2013

Handbook for Geosynthetics

डा. कावुरू सांबसिव राव
DR. KAVURU SAMBASIVA RAO, B.E.

वस्त्र मंत्री
भारत सरकार
नई दिल्ली-110011
MINISTER OF TEXTILES
GOVERNMENT OF INDIA
NEW DELHI - 110 011

MESSAGE

It gives me immense pleasure to release the report on Study on Developing Measures to Promote the Use of Geosynthetics in India conducted by the Ministry of Textiles as part of the Technology Mission on Technical Textiles. The focus of this study is to lay the foundation and set the roadmap to accrue the economic and social benefits from the usage of Geosynthetics. The final outcome of the study is to provide guidance and recommendations for the promotion of the usage of Geosynthetics materials across the country.

I am proud that the joint and tireless efforts of the stakeholders are being realized and hope that this study will provide the necessary information on the current usage of Geosynthetics along with detailed data on the key interventions required to increase the economic and environment benefits for the nation. I hope that this report leads to increased interactions in the entire Geosynthetics value chain and result in stronger partnerships amongst the various stakeholders.

I eagerly hope that this study proves beneficial to the understanding of the Geosynthetics industry in India by all stakeholders.

(K.S. RAO)

श्रीमती पनबाका लक्ष्मी
Smt. PANABAAKA LAKSHMI

राज्य मंत्री
पेट्रोलियम एवं प्रकृतिक गैस और वस्त्र
भारत सरकार
नई दिल्ली-110001
MINISTER OF STATE FOR
PETROLEUM & NATURAL GAS AND TEXTILES
GOVERNMENT OF INDIA
NEW DELHI-110 001

<u>Message</u>

In our endeavour to increase the utilization and application of geotextiles in India, I am happy to release the report on Study on Developing Measures to Promote the Use of Geosynthetics in India.

The study ensures that the Indian Geosynthetics sector has been exhaustively analysed and appropriately benchmarked against the most relevant and widely recognized best practices from across the globe. Along with a comparative analysis of the Geosynthetics industry in India and abroad, the study also provides valuable insights into the various Geosynthetic products, theirs uses & applications as well as the associated socio-economic and environmental benefits. Further, the recommendations provide a well-defined direction for promoting the development of the Indian Geosynthetics industry.

The assessment of the Geosynthetics industry in India involved the support of various Government organizations, project teams and individuals associated in the ecosystem. I am proud of our efforts and hope that various stakeholders shall utilize this report and partner with us in our pursuit of accelerating the development of this significant sector.

(Panabaaka Lakshmi)

New Delhi
January 11, 2014

Zohra Chatterji
Secretary

Tel. No. : 23061769
Fax N o. : 23063681
E-mail : secy-textiles@nic.in

सत्यमेव जयते

भारत सरकार
वस्त्र मंत्रालय
उद्योग भवन, नई दिल्ली-110 107
GOVERNMENT OF INDIA
MINISTRY OF TEXTILES
UDYOG BHAWAN, NEW DELHI - 110 107

Message

Geosynthetics have exhibited successful applications across the globe in the areas of roads and pavement stabilization, embankment protection, ground stabilization, soil erosion control, landfills and waste management etc. As our nation further develops, it becomes ever more important that we pay attention to ensuring that our initiatives in infrastructure development are carried out in an environment-friendly and sustainable manner. I, therefore, take great pleasure in the release of the report on **Study on Developing Measures to Promote the Use of Geosynthetics in India**.

One of the major drivers for conducting this study was the fact that India is yet to leverage the economic, environmental and safety benefits that are made possible by the usage of Geosynthetics. Geosynthetics provide better performance and longevity of infrastructure projects such as increasing the life of roads by 10 – 15 years. Such improvements can also be seen in the use of Geosynthetics in embankment projects where loss of life and damage to property can be significantly reduced. Geosynthetics also help prevent contamination of ground water table when used in landfills. The importance of the positive impact generated by the use of Geosynthetics can no longer be ignored. In recent years, the Indian Geosynthetics industry has witnessed increasing demand which has led to the creation of unused capacities that need to be utilized by increasing domestic consumption and further developing export markets. Thus, it is essential that due efforts are accorded to the development of the Geosynthetics industry in India.

In addition to understanding the potential benefits of Geosynthetics it is vital that we are clearly aware of the challenges that lie before us. This report seeks to address those challenges facing the industry today. The key challenges have been identified and defined through various perspectives such aseconomic policies, product specifications, application areas, technologies, manpower requirements etc. and the report includes the necessary steps required to overcome the identified impediments.

As emerging markets further develop, India is well placed to play a major role in the Geosynthetics sector at an international level. The report on Study on Developing Measures to Promote the Use of Geosynthetics in India is a critical first step towards attaining further cooperation with my fellow stakeholders in ensuring that our efforts and objectives are realized.

I congratulate the Joint Secretary, Shri Sujit Gulati and the team of officers which have taken this sector forward with great interest & devotion.

(Zohra Chatterji)

This handbook is a compilation of literature/data/photographs from various sources (including public sources including internet, manufacturers and sources cited in the handbook) as suggested by key stakeholders during the course of the assignment. This objective of the handbook is to promote the usage of Geosynthetics in the country and should be used only for the promotion of this sector.

List of Figures

List of Tables

Abbreviations

AASHTO	American Association of State Transportation and Highway Officials
AS	Standards Australia
ASTM	American Society For Testing And Materials
BC	Bituminous Concrete
BRO	Border Roads Organization
BS	British Standards Institution (BSI)
BTRA	Bombay Textile Research Association
CBR	California Bearing Ratio
CDR	Cone Drop Resistance
DBM	Dense Bituminous Macadam
DIN	German Institute for Standardizations
ECB	Erosion Control Blankets
ECM	Erosion Control Mats
EN	European Committee for Standardization (CEN)
EPA	Environment Protection Agency
EPDM	Ethylene Propylene Diene Monomer
EPS	Expanded Polystyrene
FHWA	Federal Highway Authority
FS	Factor of Safety
GCL	Geo-composite Clay Liners
GMA	Geo-synthetic Materials Association
GSC	Geo-textile Sand Containers
HDPE	High Density Polyethylene
ISO	International Organization for Standardization
LCCA	Life Cycle Cost Analysis
LTDS	Long Term Design Strength
MSE	Mechanically Stabilized Earth
MSEW	Mechanically Stabilized Earth Walls
NHAI	National Highway Authority of India
PCC	Portland Cement Concrete
POA	Percentage Open Area
PPT	Pyramid Puncture Test
PVC	Poly Vinyl Chloride
PVD	Prefabricated Vertical Drain
PWD	Public Works Department
RECP	Rolled Erosion Control Products
RESF	Reinforced Embankments Over Soft Foundations
RSS	Reinforced Soil Slopes
SGA	Soil Geo-synthetic Aggregate
TBR	Traffic Benefit Ratio
TRM	Turf Reinforcement Mats
UV	Ultra Violet
WMM	Wet Mix Macadam

Further descriptions, terms and symbols pertaining to Geosynthetics can be found in the IGS (International Geosynthetics Society) publication titled "Recommended Descriptions of Geosynthetics, Functions, Geosynthetics Terminology, Mathematical and Graphical Symbols".

Foreword

This is Handbook for Geosynthetics, detailing its types, their function and applications in different industrial and civil engineering installation.

The objective of this document is to be a guide to provide basic understanding of Geo-synthetic materials. The infrastructure industry dynamics and modus operandi with regards to geosynthetics dictates that a handbook in the applications and guidelines of geosynthetics is made available as it will be of great help to site engineers and contractors, as well as civil engineering students. Hence this handbook contains information on the various products and applications of geosynthetics, which geosynthetic products can be used for which function (as detailed above), certain case studies for geosynthetic use in applications in India and also usage guidelines to help engineers with solutions for field level realities.

This document also provide information which shall be useful to buyers, installers and those who use specifications of geosynthetics

The philosophy used in drafting this document is that a good handbook is one which embodies the following aspects:

- The document should be concise and clear
- The information in the document for each type of product should be complete and give theoretical and usability understanding to its readers
- The document should provide handy information on installation

In preparing this guide various national and other pre-existing standards have been considered and wherever possible; aspects of those documents have been included in the preparation of this Handbook.

- BTRA's (Bombay Textile Research Association) handbook on Geotextiles (INDIA)
- "Handbook of Geosynthetics" by the (GMA) Geosynthetic Materials Association (USA)
- "Geosynthetic Design & Construction Guidelines Participant Notebook" by the National Highway Institute (NHI) used for the US DOT (Department of Transportation) FHWA (Federal Highway Authority) courses

Contents

1 Geosynthetics

Geosynthetics are a rapidly emerging family of geomaterials used in a wide variety of civil engineering applications. Many polymers (plastics) common to everyday life are found in geosynthetics. The most common are polyolefins and polyester; although rubber, fiberglass, and natural materials are sometimes used. Geosynthetics may be used to function as a separator, filter, planar drain, reinforcement, cushion/protection, and/or as a liquid and gas barrier.

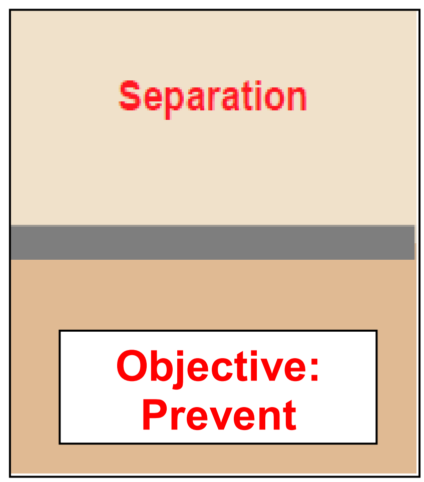
The various types of geosynthetics available, along with their specific applications, are discussed in chapter 2 of this handbook

2 Functionality Provided by Geosynthetics

Geosynthetics are usually sheet materials supplied in roll form and they are used in many geotechnical applications. There are five key categories - geogrids, geomembranes, geonets, geotextiles (subdivided into woven and non-woven) and related products (materials such as erosion mats & cuspates) that do not fall naturally into one of the other four categories. However for comprehensiveness, this handbook covers twelve products.

There are six main functions that these materials can provide and many products provide one of more of these, particularly the geocomposites which, as the name suggests, are made up of multiple components. The functions are:

2.1 Separation

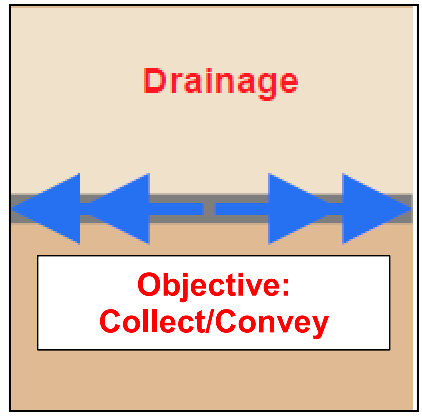


Preventing intermixing of soil types or soil/aggregate to maintain the integrity of each material yet still allow the free passage of liquids/gases. Commonly used in between sub-base/subgrade and around drainage materials.

This function is rarely used in isolation; it is normally combined with one or more of the other functions, filtration and reinforcement being most usual. One of the only pure uses of a geosynthetic as a separator is at the base of fill for a temporary haul road, but even there, in most situations the geotextile also acts as reinforcement. The design of the geosynthetic will be based on a tensile strength requirement, the puncture resistance (CBR or Cone Drop resistance) and durability tests to determine the survivability in the service environment.

The durability and mechanical properties of Geosynthetics make them ideal as separating layers. A strong and flexible geotextile is placed between different layers in the construction, preventing migration and mingling of materials, yet allowing free movement of water. This increases the bearing capacity of the construction and provides long term stability of the foundation layers. The tensile strength, puncture resistance and elongation properties of the geotextile have to be sufficient not only to fulfil the requirements of a separator but also to resist damage during installation.

2.2 Drainage



Hydraulic properties are decisive for the overall performance of the entire construction, with the water flow capacity in the plane of the geosynthetic being the most important.

The hydraulic properties of Geosynthetics are designed to drain excess water off the construction - not by passing through the Geosynthetic as when used for filtration, but by flowing in the plane of the Geosynthetic leading it away from the construction. The use of drainage synthetic ensures ongoing drainage of fluids with minimum pressure loss.

Commonly used as components in geocomposites used for surface water runoff or for gas collection under membranes

Drainage using geosynthetics is often accomplished using geonets. Other drainage products include deformed sheets, (cuspated), mini pipes or other voided polymeric structures with a geotextile filter or barrier on one or both sides as required by the service situation. Very thick needle - punched products can be used as both filters and drainage carrier layers.

Typically geosynthetic drains are used in the following applications:

- Highway edge drains to drain the pavement construction layers
- Drains in earthworks, (slope drains on cut slopes to collect ground water seepage)
- Drains behind retaining walls, to prevent the buildup of water pressures which could destabilise the structure
- Dissipation layers to reduce excess pore pressures in cohesive fills
- Drainage layers within landfill lining systems
- Venting layers below impermeable landfill capping layers to allow gasses produced in landfills to escape to the atmosphere or a gas collection system.

Design methods are based upon standard tests with large factors of safety to allow for in service 'unknowns' such as clogging and bacterial growth.

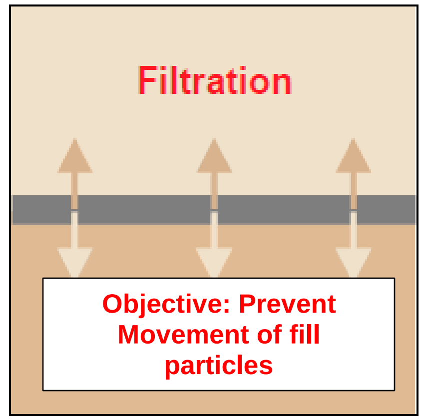
Factors to be included in specifications include:

- In-plane flow capacity under load and with geotextile obstruction of the core between the supporting elements.
- Compressive creep behaviour of the core under vertical and inclined load.
- Durability
  - Chemical – especially when in waste containment
  - Resistance to weathering (UV if to be left exposed during installation or in service).

2.3 Filtration

Restraining soil particles are subject to hydraulic forces whilst allowing the passage of liquids/gases. This function is often partnered with separation e.g. in coastal defence applications or wrapped drains

Geosynthetics are widely used for filtration in road works and railway constructions as well as coastal protection.The characteristic opening size of Geosynthetics is designed to retain particles while allowing free movement of water, making it possible to separate two layers during intense hydraulic activity. Migration of layers, which would reduce the load-bearing capacity of the construction, is thereby avoided and, at the same time, water flow is maintained with minimum pressure loss. The tensile strength, puncture resistance and elongation properties of the geosynthetic have to be sufficient not only to fulfil the requirements of a filtrator but also to resist damage during installation.



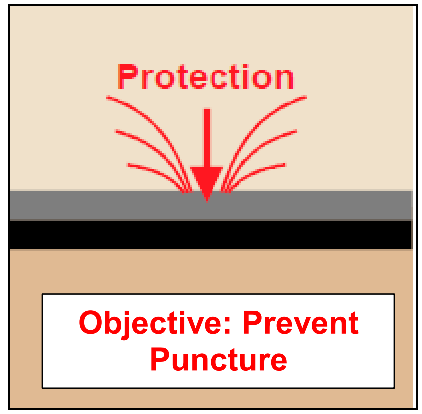
This is a a well-established function, where there are economic advantages, as geosynthetics act as a direct replacement for selected, graded granular filters. Drainage geosynthetics are commonplace in highway drainage systems, beneath revetments, sea defence groynes, sludge dewatering systems and can be used in the drainage systems of dams. The application of geotextiles in dams has taken some time to be accepted by engineers responsible for dam safety because the consequences of a failure of the drainage / filter systems in a dam structure need to be avoided. The design of filters is by relating the laboratory measured effective opening size (usually the O90 or O95), the method of manufacture of the geotextile (woven or non-woven) to one or more of the soil grading characteristics (d10, d50 or d90) and the soil plasticity with an empirical factor from one of the many texts or papers. Checks are required to ensure that the geotextile acts:

- As a filter - to stop the loss of fine particles from the protected soil
- To allow water to pass through at a rate not less than the permeability of the soil allows water to reach the surface of the geotextile
- Such that the fine soil particles do not clog the apertures in the geotextile – clogging needs to be avoided when using thick non- woven geotextiles.

Accordingly, the factors to be included in specifications may include:

- Pore size of openings (O90 or 95)
- Installation damage resistance (CBR, Drop Cone or Abrasion – normally one or two properties only)
- Tensile strength
- Water permeability normal to the plane
- Durability:
  - Resistance to weathering (UV resistance during installation)
  - Micro biological degradation resistance
  - Resistance to chemical attack

2.4 Protection



Geotextiles are widely used for protection in waste disposal systems and tunnel constructions to ensure the integrity of a sealing material (for example geomembrane) when fill material and/or loads are applied. In the EN ISO standards, the protection function is defined as "The prevention or limiting of local damage to a given element or material by the use of a geotextile". As the sole purpose of this function is to protect a given element or material, the mechanical properties are essential, whereas the hydraulic properties are of less importance. The excellent static puncture resistance feature makes them ideal for protecting waterproof membranes and other sealing materials from puncture when fill material and/or loads are being applied. When placed between sealing material and other layers, the Geotextiles withstand and distribute any local pressure from the layer above, ensuring that the protected material is not stressed to failure.

Usually a geomembrane used to line a lagoon or a landfill. Thick geotextiles prevent puncture or excessive strain in the membrane.

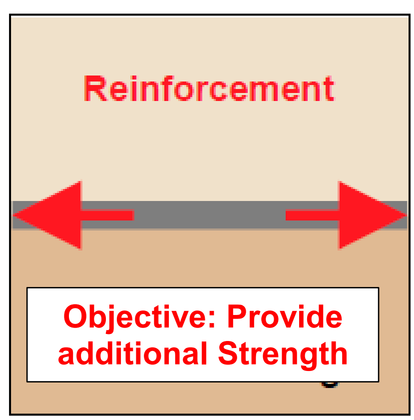
To summarise, Geotextiles with a protection function are intended to minimise damage to other materials, for example Geomembranes due to contact with fills or the underlying subgrade and asphalt overlays due to cracks in the old pavement.

2.4.1 Protection: Geomembranes

While protection is normally achieved by using thicker non-woven geotextiles, geocomposite clay liners (GCL) may also be used as protection layers. Design is by carrying out site trials or laboratory tests. Factors to be included in specifications may include:

- Protection Efficiency Test (Cylinder test or Pyramid Puncture test)
- Puncture resistance (CBR or Cone Drop),
- Damage during installation (Abrasion)
- Durability
    - Chemical – especially when in waste containment
    - Resistance to weathering (UV if to be left exposed during installation or in service).

2.4.2 Protection: Asphalt Overlays



Geotextiles may also be used to provide protection for Asphalt Overlays. Geotextiles, typically nonwovens, are placed between pavement layers to providing stress relief at the old asphalt and new asphalt interface, which retards the development and growth of reflection cracks. To provide bonding between the layers, paving geotextiles are saturated with asphalt cement, which waterproof the geotextile and creates a barrier for water infiltration into the pavement section.

2.5 Reinforcement

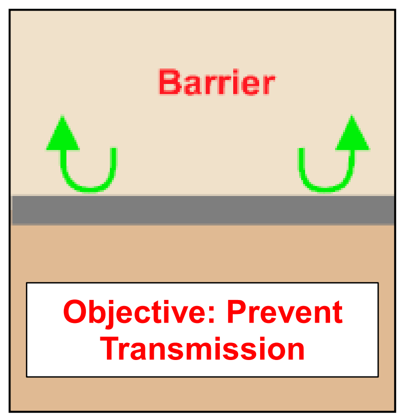
Providing additional strength to soils to enable steep slopes and soil structures to be constructed, and allow construction over weak and variable soils.

Geosynthetics used as reinforcement are normally high strength woven geotextiles or Geogrids. In some designs non-woven geotextiles are used, in particular in Japan where the use of high strain non-woven geotextiles has been shown to perform well in seismic events. The reinforcement products are subject to more analytical design than for any other function. There are numerous programs now available to allow engineers to design the reinforcements for over-steep slopes, basal reinforcements for embankments on soft ground, and reinforcements to voids and piled foundations.

Some specialised geotextiles are used to reinforce asphaltic road pavements. The products used in this application include woven glass fibre, geotextiles and geogrids.

The specification for reinforcements may include both the short term tensile strength and the creep limited tensile strength depending on the nature and the length of time the geotextile will be under load.

2.6 Containment or Barrier



Containment means isolating one material from another. The most frequent use of this function is in landfills where impermeable linings prevent contamination of surrounding soils. This is the primary purpose for any geomembrane and GCL. This includes geomembranes manufactured from polymeric, bituminous and geocomposite clay liners (GCL). They are used to prevent the escape of liquids from containments or to prevent or reduce the flow of liquids through soils or other parts of construction works.

The design should minimise the tensile forces in the membrane layer, the use of smooth and rough faced materials can help control the tensile and shear forces in the layer.

The output from the design for the specification may include:

- Type of material (polymer, rubber, bitumen, or clay)
- Formulation mixing and processing (for polymer, rubber and bitumen)
- Thickness (at 2kPa)
- Gas and water permeability
- Tensile strength (Uniaxial or axisymetric)
    - Strength
    - Strain
- Puncture Resistance
- Burst strength
- Tear Resistance
- Interface shear
- Internal shear (Bitumen, GCL and geocomposite)
- Clay mass, free swell, peel strength, moisture content and fluid loss (for GCLs)

- Durability, performance
    - UV Exposure requirements
    - Oven Aging (not GCL's)
    - Liquid immersion tests – full product testing
    - Stress crack resistance (only polymeric HDPE)
- Seaming processes and controls
- Testing of site works (seams, when mechanically jointed)

2.7 Summary of Functionality and Product Matrix

The various products of geosynthetics have varying applications. However given their current popular usage of functionalities, a matrix has been provided below for quick reference. It may be noted that the functionalities of the products mentioned below are not limited to the applications provided, but merely indicate popular usage as determined during the course of the study

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geotextile	■	■	■	■		■	
Geogrid		■					
Geonet				■			
Geomembrane					■		
GCL					■		
Geofoam	■	■					
Geocells	■	■					
Geocomposite	■	■	■	■	■		
Polymer Gabion						■	■
Geobags						■	■
Geotextile Tubes				■		■	■
PVDs			■	■			
Geomats		■		■			■
Geopipes				■			
Geonets				■		■	■
Natural Fibre Geosynthetics	■	■	■	■			

Mostly used →	■

Table 1: Summary of Functionality and Product Matrix

The subsequent chapters are structured on the basis of the products. In subsequent chapters their functionalities and installation process has been detailed out as standalone chapters.

3 Overview of Key Products

3.1 Geotextile

These are non-Biodegradable Synthetics Woven/Non-Woven Fibre and perform discrete function i.e. separation, reinforcement, filtration, drainage and moisture barrier. Applying nonwoven geotextiles stabilizes subgrades and prevents the fouling of ballast beneath railway tracks.

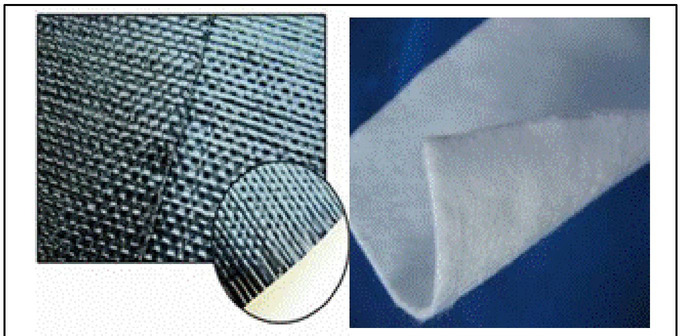


Figure 1 Microscopic View of Geotextile fibre

3.1.1 Applications

Following are the primary applications of Geotextiles:

3.1.1.1 Ground Stabilization

a) Highways
b) Railways
c) Car Parking
d) Access Roads
e) Cycle and Footpaths

Figure 2: Ground Stabilization

3.1.1.2 Landfill Engineering

a) Basal liner protection
b) Cap liner protection
c) Settlement lagoon liner protection

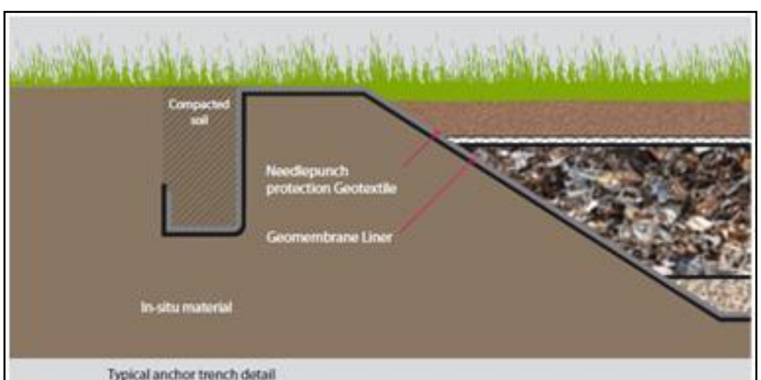


Figure 3: Landfill Engineering

3.1.1.3 *Coastal and River Control*

a) Coastal Protection
b) Dams and Flood Defence Bunds
c) River and Canal Bank Protection
d) River Revetments
e) Culvert Head Walls
f) Structured Causeways
g) Cliff Protection
h) Bridge abutments
i) Submerged breakwaters.
j) Artificial islands
k) Beaches
l) Harbours
m) Lagoons lakes & reservoirs
n) Land reclamation
o) Offshore wind generators
p) Outfalls
q) Rock groynes
r) Scour control.

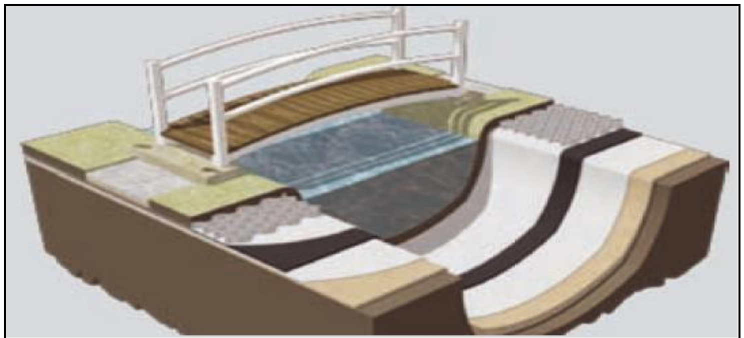


Figure 4: Cross Sectional Usage of Geo textile in coastal and River Control - 1

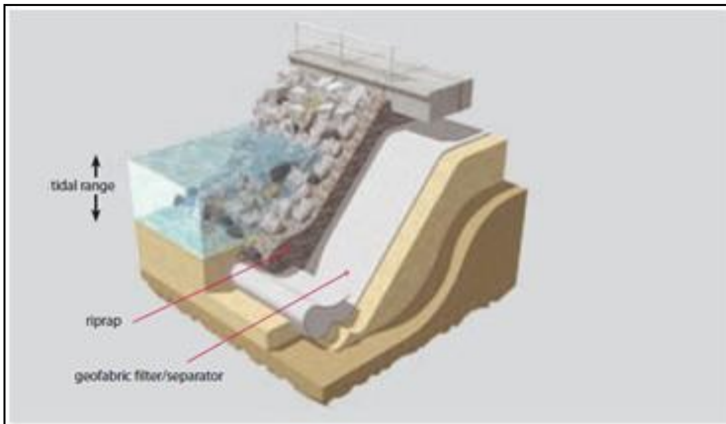


Figure 5: Geotextile usage demo in River Control - 2

3.1.1.4 *Protection and Filtration*

a) Carriageways
b) Permeable Parking Areas
c) Grass Paved Areas
d) Green Roofs.

Figure 6: Geotextile usage demo in Protection and Filtration

3.1.1.5 *Railways*

a) Steepened Embankments
b) Dams and Flood Defence Bunds
c) Retention Bunds
d) Green Walls
e) Culvert Head Walls
f) Sound Barriers.

Figure 7: Geotextile usage in Railways

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geotextile							

In construction and landscaping sector, the use of geotextiles has become fundamental in solving an increasingly diverse range of global geotechnical and environmental problems.

The primary benefit of using geotextiles is to enhance the performance and design life of development within the built environment. Typical, traditional, applications for geotextiles include soil reinforcement, ground stabilisation, filtration, drainage, protection and erosion control. However, the ongoing impact of climate change and the requirement to deliver sustainable development is increasingly creating the need for more diverse and innovative geotextile applications across all sectors.

Geotextiles are now incorporated into solutions to deal with the increasing occurrence of:

- Flooding
- Temperature extremes
- Differential ground movement and non-uniform
- Settlement problems
- Landslips and landslides
- Ground heave

Within the transportation, infrastructure and built environment sectors, applications now include pervious paving systems, green roofs, geocellular tank systems, trench soakaways and reed beds.

Through the ongoing commitment to achieve sustainability within the built environment, geotextiles are being incorporated into major infrastructure projects such as renewable energy schemes, on-shore wind farms and alternative forms of transport; such as light rail networks. Their use plays an active role in minimizing the quarrying and use of natural aggregates of which there is a limited and finite supply.

In addition to the many sustainability benefits of using geotextiles, one of the primary advantages is the potential to reduce overall construction costs and in some cases having a major influence on the financial viability of the proposed development. This is particularly the case with brownfield regeneration where the benefits of a reduced construction depth are highly significant in terms of capital costs, risk and overall contract periods.

3.1.2 Installation

1. **Railways / Road**

a) Roadway Separation/Railroad Stabilization - Applying nonwoven geotextile directly on sub grades extends road life by preventing fine sub grade soil particles from migrating and intermixing into the aggregate and ballast base course. What it does is that acts as a filter/separator to maintain the integrity of the sub-base by preventing movement of subgrade

Figure 8: Installation of Geotextile during Road Development

particles into the sub-base. Roadway pavements are basically structures for taking the high contact pressures from the vehicle tires and reducing that pressure through the depth of the pavement to a level that can be supported by the underlying soil. Pressure is dissipated down through the various layers of materials within the pavement.

b) Application of nonwoven geotextiles stabilizes the subgrade and prevents the fouling of ballast beneath railway track.

c) For temporary road construction in environmentally sensitive areas, a biodegradable woven Jute Geotextile has been developed. These fabrics will totally biodegrade after one to two seasons, eliminating the need to remove a synthetic geotextile from under the roadbed. It is economical for use on roads that will be decommissioned after use.

d) Reinforcement composite Geotextile (Geocomposites) are used for laying railway tracks over weak grounds or ground with loose soil foundation or structure.

2. Land Fill

a) Landfill Leachate Collection: When placed in intimate contact with a geonet or drainage stone, non-woven geotextiles can filter soil and waste while allowing water and leachate to pass. An efficient design utilizing recommended nonwoven geotextiles can lead to proper leachate management in new landfill cells, and rapid surface water collection and removal in closure plans

Figure 9: Installation of Geo textile during Land filling

Figure 10: Installation of Geotextile to address Soil Erosion

3. Erosion Control

a) The geotextiles are thick, robust filters used below rock armour and pre-cast concrete revetment systems to ensure that the underlying soils are not leached out by tidal action. These filters are much simpler to install than the traditional layers of graded stone. Erosion Control Blankets are used in areas where the soil is loose and is needed to be conserved

Figure 11: Installation of Geotextile to separate different layers of soil

4. Seperation of layers of Soil

a) The separation function refers to the separation of two dissimilar soils. The primary function of the geotextile is to prevent intermixing of the two soils throughout the life of the structure.

b) Geotextiles are commonly used for separation when used beneath road-way pavement sections. Although one may not be constructing pavement sections, one may want to use some aggregate over certain sections of the road, or in any other case the principles described here still apply.

5. **Pipelines / Utilities**
Flexible mesh products have been used in major pipeline projects where they can be used to replace the thick sand collar that would traditionally have acted as a cushion to a steel pipe's coating. Sand is difficult to place consistently around a pipe whereas a mesh can be installed relatively quickly and with consistency. The mesh prevents stone in the backfill from abrading and puncturing the pipe's coating which would interrupt the protection system.

Figure 12: Geotextile usage in Pipeline Installation

3.1.3 Special Considerations

Construction is largely dependent on the strength of the subgrade, which is often dictated by its moisture content. In situations where the water table is high, subsurface drainage may be advisable if the topography allows. Ground stabilisation designs require a realistic appraisal of subgrade strength, but in the absence of actual field data the subgrade CBR values given in Table below can be of guidance.

Before placement of the geotextile, the area should be cleared of any large angular objects, such as stones and tree stumps, while ruts and sharp undulations in excess of 100mm should be levelled. In addition, strong perennial weeds, such as thistles, require weed killer treatment to prevent them from penetrating the completed construction. Other surface vegetation can be left undisturbed to provide additional support, if this is allowable and not detrimental to the structure. For very soft foundation soils (subgrade CBR <1 % and undrained shear strengths <10 kN/m2), the presence of surface vegetation can actually aid construction.

Soil Type	Plastic Index %	CBR% Depth of Water table below formation level	
		>600mm	<600mm
Heavy Clay	70	2	1
	60	2	1.5
	50	2.5	2
	40	3	2
Silty Clay	30	5	3
Sandy Clay	20	6	4
	10	7	5
Silt		2	1
Sand (poorly – graded)	Non-plastic	20	10
Sand (well – graded)	Non-Plastic	40	15
Sandy gravel(well graded)	Non-Plastic	60	20
Approx CBR values for typical soils compacted at the natural moisture content			

Table 2: Plastic index and CBR value for different type of Soil

3.2 Geogrids

Geogrids have an open, grid like configuration, i.e. they have large apertures and are invariably used in some form of reinforcement. Geogrids are commonly used to reinforce retaining walls, as well as sub- bases or sub soils below roads or structures.

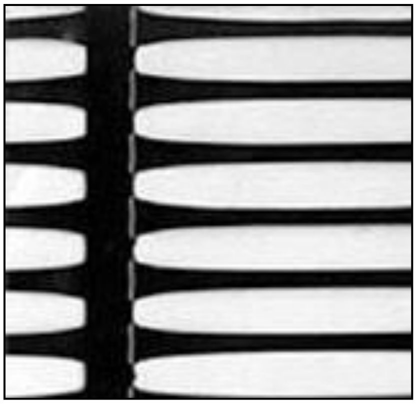
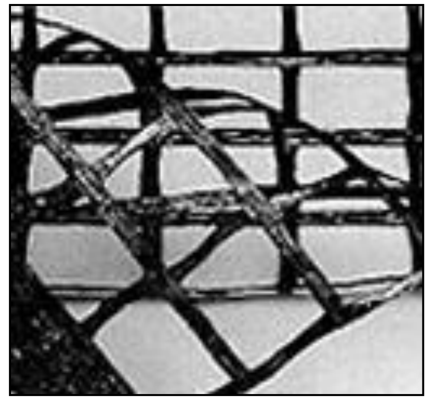



Figure 13: Cross Sectional view of Geogrids

3.2.1 Applications

Following are the primary applications of Geogrids:

a) Segmental Retaining Walls
b) Panel Faced Retaining Walls

Other applications of Geogrids include:

a) Reinforced Foundations
b) Reinforcement in paved/unpaved roads
c) Track bed stabilization
d) Landslide repair
e) Reinforced steep slopes
f) Reinforced embankments over soft soil
g) Landfill embankment
h) Reinforcement of disjointed rock sections

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geogrid							

Geogrid reinforced walls are gravity retaining walls with an expanded width (commonly known as “Reinforced Fill Zone”) created by the placement of geogrid behind a column of segmental facing units. The combination of segmental units and geosynthetic layers act together creating a coherent mass to resist the destabilizing forces generated by the retained soil and applied surcharge loadings. Essentially geogrid reinforced walls, due to their relatively low material and installation costs typically save 25 to 50% compared with conventional concrete retaining walls when above 2m in height. Again such costs are project specific and project specific constraints may dictate the type of retaining solution adopted.

3.2.2 Installations

Geogrid Installation in Retaining Walls

Figure 14: Geogrid application in retaining walls

1. Install retaining wall to designated height of first geogrid layer. Backfill and compact the wall rock and infill soil in layers not to exceed 8 in. (200 mm) lifts behind wall to depth equal to designed grid length before grid is installed
2. Cut geogrid to designed embedment length and place on top of Retaining to back edge of lip. Extend away from wall approximately 3% above horizontal on compacted infill soils
3. Lay geogrid at the proper elevation and orientations shown on the construction drawings or as directed by the wall design engineer.
4. Correct orientation of the geogrid shall be verified by the contractor and on-site soils engineer. Strength direction is typically perpendicular to wall face.
5. Follow manufacturer's guidelines for overlap requirements.
6. Place next course of retaining wall on top of grid and fill block cores with wall rock to lock in place. Remove slack and folds in grid and stake to hold in place.
7. Adjacent sheets of geogrid shall be butted against each other at the wall face to achieve 100% coverage.
8. Geogrid lengths shall be continuous. Splicing parallel to the wall face is not allowed.

Fill Placement

- Infill soil shall be placed in lifts and compacted as specified.
- Infill soil shall be placed, spread and compacted in such a manner that minimizes the development of slack or movement of the geogrid.
- Only hand-operated compaction equipment shall be allowed within 3 ft. (0.9 m) behind the wall. This area shall be defined as the consolidation zone. Compaction in this zone shall begin by running the plate compactor directly on the block and then compacting in parallel paths to the wall face until the entire consolidation zone has been compacted. A minimum of two passes of the plate compactor are required with maximum lifts of 8 in. (200 mm).
- The infill soil shall be compacted to achieve 95% Standard Proctor (ASTM D698). Compaction tests shall be taken at 3 ft. (0.9 m) behind the block and at the back of the reinforced zone.
- When fill is placed and compaction cannot be defined in terms of Standard Proctor Density, then compaction shall be performed using ordinary compaction process and compacted so that no deformation is observed from the compaction equipment or to the satisfaction of the engineer of record or the site soils engineer.
- Soil tests of the infill soil shall be submitted to the on-site soils engineer for review and approval prior to the placement of any material.

- The contractor is responsible for achieving the specified compaction requirements. The on-site soils engineer may direct the contractor to remove, correct or amend any soil found not in compliance with these written specifications.
- Tracked construction equipment shall not be operated directly on the geogrid. A minimum fill thickness of 6 in. (150 mm) is required prior to operation of tracked vehicles over the geogrid. Turning of tracked vehicles should be kept to a minimum to prevent tracks from displacing the fill and damaging the geogrid.
- Rubber-tired equipment may pass over the geogrid reinforcement at slow speeds, less than 10 mph (16 Km/h). Sudden braking and sharp turning shall be avoided.

3.2.3 Special Considerations

- Geogrid can be interrupted by periodic penetration of a column, pier or footing structure.
- Retaining walls will accept vertical and horizontal reinforcing with rebar and grout.
- If site conditions will not allow geogrid embedment length, consider the following alternatives:
    - Masonry Reinforced Walls
    - Soil Nailing
    - Increased Wall Batter
    - Earth Anchors
    - Double Block Retaining Wall
    - Rock Bolts
    - No-Fines Concrete

3.3 Geocells

The geotechnical environment was completely revolutionized with the application of geosynthetics, starting with the humble non-woven to the more complex geo-composites. Most of these systems are two-dimensional. Cellular confinement systems add the third dimension to geosynthetics, which open up more avenues of applications, ranging from providing strength to geo-systems, to protection against erosion.

Cellular Confinement Systems are popularly known as "Geocells". Geocells are strong, lightweight, three dimensional systems fabricated from ultrasonically-welded High Density Polyethylene (HDPE) strips that are expandable on-site to form a honeycomb-like structure (Fig. 15). Geocells are filled with compact non-cohesive soils which are confined within the cellular walls. The composite forms a rigid to semi-rigid structure. The depth of the geocells as well as the size of each cellular unit can vary as per design requirements.

Generally, the infill is sandy or gravelly material. However the infill may be plain concrete depending on the application such as erosion protection, water channel formation, etc.

The surface of the Geocell is textured to increase soil-Geocell wall friction. The Geocell wall is punctured (Figure 15) to assist in immediate dissipation of developed pore water pressures due to increased stresses within the infill of the individual cells.

Figure 15: Sectional View of Geocells

Geocells can be used to great advantage considering that:

1. Geocells are the only prefabricated three-dimensional geosynthetics with significant third dimension properties;
2. They are easily transported as flat strips welded width-wise at regular intervals, and logistics for large quantities is not a problem;
3. Geocells are easy to install and do not require skilled labour. They can be installed in any weather condition;
4. The in-fill has essentially to be non-cohesion material, however the material could be recycled material
5. Solutions considering geocells as a solution for any civil engineering / geotechnical issue always proves to be cost effective with reduced and economic usage of valuable natural resources, including metal / aggregates, sand, cement, etc. the cost savings can be as substantial as much as 30% for road construction and the time saving can be as much as 50%;

6. When used for roads and pavements, geocells substantially reduce cost of maintenance by improving the longevity of the road / pavement;
7. Considering all of the above, geocells help reduce carbon foot-print; since carbon black is an essential ingredient of the HDPE, geocells indirectly foster carbon sequestration

3.3.1 Applications

Today the applications of Geocells are many, and broadly include:

1. Load support systems:
   a) Increase in load carrying capacity of foundation spread and strip footings, and grade slabs.
   b) Reinforcement and support systems for embankments on weak ground;
   c) Reduction in pavement sections for all types of roads, lay-down areas and parking lots.
2. Gravity walls for earth retention and surcharge load support.
3. Erosion control:
   a) Embankment slopes and natural slopes;
   b) Water channel and water poundage linings.

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geocells							

3.3.2 Installations

3.3.2.1 Site Preparation

- Prepare the site to the design specifications (grade, Geometry, soil compaction, etc.). The area should then be dressed to be free of soil clods, roots, stones or vehicle
- Imprints of any significant size. Any voids should be filled in order to obtain a smooth laying surface allowing
- Geocell to fit flush against the ground surface contours.

3.3.2.2 Installation

Excavate anchor trench where an anchorage trench is specified, each panel should be anchored at the top of the slope in a trench whose dimensions are determined by design depending on the geometry of the slope. For shallow slopes, anchor trenches may not be required as pins used to fasten (Figure 16) the system to the slope can provide sufficient anchorage strength.

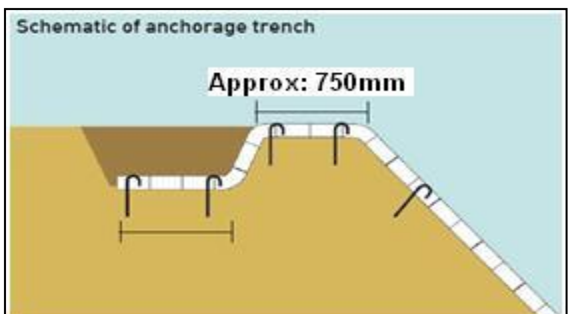


Figure 16: Anchoring Geocells on slope

Panels can be expanded to the full open dimension, parallel to the flow direction (Figure 17). Anchor the panel at the top of the slope and fasten at the bottom of the trench with pins (Min. 8mm diameter and typically 300-450mm in length depending on consistency of the sub-grade).

The anchorage trench at the top may be filled with any suitable fill material. If possible, backfill with concrete to reduce the trench embedded length.

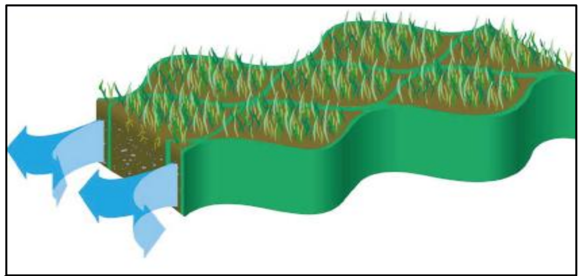


Figure 17: Flow of Water

Placement

- Along the slope the Geocells should be anchored with pins typically 300mm - 450mm in length depending on the consistency of the slope material.
- The spacing between the pins shall be determined by design with each pin placed on the junctions of the panel as shown in Figure 18.
- Securely fasten down the panel ensuring the pins are arranged in a staggered pattern like the number 5 on a dice.
- Adjacent panels should be fixed using the same pins, one pin every 2-4 cells, depending on selected Geocells. (Figure 18)

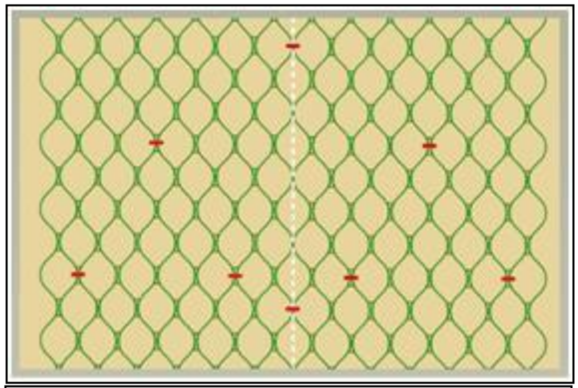


Figure 18: Schematic view showing Goecells placement with pins position

Infilling the Geocells

- Infilling can be performed manually or carried out using mechanical plant such as a front-end loader, backhoe bottom dump bucket or a conveyor system.
- Cells can be filled with top-soil, or any other material such as soil/grass, gravel or even concrete etc., depending on the final aesthetics and vegetation requirements. (Figure 19)

Figure 19: Geocells to protect Soil

- The fill material shall be placed to approximately 20mm above the top of the cells and then lightly tramped and levelled to the height of the cell.
- If seeding is specified then it is recommended to place the seeds approximately 20mm below the finished level.
- Application of a further 10-20mm layer of fine top-soil (such as sandy loam) is recommended after seeding and this final layer should be lightly raked (using the back of the rake) to evenly cover the cells.

- Seeded areas may be protected with light synthetic or natural fibre blankets (jute) especially where steep slopes are constructed.

Figure 20: Schematic Representation to pin Geocell

Key Installation Advice

<u>**Toe** anchorage</u>

It is important to ensure the lower cells at the toe of the slope are fixed in a base trench or secured carefully by pins (Figure 21). When this is not properly done, the lower cell row may lift in a 'crocodile mouth shape'. Infiltration water, passing through the cell apertures, will then cause the emptying of infill from the bottom. When the first row of cells is empty, the second row begins to rise, and so on. Erosion continues up to the first pin that is able to resist the cell from rising. Therefore it is essential that the first row of cells is properly fixed, so that this problem is resolved.

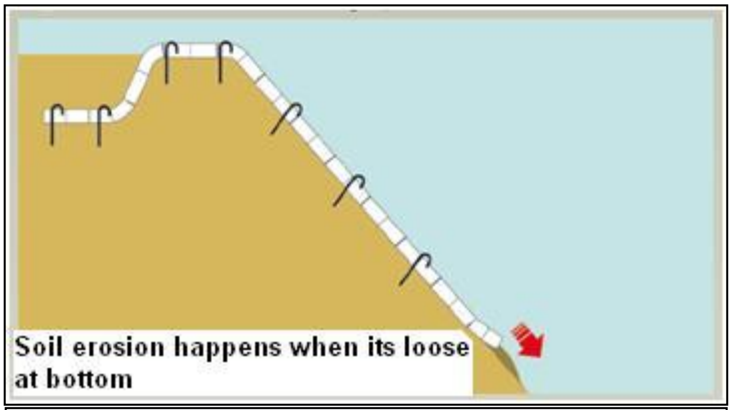


Figure 21: Toe anchorage of Geocells is a must

<u>Lack of Pins</u>

If the number of pins is less than required or if the pins used are not properly chosen, the localised stress transmitted by pins to the junctions can break them. The failure of a junction transmits an over-stress to the adjacent junction, thus producing a progressive failure. It is therefore important that the pin selection and placing is not compromised and that the pin design is carefully selected to suit the slope parameters (Figure 22).

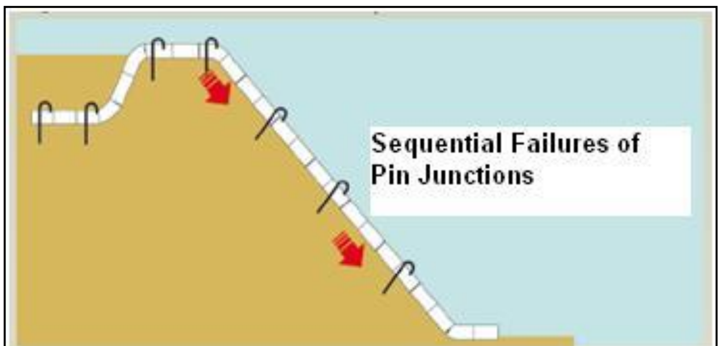


Figure 22: Sequential Failure of Pin Junctions in Geocells

Intense Run-Off

If there is a long slope upstream, or there is any possible cause of intense run-off, the top rows can be subject to intensive erosion. The change of slope angle, in fact, causes a local increase in water flow speed. To avoid the consequent erosion, it is necessary to cover the zone with a bio-mat or, better, with a geomat. It is strongly recommended to excavate a draining ditch immediately upstream the surface to be protected, thus reducing the run-off (Figure 23)

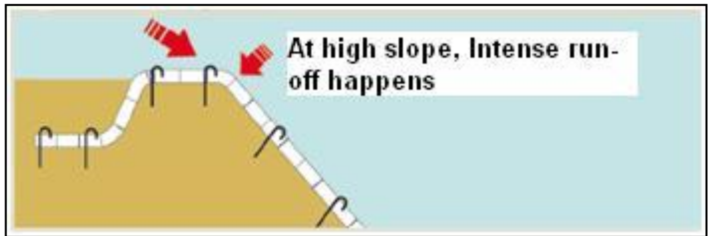


Figure 23: Intense run-off at high slope

3.4 Geomembranes

Geomembranes are also synthetic materials but they are impervious and made of thin sheets of rubber or plastic materials used primarily for lining and cover of liquid-or solid-storage facilities.

Figure 24: Geomembranes

The large scale development of PVC geomembranes began in the 1960's with the use of PVC film to prevent seepage of water from canals and reservoirs used for irrigation in the western United States.

In the US Bureau of Reclamation's 35+ years of geomembrane experience, PVC geomembranes have proven especially effective where limited access, short downtime, long haul distances, and potential for freezing and thawing are factors.

The primary use of PVC geomembrane by the Bureau of Reclamation has been for lining irrigation canals. These canals are unique structures because:

1. They are long and narrow
2. They have limited access for work
3. They have steep side slopes

Historically, PVC has been the most widely used geomembrane for canal applications for the following reasons:

1. Availability in large sheets - PVC can be factory fabricated into panels up to 30 M wide and 100 M long. Panels can be accordion folded in both directions to facilitate shipping and handling in narrow confines associated with canal construction. These large panels minimize field seaming.

2. PVC is highly flexible and retains this property over a wide range of temperatures, which permits it to conform to the subgrade better than other geomembrane materials, which were available at the time of selection, such as HDPE and EPDM.
3. PVC is easily field-spliced and repaired with a solvent-type cement.
4. PVC also has good puncture, abrasive, and tear-resistant properties, which are important to minimize damage during installation.
5. PVC geomembrane installation does not require sophisticated equipment or skilled labor.

These same material properties are advantageous to many other applications requiring containment liners. PVC geomembrane is used in all types of water and waste containment applications, including landfills, wastewater treatment lagoons, oil exploration, aquaculture, and irrigation ponds**.**

3.4.1 Applications

The following are the major application of Geomemberanes:

a) Irrigation canals
b) Landfill
c) Water Harvesting
d) Food Storage
e) Water Insulations

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geomembrane							

3.4.2 Installations

Geomembrane installation entails the following steps:

3.4.2.1 Site Considerations

- Whenever possible, site selection should avoid areas where flooding or ground water pressure can occur.
- The lining "bottom" should be well above the water table.
- If the site selected is in an area where organics are in the soil, or if gases can be generated by chemical reaction, the design must allow for venting.

3.4.2.2 Surface Preparations

- Surfaces should be level and free of all sharp rocks (all rock and stone greater than .05” diameters), objects, vegetation and stubble. Soil sterilization may be necessary to kill roots and certain types of grasses (Fig 25).

Figure 25: Surface for laying Geo-Membrane

- The subgrade surface should

provide an unyielding foundation for the geomembrane with no sharp or abrupt changes or break in grade. Proper compaction assures stability and support of the liner.

- Rough ground and standing water, mud, snow - Any excessive moisture - is counterproductive for liner deployment.

3.4.2.3 *Controlling Groundwater*

Groundwater should be taken into account and, if present, it will need to be controlled both during and after construction. One method for controlling groundwater is to develop a French drain system under the lining that allows the water to flow laterally under the lining without floating the lining.

A good design for an under-drain is to pipe it to the outside of the lake into a gravel sump. This allows the sump to run continuously during construction and, with the placement of an upright at this sump, the under drain can be pumped if needed to relieve hydrostatic pressure and gas build up under the lining system.

Slopes

Side slopes should be no steeper than 3:1 whenever feasible. Slopes are usually hand-raked to achieve proper smoothness.

Receipt of Liner and Materials

Liner panels are fabricated into large sheets to minimize field seaming. These large panels are first accordion folded, then rolled up on a core. It is recommended that the liners panels' protective covering not be removed until installation and that any uncovered panels be stored out of direct sunlight. Panels are rolled on 6" cores and can be unloaded using a 10' section of schedule 80 pipe and handling straps.

Anchor Trenches

- To secure the edges of the lining in an earthen pit, an "anchor trench" is dug. Anchor trenches are approx. two foot wide by two foot deep (2' x 2') and one foot back from the crest of the berm (standard trench dimensions and depth vary according to project design.) (Figure 26)
- Dirt removed should be raked out flat on the far side of the trench, away from the pit, to be used to backfill after the liner edges are laid out in the anchor trench, while allowing the panels to be unrolled along the berm.

Figure 26: Anchor Trench

- Slightly rounding corners of the trench avoids sharp bends in the geomembrane. The trench itself needs to be free of loose soil and rocks.

Site Structures

Structures, piping, concrete, drains, and any associated work should be completed prior to lining installation.

Liner Deployment
The roll is raised by a loader, forklift, or other lifting equipment, and then unrolled in one direction, and unfolded in the other direction (Figure 27).

Figure 27: Liner Deployment

Panel Placement

- Take time when unloading and placing rolls of lining to avoid damage.
- Verify the location of a panel or sheet before unrolling and placement to avoid improper alignment.
- Sandbags are required to keep the panels in place during installation, exposed or covered.
- It takes considerable manpower to deploy a liner. It is "pulled" but not stretched. Minor wrinkles insure the liner is installed in a relaxed condition. Care should be taken to avoid wrinkles in the seam areas and around mechanical attachments. (Figure 28)
- A ballast system (sand bags) and anchor trenches are used for all geomembrane installations.

Figure 28: Panel Placement

3.4.2.4 Field Seaming

Fabricating panels into essentially larger panels dramatically reduces the amount of field seaming a project requires. The lining material itself determines the types of field seaming techniques used. The most commonly used process is heat fusion welding, which can be done with hot air or hot wedge.(Figure 29)

Figure 29: Field Seaming

Liner Attachments to Structures
The most commonly used methods for attaching to structures are Mechanical and Embedment Strip methods (Figure 30):

- **Mechanical**: Battens are typically 1/4" x 2" and are aluminium or stainless (depending on corrosion resistance requirements).
- **Embedment Strip**: A method using the same material as liner system - placed in concrete during concrete pour. Creative methods to deal with special attachment needs are possible.

Figure 30: Linear Attachment

Pipe Boots
A pipe boot is a method of sealing the liner system to necessary pipes that penetrate the lining system (Figure 31).


Figure 31: Pipe Boots

3.5 Geonets

These are the another specialized segment of Geosynthetics. Geonets are generally used for the purpose of drainage. (It is to be noted that geonets are always used with a geotextile). Geonets used in protective works for highway structures.

Geonet is a synthetic drainage material manufactured from the highest quality high-density polyethylene (HDPE) resin to transmit fluids and gases uniformly under many field conditions. The Geonet products are available from 200 mil (5 mm) to 370 mil (9.4 mm) thickness

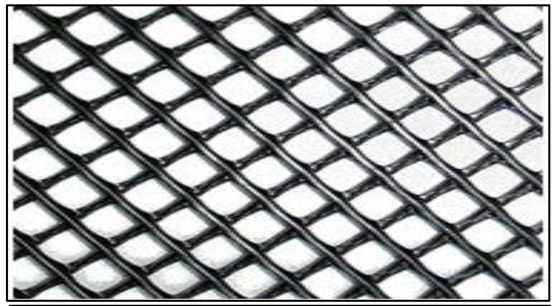


Figure 32: Geonets

The Geonet resembles the Geogrid in configuration, design pattern as two sets of coarse parallel polymeric strands, each extruded in tubular form, which cross at an acute angle. Geonets and geogrids both have an open grid-like appearance and a third layer can be introduced to increase thickness and hence flow capacity; yet they are different as the reason for their separate treatment from Geogrid lies not in the material or its configuration, but in its function. ***Geonets are used for their in-plane drainage capability, while geogrids are used for reinforcement***

3.5.1 Applications
The use of geonets is mostly done in two ways:
a) Horizontal drainage
b) Vertical drainage

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geonet							

Although of very similar configuration to geogrids, geonets are not installed for reinforcing purposes but rather for their in-plane drainage capabilities, which depends on the thickness of the ribs and their capillarity.

They are frequently bonded with one or two layers of geofabric on each side (and are therefore often


Figure 33: Geonets in Landfill Application

referred to as drainage geocomposites) or can be used sandwiched between two geomembranes. The geofabrics/membranes stop the soil clogging the grid-like openings and reducing the drainage performance.

Geonets can be used in landfill applications within drainage layers (Figure 33 and 34), to drain away infiltrating water and leachate, and within the gas collection layer, to transmit gas to collection points.

Geonets can also be used as wall, slope or roof drainage systems, under structures such as embankments and roads to drain away groundwater and contribute to stability of the structure, resistance to frost and certain protection applications.


Figure 34: Geonets in Drainage

3.5.2 Installations

The Geonet are used along with geotextiles as shown in figure 35 and figure 36.

They form the outer layer when applied with the geo textiles to increase the pressure toleration of the walls of the Geo material.


Figure 365: Geo net with Geo textiles


Figure 36: Installation of Geo net

3.6 Geocomposites

Geocomposites are geosynthetics made in laminate from a combination of two or more geosynthetic types or composite form and used for applications such as reinforcement (grids + geotextiles) and drainage (mats or nets + geotextiles) among others.
Heat and/or adhesives are used to create single components by bonding barriers, drains, filters, protectors and reinforcement in different combinations. The objective is to produce materials which are multi-functional and are faster to install than the individual components. Interface friction becomes an issue when Geosynthetics are placed on slopes and bonded materials address this potential problem.

Primary uses are drainage applications via accelerating the consolidation of soft soils, or separation and


Figure 37: Geo composites

reinforcement functions. Geosynthetic Clay Liners (GCL) and Prefabricated Vertical Drains (PVD) are the two predominant forms of Geocomposites.

Shipping and Handling

The drainage Geocomposite rolls shall be wrapped in a plastic cover. The drainage Geocomposite rolls shall be shipped to the job site in a manner not to damage the rolls. (Figure 38)

Figure 38: Handling Geo composites

3.6.1 Applications

The Geocomposites has following major applications:

- Ground reinforcement and improvement
- Gas and water drainage
- Landfill / contaminated land applications
- Filtration

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geocomposite							

Geosynthetic components can be combined together into a single geocomposite, thus providing savings in construction time and enhanced performance. Depending on the composite design, they can work as a barrier, drainage, filtration, protection, separation or reinforcement layer.

Geocomposites might be used as barriers/separation layers to separate and contain polluted soil (brownfield regeneration) or waste (landfill applications) and avoid migration of pollutants to the surrounding soil or water.

Geocomposites usually include a drainage layer to enable collection of seepage and/or gas and an impervious layer, such as a membrane. They can be mounted on solid frames to build below ground physical barriers, e.g. separation walls.

In ***railways applications***, geocomposites can replace the sand layer separating the track ballast from the foundation, performing the same function of stopping the upward migration of fines.

Drainage geocomposites include geonets , but many other forms are available, e.g. band drains mounted on a geotextile or geomembrane (e.g. for landfill lining) or geocuspates, which are formed from sheets of polymeric material with an alternate stud and canal profile, bonded to geofabric filters, used for example in trenches alongside highways, behind retaining walls and bridge abutments, under embankments built over compressible soils, etc.

Drainage geocomposites that include geofabrics are used for filtration applications when there is a need to drain water out of the soil or for water to flow with soil fines being retained without clogging. ***Reinforcing geogrids*** can be added for applications where foundations or soil require strengthening.

Protection applications, alongside barrier applications, include sealing of buildings from hazardous ground gases, including methane and radon. Specific impervious layers are mounted on drainage geocomponents to stop the gases reaching the structure and to provide a collection route.

For example, Geocomposites come to the fore in complex applications, such as in the protection of a river from potential leachate pollution from an adjoining landfill. A geocomposite membrane with geotextile bonded to both sides was mounted on a curtain wall system and then buried as vertical barrier between the landfill and the river.

3.6.2 Installation

The product consists of a capillary drainage layer and one (ST/FT) or two (STS/FTF) filter layers comprised of short synthetic fibres of 100% polypropylene or polyester which are needle punched together. Corrugated Polypropylene pipes with two perforations per valley at 180 degree spacing and rotated 90 degrees per valley are inserted longitudinally between the drainage layer and one filter layer during the manufacturing process at uniform intervals

- The geocomposite rolls shall be deployed using a spreader bar assembly attached to a loader bucket or by other methods approved by the project engineer.
- The geocomposite core consists of a circular aperture side and a cuspated side. The side with the circular apertures should be placed against the soil, while the cuspated side should be placed against the geomembrane. (Figure 39)
- The geocomposite rolls shall be deployed so that, to the maximum extent possible, the machine direction of the material aligns with the direction of the steepest slope.
- On slopes the geocomposite shall be secured in the anchor trench as shown on the project drawings and then rolled down the slope. Rolls should be deployed in such a manner as to continually keep the geocomposite panel in sufficient tension to reduce folds and wrinkles.

Figure 39: Installation of Geo composites

- In the case of a steep slope, the geocomposite must be properly anchored. For slopes longer than the length of a roll, only full length rolls should be used at the top. Overlaps shall be shingled down the slope and/or in the direction that backfilling will occur.
- In the presence of high wind, sandbags shall be placed on leading edges of the panels to prevent wind uplift.
- If there are any penetrations (such

Figure 40: Installation of geo composites in drainage pipes

as outlet pipes or monitoring wells) while deploying the drainage geocomposite, the geocomposite should be cut to fit around the penetration. Care must be taken to ensure there is no gap between the penetration and the geocomposite, to prevent soil particles from migrating into the geonet core. If the material is being cut in place, special care must be taken to protect other geosynthetic materials from damage. (Figure 40)

- Care shall be taken not to entrap stones, soil, or excessive dust that could damage the geocomposite, or generate clogging of drains or filters.

To ensure continuity of flow in the mini-pipes between rolls, transverse joints are used. The filter layer of the geocomposite is rolled back 12 inches. The end of the next roll is inserted into these openings and pipes are placed side by side or mechanically connected. Mechanical connections are recommended under high compressive loads. This is displayed in the pictures above

Longitudinal Connections (at the side of a roll)
Longitudinal joints require an overlap of 2 to 4 inches minimum (Figure 41). To avoid displacement (due to wind, backfilling, etc.) the overlap may be secured with sewn seams, additional overlap or welds (hot air or flame). The spacing between welds shall be no greater than 6 feet. Connection method requirements shall be at the direction of the engineer.

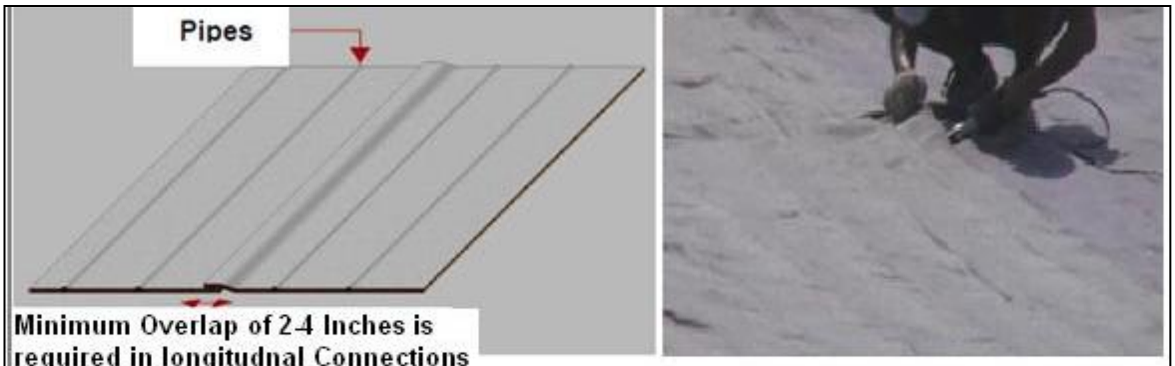


Figure 41: Installation of Geocomposite in Longitudinal Connections

Connection to Liquid Interceptor Drains
Connection to an interceptor drain requires a simple overlap of a minimum of 8 inches. (See Figure 42) for illustration

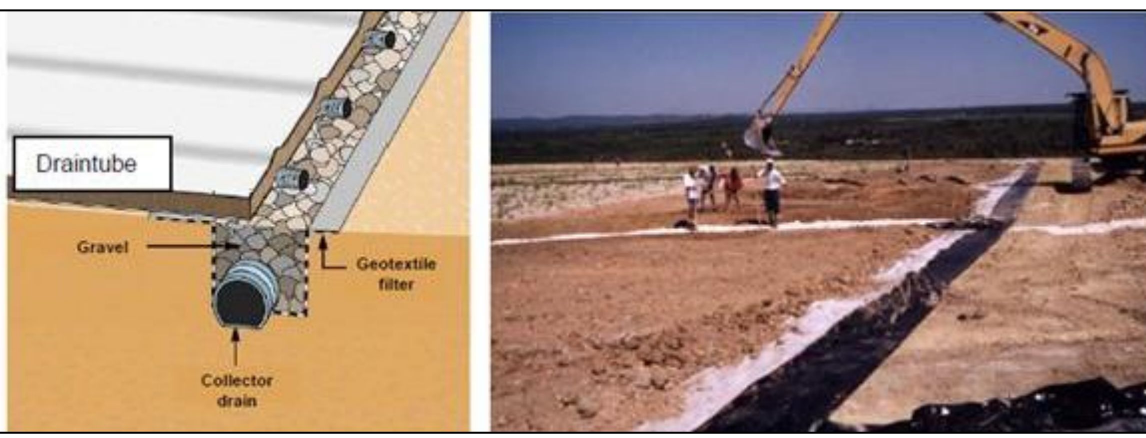


Figure 42: Connection to Liquid Interceptor Drains

Repair

- Prior to covering the deployed Geocomposite, each roll shall be inspected for damage. Any rips, tears or damaged areas on the Geocomposite shall be removed and patched. The patch can be adhered using a spray adhesive (such as 3M Super 77).
- If a section of pipe is damaged during installation, add a piece of undamaged pipe of the same size next to the damaged pipe plus a minimum 8 inches extending beyond the damaged section of pipe at each end (see longitudinal connection).
- If the protection geotextile is damaged, install an undamaged piece of the same material under the hole and extending a minimum of 6 inches beyond the hole to insure that protection of the geomembrane is maintained.
- Damaged filter must be replaced by another filter to properly protect the pipe. If the area to be repaired is more than 50 per cent of the width of the panel, the damaged area shall be cut out and replaced with undamaged material using the connection methods described above.

Backfill Placement

- The Geocomposite drainage layer shall be covered with the specified material within 14 days of deployment.
- The backfill shall be free of angular stones or other foreign matter which could damage the Geocomposite drainage layer. Care should be taken to avoid displacement of the Geocomposite. The contractor must maintain a minimum of 18 inches of backfill and the backfill equipment.

Figure 43: Backfill Placement

- The maximum particle size of the backfill should be 2 inches or less.
- The backfill shall be placed from the bottom of the slope and shall not be dropped directly onto the drainage layer from a height greater than 3 feet. The backfill shall be pushed over the Geocomposite drainage layer in an upward tumbling motion that prevents wrinkles in the drainage layer.
- No equipment shall be operated on the top surface of the Geocomposite drainage layer without permission from the Contracting Officer or Engineer.
- The initial loose lift thickness shall be 12 inches.
- Equipment exerting ground pressure no greater than 7 psi shall be used to place and compact the first lift of select fill. Compaction shall consist of a minimum of 2 passes over all areas. The loose lift thickness of each subsequent lift shall be no greater than 12 inches.
- Normal backfill placement shall be allowed on areas underlain by Geocomposite after the second loose lift of fill has been placed and compacted

3.7 Geosynthetic Clay Liners

A type of Geocomposite, Geosynthetic Clay Liners, or GCLs, are an interesting juxtaposition of polymeric materials and natural soils. They are rolls of factory fabricated thin layers of betonies clay sandwiched between two geotextiles. Structural integrity of the subsequent composite is obtained by needle-punching, stitching or physical bonding.

Figure 44: Geosynthetic Clay Liners

These comprise of a layer of low water permeability, high swelling sodium bentonite sandwiched between two layers of geotextiles. These are like carpets and are very effective barrier systems for waste and liquid containment. The use of GCLs are mandatory in western countries where environmental regulations are high

GCLs require soil cover of at least 300mm to provide sufficient normal force to confine the expansion of the bentonite core layer. The bentonite swells and extrudes through the geotextile fabric at the overlap, forming a seal by producing a dense and uniform clay barrier with the same hydraulic qualities in all parts of the clay liner

3.7.1 Applications

GCLs are used in a range of environmental and containment applications, particularly when performance is critical and when penetration risks are present. Examples include landfill cappings and cut off walls to contain pollution. On this the application of GCL is divided into following two categories:

a) **Waste containment -** In industrial, hazardous and municipal landfill liners and landfill caps. GCLs effectively prevent leachates thus protecting soil and ground water. GCLs have substituted traditional clay liners because of their high durability and cost effectiveness

b) **Liquid containment -** Minimizes leakages in above ground storage tanks, civil engineering projects - canals, waterways, dams, roadways, etc. Also for decorative ponds, lagoons, wetlands

Advantages

a) Fast and easy installation. Available in rolls of size required no cut and paste or seaming required
b) One truckload of the GCL equals almost 100 truckloads of clay for the same application
c) Self repair of any holes and rips due to swelling properties of bentonite
d) High strength chemically resistant geotextiles plus the needle punched reinforcement results in high durability and cost effectiveness

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
GCL							

3.7.2 Installation

Site Preparation: Subgrade preparation requiree removal of silt and over-excavation of 400mm to allow for covering of the GCL. Batters are trimmed to 1:3. Spool is placed adjacent to the channel to facilitate backfilling. Loose rubble is removed before rolling of subgrade

Installation: A lifting frame fitted to an excavator suspends the GCL roll and facilitates placement across the channel. The material is pulled across and up the channel bank as far as possible. It is then attached to another lifting frame (constructed for the project with grip plates attached) and a second excavator (Figure 45). The second excavator then assists in dragging the material up the bank to the required height. Each length of liner is overlapped by 300mm, with the top of the overlap on the downstream side.

Figure 45: Installation of GCL

The GCL is anchored by placing a minimum of 400mm of backfill over the material on a berm located 300mm above the high-water mark. Excavators then cover the liner with 400mm of backfill material. The recommended minimum backfill is 300mm, but this thickness is difficult to place and compact. Once the cover has been placed an excavator compacts the backfill using its tracks but has to move cautiously to avoid movement and damage to the GCL. On the sides a 3:1 bank slope is sufficient to maintain the backfill material on the liner without it slumping

The end of the GCL is keyed into the channel profile to a depth of 400mm in a 1.2m wide trench across the channel. Backfill material is then compacted in the trench.

The site is to be fenced to prevent access to sheep and cattle, and signs identifying the liner's location should be installed

Figure 46: Burying of GCL with Soil

Specialised equipment
Lifting frames are required to hold the GCL roll and to pull the material to other side of the channel. (Figure 46)

Installation issues

- The material is very heavy, difficult and labor intensive to handle. If its white colour, then it produce significant sun glare.
- The material tore up easily when any compaction equipment is turned on. Compaction therefore focused in two separate directions - up and down the bank and backwards and forwards along the channel length to avoid the need for turning. Four passes should be made to provide a reasonable compaction to ensure longevity of the cover.
- The subgrade sometime appears to settle after the backfill material is placed and this causes the joins to come apart. These had to be excavated and additional GCL has to be laid. Wet soil patches also appear to have caused differential settlement during compaction.
- The joining overlap should be of more than 300mm

Weather considerations
Installation in wet conditions is not possible as rain is absorbed by the bentonite, making the liner heavier and harder to handle.
Durability
The lifespan of covered GCL is estimated to be 25 years

3.8 Prefabricated Vertical Drains (PVD)

Another type of Geocomposite, a Prefabricated Vertical Drain (PVD) is a long flat tube of woven or non-woven geotextile with a core inside (Figure 47). For construction of structures on sites underlain by thick strata of soft cohesive soils, a method of foundation soil improvement is generally required to prevent bearing capacity

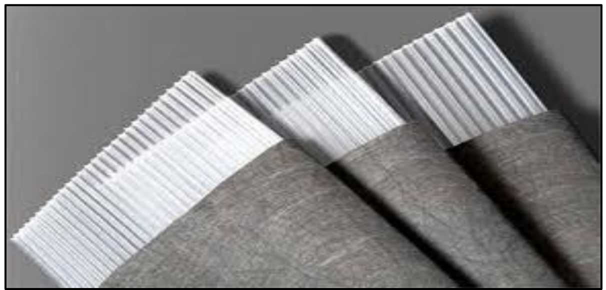


Figure 47: Prefabricated vertical drain (PVD)

failure and/ or to avoid excessive total and differential settlements. These soft soils have a very low bearing capacity due to their saturated state; the PVDs are used to increase the bearing capacity of the soil by removing the excessive water present inside.

3.8.1 Applications

The need of consolidated soil is needed almost in every industrial application. However, following are the major areas where the PVD finds their usage:

a) Roads
b) Railways
c) Land filling and canal lining
d) Coastal protection and river training
e) Ground Improvement
f) Erosion control

3.8.2 Installation

Installation of Prefabricated Drains or PVDs (Figure 48) entails the following details:

Equipment

Figure 48: Installation of PVD

- PVD shall be installed using approved equipment which can insert the material into the ground with the minimum possible disturbance to the soils and during the process of installation and maintain the mandrel in a vertical position.
- PVD shall be installed using a mandrel to protect the drain from tears, cuts and abrasion during installation and which shall be retracted after the drain has been installed to the required depth.
- The size and shape of the mandrel shall be as close as practically possible to the size and shape of the PVD so as to minimize the disturbance to the soil.
- The length of the mandrel shall not be less than the maximum installed length of the drain.
- The mandrel shall be capable of making a clean puncture through any geotextile if necessary.
- The mandrel shall be provided with an anchor plate or similar arrangement at the bottom to prevent the entry of soils into the mandrel during installation of the drain and to anchor the tip of the drain at the required depth at the time of withdrawal of the mandrel.
- The dimensions of the anchor shall conform as closely as practically possible to the dimensions of the mandrel so as to minimize disturbance to the soil.

Installation Procedure

- PVD shall be located, numbered and pegged out by the Contractor using a base line and benchmark indicated by the Engineer. The Contractor shall take all reasonable precautions to preserve the pegs and is responsible for any necessary re-pegging. (Figure 49)

Figure 49: Pegging PVDs

- The as-installed location of the PVD shall not vary by more than 150 mm from the plan locations designated on the drawings. PVD that are more than 150 mm from the design plan locations or those are damaged or improperly installed will be rejected and abandoned in place.
- PVD shall be installed from the working surface to the depth shown on the drawings, or to such depth as directed by the Engineer, who may verify the depths, spacing, or the number of drains to be installed, and may revise the plan limits for this work as necessary. The Contractor shall provide the Engineer with a suitable means of determining the depth of the advancing drain at any given time during installation and the length of drain installed at any location.
- At the end of each working day, the Contractor shall furnish a summary statement of the PVD installed that day, which shall include drain type, locations and length of PVD installed at each location.
- Equipment for installing PVD shall be plumbed prior to installing each drain and shall not deviate from the vertical more than 1 in 50 during the installation of any drain.
- The installation shall be carried out without causing any damage to the drain during advancement or retraction of the mandrel. Alternate raising or lowering of the mandrel shall not be permitted in any case. Raising of the mandrel will be permitted only after the completion of a drain installation.
- The completed drain shall be cut-off neatly at its upper end with about 300 mm projecting above the working surface, or as directed by the Engineer.
- Installation of drains should be coordinated with the placement of the geotechnical instrumentation as shown on the drawings. Adequate care should be taken to install drains in such a manner so as not to disturb instrumentation already in place. The replacement of instrumentation damaged or rendered non-functional as a result of Contractor’s activities will be the responsibility of the Contractor.

Splicing

- Splicing of the PVD shall be done by stapling with proper workmanship ensuring the structural and hydraulic continuity of the drain.
- At the splice the jacket of the upper part of the drain shall be external to the lower portion.

- A maximum of one splice per drain will be permitted without specific permission from the Engineer.
- The jacket and core shall be overlapped a minimum of 150 mm at any splice.

Quality Control in Installation

- Use appropriate size of Mandrel and anchor plate to minimize soil disturbance
- Use Mandrel with adequate stiffness to maintain verticality
- Apply appropriate penetration rate to avoid significant bending
- Check verticality during installation

Layout Configuration and Drain Influence Zone

PVDs are installed in either square or triangular patterns. A square pattern is simpler for setting out in the field. Triangular pattern however provides more uniform consolidation between drains. Relationship of drain influence zone (D) to drain spacing (S) can be expressed by;

- *For square pattern* D = 1.13 S
- *For triangular pattern* D = 1.05 S

3.9 Geofoam

Geofoam (Figure 50) is a product created by a polymeric expansion process resulting in "foam" consisting of many closed, but gas-filled, cells. The skeletal nature of the cell walls is the unexpanded polymeric material. The resulting product is generally in the form of large, but extremely light, blocks which are stacked side-by-side providing lightweight fill in numerous applications.
The first use of EPS Geofoam was in Oslo, Norway in 1972. Geofoam was used in the embankments around the Flom Bridge in an effort to reduce settlements.

Figure 50: Geo foam

Advantages

- *Low density/ high strength*: Geofoam is 1% to 2% the density of soil with equal strength.
- *Predictable behavior*: Geofoam allows engineers to be much more specific in the design criteria. This is very different than other lightweight fillers, such as soil, that can be very variable in composition.
- *Inert*: Geofoam will not breakdown, so it will not spread into surrounding soils. This means that Geofoam will not pollute the surrounding soil. Geofoam can also be dug up and reused.
- *Limited labor required for construction*: Geofoam can be installed by hand using simple hand tools. This eliminates the investment and operating cost of heavy machinery.

- *Cuts down on construction time*: Geofoam is quick to install and can be installed during any type of weather, day or night, resulting in faster installation time.

Disadvantages

- *Fire hazards*: Untreated Geofoam is a fire hazard.
- *Vulnerable to petroleum solvents*: If Geofoam comes in contact with a petroleum solvent, it will immediately turn into a glue-type substance, making it unable to support any load.
- *Buoyancy*: Forces developed because of buoyancy can result in a dangerous uplift force.
- *Susceptible to insect damage*: Geofoam should be treated to resist insect infestation. If it is not, insects such as ants can burrow into the Geofoam, weakening the material.

3.9.1 Applications

The following are the major application of Geofoam

a) Slope Stabilization
b) Embankment
c) Retaining Structures
d) Utility Protection
e) Pavement Insulation

Figure 51: Slope stabilization by Geo foam

Slope Stabilization (Figure 51) is the use of Geofoam in order to reduce the mass and gravitational force in an area that may be subject to failure, such as a landslide. Geofoam is up to 50 times lighter that other traditional fills with similar compressive strengths. This allows Geofoam to maximize the available right-of-way on an embankment. Geofoam's light weight accompanied by its ease to install reduces construction time and labor costs.

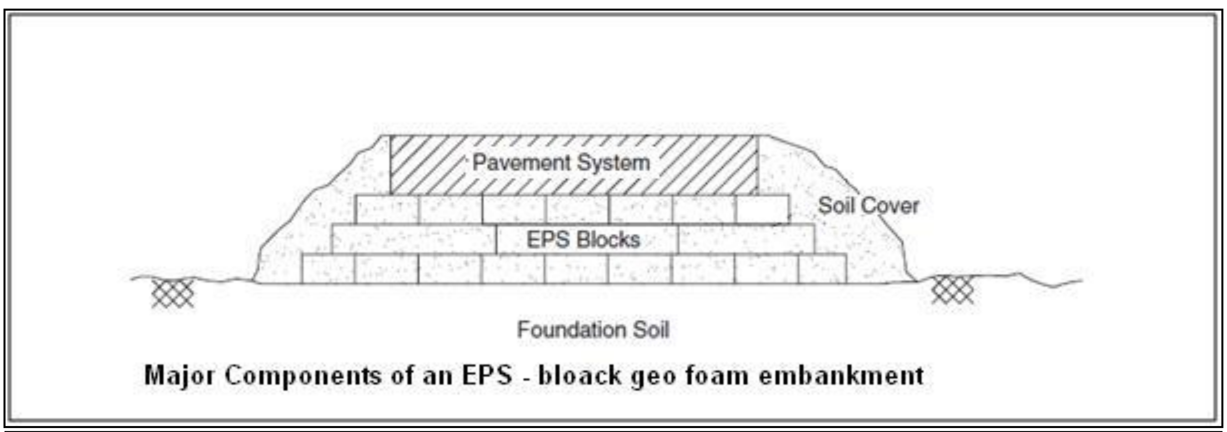


Figure 52: Embankment by Geofoam

Embankments (Figure 52) using Geofoam allow for a great reduction in necessary side slopes compared to typical fills. Reducing the side slope of the embankment can increase the usable space on either side. These embankments can also be built upon soils affected by differential settlement without being affected. Maintenance costs associated with Geofoam embankments are significantly lower when compared to embankments using natural soil.

Retaining Structures (Figure 53) using Geofoam have a reduction in lateral pressure as well as prevent settlement and improve water proofing. Geofoam light weight will reduce the lateral force on a retaining wall or abutment. It is important to install a draining system under the Geofoam to insure that you don't have problems with built up hydrostatic pressure or buoyancy.

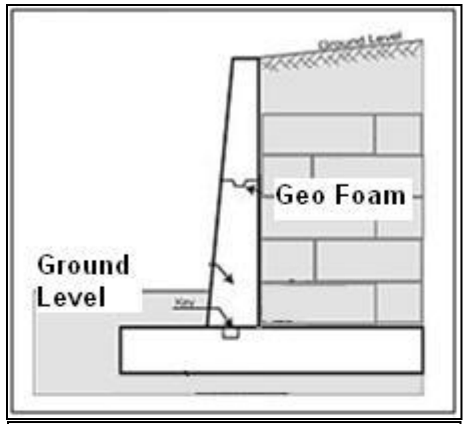


Figure 53: Geo foam used in retaining Structures

Utility Protection is possible by using Geofoam to reduce the vertical stresses on pipes and other sensitive utilities. Reducing the weight on top of a utility by using Geofoam instead of a typical soil prevents utilities from potential issues, such as collapses

Pavement Insulation is the use of Geofoam under pavement where pavement thickness can be controlled by frost heave conditions. Using Geofoam as a sub-grade insulation element will decrease this differential thickness. Geofoam is 98% air by volume, making it an effective thermal insulator. Proper installation of Geofoam is especially important as gaps between Geofoam blocks will work against Geofoam insulating effects.

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
GCL							

3.9.2 Installation

The following are the major steps in installation of Geofoam in Embankment application (Figure 54):

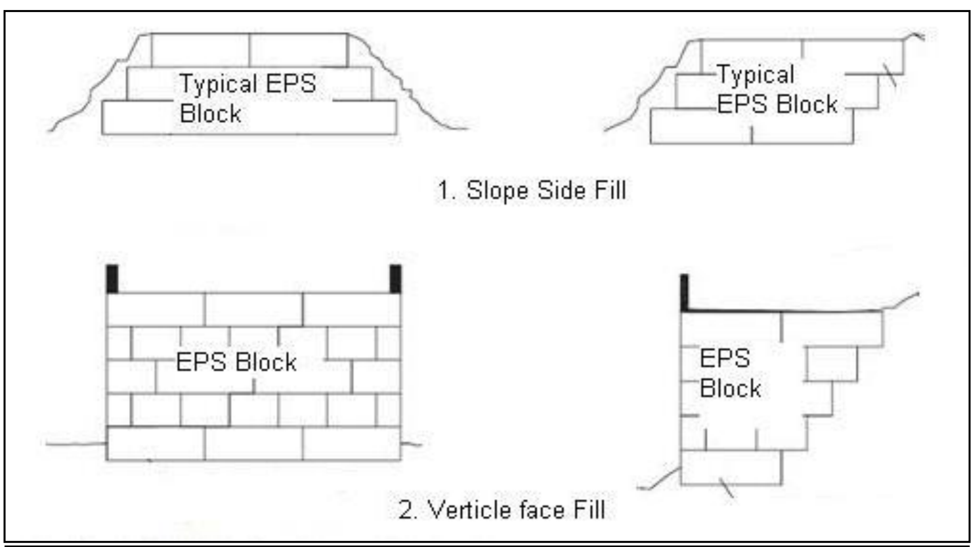


Figure 54: Instalment of Geofoam in Embankment

1. The existing foundation soil, which may or may not have undergone ground improvement prior to placement of the fill mass.
2. The proposed fill mass, which primarily consists of EPS block Geofoam, although some amount of soil fill is often used between the foundation soil and the bottom of the EPS blocks for overall economy. In addition, depending on whether the embankment has sloped sides (trapezoidal embankment) or vertical sides (vertical embankment), there is either soil or structural cover over the sides of the EPS blocks.
3. The proposed pavement system, which is defined as including all material layers, bound and unbound, placed above the EPS blocks. The uppermost pavement layer, which serves as the finished road surface, is usually either asphaltic concrete or Portland cement concrete (PCC) to provide a smooth traveling surface for motor vehicles. Asphalt concrete appears to be the predominant road surface type because asphalt concrete pavements tend to tolerate post construction settlements better than PCC pavements and because asphalt concrete pavements are less expensive. However, in certain applications (e.g., vehicle escape ramps in mountainous regions and logging roads), unbound gravel or crushed-rock surface layer may be used

3.10 Polymer Gabions

Polymer Gabions are rectangular or cylindrical baskets fabricated from polymer meshes and usually filled with stone and used for structural purposes such as retaining walls, revetments, slope protection and similar applications.

Gabions are sausages made of Polymer 3 strand ropes. These ropes are appropriately woven by a special process to fabricate the Gabions in various sizes

Figure 55: Polymer Gabions retaining wall

Gabions are generally available in a prefabricated collapsible form with the bottom & four sides held together by appropriate binding and with a flip open top lid. The border & body ropes may be of different sizes ranging from 6mm to 12mm. The sizes are selected depending upon the severity of the problem & the method of installation to be adopted

3.10.1 Applications

The following are the major applications of Polymer Gabions:

Retaining Walls

Polymer Rope Gabion walls can be built with speed and economy and are particularly suitable for landslide control in mountainous. In ground liable to subside, the capacity of Polymer Ropes gabions to deform makes them preferable to a concrete wall that would crack and collapse (Figure 55)

Energy Dissipaters

The pervious structure of Polymer Rope Gabions gives two advantages over impervious structures. First, when pounded by heavy masses of water, the impact, instead of being taken instantaneously, is gradually absorbed. Again, flexibility offers distinct advantages in coastal defenses. Huge sea walls can be constructed with high speed using these polymer Ropes gabions

Sea Wall and Revetments

Polymer Ropes Gabions walls are constructed to protect the seacoast or the River Coast against the erosion due to water and waves. Polymer Rope Gabions will withstand alternative tension and compression without losing structural passage of water throughout the structure. Also they are found to be more advantageous than other gabions in marine and river environment as they are inert to alkaline and acidic attack. They are mush reliable and long lasting than marine structures constructed using the dumping of stones. (Figure 56)

Figure 56: Polymer Gabion used in sea wall

Flexible Aprons

Designed to protect super-structures against the undermining action of river or sea water, Polymer Rope Gabion aprons will closely follow the changing contours of the bed as scouring progresses, until eventually the erosion is completely sealed off (Figure 57).

A Polymer Rope Gabion Dike or Wall

These structures are built to protect a particular area from erosion as well as to silt up the previously eroded areas. The dykes are also used for the protecting the harbors against the Built across the front of an eroded area will collect silt left behind by floodwaters. The silt gradually builds up until the required reclamation is met without any financial outlay.

Figure 57: Polymer Gabion used as Apron

Weirs

Polymer Rope Gabion weirs, check dams are constructed across water courses as grade control structures, sediment collectors, as well as to form water reservoirs. Polymer Rope Gabion weirs are normally provided with a Gabion scour protection apron both on their downstream side and at the upstream approach zone.

Soil Conservation

Polymer Rope Gabion are applied here as (a) terracing on steep slopes to retain the top soil, (b) linings for the beds and sides of water courses, (c) check dams for grade reducing weirs in steeply sloping gullies or valleys. (Figure 58)

Figure 58: Polymer gabion used for Soil Erosion

Advantages of Polymer Gabions:

a) Resistance to acidic & alkaline environments. Immune to rot, mildew
b) Flexile and can easily take the contours of the ground

c) No rusting hence long lasting in marine or river saline environment
d) No effect of water; non-biodegradable, dose not affect the marine environment and organisms
e) High tensile strength, high abrasion resistance, high thermal stability
f) Resistance to U.V. degradation
g) Very convenient for handling and placing
h) Can be filled in situ or filled and placed in position using cranes. Suitable for underwater construction

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Polymer Gabion							

3.10.2 Installations

Prepare the site where the gabions or mattresses are to be installed. The ground should be prepared to the correct lines and levels and be relatively smooth and flat. A geotextile should always be installed first under/behind gabions and under mattresses to prevent soil from being eroded from under/behind the structure in potential flow events. The prefabricated cages are then placed in the desired position on site. Adjacent cages shall be joined together to form one monolithic structure. It may be advisable that where additional gabion or mattress units need to adjoin a previous section of work that has been rock filled, that the last gabion or mattress compartment is left empty of rock to assist in lacing the new section to the completed section

3.11 Geobags

Geobags are sand-filled high-strength geotextile bags available in the various sizes and are used in riverbank, beach protection and offshore breakwater (Figure 59).

Figure 59: Geo bags

Geobags are also called as Geotextile Sand Containers (GSC) which is a low cost, soft and reversible solution for shore protection structures and for the reinforcement of existing coastal barriers and structures (Figure 60). Due to their numerous strengths (see Table 2), the GSCs become increasingly popular as an alternative to conventional hard structures. Nevertheless, the GSC is still an emerging technology and there are no proper guidelines available yet for the design of GSC structures.

Figure 60: Coastal Structure made of Geobags

3.11.1 Applications

The following are the major applications of Geobags:

a) Coast and beach protection

b) Water protections

c) Levelling water channel

Figure 61: Geobags application in water levelling

Figure 62: Geobags in coastal protection

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geobags							

Strength and Weakness of GeoBags (GSC)

Strength / weakness	Conventional Hard Structures	GSC-Structures
Applicability as a coastal structure to conventional coastal problems	high	high
Resistance against wave action and coastal related natural hazards, if properly designed.	high	high
Adaptability to changing site conditions and morphological foundation changes.	low	high
Total construction and life cycle **cost savings** (compared with conventional structures)	N/A	high
Respond to cyclic hydrodynamic loads	moderate	high
Pleasant and **"natural" appearance**	low	high
Removability, if engineering measures did not prove successful	low	high
Deep understanding of the hydraulic processes affecting the stability of GSC-structures	high	moderate
Reliable design tools which can compromise the safety under different conditions	high	low
Requirement of **consideration of site specific conditions** for design and construction	moderate	high
Understanding of long term effect on structural durability in marine environment	high	low

3.11.2 Installation

Geo bags are PVC based bags which are sand filled. The Geo bags are lifted by cranes and filled with the sand with the help of automated mechanical spades. (Figure 63)

Figure 63: Filling of Geo bags

The installation process is generally consists of following steps:

a) **Site Preparation**

The site shall be prepared and graded to the designer's requirements. Unsuitable soil must be cleared from the slope and sharp objects ie stumps, boulders or construction material that can puncture the geotextile shall be removed from the

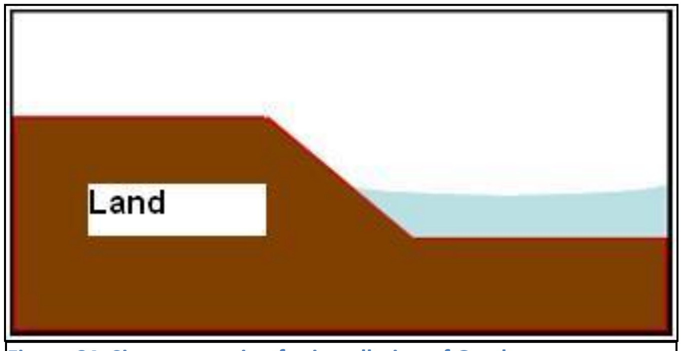


Figure 64: Site preparation for installation of Geo bags

area. Depression holes in the area should be filled to avoid geotextile bridging possible tearing when GeoBag are placed (Figure 64)

b) **Prefabricating of GeoBag**

Geotextile shall be prefabricated using "J" SSn-2 seam (Figure 65). A proper sewing equipment must be used either handheld sewing machine or double needle stitch sewing machine for the geobag fabrication. The manufacturer shall furnish type of thread, detail on method of sewing and the required overlap which fulfils the minimum physical properties. (Figure 66) The sewing must be monitored by the engineer on site.

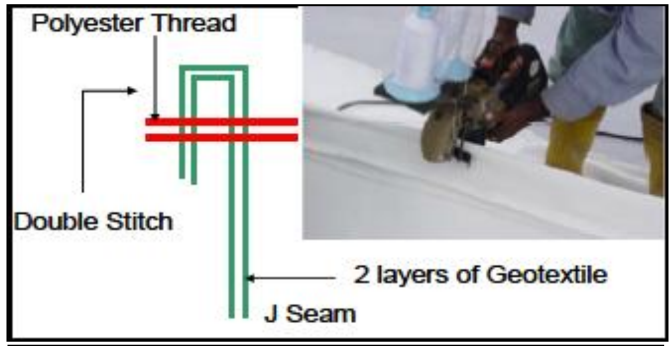


Figure 65: J seam for Stitching geo Bags

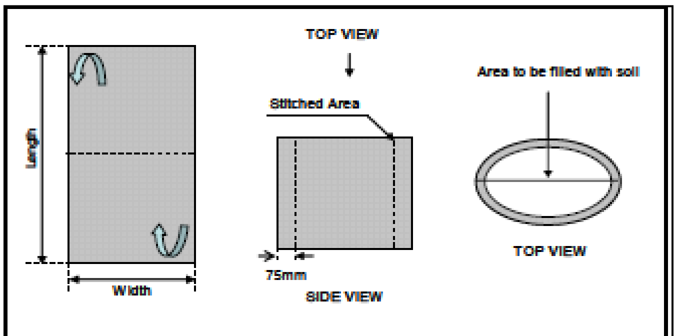


Figure 68: Top, side and front view of a geo bag

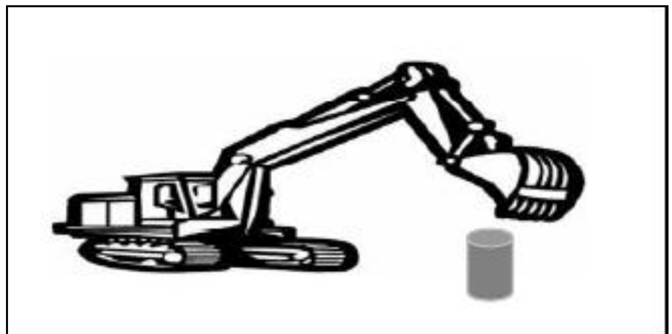


Figure 67: Filling the geo bag

c) **Filling the GeoBag with Suitable Material (or dredged material)**

The prefabricated Geo Bag shall be filled with suitable material (preferably sand) and the top cover shall be stitched to close the opening. (Figure 67)

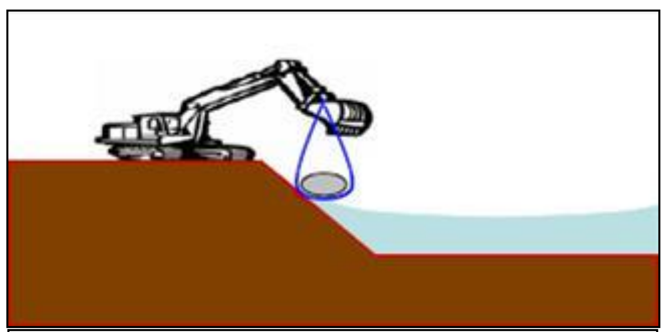


Figure 66: Deploying Geo bag

d) **Deploying the Geo Bag**

The geobag shall be deployed, positioned and secured in proper position without causing any damage to the geobag. (Figure 68)

e) **Completion and backfilling**

Upon completion of the Geobag installation, the area shall be backfilled and compacted to the required specification (Figure 69 and 70)

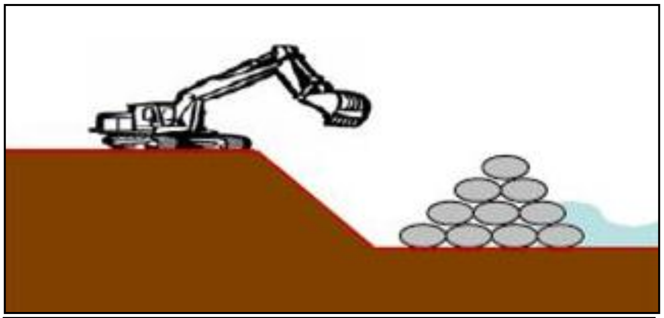


Figure 70: Arranging the geo bags

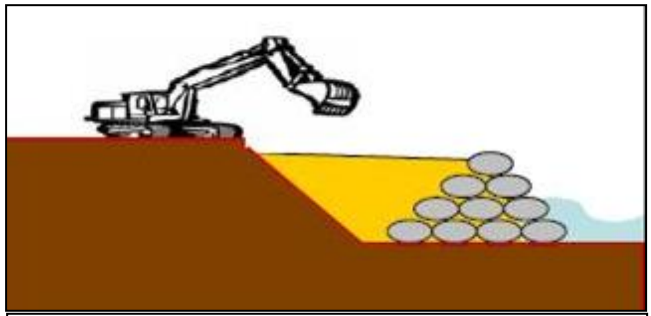


Figure 69: Back filling to make the hard surface

3.12 Geotextile Tubes

Geotextile tubes are large tube like structures fabricated from high strength geotextile with soil-in-fills (Figure 71). Geotextile tube is formed in situ by the hydraulic pumping of local soil into the prefabricated geotextile tube. This leads to a flexible, monolithic, continuous structure that is highly resistant to water currents. Sand is widely used as the soil in-fill material because of its low compressibility but other hydraulically pumped soil types can be used. Geotextile tubes are normally characterized in terms of theoretical diameter.

Figure 71: Geo textile Tube

Advantages

- The geotextile used to make geotextile tubes and bags has fine pore sizes to enable retention of the soil-infill but also has high permeability to enable easy exit of water during the hydraulic filling stage
- The geotextile has high tensile strength to enable it to resist the tensile stresses occurring during hydraulic filling and maintain its structure shape

3.12.1 Applications

Fighting and taming the ferocious power of water has always been the daunting task for human being. Geo tubes provide effective solution to coastal and river water problem and can be used to stop storm damage, protect the environment, build customs structure and even create new island. Following are the major areas where geo tubes find their applications:

Figure 72: Geotubes at river

a) Construction of groynes, breakwaters, dykes
b) Dewatering
c) Shore protection
d) Bed and bank protection
e) Scour protection

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geotextile Tubes							

3.12.2 Installation

Following are the major steps of using and installing the Geo tubes

Step 1: Conditioning

Once it has been determined what type of fabric suits the job better, the sludge should be conditioned prior to be deposited on the tubes. The conditioning could be as simple as just pumping the sludge as it sits in the reservoir, or as complex as to add different types of chemicals to help the solids consolidate and separate from the water (Figure 73)

Figure 73: Conditioning of Sludge

Step2: Filling

The sludge is then pumped into the tubes. This can be done with high pressure pumps (Figure 74)

Figure 74: Pumping and filling the sludge into tubes

Step 3: Dewatering

Once the different sections of the tube have been filled, the tube is left alone for a period of time until it has dewatered enough so that more sludge can be pumped into it. The refilling can be done as many times as necessary. (Figure 75 and 76)

Figure 75: Water coming out from Geo Tubes

Figure 77: Dewatering the geo tubes

Step 4: Disposal

Once it has been determined that the dewatering process has accomplished the desired goal the tubes can be cut open and the solids can be appropriately disposed off. (Figure 77)

Figure 76: Cutting of geo tube for disposal of sand

3.13 Geomats

Geomats are three-dimensional water permeable polymer or other synthetical materials' structures, thermally jointed with each other. These synthetic material filaments (typically polyamide and polypropylene but not always) are tangled together to form a high deformable layer of 10-20 mm thickness, featuring very high porosity (greater than 90% on average).


Figure 78: Geomat

Geomats are applied to create stable vegetation along river, pond banks and slopes to prevent erosion processes of surfaces. Geomats in form of stereoscopic honeycomb constructions are used in combination with geotextiles to reinforce foundations and increase bearing resistance.

Advantages
As nature itself does not have efficient means for erosion control, application of polymer anti-erosion mats is an efficient solution. Geomat is a light flexible material, an alternative to massive and ecologically-unfriendly concrete, stone or asphalt constructions. Application of bulky geomats due to reinforcement of root system provides with long-lasting and permanent erosion control of river and lake banks, slope and dikes, surfaces in flooded areas.

Due to open surface and strip hardness geomat can be easily filled with soil all over its area and depth, resistant to chemical and biological impact of natural origin, UV resistant, which guarantees long lifespan of the material.

Geomats are resistant to adverse environmental effects. Open surface encourages root germination, quick vegetation of slopes and thus guarantees erosion control. Geomats protect slopes and horizontal surfaces notwithstanding the soil foundation. At right choice of the material and observation of assembling technique rules erosion damages can be eliminated even on difficult areas and steep slopes.

3.13.1 Applications
The main applications of Geomats are:
a) Protection from hydro erosion, eolation and landslides in road construction;
b) Reinforcement of slopes, banks, collecting gutters, subgrades;
c) Construction of platforms with natural vegetation;
d) Reinforcement of coast line;
e) Landscaping

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geomats							

3.13.2 Installation

Site Preparation

For both slope and channel applications, prepare the site to the design specifications (grade, geometry, soil compaction, etc.). The area should then be dressed to be free of soil clods, roots, stones or vehicle imprints of any significant size. Any voids should be filled in order to obtain a smooth and compact laying surface allowing the Geomat to fit flush against the ground surface contours.

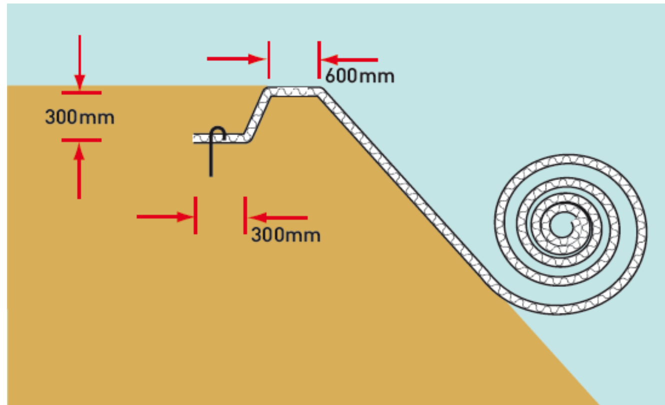


Figure 79: Geomat being rolled down slope/channel

Installation

Excavate Anchor Trenches - Anchor trenches are required to securely fasten the Geomat to the ground surface. For a slope application, anchorage at the crest can typically be provided by excavating a trench at least 600mm beyond the crest of the slope. The anchor trench should be at least 300mm wide and 300mm deep.

Note: Anchor trench details will vary depending upon application, soil type, slope or channel slope geometry, etc.

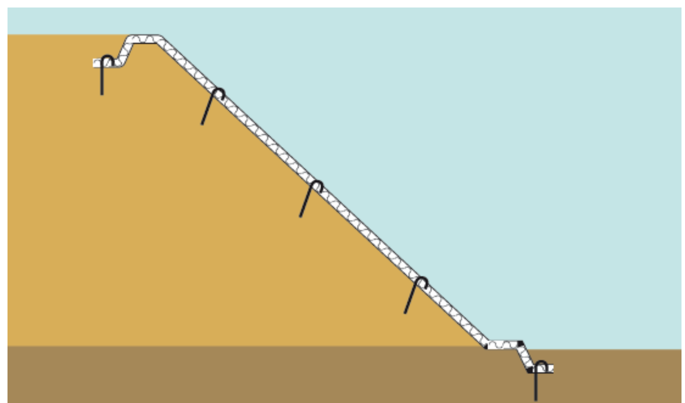


Figure 80: Geomat anchored at top and bottom and securely fastened along its length

The Geomat is installed into the trench and fastened at the bottom of the trench with 'U' shaped pins/ staples (Min. 8mm diameter and typically 150-300mm in length depending on consistency of the sub-grade) a maximum of 1metre apart along the trench.

The anchor trenches are then backfilled and compacted in a manner that does not damage the Geomat. Unrolling of the geomat and filling of it on the slope can only be carried out after the Geomat is anchored on the crest.

Geomat Placement

Once anchored, deploy the Geomat by rolling down the slope or channel. Overlaps (edge to edge) between rolls should not be less than 100mm. The end to end detail between rolls should be overlapped in a tile manner and not be less than 750mm. All overlapping areas of the geomat should be in the direction of water flow.

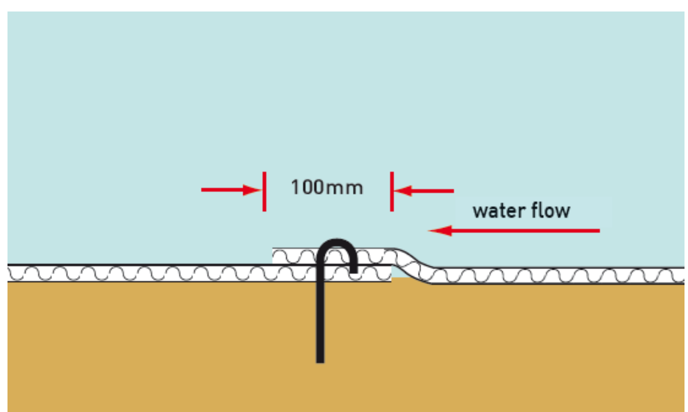


Figure 81: Fastening overlap between rolls

Always securely fasten to the ground the edges of the Geomat and overlaps at intervals of 1-2m with 'U' shaped pins/staples (depending on geometry of the slope or channel). Securely fasten down the centre of each roll staggering centreline fasteners between the outside fasteners.

Always lay Geomat so that contact with the soil is maintained at all times. After the Geomat is installed, go back over the Geomat and install additional fasteners as required to ensure the Geomat is in intimate contact with the soil.

Filling Geomat
Infilling can be performed manually or carried out using mechanical plant.

3.14 Geopipes

Geopipes are polymeric pipes used for transmission of liquid or drainage of liquids or gas (including leachate or gas collection in landfill applications). Advanced extrusion and seaming processes have led to different type of pipe wall forms such as ribs, cores, corrugated profiles. Additionally, especially for drainage purposes these Geopipes may contains holes, slots or perforations to allow for the inflow of liquid. In some cases the perforated pipe is wrapped with a geotextile filter.

Figure 82: Geopipes

Advantages
Geopipes of the nature described above are being used increasingly as they offer many advantages:

- Low in initial cost
- Lightweight
- Ease of installtion
- Ease of joining together
- Excellent flow regime
- Excellent durability

3.14.1 Applications

Solid-wall and profile-wall plastic pipe are used in a wide variety of civil engineering applications. Some that come to mind follow:

a) Highway and railway edge drains and seepage drains in tunnels.
b) Pore water drains behind retaining walls.
c) Pipes used in dewatering projects.
d) Fluid transmission lines by gravity or pressure.
e) Wastewater drainage systems.
f) Piping in leach fields of various types.
g) Primary and secondary leachate removal systems.
h) Surface water removal systems in landfill covers.
i) Dredging pipelines.

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Geotextile Tubes							

3.14.2 Installation

This section describes installation of Geopipes for leachate collection applications for which they are most commonly used.

Subgrade Preparation

The Geopipe is usually placed in a prepared trench or within other prepared subgrade materials. If soil is the subgrade then the compaction should be 95% of Standard Proctor compaction so as to minimize the deformation of the pipe while it is in service. Sufficient trench length should be available so that pipe laying can continue in uniform manner.

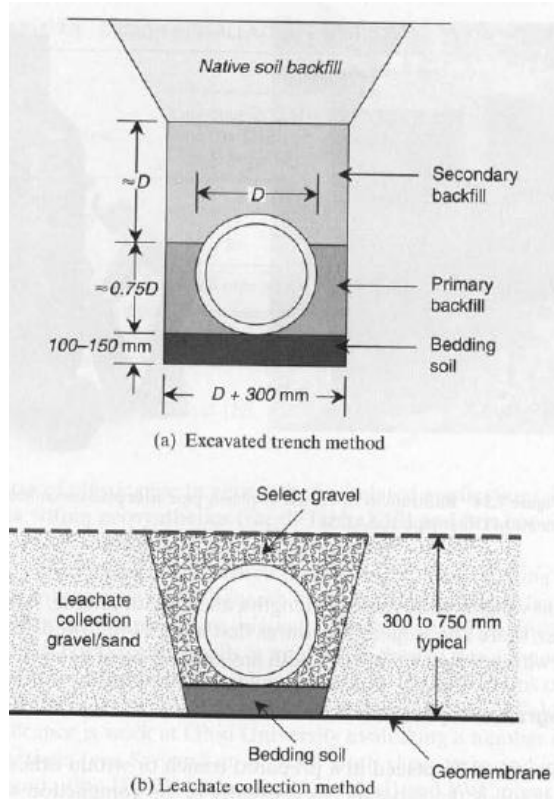


Figure 83: Geopipes

Note that various organizations have guides or practices relating to underground installation methods for plastic pipe such as:

- ASTM D2774 – Underground installation of thermoplastic pressure piping
- ASTM F481 – Standards practice for installation of thermoplastic pipe and fittings
- AWWA M23 – PVC pipe design and installation
- PPI TR8 – Installation procedures for polyethylene plastic pipe
- PPI TR31 – Underground installation of polyolefin piping

Connectors

There are a number of methods used to connect the ends of Geopipes together.

- *Butt Welding* – Used for thick walled Geopipes (either solid or perforated) where the ends of the pipe are properly aligned with a heated plate placed between them. A longitudinal force brings the ends of each pipe against opposite sides of the heat plate. When adequate thermal energy is generated the pipe ends become viscous and the heath plate is then removed with the ends brought together to fuse them. *Electric socket welding is similar*, as is the welding of PVC pipes using chemical solvents.
- *Screw Connection* – This is only used when the pipe thickness is adequate to form or machine the pipe ends to accept one another.
- *Sleeve Couplings* – These are used to connect the ends of all profiled wall pipes and some solid wall pipes where the couplings are mated to the type of pipe for which they were designed for.

Placement
The placement of plastic pipe in a prepared trench, after it has been seamed into an essentially continuous length is very rapid and straightforward. The major consideration to be addressed is the ambient temperature which results in contraction/expansion if not monitored.

Backfilling Operations
The backfilling of plastic pipe is performed in stages. The primary backfill is usually a granular soil with adequate fines to provide good placement stability. If soil is not placed beneath the pipe, voids will result and when loaded the pipe will deform into these voids. Conversely compaction will lift the pipe off the subgrade and destroy the elevation control. Care also has to be taken to not push pipe laterally out of alignment. Cavalier dumping of backfill soil adjacent to and above the pipe is not advisable as any oversized material pinging against the pipe will lead to abnormal stress concentration.

Secondary backfill provides support and load transfer to the top of the pipe and support for the subsequent backing operation. The thickness of this layer should be at least one-half the diameter of the pipe itself and preferably equal to the diameter.
Following placement of the secondary backfill, natural soil or the soil or solid waste being used to construct the facility is brought up to the final grade in lifts, as per plans and specifications.

3.15 Natural Fibre/Jute Geotextile

Jute Plant and its fibres
Jute plants are grown mostly in the gangetic delta in the eastern part of the Indian subcontinent. People consume its leaves as a vegetable and also it's a household herbal remedy. Its potential as an important natural fibre-source was a subsequent find. The use of jute fibres is on sudden rise since the middle of the nineteenth century. This led to improvement in its method of cultivation and extraction of fibres followed by manufacture of fabrics with its yarns.


Figure 84: Jute Plant

Jute plant has an erect stalk with leaves. It thrives in hot and humid climate, especially in areas where rainfall is in plenty. It grows up to about three meters in height and matures within four to six months. In China, taller Jute plants are being cultivated resulting in higher fibre production (Figure 84).

Jute has coarse natural bast fibres lying in the peripheral layer of its stem. It belongs to the genus Corchorus. There are over 30 species of this genus out of which C. Capsularis (known as White Jute) and C. Olitorius (known as Tossa Jute) are utilized for production of fibres. The fibres are extracted from the stem of the plant by a special process known as *retting.* Retting usually consists of tying the plants in bundles and immersing them in slowly flowing or stagnant water for about 2 to 3 weeks. The process of wetting makes fibre extraction easy from jute stem as it softens and dissolves the sticky substances, especially pectin. Extraction is done manually followed by washing and drying, to make the fibres suitable for commercial use. Jute research outfits are persistently endeavouring to improve retting methods.

Composition of Jute

The chemical composition of jute is as follows:

S.No	Name of Chemical	Composition in Jute
1	a-cellulose	59-61%
2	Hemicellulose	22-24%
3	Lignin	12-14%
4	Fats & Waxes	1-1.4%
5	Nitrogenous matter	1.6 – 1.9%
6	Ash Content	0.5 – 0.8%
7	Pectin	0.2 – 0.5%

Table 3: Chemical Composition in Jute

Physical properties of Jute

The average linear density of single jute filament lies between 1.3-2.6 tex for white jute and 1.8-4.0 tex for tossa jute with normal distribution. Coarseness of jute has some role in determining the strength of jute fibre. Coarse fibres are usually stronger.

Jute fibres are usually strong with low extensibility. It has a tenacity range of 4.2 to 6.3 g/ denier, depending on the length of the fibre. Elongation-at-break of jute fibres is between 1.0% and 1.8%. Tossa jute is stronger than white jute. Jute fibre breaks within elastic limit and is resilient which is evident from its recovery to the extent of 75% even when strained quite a bit (1.5%). Its flexural and torsional rigidity are high compared to cotton and wool.

Presence of hemicellulose in jute fibres makes it hygroscopic, second only to wool. Tossa jute is slightly more hygroscopic than white jute. Jute fibres swell on absorption of water.

Lateral (cross sectional) swelling of jute fibres (about 45%) far exceeds its longitudinal swelling (0.4%). During the process of addition of water, tenacity of jute fibres increases at the initial stages up to the relative humidity of 20%, does not vary for most of the period of water addition thereafter, but exhibits a downward trend when the relative humidity exceeds 80% or so. This phenomenon implies decrease in flexural and torsional rigidity of jute fibres when moisture absorption exceeds a limit.

Jute is not thermoplastic like other natural fibres. Charring and burning of jute fibres without melting is a feature of jute fibres. Due to high specific heat, jute possesses thermal insulation properties. Ignition temperature of jute is of the order of 193° C. Long exposure of jute fibres to hot ambience reduces the fibre strength.

Dry jute is a good resistant to electricity, but it loses its property of electrical resistance appreciably when moist. Dielectric constant of jute is 2.8 KHz when dry, 2.4 KHz at 65% RH and 3.6 KHz at 100% RH.

Co-efficient of friction of Jute fibres is usually 0.54 for white jute and 0.45 for Tossa variety.
Moisture content in jute helps increase its frictional property.

Jute Geotextile

Jute Geotextiles constitute a group of fabrics made from natural fibres, including cotton, jute, coir and bamboo which find wide application in all kinds of geotechnical constructions. The major functions of jute geotextiles in engineering applications are alike synthetic geotextile but some major have been identified as separation, reinforcement, drainage and filtration. Some of these functions, e.g., drainage and filtration are primarily dependent on the properties of the geotextile itself without having any predominant dependence on the geo morphological features of the area. The other functions, e.g., separation and reinforcement are dependent on the nature of the subsoil in so far as the strength and deformation characteristics of the subsoil become important in determining their suitability in a given situation.

In separation and reinforcement functions of geotextiles the major consideration that determines the effectiveness of geotextiles is the permissible deformation. For geotextiles to be effective in reinforcement of the soil, sufficient deformation has to be allowed so as to enable the tensile strength of the fabric to come into play. This makes them particularly suitable in soft clay deposits which are by nature susceptible to large deformation.

3.15.1 Applications of Jute Geotextile

The main functions of jute geotextiles make them suitable for application to many practical problems. Some of these applications are:

a) Temporary roads and yards
b) Permanent roads
c) Repair of permanent roads
d) Railway tracks
e) Embankments in soft ground
f) Retaining walls, and
g) Erosion control

Geosynthetics have been used extensively in recent years in various construction works in India. These materials are highly resistant to biological and chemical degradation and have sufficient tensile strength and permeability for direct ground treatment applications. Geotextiles made out of natural fibres, e.g., jute geotextiles, have got high permeability but they are biodegradable and possess less tensile strength, in general. Therefore they have not been promoted as widely as geosynthetics. Consequently their application, so far, has been on a limited scale

Some other applications:

a) It arrests migration of soil particles and allows water to permeate across it. Thus, it also acts as a drainage layer along its plain. Jute can be tailor-made to cater to the requirements of porometry, permittivity and transmittivity. It enhances CBR-value.
b) Jute geotextile provides effective drainage system when used as peripheral cover in trench drains, especially in hilly terrains.
c) Vertical fibre drains, help drain out entrapped water from within an embankment. Jute has widespread application in ground improvement with vertical drains.

Type of Geosynthetic (GS)	Separation	Reinforcement	Filtration	Drainage	Containment	Protection	Erosion Control
Natural Fibre Geosynthetics							

3.15.2 Installation

Jute geotextile is yet to have wide acceptance in civil engineering applications in India. However they finds reasonable use in railway construction, embankments and retaining walls, erosion control and drainage.

Some of these uses in India are highlighted below.

Temporary Roads

Most construction sites require access to the site through weak surface deposits. Temporary roads are built by spreading a carpet of coarse granular material (stone metal) over the soft subgrade to act as a load dispersing medium which keeps the stresses on subgrade low.

However, extensive rutting occurs on the surface due to the granular fill getting lost into the soft subgrade under continuous pressure from the moving vehicles. This gives rise to perennial maintenance problems. The problems can be minimised, if not overcome, by providing a suitable layer of jute geotextile at the interface of the granular fill and the subgrade. This controls subsidence of a pavement by separating and preventing intermixing of the soft sub-grade and the harder sub-base

Permanent Roads

Jute geotextile in a permanent road allows reduction in the thickness of the pavement on a soft subgrade by the reinforcement action of jute geotextiles and also gives less maintenance problems for long-term use. It prevents stagnation of water below the subgrade and allows free drainage of water into the side drains. It prevents the subgrade from getting softened due to ingress of water. When placed in the bituminous surface layer, jute geotextiles prevent reflective cracking of the road surface. Strips of fabric are placed at the crack location on a V-shaped groove filled with a bituminous tack coat. Firm contact of the jute along with tack coat is made using a heavy roller. This control reflective cracking of pavements and prolong their fatigue life when used in asphaltic overlays Observations had showed that cracks appeared within six months in areas where there was no jute while, in the treated area cracks began to appear only after two years - that too on a very minor scale.

Railway Tracks

Railway tracks are supported on a layer of ballast which disperses the load into the subgrade soil. The ballast continuously penetrates into the soft subgrade and requires regular replenishment in the same way as the pavement in the soft subgrade does. Jute geotextiles may be used to separate the ballast and the subgrade soil both in new construction and in strengthening jobs.

Embankments and Retaining Walls

The reinforcing effect of jute geotextile is used more effectively in construction of embankments and retaining walls in soft soil. With use of jute geotextile in horizontal layers within the fill and at the base it is possible to have a steeper side slope and savings can be affected by a reduction of filling in the embankment. This happens because Jute enhances the strength and stability of road embankment built with materials of uncertain behaviour like PFA, when interposed at appropriate levels. It also keeps lateral dispersion, subsidence and slides (slip circle failures) under check. More importantly, in urban areas, economy is achieved by reducing the land coverage on either side of the embankment. The usual procedure of slope stability analysis by the limit equilibrium methods is applicable to design, taking into account the tension capacity of the fabric.

Erosion Control

Jute geotextile may be used for river bank protection, as an alternative to the granular filter, below the rip-rap on the sloping sides of the bed to be protected from erosion. Construction is fast and is often cheaper than granular filter. Grouted mattresses made with jute geotextiles are also used to replace stone walls where boulder is difficult to obtain.

Slopes of embankments with problematic soil may be stabilised by applying jute geotextile to help grow vegetation faster and anchor soil for a permanent solution

4 Geosynthetics in Roads and Pavements

4.1 Introduction

A large variety of detrimental factors affect the service life of roads and pavements including environmental factors, subgrade conditions, traffic loading, utility cuts, road widenings, and aging. These factors contribute to an equally wide variety of pavement conditions and problems which must be addressed in the maintenance or rehabilitation of the pavements, if not dealt with during initial construction.

Pavement maintenance treatments are often ineffective and short lived due to their inability to both treat the cause of the problems and renew the existing pavement condition. The main cause of distress in pavements is that they are quite permeable with 30 to 50% of precipitation surface water infiltrating through the pavement, softening and weakening the pavement subgrade and base, accelerating pavement degradation. Existing pavement distress such as surface cracks, rocking joints, and subgrade failures cause the rapid reflection of cracking up through the maintenance treatment

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 road base aggregate without preventing efficient drainage of infiltrated water; and, as a last resort, enhancing the stress absorption and moisture proofing capabilities of selected maintenance treatments. Geosynthetics have proven to be cost effective tools for safeguarding roads and pavements in these ways

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

Subgrade separation and stabilization applies geosynthetics to unpaved roads although geosynthetics may be used as separators in paved roads as well. Base reinforcement is the use of geosynthetics to improve the structure of a paved road.

Geosynthetics are also helpful in rehabilitating distressed road surfaces. The application of a layer of asphalt called an overlay is often the solution for damaged pavement. Geosynthetics can be used as interlayers by placing them below or within the overlay. Some geosynthetics relieve stress and others are able to reinforce the overlay.

Though only widely recognized since the latter half of the 1900s, these advantages were initially demonstrated as early as the 1930's using conventional textile materials.

4.2 Subgrade Separation and Stabilization and Base Reinforcement

4.2.1 Subgrade Separation & Stabilization

Contextual Situation

Temporary roads used for hauling and access roads that are subject to low volumes of traffic are often constructed without asphalt or cement concrete surfacing. In these cases, a layer of aggregate is placed on the prepared subgrade of these roads to improve their load carrying capacity. Problems are usually encountered when the subgrade consists of soft clays, silts and organic soils (Figure 85). This type of subgrade is often unable to adequately support traffic loads and must be improved

Figure 85 Roads having Soft clay, silts and organic soil

Typical Solutions

Excavating and replacing unsuitable materials is costly and time consuming. Other methods of subgrade improvement include deep compaction, chemical stabilization and preloading

The Geosynthetic Solution

Geosynthetics are proving to be a cost effective alternative to traditional road construction methods. As a result, the application of geosynthetics to the construction of unpaved roads over soft subsoils has become quite popular. Design has focused on the reinforcement of the aggregate and has led to the identification of two important functions: *lateral restraint and membrane action*. Lateral restraint is the lateral interaction between the aggregate and the geosynthetic. The presence of the geosynthetic creates pressure in the aggregate that improves the strength and stiffness of the road structure. Membrane action is the ability of a geosynthetic material to reduce and spread stress arising from the weak subgrade. Additionally, when a Geogrid is involved, a third function can be described: enhanced load distribution within the aggregate (Figure 86). Crucially, the use of geosynthetics leads to reduction of subgrade thickness by upto 30% which leads to huge savings in granular material.

Separation

At small rut depth, the strain in the geosynthetic is also small. In this case, the geosynthetic only acts as a separation between the soft subgrade and the aggregate. Any geosynthetic that survives construction will work as a separator

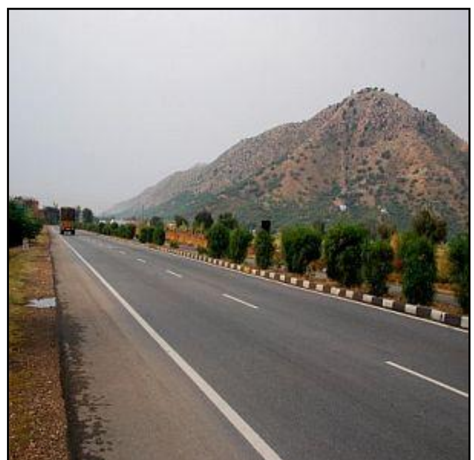


Figure 86: A Geosynthetic Road Application

Stabilization

For larger rut depths, more strain is induced in the geosynthetic. Thus the stiffness properties of the geosynthetic are essential. A considerable reduction in aggregate thickness is possible by the use of a geosynthetic that has a high modulus in the direction perpendicular to the road centerline; however, the benefits of the geosynthetic are not wholly dependent on the membrane action achieved with a stiff geosynthetic. Lateral restraint produced by the interaction between the geosynthetic and the aggregate is equally important. In general, the following conclusions can be drawn relating to a 12 inch base

- A reinforcement element that functions primarily as a separator but relatively little as reinforcement will provide a load distribution improvement ratio in the range of 1.1 to 1.4. (separation geotextiles)

- A reinforcement element that functions primarily as reinforcement but relatively little as separator will provide a load distribution improvement ratio in the range of 1.7 to 2.2. (stabilization geogrids)
- A reinforcement element that functions both as a separator and as reinforcement will provide a load distribution improvement ratio in the range of 2.0 to 2.5. (separation geotextile + stabilization geogrid or stabilization geotextile) (Figure 87)

Figure 87: Geo textile used in stabilization of roads

Design for Stabilization

The design of geosynthetic-reinforced unpaved roadways has been simplified into design charts that relate aggregate thickness requirements to a range of subgrade strengths, based on standard highway design loading and various allowable rut depths

4.2.2 Base reinforcement

Contextual Situation

Permanent roads carry larger traffic volumes and typically have asphalt or cement concrete surfacing over a base layer of aggregate. The combined surface and base layers act together to support and distribute traffic loading to the subgrade. Problems are usually encountered when the subgrade consists of soft clays, silts and organic soils. This type of subgrade is often unable to adequately support traffic loads and must be improved. If unimproved subgrade will worsen as a result of penetration of the aggregate into the subgrade and an increase in the subgrade's moisture content (Figure 88)

Figure 88: Poor Road because of moisture and poor subgrade

Typical Solutions

As with unpaved roads, a problematic subgrade is typically excavated and replaced, or it is improved by the addition of cement, lime, or excess aggregate. In any case, the traditional solution is often costly and always time consuming.

The Geosynthetic Solution

As was noted earlier, geosynthetics are proving to be a cost effective alternative to traditional road construction methods. In paved roads, lateral restraint also called confinement is considered to be the primary function of the geosynthetic. With the addition of an appropriate geosynthetic, the Soil-Geosynthetic- Aggregate (SGA) system gains stiffness. The stiffened SGA system is better able to provide the following structural benefits:

- Preventing lateral spreading of the base
- Increasing confinement and thus stiffness of the base
- Improving vertical stress distribution on the subgrade
- Reducing shear stress in the subgrade

Figure 89: Geogrid base reinforcement stiffens the aggregate base layer providing long term support

Geosynthetic Benefits
To have in-depth understanding of geosynthetic base reinforcement; the determination of a Traffic Benefit Ratio (TBR) should act as the "measure" of base course reinforcement performance. The TBR relates the ratio of reinforced load cycles to failure (excessive rutting) to the number of cycles that cause failure of an unreinforced road section. In general, geogrids have been found to provide a TBR in the range of 1.5 to 70 while geotextiles have provided TBRs in the range of 1.5 to 10.

4.2.3 Installation Process for Subgrade Separation and Stabilization, and Base Reinforcement

Site Preparation
Clear and grade the installation area. Remove all sharp objects and large stones. Cut trees and shrubs flush with the subgrade. Removal of topsoil and vegetation mat is not necessary.


Figure 90: Water graded subgrade can be graded when dry

Any soft spots or low areas are unsuitable for geosynthetic installation. Excavate these areas, backfill with select material, and compact so that the filled area provides equal stability as adjacent areas. The problem area may be enhanced by using a geosynthetic at the bottom of the excavation prior to backfilling (Figure 90).

Deployment of the Geosynthetic
Unroll the geosynthetic on the prepared subgrade in the direction of construction traffic. Hold the geosynthetic in place with pins, staples, fill material or rocks. Adjacent rolls should overlap in the direction of the construction. Depending on the strength of the subgrade, the overlaps may have to be sewn

Overlap Specifications

Soil Strength (CBR)	Overlap Unsewn (in.)	Overlap Sewn (in.)
Less than 1	-	9
1-2	38	8
2-3	30	3
3 & Above	24	-

Placement of the Aggregate
Place the aggregate by back dumping on to the geosynthetic or by end dumping onto previously placed aggregate and then spreading it on to the geosynthetic with a motor grader or bulldozer. On subgrades having a CBR < 1, a sufficient layer of aggregate must be maintained beneath all equipment while dumping and spreading to minimize the potential of localized subgrade failure.(Figure 91)


Figure 91: Aggregate Spreading

Avoid traffic directly on the geosynthetic. When using construction equipment on the aggregate, try to avoid any sudden stops, starts or sharp turns.

Maintain a minimum lift thickness of six inches except in cases of low volume roads. Smooth the aggregate to the specified density using a drum roller. Fill any ruts with additional subbase and compact as specified. (Figure 92)

Figure 92: Aggregate Compaction

Normal construction activities, including aggregate spreading and compaction are used. Caution should be used when selecting compaction equipment. When thin lifts are used, vibratory compaction is not recommended. Use of such equipment may result in damage to the geosynthetic.

Damage Repair

Repair damaged geosynthetics immediately. Clear the damaged area and an additional three feet around it of all fill material. Cover the cleared area with a piece of the geosynthetic extending. The patch should extend three feet beyond the perimeter of damage. Replace the aggregate and compact to the specified density.(Figure 93).

Figure 93: Damage repair

4.3 Overlay Stress Absorption and Base Reinforcement

4.3.1 Overlay stress absorption

Contextual Situation

Road surfaces must be maintained regularly. Commonly a paved road becomes a candidate for maintenance when its surface shows significant cracks and potholes. The rehabilitation of cracked roads by simple overlaying is rarely a durable solution. The cracks under the overlay rapidly propagate through to the new surface. This phenomenon is called reflective cracking.(Figure 94)

Figure 94: Typical cracked road

Cracks in the pavement surface cause numerous problems, including:

- Riding discomfort for the users
- Reduction of safety
- Infiltration of water and subsequent reduction of the bearing capacity of the subgrade
- Pumping of soil particles through the crack
- Progressive degradation of the road structure in the vicinity of the cracks due to stress concentrations

Typical Solutions

In spite of reflective cracking, overlays are still the only viable option for extending the life of distressed pavement. To lengthen the lifetime of an overlay, special asphalt mixes can be specified. Also, the thicker the overlay the longer it will last. Thick overlays are expensive as are special asphalt mixes, but the alternative is reconstruction. Depending on the cause of the problem, this can involve removing layers of pavement, improving subgrades, and repaving. This is extraordinarily expensive and time consuming.

The Geosynthetic Solution
A geosynthetic interlayer can be placed over the distressed pavement or within the overlay to create an overlay system. The geosynthetic interlayer can contribute to the life of the overlay via stress relief and/or reinforcement.

A stress relieving interlayer retards the development of reflective cracks by absorbing the stresses that arise from the damaged pavement. It also waterproofs the pavement so that when cracking does occur, water cannot worsen the situation.(Figure 95)


Figure 95: Paving fabric for stress absorption

Reinforcement occurs when an interlayer is able to contribute significant tensile strength to the pavement system. The reinforcement attempts to prevent the cracked old pavement from moving under traffic loads and thermal stress by holding the cracks together.

Newly manufactured composites can provide both stress relief and reinforcement.

The benefits of geosynthetic interlayers include:

- Saving 1.3 to 2 inches of overlay thickness
- Delaying the appearance of reflective cracks
- Lengthening the useful life of the overlay

Geosynthetic Benefits
Stress Relief
Nonwoven geotextiles, a.k.a. paving fabrics, have high elongation and low tensile strength and are commonly used for stress relief. When saturated with asphalt, the flexible interlayer allows considerable movement around a crack but nullifies or at least lessens the effect the movements have on the overlay. This type of interlayer also waterproofs the road structure.

The crucial parameters in a stress relieving overlay system are the overlay thickness and the tack coat application rate. The addition of the interlayer allows the overlay thickness be reduced by as much as 1.3 inches; however, the overlay must be at least 1.5 inches thick. Tack coat application rates vary with temperature and site specific conditions. Too much tack coat can cause the liquid asphalt to bleed up through the overlay; too little will cause the overlay to slip and will not waterproof the structure.

4.3.2 Reinforcement
To reinforce, an interlayer has to hold the crack together and dissipate the crack propagation stress along its length. If the interlayer elongates under stress, it will allow the crack to open. Consequently, the interlayer must have high axial stiffness so that little elongation takes place. When used over a leveling course or a nonwoven paving fabric, the grid can hold the overlay together while allowing the cracked pavement underneath to move independently.

4.3.3 Installation of interlayers

The key to the performance of overlay systems is proper installation. There are four steps in the installation of an overlay system with a geosynthetic interlayer. Surface preparation is followed by the application of the tack coat, installation of the geosynthetic, and finally the placement of the asphalt overlay.

Surface Preparation

Clean the roadway of dirt, water, oil and debris. Smaller cracks should be sealed. Large cracks in excess of 1/8 inch (0.32 cm) and potholes should be filled. Milling of severely cracked pavement may be required, or a thin layer of asphalt called a leveling course may be applied (Figure 96). Sections of broken asphalt that sink when loaded should be removed down to the subgrade and reconstructed. The old surface should be dry and clean at the conclusion of this step.

Figure 96: Sweeping road to make surface ready

Application of the Tack Coat

Proper installation of the asphalt cement tack coat is crucial; mistakes can lead to early failure of the overlay. (Figure 97) Uncut paving grade asphalt cements are recommended with AC-20 and AR- 4000 being the most popular. Emulsions can be used successfully, but they must be applied at a higher rate and allowed to cure completely. The proper grade will be chosen with regard to climate, geography and time of year. The grade of the tack coat and the asphalt used in the overlay should match. The maximum temperature of the tack coat is 163°C, and the minimum is between 138-143°C.

Figure 97: Application of Tack Coat and Geosynthetic is above tack coat

The distributor truck must be capable of uniform application of the tack coat. The bar should be adjusted to obtain uniformity and the correct width of spray usually 5.1 to 7.6 cm past the edge of the geosynthetic. The spray of the nozzles should overlap so that uniform double coverage occurs. Heavy spots, streaks, or gaps will cause problems in the system. As spraying begins and ends, care should be taken to avoid dripping and unevenness.

For a typical paving fabric, the application rate is 0.25gal/yd^2 (1.13 L/m^2). The waterproofing element of a stress absorbing system will not be present unless the fabric absorbs more than 0.68 L/m^2. The membrane attains optimum impermeability between .73 and .77 L/m^2. The roughness of the surface, the porosity of the road, and the presence or absence of a leveling course effects the desired application rate. Once in progress, the rate of application should be measured and verified.

Geogrid and geocomposite systems vary. Therefore, the manufacturer's recommendations for tack coat, if any, should be followed.

Deployment of the Geosynthetic

Geosynthetics may be deployed manually or mechanically with equipment designed specifically for this application. In either case, the geosynthetic must not be allowed to wrinkle. The surface temperature of the tack coat should not exceed 164°C when a paving fabric is. In cool weather, the paving fabric needs to be placed as soon after the tack coat as possible. Allowing time for the tack coat to set and become sticky is advisable in hot weather.

The fuzzy side of the paving fabric should be laid down into the tack coat leaving the smooth side up. The fabric should be broomed into the tack coat. In cool weather, rolling may be required to force the fabric to adhere to the surface. When two segments of fabric come together, an overlap of 2.5 to 7.6 cm should be created and treated with extra tack coat. The overlap should be shingled in the direction of the paving operation.

To install a geogrid, the leading edge of the first roll must be attached to the old asphalt using nails about 1-1/2 inches long (40 mm) and flat washers about 1-3/8 inches (36 mm) in diameter. At each roll change, place the leading edge under the preceding roll and secure the lap by nailing to the old asphalt. On roads without curbs, the geogrid must be placed 4 inches (100 mm) from the edge of the roadway. Also, allow a clearance of 4 inches (100 mm) from the edges of obstructions. An overlap up to 6 inches (100 mm) is required at both longitudinal and transverse joints.

In the case of drains, joints, or other irregularities, the geosynthetic should be placed normally and then cut out around the inside of the obstruction. Any wrinkles especially those occurring on sharp curves need to be slit open and treated as overlaps. Caution should be exercised when allowing traffic on the geosynthetic. Sharp turning and braking will damage the fabric. Sand may be broadcast to reduce the likelihood of skidding

Installation of the Overlay

Installation of the geosynthetic and the asphalt concrete overlay should take place on the same day. Paving can commence as soon as the product is laid down (Figure 98). The temperature of the asphalt should not be less than 121°C or exceed 163°C. Grain mix, amount and grade of bitumen, type of filler, aggregate, and additives must all be considered in selecting the kind of asphalt. The minimum compacted thickness of the overlay at its thinnest point is 3.8 cm (1.5 in). This thickness is necessary to produce enough heat to guarantee saturation of the paving fabric or bonding of the geogrid to the lower pavement. In cold weather, a thicker overlay may be necessary to achieve the same objective.

Figure 98: Installing Overlay

Asphalt can be placed by any conventional means. Compaction should take place immediately after dumping in order to ensure that the different layers are bonded together

4.4 Design Considerations

Combined use of geotextile and soil has proved that the geotextiles gives a better solutions in number of situation in which alone in soil are not stable or feasible.

In present world, role of geosynthetics is significantly important both in unpaved roads and paved roads. In this section we ill discuss the design considerations in selecting geosynthetics material during implementation process.

Unpaved Roads

Unpaved roads are roads built without an asphalt or concrete wearing surface, so they derive all structural support from their aggregate base layers. Unpaved roads are used for many purposes including:

- All types of industrial and private access roads
- Haul roads for quarries, mines and forestry operations
- Temporary construction site roads
- Low volume rural roads
- Detours

Since unpaved roads have no asphalt or concrete wearing surface to help support traffic loads, they require a greater depth of aggregate base. When the aggregate base and subgrade soil intermix, it reduces the effective thickness, thus the load-bearing capacity of the road structure results in ruts. In typical solution, these ruts must be periodically refilled with more aggregate.

However, while using geotextile, the depth of aggregate and class of geotextile required are dependent upon a number of factors. Some major ones are:

i. *Determination of traffic volume*

   Two categories of roads are normally identified –temporary and permanent. Temporary is considered less than 1,000 passes over the design life of the road. Permanent is considered greater than 1,000 passes. Determine the category that has been chosen.

ii. *Determination of soil subgrade strength*

   Determine subgrade soil strength using the field California Bearing Ratio (CBR), cone penetrometer, vane shear, resilient modulus or other appropriate test (ASTM D1883). Soil samples should be taken from the weakest area. Tests should be performed when the soil is at its weakest–wet or saturated. If necessary, estimate the soil CBR using the rule of thumb in Table 4 below:

APPROXIMATE CBR	IDENTIFICATION PROCEDURE
Less than 2	Easily penetrated with thumb
2 – 3	Moderate effort to penetrate with thumb
3 – 6	Indented by thumb
6 – 16	Indented by thumbnail
Over 16	Difficult to indent with thumbnail
Note: This CBR testing method is a non-scientific approximation of soil strength in unsoaked conditions.	

Table 4: Simple CBR identification procedure

iii. *Determination of the required aggregate thickness*

In determining aggregate thickness, an allowable rut depth of 3 inches is recommended. Refer Figure 99 for temporary installations (< 1,000 passes) and Figure 100 for permanent installations (> 1,000 passes) to determine the depth of aggregate needed. The resultant thickness is based on maximum axle load of 18,000 lbs.

For example, from the chart for permanent installations and a CBR test of 2.0, the approximate aggregate depth recommended is 13 inches

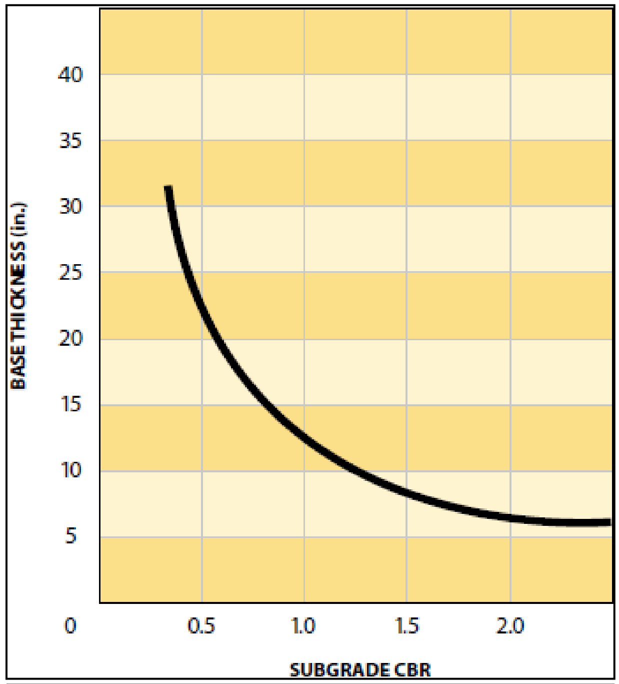


Figure 99: 3″allowable rut depth with less than 1000 vehicle passes

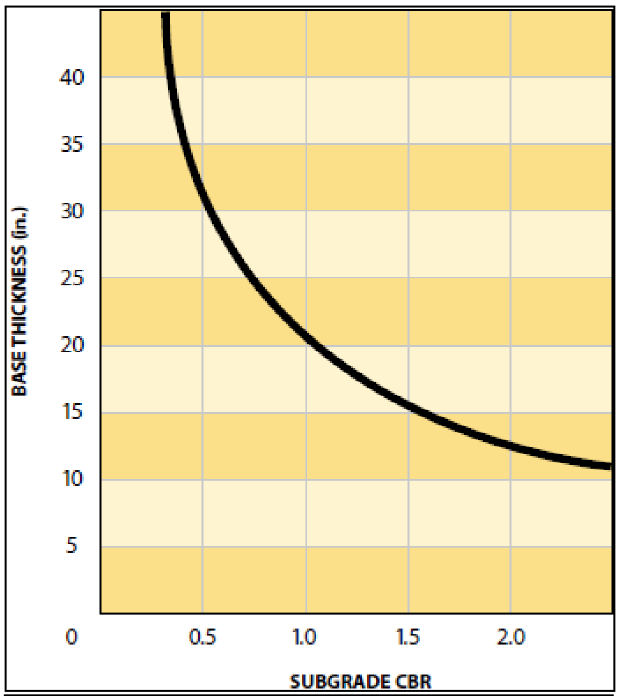


Figure 100: 3″allowable rut depth with more than 1000 vehicle passes

iv. *Calculation of aggregate thickness adjustment for wheel loading*

The aggregate thickness obtained from Figure 99 or Figure 100 is based on a maximum axle load of 18,000 lbs. As axle loads other than 18,000 lbs are frequently encountered, a thickness adjustment for various axle loads can be obtained from Figure 101. The thickness adjustment should be added to or subtracted from the value obtained from Figure 99 or 100.

The following maximum axle load values are a guide to the class of vehicle that might be making use of the road:

a) Light duty (i.e. cars and light trucks, 3,000 lbs)
b) Medium duty (i.e. typical truck loads, 18,000 lbs)
c) Heavy duty (i.e. earth moving equipment, 25,000+ lbs)

For example, the heavy-duty earth moving equipment 6using the unpaved road will require an increase in the aggregate indicated in Figure 101.

The axle load of 25,000 pounds, Figure 101 indicates approximately 4 inches of aggregate should be added to the 13 inches resulting in a total 17 inches of aggregate *v. Selection of the aggregate and adjustment of the thickness for the load*

The selection of the aggregate base material is based on cost or availability. Angular crushed stone is standard base aggregate material. When other materials or blends are used, the efficiency varies and adjustments need to be made to the calculated aggregate thickness. The efficiency factors of various road base materials are tabulated in table 5.

For example, if we choose ripable hardpan, it is 54 percent as effective as crushed stone so the thickness needs to be increased by dividing the axle load adjusted aggregate value by 0.54, which gives us a final total aggregate thickness of approximately 31 inches

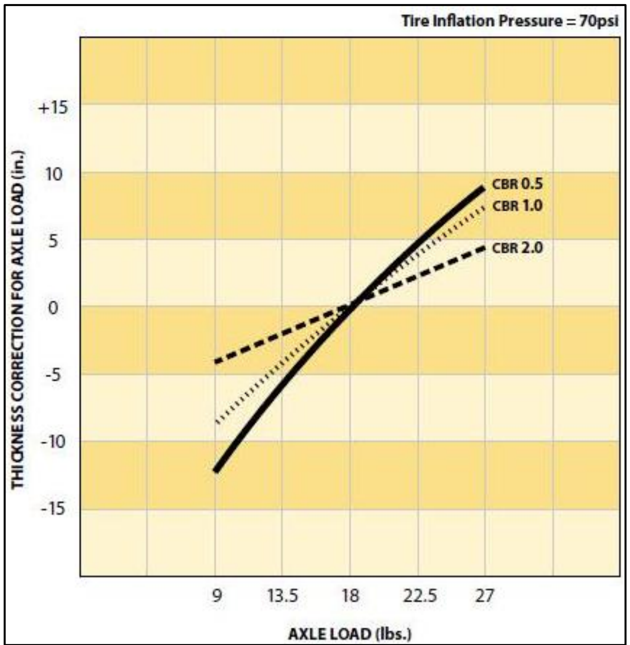


Figure 101: Aggregate thickness adjustment for various axle loads

AGGREGATE MATERIAL	TYPICAL EFFICIENCY
Hard rock (will scratch with a knife)	100%
Medium rock (will scratch with a coin)	80%
Shell	70%
Ripable hardpan	54%
Soft rock (will scratch with a fingernail)	44%
Loose gravel and sandy gravel	38%
Compactible sand	38%

Table 5: Efficiency factor of various road base materials

vi. Selection of the Geotextile

SOIL STRENGTH	SOAKED CONDITIONS	
	Notes	AASHTO M288 Class
CBR less than 1	1	–
CBR between 1 and 3	2	Class 1 or 2
CBR greater than 3	3	Class 2 or 3
Note: Reinforcement is required		

Table 6: Selection of AASHTO M288 Class based on soil conditions at the time of installation

The maximum stress experienced by the geotextile is during installation. Once aggregate has been placed, the geotextile is “insulated” by the layer of aggregate and can be relied upon to remain in position and perform the separation and stabilization function throughout the life of the unpaved road

AASHTO M288 is the applicable specification for the use of geotextiles as a separator to prevent mixing of a subgrade soil and an aggregate cover material based on survivability from installation stress. Selection of the appropriate AASHTO Geotextile Class is dependent on the harshness of the subgrade surface, strength of the subgrade soil and whether the soil is saturated or unsaturated during installation. Please refer table 6 to select the appropriate AASHTO Class

Reference for ground (tire) pressure

Subgrade Conditions	**Low ground pressure equipment (i.e. cars and light trucks) < 25 kPa < 4 psi**	**Medium ground pressure equipment (i.e. typical trucks) > 25 kPa < 50 kPa > 4 psi < 8 psi**	**High ground pressure equipment (i.e. earth moving equip.) > 50 kPa > 8 psi**
Subgrade has been cleared of all obstacles except grass, weeds, leaves and fine wood debris. Surface is smooth and level so that any shallow depressions and humps do not exceed 18 inches in depth or height. All larger depressions are filled. Alternatively a smooth working table may be placed.	Low N/A	Moderate Class 3	High Class 2
Subgrade has been cleared of all obstacles larger than small to moderate size tree limbs and rocks. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 18 inches in depth or height. Larger depressions should be filled.	Moderate Class 3	High Class 2	Very High Class 1
Minimal site	High	Very High	Not recommended

<table>
<tr><td>preparation is intended. Trees may be felled, de-limbed, and left in place. Stumps should be cut to project not more than 6 inches above subgrade. Fabric 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 fabric cover material over them will distort the finished road surface.</td><td>Class 2</td><td>Class 1</td><td>N/A</td></tr>
<tr><td colspan="4">Recommendations are for 6-12 inch initial lift thickness. For other lift thicknesses:
12-18 inch – Reduce survivability requirement one level
18-24 inch – Reduce survivability requirement two levels
> 24 inch – Reduce survivability requirements three levels

For special construction conditions like pre-rutting, increase fabric survivability requirement are one class. Placement of excessive initial thickness may cause bearing failure of the soft subgrade.</td></tr>
</table>

Table 7: Reference for ground (tire) pressure

Paved Roads:
Paved roads are built for the comfort and convenience of the public. The key characteristics of paved roads and parking lots are their high initial cost, reliability, design life/length of useful service and cost of maintenance. The design of paved roads takes into consideration volumes and loads, sub-base soil, construction materials, environment, drainage and expected life-cycle.

Paved roads will fail prematurely if they can't support traffic loads over the subgrades on which they are built. Intermixing of the aggregate base and subgrade soil greatly reduces the load a road can support and consequently its expected life. Signs of premature failure include rutting, cracking and potholing of the pavement. Repairing a rutted and cracked roadway means large maintenance or capital improvement costs, not to mention traffic disruption

Geotextiles are now a standard element in the construction of both rigid and flexible pavements due to their:

- Low cost

- Long-lasting separation of the base and subgrade material
- Preservation of load-bearing capacity
- Ability to extend the life of paved roads

An effective geotextile is one that provides separation to preserve the aggregate base and maintain the designed structure and load-bearing capacity of the road. It helps prevent failure of the base and therefore the pavement by allowing the passage of water and preventing fine soil from mixing with the base.

Light-use roads are usually constructed with thinner than required pavement thickness; these construction methods result in damage from the occasional passes of heavy delivery trucks or dumpsters, especially when the road is wet.
Complete replacement of faulty asphalt or concrete sections using geotextiles to maintain the base and provide drainage is the most effective and permanent corrective action.

Paved roads should be designed for peak loads, not average loads. For instance, according to AASHTO, the pass of one 18-wheeler truck (20,000 lb. axle load) is equivalent to 5,000 passes of an automobile. Major factors that need to be considered while selecting the geotextile for paved Roads are same as for unpaved roads, however following things needs to be noted:

i. The maximum stress experienced by the geotextile used in paved roads with an asphalt or concrete surface–including light-use roads, heavy-use roads and interstate highways–is experienced at the time of installation.
ii. This stress is influenced by the subgrade and the thickness of the first lift.
iii. Once aggregate has been placed, the geotextile is insulated by the depth of aggregate and can be relied on to remain in position and perform the separation and stabilization function throughout the life of the road

Summary table detailing various test and assumption done for review of geotextile for reinforcement and separation in unpaved and paved roads is given below in table 8 can be used for precise selection of geotextile:

Author(s) and Reference Number	**Overview of Work and Findings**	**Key Assumptions**
Barenberg	Developed reinforced unpaved road design criteria • Found geotextile properties have a significant effect on behavior of SFA system −specifically, the geotextile modulus • Permissible values for allowable subgrade stress were found to be: • *with geotextile:* σ = *6cu* • *without geotextile:* σ = *3.2cu*	• Deflected shape of geotextile was a circular arc • No slip
Kinney	• Developed the fabric tension model (FTM) • Included methods for determining geotextile shear and normal stresses and geotextile strain energy • FTM was basis for Barenberg's (1980) revised SFA	No slip

Author(s) and Reference Number	Overview of Work and Findings	Key Assumptions
	design procedure	
Barenberg	Developed procedure using Kinney's (1979) FTM *Procedure:* 1. $\sigma all = 3.2Acu$ $A = 1.0\text{-}2.0$ 2. Estimate gravel thickness 3. Establish rut geometry: depth, *d*, chosen width, *W*: $W=B+2X$ B = gravel rut width X = spreading effect 4. Geotextile strain: $\varepsilon_{f=\left(\frac{4\pi R\theta}{135W}-2\right)X100\%}$ $R = \frac{3W}{8\ \sin\theta}$ $\theta = 2\tan^{-1}\left(\frac{5\ d}{3\ W}\right)$ 5. Fabric tension, *tf*: $tf=K\ \varepsilon f$ 6. Differential stress across fabric, $\Delta\sigma z\text{-}f : \Delta\sigma z\ f\ f - t\ R =$ 7. Permissible stress on fabric: $\sigma\ \sigma\ p\ f\ z\ f\ u - - Ac = \Delta + 3.2$ 8. Using Boussinesq equation, calculate vertical stress on fabric and check to see if less than permissible.	Developed for Mirafi 140 and 500X Deflected shape of geotextile was a circular arc No slip
Bell et a	• Performed laboratory tests to investigate subbase contamination • Found relatively thick geotextiles with small pore sizes to be effective in limiting contamination • High pore water pressure dissipation rates were associated with high contamination and low dissipation rates with low contamination • Nonwoven geotextiles found to be ineffective in preventing clayey fines contamination but more successful in preventing subbase penetration • Geotextiles with effective opening sizes less than 100 mm reduced clay pumping significantly • Cushioning effect of thick geotextiles reduced stone penetration into soil • All geotextiles tested performed a useful separation function	Separation function only
Giroud and Noiray	Developed an equation to determine the required aggregate layer thickness, *h*, as a function of loading, subgrade undrained shear strength, and geotextile properties.	• No slip of geotextile relative to aggregate and subgrade

Author(s) and Reference Number	Overview of Work and Findings	Key Assumptions
	Analytic expression: $$(\pi+2)c_u = \frac{P}{2(B+2h\tan\alpha)(L+2h\tan\alpha)} + \frac{K_\varepsilon}{\sqrt[a]{1+(\frac{a}{2s})^2}}$$	• <10,000 cycles • Aggregate CBR of 80 • Purely cohesive subgrade soils • Membrane action
Hoare	• Performed lab tests to investigate subgrade pumping • Used soil contamination value, SCV (weight of subgrade soil passing the fabric per unit area of fabric) to measure pumping • Soil found to migrate through fabric at contact points between subbase and subgrade • SCV found to be insignificantly reduced by the use of a heavier needle-punched fabric rather than a light melt-bonded fabric	Separation function only
Haliburton and Barron	• Investigated effect of fabric location on SFA performance • Optimum placement depth found to be 1/3 the width of the loaded area • At large deformations, membrane support (even for high modulus fabrics) was small compared to total load capacity • Separation seen as allowing pore pressure dissipation and consolidation	Observations from field and lab tests
Douglas an Kelly	• Performed fatigue tests on SFA systems • Rutting found to be less for stiffer geotextiles • More anchorage resulted in better conditions • Use of two geotextiles-one at the interface the other at the base middepth-performed better than one • geotextile at interface	Based on performance tests
Page	• Reported on 8 sites where geotextiles were exhumed • Worst blinding was observed in the woven slit films • It was recommended that lightweight (3.5 oz/yd2) nonwoven geotextiles not be used for separation	Findings based on tests and observations
Espinoza	• Developed an expression for evaluating the increase in bearing capacity due to membrane action. • Allowable applied stress; q_{ap} $q_{ap} = q_s + q_{avg}$ q_s = *Soil reaction* q_{avg} = *additional capacity due to geotextile* • $q_{avg} = \frac{2E}{L}\varepsilon In\left(\tan\beta_o + \sqrt{1+\tan\beta_o^2}\right)$ *Parabolic Deformation:*	• No slip • τlower = 0, τupper = τ • Constant strain

Author(s) and Reference Number	Overview of Work and Findings	Key Assumptions
	$$\varepsilon = \frac{1}{2}\left[\sec\beta_o + \frac{In(\tan\beta_o + \sec\beta_o)}{\tan\beta_o}\right]$$ *Circular Deformation:* $$\varepsilon = \frac{1+(2\alpha)^2}{4\alpha}\tan^{-1}\beta_o - 1$$	
Nishida and Nishigata	• Investigated relationship between reinforcement and separation in geotextile reinforced unpaved roads • Separation found to be primary function when σ *cu* < 8 and reinforcement found to be primary function when σ *cu* > 8 σ = vertical stress on subgrade *cu* = subgrade undrained shear strength	Results not applicable to nonwovens
Espinoza and Bray	• Developed procedure for evaluating the load capacity of reinforced soils • Analysis incorporated two important membrane support contributions: normal stress and interfacial shear stress support • An expression for admissible surface stress, padm, was developed based on a modified bearing capacity equation $$P_{adm} = \frac{(c_u N_c + T_o \sin\beta_o/L + 2a_r\gamma h\tan\psi_m)}{a_b(1-2a_r\tan\psi_m)}$$ *Where:* $$\tan\psi_m = \frac{\left[a_h(K-K_{pm}) + M_c(\eta K - \tan\delta_m)\right]}{\left(1 + M_c + 2a_r\left(a_h(K-K_{pm}) - \eta K - \tan\delta_m\right)\right)}$$	Slip considered
Metcalfe et al	• Investigated the performance of 22 geotextile separators installed between 1978 and 1991 • Short-term separation and drainage functions were found to be more critical than their long-term performance due to subgrade strength gain due to consolidation • Subgrades of excavated sites found to be consolidated and strong • Even if geotextiles became blinded or clogged in short-term still able to perform while subgrade consolidated • Found to be little need for longterm separation	Separation function only

Table 8: Summary of different test which can be considered for selecting geotextil

5 Geosynthetics In Subsurface Drainage

5.1 Introduction

One major area of geosynthetics use is as filters in drain applications such as trench and interceptions drains, blanket drains, pavement edge drains, structure drains, and beneath permeable roadway bases. The filters resist movement of soil particles as water flows into the drain structure and is collected and/or transported downstream. Geocomposite consisting of a drainage core surrounded by a geotextile filter are often used as a drain itself in these applications. Geo textiles are also used as filters beneath hard armor erosion control system.

Figure 102: High Ground Water is a threat to any construction Project

Because of their comparable performance, improved economy, consistent properties and ease of placement, geotextile have been used successfully to replace graded granular filters in almost all drainage applications. The use of geosynthetics is many applications of drainage is more deeply explained in this chapter.

5.2 Subgrade Dewatering

5.2.1 Contextual situation

A high groundwater table can, and often does, interfere with the stability of subgrade soils. For instance, some clay soils can swell or shrink as their water content increases or decreases, respectively. Also, most soils are considerably weaker when they have high water contents or have not been drained prior to loading. This means that weather-related or seasonal fluctuations in groundwater levels can adversely affect permanent structures founded on undrained soils.

Unfortunately, soils will only drain if there is an adjacent soil layer or zone of higher permeability into which the water can escape. The lower the permeability of the subgrade soils, the closer together the drainage layers/zones must be to provide effective dewatering

5.2.2 Typical Solutions

The traditional approach to subgrade dewatering is to dig a trench to the depth to which the water table is to be lowered and filling the trench with coarse drainage stone. Sometimes a perforated pipe is placed at the base of the trench to more efficiently transport collected seepage to an outlet. Trenches are spaced to assure drainage of the soil within a desired time period.

Alternatively, in new construction, a coarse aggregate drainage layer or "blanket" can be constructed beneath and before placing the subgrade soil. Similarly, a pipe system is commonly placed within the drainage layer to transport collected seepage.

Since groundwater seeping into a drainage layer can carry subgrade soil particles with it – a phenomenon called "piping" – a layer of fine sand is commonly used as a filter over a drainage layer or in lieu of coarse stone in a trench.

5.2.3 The Geosynthetic Solution

Effective subgrade dewatering requires a very porous drainage media to accept seepage and a properly graded filter to prevent piping. Coarse aggregate and sand have not proven to be the most desirable drainage and filtration materials.

Figure 103: Geosynthetic material is being applied as a filter in trenches along the pavements

Geosynthetic materials have become commonplace in subsurface drainage applications. Commonly, geotextiles are being used in lieu of select grades of sand because they are less expensive, provide more consistent properties, and are much easier to install.

The advantages of geotextile filters can be extended to the drainage medium. Where coarse aggregate can be costly, have variable gradations, and be costly and burdensome to install, a geocomposite drain incorporating a 3-dimensional plastic drainage core wrapped with a filtration geotextile overcomes all of these limitations.

5.2.4 Installation of geosynthetics for subgrade dewatering

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 surface shall be smooth and free of debris. In the placement of the geotextile for drainage applications, the geotextile shall be placed loosely with no wrinkles or folds, and with no void spaces between the geotextile and the ground surface. Successive sheets of geotextiles shall be overlapped a minimum of 300 mm, with the upstream sheet overlapping the downstream sheet.

Figure 104: Installation of Geo textile in subgrade dewatering

In trenches equal to or greater than 300 mm in width, after placing the drainage aggregate the geotextile 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 m wide, the overlap shall be equal to the width of the trench. Where the trench is less than 100 mm, the geotextile overlap shall be sewn or otherwise bonded.

Should the geotextile be damaged during installation, or drainage aggregate placement, a geotextile patch shall be placed over the damaged area extending beyond the damaged area a distance of 300 mm, or the specified seam overlap, whichever is greater.

Placement of drainage aggregate should proceed immediately following placement of the geotextile. The geotextile 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 a minimum required construction depth. The aggregate should be compacted with vibratory equipment unless the trench is required for structural support.

5.3 Road Base Drainage

5.3.1 Contextual Situation

Designing without positive rapid subsurface drainage costs billions of dollars a year due to increased rates of pavement damage caused by poor drainage. Most road builders recognize the role of water in pavement deterioration. Yet, most emphasize strength and quality of pavement improvement, neglecting improved drainage techniques

5.3.2 Typical Solutions

Most traditional positive drainage systems use an open-graded drainage layer under the full width of a roadbed with adequate collector pipes and outlet pipe. Additionally, pavement edge drains can be retrofit to greatly reduce the rate of water-related damage to existing pavements.

5.3.3 The Geosynthetic Solution

Recent moves toward greater use of subsurface pavement drainage stem from the development of improved and economical drainage materials, along with greater awareness of the nature and extent of the problem.

The introduction of geotextiles into drainage applications has enhanced the economical application of blanket and trench drains under and adjacent to the pavement structure, respectively. The excellent filtration and separation characteristics associated with filtration geotextiles permits the use of a single layer of open-graded base or trench aggregate enveloped in a geotextile. The thin filtration geotextile reduces the required excavation as well as the cost of the drained structural section.

The following enhanced performance has been identified for pavements having an efficient functioning edge drain system:

Flexible Pavements: 25% increase in service life.
Rigid Pavements: 50% increase in service life.

5.3.4 Installation of geosynthetics for road base drainage

New Construction

When constructing a new road with an open graded base course designed to also provide blanket drainage, a filtration geotextile is deployed prior to placement of the base course in the same manner as a separation geotextile Commonly, the base course terminates along the road edges into deepened edge drains. These edge drains should also be wrapped with the geotextile as shown in the above photos.

Retrofit
Excavations for retrofit edge drains should be done in such a way so as to prevent large voids from occurring in the sides and bottom of the trench. The edge drain can be an aggregate trench drain with a collector pipe in the bottom

Geocomposite Edge Drain
Alternately, a geocomposite edge drain can be used. The excavator, if appropriately equipped, will lay a geocomposite drain into a narrow trench and backfill with sand between the drain and the exposed base course.

5.4 Structure Drainage

5.4.1 Contextual Situation

According to Cedergren, 1989, any well drained structure is inherently safer and more economical than if constructed without drainage. This is because the placement of relatively impermeable structural elements, such as a concrete foundation or retaining walls, against water-bearing earth leads to two damaging conditions

1. Excess uplifting or overturning pressures caused by trapped water.
2. Channeling of seepage and piping caused by the presence of permeable discontinuities.

Strict adherence to sound drainage principles is probably the most important single aspect of the design of structures constructed adjacent to water-bearing soils. Almost every serious failure of structures of these kinds has been caused by lack of control of groundwater or seepage.

5.4.2 Typical Solutions

The objective of structural drainage is to control water pressures and seepage forces in the earth adjacent to structures and thus prevent their untimely damage, deterioration, or failure.

It has become customary to place a vertical blanket of "pervious" sand or gravel behind retaining walls for protection against hydrostatic pressures. Yet, it has been demonstrated that even when the back face of a wall is drained with a vertical blanket significant pore pressures can exist in the earth behind the blanket. This leads to increased pressure on the wall. An inclined drainage layer overcomes this deficiency by causing seepage to occur in the vertical direction.

Still, whether vertical or inclined, a drainage layer is difficult to construct using sands and gravels and the drainage layer should be protected by a thin filter layer of carefully graded sand which is even more difficult, or impossible, to place at a steep angle.

5.4.3 The Geosynthetic Solution

Geosynthetic drainage materials can eliminate the difficulties associated with conventional gravel and sand drains and filters.
One of the best ways to assure effective aggregate drainage is to sandwich an aggregate layer within layers of filtration geotextiles. The inclusion of a perforated drain pipe that collects and discharges seepage will increase the drain's efficiency. Back fill is placed directly against the drain.

A prefabricated geocomposite drain is an even better alternative. The geocomposite drain replaces the aggregate with 3-dimensional plastic core and comes to the site already covered with the necessary filtration geotextile. This allows the entire drain to be installed in one step.

5.4.4 Installation of drains around structures

Excavations will be done according to project plans and in such a way so as to prevent large voids from occurring in the sides and bottom of the trench.

Figure 105: Installation of geo synthetic drain around the structure

To assure an effective aggregate drain, place a filtration geotextile on the excavated stable slope in back of the wall, place a few inches of permeable crushed rock ¼ to 1 inch in size over the geotextile, and cover the rock with another layer of the filtration geotextile.

A prefabricated geocomposite drain may be used in horizontal or vertical applications. In vertical applications, installation begins at the bottom of waterproofed wall where first panel is attached, filter fabric side away from the wall surface. As additional panels are added, insure that the fabric overlay is in optimal position. Overlap panels in the direction of water flow. If a drainpipe discharge system is used, place bottom of drain panel behind geotextile-covered drain pipe and aggregate. Soil should be placed and compacted adjacent to drain.

In horizontal applications, such as plaza decks, lay initial panel horizontally, filter fabric side up, at outflow drain and attach panels in like manner insuring that overlapping fabric is properly positioned. Place temporary ballast atop the panels until overlayer is applied

5.5 Design Considerations

One major area of geotextile use is as filters in drain applications such as trench and interception drains, blanket drains, pavement edge drains, structure drains, and beneath permeable roadway bases . *The ftlter* restricts movement of soil particles as water flows into the *drain* structure and is collected and/or transported downstream. Geocomposites consisting of a drainage core surrounded by a geotextile filter are often used as the drain itself in these applications.

Thus, geotextile and geocomposites perform the same functions as graded granular filters:

- allow water to flow through the filter into the drain, and to continue doing this throughout the life of the project; and
- retain the soil particles in place and prevent their migration *(piping)* through the filter (if some soil particles do move, they must be able to pass through the filter without blinding or clogging the downstream media during the life of the project).

Geotextiles, like graded granular filters, require proper engineering design or they may not perform as desired. All geosynthetic designs should begin with a criticality and severity assessment of the project conditions (see Table 9) for a particular application. Although first developed by Carroll (1983) for drainage and filtration applications, the concept of critical-severe projects -- and, thus, the level of engineering responsibility required -- will also be applicable on other geosynthetic applications.

Information for evaluating the critical nature or severity of drainage and erosion control applications		
A. *Critical Nature of the Project*		
Item	**Critical**	**Less Critical**
Risk of loss of life and/or structural damage due to drain failure	High	None
Repair costs versus installation costs of drain	>>>	= or <
Evidence of drain clogging before potential catastrophic failure	None	Yes
B. *Severity of the Conditions*		
Item	**Critical**	**Less Critical**
Soil to be drained	Gap-graded, pipable, or dispersible	Well-graded or uniform
Hydraulic gradient	High	Low
Flow conditions	Dynamic, cyclic, or pulsating	Steady state

Table 9: reference for evaluating critical nature of drainage or erosion control application

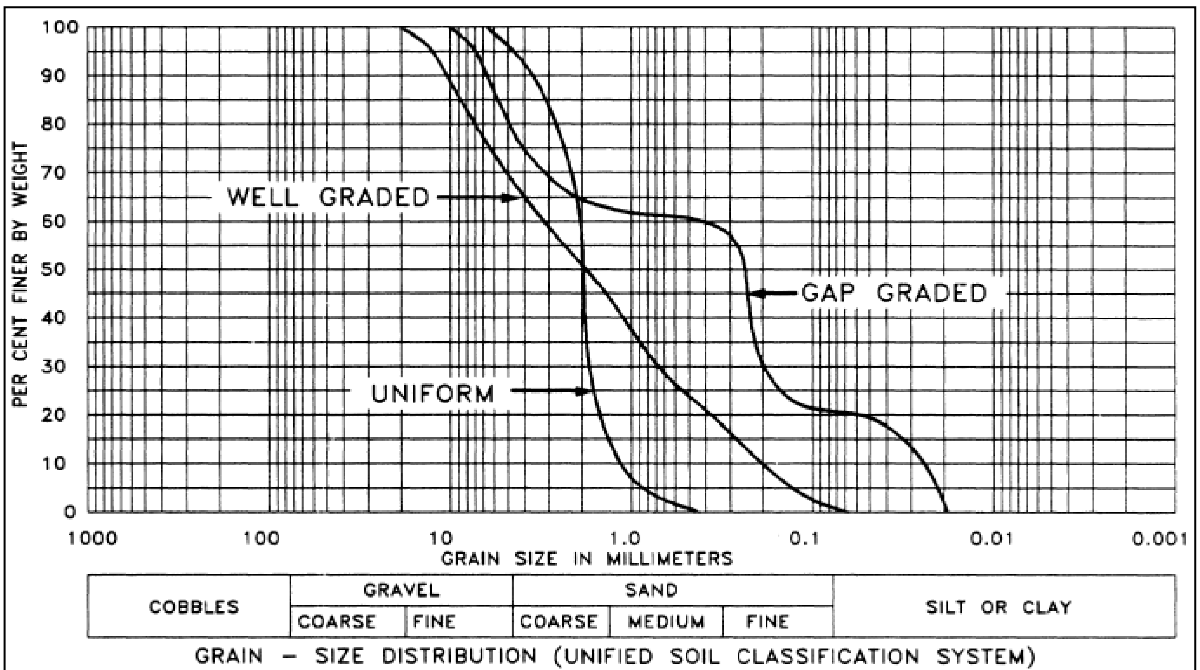


Figure 106: Soil Descriptions for Subsurface Drainage

Gap graded, well-graded and uniform soils are shown in Figure 106. Certain gap-graded and broadly graded soils may be *internally unstable;* that is, they can experience piping or internal erosion. On the other hand, a soil is *internally stable* if it is self-filtering and if its own fine particles do not move through the pores of its coarser fraction (LaFluer, et al., 1993).

Dispersible soils are fine-grained natural soils which deflocculate in the presence of water and, therefore, are highly susceptible to erosion and piping (Sherard, et al., 1972).

Designing with geotextiles for filtration is essentially the same as designing graded granular filters.A geotextile is similar to a soil in that it has voids (pores) and particles (filaments and fibers). However, because of the shape and arrangement of the filaments and the compressibility of the structure with geotextiles, the geometric relationships between filaments and voids are more complex than in soils.

In geotextiles, pore size is measured directly, rather than using particle size as an estimate of pore size, as is done with soils. Since pore size can be directly measured; relatively simple relationships between the pore sizes and particle sizes of the soil to be retained can be developed. Three simple filtration concepts are used in the design process:

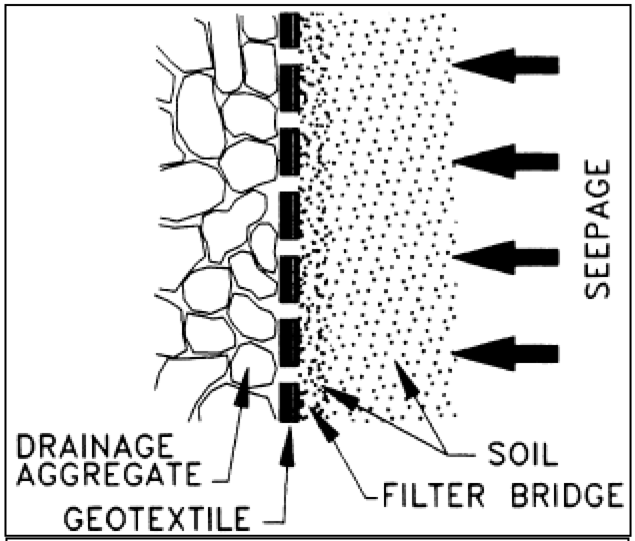


Figure 107: Filter Bridge formation

1) If the size of the largest pore in the geotextile filter is smaller than the larger particles of soil, the soil will be retained by the filter. As with graded granular filters, the larger particles of soil will form a filter bridge over the hole, which in turn, filters smaller particles of soil, which then retain the soil and prevent piping. (Figure 107)
2) If the smaller openings in the geotextile are sufficiently large enough to allow smaller particles of soil to pass through the filter, then the geotextile will not *blind* or *clog* (Figure 108).
3) A large number of openings should be present in the geotextile so proper flow can be maintained even if some of the openings later become plugged

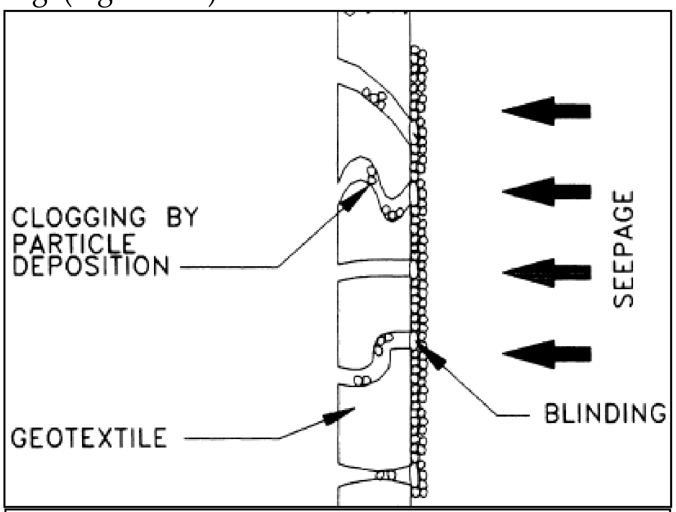


Figure 108: Clogging and blinding

These simple concepts and analogies with soil filter design criteria are used to establish design criteria for geotextiles. Specifically, these are:

- The geotextile must retain the soil (retention criterion)
- Allow water to pass (permeability criterion)
- The life of the structure should be long (clogging resistance criterion).

- They should survive during the installation process (survivability criterion)

Christopher and Holtz (1985)[1] design procedure for geotextile filters for drainage:

5.5.1 Retention Criteria

1. *Steady State Flow Conditions*

AOS or $O_{95\ geotextile} \leq B\ D_{85}$ (soil)

Where:
AOS: Apparent Opening Size (mm);
O_{95}: Opening size in the geotextile for which 95% are smaller (mm);
AOS ≈ O_{95};
B: a coefficient (dimensionless); and
D_{85}: Soil particle size for which 85% are smaller (mm).

The coefficient B ranges from 0.5 to 2 and is a function of the type of soil to be filtered, its density, the uniformity coefficient C_u if the soil is granular, the type of geotextile (woven or nonwoven), and the flow conditions.

For *sands, gravelly sands, silty sands,* and *clayey sands* (with less than 50% passing the 0.075 mm sieve per the Unified Soil Classification System), B is a function of the uniformity coefficient, C_u.

Therefore, for

$C_u \leq 2$ or ≥ 8:	B=1
$2 \leq C_u \leq 4$:	$B=0.5\ C_u$
$4 < C_u < 8$:	$B = 8/C_u$

Where: $C_u = D_6/D_{10}$

Sandy soils which are not uniform (Figure 106) tend to bridge across the openings; thus, the larger pores may actually be up to twice as large (B ≤ 2) as the larger soil particles because, quite simply, two particles cannot pass through the same hole at the same time. Therefore, use of the criterion B = 1 would be quite conservative for retention, and such a criterion has been used.
If the protected soil contains any fines, use only the portion passing the 4.75 mm sieve for selecting the geotextile (*i.e.*, scalp off the +4.75 mm material).

[1]*Note: For critical projects, consideration of the risks and the consequences of geotextile filter failure require great care in selecting the appropriate geotextile. For such projects, and for severe hydraulic conditions, conservative designs are recommended. Geotextile selection should not be based on cost alone.*

For silts and clays (with more than 50% passing the 0.075 mm sieve), B is a function of the type of geotextile:

for wovens,	B=1; $O_{95} \leq D_{85}$;
for nonwovens,	B = 1.8; $O_{95} \leq 1.8\ D_{85}$;
and for both[2],	AOS or $O_{95} \leq 0.3$ mm

In absence of detailed design, the AASHTO M 288 Standard Specification for Geotextiles (1997) provides the following recommended maximum AOS values in relation to percent of situ soil passing the 0.075 mm sieve: (i) 0.43 mm for less than 15 % passing; (ii) 0.25 mm for 15 to 50% passing; and (iii) 0.22 mm for more than 50% passing. However, for cohesive soils with a plasticity index greater than 7, the maximum AOS size is 0.30 mm. These default AOS values are based upon the predominant particle sizes of the in situ soil. The engineer may require performance testing based on engineering design for drainage systems in problematic soil environments. Site specific testing should be performed especially if one or more of the following problematic soil environments are encountered: unstable or highly erodible soils such as noncohesive silts; gap graded soils; alternating sand/silt laminated soils; dispersive clays; and/or rock flour

2. *Dynamic Flow Conditions*

If the geotextile is not properly weighted down and in *intimate contact* with the soil to be protected, or if dynamic, cyclic, or pulsating loading conditions produce high localized hydraulic gradients, then soil particles can move behind the geotextile.
Thus, the use of B = 1 is not conservative, because bridging network will not develop and the geotextile will be required to retain even finer particles.
When retention is the primary criteria,

B should be reduced to 0.5; or:
$O_{95} \leq 0.5\ D_{85}$

Dynamic flow conditions can occur in pavement drainage applications. For reversing inflow-outflow or high-gradient situations, it is best to maintain sufficient weight or load on the filter to prevent particle movement.

3. *Stable versus Unstable Soils*

The retention criteria detailed earlier assumes that the soil to be filtered is internally stable -- it will not pipe internally. If unstable soil conditions are encountered, performance tests should be conducted to select suitable geotextiles.
According to Kenney and Lau (1985, 1986) and LaFluer, et al.(1989), broadly graded ($C_u > 20$) soils with concave upward grain size distributions tend to be internally unstable.

Note[2]: Due to their random pore characteristics and, in some types, their felt-like nature, nonwovens will generally retain finer particles than a woven geotextile of the same AOS. Therefore, the use of B = 1 will be even more conservative for nonwovens.

5.5.2 Permeability/Permittivity Criteria

<u>Permeability requirements:</u>

For less critical applications and less severe conditions*:*

$K_{geotextile} \geq K_{Soil}$

and, for critical applications and severe conditions:

$K_{geotextile} \geq 10\ K_{Soil}$

<u>Permittivity requirements:</u>

$\Psi \geq 0.5\ sec^{-1}$ for < 15% passing 0.075 mm

$\Psi \geq 0.2\ sec^{-1}$ for 15 to 50% passing 0.075 mm

$\Psi \geq 0.1\ sec^{-1}$ for > 50% passing 0.075 mm

In these equations:

K = Darcy coefficient of permeability *(m/s);* and

Ψ = geotextile permittivity, which is equal to $K_{geotextile}/t_{geotextile}$ (l/s) and is a function of the hydraulic head.

For actual flow capacity, the permeability criteria for noncritical applications is conservative, since an equal quantity of flow through a relatively thin geotextile takes significantly less time than through a thick granular filter. Even so, some pores in the geotextile may become blocked or plugged with time. Therefore, for critical or severe applications, above equation is recommended to provide an additional level of conservatism. Equation for leass critical application can be used where flow reduction is judged not to be a problem, such as in clean, medium to coarse sands and gravels.

The AASHTO M 288 Standard Specification for Geotextiles (1997) presents recommended minimum permittivity values in relation to percent of situ soil passing the 0.075 mm sieve. The values are the same as presented in permittivity requirements above. The default permittivity values are based upon the predominant particle sizes of the in situ soil. Again, the engineer may require performance testing based on engineering design for drainage systems in problematic soil environments.

The required flow rate, q, through the system should also be determined, and the geotextile and drainage aggregate selected to provide adequate capacity. As indicated above, flow capacities should not be a problem for most applications provided *the geotextile permeability is greater than the soil permeability*. However, in certain situations, such as where geotextiles are used to span joints in rigid structures and where they are used as pipe wraps, portions of the geotextile may be blocked. For these applications, the following criteria should be used together with the permeability criteria

$$q_{\text{Required}} = q_{\text{geotextile}}\ (A_g/A_t)$$

where:

A_g = geotextile area available for flow; and

A_t = total geotextile area

5.5.3 Clogging Resistance

1. *Less Critical/Less Severe Conditions*

   For less critical/less severe conditions:

   $O_{95(geotextile)} \geq 3\ D_{15(Soil)}$

   The above equation applies to soils with $C_u > 3$. For $C_u \leq 3$, select a geotextile with the maximum AOS value from Section 5.5.1

   In situations where clogging is a possibility *(e.g.,* gap-graded or silty soils), the following *optional* qualifiers may be applied:

   for *nonwovens* –

   porosity of the geotextile, $n \geq 50\%$

   for *woven* monofilament and slit film wovens -

   percent open area, $POA \geq 4\%$

   Most common nonwovens have porosities much greater than 70%. Most woven monofilaments easily meet the criterion of above Equation; tightly woven slit films do not, and are therefore not recommended for subsurface drainage applications.

   Filtration tests provide another option for consideration, especially by *inexperienced users.*

2. *Critical/Severe Conditions*

   For *critical/severe* conditions, select geotextiles that meet the retention and permeability criteria in Sections 5.5.1 and 5.5.2. Then perform a filtration test using samples of on-site soils and hydraulic conditions. One type of filtration test is the gradient ratio test (ASTM D 5101).

   Although several empirical methods have been proposed to evaluate geotextile filtration characteristics *(i.e.,* the clogging potential), the most realistic approach for all applications is to perform a laboratory test which simulates or models field conditions. We recommend the gradient ratio test, ASTM D 5101, Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio. This test utilizes a rigid-wall soil permeameter with piezometer taps that allow for simultaneous measurement of the head losses in the soil and the head loss across the soil/geotextile interface (Figure 109). The ratio of the head loss across this interface (nominally 25 mm) to the head loss across 50 mm of soil is termed the *gradient ratio.* As fine soil particles adjacent to the geotextile become trapped inside or blind the surface, the gradient ratio will increase. A gradient ratio less than 3 is recommended by the U.S. Army Corps of Engineers (1977), based upon limited testing with severely gap-graded soils. Because the test is conducted in a rigid-wall permeameter, it is most appropriate for sandy and silty soils with $k \geq 10^{-7}$ m/s.

   For soils with permeability less than about 10^{-7} m/s, long-term filtration tests should be conducted in a flexible wall or tri-axial type apparatus to insure that flow is through the soil rather than along the sides of the specimen. The soil flexible wall test is ASTM D 5084, while the Hydraulic Conductivity Ratio (HCR) test (ASTM D 5567) has been suggested for geotextiles. Unfortunately, neither test is able to measure the permeability near the soil-geotextile interface nor determine changes in permeability and hydraulic gradient within the soil sample itself - a serious disadvantage (Fischer, 1994). Fortunately, very fine-grained, lowpermeability soils rarely present a filtration problem unless they are dispersive

(Sherard and Decker, 1977) or subject to hydraulic fracturing, such as might occur in dams under high hydraulic gradients (Sherard, 1986).

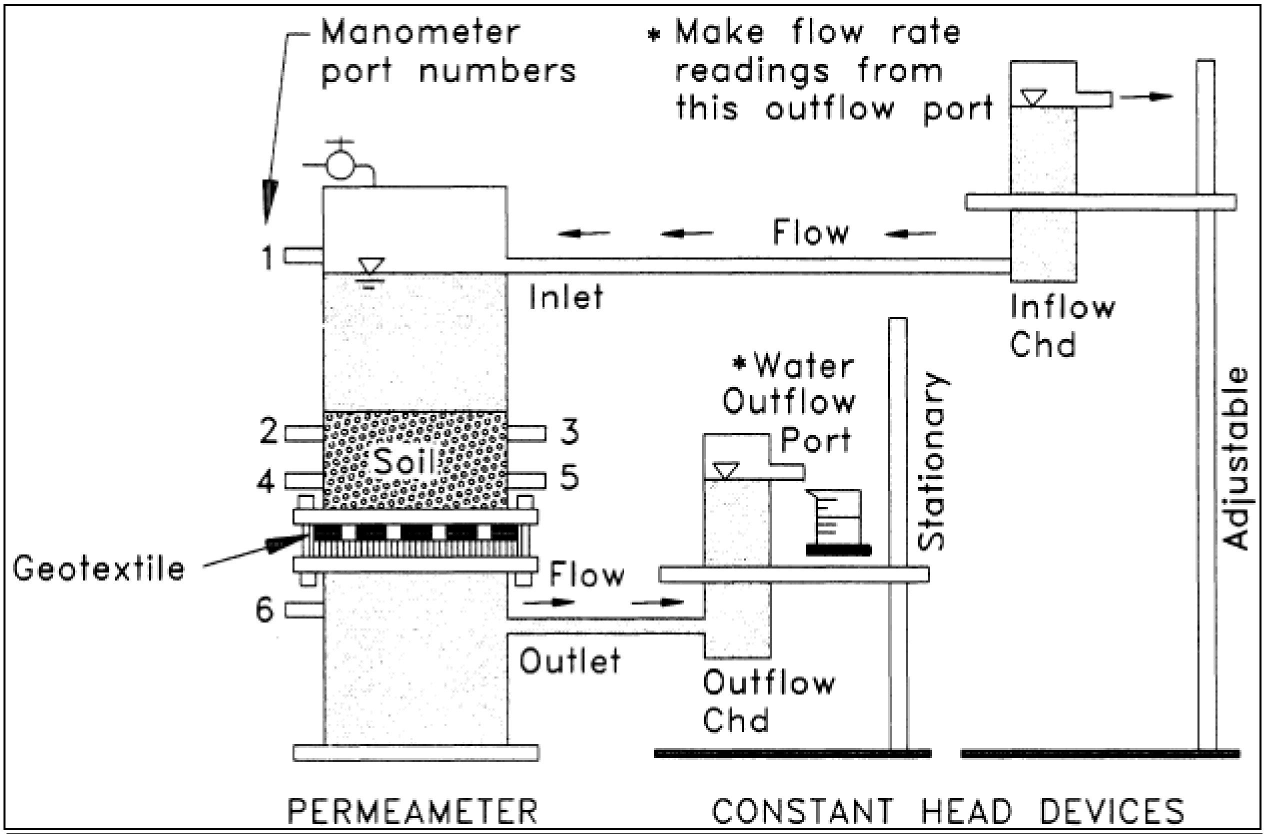


Figure 109: U. S. Army Corps of Engineers gradient ratio test device

For soils with permeability less than about 10^{-7} m/s, long-term filtration tests should be conducted in a flexible wall or tri-axial type apparatus to insure that flow is through the soil rather than along the sides of the specimen. The soil flexible wall test is ASTM D 5084, while the Hydraulic Conductivity Ratio (HCR) test (ASTM D 5567) has been suggested for geotextiles. Unfortunately, neither test is able to measure the permeability near the soil-geotextile interface nor determine changes in permeability and hydraulic gradient within the soil sample itself - a serious disadvantage (Fischer, 1994). Fortunately, very fine-grained, lowpermeability soils rarely present a filtration problem unless they are dispersive (Sherard and Decker, 1977) or subject to hydraulic fracturing, such as might occur in dams under high hydraulic gradients (Sherard, 1986).

Again, we emphasize that these filtration tests are *performance tests.* They must be conducted on samples of project site soil by the specifying agency or its representative. These tests are the responsibility of the engineer because manufacturers generally do not have soil laboratories or samples of on-site soils. Therefore, realistically, the manufacturers are unable to certify the clogging resistance of a geotextile.

For *less critical/less severe* conditions, a simple way to avoid clogging, especially with silty soils, is to allow fine particles already in suspension to pass through the geotextile. Then the *bridge network* (Figure 107) formed by the larger particles retains the smaller particles. The bridge network should develop rather quickly, and the quantity of fine particles actually passing through the geotextile is relatively small. This is why the less critical/less severe clogging resistance criteria requires an AOS *(0_{95})* sufficiently larger than the finer soil particles (D_{15}). Those are the particles that will pass through the geotextile. Unfortunately, the AOS value only indicates the size and not the number of O_{95}-sized holes available. Thus, the finer soil particles will be retained by the smaller holes in the geotextile, and if there are sufficient fines, a significant reduction in flow rate can occur.

Consequently, to control the number of holes in the geotextile, it may be desirable to increase other qualifiers such as the porosity and open area requirements. There should always be a sufficient number of holes in the geotextile to maintain permeability and drainage, even if some of them clog.

It should be pointed out that some soil types and gradations, may result in calculated AOS values that cannot reasonably be met by any available product. In these cases, the design must be modified accordingly to accommodate available products or possibly use multistage filters. In either case, performance tests should then be performed on the selected system.

3. *Survivability and Endurance Criteria*

To be sure the geotextile will survive the construction process, certain geotextile strength and endurance properties are required for filtration and drainage applications. These minimum requirements are given in Table 10. Note that stated values are for less critical/less severe applications.

It is important to realize that these ***minimum survivability values*** are not based on any systematic research, but on the properties of existing geotextiles which are known to have performed satisfactorily in drainage applications. The values are meant to serve as guidelines for inexperienced users in selecting geotextiles for routine projects. They are not intended to replace site-specific evaluation, testing, and design.

Geotextile endurance relates to its longevity. Geotextiles have been shown to be basically inert materials for most environments and applications. However, certain applications may expose the geotextile to chemical or biological activity that could drastically influence its filtration properties or durability. For example, in drains, granular filters and geotextiles can become chemically clogged by iron or carbonate precipitates, and biologically clogged by algae, mosses, etc. Biological clogging is a potential problem when filters and drains are periodically inundated then exposed to air. Excessive chemical and biological clogging can significantly influence filter and drain performance. These conditions are present, for example, in landfills.

Biological clogging potential can be examined with ASTM D 1987, Standard Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters (1991). If biological clogging is a concern, a higher-porosity geotextile may be used, and/or the drain design and operation can include an inspection and maintenance program to flush the drainage system.

Geotextile strength property requirements[1,2,3,4] for drainage geotextiles (After AASHTO, 1997)				
Property	ASTM Test Method	Units	Geotextile Class 2[5]	
			Elongation	
			< 50%[6]	≥ 50%
Grab Strength	D 4632	N	1100	700
Sewn Seam Strength[7]	D 4632	N	990	630
Tear Strength	D 4533	N	400	250
Puncture Strength	D 4833	N	400	250
Burst Strength	D 3786	kPa	2700	1300

NOTES:
1. Acceptance of geotextile material shall be based on ASTM D 4759.
2. Acceptance shall be based upon testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer's certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354.
3. Minimum; use value in weaker principal direction. All numerical values represent minimum average roll value (i. *e.*, test results from any sampled roll in a lot shall meet or exceed the minimum values in the table). Lot samples according to ASTM D 4354.
4. Woven slit film geotextiles will not be allowed.
5. Default geotextile selection. The engineer may specify a Class 3 geotextile for trench drain applications based on one or more of the following:
   a) The engineer has found Class 3 geotextiles to have sufficient survivability based on field experience.
   b) The engineer has found Class 3 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
   c) Subsurface drain depth is less than 2 m, drain aggregate diameter is less than 30 mm and compaction requirement is equal to or less than 95 % of AASHTO T-99.
6. As measured in accordance with ASTM D 4632.
7. When seams are required. Values apply to both field and manufactured seams.
8. The required MARV tear strength for woven monofilament geotextiles is 250 N.

Table 10: Geotextile strength property requirements for drainage geotextiles

5.5.4 Design Guidelines

Here, step-by-step design procedures are given. As a link chain, the integrity of the resulting design will depend on its weakest link; thus, it's recommended that no steps should be compromised or omitted.

<u>Step 1</u>: *Evaluate the critical nature and site conditions (Table 9) of the application*

Since there may be a significant cost difference for geotextiles required for critical/severe conditions, a reasonable judgment should be used in categorizing a project. Final selection should ***not*** be based on the lowest material cost alone, nor should costs be reduced by eliminating laboratory soil-geotextile performance testing, if such testing is appropriate.

Step 2: Obtain soil samples from the site, and

a) *Perform grain size analyses*

   i. Calculate Cu = D_{60}/D_{10};
   ii. Select the worst case soil for retention (i. e., usually the soil with smallest B x D85)

b) *Perform field or laboratory permeability tests*

   i. Select worst case soil (i. *e*., soil with highest coefficient of permeability, k)
   ii. The permeability of clean sands with 0.1 mm < D_{10} < 3 mm and C_u < 5 can be estimated by the Hazen formula, k = $(D_{10})^2$ (k in cm/s; D_{10} in mm). This formula should ***not*** be used for soils with appreciable fines.

c) *Select drainage aggregate*
Use free-draining, open-graded material and determine its permeability (e.g, Figure 110). If possible, sharp, angular aggregate should be avoided. If it must be used, then a geotextile meeting the property requirements for high survivability in Table 10 should be specified. For an accurate design cost comparison, compare cost of open graded aggregate with select well-graded, free-draining filter aggregate

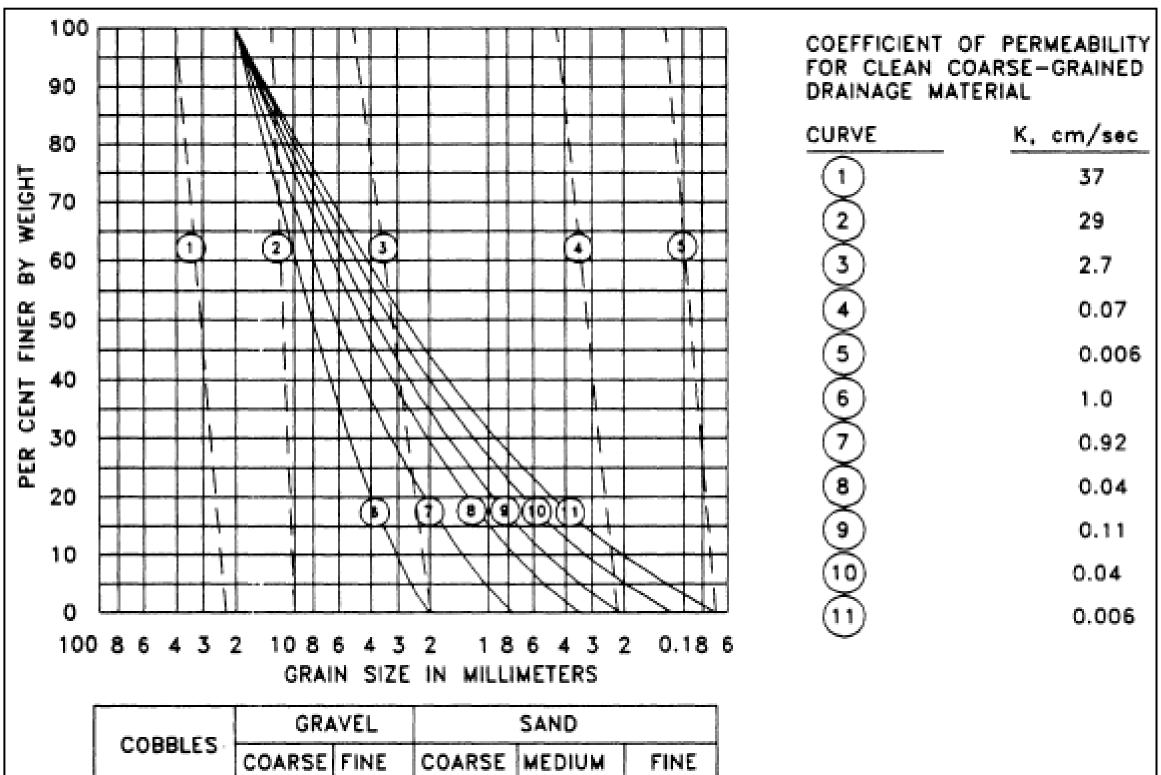


Figure 110: Typical gradations and Darcy permeabilities of several aggregate and graded filter materials

NOTE: While performing grain size analysis, when the soil contains particles 25 mm and larger, use only the gradation of soil passing the 4.75 mm sieve in selecting the geotextile (i.e., scalp off the +4.75 mm material).

<u>Step 3:</u> Calculate anticipated flow into and through drainage system and dimension the system. Use collector pipe to reduce size of drain.

a) *General Case*

Use Darcy's Law

q = k i A

where:

q	=	infiltration rate *(L^3/T)*
k	=	effective permeability of soil *(LIT)*
I	=	average hydraulic gradient in soil and in drain (L/L)
A	=	area of soil and drain material normal to the direction of flow (L^2)

Use conventional flow net analysis to calculate the hydraulic gradient (Cedergren, 1977) and Darcy's Law for estimating infiltration rates into drain; then use Darcy's Law to design drain *(i.e.,* calculate cross-sectional area A for flow through open-graded aggregate). Note that typical values of hydraulic gradients in the soil adjacent to a geotextile filter (Giroud, 1988) are:

- $i < 1$ for drainage under roads, embankments, slopes, etc., when the main source of water is precipitation; and
- $i = 1.5$ in the case of drainage trenches and vertical drains behind walls.

b) *Specific Drainage Systems*

Estimates of surface infiltration, runoff infiltration rates, and drainage dimensions can be determined using accepted principles of hydraulic engineering (Moulton, 1980). Specific references are:

a. *Flow into trenches* -- Mansur and Kaufman (1962)
b. *Horizontal blanket drains* -- Cedergren (1977)
c. Slope drains -- Cedergren (1977)

<u>Step 4: Determine geotextile requirements</u>

a) *<u>Retention Criteria</u>*

From section 5.5.1, obtain D_{85} and C_u ; Then determine largest pore size allowed.

Keep B = 1 for a conservative design and for a less-conservative design, and for ≤ 50% passing 0.075 mm sieve:

$C_u \leq 2$ or ≥ 8:	B=1
$2 \leq C_u \leq 4$:	$B=0.5\ C_u$
$4 < C_u < 8$:	$B = 8/C_u$

and, for ≥ 50% passing 0.075 mm sieve:

B = 1 for wovens,
B = 1.8 for nonwovens,
and *ADS* (geotextile) !> 0.3 mm

b) *<u>Permeability/Permittivity Criteria</u>*

Obtain the value for criticality ($k_{geotextile}$) , permittivity requirements (Ψ) and flow capacity requirements ($q_{required}$) from section 5.5.2.

Flow capacity requirements can also be calculated by:

$(k_{geotextile}/t)\ h\ A_g \geq q_{required}$

Where:

$q_{required}$ is obtained from above equation;

$k_{geotextile}/t$ = Ψ = permittivity;

t = geotextile thickness;

h = average head in field;

A_g = geotextile area available for flow *(i.e* .if 80% of geotextile is covered by the wall of a pipe, A_g = 0.2 x total area); and

A_t = total area of geotextile.

c) *Clogging criteria*

1. *Less Critical/Less Severe*
   a) From Section 5.5.1 obtain D_{15}; then determine minimum pore size requirement from $O_{95} \geq 3\ D_{15}$. for Cu > 3

   b) Other qualifiers:
   Nonwovens:
   Porosity (geotextile) ≥ 50%
   Wovens:
   Percent open area ≥ 4%

Alternative: Run filtration tests

2. *Critical/Severe*

Select geotextiles that meet retention, permeability, and survivability criteria, as well as the criteria in Step 4.c.1 above, and perform a filtration test.

Gradient ratio test is suggested as a filtration test for sandy and silty soils. The hydraulic conductivity ratio test is recommended by some people for fine-grained soils, but as noted n Section 5.5.3, the test has serious disadvantages.

Alternative: Long-term filtration tests, F^3 tests, etc.

d) *Survivability*

Select geotextile properties required for survivability from Table 5-2. Add durability requirements if appropriate.

Step 5: Estimate costs

Calculate the pipe size (if required), the volume of aggregate, and the area of the geotextile. Apply appropriate unit cost values.

Pipe (if required) (1m)	_______________
Aggregate (1m3)	_______________
Geotextile (1m2)	_______________
Geotextile placement (1m2)	_______________
Construction (LS)	_______________
Total Cost:	_______________

Step 6: Prepare specifications

Include for the geotextile:

a) General requirements
b) Specific geotextile properties
c) Seams and overlaps
d) Placement procedures
e) Repairs
f) Testing and placement observation requirements

Step 7: Collect samples of aggregate and geotextile before acceptance.

Step 8: Monitor installation during and after construction.

Step 9: Observe drainage system during and after storm events.

6 Geosynthetics in Erosion and Sediment control

6.1 Introduction

Man-made changes to the environment including unrestricted development, overtaxed resources, removal of surface cover, paving, or simply poor stewardship expose more soil to greater erosive forces and thereby substantially accelerate the rate of erosion. (Figure 111)

Figure 111: Road side soil erosion

Negative Effects of Erosion

- Turbidity caused by eroded soil particles reduces beneficial uses of water by people and can harm aquatic wildlife.
- Eroded sediments carrying chemical molecules have become a major water pollutant.
- As sediments accumulate, they fill up drainage channels and reduce the area available for storm water runoff.
- Flooding occurs when the outlets for storm water are clogged with sediment.

Erosion vs. Sedimentation

Erosion occurs when soil particles are displaced due to the impact of raindrops, moving water, or wind. Sedimentation occurs when eroded particles (sediments), carried by water or wind, are deposited in another location where they can cause problems. (Figure 112) Clearly, sediments (suspended eroded particles) and sedimentation (redeposited soil particles) cause the problems commonly associated with erosion.

Erosion control can prevent problems from ever starting. Sediment control can only attempt to minimize the extent of the problems.

Figure 112: Sedimentation on road

Erosion Basics

- Raindrops dislodge soil particles and seal the surface. Water cannot infiltrate the sealed surface so overland flow increases.
- Vegetation or any other cover can reduce the momentum or energy of raindrops and prevent sealing of the surface.
- Most construction site erosion results from rainfall impact and overland, or sheet, flows

6.2 Hard Armor Systems

6.2.1 Contextual Situation

Soil banks or slopes exposed to constant concentrated flows, currents, or waves cannot support vegetation so they must be protected from erosion by hard armor systems. Hard armor systems include fabric formed revetments, geocellular confinement systems, gabions, articulating concrete blocks, and, of course, riprap.

When a hard armor system is in place, water can seep in and out of the bank or slope, but the force of the water is resisted by the armor. As the water seeps, it can gradually carry soil particles with it. The resulting voids cause armor support to be lost over time. This process is called *piping*. Piping can culminate in shifting, rolling, or other instability in the hard armor system.

6.2.2 Typical Solutions

In a properly constructed armor system, a filter layer is placed between the bank soil and the armor to prevent piping. Traditional filter layers have been graded sand and aggregate layers. These graded filters are very costly to construct because they are constructed of select graded materials. Also, the filter layer must be a controlled thickness. On a steep slope, it can be very difficult to properly construct. For these two reasons, filter layers are often – and mistakenly - not included.

6.2.3 The Geosynthetic Solution

Hard armor systems are quite expensive to construct. Costs can range as high as $60 per square yard or more. The performance of even the most expensive system can only be assured if it is protected against piping. Consequently, a filter layer should always be used beneath hard armor system in an erosive environment. Geotextiles have become standard filter layers for hard armor systems because they overcome the drawbacks of graded sand and aggregate filters. First, they are manufactured with specific hydraulic and soil retention properties, which can be easily selected to complement the soil that needs protection. Secondly, they can be installed with ease on slopes – even under water (Figure 113).

Figure 113: Geo Synthetic solution for Armor system

Geotextile Properties

Depending on the gradation of the bank soil, either a nonwoven or a woven geotextile can be selected.

6.2.4 Installation of geotextiles under hard armor

Site Preparation

The site should be prepared in accordance with good engineering practices. The slope or bank should be graded smoothly and be free from stumps or debris. The surface should be compacted. Any pockets of soft soil should be removed and replaced with compacted earth material to provide a consistently uniform and strong, stable surface.

Deployment of the Geotextile

Unroll the geotextile on the prepared soil. The geotextile should be placed parallel to small ditch and stream alignments and perpendicular to lake or ocean shores. This arrangement minimizes the exposure of the geotextile to current or wave uplift.

Overlap the geotextile a minimum of 0.5 in order to provide continuous erosion protection. Secure the geotextile in place using pins, staples, fill material or rocks.

Placement of the Armor Layer

The armor, such as riprap or concrete blocks, should be placed in accordance with accepted practices. The drop height should be held to a minimum, and care must be exercised to avoid damage to the geotextile. If a drop height greater than 3 feet is anticipated, a heavier, more durable geotextile will be required (Figure 114)

Figure 114: Placement of Armor layer on geosynthetic material

Damage Repair

To repair portions of the geotextile damaged during placement of the armor, clear the damaged area, plus an additional three feet around it, of all armor material. Cover the area with a geotextile patch that extends three feet beyond the perimeter of damage. The patch should be placed beneath the damaged geotextile. Then carefully replace the armor material.

6.3 Rolled Erosion Control Products

6.3.1 Contextual Situation

Straw or hay can be chopped and blown onto a pre-seeded soil bed to provide mulching benefits during seed germination. The straw or hay fragments are secured to the ground surface by crimping, punching, tacking, netting or, in many cases, by nothing at all. Yet, the integrity of these mulches can be severely effected by:

- rain;
- wind;
- overland flow; and
- biological forces.

As a result, conventional mulches provide, at best, only a few weeks or months of protection to the bare soil often making grading and reapplication necessary.

6.3.2 Typical Solutions

Cellulose-based fibrous mulches can be hydraulically spray-applied with the seed. The fibers are dispersed in a solution that, when sprayed on bare soil, causes the fibers to stick to each other and to the soil. These "spray-on" mulch systems are somewhat more resistant to erosion than are dry-applied systems. Very heavy applications, called bonded fiber matrices, can be more erosion resistant, but are also more costly.

6.3.3 The Geosynthetic Solution – Green Engineering and RECPs

Erosion is often a problem when there is not enough protective cover on steep slopes or in drainage channels that have been designed to rely on vegetation for long-term erosion control. Vegetation is ideal for erosion control because it is relatively inexpensive to establish and maintain, it poses few safety problems, and it looks natural. Additionally, grasses can filter harmful chemicals out of contaminated water.

The maximum use of vegetation in erosion and sediment control is often referred to as ***green engineering*** and produces the following longterm benefits:

a) modest cost
b) improved visual aesthetics
c) proven performance
d) ease of installation
e) enhanced infiltration/groundwater recharge
f) reduced flow velocities
g) capture of sediments
h) hydrostatic pressure relief
i) resistance to heaving and differential settlement
j) self healing

Rolled erosion control products (RECPs) are designed to encourage and enhance the effectiveness of vegetation as an erosion control material. RECPs were introduced in the late 1960s to remedy the limitations of conventional mulches by dependably meeting the two principal objectives of mulches (Figure 115):

a) reducing soil loss
b) enhancing site re-vegetation.

Figure 115: Rolled erosion control products (RECPs)

Additionally, some RECPs can form a longterm composite layer with the vegetation – tying together the individual plants at the root level - to create "reinforced turf".

RECPs, used in lieu of or in combination with conventional materials, offer the potential to limit erosion while providing the following advantages over traditional materials:

a) RECPs undergo rigorous quality control in a controlled manufacturing environment to minimize material variation.
b) Large RECPs rolls can be easily and efficiently deployed.
c) RECPs are often less costly to purchase, transport and install than alternative hard systems.
d) RECPs are engineered for optimal performance.
e) RECPs can be installed quickly.
f) RECPs are easily shipped, competitively priced and readily available to any location.
g) RECPs performance is not dependent upon weather conditions.

Temporary, Degradable RECPs for Slopes

Temporary, degradable materials are used to prevent loss of soil from the seedbed and to enhance the establishment of vegetation where the vegetation alone should provide sufficient site protection once established (Figure 116). Open weave meshes (ECM), and erosion control blankets (ECB) are the most common temporary, degradable RECP systems. Typically natural fibers are used in these RECPs. The fibers are derived from the cultivation of various types of straw/hay or jute, or by the processing of coconut hulls (coir) or wood shavings (excelsior) and photodegradable polypropylene

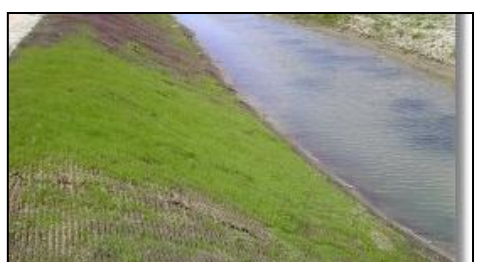


Figure 116: Temporary degradable RECPs

Long-Term, Non-Degradable RECPs

Figure 117: Long term non-degradable RECPs

Long-term, non-degradable RECPs, often called turf reinforcement mats (TRMs), furnish erosion protection and extend the erosion control limits of vegetation, soil, rock and other materials. These materials retain seeds and soil, stimulate seed germination, accelerate seedling development, and most importantly synergistically mesh with developing plant roots and shoots.

TRMs are composed solely of UV stabilized, non-degradable, polymeric fibers, nettings and/or filaments processed into three dimensional reinforcement matrices where design discharges exert velocities and shear stresses that exceed the limits of mature, natural vegetation. TRMs provide sufficient thickness, strength and void space to permit soil filling and/or retention and the development of vegetation within the matrix (Figure 117).

These materials may be installed at 1/3 to ½ the cost of hard armor techniques such as rock riprap and concrete. TRMs have been documented to withstand hydraulic shear stresses of up to 8 psf (400 kPa) and velocities of 20 ft/sec (6 m/sec). Newer generation high performance TRMs will resist shear stresses of up to 11 psf (550 kPa) and velocities of 25 ft/sec (8 m/sec). These levels of performance, combined with their cost effectiveness, improved aesthetics, and positive environmental attributes have lead to their endorsement by the EPA in a Storm Water Technology Fact Sheet-"Turf Reinforcement Mats"

6.3.4 Installing recps on slopes and in channels

Site Preparation

Grade the surface of installation areas so that the ground is smooth and compact. When seeding prior to installation, prepare for seeding by loosening the top 2" to 3" of soil. All gullies, rills, and any other disturbed areas must be fine graded prior to installation. Spread seed before or after mat installation as directed.

(*Note*: *Remove all large rocks, dirt clods, stumps, roots grass clumps, trash and other obstructions from the soil surface to allow for intimate contact between the soil surface and the mat.)*

Terminal anchor trenches are required at mat ends and intermittent trenches must be constructed across channels at 25' intervals. Terminal anchor trenches should be a minimum of 12" in depth and 6" in width, while intermittent trenches need be only 6" deep and 6" wide.

Installation on Slopes

Figure 118: Installing RECP on Slopes

Place the mat 2 to 3' over the top of the slope and into an excavate end trench measuring approximately 12" deep by 6" wide. Pin the mat at 1' intervals along the bottom of the trench, backfill and compact. (See note above for details of mat placement in trench.) Unroll the mat down (or along) the slope maintaining intimate contact between the soil and the mat. Overlap adjacent rolls a minimum of 3". Pin the mat to the ground using staples or pins in a 3' center-to-center pattern. Less frequent stapling/pinning is acceptable on moderate slopes (Figure 118).

Installation in Channels

Excavate terminal trenches (12" deep and 6" wide) across the channel at the upper and lower end of the lined channel sections. At 25' intervals along the channel, anchor the mat across the channel either in 6"x 6" trenches or by installing two closely spaced rows of anchors. Excavate longitudinal trenches 6" deep and wide along channel edges (above water line) in which to bury the outside mat edges (Figure 119).

Figure 119: Installation of RECP in Channel

Place the first mat at the downstream end of the channel. Place the end of the first mat in the terminal trench and pin it at 1' intervals along the bottom of the trench. The RECP should be placed upside down in the trench with the roll on the downstream side of the trench. Once pinned and backfilled, the mat is deployed by wrapping it over the top of the trench and unrolling it upstream. If the channel is wider than the provided rolls, place ends of adjacent rolls in the terminal trench, overlapping the adjacent rolls a minimum of 3'. Pin at 1' intervals, backfill and compact. Unroll the RECP in the upstream direction until reaching the first intermittent trench. Fold the mat back over itself, positioning the roll on the downstream side of the trench, and allowing the mat to conform to the trench. Then pin the mat (two layers) to the bottom of the trench, backfill and compact.

Continue up the channel (wrapping over the top of the intermittent trench) repeating this step at other intermittent trenches, until reaching the upper terminal trench. At the upper terminal trench, allow the mat to conform to the trench and secure with pins or staples. Backfill, compact, and then bring the mat back over the top of the trench and onto the existing mat (2' to 3' overlap in the downstream direction). Finally pin at 1' intervals across the mat.
When starting installation of a new roll, begin in a trench or shingle-lap ends of rolls a minimum of 1' with upstream mat on top to prevent uplifting. Place the outside edges of the mat(s) in longitudinal trenches, pin, backfill and compact.

Anchoring Devices

Eleven (11) gauge, at least 6" L x 1" W staples, 18" pins with 1.5" diameter washers, wooden stakes, or 12"-30" J-shaped pins (or bent rebar) having at least 1/4" diameter, are recommended for anchoring the RECP to the ground. Drive staples or pins so that the top of the staple or pin is flush with the ground surface. Anchor each mat every 3' along its center. Longitudinal overlaps must be sufficient to accommodate a row of anchors and uniform along the entire length of overlap and anchored every 3' along the overlap length. Roll ends may be spliced by overlapping 1' (in the direction of water flow), with the upstream/upslope mat placed on top of the downstream/downslope mat. This overlap should be anchored at 1' spacing across the mat. When installing multiple width mats heat seamed in the factory, all factory seams and field overlaps should be similarly anchored.

6.4 Silt Fence

6.4.1 Contextual Situation

Because accelerated erosion can result from denuded areas during construction, sediment control measures are needed to prevent construction-generated silt from being carried into nearby waterways or onto adjoining properties. Various types of sediment control measures are used to impede the flow of sediment-laden waters and to filter out sediment.

6.4.2 Typical Solutions

Sediment control structures composed of permeable material are placed so as to intercept sheet flow and low level channel flow from denuded areas. These barriers serve (1) to decrease the velocity of moving water, and (2) to trap suspended sediment. Traditional measures include barriers made of straw, gravel or crushed stone, and brush (Figure 120)

Figure 120: Typical silt fence made of straw

Improper use of filter barriers has been a major problem. For instance, straw barriers have been used in streams and drainage ways where high water velocities and volumes have destroyed or impaired their effectiveness. Another major problem has been that improper placement of the barriers has allowed undercutting and end flow, which have actually resulted in additions to rather than removal of sediment from runoff waters. Finally, inadequate maintenance and cleaning efforts have tended to greatly lower the effectiveness of the barriers.

Because of the problems noted above, straw barriers have generally shown low trapping efficiencies and high failure rates.

6.4.3 The Geosynthetic Solution – Silt Fence

Faced with the ineffectiveness of straw barriers, a second type of filter barrier, the silt fence, has emerged. Silt fences are composed of tough, durable, commercially available geotextiles attached to support posts (Figure 121). Silt fences can trap a much higher percentage of the suspended sediments than can straw bales. When properly performing, a well designed silt fence will:

a) initially screen silt and sand particles from runoff.
b) form a soil filter adjacent to the sift fence, reducing the flow of water through the fence.
c) create a pond behind the fence which serves as a sedimentation basin to collect suspended soils from runoff water.

Figure 121: A geo Synthetic Silt Fence

Over 20 million square yards of silt fence are used annually providing the following benefits over traditional sediment control structures:

a) Minimal labor required to install;
b) Low cost;
c) Highly efficient in removing sediment;
d) Very durable and sometimes reusable.

6.4.4 Installation of silt fence

Proper installation of sediment control structures is critical to their proper functioning. For example, it is not uncommon to observe a silt fence around a construction site that is not toed in. In these cases, runoff will be allowed to run under the fence and cause off-site migration of sediments. Following are some generally accepted installation guidelines for silt fences.

Figure 122: Silt fence Installed in trench

There are important details associated with proper installation of silt fence. The keys to performance are installation details, location, and maintenance.

Figure 123: Installation of post for Silt Fencing

Installation Details

1. Dig a minimum 150 mm x 150 mm (6 in. deep x 4 in. wide) trench where the silt fence will be installed (Figure 122).
2. Unroll the fence and position it in the down slope side of the trench. Place about 150 mm (6 in) of the fabric below ground level. For greater effectiveness, lay this portion of fabric along the bottom of the trench.
3. Backfill and compact soil in the trench to prevent runoff from getting underneath the fence. Fill the trench with soil and tamp by foot or with equipment.
4. Place posts on the down-slope side of the fabric (the side away from the expected runoff flow) and drive them into the ground (Figure 123).
5. Attach fabric and mesh reinforcement to the up-slope side of the posts (Figure 124).

Figure 124: Attaching geo synthetic fabric to post for silt fencing

Location

Unless otherwise specified, silt fence should be placed where it will intercept all runoff from the site. Extend the fence far enough uphill to prevent runoff from escaping around the ends. When continuing the fence line with a new roll of fencing, install the new fence to prevent silt from passing between the end of the existing fence and the beginning of the new.

Silt Fence Maintenance

Over the time required for any given Construction project, the control of erosion and sedimentation will be no better than the quality of the maintenance effort. The value of careful and prompt attention to maintenance cannot be overemphasized. Routine maintenance should be performed on all silt fencing. The fence line should be inspected after each significant rain event as well as at specified intervals. If silt buildup is discovered, it should be cleaned from the fabric either by sweeping or by hand shoveling. When fabric begins deteriorating either because of U.V. exposure or vandalism/debris, it should be replaced or a new fence line should be established adjacent to the old.

6.5 Design Consideration

Geotextiles are frequently used in armored erosion control and drainage applications. Some of the most common applications include slopes, dam embankments/ spilllways, shorelines armored with riprap, flexible block mats and concrete filled fabric formed systems. Drainage applications include pavement edge drains, french drains, prefabricated drainage panels and leachate collection/leak detection systems.

In all of the above applications, geotextiles are used to retain soil particles while allowing liquid to pass freely. But the fact that geotextiles are widely used where their primary function is filtration, there remains much confusion about proper filtration design procedures.

Therefore the design procedures for using geotextile in soil erosion application remain more or less same as of subsurface drainage system. The section 5.5.1 to 5.5.3, *Christopher and Holtz (1985)* details the assessment of variables that will be helpful in selection of the geotextile material for soil erosion control application.

However, following are the major guiding steps that should be considered before selecting the geotextile:

Step[1] 1: Application evaluation

A. *Critical/less critical*
   1. If the erosion control system fails, will there be a risk of loss of life?
   2. Does the erosion control system protect a significant structure,. and will failure lead to significant structural damage?
   3. If the geotextile clogs, will failure occur with no warning? Will failure be catastrophic?
   4. If the erosion control system fails, will the repair costs greatly exceed installation costs?

B. *B. Severe/less severe*
   1. Are soils to be protected gap-graded, pipable, or dispersive?
   2. Are soils present which consist primarily of silts and uniform sands with 85 % passing the 0.15 mm sieve?
   3. Will the erosion control system be subjected to reversing or cyclic flow conditions such as wave action or tidal variations?
   4. Will high hydraulic gradients exist in the soils to be protected? Will rapid drawdown conditions or seeps or weeps in the soil exist? Will blockage of seeps and weeps produce high hydraulic pressures?
   5. Will high-velocity conditions exist, such as in stream channels?

Step[2] 2: Obtain soil samples from the site

A. *Perform grain size analyses*
   1. Determine percent passing the 0.075 mm sieve.
   2. Determine the plastic index (PI).
   3. Calculate $C_u = D_{60}/D_{10}$'
   4. Obtain D_{85} for each soil and select the worst case soil (i.e., soil with smallest $B.D_{85}$) for retention.

[1]*Note: If the answer is yes to any of the above questions, the design should proceed under the critical/severe requirements; otherwise use the less critical/less severe design approach.*

[2]*Note: When the protected soil contains particles passing the 0.075 mm sieve, use only the gradation of soil passing the 4.75 mm sieve in selecting the geotextile (i.e., scalp off the +4.75 mm material).*

B. *[3]Perform field or laboratory permeability tests*

1. Select worse case soil (i.e., soil with highest coefficient of permeability k).

Step[4,5] 3: Evaluate armor material and placement

Geotextile filters are used between the soil and drainage or armoring medium. Typical drainage media include natural materials such as gravel and sand, as well as geosynthetic materials such as geonets and cuspated drainage cores. Armoring material is often riprap or concrete blocks. Often, an armoring system includes a sand bedding layer beneath the surface armor. The armoring system can be considered to act as a "drain" for water seeping from the protected slope.

The drainage medium adjacent to the geotextile must be identified. The primary reasons for this include

- Large voids or high pore volume can influence the selection of the retention criterion
- Sharp contact points such as highly angular gravel or rock will influence the geosynthetic survivability requirements.

A. *Size armor stone or riprap*

Where minimum size of stone exceeds 100 mm, or greater than a 100 mm gap exists between blocks, an intermediate gravel layer 150 mm thick should be used between the armor stone and geotextile. Gravel should be sized such that it will not wash through the armor stone *(i.e.,* D_{85} gravel $\geq D_{15}$ riprap/5).

B. *Determine armor stone placement technique (i.e., maximum height of drop).*

Step 4: Calculate anticipated reverse flow through erosion control system i.e. define boundary conditions

Here we have to estimate the maximum flow from seeps and weeps, maximum flow from wave runout, or maximum flow from rapid drawdown.

Defining boundary conditions:

a. Evaluate Confining Stress

The confining pressure is important for several reasons:

a) High confining pressures tend to increase the relative density of coarse grained soil, increasing the soil's resistance to particle movement. This affects the selection of retention criteria
b) High confining pressures decrease the hydraulic conductivity of fine grained soils, increasing the potential for soil to intrude into, or through, the geotextile filter.
c) For all soil conditions, high confining pressures increase the potential for the geotextile and soil mass to intrude into the flow paths. This can reduce flow capacity within the drainage media, especially when geosynthetic drainage cores are used.

---

[3]*Note: The permeability of clean sands (< 5 % passing 0.075 mm sieve) with 0.1 mm* D_{10} *< 3 mm and* C_u *< 5 can be estimated by Hazen's formula,* $k = (D_{10})^2$ *(k in cm/s;* D_{10} *in mm). This formula should not be used for finer-grained soils.*

[4]*Retention vs. Permeability Trade-Off: The drainage medium adjacent to the geotextile often affects the selection of the retention criterion. Due to the conflicting nature of filter requirements, it is necessary to decide whether retention or permeability is the favored filter characteristic. For example, a drainage material that has relatively little void volume (i.e., a geonet or a wick drain) requires a high degree of retention from the filter. Conversely, where the drainage material void volume is large (i.e., a gravel trench or riprap layer), the permeability and anti-clogging criteria are favored.*

[5]*Design reference: FHWA Hydraulic Engineering Circular No. 15 (FHWA, 1988).*

b. Define Flow Conditions

Flow conditions can be either steady-state or dynamic. Defining these conditions is important because the retention criterion for each is different. Examples of applications with steady-state flow conditions include standard dewatering drains, wall drains and leachate collection drains. Inland waterways and shoreline protection are typical examples of applications where waves or water currents cause dynamic flow conditions.

A. *General case – use Darcy's law*

$$q = kiA$$

where:

q = outflow rate *(L^3/T)*

k = effective permeability of soil (from Step 2B above) *(L/T)*

I = average hydraulic gradient in soil (*e.g.,* tangent of slope angle for wave runoff) (dimensionless)

A = area of soil and drain material normal to the direction of flow *(L^2)*. It can be evaluated using a unit area.

Use a conventional flow net analysis (Cedergren, 1977) for seepage through dikes and dams or from a rapid drawdown analysis.

B. *Specific erosion control systems*

Hydraulic characteristics depend on expected precipitation, runoff volumes and flow rates, stream flow volumes and water level fluctuations, anticipated normal and maximum wave heights, direction of waves and tidal variations. Detailed information on determination of these parameters is available in the FHWA (1989) Hydraulic Engineering Circular No. 11.

Step 5: Determine geotextile requirements

A. *Retention Criteria*

From Step 2A, obtain D_{85} and C_u; then determine largest pore size allowed.

AOS or $O_{95(geotextile)} < BD_{85(soil)}$

where:

B = 1 for a conservative design.

For a less-conservative design and for ≤ 50% passing 0.075 mm sieve:

B = 1	for $C_u \le 2$ or ≥ 8
B = 0.5	C_u for $2 \le C_u \le 4$
$B = 8/C_u$	for $4 < C_u < 8$

For ≥ 50% passing 0.075 mm sieve:

B = 1	for wovens
B = 1.8	for nonwovens

and AOS or $O_{95(geotextile)} \le 0.3$ mm

For non dispersive cohesive soils (PI> 7) use:

AOS or $O_{95} \le 0.3$ mm

If geotextile and soil retained by it can move:

B = 0.5

B. *Permeability/Permittivity Criteria*

1. Less Critical/Less Severe
   $K_{geotextile} \geq K_{soil}$

2. Critical/Severe
   $K_{geotextile} \geq 10\ K_{soil}$

3. Permittivity Requirement Ψ
   $\Psi \geq 0.7\ sec^{-1}$ for < 15% passing 0.075 mm
   $\Psi \geq 0.2\ sec^{-1}$ for 15 to 50% passing 0.075 mm
   $\Psi \geq 0.1\ sec^{-1}$ for> 50% passing 0.075 mm

4. Flow Capacity Requirement
   $q_{geotextile} \geq (A_t/A_g)\ q_{required}$
   or
   $(k_{geotextile}/t)\ h\ A_g \geq q_{required}$

   where: $q_{required}$ is obtained from Step 4 above.
   $k_{geotcxtile}/t = \Psi$ = permittivity
   h = average head in field
   A_g = area of fabric available for flow *(e.g.,* if 50% of geotextile covered by flat rocks or riprap, A_g = 0.5 total area)
   A_t = total area of geotextile

C. *Clogging Criteria*

1. Less critical/less severe
   a. Perform soil-geotextile filtration tests.
   b. Alternative: From Step 2A obtain D_{15}; then determine minimum pore size requirement, for soils with $C_u > 3$, from
      $O_{95} \geq 3\ D_{15}$
   c. Other qualifiers

For soils with % passing 0.075 mm	> 5 %	< 5%
Woven monofilament geotextiles: Percent Open Area ≥	4 %	10%
Nonwoven geotextiles: Porosity ≥	50%	70%

   To minimize the risk of clogging, follow these criteria:
   a. Use the largest opening size (O_{95}) that satisfies the retention criteria
   b. For nonwoven geotextiles, use the largest porosity available, never less than 30%.
   c. For woven geotextiles, use the largest percentage of open area available, never less than 4%.

2. Critical/severe
   Select geotextiles that meet retention, permeability, and survivability criteria; as well as the criteria in Step 5C.1 above; perform a filtration test.

For sand and silt soils (*i.e.*, k > 10^{-7} m/s) gradient ratio filtration test is suggested. The hydraulic conductivity ratio test is recommended for fine-grained soils (*i.e.*, k < 10^{-7} m/s), if appropriately modified.

D. *Survivability*

Select geotextile properties required for survivability from Table 10 given below. Add durability requirements if applicable. Check for abrasion and check drop height *should not be missed*. Evaluate worst case scenario for drop height.

Geotextile strength property requirements[1,2,3,4] For permanent erosion control geotextiles (after AASHTO, 1997)						
Property	**ASTM**	**Units**	**Geotextile Class 1[5,6] Elongation[8]**		**Geotextile Class 2[5,6,7] Elongation[8]**	
			< 50%	≥ 50%	< 50%	≥ 50%
Grab Strength	D 4632	N	1400	900	1100	700
Sewn Seam Strength[9]	D 4632	N	1260	810	990	630
Tear strength	D 4533	N	500	350	400[10]	250
Puncture strength	D 4833	N	500	350	400	250
Burst Strength	D 3786	kPa	3500	1700	2700	1300
Ultraviolet stability	D 4355	%	50%strength retained after 500 hours of exposure			

NOTES:

1. Acceptance of geotextile material shall be based on ASTM D 4759.
2. Acceptance shall be based upon testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer's certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354.
3. Minimum; use value in weaker principal direction. All numerical values represent minimum average roll value (i. *e.*, test results from any sampled roll in a lot shall meet or exceed the minimum values in the table). Lot samples according to ASTM D 4354.
4. Woven slit film geotextiles will not be allowed.
5. Use Class 2 for woven monofilament geotextiles, and Class 1 for all other geotextiles.
6. As a general guideline, the default geotextile selection is appropriate for conditions of equal or less severity than either of the following:
   a. Armor layer stone weights do not exceed 100 kg, stone drop is less than 1 m, and no aggregate bedding layer is required.
   b. Armor layer stone weights exceed 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150 mm thick aggregate bedding layer designed to be compatible with the armor layer.

   More severe applications require an assessment of geotextile survivability based on a field trial section and may require a geotextile with higher strength properties.
7. The engineer may specify a Class 2 geotextile based on one or more of the following:
   a. The engineer has found Class 2 geotextiles to have sufficient survivability based on field experience.
   b. The engineer has found Class 2 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
   c. Armor layer stone weighs less than 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150 mm thick aggregate bedding layer designed to be compatible with the armor layer.
   d. Armor layer stone weights do not exceed 100 kg, stone is placed with a zero drop height.
8. As measured in accordance with ASTM D 4632.
9. When seams are required. Values apply to both field and manufactured seams.
10. The required MARV tear strength for woven monofilament geotextiles is 250 N.

Table 11: Geotextile strength property requirements for permanent soil erosion

For convineance, Charts 1 and 2 below indicate the use of particle-size parameters for determining retention criteria. These charts show that the amount of gravel, sand, silt and clay affects the retention criteria selection process. Chart 1 shows the numerical retention criteria for steady-state flow conditions; Chart 2 is for dynamic flow conditions.

For predominantly coarse grained soils, the grainsize distribution curve is used to calculate specific parameters such as Cu, C'u, Cc, that govern the retention criteria

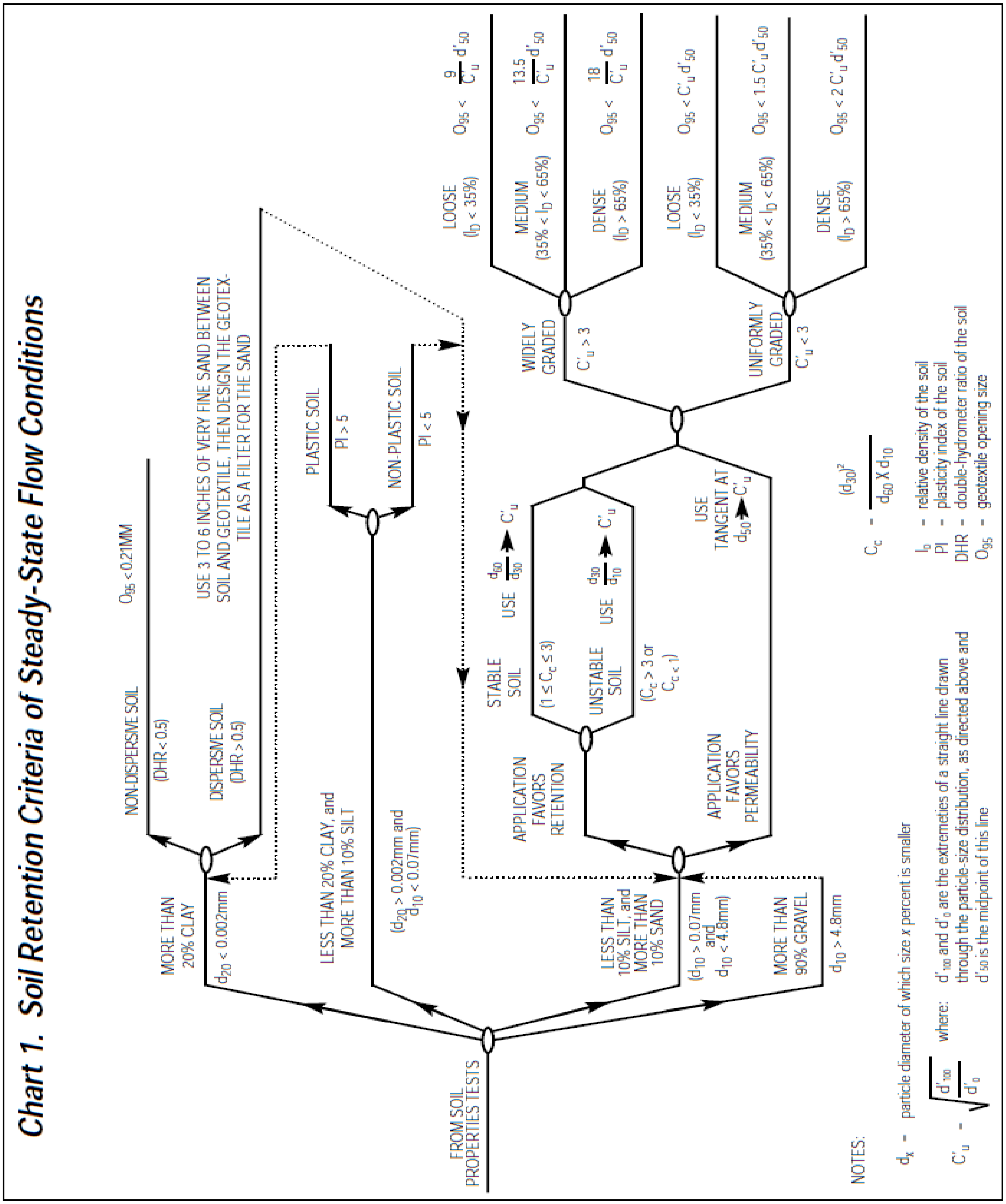
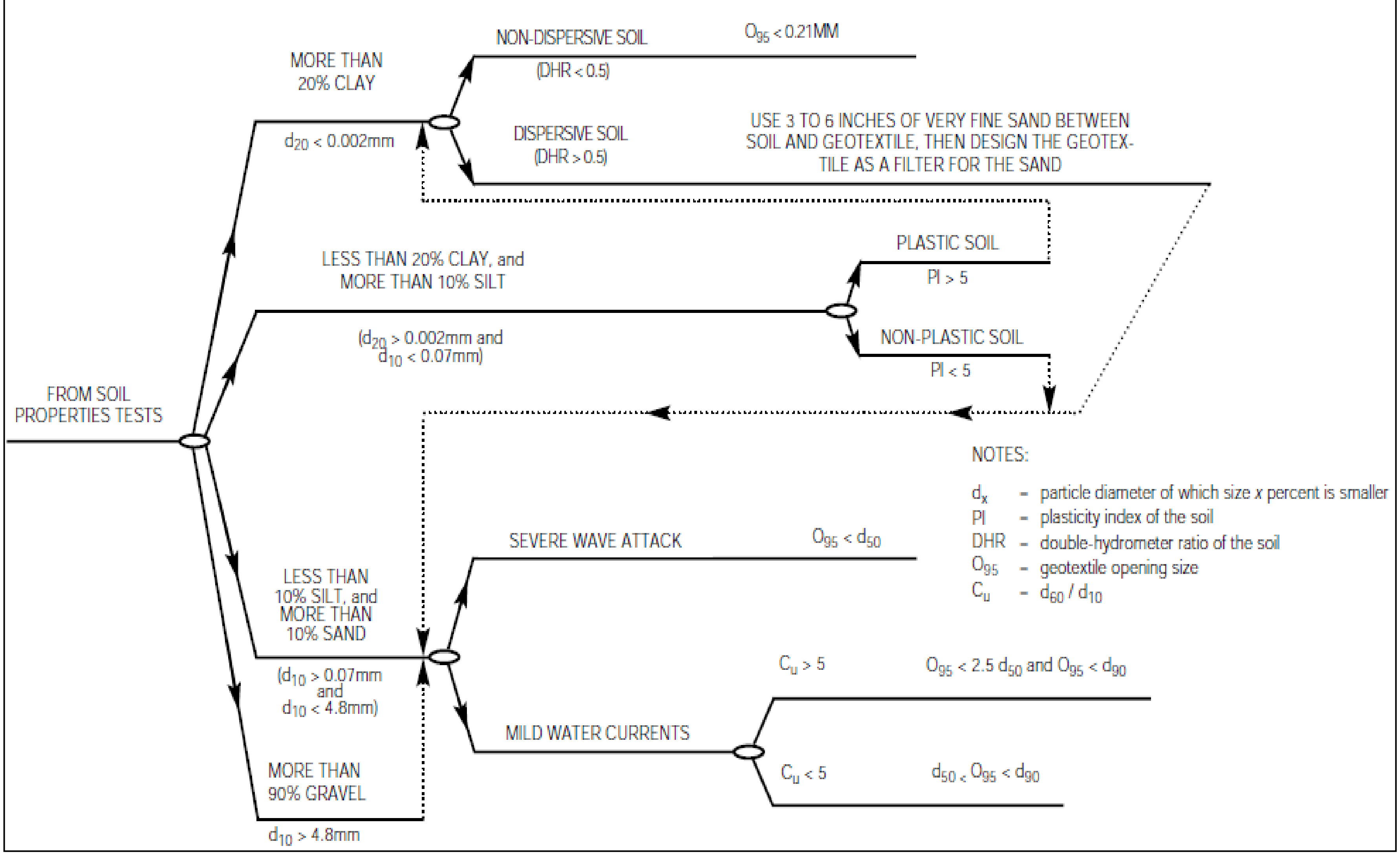


Chart 2. Soil Retention Criteria of Dynamic Flow Conditions



The soil hydraulic conductivity, often referred to as permeability should be done. *For critical applications*, such as earth dams, soil permeability should be lab measured using representative field conditions in accordance with test procedure ASTM D 5084 while *for non-critical applications*, estimated typical value of soil-hydraulic conductivity are given in table 12 below:

Typical Hydraulic Gradients[a]	
Drainage Applications	**Typical Hydraulic Gradient**
Channel Lining	1.0
Standard Dewatering Trench	1.0
Vertical Wall Drain	1.5
Pavement Edge Drain	1.0
Landfill LCDRS	1.5
Landfill LCRS	1.5
Landfill SWCRS	1.5
Shoreline Protection Current Exposure	1.0[b]
Shoreline Protection Wave Exposure	10[b]
Dams	10[b]
Liquid Impoundments	10[b]
[a]*Table developed after Giroud, 1988.* [b]*Critical applications may require designing with higher gradients than those given.*	

Table 12: Typical hydraulic gradients

Step 6: Estimate costs

Calculate the volume of armor stone, the volume of aggregate and the area of the geotextile. Apply appropriate unit cost values.

A. Grading and site preparation (LS) ______________
B. Geotextile *(/m²)* ______________
C. Geotextile placement *(/m²)* ______________
D. In-place aggregate bedding layer *(/m²)* ______________
E. Armor stone (/kg) ______________
F. Armor stone placement *(/kg)* ______________
G. Total cost ______________

Step 7: Prepare specifications

Include for the geotextile:

A. General requirements
B. Specific geotextile properties
C. Seams and overlaps
D. Placement procedures
E. Repairs
F. Testing and placement observation requirements

Step 8: Obtain samples of the geotextile before acceptance.

Step 9: Monitor installation during construction, and control drop height. Observe erosion control systems during and after significant storm events.

7 Geosynthetics in Reinforced Soil Systems

7.1 Introduction

Though the use of tensile inclusions in soil structures dates back several thousand years to the construction of religious structures in ancient Babylonia, it was only three decades ago that Henri Vidal, a French architect, pioneered modern earth reinforcement techniques. These techniques involved the incorporation of tensile elements into a soil mass to complement the soil's compressive strength and to improve the mechanical properties of the soil mass.

Figure 125: Engineered Soil Fill

Beginning in the early 1970's, experimentation using geotextiles as soil reinforcement was conducted in Europe and the United States. The U.S. Forest Service constructed full-scale wrapped-face walls using geotextiles in 1974 and 1975 and the U.S. Army Corps of Engineers began using geosynthetics in reinforcement applications in 1978. Under FHWA sponsorship, highway departments in New York, Colorado, and Oregon constructed geotextile reinforced walls in the early 1980's. These successes attracted other candidate forms of plastic inclusions such as geogrids manufactured of polyethylene and coated polyester.

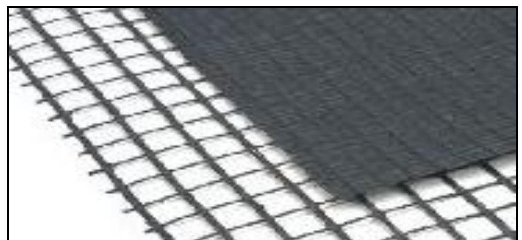


Figure 126: Geosynthetic Reinforcement

These and other reinforced soil systems have become known as mechanically stabilized earth (MSE) and their use has significantly increased. The primary types of MSE systems which have emerged include: mechanically stabilized earth walls (MSEW); reinforced soil slopes (RSS); reinforced embankments over soft foundations (RESF). MSEW and RSS have become especially important in highway construction as their use reduces the required width of new right-of-way and facilitates construction within existing limited right-of-way. RESF are recognized as a cost-effective alternative to traditional techniques for constructing earthen embankments over low strength foundations.

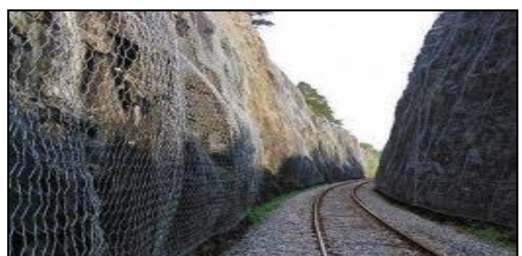


Figure 127: Face or Slope Protection

Geosynthetic reinforced soil systems include:

- Engineered soil fill (Figure 125)
- Geosynthetic reinforcement (Figure126)
- Facing or slope protection system (Figure 127)

7.2 Embankment over Soft Foundations

7.2.1 Contextual Situation

Historically, construction of embankments is costly and environmentally sensitive when very soft soils, especially in wetlands, are encountered. The primary problem with these soft soils results from their low shear strength and excessive consolidation settlements requiring special construction practices and leading to high construction costs. (Figure 128)

Figure 128: Soft Soil

7.2.2 Typical Solutions

Several methods of treatment are available to reduce the problems associated with soft foundations. These methods include:

a) Removal and replacement of soft soil.
b) Displacement of compressible material by end-loading.
c) Staged construction - placing fill at controlled rates to allow for consolidation and strength gains.
d) Installation of drains to facilitate consolidation.
e) Pre-loading the site to reduce settlements of the structure and provide higher strength.
f) Deposit improvement using admixtures (e.g. soil, cement, lime) or injections
g) Reinforcement of the soil matrix using a structural element.

7.2.3 Geosynthetic Solutions

Geosynthetic solutions include geotextiles, geogrids and combinations of geotextiles and geogrids. While a wide variety of site improvement methods have been used during the past decade, soil reinforcement has emerged as an efficient, economical and effective solution to the problem of constructing embankments over soft soils (Figure 129).

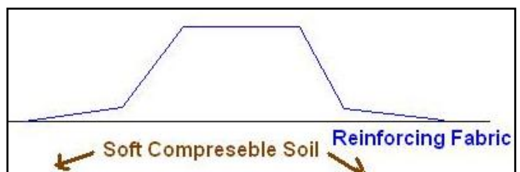


Figure 129: Reinforced Embankment Concept

Geotextiles

For many years very strong fabrics have been employed in constructing embankments over soft ground. Very strong fabrics, with tensile strengths ranging from 1000 lb/in to 4500 lb/in, are placed over a prepared working table and earthen embankments are erected using a system of controlled height lifts to maintain uniform pressure on the subgrade.

Geogrids

Smaller embankments may also be designed and constructed using single or multiple layers of high strength, high modulus reinforcing geogrids at the base. The geogrid(s) reduce lateral displacement and improve the overall stability of the soil embankment.

Combination systems

Geogrids are limited in ultimate strength by structure and polymer properties. In a combined system, a geogrid can be employed to facilitate the development of a working platform which is subsequently covered with the very strong(>2000 lb/in) geotextile. The embankment is then constructed on the geotextile

7.3 Reinforced Steepened Slopes

Advantages of RSS Systems

Slopes are common geographic features and can be found everywhere with steepness ranging from gentle swales to ultra steep mountain sides. The full range of these terrain features is commonly found adjacent to transportation rights of way and building sites. The economics associated with a particular highway alignment or with the development of a parcel of land may be determined by the ability to create sufficient flat, or level, land to satisfy space, safety, or access requirements. On highway and building projects relatively flat areas are preferred. These areas must be constructed by excavation or filling in the existing terrain, often leaving significant grade changes at the edges of the excavation.

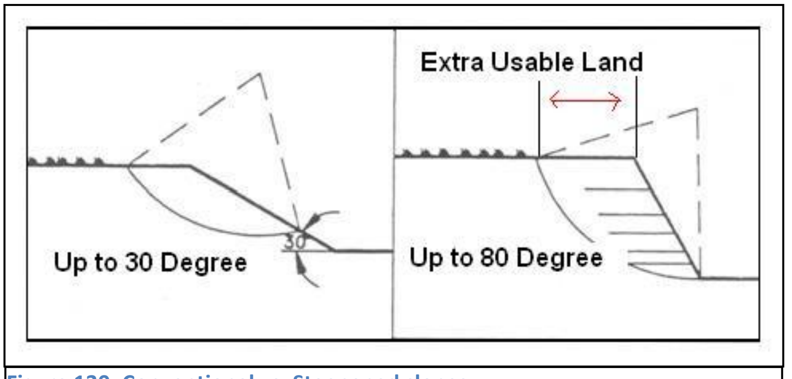


Figure 130: Conventional vs. Steepened slopes

Reinforced steepened slopes provide a costeffective means to achieve more efficient grade changes than is possible with conventional unreinforced slopes (Figure 130).

Geosynthetic reinforced steepened slopes are soil structures constructed with a slope face angle up to as high as 80 degrees from the horizontal. Typical unreinforced soil slopes are limited to a slope face angle of approximately 30 degrees, or less, depending on the angle of repose of the slope soil. The additional steepness provided by reinforced slopes minimizes the extent to which grade change structures, i.e. slopes, must encroach into highway right-of-way or onto building sites.

Details of RSS Systems

Like conventional soil slopes, reinforced slopes are constructed by compacting soil in layers while stepping the face of the slope back at an angle. Subsequently, the face is protected from erosion by vegetation or other protective systems ranging from concrete slabs to Geocell walls and including a wide variety of systems. Additional geosynthetic elements are incorporated into reinforced steepened slopes to facilitate drainage, minimize ground water seepage and to assure the stability of the steepened slope and the

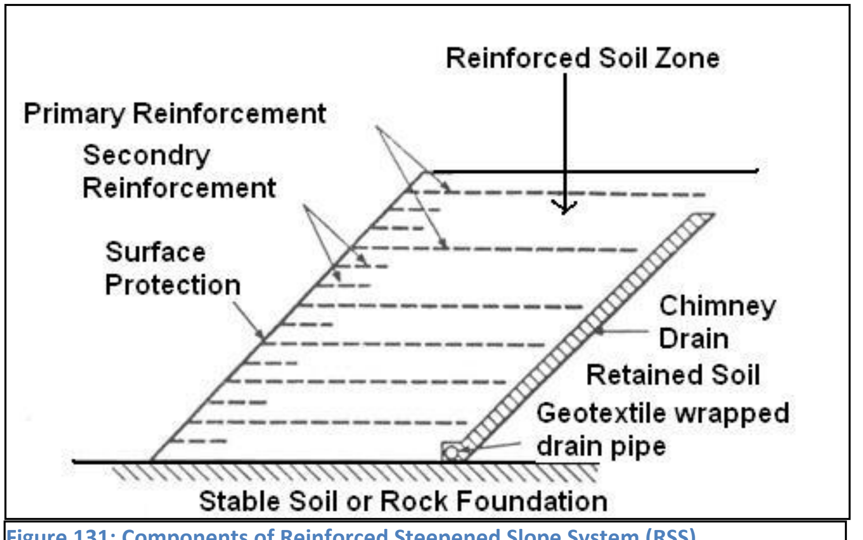


Figure 131: Components of Reinforced Steepened Slope System (RSS)

erosion resistance of the facing (Figure 131). Following are the detailed components of a geosynthetic reinforced steepened slope system:

a) Foundation - Stable soil or bedrock upon which the slope is constructed. Stability in the foundation is assumed.
b) Retained Soil - The soil which remains in place beyond the limits of the excavation.
c) Subsurface Drainage – Geosynthetic drainage medium installed at the limits of the reinforced soil zone to control and collect ground water seepage.
d) Reinforced Soil - The soil which is placed in lifts adjacent to the retained soil and incorporates horizontal layers of reinforcing to create the sloped structure.
e) Reinforcement - Geosynthetic, either geogrid or geotextile with sufficient strength and soil compatible modulus, placed horizontally within the slope to provide tensile forces to resist instability.
f) Surface Protection - The erosion resistant covering of the finished slope surface.

7.4 Reinforced Soil (RS) Walls or Mechanically Stabilized Earth (MSE) Walls

Advantages of MSE Wall Systems

The economics associated with a particular highway alignment or with the development of a parcel of land may be determined by the ability to create sufficient flat, or level, land to satisfy space, safety, or access requirements. Retaining walls are a common structural feature located adjacent to highways and building sites in many areas of the country. Retaining walls are popular because their vertical or near vertical faces increase the width of the relatively flat areas which are preferred for both highways and building sites. These areas must be excavated out of the existing terrain often requiring significant grade changes at the edges of the excavation. Though there are many types of retaining walls, geosynthetic reinforced (MSE) soil walls provide vertical grade changes at significantly less cost than conventional retaining walls.

Geosynthetic reinforced soil walls are soil structures constructed with the face at an angle of close to 90 degrees from the horizontal. Conventional retaining walls are gravity structures which must be massive enough to resist the destabilizing forces of the retained fill. Reinforced soil walls create gravity retaining structures out of the fill itself by incorporating geosynthetic reinforcement into the design.

Details of an MSE Wall System

Unlike conventional retaining walls, reinforced soil walls are constructed by compacting fill soil in layers between intermittent horizontal geogrid layers. These geosynthetic elements are incorporated into fill soil to assure the stability of the entire soil/facing system. Following are the detailed components of a geosynthetic reinforced soil wall system:

Figure 132: MSE Wall

a) *Foundation* - Stable soil or bedrock upon which the slope is constructed. Stability in the foundation is assumed.
b) *Retained/Backfill Soil* - The soil which remains in place beyond the limits of the excavation or is placed behind the reinforced zone.

c) *Subsurface Drainage* – Geosynthetic drainage medium installed at the base and back of the reinforced soil zone to control and collect ground water seepage.
d) *Reinforced Soil* - The soil which is placed in lifts between the facia and the retained soil and which incorporates horizontal layers of reinforcing to create the gravity wall structure.
e) *Reinforcement* - A geogrid or geotextile with sufficient strength and soil compatible modulus, placed horizontally within the soil to provide tensile forces to resist instability.
f) *Facia* - The nearly vertical covering, or face, of the reinforced zone which provides the desired appearance and retains near surface soils. A positive connection must be provided between the facia and the geogrid reinforcement.

7.5 Design Consideration

Steepened slopes have become increasingly advantageous due to the desire to increase land usage and decrease site development costs. The proven concept of tensile reinforcement allows construction of slopes with far steeper face angles than are permitted by the soils natural angle of repose. Steepened slopes reinforced with geosynthetics can increase land usage substantially while providing a natural appearance.

The stability of a reinforced soil slope can be threatened by erosion due to surface water runoff, or more severe forces associated with water currents and wave attack. Slope face erosion may create rills and gullies, and result in surface sloughing and possibly deep-seated failure (Berg.1993). Erosion control and re-vegetation measures must, therefore, be an integral part of all reinforced soil slope system designs. The type of erosion control facing option selected depends on the finished slope face angle

Erosion protection options

1. Soft Armor (Slope Face Angle < 45°)
   a. Rolled-Erosion Control Product (RECP)
   b. Cellular Confinement Stabilization

2. Hard Armor (Slope face angle > 45°)
   a. Welded Wire Basket Facing
   b. Stacked Cellular Confinement Facing
   c. Open Face SRW Facing
   d. Gabion Basket Facing

System Components for RSS

Reinforced slopes are constructed by compacting soil in layers while shifting the face of the slope back to create the desired angle. Subsequently, the face is protected from erosion by vegetation or other means. In addition, geosynthetic elements maybe incorporated into reinforced steepened slopes to minimize ground water seepage and to enhance the stability of the steepened slope and the erosion resistance of the facing. The following are the typical components of a geosynthetic reinforced steepened slope system:

- Foundation - Stable soil or bedrock upon which the slope is constructed. Stability in the foundation is assumed.
- Retained Soil - The soil which remains in place beyond the limits of the excavation.

- Subsurface Drainage - Geosynthetic drainage medium installed at the limits of the reinforced soil zone to control, collect, and route ground water seepage.
- Reinforced Soil - The soil which is placed in lifts adjacent to the retained soil and incorporates horizontal layers of reinforcement to create the sloped structure.
- Primary Reinforcement- Geosynthetic, either geogrid or geotextile with sufficient strength and soil compatible modulus, placed horizontally within the slope to provide tensile forces to resist instability.
- Secondary Reinforcement - Geosynthetic, either geogrid or geotextile that is used to locally stabilize the slope face during and after slope construction.
- Surface Protection - The erosion resistant covering of the finished slope surface.

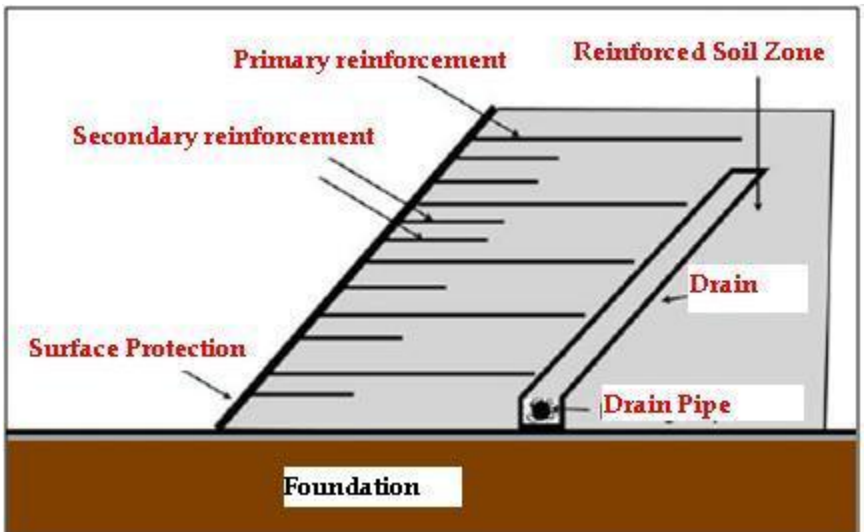


Figure 133: Components of Geosynthetic RSS

7.5.1 Site Specific Design Considerations

1. Slope Geometry

The actual steepness requirements for a slope will result from the site layout and engineers should determine it by assessing the topographic relationship between the toe line and the crest line. The grades, or steepness, of the slope as well as slope height, will generally vary along the slope alignment requiring the engineer to select reasonably spaced, representative cross-sections for reinforcement design. When selecting slope angle, b, and slope height, H, slope angles should not be steeper than 70° and slope heights may be limited by surface water runoff considerations.

2. Foundation Conditions

Slope stability analysis generally assumes that the foundation is firm, i.e. strong and stable, relative to the slope fill soils and thus deep-seated failure modes are not typically a concern. However, it's still recommended that the engineer must assess the foundation conditions in the proximity of a proposed reinforced slope to assure that plane passing through the foundation will not fail. Soil test borings can be made to estimate subsoil strength and to locate geologic faults and ground water elevations.

3. Ground Water

Ground water is a potential source of problems in soil structures. Unexpected ground water seepage can alter fill and foundation properties, cause internal erosion, "slicken" potential failure surfaces or increase horizontal and vertical loadings. All of these conditions can be minimized by identifying ground water sources, controlling seepage from them, and designing for the resulting expected soil moisture conditions. Whenever possible, ground water elevations should be maintained well below the foundation level.

4. Fill

Reinforced slopes can be constructed from a wide variety of soils. This often allows on-site soils to be used, minimizing the need to transport material on or off site. Preferred fill materials are predominately granular or low plasticity fine-grained soils. Fill soil properties should be obtained from laboratory testing of the candidate soils. Selecting soil properties for use in design are given in Table 13

5. Surcharge Loading

Additional vertical and horizontal loads are applied to the reinforced slope system by any surcharge or externally applied loading, that is imposed upon the system. These loadings can result from structures, vehicles, or even additional soil masses. Applicable surcharge loadings must be resolved into corresponding horizontal and vertical forces on the reinforced slope system. One way of doing this is to transform the surcharge load, q, into an equivalent additional soil layer equal to q/g.

6. Other External Loading

Other externally applied loading such as point loads, seismic loads, or hydrostatic loads are beyond the scope of this document, but must still be addressed by the designer if they are present. This includes pseudo-static earthquake design.

Soil fill and Geosynthetic Reinforcement Properties

7. Selection of material

Each prospective fill type will develop unique strength and reinforcement interaction properties under the expected compaction and soil moisture conditions. Therefore, the cost-effectiveness of a reinforced slope can be affected by the fill and corresponding reinforcement type selected. A thorough evaluation of potential fill and reinforcement materials is necessary to identify the best possible combination.

8. Soil Properties

The critical equilibrium for steep reinforced slopes is usually governed by long term stability conditions. The soil strength is thus described in terms of its maximum unit weight, γ_{max}, effective friction angle φ'_f, and effective cohesion, c'(2). These properties are used to determine the stability of soil layers under design loadings. Table 13 outlines some typical soil types and ranges of associated soil properties. This information is for general groups of soils and should be used only as a guide. Specific soil properties for the foundation, fill and embankment soils on a given project should be determined from field and laboratory testing.

Typical Soil Properties(1)				
Soil Description	**USCS Class***	**(Deg) 0′**	**MDD** Std Compact (lb/ft3)**	**Optimum Moisture Content (%)**
Well-graded sand-gravel	GW	>38	125-135	11 - 8
Poorly-graded sand-gravel	GP	>37	115-125	14 – 11
Silty gravels, poorly graded sand-gravel-silt	GM	>34	120-135	12 – 8
Clayey gravels, poorly graded sand-gravel-clay	GC	>31	115-130	14 – 9
Well graded clean sand, gravelly sands	SW	38	110-130	16 – 9
Poorly-graded clean sands, gravelly sands	SP	37	100-120	21 – 12
Silty clays, sand-silts - clays	SM	34	110-125	16 – 11
Clayey sands, sand-clays	SC	31	105-125	19 – 11
Silts and clayey silts	ML	32	95-120	24 – 12
Clays of low plasticity	CL	28	95-120	24 – 12
Clayey silts, elastic silts	MH	25	70-95	40 – 24
Clays of high plasticity	CH	19	75-105	36 – 19
**Unified Soil Classification System* ***MDD=max dry density*				

Table 13: Typical Soil Properties

Soil properties used in the design of reinforced slopes must reflect the expected *in-situ* conditions. Cohesion in the soil is often neglected which provides additional conservatism to the design. The controlled placement of the fill and the flexibility of the finished structure generally assure a drained, large strain condition. The soil strength is properly described by either a large strain or a factored peak effective soil friction angle, φ'_f. The factored soil friction angle is calculated using Equation 1 below:

$$\varphi'_f = \tan^{-1}[(\tan\varphi')/FS] \qquad \text{Eq. 1}$$

9. Geosynthetic Reinforcement

The geosynthetic reinforcement, i.e. geogrids or geotextiles, used in slopes must satisfy both strength and soil interaction requirements. The strength requirements focus on the long term design strength (LTDS) of the reinforcement. Soil interaction properties include coefficients of direct sliding, C_{ds}, and pullout, C_i.

10. Strength Properties

For reinforced soil structures it is important that the reinforcement be "compatible" with the soil. This means that the long term design strength of the reinforcement should be acheived at a total strain level (elastic + creep) corresponding to a strain in the soil matching peak soil strength. For most soils the strain level at peak soil strength is between 3% and 10% and is easily determined by laboratory testing. As a result, a total strain level not to exceed 10% is commonly used for steepened slopes, though a limiting strain of 5% may be appropriate if sensitive structures are adjacent to the slope.

The long term design strength (LTDS) of reinforcement is determined by applying partial factors of safety to the ultimate tensile strength. Partial factor of safety are responsible for creep, chemical & biological durability and installation damage. Below equation 2 is used to calculate LTDS.

$$LTDS = T_{ult} / [RF_{cr} \times RF_{id} \times R_{Fd}] \qquad \text{Eq. 2}$$

Where:

T_{ult} = ultimate wide width tensile strength
RF_{cr} = reduction factor for creep deformation
RF_{id} = reduction factor for installation damage
RF_d = reduction factor for durability

11. Soil Interaction Properties

The coefficient of direct sliding, C_{ds}, and the pullout interaction coefficient, C_i , are both measures of the interaction between the geosynthetic and the soil and are determined by laboratory testing. The value C_{ds} is used in the calculation of factors of safety involving a block of soil sliding over a geosynthetic layer. C_i is used to determine the length of geosynthetic which must extend beyond the *critical failure surface* to fully develop, or anchor, the reinforcement. Equation 3 below is used to calculate this 'embedment' length, L.

$$T_{pull} = 2 \times C_i \times L \times o'_v \times \tan\varphi'_f \qquad \text{Eq. 3}$$

7.5.2 Stability analysis for embankments over stable foundations and steepened slopes

1. **Two-part Wedge Analysis**

The two-part wedge analysis method for a soil slope or embankment over a stable foundation can be referenced to Figure 134. A trial failure mechanism is defined by potential linear failure surfaces that are assumed to propagate from a point on the slope (point A) to a breakpoint (B) and then exit at the slope surface at point (C) located at or beyond the slope crest. The potential failure zone therefore comprises two soil masses (wedges) identified as regions 1 and 2 in the figure. If a reinforcement layer intersects a potential failure surface then it provides a horizontal restraining force that is included in the overall calculation of horizontal force equilibrium

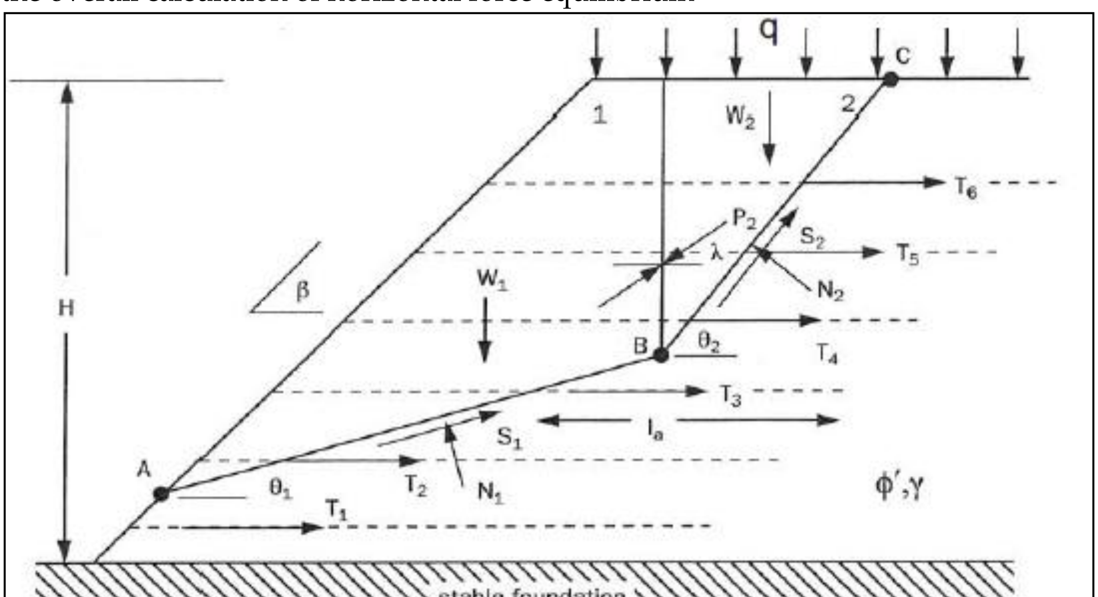


Figure 134: Two-part wedge analysis

In a typical analysis a large number of two-part wedge geometries must be inspected in order that the critical geometry is found (i.e. the two-part wedge giving the lowest factor-of-safety against slope failure). It is clear that the only practical method of identifying the critical failure mechanism is to use a computer program. Computer programs RSS, available from Federal Highway Administration by ADAMA (FHWA NH1-00-043) engineering can be used to carry out two and three part wedge analysis for slopes with varying geometrics, soil properties, and groundwater elevations. Other commercial software programs are also available.

a. Stability Calulations

The stability calculations for an assumed two-part wedge failure mechanism are in reference to Figure 134

For illustration, the procedures described in this section are restricted to reinforced slopes with uniform, cohesion-less soils (i.e., c'= 0, φ′ > 0) and the groundwater table well below the toe elevation.

The destabilizing forces acting on the slope include the bulk weight of the trial wedges W_1 and W_2 and any uniformly distributed surcharge q. The resisting forces include the shear resistance developed along the bottom and top failure planes, S_1 and S_2 and the horizontal tensile forces developed by the intersected reinforcement layers. The shearing resistance along the failure planes AB and BC are assumed to be Coulomb type with $S_1 = N_1 \times \tan\varphi'_f$ and $S_2 = N_2 \times \tan\varphi'_f$. The soil friction angle used in the computation is the factored soil friction angle (φ'_f) calculated according to Equation 1.

The quantity P_2 in Figure 134 is the unbalanced force that is required to keep the upper wedge at limit equilibrium. In general, the orientation of the inter-slice friction angle will be $0 < \lambda < \varphi'_f$. *A conservative assumption is $\lambda = 0$ (i.e., results in a safer design).*

The factor-of-safety (FS) against failure of a trial two-part wedge is the minimum value that can be applied to the peak soil friction coefficient so that the horizontal destabilizing force P is just equal to the sum of the factored horizontal tensile capacities of the reinforcement layers ST/FS. The sum ST is calculated from the tensile capabilities of the reinforcement layers that are intersected by the trial failure surfaces (i.e., T_2 through T_6 in Figure 134).

The out-of-balance horizontal force P is calculated using Equation 4a, 4b and 4c. The wedge weights W_1 and W_2 include the net vertical force due to any uniformly distributed surcharge load acting over the slope surface.

The maximum tensile force T_i available from any individual reinforcement layer is the lesser of the long term design strength (LTDS) or the design pullout capacity of the geosynthetic, T_{pull}.

$$P = P_2 \cos\lambda + (P_2 \sin\lambda + W_2)\left\{\frac{\sin\theta_2 - \cos\theta_2 \tan\varphi'_f}{\cos\theta_2 + \sin\theta_2 \tan\varphi'_f}\right\}$$ Eq. 4a

Where:

$$P_2 \cos\lambda = W_1 \left\{\frac{\tan\theta_1 - \tan\varphi'_f}{1 + \tan\theta_1 \tan\varphi'_f}\right\}$$ Eq. 4b

$$\varphi'_f = \tan^{-1}\left\{\frac{\tan\varphi'_f}{FS}\right\}$$ Eq. 4c

A summary of possible failure mechanisms that must be examined to find the critical mechanism is illustrated in Figure 135. Other permutations include external base sliding in which no reinforcement layers are intersected by the upper wedge.

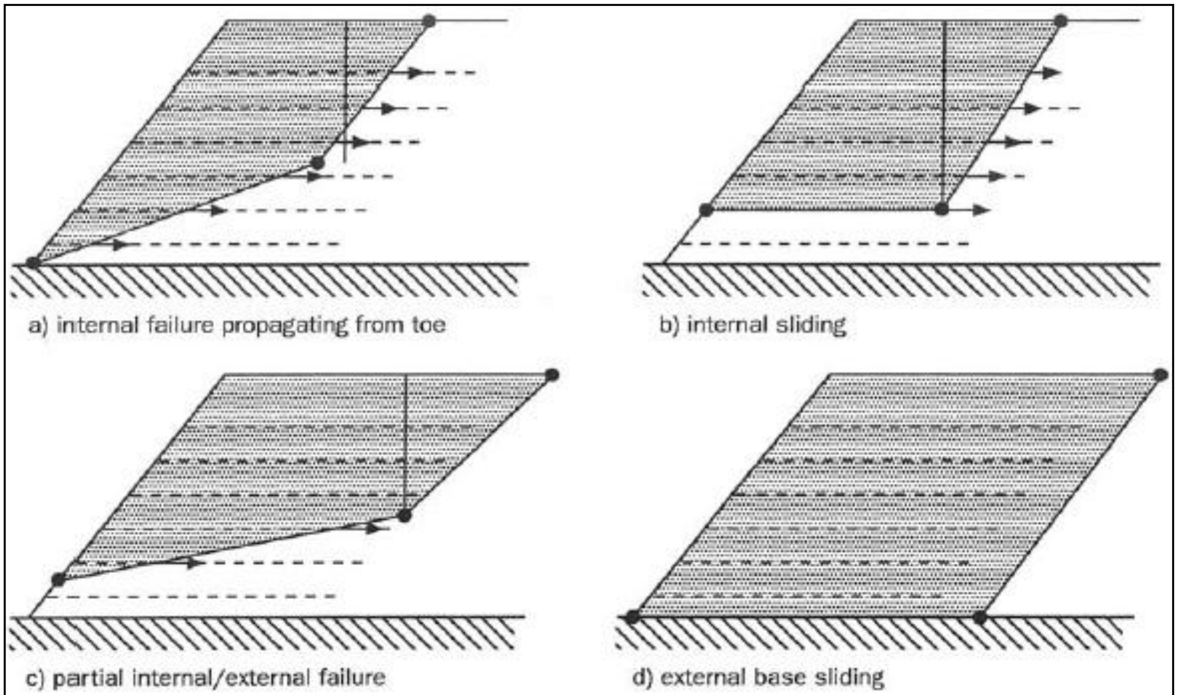


Figure 135: Few Two-Part Wedge Failure Mechanisms

b. Internal Sliding

Figure 135(b) illustrates an internal direct sliding mechanism in which the bottom wedge boundary coincides with a layer of reinforcement. Conventional practice is to assume that the potential shear resistance along this bottom surface is modified by the presence of the reinforcement layer. For this condition the friction coefficient term ($\tan\varphi'_f$) in the denominator and numerator of Equation 4a becomes (α x $\tan\varphi'_f$) where α is the direct sliding coefficient. The magnitude of the direct sliding coefficient is restricted to $\alpha < \varphi'_f$.

For final design and analysis purposes a representative value of the direct sliding coefficient can be determined from the results of direct shear box testing. These tests should use the proposed geosynthetic reinforcement material and slope soils prepared to the same conditions as in the field.

c. Factor-of-Safety

A minimum factor-of-safety for reinforced slopes with frictional soils is FS=1.5 applied to Eq. 1. The actual choice of factor of-safety should be based on the recommendation of a geotechnical engineer who is familiar with the soils at the site, slope function, additional loads, proposed reinforcement material and method of construction.

2. Circular Slip Analysis

This section reviews circular slip methods of analysis for the design and analysis of steepened slopes and embankments over stable foundations. For design purposes, the slopes are assumed to be seated on competent foundation soils or rock that are incompressible. Potential failure surfaces are assumed to be restricted to the slope soils or embankment fill above the stable foundation.

The method of analysis described in this manual is based on a modified "Bishop's Simplified Solution" in which the factor-of- safety against slope failure is described by the ratio of the sum of resisting moments to the sum of driving moments calculated using the method of slices. The driving moments are due to soil self weight and any surface loadings. The resisting moments are proportional to the mobilized soil shearing resistance developed along the failure surface. This conventional and widely used method of analysis can be easily modified to include the resisting moment due to any reinforcement layer that intersects a trial failure surface. The methodology described in this section follows the recommendations contained in the FHWA guidelines for reinforced slopes.

To follow an example; the soils are assumed to be granular materials and stability calculations are based on an effective stress analysis. The analyses are therefore appropriate for drained soils.

a. Unreinforced Slope

The factor-of-safety FS_u for an unreinforced slope is expressed as:

$$FS_u = \frac{\text{Resisting Moment}}{\text{Driving Moment}} = \frac{M_r}{M_d} \qquad \text{Eq. 5}$$

The slope can be divided into a convenient number of slices as illustrated in Figure 136 for a prescribed center-of-rotation O and Radius R. The factor-of-safety Equation 5 can be expanded as shown in Equation 6.
Here the summation signs are with respect to the vertical slices.

$$FS_u = \frac{1}{\Sigma W \sin\Psi} \, \Sigma \left[\frac{\{c'b + W(1-r_u)\tan\varphi'\} \sec\Psi}{1 + \frac{\tan\Psi \tan\varphi'}{FS_u}} \right] \qquad \text{Eq. 6}$$

Where:

W = total weight of slice based on bulk unit weight of soil plus surcharge loading (q x b) if present

q = uniformly distributed surcharge acting at crest of slope

b = the horizontal width of the slice

Ψ = the angle formed by the tangent to the midpoint of the slice and the horizontal

c′ = soil cohesion at base of slice

φ′ = peak soil friction angle at base of slice

r_u = dimensionless pore water pressure coefficient

The pore water pressure coefficient r_u can be approximated using the approach illustrated in Figure 136. The result may be a small error that is conservative. For any slice that does not intersect the groundwater table r_u = 0.

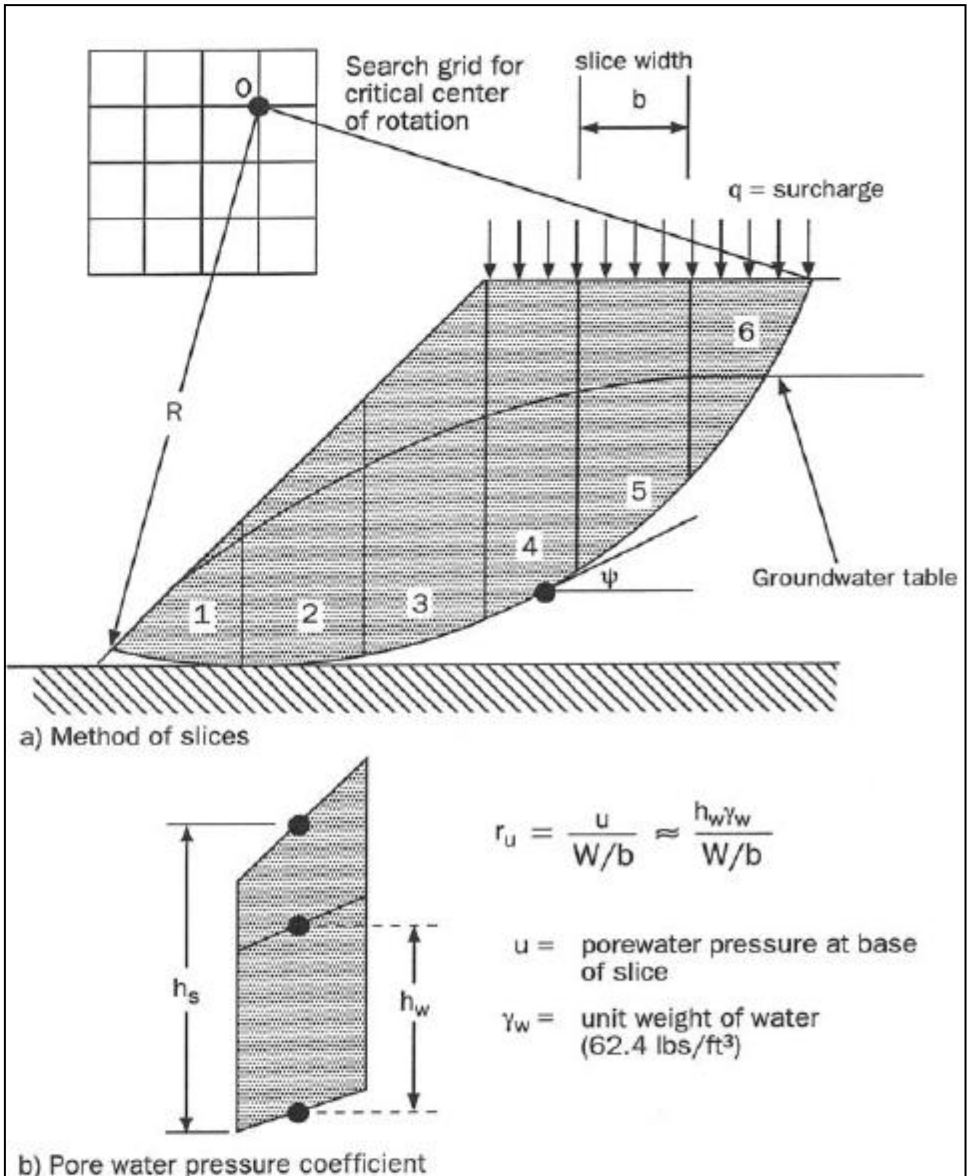


Figure 136: Method of Slices for Unreinforced Slope and Circular Slip Analysis

The presence of the factor-of-safety term on both sides of Equation 6 means that for a prescribed trial failure circle, a process of successive iterations is required until the solution converges to a unique value of FS_u. Clearly, the computations required to perform this calculation and to inspect a potentially large number of critical slip circles means that the analysis is best performed using a computer program.

Commercially available computer programs such as G Slope from Mitre Software Corporation, RSS from FHWA, ReSSA and ReSlope from ADAMA Engineering, STABL from Purdue Universiy, and UTEXAS4 from the University of Texas, as well as others, can be used for this purpose.

b. Reinforced Slope

The factor-of-safety FSr for a reinforced slope is expressed as:

$$FS_r = FS_u + \frac{\text{resisting movement due to reinforcement}}{\text{driving moment}} \qquad \text{Eq. 7}$$

The right hand term represents the additional factor-of-safety against slope failure due to the stabilizing effect of the tensile geosynthetic reinforcement. Referring to Figure 137, the factor-of-safety expression for the reinforced slope case can be expressed as:

$$FS_r = FS_u + \left(\frac{\Sigma T_i R_{Ti} / \cos \Psi_1}{M_D}\right) \qquad \text{Eq. 8}$$

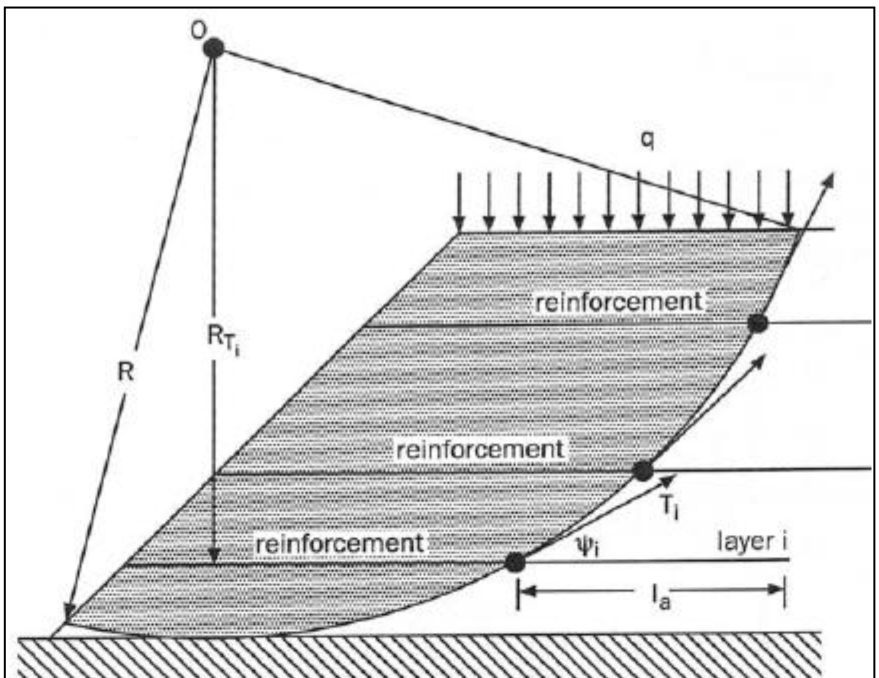


Figure 137: Method of Slices for Reinforced Slope and Circular Slip Analysis

Here the summation term is with respect to the reinforcement layers and the tangent slopes Ψ_i of the circular slip surface at the point of intersection with each reinforcement layer i. Some engineers may say that the restoring force T_i will act parallel to the slip surface if the reinforcement products are extensible materials. Extensible reinforcement products are able to conform to the geometry of the failure surface at incipient collapse of the slope.

The magnitude of the tensile force T_i used for each layer in the summation term in Equation 8 is the lesser of:

i. The long term design strength of the reinforcement (LTDS). This is the working tensile load level below which the reinforcement remains intact and does not undergo excessive straining.

ii. The pullout capacity of the embedded length of the reinforcement beyond the slip circle (i.e. length l_a in Figure 137). The quantity T_i must not exceed the pullout capacity (T_{pull}) of the reinforcement. The calculation of pullout capacity is performed by using equation 3.

The above method can be used with commercially available software for circular slip analysis of unreinforced slopes provided that the magnitude of the driving moment M_D is available in the output. The magnitude of the right hand term in Equation 8 can then be computed by hand or by using a simple computer spreadsheet. Alternatively, the approximate method described in the following section can be used to give a reasonably conservative estimate of the reinforced slope factor-of-safety.

3. <u>Approximate Method to Calculate Factor-of-Safety for Trial Reinforced Slope</u>

For preliminary design purposes the factor-of-safety from the results of an unreinforced slope stability analysis can be modified to estimate the factor-of-safety for the corresponding reinforced slope using extensible reinforcement (Figure 138):

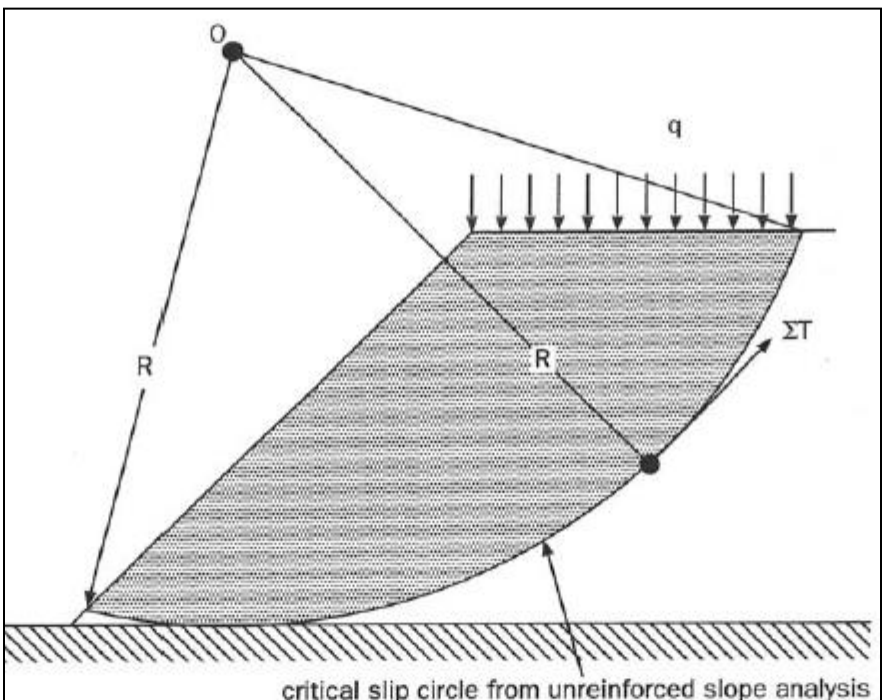


Figure 138: Approximate Method to Calculate the Factor-of-Safety for a Reinforced Slope

1. *Step 1:* Calculate FSu for the unreinforced slope and determine the geometry of the corresponding critical slip circle.
2. *Step 2:* Calculate the total available restoring force $\sum T_i$ based on the sum of the LTDS of all reinforcement layers that intersect the critical slip circle from Step 1.
3. *Step 3:* Assume that $\sum T_i$ acts parallel to the critical unreinforced slip circle and calculate the factor-of-safety for the reinforced slope as follows:

$$FS_r = FS_u + R \times \frac{\Sigma T_i}{\mathrm{MD}} \qquad \text{Eq. 9}$$

4. **External Stability of a Reinforced Soil Mass over a Stable Foundation**
It is important to check for the rotational and sliding stability, and the bearing capacity and settlement considerations.

The FHWA guidelines contain recommendations for the analysis of external sliding stability of a reinforced soil mass over a stable foundation. The sliding mechanism assumed in these calculations is conceptually identical to the sliding mechanism illustrated in Figure 135(d). The reinforced soil mass is treated as an equivalent gravity structure with a mass equal to the reinforced zone above the base. The factor-of-safety against base sliding is calculated as the ratio of base sliding resistance (force/unit width of slope) to driving force resulting from the retained slope materials.

The limits of the reinforced soil mass can be estimated using the Design Chart Method described below or the results of circular slip analysis described in the previous section.

7.5.3 Design Charts Method for preliminary design of steepened slopes and embankments over stable foundations

This section describes how the designer can use a series of charts to carry out a preliminary design of a reinforced soil slope or embankment. The preliminary designs that result from this approach are restricted to slopes or embankments composed of free-draining granular soils and constructed over stable foundations. The charts have been generated using a conventional two-part wedge limit equilibrium method of analysis and cover the case of simple geometry with a range of slopes from 90 degrees (vertical) to 30 degrees and a range of soils with friction angles from 15 degrees to 50 degrees. A factored soil friction angle f′f (Equation 1) should be used with the design charts to account for variability in soil properties and uncertainty in slope geometry and loading.

Key Assumptions

1. The foundation soils below the toe of the slope are stable and any potential instability is restricted to the free-draining cohesion-less granular soil mass above the elevation of the toe.
2. The groundwater table is well below the toe of the slope.
3. The properties of the soil are uniquely described by a uniform bulk unit weight λ and a peak friction angle φ′ (degrees).

4. The intersection of failure surfaces with the slope boundaries occurs at the toe of the slope and at points beyond the crest.
5. Inter-slice forces have been assumed to act at an angle of λ = φ′ to the horizontal.
6. No additional slope loadings due to seismic forces are present.

1. **Calculation of Factored Soil Friction Angle for Design**

A factor-of-safety FS should be applied to the soil peak friction angle to account for variability in soil properties and uncertainty in slope geometry and loading. For routine slopes a value of FS = 1.5 is typical. However, it is the responsibility of the geotechnical engineer to recommend an appropriate factor-of-safety based on site conditions, external loading and slope function. The factored soil friction angle φ'_f is used in the calculations below. The factored soil friction angle is calculated as follows:

$$\varphi'_f = \tan^{-1}\left\{\frac{\tan\varphi'}{FS}\right\} \qquad \text{Eq. 10}$$

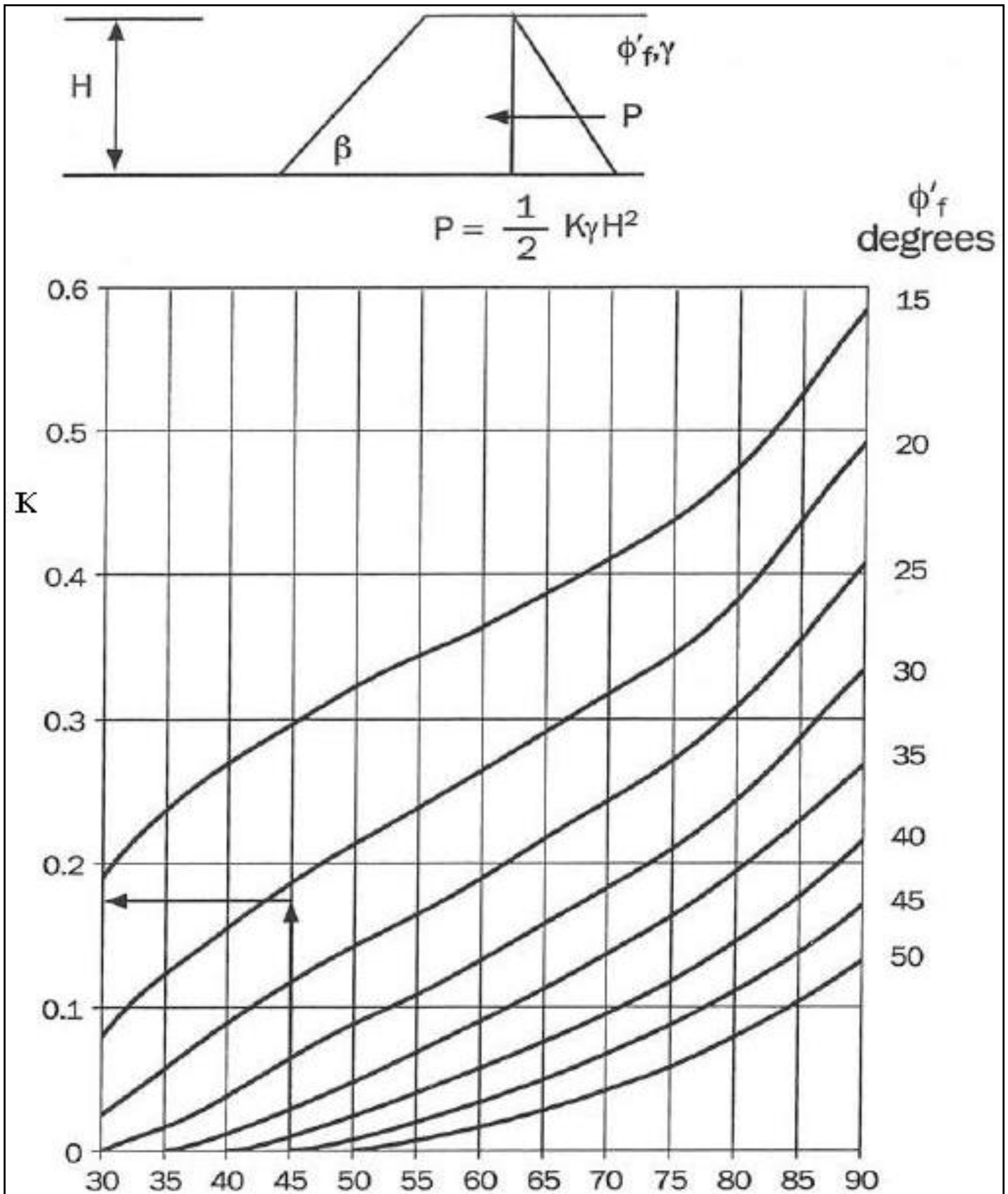


Figure 139: Chart 1: Equivalent Coefficient of Earth Pressure, K= f(φ′f, β)

Design Charts

Coefficient of Earth Pressure (Chart 1)

In order to estimate the minimum number of primary reinforcement layers in a slope it is necessary to calculate the net horizontal force P required to just maintain the slope at limit equilibrium. The approach adopted to generate the design charts is to determine the critical two-part wedge that yields the maximum required horizontal force P. The geometry used in the two-part wedge analysis is illustrated in Figure 140.

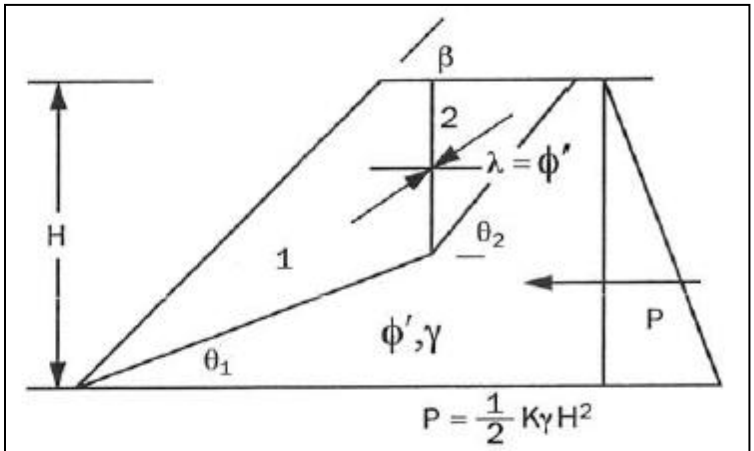


Figure 140: Two-Part Wedge Analysis to Calculate Unbalanced Horizontal Force P

In Figure 139; Chart 1 gives the maximum equivalent coefficient of active earth pressure K based on a search of all potential two-part wedges for a given β and factored friction angle (i.e $\varphi' = \varphi'_f$). The magnitude of force P is determined by examining a very large number of wedge geometries defined by a grid of break-points superimposed on the slope cross-section. For each breakpoint the angle θ_2 was varied to determine the maximum out-of balance force P. The analysis assumed that inter-slice forces act at 1/3 the height of the inter-slice boundary (the point of application is a concern in eccentricity calculations described in the next section).

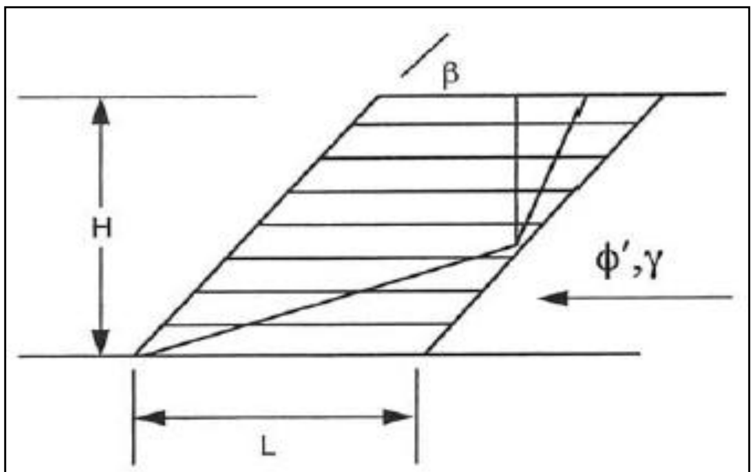


Figure 142: Reinforced Zone Containing Critical Two-Part Wedge

The constraint that the width L of the reinforced zone must be sufficient to capture the critical two-part wedge is illustrated in Figure 141. The calculation for adequate reinforcement zone width to prevent base sliding can be referred to Figure 142. The calculations to determine the minimum base width to

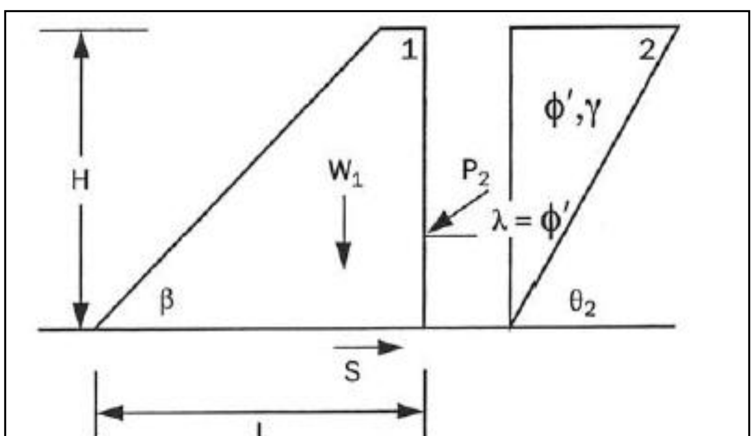


Figure 141: Free Body Diagram for Calculation of Base Sliding

prevent sliding were based on the following factor-of-safety relationship:

$$FS = \frac{S}{P_2 \cos\lambda} = \frac{\alpha(W_1 = P_2 \sin\lambda)\tan\varphi'}{P_2 \cos\lambda} = 1 \qquad \text{Eq. 11}$$

<u>*Minimum Reinforcement Length (Chart 2)*</u>

The calculations are based on following criteria:

1. All reinforcement lengths are equal (i.e. truncation parallel to the slope face).
2. The reinforced zone must have sufficient length L to contain the critical unreinforced two-part wedge.
3. The reinforced zone must have sufficient length L that the slope does not slide outward.
4. The reinforced zone must have sufficient length L that tensile vertical stresses are not developed along the surface of the foundation soils (i.e., base eccentricity must fall within the middle third of the base width L).

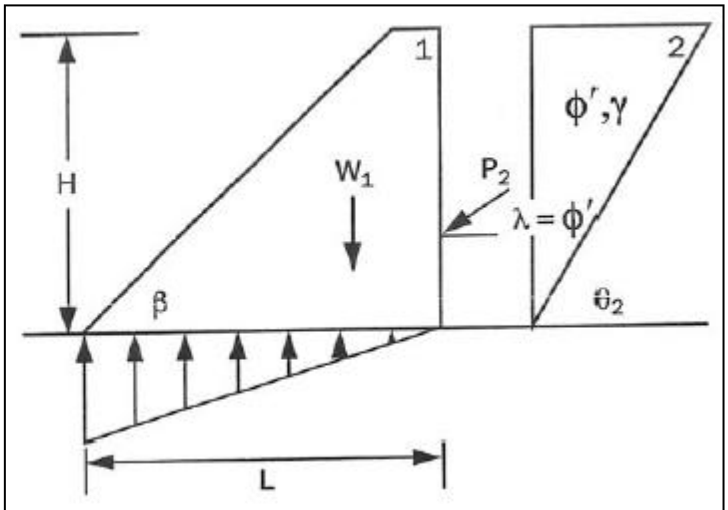


Figure 143: Free body Diagram for calc. of min reinforcement length L to ensure compressive bearing pressure at base of slope i.e. base eccentricity < L/6

Here the parameter S is the shearing resistance acting at the base of the slope and is controlled by the friction angle of the slope soils φ′, the weight of wedge W_1 (hence width of the reinforced zone L) and the coefficient of direct sliding (which has been taken as α = 0.9). The quantity P2 is the unbalanced interslice force acting on wedge 1 by the right hand side wedge 2.

The calculation for base eccentricity can be referenced to Figure 143. The analysis involves progressively increasing the base dimension L until the linear distribution of vertical base pressure σ'_v, is compressive everywhere for maximum values of P_2.

The results of analysis are presented in normalized form L/H on Chart 2 for the condition λ = φ′ (where φ′ = φ'_f). Here, L is the length of reinforcement and H is the height of the slope.

2. Calculation of Minimum Number of Reinforcement Layers

The equivalent coefficient of earth pressure K for design is determined from Chart 1 using φ'_f. The minimum number of reinforcement layers N_{min} can be calculated as follows:

$$N_{min} >= \frac{P}{LTDS} = \frac{(1/2)K\gamma H^2}{LTDS} \qquad \text{Eq. 12}$$

The LTDS denotes the long term design strength (allowable working stress) of the reinforcement products.

Calculation of Minimum Length of Reinforcement

The minimum reinforcement length L is calculated from Chart 2 (Figure 144) based on φ'_f, β, and the height of the slope H.

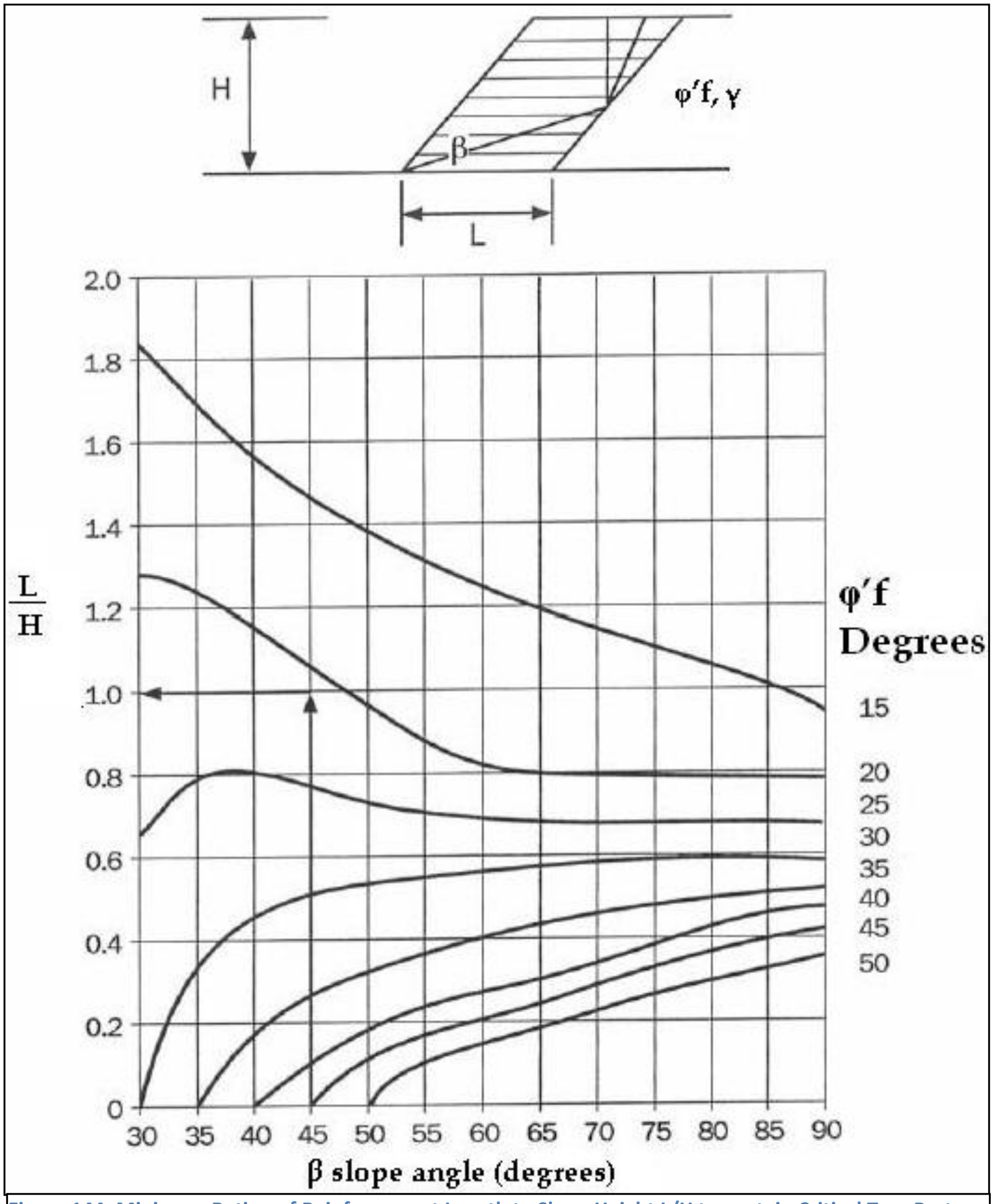


Figure 144: Minimum Ration of Reinforcement Length to Slope Height L/H to contain Critical Two-Part Wedge and Satisfy Sliding and Eccentricity Criteria

Calculation of Maximum (Primary) Reinforcement Spacing

The calculation of maximum reinforcement spacing S_{vmax} at any depth z below the crest of the slope can be carried out using the following relationship:

$$S_{vmax} => \frac{LTDS}{K\gamma z} \qquad \text{Eq. 13}$$

Here the quantity LTDS refers to the long term design strength of the reinforcement and parameter K to the coefficient of earth pressure established from Chart 1. The value of S_{vmax} in Equation 13 is dependent on the magnitude of bulk moist unit weight of the soil γ, the value K and the LTDS of the reinforcement. Hence, it is not practical to provide a general chart to estimate S_{vmax}.

Uniform Surcharge

The influence of a uniformly distributed surcharge q acting at the crest of the slope (Figure 145) can be considered by analyzing a slope with an equivalent unsurcharged height H' where:

$$H' = H + q/\gamma \qquad \text{Eq. 14}$$

The replacement of the surcharged slope height by an equivalent unsurcharged height H' is valid for q/g < O.2H. For greater surcharge pressures a more detailed slope stability analysis should be carried out.

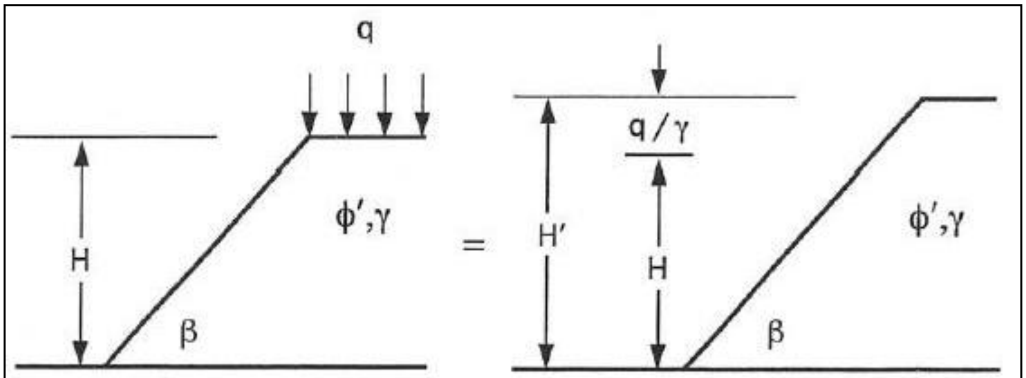


Figure 145: Modified Slope Height to Incline Influence of Uniformly Distributed Surcharge

7.5.4 Step by Step Solution

Step 1: Select design parameters for soil and Geotextile/Geogrid properties

Step 2: Calculate factored friction angle φ'_f

Step 3: Calculate equivalent slope height H

Step 4: Determine the force coefficient K, from Chart 1 using the slope angle b, and the factored friction angle φ'_f

Step 5: Determine the total horizontal force P that must be resisted by the geotextile/geogrid reinforcement layers

Step 6: Calculate minimum number of geotextile/geogrid layers N_{min} required to counter unbalanced force P

Step 7: Determine the required embedment length of primary geogrid from Chart 2 using factored friction angle φ'_f, slope angle β and modified slope height H'

Step 8: Calculate the maximum allowable vertical spacing for each Miragrid product using

Step 9: Select geotextile/ geogrid and calculate maximum geogrid spacing at bottom of embankment zone

Step 10: Details should be added to depict the completed slope. If primary reinforcement spacing exceeds 18 inches, use geotextile/ geogrid at 18 to 24 inch intervals as secondary slope reinforcement. If $\beta < 45^o$, treat slope surface with an appropriate surface erosion control/re-vegetation system. If $\beta > 45^o$, wrap slope face with geogrid and provide appropriate erosion control/re-vegetation to provide additional slope protection.

Step 11: Sketch slope showing primary and secondary reinforcement. The final recommended design should be based on a layout which is a compromise between the requirement layers and the desire to keep the layout as simple as possible to ease construction

Step 12: Verify the internal stability and calculate the external stability of the cross section using slope stability methods. Since the computations required to perform the required number of calculations would be prohibitive to perform by hand, the analyses are best performed by computer program. Failure modes including, by not limited to, multiple wedge type internal failure modes, sliding block or translational and circular arc rotational external failure modes should be considered. Site-specific conditions will often control the reinforcement scheme chosen for the final reinforced slope cross sections.

8 Geosynthetics in Seepage Control Systems

8.1 Introduction

Geosynthetics have been utilized in numerous civil and environmental engineering applications worldwide for more than 20 years to prevent seepage of liquids. Such seepage control applications as water containment and conveyance, structure waterproofing, and environmental protection make extensive use of geomembranes and geosynthetic clay liners (GCLs) along with other geosynthetics.

The materials used for seepage control may be exposed, as with pond linings, or buried, as with landfill linings. They may be subject to significant stresses, as with a pond cover, or exposed to very aggressive environments, as with a chemical tank lining (Figure 146).

Figure 146: Tank Lining

The wide variety of potential exposure conditions is why there is such a wide variety of geosynthetic barrier materials. Material selection and installation details are, therefore, project specific.

8.2 Structure Waterproofing

8.2.1 Contextual Situation

The protection of structures (even soil and rock structures) from the effects of seeping water is a common need. As noted earlier, this need is typically addressed with a drainage layer, often accompanied by a waterproofing layer.

8.2.2 Typical Solutions

Conventional soil barrier layers silts and clays attempt to minimize liquid migration. Where readily available, clay can be compacted in multiple layers to achieve a durable, low permeability barrier, although placement against a vertical structure can be difficult, costly or impossible. Additionally, the integrity of clay barriers is adversely effected by:

a) variations in texture (i.e. presence of clods),
b) fluctuating moisture content and compaction effort,
c) extreme temperature exposure, and
d) exposure to certain chemicals.

Gravel and sand layers, if locally available, can be cost-effectively engineered into systems to collect and remove liquids and gasses. Additionally, assuring proper gradations, facilitating vertical placement on slopes, and obtaining uniform layer thickness often requires large construction tolerances and numerous duplicate inspections.

8.2.3 The Geosynthetic Solution

Since geomembranes and GCLs can be easily deployed in horizontal, vertical or even overhead configurations, they are especially useful for waterproofing tunnel linings as well as foundation and basement walls and other wall structures such as bridge abutments.

Taking advantage of their "sheet-like" nature, geomembranes and GCLs can be used to isolate or encapsulate water-sensitive roadway soils a-- and subgrades in order to maintain the soils at their desired water content. They are also quickly and easily deployed as protective covers over material stockpiles to prevent wetting and erosion.

Figure 147: Geo membranes are used for water proofing

Geosynthetics, specifically geomembranes and GCLs, can offer a more economical, less installation-intensive alternative to clay barriers. In areas where naturally occurring clays and silts are scarce, GCLs can provide the impermeability required to protect structures. In addition, it is not always possible to place and compact natural clay in non-planar forms as in a tunnel lining or wall. GCLs also take up less space and are somewhat resistant to freeze/thaw and wet/dry cycles.

Figure 148: Tunnels require sophisticated waterproofing

Geomembranes can be effectively incorporated in the construction of earthen and earth/rock dams which require an impervious core. These structures are traditionally constructed with silts and clays. In addition, concrete dams must be protected from seepage into the structure. Geomembranes are often used to cover the upstream sides of these dams.

8.3 Water Supply Preservation

8.3.1 Contextual Situation

Water Containment Systems

The containment and protection of important water supplies is a challenge to public works agencies as well as to industry. Effective lining of potable water reservoirs can conserve millions of gallons of water by preventing seepage losses. Additionally, covers can prevent contamination, control evaporation and prevent chlorine loss. Similar containment and protection is needed in waste water treatment facilities, though the purpose is to prevent leakage of untreated liquids and to collect biodegradation gases such as methane.

Water Conveyance Systems

The prevention of seepage from lined and relined canals is critical in arid regions.
Similarly, storm water retention and detention facilities are lined with a geomembrane or GCL to prevent excess wetness or instability of surrounding property resulting from seepage of contained runoff.

8.3.2 Typical Solutions

Most water reservoirs, because of their magnitude, are often lined with low permeability soil and left uncovered. This often results in high water treatment costs and potentially serious contamination.

Clay or concrete linings have commonly been used for water and wastewater conveyance.

8.3.3 The Geosynthetic Solution

Geomembranes serve as effective protection against evaporation and contamination and can prevent seepage losses when used as liners and floating covers. Though generally used in more "highly engineered" installations, their low cost, wide spread availability, and relative ease of installation make geomembranes and GCLs more and more popular for lining architectural ponds, recreational ponds, and fire fighting ponds as well as for facing dams (Figure 149).

Figure 149: Installation of cushion and geo membrane on the ground

Geomembrane and GCL barrier systems provide flexibility and ease of installation which is especially beneficial when lining and relining is done over existing rigid linings of clay, asphalt, or concrete.

8.4 Environmental Protection

8.4.1 Contextual Situation

The increase in environmental sensitivity of the last two decades has led to important regulations requiring "de minimus" leakage of contamination to the environment from landfills and other waste deposits. Additionally, as soon as a landfill reaches capacity, it must be capped to minimize future leachate generation

Figure 150: Pond complete with geo membrane

8.4.2 Typical Solutions

Conventional Systems

Conventional capping and lining systems have incorporated very low permeability soil barrier layers such as thick layers of silts and clays, along with drainage layers of coarse uniformly graded sands or gravels and specially graded sand filters in an attempt to minimize liquid migration.

Where readily available, clay can be compacted in multiple layers to achieve a durable, very low permeability barrier. Yet, the integrity of clay barriers is adversely effected by:

a) variations in texture (i.e. presence of clods),
b) fluctuating moisture content and compaction effort,
c) extreme temperature exposure, and
d) exposure to certain chemicals.

Gravel and sand layers, if locally available, can be cost-effectively engineered into systems to collect and remove liquids and gasses. Yet, assuring proper gradations, facilitating placement on slopes, and obtaining uniform layer thickness often requires large construction tolerances and numerous duplicate inspections.

8.4.3 The Geosynthetic Solution

The chemical resistance and flexibility of geomembranes and GCLs makes them technically superior to any other alternative for providing a positive barrier to the movement of fluids and gases. In the case of environmental protection, that movement usually includes containment of contaminated liquids and gases while keeping clean water, in the form of rain or runoff, from becoming contaminated

There are many ways that geomembranes and GCLs have been incorporated into environmental protection barrier systems, including:

a) final covers over waste materials,
b) liners for solid, hazardous and monofill waste landfills,
c) liners for lagoons and other surface impoundments such as geothermal, aquaculture, solar, or specific chemical ponds.
d) secondary containment for underground storage tanks,
e) vertical barriers to contain subsurface contaminant plumes,
f) horizontal and vertical barriers to radon and methane emissions,
g) pit liners for the collection and recycling of leached solutions from ore piles or even manure piles.

8.5 Design Considerations

The installation of geosynthetics in seepage control happens in below major systems:

a) Landfills
b) Septic Systems

The Geotextile design for landfill systems and septic system is essentially the same as geotextile design for filters in subsurface drainage systems. The primary function of the geotextile is filtration. The design requires evaluation of two criteria:

- Retention criteria: It ensures the geotextile openings are small enough to prevent migration of soil particles (piping).
- Permeability criteria: It ensures the geotextile is permeable enough to allow liquids to pass freely through. “Permeability” of a geotextile is measured by permittivity (or cross-plane flow rate).

a. *Retention criteria*
Soil identification based on grain size is a useful indicator of the soil behavior when filtered by a geotextile. The selection of a geotextile is normally based on the percent of the subgrade soil passing through a 0.075 mm sieve (No. 200 sieve). Table 14 below describes the different types of soil based on typical grain size.

b. *Permeability criteria*
The default geotextile selection is based on the simple premise that permeability of the geotextile is greater than permeability of the soil. Most of the geotextiles are more permeable than clean well graded sand and gravel, making it suitable in most environments (Table 15).

<u>Selection of geotextile</u>
The EPA has Guidelines and Standards that differ from state to state. Most landfills are designed by a registered engineer or geologist referencing EPA Guidelines and Standards. Selection of the appropriate geotextile is dependent on the appropriate EPA Guidelines and Standards.

The engineer should always refer to the full EPA Guidelines and Standards for final selection of the geotextile.

Soil name	Diameter		Us standard sieve size	familiar example
	mm	inches		
Boulders	Over 300	Over 12	> 12″	Larger than basketball
Cobbles (rounded)	76-300	3 to 12	3-12"	Grapefruit
Coarse gravel	19-76	0.75-3.0	0.75-3″	Orange or lemon
Fine gravel	4.75-19	0.19-0.75	No. 4-0.75	Grape or pea
Coarse sand	2.0-4.75	0.08-0.19	No. 10-No. 4	Rock salt
Medium sand	0.42-2.0	0.016-0.08	No. 40-No. 10	Sugar or table salt
Fine sand	0.074-0.42	0.003-0.016	No. 200-No. 40	Powdered sugar
Silt sizes	0.002-0.074	0.0008-0.003	Rock flour and finer; particles cannot be distinguished with naked eye at distances of 20cm (8″).	
Clay sizes	< 0.002	< 0.00008		

Table 14: Different type of soils based on their size

Soil type	**Permeability Coefficient k (cm/sec)**
Uniform coarse sand	0.4
Uniform medium sand	0.1
Clean, well-graded sand and gravel	0.01
Uniform fine sand	0.004
Well-graded silty sand and gravel	0.0004
Silty sand	0.0001
Uniform silt	0.00005
Sandy clay	0.000005
Silty clay	0.000001
Clay	0.0000001
Colloidal clay	0.000000001

Table 15: Typical permeability of soil types

Good reference documents for design and construction of Geosynthetics barriers for MSW landfills are:

- Rowe, R.K. and Lake, C.B. (2000) Geosynthetic Clay Liners (GCLs) for municipal solid waste landfills. Pp 395-406 in: Environmental Mineralogy: Microbial Interactions, Anthropogenic Influences, Contaminated Land and Waste Management, J.D. Cotter-Howells, L.S. Campbell, E. Valsami-Jones and M. Batchelder, editors. Mineralogical Society Series 9. Mineralogical Society, London. ISBN 0903056 20 8.

- Rowe, R.K., Quigley, R.M., Brachman, R.W.I., Booker, J.R. (2004) Barrier Systems for Waste Disposal Facilities, Taylor & Francis Books Ltd (E & FN Spon) London, 587 p.

9 Geosynthetic Support Systems

9.1 Introduction

Innovation is a tradition in the geosynthetics industry. In partnership with contractors, engineers are constantly developing costeffective installation techniques, advanced new products and specially fabricated systems. Such innovations include prefabricated soil containment systems and preassembled fences and specially developed installation equipment and techniques for on-site fabrication. Additionally, the industry has developed an extensive array of tests for establishing the quality of geosynthetics and facilitating their specification

9.2 Prefabricated Systems, On-site Fabrication

9.2.1 Prefabricated systems

Factory fabrication is an effective way of minimizing field operations. Fabricated geosynthetic products lead to faster, easier and more accurate installation, plus significant cost savings. Many geosynthetic suppliers offer factory fabrication capabilities including seaming of extra wide panels, joining multiple rolls and re-rolling them onto pipe cores, or specialty folding and bundling to facilitate field installation. Common prefabricated systems include:

a) Geotextile socks for perforated pipe
b) Reinforced selveges and grommets for silt (turbidity) curtains and geomembrane covers.
c) Special widths, lengths or shapes of geosynthetic panels for installation in curves, on slopes or in other irregular configurations.

Some prefabricated "systems" mentioned earlier in this handbook include:

a) Dredged Soil Containment System
b) Barge-Placed Soil Containment System
c) Sandbags
d) Silt Fences and Turbidity Curtains
e) Safety Fences

Dredged Soil Containment System

Geotextile tube systems use a woven geotextile that is formed into a tube. The tube's diameter and length is determined by project requirements. The tube is filled by a hydraulic piping system conveying dredged material. Designed with appropriately sized openings, the geotextile tube retains fill material while allowing water to permeate out through the tube wall. Geotextile tubes permanently trap granular material in both dry and underwater construction.

Figure 151: Dredged Soil Containment System

Barge-Placed Soil Containment System

Geotextile containers are constructed of woven geotextiles using special seaming techniques to contain available granular fill material. Sunk accurately into position by barge, geotextile containers are designed to provide a desirable alternative to loose soil placement. Geotextile containers can be used for preventing erosion around piers and revetments, protecting and ballasting pipelines, and constructing groins, breakwaters, embankment cores and breach repairs.

Sand Containers - Pre-Fabricated
Geotextile sandbags provide incomparable convenience to contractors needing fast, easy access to sand-filled bags. Geotextile sandbags are perfect for weighing down sign bases, anchoring plastic sheets or redirecting storm runoff.

Sand Containers – Custom Fabricated
Sandbags can also be custom engineered. Facing storm-induced erosion, large bags offer a flexible, stable armoring system that can be quickly installed to protect against storm induced erosive forces. Multiple bags can be stacked as required to create larger erosion protection structures (Figure 152). Large sandbags can be fabricated to the size and material specifications of each customer. Bags are positioned and filled by hand. Ends are closed using a hand-held sewing machine

Figure 152: Sand Bags

Turbidity Curtains
Turbidity curtains are reusable floating geotextile or reinforced geomembrane panels that prevent water-polluting sediment from shore-side construction or off-shore filling and dredging operations from moving off-site. The top edge of each curtain contains floats and a cable or chain. Weights are attached to the lower edge of the curtain to keep it vertical in the water. Posts, piling, or anchors hold the curtains in place (Figure 153).

Figure 153: Typical Turbidity Curtain

9.2.2 On-site fabricated systems
Installation of a geosynthetic is only a small part of many projects. But if there are installation delays, work schedules and budgets can be drastically effected. By subcontracting geosynthetic installation including field seaming, project delays and overruns are avoided. Experienced installers work closely with contractors assuring timely deliveries and proper installation (Figure 154).

Figure 154: Workers Installing the Geo membrane

When time and quality matter, an experienced fabricator/installer with specialty equipment and knowhow makes the ideal partner on projects involving field seaming of geosynthetics (Figure 155).

Figure 155: Workers pulling the geo membrane

9.3 Testing and Specifying

9.3.1 Testing
Most specifiers and users of geosynthetics establish

required physical property values for the geosynthetics to be utilized in their project based on standard tests. This practice is common for most engineering materials and is certainly recommended for geosynthetics.

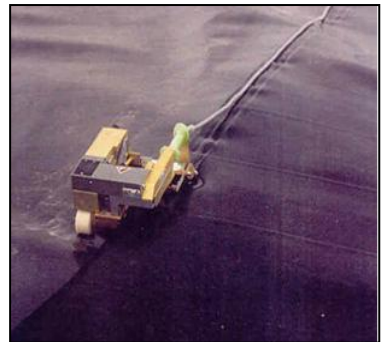


Figure 156: On site seaming of geo membrane

National standards bodies, such as the American Society for Testing and Materials (ASTM) have established standard tests for geosynthetics. These standard tests can be used to compare specific properties of different geosynthetics.

Geosynthetics test procedures can generally be placed in two categories: index tests and design tests. These two categories tend to overlap at times, and this distinction is not always clear.

Index tests are those tests a specifier or user can use to compare different geosynthetics. They do not, generally, provide a designer with "hard numbers" to use in his design, but they do allow for a quantitative comparison of physical property data. Most standard geosynthetics testing methods fall into this category.

Index tests are further divided by geosynthetics manufacturers into quality control tests and performance tests. Quality control tests are run routinely by the manufacturer in their labs and are used as a means of insuring product quality. Performance index tests are run at regular intervals (sometimes by an independent lab) in order to provide necessary test results for the manufacturer's products.

Design tests, as the term implies, provide a designer with additional performance values he can use in his calculations. An index test may be converted to a design test by changing boundary conditions, soil types, etc. The basic premise of a design test is that the test set-up accurately models field conditions

9.3.2 Specifying Geosynthetics

For all applications, four selection criteria should be considered.

Quality Control - Geosynthetics must be tested to insure they meet the specification. Most manufacturers test their geosynthetics and will supply certificates of compliance to the specification. However, on critical applications, additional testing should be performed by the user or an independent lab to guarantee that the geosynthetic complies with the specification.

Geosynthetics are commonly specified using Minimum Average Roll Values which statistically assures the contractor that the material purchased will consistently meet specs.

Survivability - Geosynthetics must be able to withstand installation stresses. Often these stresses are significantly more severe than application stresses.

Long-term Design - Geosynthetics must be able to function as designed over the life of the project. Most specifications include properties related to long-term performance.

Durability - Geosynthetics must be able to function in the application's environment over the design life of the project. Durability considerations are particularly critical for waste facilities and chemical storage areas, but should be examined whenever acidic or alkaline soils are present or unusual geosynthetic design conditions are known, (e.g. prolonged exposure to sunlight. etc.)

10 Cost Benefit Analysis of Select Applications

Certain key applications where monetary benefit can be calculated have been identified and should be used to demonstrate the advantages of using Geosynthetics. A summary of benefits can be seen below:

10.1 Cost Benefit using Geotextiles and Geomembranes in Landfills

While landfills aren't the most obvious applications where a cost benefit can be seen via use of geosynthetics, in some cases there is an increase in volume due to the following innovative modifications to landfill design: Increasing the internal cut slopes of the excavation from 3 horizontal to 1 vertical (3:1) to a slope of 2:1 that was only possible by utilizing a Geosynthetic clay liner in place of a compacted clay liner

Increasing the final refuse slopes of the landfill from 4:1 to 3:1 using a textured HDPE Geomembrane for increased stability, which then expands the waste capacity.

The associated revenue benefits and cost savings that would result from these changes are outlined below.

Note: Figures are in USD as assumptions and revenues are based on US scenario

Increasing Internal Cut Slopes

Cutting the west slope of Module 4 from 3:1 to 2:1		
Increase in volume =	*39,435 cu. m.*	
Approx. waste disposal rate =	*$19.62 per cu. m.*	
Increase in Revenue =		$773,625
Excavated sand		
Volume =	*39,435 cu. m.*	
Sand commercial sales value =	*$4.90 per cu. m.*	
Increase in Revenue =		$193,406
Slope area & liner system modification		
3:1 slope area =	*11,889 sq. m.*	
Avg. cost of construction for clay liner of thickness 0.67 m =	*$7.01 per cu. m.*	
Construction cost for clay liner on 3:1 slope =	*$55,872*	
2:1 slope area =	*8,314 sq. m.*	
Avg. cost of installation for Geosynthetic Clay Liner =	*$5.70 per cu. m.*	
Construction cost for GCL on 2:1 slope =	*$47,414*	
Decrease in slope area and liner system modification results in construction cost net savings of =		$8,458
Initial Cost Benefit =		**$894,516**

Table 16: Cost Benefit by increasing cut slopes using Geosynthetics in $ USD

Increasing Final Slopes

The final refuse slopes at the MPL were permitted at a slope of 4:1. By increasing the final slope of the refuse to 3:1, a significant amount of additional waste volume could be realized. This increased waste volume would also significantly extend the site life of the MPL. Based on an analysis of the entire MPL site development, an increase in the final refuse slopes to 3:1 would result in a gain in capacity of 5.9 million cubic meters. Over the life of the site, this would result in additional revenues of approximately **$115 million**.

10.2 Cost Benefit using Geotextiles in Subgrade Reinforcement

The use of a geotextile layer along the interface between existing subgrade and granular base helps extend the life of the road by reducing annual maintenance costs as well the intervals between pavement overlays required. This is in addition to initial cost savings due to reduction in thickness of the various road layers. The quantitative Cost Benefit analysis can be seen below:

		Without Geosynthetics		With Geosynthetics	
Layers	**Rate (Rs/m^3)**	**Thickness (m)**	**Rate (Rs/m^2)**	**Thickness**	**Rate (Rs/m^2)**
BC (Bituminous/Base Course)	₹ 7,060	0.05	₹ 353	0.05	₹ 353
DBM (Dense Bitumen Macadam)	₹ 6,365	0.17	₹ 1,082	0.14	₹ 891
WMM (Wet Mix Macadam)	₹ 1,588	0.25	₹ 397	0.1	₹ 159
GSB (Granular Sub Base)	₹ 857	0.3	₹ 257	0.2	₹ 171
Geotextile					₹ 100
TOTAL =		0.77	₹ 2,089	0.49	₹ 1,674
Area/km (3.75m width) =	3750	sq m			
Total Upfront Cost/km (3.75m width) =			₹ 7,834,313		₹ 6,278,625
Cost of 25mm Overlay per sq m =	₹ 250.00				

Table 17: Initial savings using Geosynthetics

Lifetime Maintenance Costs								
	Without Geosynthetics			**With Geosynthetics**				
Year	**Overlays**	**Maintenance**	**Cost/km**	**Overlays**	**Maintenance**	**Cost/km**	**Savings**	**PV @8% Rate**
1		2.5%	₹ 195,858		1.5%	₹ 94,179	₹ 101,678	94147
2		2.5%	₹ 195,858		1.5%	₹ 94,179	₹ 101,678	87173
3		3.5%	₹ 274,201		2.0%	₹ 125,573	₹ 148,628	117986
4		3.5%	₹ 274,201		2.0%	₹ 125,573	₹ 148,628	109246
5	₹ 937,500	3.5%	₹ 1,211,701		2.0%	₹ 125,573	₹ 1,086,128	739201
6		3.5%	₹ 274,201		2.0%	₹ 125,573	₹ 148,628	93661
7		3.5%	₹ 274,201		2.0%	₹ 125,573	₹ 148,628	86723
8		4.5%	₹ 352,544		3.0%	₹ 188,359	₹ 164,185	88704
9		4.5%	₹ 352,544	₹ 937,500	3.0%	₹ 1,125,859	₹ -773,315	-386850
10	₹ 937,500	4.5%	₹ 1,290,044		3.0%	₹ 188,359	₹ 1,101,685	510293
11		4.5%	₹ 352,544		3.0%	₹ 188,359	₹ 164,185	70416
12		4.5%	₹ 352,544		3.0%	₹ 188,359	₹ 164,185	65200
13		6.0%	₹ 470,059		4.0%	₹ 251,145	₹ 218,914	80494
14		6.0%	₹ 470,059		4.0%	₹ 251,145	₹ 218,914	74532
15		6.0%	₹ 470,059		4.0%	₹ 251,145	₹ 218,914	69011
TOTAL =			₹ 6,810,617			₹ 3,448,950	₹ 3,361,667	
GRAND TOTAL COST/KM (3.75m RD) =			**₹ 14,644,929**			**₹ 9,727,575**		
Net Present Value ---->					**NPV with Geotextiles =**	**₹ 1,524,938**		

Table 18: Lifetime savings using Geosynthetics

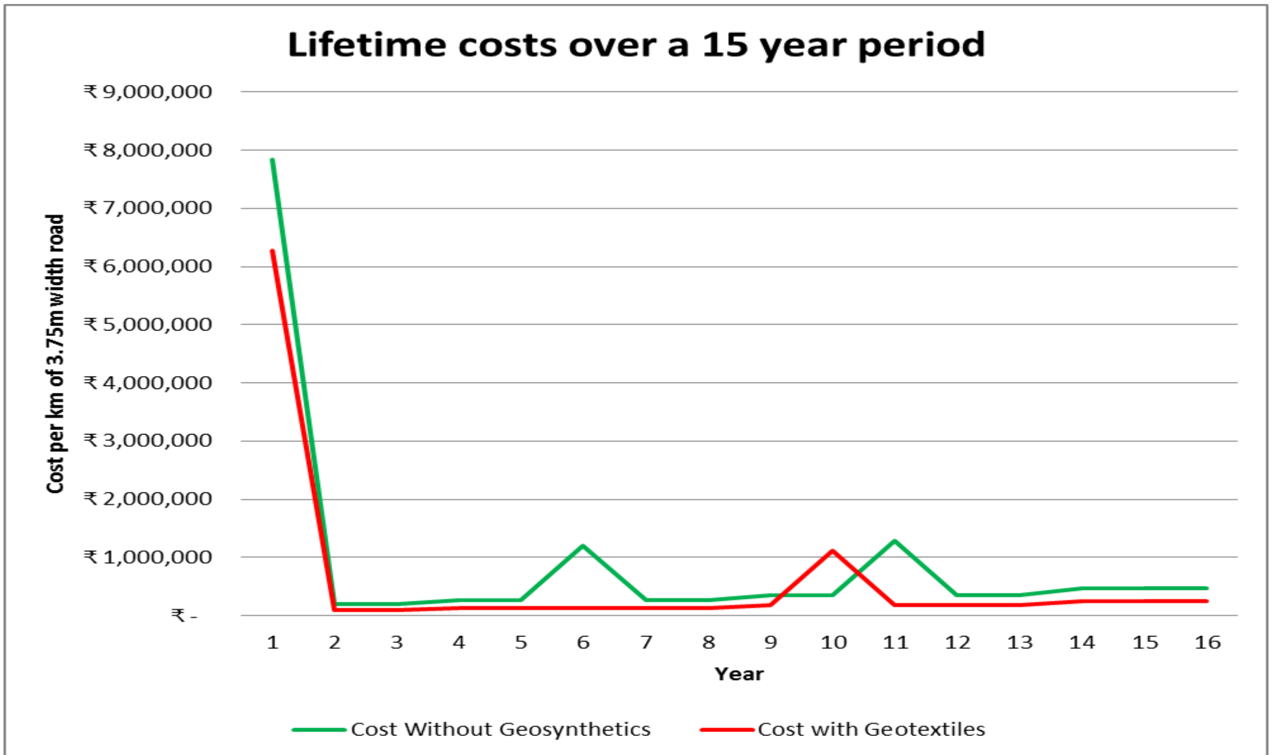


Figure 157: Lifetime costs per km of 3.75m width road with and without Geotextiles use for subgrade reinforcement

10.5 Cost Benefit using Geotextiles and Geomembrane Canal Lining

Cemented canals often suffer from severe leakage and seepage of canal water that results in upto 40% loss of water flowing through the canal. Adjoining creeks and villages see greater incidences of water logging and marshy terrain due to this seepage. The solution consists of the following steps:

- Repair the existing concrete lining
- Line the canal with 22,000 m^2/km of Geomembrane and 44,000 m^2/kmof nonwoven Geotextile:
    - Nonwoven Geotextile, 250 gsm for Drainage
    - HDPE Geomembrane, 1mm thick for the Barrier
    - Nonwoven Geotextile, 250 gsm for Protection
    - Concrete cover, 75mm (M15 grade)

Costs per km

Using Geosynthetics = Rs 493 Lacs
-- Conventional Method = Rs 198 Lacs
Difference in Cost = Rs 295 Lacs

Direct Benefit using Geosynthetics per km

Water Savings = 62 m^3/s
=> Additional Water Revenue = Rs 87 Lacs
+ Savings in Maintenance = Rs 348 Lacs
Total Direct Benefit = Rs 435 Lacs

-- Net Cost = Rs 295 Lacs

Net Direct Benefit = Rs 140 Lacs

Indirect Benefits using Geosynthetics per km

- Additional Farm Products = Rs 276 Lacs
- Generation of Employment = 767 people
- Value Addition due to Extra Irrigation = Rs 35 Lacs

10.4 Cost Benefit using Geocells in road laying applications

Geogrids are increasingly finding use in road laying applications around the world due to their prefabricated nature and structural properties which allow for extremely swift laying of base/sub-base allowing for a reduction in pavement and sub base thickness while providing extremely effective stabilization and reinforcement properties to the pavement. It also helps in reducing thickness of upper layers such as WMM (Wet Mix Macadam), DBM (Dense Bituminous Macadam) and BC (Bituminous Concrete).

Geogrids also allow for use of low quality aggregates to fill the geocells that can be sourced locally, eliminating the need to import better quality material. The difference in pavement layers and the reduction in thickness can be seen below.

A cost analysis carried out by Strata Geosystems comparing the two scenarios – the conventional method, with the use of Geocells in road laying application similar to the manner above gives the following savings in up front material cost.

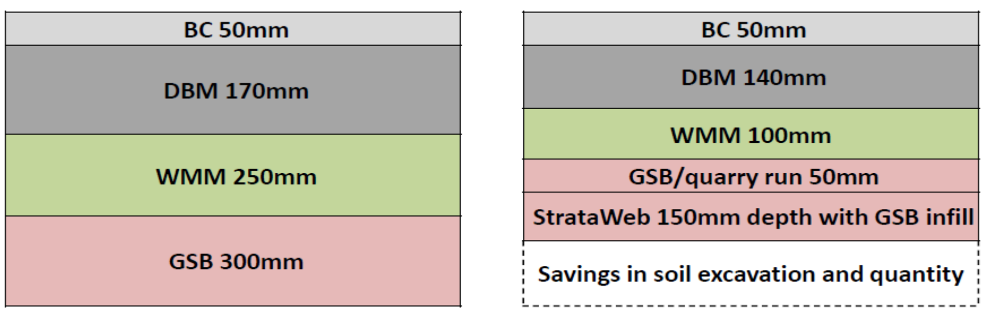


Figure 158: Illustration showing difference in pavement layers by using StrataWeb (Strata Geosystem's geocell solution)

Item	Rate (Rs/m³)	Conventional Thickness (m)	Conventional Amount (Rs/m²)	With StrataWeb Thickness (m)	With StrataWeb Amount (Rs/m²)
BC	7060.00	0.050	353	0.050	353
DBM	6364.70	0.170	1,082	0.140	891
WMM	1588.00	0.250	397	0.100	159
GSB	856.60	0.300	257	0.200	171
StrataWeb (150)		-	-	0.150	430
TOTAL =		**0.77**	**2,088**	**0.49**	**2,004**
Savings in %					**4.03 %**

Table 19: : Material Cost Analysis using Strata Geocells in road laying application

Further savings due to reduction in maintenance costs and increased life of road can be calculated as per previous example in chapter 10.2.

		Without Geosynthetics		With Geosynthetics	
Layers	Rate (Rs/m³)	Thickness (m)	Rate (Rs/m²)	Thickness	Rate (Rs/m²)
BC (Bituminous/Base Course)	₹ 7,060	0.05	₹ 353	0.05	₹ 353
DBM (Dense Bitumen Macadam)	₹ 6,365	0.17	₹ 1,082	0.14	₹ 891
WMM (Wet Mix Macadam)	₹ 1,588	0.25	₹ 397	0.1	₹ 159
GSB (Granular Sub Base)	₹ 857	0.3	₹ 257	0.2	₹ 171
Geotextile				0.15	₹ 430
TOTAL =		0.77	₹ 2,089	0.64	₹ 2,004
Area/km (3.75m width) =	3750	sq m			
Total Upfront Cost/km (3.75m width) =			₹ 7,834,313		₹ 7,516,125

Table 20: Up front savings using Geosynthetics

Lifetime Maintenance Costs								
	Without Geosynthetics			With Geosynthetics				
Year	Overlays	Maintenance	Cost/km	Overlays	Maintenance	Cost/km	Savings	PV @8% Rate
1		2.5%	₹ 195,858		1.5%	₹ 112,742	₹ 83,116	76959
2		2.5%	₹ 195,858		1.5%	₹ 112,742	₹ 83,116	71259
3		3.5%	₹ 274,201		2.0%	₹ 150,323	₹ 123,878	98339
4		3.5%	₹ 274,201		2.0%	₹ 150,323	₹ 123,878	91054
5	₹ 937,500	3.5%	₹ 1,211,701		2.0%	₹ 150,323	₹ 1,061,378	722356
6		3.5%	₹ 274,201		2.0%	₹ 150,323	₹ 123,878	78064
7		3.5%	₹ 274,201		2.0%	₹ 150,323	₹ 123,878	72282
8		4.5%	₹ 352,544		3.0%	₹ 225,484	₹ 127,060	68647
9		4.5%	₹ 352,544	₹ 937,500	3.0%	₹ 1,162,984	₹ -810,440	-405422
10	₹ 937,500	4.5%	₹ 1,290,044		3.0%	₹ 225,484	₹ 1,064,560	493097
11		4.5%	₹ 352,544		3.0%	₹ 225,484	₹ 127,060	54494
12		4.5%	₹ 352,544		3.0%	₹ 225,484	₹ 127,060	50457
13		6.0%	₹ 470,059		4.0%	₹ 300,645	₹ 169,414	62293
14		6.0%	₹ 470,059		4.0%	₹ 300,645	₹ 169,414	57679
15		6.0%	₹ 470,059		4.0%	₹ 300,645	₹ 169,414	53406
TOTAL =			₹ 6,810,617			₹ 3,943,950	₹ 2,866,667	
GRAND TOTAL COST/KM (3.75m RD) =			₹ 14,644,929			₹ 11,460,075		
Net Present Value ---->					NPV with Geotextiles =	₹ 32,465		

Table 21: Lifetime savings using Geosynthetics

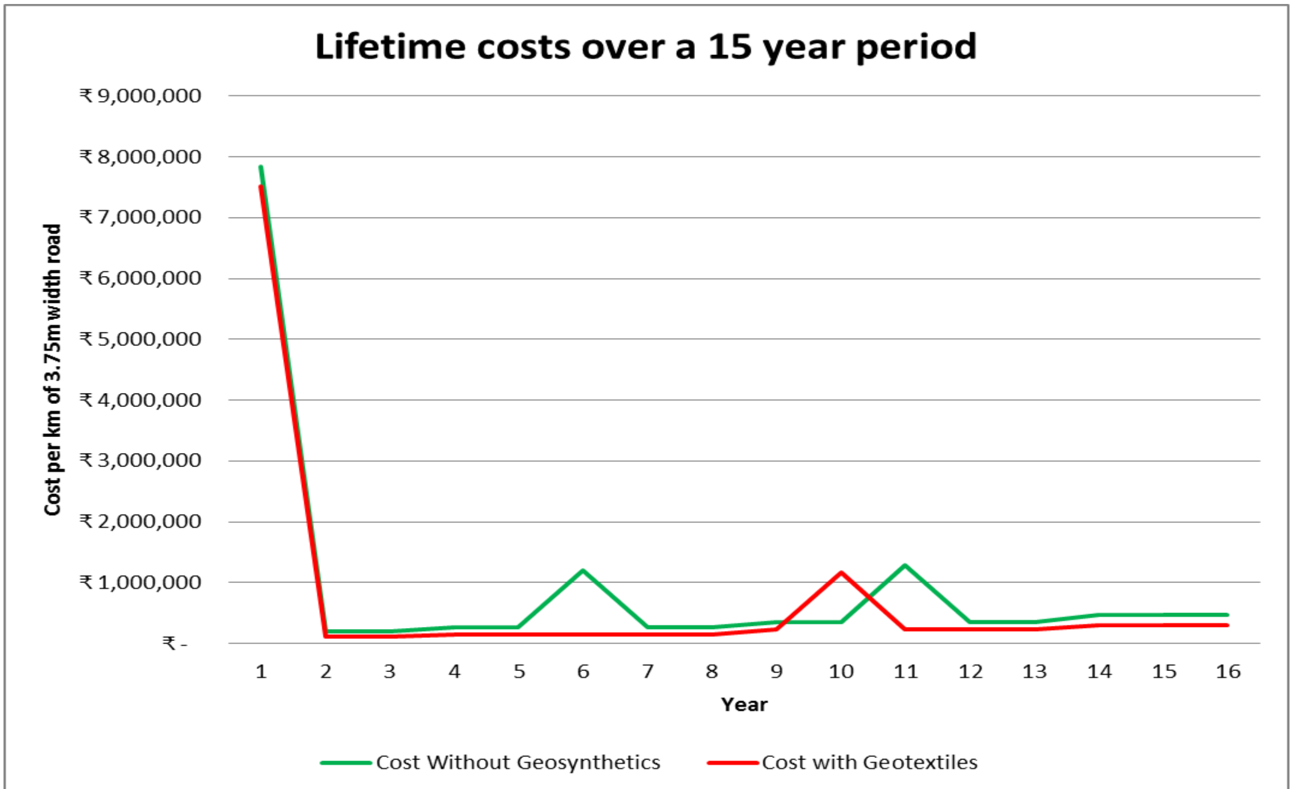


Figure 159: Lifetime costs per km of 3.75m width road with and without Geotextiles use for subgrade reinforcement

10.5 Cost Benefit using Geogrids in Reinforced Soil Wall applications

The use of Geogrids in reinforced soil walls is perhaps the biggest success story for Geosynthetics in India. This is because of the design and space advantages that can be leveraged by Reinforced Soil Walls (RS) when compared to Reinforced Cement Concrete (RCC) Walls are significant as the footprint of the foundation is smaller hence requires less land and material. A cost benefits analysis is as follows.

Cost Consideration for RCC Wall

Considering a 10m length of wall of 7m height:

Component	Number	Length (m)	Height (m)	Width (m)	Volume (m^3)
Base Slab	1	10	0.3	4.9	14.70
Vertical Wall (W_1)	1	10	8.7	0.3	26.10
Counterfort (W_3)	3	3.75	8.7	0.3	14.68
Shear Key (W_2)	1	10	0.6	0.3	1.80
				Total =	**57.28 m^3**

Table 22: Volume calculation of 10m running length of RCC wall of 7m height

Hence total consumption of concrete for 7m high retaining wall above ground level is 57.28 m^3 for 10 m length of wall, or 5.73 m^3 per running metre of wall.

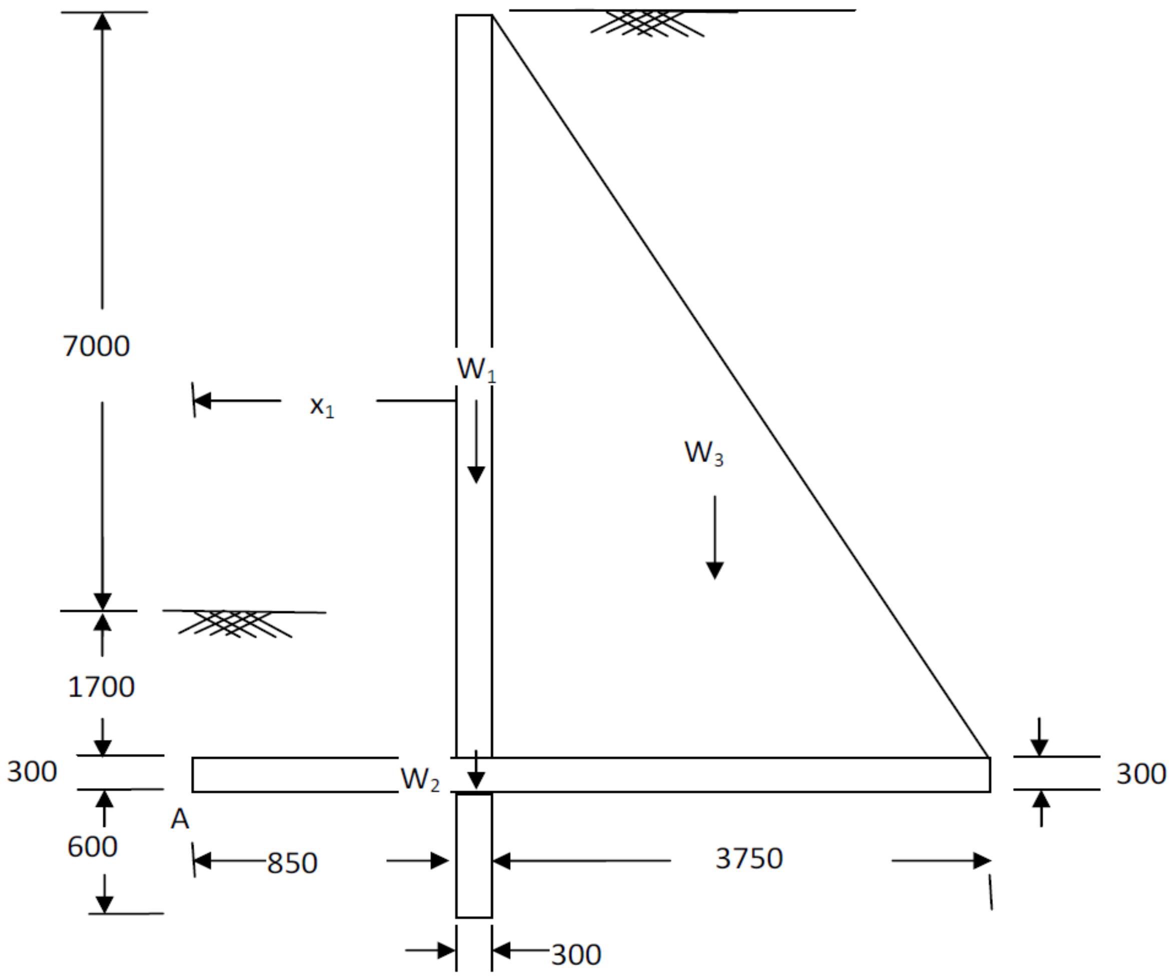


Figure 160: RCC Counterfort Wall cross section

Cost estimation for the RCC counterfort wall using M_{35} concrete with Fe415 reinforcement:

Quantity = 5.73 m^3

Rate = ₹6100 *per* m^3

Total = ₹34,953 *per metre running length for 7m high (above ground) RCC wall*

Cost estimation for Reinforced Soil Wall (RSW)

Design for the reinforced retaining wall is based on BS-8006 for static and seismic with FHWA-043 and uses knitted and PVC coated polyester Geogrids.

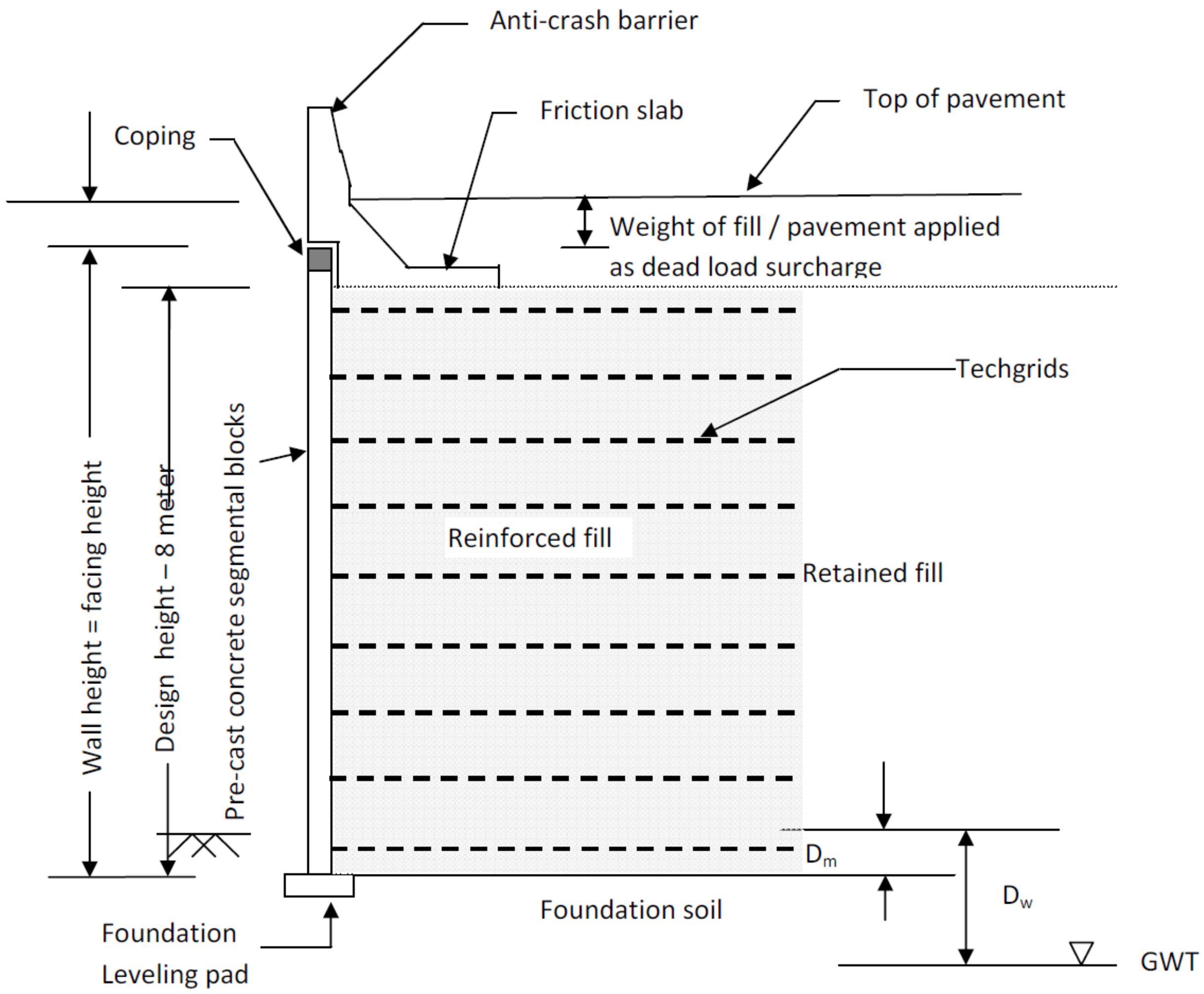


Figure 161: Reinforced Soil (RS) Wall cross section

Cost estimation per metre running length of 8m high wall is as follows:

Cost of Geogrids (design and supply) = ₹14,800

Cost for casting and erection of panels = ₹12,000

Total Cost per metre running length for 8m high RS Wall = ₹26,800

<u>Conclusion</u>

The cost benefit from using Reinforced Soil wall vs. Reinforced Cement Concrete wall is:

$$1 - \frac{₹26,800}{₹34,953} = 23.3\% \; in \; savings$$

This shows the significant upfront cost benefit from the use of Geogrids. Not taken into account is the savings in land cost due to smaller footprint and hence less requirement of area for flyover construction.

Annexure I: List of Manufacturers in India

1. CTM Geo Synthetics

Name of the Company	**CTM Geo Synthetics**
Head Office Address	205, New Cloth Market, Ahemdabad-380002
Email ID	info@ctmgeosynthetics.com
WebSite	www.ctmgeosynthetics.com
Contact No	079-22165163/09327988555
Branch Office	Hyderabad, Guawhati, Kolkata
YOE	Group Established-1948, CTM Technical Textiles Ltd. -2005
Manufacturing Location	Ahemdabad
Product Types	Polyester geo grids
Capacity	15,00,000 sq meter in first phase
InHouse Testing Facility	All Basis testing to be done in house
Accreditations	-
Export	-
Major Customers	-

2. Gareware-Wall Ropes Ltd.

Name of the Company	**Gareware-Wall Ropes Ltd.**
Head Office Address	Plot No-11, Block-D-1, MIDC, Chinchwad, Pune-411019, Maharastra, India
Email ID	geo@garewareropes.com; mvoffice@garewareropes.com
WebSite	www.garewareropes.com
Contact No	91-20-30780000/30780187, Fax: 91-20-30780350
Branch Office	New Delhi, Mumbai, Chennai, Kolkata, Vishakhapattanam
YOE	1976
Manufacturing Location	Pune & Wai (Maharastra)
Product Types	Polyemer rope gabion, Woven Geotextiles, Steel Gabion, Geotextiles Tubes, Geotextle bag & container, Anti-buoyancy geotextile bags, Galvenized Steel Wire ropenet, Garmet-Erosion Control Mat, HDPE geomembrane, Nonwoven Textiles, Geosynthetic clay liner, ploymer geogrid, Geocell, Geonet & Geocomposite, Ancodrain(R)
Capacity	NA
InHouse Testing Facility	Universal Testing Machine, Cone Drop Testing Machine, Mullen Burst Testing Machine, Water Permeability testing appratus, Sieve Tester, Adhesion Tester, FRI Tensile Tester, Creep Tester, etc.
Accreditations	ISO 9001:2008
Export	Australia, Srilanka, UAE, etc.

Major Customers	Konkan Railway Corporation Ltd., Hindutan Zinc Ltd, Vedanta Alumini Ltd, Ranbaxy Laboratory, Jubilant Organosys Ltd, Southern Railway, PWD, Surat Municipal corporation, CIDCO, MIDC< Gujarat Electricity Board, NMRDA, Kandla Port Trust, Cochin Port Trust, Swaminarayan Sanstha, L&T ECC, L&T Hochtief, Patel Engineering, Delhi Metro Corporation, ACC Ltd, HCC Ltd, Tata Power Company, HLL, NCL, Essar Projects, Gammon India Ltd, AFCONS, MSRDC

3. Kusumgar Corporates Pvt. Ltd

Name of the Company	Kusumgar Corporates Pvt. Ltd
Head Office Address	101/102, Manjushree, V M Road, Corner of N S Road No:5, JVPD Scheme, Vile Parle (West), Mumbai-400056
Email ID	info@kusumgar.com
WebSite	www.kusumgar.com
Contact No	022-61125100
Branch Office	NIL
YOE	1970
Manufacturing Location	Kusumgar Corporates Pvt. Ltd, 2834, GIDC Area, Phase III, Umbergaon-396171, Distt: Valsad, Gujarat, Kusumsagar Corporates Pvt.Ltd, Vasundhara Canning Compound, Near Pardi rly Station, Killa Pardi, Valsad-396125, Gujarat, Kusumsagar Corporates Pvt. Ltd, Plot: 1809, UU Road, GIDC, Vapi-396195, Gujarat
Product Types	Woven Textiles
Capacity	10 Lakhs Sq. meter per annum of woven geotextiles
InHouse Testing Facility	Tensile Strength upto 10 ton, CBR Puncture, Index Puncture, Tear, Permeability, AOS
Accreditations	ISO 9001:2008
Export	
Major Customers	All Leading Contractors

4. Maccaferri Environmental Solutions Pvt. Ltd

Name of the Company	Maccaferri Environmental Solutions Pvt. Ltd.
Head Office Address	402, 4th Floor,Salcon Aurum, Plot No:4, Jasola District Center, New Delhi-110044
Email ID	technical@maccaferri-india.com, info@maccaferri-india.com
WebSite	www.maccaferri-india.com
Contact No	011-43798400, 020-41001932
Branch Office	Navi Mumbai, Ahemdabad, Chennai, Pune
YOE	1998

Manufacturing Location	D-40, MIDC, Ranjangaon, Taluka Shirpur, Pune-441220
Product Types	Geotextile (Woven & Non Woven), Paraweb polymeric strips, Paragrid & Paralink, Gabions, mattresses, sack gabions, Terramesh & Green Terramesh, Snow Fencing, Geomembrane & GCL'S, Geocomposites, Glass Grids, Geocells, Fabric form Mats, Prefebricated vertical Drains, Geo Coir & Geo Jute Products, Geobags & Geotubes, Rockfall Netting, Steel Grid, HEA Panels & Rockfall Barrier.
Capacity	NA
InHouse Testing Facility	Yes
Accreditations	ISO 9001
Export	Yes
Major Customers	NA

5. Shri Ambika Polymer Pvt Ltd.

Name of the Company	**Shri Ambika Polymer Pvt Ltd.**
Head Office Address	Safal Profitaire, A/3 First Floor, Near Auda Garden, prahladnagar, Ahemdabad, 380501, Gujarat, India
Email ID	jyotika@ambicapolymer.com, anuja@ambicapolymer.com
WebSite	www.ambicapolymer.com
Contact No	91-79-65453665, 09560556651
Branch Office	
YOE	2005
Manufacturing Location	Plot No: 503, Opp Bharat Gas Plant, Hariyala, Kheda, Gujarat
Product Types	Woven Geotextiles, Ground Covers, Silt Fence, Mulching, Needle Punched Non Woven
Capacity	4800 MT per Annum
InHouse Testing Facility	All testing pertaining to Geo-Textiles
Accreditations	ISO 9001-2008
Export	USA, Europe, UK
Major Customers	Bridge & Roof, HDC, GR Infra and International Stockists & Distributors

6. Skaps Industries Ltd

Name of the Company	**Skaps Industries Ltd**
Head Office Address	Darshan Society, Stadium Road, Navarangpura, Ahemdabad-380009
Email ID	utkarsha@skaps.com
WebSite	www.skaps.com
Contact No	9974042256
Branch Office	Vadodara
YOE	2003

Manufacturing Location	Ahemdabad & Mudra
Product Types	Woven Geotextiles, Non Woven Geotextiles and Geocomposites
Capacity	75 million M^2, 10,000 MT
In House Testing Facility	Yes, at Factory Location
Accreditations	NA
Export	US
Major Customers	Export Oriented Unit

7. Strata Geosystems (India) Pvt. Ltd

Name of the Company	**Strata Geosystems (India) Pvt. Ltd**
Head Office Address	317, Tantia Jogani Industrial Premises, J R Boricha Marg, Lower Parel, (East), Mumbai-400011
Email ID	info@strataindia.com
WebSite	www.strataindia.com
Contact No	022-40635100
Branch Office	Hyderabad
YOE	2004
Manufacturing Location	Daman
Product Types	Strata Grid (Geogrid), Strata Web (Geocell)
Capacity	6 Million M^2 per Annum
InHouse Testing Facility	For Raw Metarials
Accreditations	ISO 9001:2008
Export	Egypt
Major Customers	NHAI, IRB, Soma, IL&FS

8. Terram Geosynthetics Pvt. Ltd.

Name of the Company	**Terram Geosynthetics Pvt. Ltd.**
Head Office Address	A-704, Safal Pagasus, Anandnager Road, Satellite, Ahemdabad-380015
Email ID	pparekh@terramgeosynthetics.com
WebSite	www.terramgeosynthetics.com
Contact No	079-40064529, Fax: 079-400645, 09724302188
Branch Office	Survey No: 141, MITAP, MPSEZ, Village Mundra, Distt: Kutchh, Gujarat-370421
YOE	Apr-08
Manufacturing Location	Mundra- Katchh (MPSEZ)
Product Types	Non Woven Geosynthetics
Capacity	6000 MT
InHouse Testing Facility	R&D Lab established for inhouse testing
Accreditations	NA
Export	NA
Major Customers	Na

9. Techfab India Industries Ltd.

Name of the Company	Techfab India Industries Ltd.
Head Office Address	711-712, Embassy Centre, Nariman Point, Mumbai-400021
Email ID	office@techfabindia.com, anant@techfabindia.com, p.salvekar@techfabindia.com
WebSite	www.techfabindia.com
Contact No	022-22876224/25/ 022-22839733, fax: 022-22876218
Branch Office	Delhi, Ahemdabad, Bangaluru, Kolkata, Chennai
YOE	2003
Manufacturing Location	Khadoli, Silvassa, Daman
Product Types	Multifilament Polypropylene woven geotextiles, woven polypropylene geotextiles made of silt film, woven multifilament polyster geotextiles, copper and polymer Gabions & Mattresses, Knitted and PVC Coated polyster geogrids, Glass Geogrid, Geocomposites, Non woven geotextiles, Prefabricated vertical drain, Steel Gabion, Rockfall Netting
Capacity	Woven: 2400 T, Non Woven: 8040T, Geogrid: 15 Million $M^{2,}$ Gabions: 7200 T
InHouse Testing Facility	Our Labs are equiped with modern testing equipments to test most of the parameters.
Accreditations	IRC, PWD, Airport Authority of India, MES, PMGSY, BBA, CIDCO
Export	Techfab India has its own export house and the certificate is issues by GOI
Major Customers	Most of leading contractors in India

10. Techno Fabrics Geosynthetics Pvt. Ltd.

Name of the Company	Techno Fabrics Geosynthetics Pvt. Ltd.
Head Office Address	21/A, Shri Satyanarayan Industrial Society, Udhna Magdalla Road, Surat – 395017
Email ID	info@technofabrics.com, ro@technofabrics.com
WebSite	www.technofabrics.com
Contact No	0261-2633209/210, fax: 0261-2633230
Branch Office	Surat, Patna
YOE	2005
Manufacturing Location	Surat
Product Types	Erosion control and soil reinforcement products
Capacity	N/A
InHouse Testing Facility	The company has well equipped in-house Geosynthetic Testing Laboratory. The company has also tie up with Bombay Textile Research Association (BTRA, Mumbai) for carrying out third party testing of materials.

Accreditations	The company is an ISO 9001: 2008 certified company.
Export	
Major Customers	

Additional Manufacturers:

11. Capital Nonwovens Pvt. Ltd., Nashik
12. Dynamic Wooltex, Jaipur
13. Flexituff International, Kashipur, Uttaranchal
14. Gridhar Techfab, Ahmedabad
15. Hi-Tech Speciality Fabrics, Baroda, Gujarat
16. H.M.B.S. Textiles Pvt. Ltd.
17. Jeevan Products Pvt. Ltd., Navi Mumbai
    Marutiplast (Techno rubber), Noida
18. Parishudh Fibres, Jaipur
19. Veer Plastics, Ahmedabad
20. Virendra Textiles, New Delhi
21. Charankattu Coir Geotextiles, Cochin

Annexure II : List of Design Consultants for Geosynthetics in India

List of Consultants		
S.No	**Name of Consultant**	**Address of Consulting Firm**
1	M/s ICT Pvt Ltd	A 11, Green Park, New Delhi - 110 016 , Tel : 26964757
3	M/s SMEC International Pvt. Ltd.,	A-20,Kailash Colony, New Delhi - 48 , Tel : 011-6421513/14 ,Fax : 011-6421515
4	CES-BECA (JV)	57,Nehru Place , Fifth Floor, New Delhi - 110 019, Fax :011 - 6460409
5	M/s STUP Consultants Ltd	1112,Vishal Tower,Distt. Center Janakpuri. New Delhi 110018
6	M/s STUP Consultants Ltd	Placedes Freses,Montogolfier Cedex.Phone No:-331-30124800 , Fax:-331-3012-1095
7	MEINHARDIT (Singapore) Pvt Ltd,	93,Havelock Road, Singapore 160093, Tel :65-273 5255, Fax : 065-2740788
9	Lea International	B-1/E-27, 2nd floor, Mohan corporation Ind Estate, Muthra Road, New Delhi-44, Tel:6973950,Fax:6971062
10	M/s ICT Pvt Ltd	A 11, Green Park, New Delhi - 110 016 , Tel : 26964757
11	Lea International	B-1/E-27, 2nd floor, Mohan corporation Ind Estate, Muthra Road, New Delhi-44, Fax:6971062
13	M/S SMEC International Pvt Ltd	A-20,Kailash Colony, New Delhi - 48 , Tel : 011-26421513/14, Fax : 011-26421515
14	M/S Rites - Halcrow (JV)	Indian Arunachal, 6th Floor , 19, Barakhamba , Tel : 3350760 / 3316071 ,Fax : 3350989
16	Halcrow Ltd.	C-253, 1st Floor, Defence Colony, New Delhi 110 024., Tel : 464-5790, 4603253.Fax : 4645986.
17	M/s Dorsch Consultant	Oshiwara indl. center,Opp Goregaon bus depot,Goregaon,Mumbai , Tel:-022-8778548
18	M/S RITES	Indian Arunachal, 6th Floor , 19, Barakhamba Road , New Delhi-110001 , Tel : 3350760 / 3316071 , Fax : 3350989
19	M/s SPAN Consultants - Symonds	Plot No 12,Pratap Colony,Near HoTel Ajanta ,MIDC , Satara.
20	Roughton International - CEG	321 Millbrook Road WestSouthampton, SO15 0HWU.K, Tel : 0044 1703 705533.Fax : 0044 1703 701060.
21	M/S Louis Berger International Inc.	1819,H Street, NW Washington, D.C 20006, Tel :001-202-3317775, Fax :001-202-2930237Email:answers@louisberger.com
22	SPAN Consulatants Pvt Ltd	E-3-5,Second Floor, Local Shopping Complex, J-Block Sacket, New Delhi -17 , Tel: 011-6565838/6861825, Fax:6866766
23	M/S RITES-Sowil-Secon (JV)	Indian Arunachal, 6th Floor , 19, Barakhamba Road , New Delhi-110001 , Tel : 3350760 / 3316071 , Fax : 3350989

S.No	Name of Consultant	Address of Consulting Firm
24	M/S Sauti - Gherzi JV	Ms Sauti- Gherzi JV, Uffici E Sede Legale , Via Petritoli, 19/23-00138 Roma. Tel :3906-8819180 ,Fax:3906-8819101
25	Sheladia Associates Inc (USA)	4,Kuldip Society,Near Ishwar Bhuwan,Navrangpura, Ahmedabad -380009, Tel: 079 2646 - 3147/1929/3625, Fax No:079 -2646 5909, Email: mail@sheladiaindia.com
26	SMEC-SPAN Consltants (P) Ltd	E-3-5, Second Floor, Local Shopping Complex, J-Block Sacket,New Delhi-17 Tel: 011-26565838/26861825 Fax: 26866768
27	M/s DHV Consultant	DHV International BV, LAAN 1994,nr-35,380 Bj Amersfood, Netherland
28	M/s CES-BECA-RITES	7-3-12/B-2,Gonti Road, Srikakulam Tel: 08942 -21598, Fax : 08942-21958
29	M/s Sheladia - Rites	202,HIG - Sector 4, MVP Colony, Vishakhapatanam, Tel: 0891-718895/718896
30	M/s Dorsch Consultan	Oshiwara indl. center, Opp Goregaon bus depot, Goregaon,Mumbai, Tel: 022-8778548
31	SNC Lavalin International Inc. - Aarvee Associates (JV)	D.No. 78-14-21, Ground Floor, Shyamala Nagar, Rajahmundry-533103, Andhra Pradesh.Tel: 0883-435639, Fax: 0883-449349
32	SNC Lavalin International Inc. - Aarvee Associates (JV)	D.No. 78-14-21, Ground Floor, Shyamala Nagar, Rajahmundry-533103, Andhra Pradesh. Tel: 0883-435639, Fax: 0883-449349
33	Louis -Berger Nippon KOEI & CES JV	INC M-122, First Floor, Greater Kailash , Part-I,New Delhi - 110 048 , Tele: 6281695 , Fax : 6232945, Email : lbii@giasdl01.vsnl.net.in
34	KM International AB-Secon Surveys JV	Opp.Priyadarshini Degree College, Buja Buja, Nellore - 524004 , Tel: 0861-300044 , Fax: 0861-300033
35	Scott Wilson Krikpatrick	SKLS Building ,Sembulivaram Village, Cholavaram, Chennai -600067, Tel : 044-633 0807/633 0808 , Fax : 044-633 0807/0808
36	Bceom-French Engineering Consultants	N-118, Ground Floor, Panchsheel Park, New Delhi 110 017.Tel : 6495298,6495299, Fax : 6495297.
37	M/s Dorsch Consultant	Oshiwara indl. center,Opp Goregaon bus depot,Goregaon,Mumbai , Tel:-022-8778548
38	M/s CES-Halcrow Association	Plot No. 1601-1602, Karnavati Estate Ist Floor, Vatwa GIDC Phase III , Ahmedabad 382445 , Gujarat. Fax: 079-5878135
39	M/s CES-Halcrow Association	Plot No. 1601-1602, Karnavati Estate Ist Floor,Vatwa GIDC Phase III , Ahmedabad 382445, Gujarat. TelFax: 079-5878135

Annexure III: Information Sources

Books:

- ✓ Geofabrics, An introduction to geosynthetics; GEOfabrics Limited, Skelton Grange Rd, Stourton Leeds LS10 1RZ,United Kingdom
- ✓ Guide to the Specification of Geosynthetics; August 2006, IGS Secretariat, 226 Sitton Road, Easley, South Carolina 29642, U.S.A.
- ✓ Handbook of geosynthetics; Geosynthetic Materials Association (GMA), 1801 County Rd B West, Roseville MN
- ✓ Designing with Geosynthetics; Koerner, Robert M; Dec 15, 1997

Paper Abstracts:

- ✓ Timothy D. Stark, Luis F. Pazmino, Stanford Slifer, and Duff Simbeck; Fabricated geomembranes: advantages and uses; Waste Age Magazine, September 2010.
- ✓ Technical note; Gabions Durability; MACCAFERRI, April 04, 2012
- ✓ Thomas G. Stam; Geosynthetic clay liner - field performance; Bentofix Technologies, Inc., Serrot International, Inc., Henderson, NV, USA;
- ✓ Shahrokh P. Bagli; Geocells: the way forward with the three dimensional innovation; Chief Technology Officer - Strata Geosystems (India) Pvt Ltd
- ✓ Julie B. Bearden and Joseph F. Labuz; Fabric for reinforcement and separation in unpaved roads, Department of Civil Engineering, University of Minnesota, 500 Pillsbury Drive S.E., Minneapolis, Minnesota 55455-0220
- ✓ Limit Equilibrium as basis for design of geosynthetic reinforced slopes, Jorge G. Zornberg, Nicholas Sitar, ASCE
- ✓ Geosynthetic engineering: Geosynthetic Protectors; Dr. Yun Zhou, Continuing Education and Development, Inc., 9 Greyridge Farm Court, Stony Point, NY 10980
- ✓ Design Funundamentals for Geosynthetic Soil Technique; R. Floss & G. Bräu, Technische Universität München, Zentrum Geotechnik, Germany

Websites:

- ✓ www.geosyntheticsmagazine.com
- ✓ www.interdrain.net
- ✓ www.terramgeosynthetics.com
- ✓ www.maccaferri-india.com
- ✓ www.strataindia.com
- ✓ www.techfabindia.com
- ✓ www.jutegeotech.com
- ✓ www.lrrb.org

- ✓ www.tensar.co.uk
- ✓ www.typargeotextiles.com
- ✓ www.caee.utexas.edu
- ✓ www.reinforcement.ch
- ✓ www.tencate.com
- ✓ www.michigan.gov
- ✓ http://geosynthetica.net
- ✓ www.cedengineering.com
- ✓ www.gw.govt.nz
- ✓ www.tenax.net
- ✓ www.kaytech.co.za
- ✓ www.geo-textiles.ru/en/

Search Engine:

- ✓ www.google.com
- ✓ www.search.yahoo.com
- ✓ www.bingo.com