Guide to the Specification of Geosynthetics 2018

Foreword

This is the fifth and current edition of the Guide to the Specification of Geosynthetics and as such represents the recommendations of the IGS. This edition is placed on the IGS Web Site to provide IGS members with ready access to the guide to the specification of geosynthetics.

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1 Introduction

This Guide to Specification has been prepared by the International Geosynthetics Society.

The objective of this document is to be a generic guide and aid to those writing specifications.

The guide will provide information which is useful to those who use specifications, buyers of geosynthetics and installers.

Definitions and usage of specialist terms used in this guide are consistent with the IGS publication ‘Recommended Descriptions of Geosynthetics Functions, Geosynthetics Terminology, Mathematical and Graphical Symbols’.

Example Specifications are referenced and linked in this document, these may be used as a basis for writing project specifications. The user is responsible for ensuring that any values used are correct and appropriate for the application and materials. All values must be verified by the user based on the designs for the project, the understanding of the site and processes, and the appropriate regulations and requirements.

2 Philosophy

2.1 Philosophy

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

- The specification should be concise.
- The specification should allow for both commodity and speciality products if possible.
- The specification should use established testing protocols.
- The specification should both validate the design and assure the important properties are monitored (performance vs. index testing).
- The specification should address durability and lifespan consistent with design assumptions.
- The specification should allow for future improvements and changes.
- The specification should be based on the desire to achieve an engineering design.

Although the following sections list components that are specific to each material type, there are several considerations and components that are common to any good specification, those are briefly discussed here.

A good specification should be brief. Unnecessary language should be removed, it will likely cause problems and undesired restrictions.

A good specification will consider the continuity between commodity materials and specialty materials. A commodity material likely already has existing specifications by definition. In contrast, specialty materials likely have fewer existing specification resources. It has been common for modification of commodity materials to result in the next advancement or stage of material with additional performance characteristics. A comment should be made regarding commodity materials vs. specialty or innovative materials. If you specify and buy a commodity material at the lowest possible price, while you may profit in the short term, you will likely be surpassed by those who are being innovative. Innovation costs more in the short term, but always less in the long term as the new benefits are applied.

A good specification will utilize established test protocols. ISO, ASTM, CEN and other national or international organizations have created existing test protocols that address the details of a test, the number of replicates, the variability of a test, the recommended frequency of testing and other factors. These test protocols should be utilized whenever possible and clear statement of minimum or maximum target values (ranges are preferred) and test frequencies established.

A good specification must offer a compromise between index testing and performance testing. In an oversimplification, a design test directly assures that a material will perform as expected to achieve the design goal, an index test does not directly relate to the design, but instead usually speaks more to product consistency or other considerations. Index tests are generally faster and more broadly utilized with a larger collection of data for comparison. Design tests are usually unsuitable as quality control techniques.

A good specification will address the critical performance indicators: it is most important to assure the material possesses those properties that are “most important”. For example, a design test may be included in a specification with a “one-per-project” frequency, where an index test may have a frequency that is orders of magnitude more frequent. It is a normal compromise to balance the direct design utility of a test with a desire for a higher frequency. Geotextile filtration is a good example of this: a long-term filtration design test, utilizing the exact materials to be filtered may take months, or even years to complete. In index test measuring the filtration of glass beads is a common index test, can be completed in hours, but is a compromise in that it does not use the exact material to be filtered. The specification writer must make a compromise between design goals and quality testing ease and utility.

A good specification will address product and manufacturing consistency. This is usually done with one or more types of index testing and defined tolerances. One of the benefits of geosynthetic materials as contrasted with incumbent (soil) materials is that a manufactured product should be more consistent. A good example is the drainage rate of a geosynthetic geocomposite or vertical drain as contrasted with sand. As the sand quality varies with particle size, compaction and other variables, the drainage performance will vary. A manufactured geosynthetic material should be expected to be much more consistent than a soil on a lot to lot and even year on year basis.

A good specification addresses the durability and lifespan of a material. This is typically done through the use of some accelerated testing. This may involve time-temperature superposition and/or the stepped isothermal methodology or exposing the material to higher temperatures than anticipated during normal life or to higher intensity light or chemical concentrations, or some combination of the above. The methods are very complex and should be constructed carefully, however it is important for a specification to contain a component that assures the durability of the material matches the expected design lifespan. Again, this may be an (accelerated) design test such as exposure in a weatherometer, or an index test such as verification of proper concentrations of longer term stabilizers.

A good specification should allow for variation and improvement. Most specifications accommodate this by allowing for “an approved equal”. It is important to allow room for advancements in material composition and performance.

There are a few items that should not be included in a specification. It is not advisable to include pricing information – this tends to change over time and while a part of a purchasing decision, it is not suitable for technical analysis. It is further not advisable to include tradenames or specific manufacturers; if you are going to source from a single specific supplier the requirements are of a different type than discussed here. Also, the specification should not address the fate or actions to be taken if a material does not meet some aspect of the specification; this issue is properly a component of an overall quality system and the specification is generally not sufficiently flexible to properly address this situation.

2.2 Existing Specifications

In preparing this guide various national and other standards which pre-exist have been considered as well as other literature on the subject and use of geosynthetics for a variety of applications. A weblink to many specifications and useful related documents is included near the end of this document and can also be found on the IGS website. It is the responsibility of the specification author to assure that any and all regulatory requirements in place at the location of the project are complied with.

2.3 Testing Protocols

Geosynthetic properties are measured using a number of test procedures published by standardisation organisations on an international, regional or national basis:

- International Standards Organisation (ISO): used in many countries worldwide, often issued as dual numbered standards with European Norms, published in English and French
- Europe – European Norms (ENs), standards published in English, German and French as official versions, other language editions also exist as prepared by individual countries and registered with CEN
- North America – ASTM International test procedures are used extensively in North America and other parts of world where authorities have adopted the ASTM standards.
- AS – standards used in Australia and some Pacific areas
- Japan – based on ISO standards or translations of ISO document
- China and Korea – national standards and other documents based on ASTM and/or ISO standards

For typical/general values of properties of geosynthetic products there exist useful directories published by the Industrial Fabrics Association International (IFAI), Geosindex, The Geosynthetic Institute, Multiple national IGS chapters including the French, Italian, and other chapters, documents available on the International Geosynthetics Society website and multiple other sources.

3 Applications

The applications will be considered by product types;

- Geotextiles
- Geogrids
- Geomembranes and Geosynthetic Clay Liners (GCLs)
- Geomats and Erosion control products
- Geocells

The descriptions of each application and function are described in the IGS Education brochures. The brochures can be downloaded from the IGS web site at http://www.geosyntheticssociety.org/ . The brochures are available in English, and other languages supported by the IGS, the subjects include:

- Geosynthetics Functions
- Geosynthetics Classification
- Geosynthetics in Filtration and Drainage
- Geosynthetics in Embankments on Soft Soils
- Geosynthetics in Erosion Control
- Geosynthetics in Hydraulics Projects
- Geosynthetics in Railroads
- Geosynthetics in Landfills
- Geosynthetics in Road Engineering
- Geosynthetics in Unpaved Roads
- Geosynthetics in Slopes over Stable Foundations
- Geosynthetics in Walls
- Geosynthetics in Waste Water Treatment
- Geosynthetics in Seismic Applications
- Geosynthetics in Agricultural Applications

The respective functions are listed in the table below (modified from Koerner, *Designing with Geosynthetics*):

Table 1. Primary Functions of Geosynthetics

	Separation	Reinforcement	Stabilization	Filtration	Drainage	Barrier	Surface erosion control	Protection	Stress relief (for asphalt overlay)
Geotextiles	X	X		X	X			X	X
Geogrids		X	X						X
Geonets					X			X	
Geostrip		X							
Geospacer					X			X	
Drainage geocomposites (with geonet core, geomat core, or other types of core)	X			X	X			X	
Geosynthetic barriers (synthetic, bituminous, clay)	X					X			
Geocells			X				X		
Geomats							X		
Geoblanket							X		

Note: More detailed Tables citing important application-dependent parameters can be found as CEN-documents.

In nearly all applications, geosynthetic materials are used in place of traditional building materials – sand, soil, gravel, concrete, asphalt and other materials. In most cases, the geosynthetic is used to provide some function that the traditional incumbent material cannot supply. These materials have been developed and commercialized into a more than 3-billion-dollar annual global business because the products have capabilities that traditional materials do not. A short list of these capabilities might include:

- Longer durability and lifespan
- Capability to construct designs with geosynthetics that are simply impossible without geosynthetics.
- Shorter construction schedules much less likely to be impacted by weather, etc.
- More consistent performance than naturally occurring materials
- Much improved and reduced environmental impact with geosynthetics
- Give cost benefits over conventional solutions

Geosynthetics are used because they work better, last longer and allow new and improved designs. Despite their great benefits, geosynthetics are usually a very minor cost percentage of an overall project. This is in contrast with the geosynthetic commonly being essential to the success of the project. Most vertical walls could not be built without geosynthetic reinforcement, landfills and water containment projects that are literally too numerous to count require geosynthetic barrier materials, roadways over soft soils require geosynthetics to service their first traffic. Yet in each of these cases, the geosynthetic is commonly < 10% of the total project cost. Yet without the geosynthetic, or with a geosynthetic mis-installed, the project will fail, as several have, with significant cost, in the worst instances billions of dollars in remediation expense. Specifications should help to prevent these issues, particularly if properly constructed.

4 Functions

The functions of each type of geosynthetic considered for each section of the specification are those functions which are commonly ascribed to these products; other special functions can be satisfied by the use of more specialized products or combinations thereof. These special functions can be described by the specifier by using application specific clauses.

The normal functions used in specifications and standards are:

- Separation: the prevention from intermixing of adjacent dissimilar soils and/or materials
- Filtration: the restraining of uncontrolled passage of or other particles subjected to hydrodynamic forces, while allowing the passage of fluids into or across a geosynthetic material.
- Drainage: the collecting and transmitting of precipitation, groundwater and/or other liquids or gases along the plane of the geosynthetic.
- Reinforcement: the use of the stress-strain behaviour of a geosynthetic to improve the mechanical properties of soil or other construction materials.
- Barrier: the use of geosynthetics to prevent or limit the migration of fluids
- Protection: the use of a geosynthetic material as a localised stress reduction or dissipation layer to prevent or reduce damage to a given surface, material or layer.
- Surface erosion control: the use of a geosynthetic to prevent soil or other particle movements on the surface of a slope.
- Stabilization: improvement of the mechanical behaviour of an unbound granular material by including one or more geosynthetic layers such that deformation under applied loads is reduced by minimizing movement of the unbound granular material.
- Stress relief (for asphalt overlays)

If the functions are assigned to the products the normal functions for each type of geosynthetic are as reported in Table 1.

Geocomposites may be formed that have multiple functions.

5 Geotextiles

As the oldest of the geosynthetics and the product with the broadest range of applications, there are a large number of specifications available for geotextiles. It is important to note that geotextiles are supplied in two primary varieties: woven geotextiles that are made by “loom-type” methods and nonwoven (‘needle punched” or heat-bonded) geotextiles. The products share common applications, but also have significant differences, particularly in mechanical behavior and filtration properties.

Geotextiles are used in many applications and perform several functions; in the order discussed below common functions are separation, filtration, reinforcement, protection (of other materials) and drainage. The function of reinforcement, while possibly fulfilled by geotextiles, is also supplied respectively by geogrids, and the function of drainage now is commonly fulfilled by geocomposites.

5.1 Geotextiles in Separation

For separation, the primary function of the geosynthetic is to prevent the mixing of multiple soil types, usually where the soil types provide different functionality. The most common application is in road construction, both paved and unpaved roads. A large particle sized base course for physical stabilization is placed on a finer subgrade and is usually topped with a finer grain soil designed to provide a smoother road surface. If these soil types are mixed, neither function will be provided to an optimum degree. The geotextile prevents this mixing. One of the common critical attributes in this application is the survivability and durability of the materials. This is measured and controlled by multiple properties. Again, specification resources are listed in the references and linked below.

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. The design of the geotextile will be based on a tensile strength requirement, the puncture resistance (CBR and/or Cone Drop resistance) and durability tests to determine the survivability in the service environment.

5.2 Geotextiles in Filtration

A well-established geosynthetic function is filtration, where there are economic advantages, as geosynthetics as a direct replacement for selected, graded granular filters. Drainage geosynthetics are commonplace in highway drainage systems, behind bridge abutments and retaining walls, beneath revetments, sea defence groynes, sludge dewatering systems and can be used in the drainage systems of dams.

Soils are porous media containing 20 to 40% voids in between soil particles, which are typically filled with gas such as air, liquid such as water, or both. Displacement of water within the voids of the soil generates a dragging force on each of the grains of the soil. When the grains are supported, i.e. by other grains, they stay in place and the water moves without disturbing the soil structure. However, if the grains of soil are not in contact with a solid that can offer a resisting force, internal erosion can develop: soil particle are dragged by the water until they reach an obstacle, or until they exit the soil structure.

Soil structures often include configurations where the water has to flow away from the soil, i.e. into a drain. To prevent internal erosion, a filter media shall be installed, in order to offer a resisting force to the largest particles of the soil, called the soil skeleton, and to prevent it from being dragged away by the water. However, this filter media should not restrain the flow of water, in particular to avoid pore pressure build-up, which could also adversely affect the stability of the soil structure.

With geosynthetics, the filtration function is to stabilize the soil by maintaining in place the soil skeleton in contact with the geotextile surface and restrain uncontrolled passage of soil, while allowing the passage of water or other fluids and some of the finest particles transported in suspension across the filter. The geotextile filter may be considered as a catalyst to create a natural granular filter in the thin soil layer in contact. When the geotextiles are not covered and laid alone, i.e. as silt fences, etc., the filtration behaviour is different: there is no soil skeleton to stabilize, the geotextile is intended to trap all moving particles.

The performance of a filter may be qualified by its ability to fulfil the two contradictory functions required for filtration: one is to prevent damages caused by the transport of an excessive quantity of particles from one side of the filter to the other (piping), such as internal erosion of the soil being filtered which could be modified in its engineering properties, formation of cavities on the upstream side of the filter. Such damages also include excessive contamination of the structure located downstream by particles piped through the filter, i.e. blocking of a drainage pipe. The second is to minimize restriction to the flow of water passing through the filter, to avoid pore pressure build-up on the upstream side of the filter.

Long term performance of geotextile filters can be endangered by the blocking of the surface (blinding) or of the pores (clogging) of a soil or geotextile filter. These mechanisms can be caused by the accumulation of fine particles and development of a "cake" on the surface of the geotextile (blinding), or inside the geotextile structure (clogging), resulting in a drastic reduction of the permeability of the filter.

In some cases, reduction of the capacity of the geotextile filter to let water pass across its plane might also be caused by the precipitation of chemicals, e.g. iron ochre, calcium, or the development of a biological activity. Evidences of clogging caused by the presence of air pockets trapped into, or in the vicinity of the filter have also been observed.

These mechanisms suggest that the best performance for a filter is obtained when using a material which openings are small enough to stabilize the largest particles in contact (soil skeleton) but large enough to let pass the finest particles in suspension and to avoid internal erosion of the soil, and piping.

For both piping and clogging mechanisms, the parameter controlling the performance of a filter is the size of the voids through which particles of the soil are likely to travel at the surface or inside the geotextile. Proper design of a geotextile filter thus requires selection of its filtration characteristics, such as opening size or permeability. These properties shall be selected with consideration to the properties of the soil to be filtered and hydraulic conditions prevailing on a particular site.

Other parameters characterizing the structure of a geotextile have also been investigated, such as the pore size distribution (determined using ASTM D6767 or ISO 11058) or the number of constriction (determined using ASTM D7138). However, if there is a consensus regarding the fact these parameters can influence the filtration performance of a filter, they are still being investigated by the research community.

Depending on their structure, some geotextiles can be compressed under load. Consequently, their permeability might decrease when compared to the property measured without load. ISO 10776 norm allows to test the water permeability characteristics normal to the plane, under load.

In some cases, consideration shall also be given to potential loading mechanisms, presence of iron ochre, potential biological activity, mineralogy of the soil, which can all affect the long-term performance of the filter. For extreme situations, the designer may consider using alternatives to geotextiles.

If properly specified and installed, geosynthetics can provide cost-effective solutions for drainage and filtration in civil and environmental engineering works. A variety of geotextiles are available that supply the proper opening size and filtration characteristics to accommodate a very broad range of soils and mixtures. Specifications commonly include apparent opening size, mass per unit area, physical properties and other aspects. Nonwoven geotextiles are commonly used for filters as the opening size of woven geotextiles can vary under load; woven mono filament geotextiles can be used when high design flows through coarse granular soils are being filtered. The design and subsequent specification of filters is done by relating the laboratory measured effective opening size (usually the O_{90} or O_{95}), the method of manufacture of the geotextile (woven or nonwoven) to one or more of the soil grading characteristics (d_{10}, d_{50} or d_{90}) 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 nonwoven geotextiles.

Specific factors to be included in specifications may include:

- Thickness
- Pore size of openings (O_{90} or O_{95})
- Installation damage resistance (CBR, Cone Drop or Abrasion – normally one or two properties only)
- Tensile strength (Wide Width Tensile Test)
- Water permeability normal to the plane
- Durability
    - Resistance to weathering (UV resistance prior to covering with soil)
    - Resistance to chemical attack/Micro biological degradation for special situations
    - Clogging resistance

5.3 Geotextiles in Reinforcement

Geotextiles used as reinforcement are normally high strength woven geotextiles. In some designs nonwoven geotextiles are used, in particular in Japan where the use of high strain nonwoven geotextiles has been shown to perform well in seismic events. The reinforcement products are subject to more analytical or numerical 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, reinforcements on voids, and as load transfer platforms over foundations with piles or improved with vibro-compacted stone columns or grouted compaction columns.

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

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.

Factors to be included in specifications may include:

- Short term tensile strength
- Long term design tensile strength
- Strain at design stress respective short- and long-term tensile stiffness.
- Puncture resistance (CBR and/or Cone Drop)
- Coefficients of interaction between the geotextile and the soils
- Installation damage resistance (damage during soil compaction, CBR, Cone Drop or Abrasion)
- Durability
    - Chemical – especially when in waste containment
    - Resistance to weathering (UV if to be left exposed during installation or in service).

5.4 Geotextiles in asphalt applications (Reinforcement, Stress-relief, Interlayer barrier)

Geotextiles used to reinforce asphalt paving layers must provide sufficient tensile strength at a low strain. They must be compatible with the asphalt to provide a strong bond to the asphalt layers. They must be sufficiently thermally stable and physically durable to withstand the rigours of the paving operation, and long-term durability is a must as well, as for the most geosynthetic applications.

Asphalt reinforcement is regularly placed between two bituminous layers or between old concrete pavement and new asphalt paving layers, thus redistributing thermally or mechanically induced peak stresses. This results in higher crack resistance and less deformations.

Design methods are normally empirical but with the advent of analytical methods for pavement design the realistic estimates of service strains and stresses, specific stress strain relationships for asphalt reinforcement can be calculated and hence specified.

Depending on the product composition, asphalt interlayers can provide following functions, or a combination of them, in a pavement system:

- Reinforcement
- Stress-relief
- Interlayer barrier

To maximise performance asphalt reinforcement should be installed following manufacturers guidance. Different forms of geosynthetic may require different installation techniques depending upon the substrate and the type and thickness of the overlaying asphalt layer.

Factors to be included in specifications for asphalt reinforcement may include:

- Material type (material description, raw material)
- Tensile strength
- Tensile stiffness at low strain
- Elongation at Break
- Bond efficiency to the asphalt layers
- Melting point
- Mass/unit area
- Installation damage resistance

5.5 Geotextiles in Protection of Geomembrane Barriers

Geotextiles with a protection function are intended to minimise damage to other materials, for example Geomembranes due to contact with soils both above and below the geomembrane. The protection is normally achieved by using heavyweight per unit area nonwoven geotextiles as protection layers. Design is carried out by carrying out site trials or laboratory tests to simulate the coarse grain impact.

Factors to be included in specifications may include:

- Protection Efficiency Test (Cylinder test and/or Large Scale Hydrostatic and/or Pyramid Puncture test)
- Puncture resistance (CBR and/or Cone Drop),
- Damage during installation
- Mass per unit area
- Durability
- Chemical – especially when in waste containment
- Resistance to weathering (UV if to be left exposed during installation or in service).

5.6 Geotextiles in Waterproofing of Asphalt Overlays

Geotextiles and geocomposites may also be used to provide protection from water penetration for Asphalt Overlays. Geotextiles, typically nonwovens, are placed between pavement layers to providing a water barrier at the old asphalt and new asphalt interface, which retards the development and growth of reflection cracks. Paving geotextiles are saturated with bitumen which waterproofs the geotextile, creates a barrier for water infiltration into the pavement section and provides a bond with the pavement layers.

5.7 Geotextiles and related products in Drainage

Drainage using geosynthetics is accomplished using geosynthetics with significant thickness respectively with a three-dimensional structure. These are commonly called geocomposites and include: geonets, geomats, geospacers, mini pipes or other voided polymeric structures. These are most commonly used with a geotextile filter component on one or both sides as required by the service situation. Very thick needle-punched nonwoven geotextiles 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 groundwater seepage),
- Drains behind retaining walls, to prevent the build-up 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 intrusion in the core between the supporting elements.
- Compression strength
- Compressive creep behaviour 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).
    - Resistance to clogging

Again, the drainage function is commonly addressed using geocomposite products as described below.

6 Geogrids

Geogrids are geosynthetics that are used in the construction industry in the form of a reinforcing or stabilizing material. They can be used in the reinforcement of retaining walls, steep slopes, dams, levees and other structural bodies. They can also be used for the reinforcement or stabilization or granular materials in unpaved and paved roads, railways, working platforms and other trafficked areas. There is a broad range of geogrids available with a variety of materials and constructions. Geogrids are made from polymers such as polypropylene, polyethylene, polyester, aramid, polyvinyl alcohol or other polymers. Geogrids are planar, polymeric structures consisting of regular open networks of connected tensile elements, which may be integrally linked by extrusion, by bonding or interlacing, whose openings are larger than the constituent tensile elements.

A good geogrid specification should include parameters relevant to the intended application. Critical performance criteria are commonly some variant of tensile properties; this may be short-term, longer term, low strain or interaction with the soils. Other parameters methodologies to evaluate critical performance may be pull-out strength; measuring the force required to remove the reinforcing materials from the soils that are being reinforced as well as sliding interaction between geogrid and soil. The specifications will vary with the applications: soil stabilization is different from wall construction and as the scope and scale of applications vary, additional testing or types of testing could be necessary.

As these products are nearly always buried, the lifespan and durability component of the specification commonly refers to survivability or some sort of reduction factor for damage that is done to the materials during the installation processes. These materials cannot be repaired/replaced after installation, so the requirement to “get it right” the first time is legitimate.

Depending on the chemical composition, these materials could be subjected to chemical reactions that will reduce the strength of the material with time. Chemical compatibility, as well as other long-term performance characteristics should be considered, and possible estimates verified by testing or historical performance data. Testing for the investigation of durability could go beyond simple screening tests and may include life-time prediction investigations.

They may be used in contact with soil/rock and/or any other geotechnical material in civil engineering applications. Geogrids can be manufactured using a variety of different methods which include:

- Punched and drawn sheet, either uniaxial drawn or biaxial drawn
- Strips of polymer welded at nodes or crossing points*
- Knitting / weaving and coating of strands or fibre bundles*

  Note: * It is possible to produce very high strength geogrids (> 1000 kN/m width)

6.1 Geogrids in Reinforced Slopes and Walls

The strengthening of slopes and walls is normally considered in three groups:

- Slopes with a face angle up to 45 degrees to the horizontal – reinforcement normally terminated close to or at the face, topsoil cover supported using erosion control geosynthetics.
- Slopes with a face angle of between 45 and 70 degrees to the horizontal – normal to provide a wraparound facing with the main reinforcement on the face and tucked into the fill at the top of the layer, steel mesh facing can also be used to support the face – topsoil or other growing medium retained behind the facing.
- Slopes with a face angle steeper than 70 degrees to the horizontal up to vertical (Walls) – these slopes are often provided with a hard or semi-hard facing system, precast concrete panels, concrete modular blocks, king post and infill planks, flexible steel units.

The design of reinforced soil slopes and walls involves considering the internal stability of the reinforced soil mass to determine the geometric arrangement of the geogrids and the tensile strength required to maintain stability. The overall stability of the reinforced soil block is also considered to ensure that failure by sliding, overturning, foundation bearing capacity, and along deep seated surfaces is avoided.

The design of slopes and walls should include details of repair methods which can be used in the event of a loss of face support e.g. by fire to covering vegetation, mechanical damage or vandalism.

The output from the design for the specification may include:

- Short term tensile strength
- Long term design strength
- Maximum allowable strain (time-dependent)
- Pull out resistance
- Interaction coefficients between fill and geogrids
- Connection strengths when connected to facing systems.
- Installation damage resistance (damage during soil compaction)
- Durability considerations
  - UV resistance for geogrids exposed on wrap around facings
  - Chemical resistance for contact with soil or backfill materials, especially if demolition or recycled material is used as fill.

6.2 Geogrids in Basal Reinforcement

Basal reinforcement of embankments is designed to prevent their global or local failure while founded on soft soils. The design of basal reinforcement is normally undertaken using standard slope stability methods modified to allow for the tensile resistance acting at the base of the embankment, and considering also soft soil extrusion mechanisms. In most approaches the peak tensile resistance from the reinforcement is needed during construction; as the foundation soils consolidate and increase in strength the force required from the reinforcement to maintain stability will / should reduce.

The output from the design for the specification may include:

- Short term tensile strength
- Long-term design strength
- Maximum allowable strain
- Coefficients of interaction between the geogrids and soils
- Installation damage resistance (damage during soil compaction)
- Durability –
    - UV or Weathering Resistance during installation
    - Chemical durability in contact with soils and/or groundwater

Note that for the same purpose typically high-strength woven geotextile may be used as well. In such a case, the above specification principles should be used.

6.3 Geogrids in Reinforcement Mattresses

Geogrid mattresses are a special basal reinforcement which due to the inherent bending stiffness will redistribute the settlement of the embankment – the normal 'dishing' with the maximum settlement at the centre of the fill will be reduced. The bearing capacity of the foundation soils becomes one of the major design considerations.

The output from the design for the specification may include:

- Short term tensile strength
- Elongation or strain at design load.
- Long term strain limited tensile strength for the long term loading.
- Strain at long term loading
- Installation damage resistance and damage during soil compaction
- Durability –
    - UV or Weathering Resistance during installation
    - Chemical durability in contact with soils and/or groundwater

6.4 Geogrids in Reinforcement - Void Spanning

Void spanning may be beneficial in areas of old mine workings or over soils or rocks with a potential to develop sinkhole features. In the void spanning case, the geogrid required to remain in place for many years without any loading, the loading will only be applied when a void propagates to the level at which the geogrid sits in the construction. The geogrid is normally installed to provide a short-term capacity to control deflection i.e. trafficability and/or to prevent a total collapse of the construction into the void, such that there is time to stabilise the void.

The output from the design for the specification may include:

- Short term tensile strength
- Acceptable strain for a given design period.

- Short- and long-term tensile stiffness.
- Design strength for a given design period.
- Installation damage resistance and damage during soil compaction
- Interaction coefficients between geogrids and soils
- Durability –
    - UV or Weathering Resistance during installation
    - Chemical durability in contact with soils and/or groundwater.

6.5 Geogrids in Stabilization

Stabilization has been introduced as a function to describe the way in which geogrids act when used with unbound granular materials such that the movement of the particles is minimised when loads are applied to the surface of the unbound material. The loads can be rolling loads from wheeled vehicles, tracked plant or static loads from foundations or crane outrigger pads applied on a limited area. By reducing particle movements, deformation of the granular layer may be reduced with a resulting improvement in load carrying capacity or trafficking performance.

The output from the design for the specification may include:

- Short term tensile strength
- Tensile stiffness at strains appropriate to the stabilization function
- Dimensions of the aperture related to the fill particle size distribution
- High coefficient of interaction to the coarse fill over the geogrid
- Installation damage resistance and damage during soil compaction
- Coefficients of friction and interaction between geogrids and soils
- Durability –
    - UV or Weathering Resistance during installation
    - Chemical durability in contact with soils and/or groundwater.

6.6 Geogrids in Asphalt Reinforcement Applications

The function is analogous to that of geotextiles in Chapter 5.4. However, geogrids (and geocomposites based on them) are recently more popular mainly due to their better interaction (bond) to the asphaltic layers and their mineral grain constituents. The main specification requirements are analogous to Chapter 5.4, but special attention has to be paid to the installation damage of some more brittle materials.

7 Geosynthetic barriers, synthetic, bituminous or clay (Barriers)

There is a broad range of barrier materials available. It is not unusual to combine different barrier materials in a composite system, utilizing both a geomembrane and a clay component. The effectiveness and utility of composite barrier systems is well recognized and most of the world disposes of household waste into facilities using a composite barrier system by regulatory requirement.

An important consideration is the amount of acceptable leakage. While it is certainly desired that every barrier be “perfect” with no leakage, that goal is expensive. Further, without considerable support in the form of Construction Quality Assurance, Barrier Integrity Surveys and other additional steps, zero leakage is not a realistic goal. However, for many applications, the consequences of minor leakage are not harmful or significant. This is most evident where the liquid being contained is water; be it potable, wastewater, process water, saline water or other. If the emission through the barrier system is water, it is highly unlikely that the consequences of a leak would be seriously damaging to the environment. Thus, designs have moved from composite systems to systems that potentially may have some leakage, but are significantly less costly and easier to install; geomembrane only or Geosynthetic Clay Liner (GCL) only barriers.

There are well established globally applicable specifications for geomembranes published by the Geosynthetic Institute and others. Additionally, there are many fine examples of national regulations that address the requirements of a barrier material(s). For geomembranes, suitability is commonly evaluated via physical properties with durability of the materials being tested on an annual or unique formulation frequency. For GCL’s the quantity per unit area and type of clay (bentonite) is critical to the performance level and this is commonly tested and required. Durability of the clay component of the GCL is commonly not a concern, as most of these clays are mined materials that only change format when exposed to specific chemicals or environments. However, the durability of the non-clay components (fabrics, textiles, etc) should be verified.

For both these material types another performance considerations are interface friction and slope stability. Evaluations, or historical data should be reviewed to assure that the materials have sufficient stability if placed on a slope and that soils placed on these materials will also be stable at the slope angles expected, plus an additional safety factor. The effects of water, rain events, storms, drainage rates and moisture levels should be a part of this consideration.

The barrier function is the primary purpose for any geomembrane and GCL. This section includes geomembranes manufactured from polymeric, bituminous and geosynthetic 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 or eliminate 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; for clay describe bentonite type)
- Thickness (only for geomembrane, not for GCL)

- Gas and water permeability
- Tensile properties (Uniaxial or axisymmetric)
    - Strength
    - Strain
- Puncture Resistance
- Burst strength (only for geomembrane, not for GCL)
- Tear Resistance (only for geomembrane, not for GCL)
- Internal peel strength (only for GCL)
- Interface shear
- Internal shear (Bitumen, GCL and geocomposite)
- Clay mass, free swell, peel strength, moisture content and fluid loss (for GCLs)
- Clay modification (polymer addition or clay chemical composition)
- Durability, performance
    - UV Exposure requirements
    - Oven Aging (not for GCL)
    - Liquid immersion tests – full product testing
    - Stress crack resistance (only polymeric HDPE – High Density Polyethylene)
- Seaming processes and controls
- Testing of site works (seams, when mechanically jointed)

8 Geomats, Geoblankets and other Erosion Control Products

Similarly to drainage geosynthetics, there is a broad range of erosion control materials manufactured with a variety of constructions. Further, erosion control products have perhaps the least developed number and specificity of specification requirements.
Erosion control falls into two general categories – hard armoring, utilizing stone, concrete or other materials with a geosynthetic component, or softer installations where the erosion is controlled through other mechanisms. Again, durability is a concern and a conscious decision should be made which technique will be used. For hard armoring, strength, surface impact resistance and durability are important. The softer techniques tend to be shorter term and designed to promote plant growth that take over and provides the erosion control at longer term. The geosynthetic component of the soft armor has the function of protecting and sometimes sustaining the plant growth for one or more growing seasons, but the eventual longer-term protection is provided by adult plants. Thus, durability is design specific. There also exists a hybrid hard - soft material formed using a 3D geotextile and a concrete infill that is supplied dry, rolled into place before being hydrated with water, the concrete setting to form a permeant protection to the underlying material.

With these materials it is also somewhat more common to conduct large scale testing and some of the laboratories have been established around the world with specific goals to meet this requirement.

Anchoring of the product and other installation techniques are also an important factor and should be a consideration in specification writing. As with all the other materials, there is a cost-performance trade off to be made. There exist organizations specifically established to support the erosion control marketplace.

8.1 Geomats and Geoblankets

Geomats and geoblankets are used for surface erosion control, to prevent or reduce the transport of soil by erosion agencies (water or wind). Some products may be intended to be for permanent applications while others may only be designed for a short term life to prevent erosion until vegetation becomes established. They are manufactured from polymers, while can be manufactured from polymers and/or natural fibres such as Jute or Coir.

The output from the design for the specification of and as erosion control products may include:

- Protection capacity from rainfall induced erosion (when used on slopes)
- Protection capacity from channel flow induced erosion
- Protection capacity for wave induced erosion.
- Soil filling capacity
- Shear strength
- Bio degradability for temporary applications
- UV Resistance for permanent applications
- Tensile strength (secondary)
- Fixing of the product to the slope, pegging and anchor trenches.

8.2 Geocells

Geocells are geosynthetic materials that are used in the construction industry as stabilising materials. They have a three-dimensional, permeable, polymeric (synthetic or natural) honeycomb, or similar cellular structure, made of linked strips of geosynthetics. They are most commonly used to prevent erosion or to provide soil stabilisation of roads, railways, ports, retaining walls, steep slopes, and other structure. Their general principle of working is providing full-area lateral confinement and immobilization of the infilled soil resulting in increased stability, bearing capacity and stiffness. They restrain lateral movement by hoop tensile forces, passive earth pressure and friction between cell wall and fill. The two materials (soil and geocell) work together to give an improved stiffness mechanical performance of the composite system. When used to provide control of erosion laid on the surface of slopes, Geocells are used to physically prevent the sliding of soil down slope under the action of self weight and erosion agents (commonly water). Geocells can be used for the construction of steep reinforced soil slopes, the Geocells are installed in layers, each layer being filled with soil. Geocells can be used to strengthen or stabilize unbound granular material in roads and working platforms over poor sub-grades.

The output from the design for the specification of Geocells may include:

- Physical dimensions of cells (length, breadth and height)
- Long-term tensile stiffness of the strips
- Dynamic modulus of elasticity of the strips
- Long-term-design strength of strips
- Strength of joints / nodes
- Bio degradability for temporary applications
- UV Resistance for permanent applications
- Permeability of cell materials
- Frictional or bond characteristics with soils and fills
- Dimensional stability during filling
- Fixing and anchoring

8.3 Drainage Geocomposites

There is a very wide range of materials manufactured for drainage within the geosynthetic families and specifications tend to have less commonality than other categories. However, the basic structure and objectives still apply.

The defining parameter is movement of liquid or gases through the geosynthetic: how much, how fast and under what conditions. This may be well defined such as transmissivity or flow rate; key conditions should be documented and the performance requirements, both initially and over the long time periods of use should be established.

The determined flow rate, as the critical performance mechanism, should be evaluated or compared to historical performance at both design and index conditions. The compression forces that will, over time or as the result of a single event (commonly heavy equipment traffic) reduce the flow through the drainage media should be understood and applied to this testing. Commonly, these materials lack the structure to resist severe mechanical forces and thus should not be used above the limits that they can be exposed to and continue to supply the needed liquid or gas movement. A particular problem can be compressive creep resulting in reduction of thickness and in-plane flow rate.

Durability is also a concern as these materials commonly cannot be repaired/replaced after installation. This may be evaluated as flow rate reduction over time, or a change in the dimensions of the material. This is commonly accelerated by time temperature superposition, or some other manner. Physical properties are commonly used as index tests and thickness and filtration properties are also common components of specifications.

The output from the design for the specification of Drainage Geocomposites may include:

- Flow Rate or Transmissivity requirements
- Compression strength respectively compression stiffness (both long term and instantaneous)
- Durability and filtration performance for permanent applications
- Physical dimensions (length, breadth and height, pattern consistency)
- Methods of joining sections (seams)
- Methods of terminating the geosynthetic drainage (proper transfer to pipes, etc.)

9 Site control of geosynthetic products delivered to the works

All products delivered to sites for incorporation into works should have the properties described in the specification verified. The verification of these properties can be carried out by one of the following procedures:

- Prior to delivery with certificates or declaration of conformity or actual test results provided to the purchaser e.g. CE marking, NTPEP (USA state agency approval),
- Type approval, agency for national, state or other client bodies,
- Testing of samples taken from products to be or delivered to the works – tests to be completed prior to building in to the works,
- Simple measurements on site – thickness or mass per unit area.

Checks need to be carried out to ensure that installation instructions are followed as described in the project specification are followed explicitly, that is:

- The formation or substrate is prepared properly, line and level
- Rolls are laid/installed in the correct directions
- Overlaps are set as described
- Seams are made as required and meet the required properties
- Cover soils are placed such that damage beyond that allowed for in the design does not occur and to required density or strength.
- Supervision - A suitably qualified and experienced person shall be responsible for checking that the construction complies with the design and all other contract documents. The level of supervision, monitoring and testing should be in accordance with the specification
- Monitoring - Monitoring of all works connected with the execution of various stages of construction shall be in accordance with the requirements to fulfil the design and the project specification.
- Testing - The testing shall be in accordance with the specifications of the design. The records of any testing shall provide the test method and procedure, test results and the conclusions and relevance.

The type, extent and accuracy of monitoring and testing requirements on and off site should be clearly shown in the specification and organised before work commences on site.

Unless specified in the design, supervision should relate to site preparation topography, geotechnical data, set-up, geometry of excavations, foundation pad (if applicable); fills: conformity with design: characteristics, placing and compaction, moisture levels, monitoring and testing when necessary; reinforcement : conformity with design, reception, handling, storage, placing, damage during installation, prestressing of reinforcement (if applicable), monitoring and testing when necessary; facing materials : conformity with design, installation of facing elements, alignments and displacements, finishing, monitoring and testing when necessary; drainage : base / foundation, back slope, layer drainage during installation, other drainage systems needed.

10 Example Specifications

10.1 Disclaimer

The specifications and test protocols which are included in and linked from this document are provided as an example to designers and others preparing specifications for the use of geosynthetic products in civil engineering and building works.

When using these specifications DO NOT mix and match between different documents.

The IGS does not warrant that the use of these specifications will avoid contractual disputes and it is the responsibility of the user to ensure that the contract documents are mutually compatible.

Where values of characteristics are given in the Guide or in linked example, these are NOT given as definitive values to be used in any project. The designer or person preparing the specification MUST check and insert values which have been based on a project specific analysis.

The terminology used in official documents should comply with ISO 10318-1:2015 +Amd 1;2018

10.2 Links to example specifications

Links to example specifications, technical documents, testing protocols and other useful examples can be found on the IGS webpage and are linked here:

http://www.geosyntheticssociety.org/igs-spec-paper-docs/