year, wind, etc.) and the assumptions used by the Engineer during design.

6.4.4.2 The geosynthetic material should always be installed within the period required by the project specifications. If no time requirements are specified, it is generally recommended that geosynthetic exposure to ultraviolet light be limited to a period of approximately two weeks. Excessive cold temperatures normally found at construction sites, even in the coldest climates, do not pose a threat to geosynthetics.

Annexure I

DETERMINATION OF LAYER COEFFICIENTS

Layer coefficients are empirical relationships between Structural Number (SN) and layer thicknesses which expresses the relative ability of a material to function as a structural component of the pavement. They are typically determined empirically based on the performance of the material. Clear information on determining of the layer coefficients are provided in 2.3.5 of Part II, AASHTO 1993. Determination of layer coefficients from FWD and CBR values shall be as follows:

Determination of layer coefficient from FWD data (Layer coefficients for NHDOT pavement materials, Vincent - C. Janoo - 1994)

Rohde (1994) developed a method for determining the SN of a pavement structure using the FWD measurements. The SN equation used is the one modified by TRL in 1975 and used in the World Bank Highway Design and Maintenance Pavement Performance Model (HDM-111 model). The modified Structural Number (SNC) is defined as

$$SNC = 0.0394 \sum_{i=1}^{n} a_i\, h_i + SNSG$$

Where, SNSG is that portion of the structural number contributed by the subgrade. The following relationship for SNSG in terms of CBR has been used:

$$SNSG = 3.51 \log_{10} CBR - 0.85 (\log_{10} CBR)^2 - 1.43$$

Where CBR = in-situ California Bearing Ratio of the subgrade (%)

Based on Irwin's (1983), " two thirds rule" of stress distribution under pavement structure, Rohde assumed that the deflection ($D_{1.5}h$) measured at a distance on the surface equal to 1.5 times the structural section thickness (h) is due to the subgrade only. He then developed the Structural Index of the Pavement (SIP). SIP is associated with the deflection above the subgrade only:

$$SIP = D_0 - D_{1.5}h$$

The hypothesis is that SIP should be strongly correlated with stiffness of the pavement structure and thus to SN. Based on the regression analysis, Rohde developed a relationship between SN and SIP:

$$SN = k_1\, SIP^{k2}\, h^{k3}$$

The following values, 0.1165, -0.3248 and 0.8241 were used for K_1, K_2 and K_3 (Reclaimed Stabilized Base layers (RSB) at 2%, 3% and 4%) for all the base courses with the exception of the asphalt layer. For the asphalt layer, 0.4728, -0.4810 and 0.7581 were used as recommended by Rohde, respectively. For a two-layer system, the layer coefficient was calculated using

$$a_i = \frac{SNC - SNSG}{0.0394 * h}$$

He developed another index called Structural Index of Subgrade (SIS):

$$SIS=D_{1.5h}-D_s$$

Where D_s is the deflection measured at a distance of 762 mm from the center plate. The subgrade modulus is

$$E_{sg} = 10^{k4}\ SIS^{k5}\ h^{k6}$$

The following recommended values of 23138, -1.236 and -1.903 (Rohde 1994) were used for k_4, k_5 and k_6. The CBR% of the subgrade was back calculated from

$$E_{sg} = [1500 \times CBR^{0.73}] / 6.9,\ (kPa)$$

The subgrade moduli obtained from the modified Boussinesq equation were also used in place of E_{sg} and layer coefficient can be back calculated.

Determination of layer coefficients using CBR results

Field CBR data were obtained from the Clegg hammer and in-situ CBR testing. Dynamic Cone Penetrometer (DCP) data also can be converted to CBR. The DCP data are converted to penetration per blow rate. The Corps of Engineers use the following relationship to convert the DCP rate to CBR:

$$CBR(\%) = \frac{292}{DCP^{1.12}}$$

where DCP = millimetres/blow

The World Bank Highway Design and Maintenance (HDM-111) pavement performance model, provided a correlation between CBR and a_i as given below

$$a_i = (29.14 \times CBR - 0.1977\ CBR^2 + 0.00045\ CBR^3)\ 10^{-4}$$

Annexure II

DEVELOPMENT OF THE LAYER COEFFICIENT RATIO & MODULUS IMPROVEMENT FACTOR

1 Layer Coefficient Ratio

General

Layer Coefficient Ratio (LCR) represents impact provided by a specific geogrid to the layer coefficient of the layer in which the geogrid is placed. The LCR approach applies and limits the geosynthetic benefit derived from trials to the specific layer improved by inclusion of reinforcement (granular layers). Using the LCR approach, a designer may quantify the benefits of geogrid reinforcement either through increased pavement life or reduced layer thickness or a combination of both.

Typical LCR determination procedure through full scale traffic tests and laboratory tests on geogrid reinforced and unreinforced flexible pavements are as follows:

1.1 Full Scale Traffic Tests

1.1.1 *Test section layout and design*

The full scale traffic tests shall be performed outdoors and subject to local environmental conditions just as any other road or pavement with the following features:

- Full scale highway construction equipment and practices
- Extended exposure to weather over multiple seasons
- Incorporation of local subgrade soils, aggregate and paving material
- A driven traffic vehicle capable of applying 80 kN standard axle loads to eliminate the steering axle effect; "super-single" tires
- Channelized traffic with minimal wander
- Laser profiling of the rutting pattern

The test tracks are usually laid out as an oval as shown in **Fig. II-1**, to provide a one-directional wheel loading pattern during continuous traffic. Straight sections used for testing should be sufficiently long to accommodate multiple, full lane width test sections. A typical test cross section accommodating two wheel paths is shown in **Fig. II-2**.

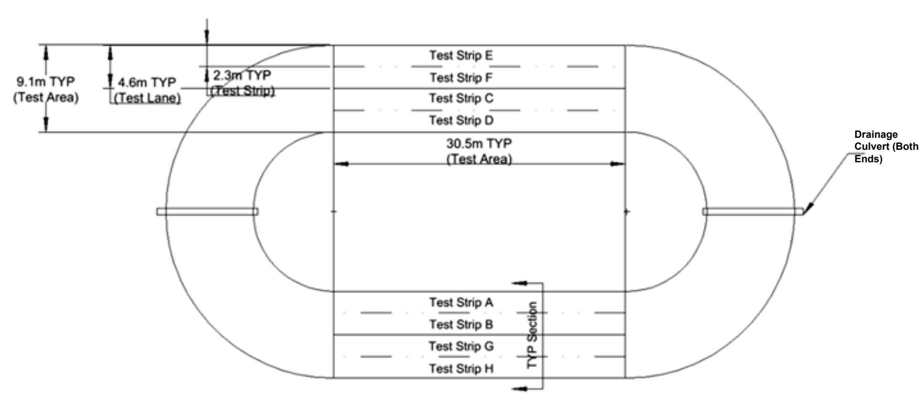


Fig. II-1 Test Track Layout

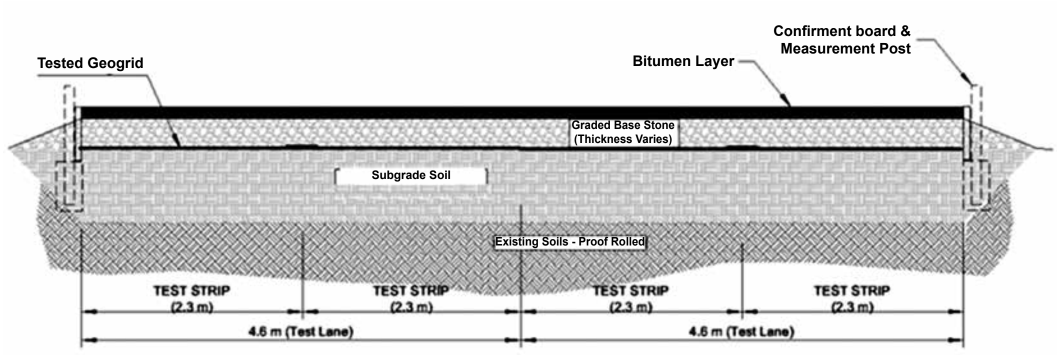


Fig. II-2 Typical Cross Section of Test Area

Test sections shall be constructed in groups having different target subgrade CBR values indicating different subgrade strength. All test sections shall be designed to reach at least 25 mm of permanent centreline deflection before reaching target traffic load in terms of Equivalent Single Axle Loads (ESALs). All sections shall be subjected to identical compactive effort on all the surface, base and subbase layers. **Fig. II-3** illustrates construction of a typical set of test sections.

Fig. II-3 Construction of Typical Test Sections

In order to maintain realistic conditions, pavement sections shall be prepared with standard local pavement materials (BC, DBM, WMM, GSB, and subgrade soils). High quality control standards and a rigorous quality assurance regimen must be applied to the construction process. Measured as-constructed section properties for several tests shall be taken note.

1.1.2 *Traffic*

A commercial truck may be modified for use as the loading vehicle for test sections. Modifications include adding carefully distributed weight to the vehicle such that each axle applied a load of 80-kN. In addition, all tires with tyre pressure of 0.56 MPa should be used during testing. The tires shall be aligned from front to rear such that each travelled in the same path when the vehicle is driving straight.

These modifications ensure that each passage of the loading vehicle applies two identical loads to the test sections thereby negating the complicating effects of a steering/load axle combination often associated with full scale testing. A loading vehicle used for traffic is shown in **Fig. II-4**. The truck shall be made to run along the test sections for a predetermined number of passes before stopping for surface rut depth measurements.

Wheel path centreline and transverse profile rut data shall be collected at the centre point of each test section using a stiff beam placed on the measurement posts which is shown in **Fig. II-4**. A laser distance measuring device, accurate to one mm, shall be placed at predetermined points along the measurement beam to gather these measurements as illustrated in **Figs. II-4** and **II-5**. A full transverse surface profile shall be collected on each test section before allowing traffic and at various intervals during traffic. Centreline deflection data are collected more frequently to assess ongoing deformation.

FWD (Falling Weight Deflectometer) technique can be used to evaluate the layer moduli of pavement test sections. This FWD deflection data from unreinforced and reinforced pavement sections shall be used to analyse the pavement for critical strains which are indicators of pavement performance in terms of rutting and fatigue cracking. Difference in modulus values obtained from FWD test data may be used to determine improvement by using geogrid in pavement layers.

Fig. II-4 Loading Vehicle and Beam for Surface Rut Measurements during Traffic

Fig. II-5 Positioning of Laser Distance Measuring Device for Profiling

Traffic is applied to the test sections until each of the individual test paved sections reaches 25 mm of permanent centreline deflection before reaching target traffic load in terms of Equivalent Single Axle Loads (ESALs).

Test sections that fail early are repaired to maintain traffic ability of the vehicle and limit carryover damage to adjacent test sections. This repair is accomplished by adding extra base course aggregate in the rutted areas and smoothing the area out with a light weight skid steer loader.

Standard axle passages for each test section to reach predetermined levels of permanent deformation are determined, followed by application of a normalization procedure to the data, which is required to eliminate the section to section variability in full scale, realistic test sections. All values are interpolated using a best fit line of data near the 25 mm threshold.

1.2 Laboratory Tests

Large scale experimental program in lab can be conducted to evaluate and understand the structural contribution of geogrid to flexible pavement systems under simulated traffic conditions. Geogrid shall be placed in one half of the box section, while the other half may be left unreinforced to be used as control section for comparison. Geogrid shall be placed in flat prepared bed as per the requirements and then folded at 90° at the box sides. Geogrid is folded to metal box sides to model the anchorage effect in a typical wide road base. Load in the form of sinusoidal cycles shall be applied through circular loading plate having 300 mm diameter. Loading may range from 0 to 40kN with an equivalent applied pressure of 560kPa. Vertical settlements (ruts) have to be recorded as a function of number of cycles together with the permanent deformation in the road section. Test sections may be constructed and loaded in either a test-box facility or a facility allowing for the construction of a test-track. Minimum dimensions for the geometry of a test-box are given in **Fig. II-6**.

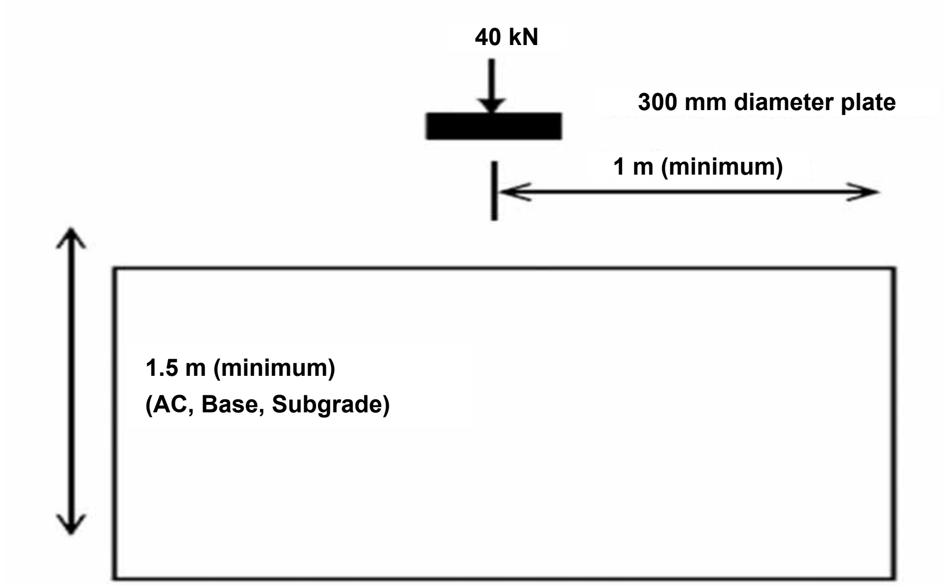


Fig. II-6 Typical Schematic of Laboratory Test-Box Pavement Test Facility/Set up Showing Minimum Box Dimensions, Plate Load and Plate Dimensions (GMA White Paper-II)

Settlements and elastic rebounds of the asphalt layers shall also be measured during the tests, under the loading plate for every 100 cycles but not limited to, interval may be chosen based on the requirements. Distribution of the permanent deformation on the aggregate during the tests determined by measuring the displacements of the asphalt surface in several locations, and of the bitumen aggregate and aggregate/subgrade interfaces at the end of each test. Series of tests should be done with several subgrade shear strengths with different CBR values for different densities. Rut geometry for reinforced and unreinforced sections shall be analyzed to determine differences in depth and shape of the deformed sections.

LCR can be determined using the equation below, by results obtained from tests on flexible pavement system with and without reinforcement.

$$\frac{\alpha_r}{\alpha_u} = \frac{(SN_r - a_1 * d_1)d_u}{(SN_u - a_1 * d_1)d_r}$$

Where α_r / α_u = layer coefficient ratio LCR

SN_r and SN_u are the structural numbers for reinforced and unreinforced pavement systems.

2 Modulus Improvement Factor for Geogrid and Geocell

Modulus of the system with or without geosynthetic material is essentially the slope of the stress versus strain curve. The Modulus Improvement Factor (MIF) is the ratio of improvement of the modulus of a system where geosynthetic materials are incorporated, as compared to the system without geosynthetic materials. This factor is evaluated by conducting plate load tests on soil subgrade and evaluating the respective moduli without and with geosynthetic materials and comparing the two moduli to estimate the MIF.

Determination of MIF for Geocell

Two sections, viz. unreinforced section and geosynthetic reinforced section are considered for analysis. Schematics of both sections are shown in **Fig. II-7** below. Strain gauges are placed in position to monitor deformations. Earth pressure cells are placed in position below the geosynthetic materials to monitor pressures. This is highlighted in the section view in **Fig. II-7**.

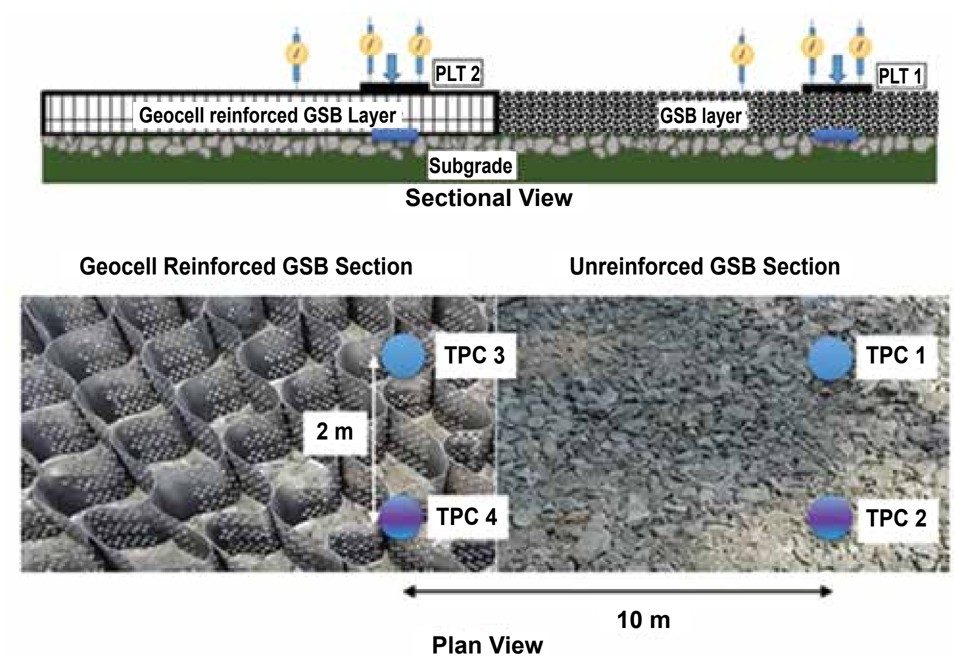


Fig. II-7 Schematic of Unreinforced and Reinforced Section

MIF is defined as:

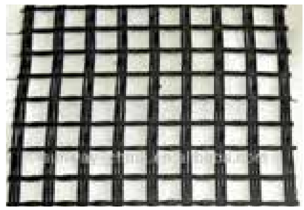
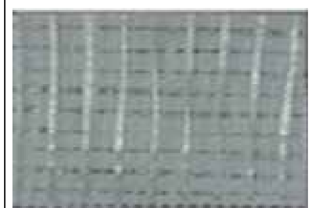
$$\text{MIF} = \frac{\text{Modulus of reinforced section at a given settlement}}{\text{Modulus of unreinforced section for a given settlement}}$$

For future enhancement of the design procedure, Research has started focus on Mechanistic-Empirical (ME) design procedures—specifically, how to incorporate the AASHTO Mechanical-Empirical Pavement Design Guide (MEPDG) procedures (AASHTO 2008). Discrete element modelling of geogrid and aggregate, mechanistic response modelling with finite element method analyses, full scale testing, and laboratory testing are being employed to develop/refine an M-E design procedure.

MIF for geogrid can also be determined in the similar procedure.

Annexure III

Table III-1 Various Design Considerations for Different Asphalt Reinforcements (Technical Guideline-Asphalt Reinforcement for Road Construction, 2008)

Issues to consider	Paving Fabric	Paving Grids		Composite Paving Grids	
	a) Polyester or Polypropylene[1)]	a) Glass fibre grids[2)]	b) Polyester grids[3)]	a) Stitched or Wrap knitted[4)]	b) Bonded[5)]
Photos of Typical Products					
Overlay Stress Absorption	1. Act as stress absorbing interlayers 2. Prevent ingress of water into pavement layers 3. Bridge shrinkage cracks 4. Provides increased overlay performance by 20 to 40 %	1. Modulus ratio of upto 20;1 over Asphalt 2. High stiffness redirects crack energy	1. Increases tensile strength of asphalt layer 2. Reduces tensile peak stress 3. Assists with Asphalt fatigue 4. Reduces formation of ruts	1. High stiffness redirects crack energy 2. Reduces peak tensile stress 3. Improve asphalt fatigue	1. Increase fatigue life of pavement with weak foundations 2. Used in above application, reduces rutting and control cracking 3. Susceptible to creep
Overlay Thickness	1. Generally 35 mm but can be as little as 25 mm	1. Minimum overlay thickness of 40 mm 2. 25 mm overlay thickness achieved under controlled conditions	1. 50 mm with paver	1. 40 mm minimum 2. 25 mm used successfully in light trafficked areas with low loadings	1. Stiff bi-axial grids used in 70 mm overlays 2. Thinner composite polyester grids used in 60 mm overlays

Issues to consider	Paving Fabric	Paving Grids		Composite Paving Grids	
	a) Polyester or Polypropylene[1)]	a) Glass fibre grids[2)]	b) Polyester grids[3)]	a) Stitched or Wrap knitted[4)]	b) Bonded[5)]
Compatibility Bond with Asphalt	1. Paving fabrics resistant to shrinkage 2. Polyester heat resistance at 210°C and perform better than polypropylenes which are sensitive at temperature >145°C 3. Rough texture provides interlock adhesion 4. Robustness which withstands high installation damage	1. Melting point 1000°C 2. Polymer modified bitumen coat of grid has good compatibility with tack coat and asphalt	1. Polyester heat resistance upto 210°C 2. Good compatibility with tack coat and asphalt	1. No pre-dressing or tensioning require 2. Fabric impregnated with bitumen 3. Impregnated layer provides moisture proofing 4. Non woven fleece good compatibility with tack coat and asphalt 5. Check stability of reinforcement when subjected to operation heat. Glass 1000°C, Polyester 260°C, Polypropylene 165°C	1. No pre-dressing or tensioning require 2. Fabric impregnated with bitumen 3. Impregnated layer provides moisture proofing 4. May increase pavement life by a factor of 3
Durability and corrosion	1. Polyester or polypropylene are non corrodible and resistant to most chemicals	1. Non corrodible 2. Resistance to oil and fuel spillage, biological attack, UV light, weather	1. Non corrodible 2. Resistance to oil and fuel spillage	1. Non corrodible 2. Resistance to oil and fuel spillage 3. Thermally stable upto 165°C	1. Non corrodible 2. Resistance to oil and fuel spillage 3. Thermally stable upto 165°C

Issues to consider	Paving Fabric	Paving Grids		Composite Paving Grids	
	a) **Polyester or Polypropylene**[1)]	a) **Glass fibre grids**[2)]	b) **Polyester grids**[3)]	a) **Stitched or Wrap knitted**[4)]	b) **Bonded**[5)]
Melting and Recycling	1. Hot milling and heat scarification can cause problems 2. Cold milling does not usually present problems 3. Fabrics in excess of 150 g/m^2 may interfere with milling process 4. Polyester fabrics less susceptible to hot milling 5. Chisel teeth preferred over conical teeth 6. Milling speed range 3-6 m/min	1. Fibre broken down during milling process and easily recycled	1. Easily milled (including hot milling) by chisel teeth and recycled	1. Cold milling does not present problems 2. Hot milling and heat scarification may cause problem where geosynthetic is present 3. Cognisance should be taken of the different behaviour of the paving fabric as opposed to the gird or mesh component 4. Chisel teeth preferred 5. Milling speeds of 3-6 m/min 6. Glass fibre strands easily mixed into new asphalt fabric will determine mixed design which may contain up to 0.5% paving fabric pieces by weight	1. Strong plastic grids may interfere with milling operations 2. Aggressive milling require due to thick and hard extruded polymer strands 3. Nonwoven milled as mentioned in woven paving fabrics 4. Recycling unlikely as contamination of mix is high

Issues to consider	Paving Fabric	Paving Grids		Composite Paving Grids	
	a) Polyester or Polypropylene[1)]	**a) Glass fibre grids[2)]**	**b) Polyester grids[3)]**	**a) Stitched or Wrap knitted[4)]**	**b) Bonded[5)]**
Boundary Operating Conditions/ Limitations and Constrains	De-lamination of the fabric could occur if: 1. Presence of water in base 2. Insufficient tack-coat or saturation of the fabric 3. Fabric load in rain or wet conditions 4. Fuel leakage or contamination between fabric and overlay Shoving or heaving could occur; due slippage on an old, rich surface Bleeding could occur if: 1. Too much binder applied as a tack or saturation coat 2. Volatiles from cutback or winter grade bitumens cannot applying overlay. 3. If cut or winter grades have to be used. Avoid using them in the tack coat.	1. Glass grids with adhesive surface cannot be applied in wet conditions 2. Tack coat must be cured 3. Glass fibre is skin irritant, worker must wear PPE 4. Laid glass fibre paved same day 5. Sensitive to mechanical abrasion when exposed	1. Tack coat applied to clean dry sub-structure 2. Poor resistance to creep	De-lamination of the grid could occur due to: 1. Presence of water in base 2. Insufficient tack coat or saturation of the fabric 3. Fabric laid in rain or wet conditions 4. Fuel leakage or contamination between fabric and overlay Shoving or heaving could occur; due slippage on an old, rich surface Bleeding could occur if: 1. Too much binder applied as a tack or saturation coat 2. Volatiles from cutback or winter grade bitumens cannot applying overlay. 3. If cut or winter grades have to be used. Avoid using them in the tack coat.	De-lamination of the fabric could occur if: 1. Presence of water in base 2. Insufficient tack coat or saturation of the fabric 3. Fabric laid in rain or wet conditions 4. Fuel leakage or contamination between fabric and overlay Shoving or heaving could occur; due slippage on an old, rich surface Bleeding could occur if: 1. Too much binder applied as a tack or saturation coat 2. Volatiles from cutback or winter grade bitumens cannot applying overlay. 3. If cut or winter grades have to be used. Avoid using them in the tack coat.

Issues to consider	Paving Fabric	Paving Grids		Composite Paving Grids	
	a) Polyester or Polypropylene[1)]	**a) Glass fibre grids[2)]**	**b) Polyester grids[3)]**	**a) Stitched or Wrap knitted[4)]**	**b) Bonded[5)]**
Boundary Operating Conditions/ Limitations and Constrains (Continued)	Mechanical failure if; 1. Crack movement is excessive and tears fabric 2. Insufficient or no overlap of fabric 3. Laid in areas of extreme shear stress conditions 4. Patholes not repeated 5. Cracks>7 mm not pre-filled				

Notes:

1) Nonwoven polyester or polypropylene filaments either needle-punched or thermally bonded
2) Coated multi filament woven or warp knit glass fibre grids
3) Coated multi filament woven or warp knit polyester grids
4) A glass fibre or polymeric grid structure stitched or knitted to a nonwoven paving fabric
5) An extruded or woven polymer grid bonded to a light nonwoven fabric

Annexure IV

WORKED-OUT EXAMPLES ILLUSTRATING THE DESIGN METHODS

Example 1: Design the Pavement for Construction of a New Flexible Pavement with the following Data:

Input data:

Design traffic: 50 msa

Subgrade CBR = 6%

Solution:

i. Design resilient modulus of the compacted subgrade

M_R (MPa) = 10 × CBR ; for CBR 5

= 17.6 × $(CBR)^{0.64}$; for CBR > 5

Where M_R = Resilient modulus of subgrade soil

M_R subgrade =17.6 × $6^{0.64}$= 55.4 MPa

ii. Thickness of unreinforced granular layers: For design traffic of 50 msa and obtained CBR of 6 per cent, the thickness values are taken as below with reference to design plates (Assume Plate 4) from IRC:37.

Thickness of granular base (D_2) = 250 mm,

Thickness of granular sub-base (D_3) = 260 mm

$$M_{R\_G}=0.2\times h^{0.45}\times M_{R\_subgrade}$$

Where h= thickness of granular base and sub-base layers, mm

Therefore, resilient modulus of granular layer = 0.2 × $(510)^{0.45}$ × 55.4= 183.20 MPa.

Thickness of proposed bituminous layer with VG 40 bitumen with bottom DBM layer having air void of 3 per cent (0.5 per cent to 0.6 per cent additional bitumen over OBC) over WMM and GSB mm at reliability of 90 per cent.

(A) Design calculations of bitumen pavement with geogrid reinforced granular base and subbase layers using LCR of geogrid

Reducing thickness of pavement section

In this case the effect of reinforcement is shown as the reduction in the pavement section thickness.

i. Design Traffic = 50 msa

ii. Subgrade CBR = 6 per cent

iii. Reliability = 90 per cent

iv. Resilient Modulus of Subgrade (MR):

$$M_R \text{ (MPa)} = 17.6\times 6^{0.64}= 55.40 \text{ MPa}$$

Resilient modulus of Subbase and Base layers:

Granular sub-base thickness (M_{R_GSB}) = 260 mm

$$M_{R\_GSB} = 0.2 \times h^{0.45} \times M_{R\_subgrade}$$

Where h= thickness of granular sub-base layer, mm

M_R of unreinforced subbase layer = $0.2 \times (260)^{0.45} \times 55.4$ = 136 MPa = 19724.624 Psi

Granular Base thickness = 250 mm

$$M_{R\_GB} = 0.2 \times h^{0.45} \times M_{R\_GSB}$$

Where h = thickness of granular base layer, mm

M_R of unreinforced base layer = $0.2 \times (250)^{0.45} \times 136$ = 327MPa = 47426.118Psi

Resilient modulus of Bituminous Mixes = 3000 MPa=435102 Psi

v. Structural layer coefficient of each layer:

Layer coefficient for bituminous layer (a_1) = 0.171 x (LN (MR))-1.784

= 0.171 x (LN (435102))-1.784=0.436

a) Structural Layer coefficient for base layer shall be taken from the equations given in AASTHO 1993.

Structural layer coefficient for base layer

$a_2 = 0.249 \times (\log_{10} M_{R\_BC}) - 0.977 = 0.249 \times (\log_{10} 47426.118) - 0.977 = 0.188$

b) Structural layer coefficient for subbase layer

$a_3 = 0.227 (\log_{10} M_{R\_SB}) - 0.839 = 0.227 \times (\log_{10} 19724.624) - 0.839 = 0.136$

Therefore,

Layer coefficient for base layer (a_2) = 0.188

Layer coefficient for sub base layer (a_3) = 0.136

vi. Layer Coefficient Ratio: Layer coefficient for geogrid is taken on the basis on the laboratory tests/filed tests; or it can be provided by the manufacturer.

(LCR_{base}) for geogrid used in base layer = 1.4

($LCR_{Subbase}$) for geogrid used in sub base layer = 1.61

(B) Modified layer thickness values for reinforced sections by IITPAVE

Thickness of sub base layer = 180 mm

Thickness of base layer = 160 mm

Resilient modulus of reinforced Subbase and Base layers

Granular sub-base thickness = 180 mm

$$M_{R\_GSB} = 0.2 \times h^{0.45} \times M_{R\_subgrade}$$

Where h= thickness of granular sub-base layer, mm

M_R of reinforced subbase layer = $0.2 \times (180)^{0.45} \times 55.40$ = 115 MPa = 16678.91Psi

Granular Base thickness = 160 mm

$$M_{R\_GB} = 0.2 \times h^{0.45} \times M_{R\_GSB}$$

Where h = thickness of granular base layer, mm

M_R of reinforced base layer = $0.2 \times (160)^{0.45} \times 115$ = 225 MPa = 32632.65 Psi

Layer coefficient for bituminous layer (a_1) = 0.436

c) Structural Layer coefficient for base layer shall be taken from b equations given in AASTHO 1993.

Structural layer coefficient for base layer

$a_2 = 0.249 \times (\log_{10} M_{R\_GB}) - 0.977 = 0.249 \times (\log_{10} 32632.65) - 0.977 = 0.147$

d) Structural layer coefficient for subbase layer

$a_3 = 0.227 (\log_{10} M_{R\_GSB}) - 0.839 = 0.227 \times (\log_{10} 16678.91) - 0.839 = 0.120$

Therefore,

Modified Layer coefficient for base layer (a_2) = 0.147

Modified Layer coefficient for sub base layer (a_3) = 0.120

Modified layer coefficient for base layer ($a_{2'}$) = $LCR_{base} \times a_2$
= 1.4*0.147= 0.2058

Modified layer coefficient for sub-base layer ($a_{3'}$) = $LCR_{Subbase} \times a_3$
= 1.61*0.120= 0.1932

With the improved layer coefficients, improved elastic modulus of respective layers shall be back calculated using below equations.

$a_2^1 = 0.249 \times (\log_{10} M_{R\_GB}) - 0.977$

$M_{R\_GB1} = 393$ MPa

$a_3^1 = 0.227 (\log_{10} M_{R\_GSB}) - 0.839$

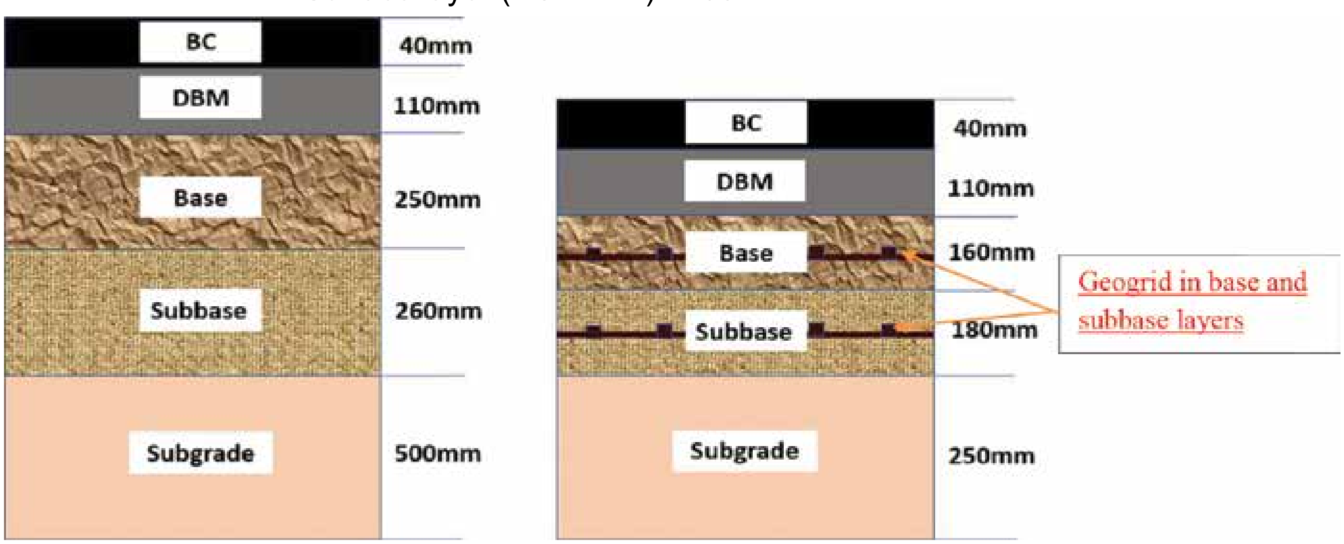
$M_{R\_GSB1} = 244$ MPa

Using above improved elastic modulus corresponding improved layer coefficients, reinforced layer thickness shall be determined.

Reinforced base layer thickness = 160 mm

Reinforced subbase layer thickness = 180 mm

Surface layer (BC+DBM) =150 mm



(a) Conventional Unreinforced Pavement Section (b) Geogrid Reinforced Pavement Section

Fig. IV-1 Pavement Sections with and without Reinforcement

This reinforced pavement section shall be designed as per IRC:37 i.e. section shall be checked for fatigue and rutting failure criterion by inputting this improved elastic modulus into IITPAVE. **Fig. IV-4**, shows the input parameters in IITPAVE, in which improved E values are used. **Fig. IV-5** represents the vertical and tensile strains induced in the pavement layers. Obtained vertical strain at subgrade level is 360.4×10^{-6} which is less than the permissible vertical strain 372×10^{-6} obtained as per Eq 6.5 in IRC:37 and obtained tensile strain at bottom of bitumen layer is 146.7×10^{-6} is less than permissible 155×10^{-6} tensile strain obtained as per Eq 6.2 of IRC:37. Hence the reduced section with geogrid reinforcement in base and subbase layers is acceptable for design traffic 50 msa.

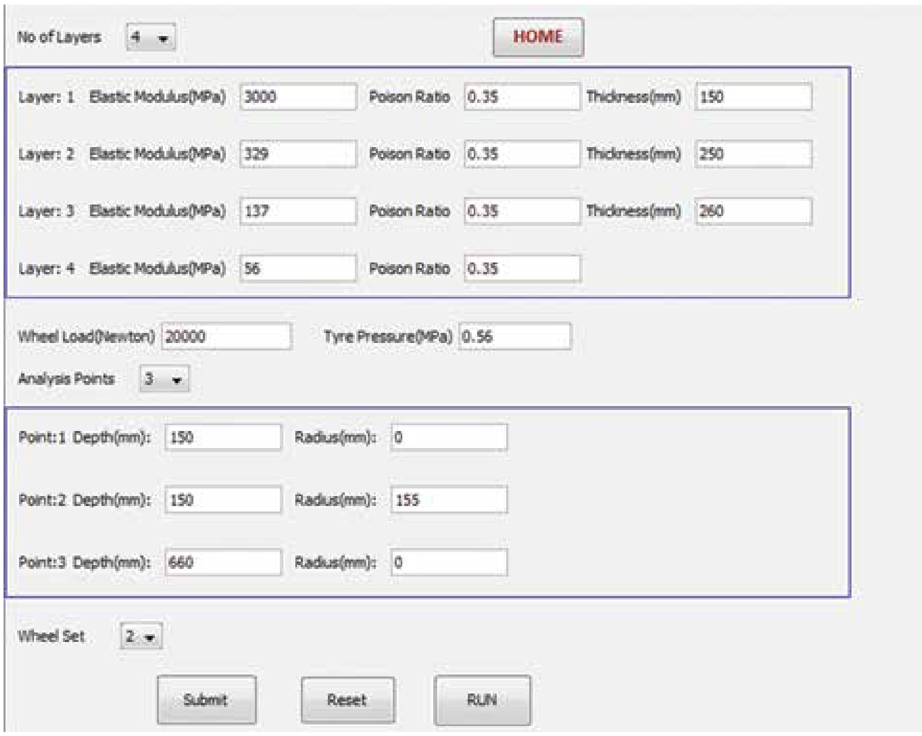


Fig. IV-2 Input Parameters in IITPAVE for Unreinforced Section

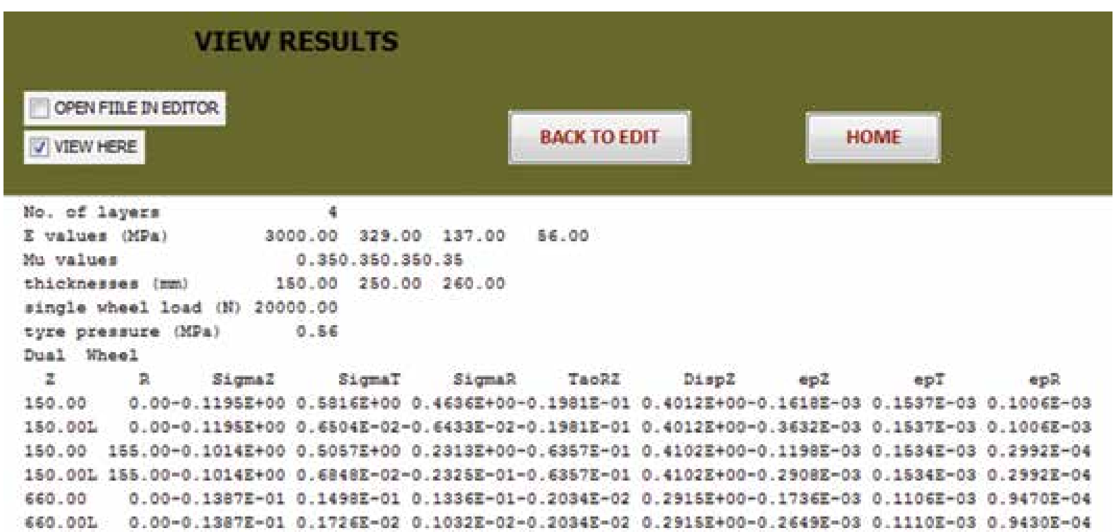


Fig. IV-3 Vertical and Tensile Strains Induced in the Pavement Layers for Unreinforced Section

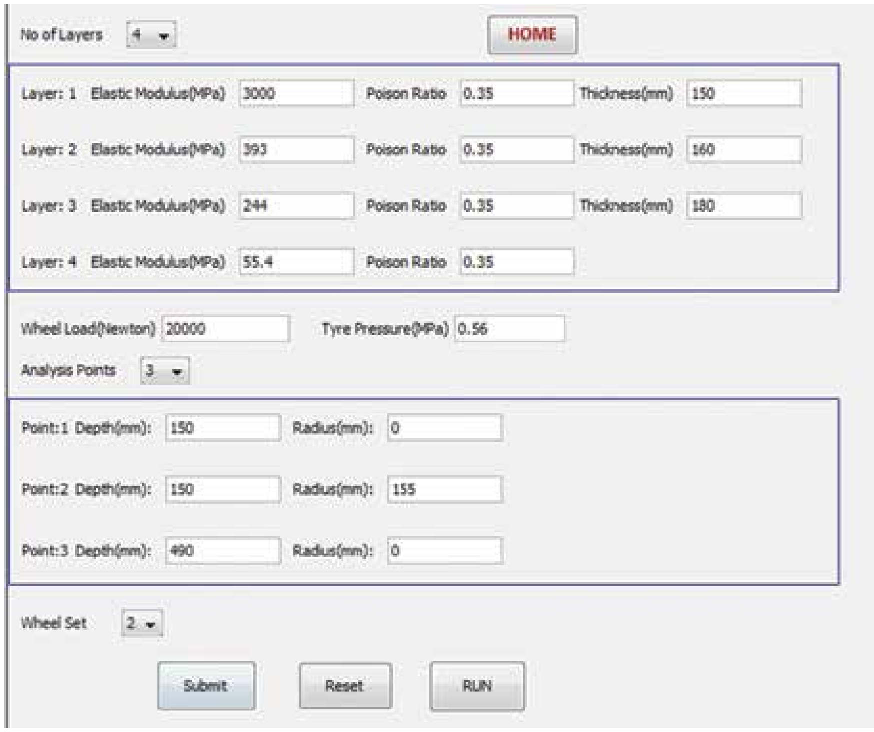


Fig. IV-4 Input Parameters in IITPAVE for Reinforced Section

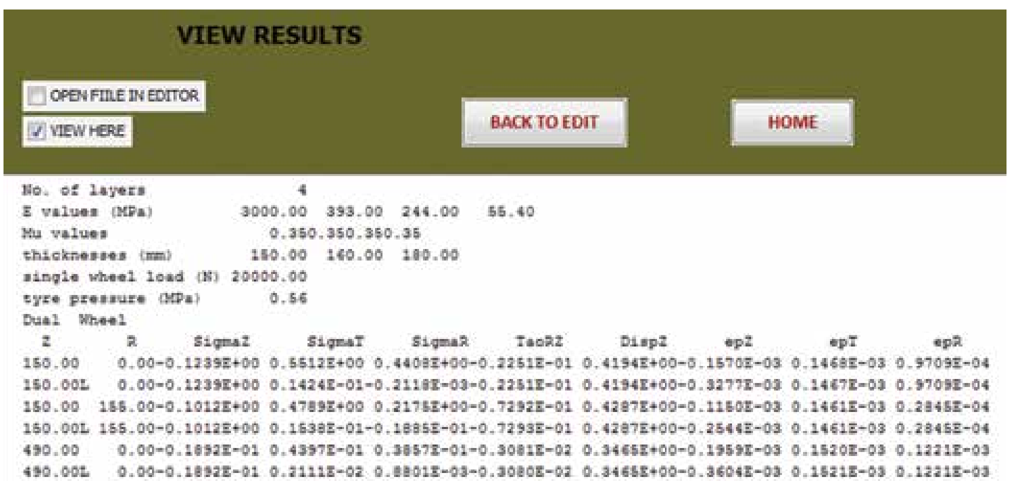


Fig. IV-5 Vertical and Tensile Strains Induced in the Pavement Layers for Reinforced Section

Example 2: Design Example for Flexible Pavement using Geocell

Consider a pavement to be constructed on marine clay with a CBR of 2%. The design life of the structure, reflected as million standard axles (msa), as 100 msa.

Solution:

As a matter of good practice and as per IRC:37 Clause 5.1, it would be prudent to provide a 500 mm thick layer of select earth over the dressed clay surface. With the soft marine clay below, the CBR of the earth fill may not be considered greater than 3%, which is also the lowest CBR considered by IRC:37. On the basis of the Plate shown in **Fig. IV-6**, the section of the conventional pavement for 100 msa traffic is as per **Fig. IV-7**.

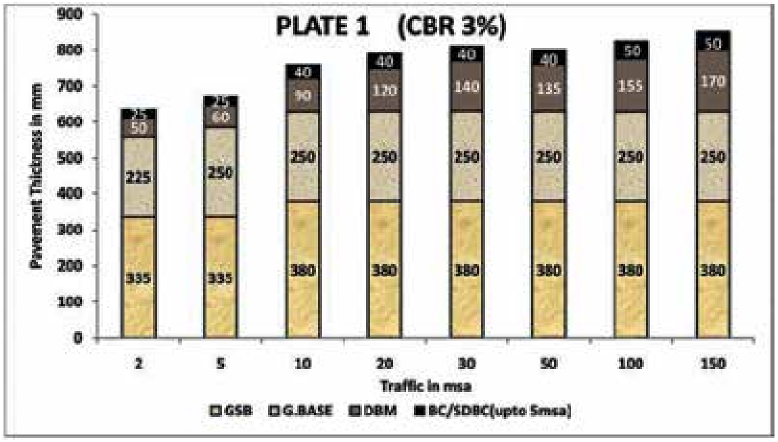


Fig. IV-6 Plate 1 from IRC:37

In **Fig. IV-7**, it may be noted that nonwoven geotextile is provided at the interface between the marine clay and the select earth fill as a separation layer.

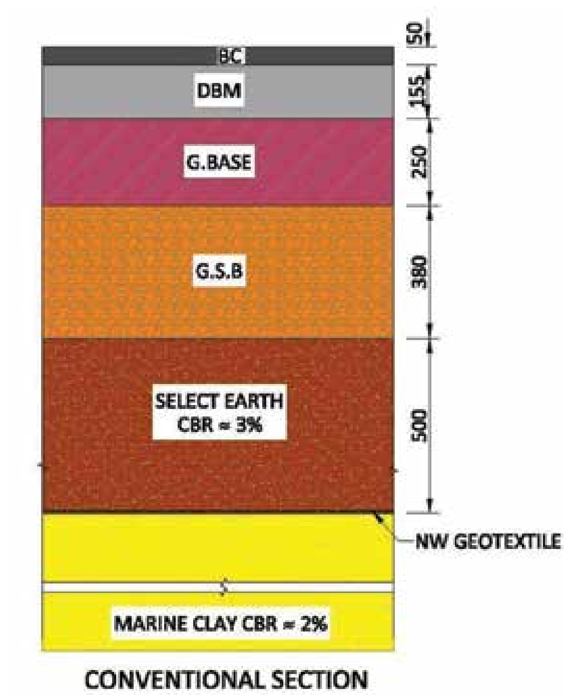


Fig. IV-7 Conventional Pavement Section as per IRC:37

Considering Design Traffic as 100 msa and for 90% reliability,

1. Determination of Vertical Subgrade strain (ε_v):

$$N_r = 1.41 \times 10^{-08} \times \left(\frac{1}{\varepsilon_v}\right)^{4.5337}$$

$$100 \times 10^{6} = 1.41 \times 10^{-08} \times \left(\frac{1}{\varepsilon_v}\right)^{4.5337}$$

$\varepsilon_v = 319.0 \times 10^{-6}$ micro-strain units.

2. Determination Horizontal Tensile strain (ε_t):

$$N_f = 0.711 \times 10^{-4} \times \left(\frac{1}{\varepsilon_t}\right)^{3.89} \times \left(\frac{1}{M_R}\right)^{0.854}$$

$$100 \times 10^6 = 0.711 \times 10^{-4} \times \left(\frac{1}{\varepsilon_t}\right)^{3.89} \times \left(\frac{1}{3000}\right)^{0.854}$$

$\varepsilon_t = 129.94 \times 10^{-6}$ micro-strain units.

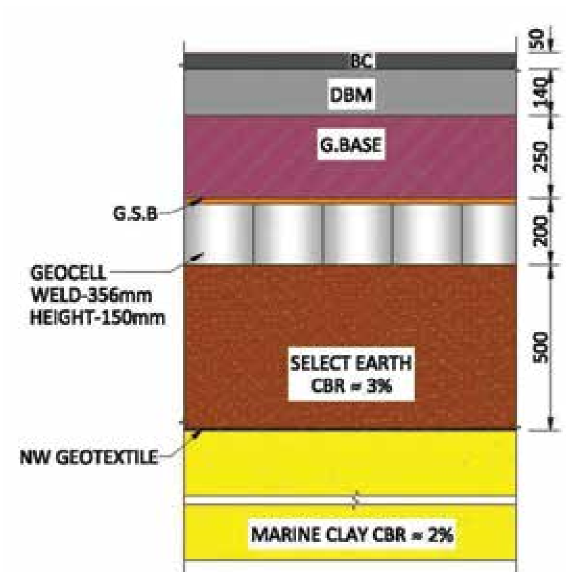
Hence for the recommended conventional pavement section, permissible vertical subgrade strain and horizontal tensile strain are 319.0×10^{-6} and 129.94×10^{-6} respectively.

These values will form the basis of checking the reduced thicknesses of pavement components with the introduction of geocells within the appropriate pavement layer. For the reduced section with geocells, the strains should be equal to or less than those for the conventional section at the corresponding locations. These criteria must be satisfied for the various options using geocells as discussed below.

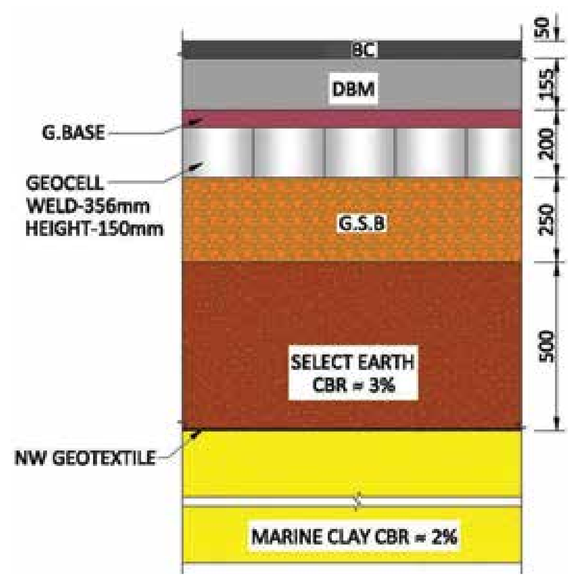
The Geocell Options

The geocell panels are placed within either Granular Base layer or Granular Sub-base layer. Modulus of the portion of the layer within which the geocells are placed is increased by a Modulus Improvement Factor. With the geocell layer in place, thickness of the costliest layer may be first selected for reduction.

Computations are repeated with IITPAVE with the appropriate moduli values. Varying the thicknesses by trial and error, two sections were arrived at as shown in the **Fig. IV-8**. These were compared separately with the conventional section.



Option-1: Geocell placed within GSB and overall thickness of GSB reduced to 200 mm and DBM reduced to 140 mm



Option-2: Geocell placed within Granular Base and overall thickness of Granular Base reduced to 200 mm and GSB reduced to 250 mm

Fig. IV-8 Design Sections using Geocells

Note:

1. In all cases, Semi Dense Bituminous Concrete (SDBC) thickness has been retained as 50 mm.
2. If DBM is maintained at 50 mm, the strains exceed those for Conventional Section.

Option 1

Material properties for the geocell section are shown in **Fig. IV-9** are as following:

i. CBR of Subgrade soil = 3%

ii. Traffic = 100 msa.

iii. Geocell Style = Weld spacing = 356 mm; Depth of geocell = 150 mm

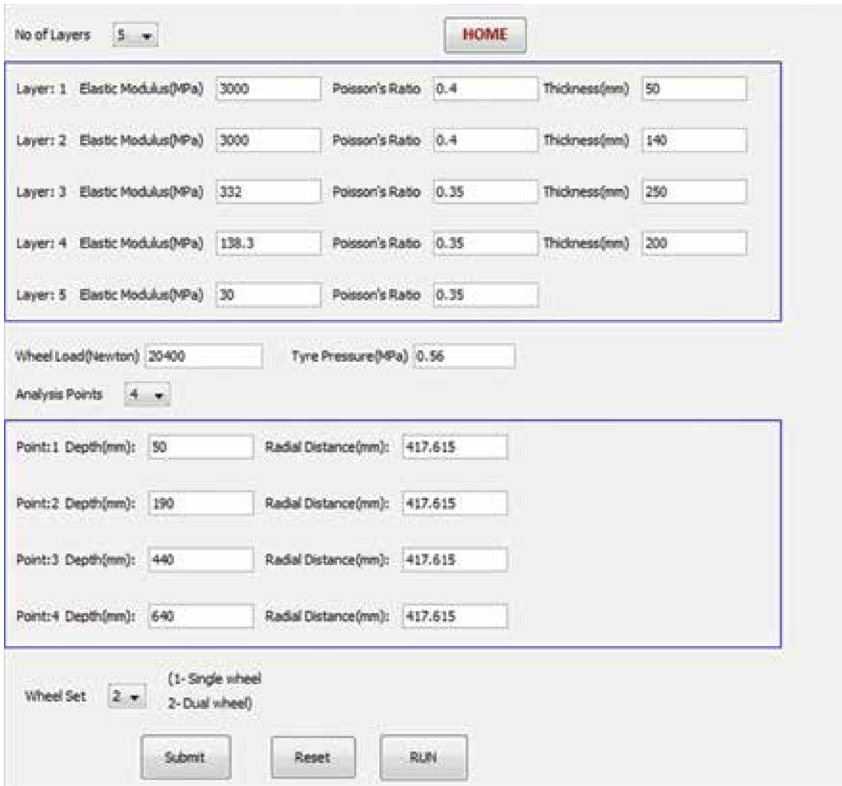


Fig. IV-9 Material Properties for the Analysis of Geocell Section

Results of the corresponding stress strain analysis are shown in **Fig. IV-10**.

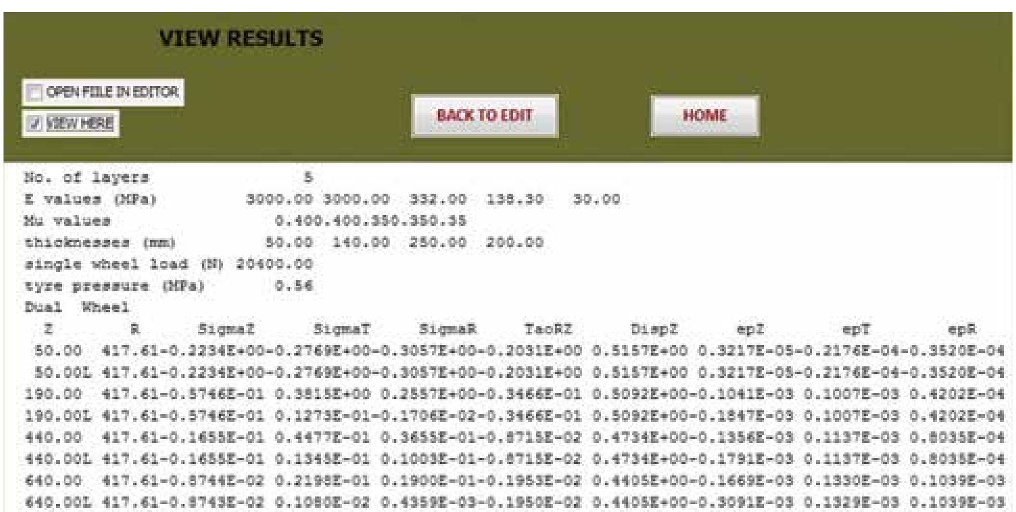


Fig. IV-10 Stress Strain Values from the Analysis

Vertical strain at the interface with the subgrade is 309.1 x 10^{-6} micro-strain units. The corresponding strain for the Conventional Section is 100.7 x 10^{-6} micro-strain units. Hence the thinner section with geocells is acceptable. Furthermore, considering the rutting model the as per IRC:37, the number of standard axles over the pavement with the new moduli with geocells works out to 115 msa with 90% reliability.

In the similar way, geocell placed in granular base shall be computed.

REFERENCES

Indian Codes

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4. IRC HRB Special Report No. 12, "State-of-the-Art: Application of Geotextiles in Highway Engineering".
5. IS:2720: Part-7 "Methods of Test for Soils-Determination of Water Content-Dry Density Relation using Light Compaction".
6. IS:13162 (Part 2) "Geotextiles-Methods of Test-Determination of Resistance to Exposure of Ultraviolet light and Water (Xenon Arc Type Apparatus)".
7. IS:13162 (Part 3) "Geotextiles-Methods of Test-Determination of Thickness at Specified Pressures".
8. IS:13162 (Part 4) "Geotextiles-Methods of Test-Determination of Puncture Resistance by Falling Cone Method".
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