Chapter 6
Geosynthetic Drainage Systems

6.1 Overview

The collection of liquids in waste containment systems, their drainage and eventual removal represents an important element in the successful functioning of these facilities. Focus in this chapter is on the primary and secondary leachate collection systems beneath solid waste and on surface water and gas removal systems in the cover above the waste. This chapter parallels Chapter 5 on natural soil drainage materials but now using geosynthetics. Combined systems such as geocomposites and geospacers are often used; however we will generally focus on the individual geosynthetic components. The individual materials to be described are the following:

- geotextiles used as filters over various drainage systems (geonets, geocomposites, sands and gravels)
- geotextiles used for gas collection
- geonets used as primary and/or secondary leachate collection systems, and gas collection
- other geosynthetic drainage systems used as surface water collection systems and possibly as primary and/or secondary leachate collection systems

The locations of the various geosynthetic materials listed above are illustrated in the sketch of Fig. 6.1.

6.2 Geotextiles

Geotextiles, which some refer to as filter fabrics or construction fabrics, consist of polymeric yarns (fibers) made into woven or nonwoven textile sheets and supplied to the job site in large rolls. When ready for placement, the rolls are removed from their protective covering, properly positioned and unrolled over the substrate material. The substrate upon which the geotextile is placed is usually a geonet, geocomposite, drainage soil or other soil material. The roll edges and ends are either overlapped for a specified distance, or are sewn together. After approval by the CQA personnel, the geotextile is covered with the overlying material. Depending on site specific conditions, this overlying material can be a geomembrane, geosynthetic clay liner, compacted clay liner, geonet, or drainage soil.

This section presents the MQA aspects of geotextiles insofar as their manufacturing is concerned and the CQA aspects as far as handling, seaming and backfilling is concerned.

6.2.1 Manufacturing of Geotextiles

The manufacturing of geotextiles made from polymeric fibers follows traditional textile manufacturing methods and uses similar equipment. It should be recognized at the outset that most manufacturing facilities have developed their respective geotextile products to the point where product quality control procedures and programs are routine and fully developed.

Three discrete stages in the manufacture of geotextiles should be recognized from an MQA perspective: (1) the polymeric materials; (2) yarn or fiber type; and (3) fabric type (IFAI, 1990).
Solid Waste Perforated Pipe

Figure 6.1 - Cross Section of a Landfill Illustrating the Use of Different Geosynthetics Involved in Waste Containment Drainage Systems

LEGEND
GT = Geotextile
GN = Geonet
GM = Geomembrane
GCL = Geosynthetic Clay Liner
GC = Geocomposite
CCL = Compacted Clay Liner
### 6.2.1.1 Resins and Their Additives

Approximately 75% of geotextiles used today are based on polypropylene resin. An additional 20% are polyester and the remaining 5% is a range of polymers including polyethylene, nylon and others used for specialty purposes. As with all geosynthetics, however, the base resin has various additives formulated with it resulting in the final compound. Additives for ultraviolet light protection and as processing aids are common, see Table 6.1.

<table>
<thead>
<tr>
<th>Generic Name</th>
<th>Resin</th>
<th>Carbon Black</th>
<th>Other Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>95 - 98</td>
<td>0 - 3</td>
<td>0 - 2</td>
</tr>
<tr>
<td>Polyester</td>
<td>97 - 98</td>
<td>0 - 1</td>
<td>0 - 2</td>
</tr>
<tr>
<td>Others</td>
<td>95 - 98</td>
<td>1 - 3</td>
<td>1 - 2</td>
</tr>
</tbody>
</table>

The resin is usually supplied in the form of pellets which is then blended with carbon black, either in the form of concentrate pellets or chips, or as a powder, and the additive package. The additive package is usually a powder and is proprietary with each particular manufacturer. For some manufacturers, the pellets are precompounded with carbon black and/or the entire additive package. Figure 6.2 shows polyester chips and carbon black concentrate pellets used in the manufacturer of polyester geotextiles. Polypropylene pellets and carbon black are similar to those shown in the manufacture of polyethylene geomembranes. Refer to Chapter 3 for details and in particular to Section 3.2.2 for use of recycled and/or reclaimed material.

The following items should be considered for a specification or MQA document for resins and additives used in the manufacture of geotextiles for waste containment applications.

1. The resin should meet MQC requirements. This usually requires a certificate of analysis to be submitted by the resin vendor for each lot supplied. Included will be various properties, their specification limits and the appropriate test methods. For polypropylene resin, the usual requirements are melt flow index, and other properties felt to be relevant by the manufacturer. For polyester resin, the usual requirements are intrinsic viscosity, solution viscosity, color, moisture content and other properties felt to be relevant by the manufacturer.

2. The internal quality control of the manufacturer should be reported to verify that the geotextile manufactured for the project meets the proper specifications.

3. The frequency of performing each of the preceding tests should be covered in the MQC plan and should be implemented and followed.
Figure 6.2 - Polyester Resin Chips (Upper) and Carbon Black Concentrate Pellets (Lower) Used for Geotextile Fiber Manufacturing
4. The percentage, according to ASTM D-1603, and type of carbon black should be specified for the particular formulation being used, although it is low in comparison to geomembranes.

5. The type and amount of stabilizers are rarely specified. If a statement is required it should signify that the stabilizer package has been successfully used in the past and to what extent.

6.2.1.2 Fiber Types

The resin, carbon black and stabilizers are introduced to an extruder which supplies heat, mixing action and filtering. It then forces the molten material to exit through a die containing many small orifices called a "spinnerette". Here the fibers, called "yarns", are usually drawn (work hardened) by mechanical tension, or impinged by air, as they are stretched and cooled. The resulting yarns, called "filaments", can be wound onto a bobbin, or can be used directly to form the finished product. Other yarn manufacturing variations include those made from staple fibers and flat, tape-like, yarns called "slit-film". Each type (filament, staple or slit-film) can be twisted together with others as shown in Fig. 6.3. Note that "yarn" is a generic term for any continuous strand (fiber, filament or tape) used to form a textile fabric. Thus all of the examples in Fig. 6.3 are yarns, except for staple, and can be used to manufacture geotextiles.

Figure 6.3 - Types of Polymeric Fibers Used in the Construction of Different Types of Geotextiles
6.2.1.3 Geotextile Types

The yarns just described are joined together to make a fabric, or geotextile. Generic classifications are woven, nonwoven and knit. Knit geotextiles, however, are rarely used in waste containment systems and will not be described further in this document.

The manufacturer of a woven geotextile uses the desired type of yarn from a bobbin and constructs the fabric on a weaving loom. Fabric weaving technology is well established over literally centuries of development. Most woven fabrics used for geotextiles are “simple”, or “basket-type” weaves consisting of each yarn going over and under an intersecting yarn on an alternate basis. Figure 6.4(a) shows a micrograph of a typical woven geotextile pattern.

In contrast to this type of uniformly woven pattern are nonwoven fabrics as shown in Figs. 6.4(b) and (c). Here the yarns are utilized directly from the extruding spinnerette and laid down on a moving belt in a random fashion. The speed of the moving belt dictates the mass per unit area of the final product. While positioned on the belt the material is “lofty”, and the yarns are not structurally bound in any way. Two variations of structural bonding can be used, which gives rise to two unique types of nonwoven geotextiles.

- Nonwoven, needlepunched geotextiles go through a needling process wherein barbed needles penetrate the fabric and entangle numerous fibers transverse to the plane of the fabric. Note the fiber entanglement pattern in Fig. 6.4(b). As a post-processing step, the fabric can be passed over a heated roller resulting in a singed or burnished surface of the yarns on one or both sides of the fabric.

- Nonwoven, heat bonded geotextiles are formed by passing the unbonded fiber mat through a source of heat, usually steam or hot air, thereby melting some of the fibers at various points. Note the fiber bonding pattern in Fig. 6.4(c). This compresses the mat and simultaneously joins the fibers at their intersections by melt bonding.

6.2.1.4 General Specification Items

There are numerous items recommended for inclusion in a specification or MQA document for geotextiles used in waste containment facilities.

1. There should be verification and certification that the actual geotextile properties meet the manufacturers specification for that particular type and style.

2. Quality control certifications should include, at a minimum, mass per unit area per ASTM D-5261, grab tensile strength per ASTM D-4632, trapezoidal tear strength per ASTM D-4533, burst strength per ASTM D-3786, puncture strength per ASTM D-4833, thickness per ASTM D-5199, apparent opening size per ASTM D-4751, and permittivity per ASTM D-4491.

3. Values for each property should meet, or exceed, the project specification values, (note in some cases the property listed is a maximum value in which case lower values are acceptable).

4. A statement should be included that the property values listed are based upon the minimum average roll value (MARV) concept.
(a) Woven Geotextile at 4X Magnification

(b) Nonwoven Needlepunched Geotextile at 24X Magnification

Figure 6.4 - Three Major Types of Geotextiles (Continued on Next Page).
5. The ultraviolet light resistance should be specified which is usually a certain percentage of strength or elongation retained after exposure in a laboratory weathering device. Usually ASTM D-4355 is specified and retention after 500 hours is typically 50% to 90%.

6. The frequency of performing each of the preceding tests should be covered in the manufacturer’s MQC plan and it should be implemented and followed.

7. Verification that needle-punched, nonwoven geotextiles have been inspected continuously for the presence of broken needles using an in-line metal detector with an adequate sweep rate should be provided. Furthermore, a needle removal system, e.g., magnets, should be implemented.

8. A statement indicating if, and to what extent, reworked polymer, or fibers, was added during manufacturing. If used, the statement should note that the rework polymer, or fibers, was of the same composition as the intended product.

9. Reclaimed or recycled, i.e., fibers or polymer that has been previously used, should not be added to the formulation unless specifically allowed for in the project
specifications. Note, however, that reclaimed fibers may be used in geotextiles in certain waste containment applications. The gas collection layer above the waste and the geotextile protection layer between drainage stone and a geomembrane are likely locations. These should be design decisions and should be made accordingly.

6.2.2 Handling of Geotextiles

A number of activities occur between the manufacture of geotextiles and their final positioning at the waste facility. These activities involve protective wrapping, storage at the manufacturing facility, shipment, storage at the site, product acceptance, conformance testing and final placement at the facility. Each of these topics will be described in this section.

6.2.2.1 Protective Wrapping

All rolls of geotextiles, irrespective of their type, must be enclosed in a protective wrapping that is opaque and waterproof. The object is to prevent any degradation from atmospheric exposure (ultraviolet light, ozone, etc.), moisture uptake (rain, snow) and to a limited extent, accidental damage. It must be recognized that geotextiles are the most sensitive of all geosynthetics to degradation induced by ultraviolet light exposure. Geotextile manufacturers use tightly wound plastic wraps or loosely fit plastic bags for this purpose. Quite often the plastic is polyethylene in the thickness range of 0.05 to 0.13 mm (2 to 5 mil). Several important issues should be considered in a specification or MQA document.

1. The protective wrapping should be wrapped around (or placed around) the geotextile in the manufacturing facility and should be included as the final step in the manufacturing process.

2. The packaging should not interfere with the handling of the rolls either by slings or by the utilization of the central core upon which the geotextile is wound.

3. The protective wrapping should prevent exposure of the geotextile to ultraviolet light, prevent it from moisture uptake and limit minor damage to the roll.

4. Every roll must be labeled with the manufacturer’s name, geotextile style and type, lot and roll numbers, and roll dimensions (length, width and gross weight). Details should conform to ASTM D-4873.

6.2.2.2 Storage at Manufacturing Facility

The manufacturing of geotextiles is such that temporary storage of rolls at the manufacturing facility is necessary. Storage times range from a few days to a year, or longer. Figure 6.5(a) shows geotextile storage at a manufacturer’s facility.

Regarding specification and MQA document items, the following should be considered.

1. Handling of rolls of geotextiles should be done in a competent manner such that damage does not occur to the geotextile nor to its protective wrapping. In this regard ASTM D-4873 should be referenced and followed.

2. Rolls of geotextiles should not be stacked upon one another to the extent that deformation of the core occurs or to the point where accessibility can cause damage in handling.
(a) Storage at Manufacturing Facility

(b) Storage at Field Site

Figure 6.5 - Photographs of Temporary Storage of Geotextiles
3. Outdoor storage of rolls at the manufacturer’s facility should not be longer than six months. For storage periods longer than six months a temporary enclosure should be put over the rolls, or they should be moved to within a enclosed facility.

6.2.2.3 Shipment

Geotextile rolls are shipped from the manufacturer’s (or their representatives) storage facility to the job site via common carrier. Ships, railroads and trucks have all been used depending upon the locations of the origin and final destination. The usual carrier from within the USA, is truck. When using flat-bed trucks the rolls are usually loaded by means of a crane with slings wrapped around the individual rolls. When the truck bed is closed, i.e., an enclosed trailer, the rolls are usually loaded by fork lift with a “stinger” attached. The “stinger” is a long tapered rod which fits inside the core upon which the geotextile is wrapped.

Insofar as specification and MQA/CQA documents are concerned the following items should be considered.

1. The method of loading the geotextile rolls, transporting them and off-loading them at the job site should not cause any damage to the geotextile, its core, nor its protective wrapping.

2. Any protective wrapping that is accidentally damaged or stripped off of the rolls should be repaired immediately or the roll should be moved to a enclosed facility until its repair can be made to the approval of the CQA personnel.

6.2.2.4 Storage at Field Site

Off-loading of geotextile rolls at the site and temporary storage which must be done in an acceptable manner. Figure 6.5(b) shows typical storage at the field site. Some specification and CQA document items to consider are the following.

1. Handling of rolls of geotextiles should be done in a competent manner such that damage does not occur to the geotextile nor to its protective wrapping. In this regard ASTM D-4873 should be referenced and followed.

2. The location of field storage should not be in areas where water can accumulate. The rolls should be elevated off of the ground so as not to form a dam creating the ponding of water.

3. The rolls should be stacked in such a way that cores are not crushed nor is the geotextile damaged. Furthermore, they should be stacked in such a way that access for conformance testing is possible.

4. Outdoor storage of rolls should not exceed manufacturers recommendations or longer than six months, whichever is less. For storage periods longer than six months a temporary enclosure should be placed over the rolls, or they should be moved within an enclosed facility.

6.2.2.5 Acceptance and Conformance Testing

Upon delivery of the rolls of geotextiles to the project site, and temporary storage thereof, the CQA engineer should see that conformance test samples are obtained. These samples are then
sent to the CQA laboratory for testing to ensure that the supplied geotextile conforms to the project plans and specifications. The samples are taken from selected rolls by removing the protective wrapping and cutting full-width, 1 m (3 ft) long samples off of the outer wrap of the selected roll(s). Sometimes the outer revolution of geotextile is discarded before the test sample is taken. The rolls are immediately re-wrapped and replaced in temporary field storage. The samples rolls must be relabeled for future identification. Alternatively, conformance testing could be performed at the manufacturer’s facility and when completed the particular lot should be marked for the particular site under investigation. Items to be considered in a specification and CQA documents in this regard are the following:

1. The samples should be identified by type, style or, lot and roll numbers. The machine direction should be noted on the sample(s) with a waterproof marker.

2. A lot is defined as a unit of production, or a group of other units or packages having one or more common properties and being readily separable from other similar units. Other definitions are also possible and should be clearly stated in the CQA documents, see ASTM D-4354.

3. Sampling should be done according to the job specification and/or CQA documents. Unless otherwise stated, sampling should be based on one per lot. Note that a lot is sometimes defined as 10,000 m² (100,000 ft²) of geotextile. Utilization of ASTM D-4354 may be referenced and followed in this regard but it might result in a different value for sampling than stated above.

4. Testing at the CQA laboratory may include mass per unit area per ASTM D-5261, grab tensile strength per ASTM D-4632, trapezoidal tear strength per ASTM D-4533, burst strength per ASTM D-3786, puncture strength per ASTM D-4833, and possibly apparent opening size per ASTM D-4751, and permittivity per ASTM D-4491. Other conformance tests may be required by the project specifications.

5. Conformance test results should be sent to the CQA engineer prior to deployment of any geotextile from the lot under review.

6. The CQA engineer should review the results and should report any nonconformance to the Owner/Operator’s Project Manager.

7. The resolution of failing conformance tests must be clearly stipulated in the specifications or CQA documents. Statements should be based upon ASTM D-4759 entitled “Determining the Specification Conformance of Geosynthetics”.

8. The geotextile rolls which are sampled should be immediately rewrapped in their protective covering to the satisfaction of the CQA personnel.

6.2.2.6 Placement

The geosynthetic installation contractor should remove the protective wrappings from the geotextile rolls to be deployed only after the substrate layer, soil or other geosynthetic, has been documented and approved by the CQA personnel. The specification and CQA documents should be written in such a manner as to ensure that the geotextiles are not damaged nor excessively exposed to ultraviolet degradation. The following items should be considered for inclusion in a specification or CQA document.
1. The installer should take the necessary precautions to protect the underlying layers upon which the geotextile will be placed. If the substrate is soil, construction equipment can be used provided that excess rutting is not created. Excess rutting should be clearly defined and quantified by the design engineer. In some cases 25 mm (1.0 in.) is the maximum rut depth allowed. If the ground freezes, the depth of ruts should be further reduced to a specified value. If the substrate is a geosynthetic material, deployment must be by hand, by use of small jack lifts on pneumatic tires having low ground contact pressure, or by use of all-terrain vehicles, ATV’s, having low ground contact pressure.

2. During placement, care must be taken not to entrap (either within or beneath the geotextile) stones, excessive dust or moisture that could damage a geomembrane, cause clogging of drains or filters, or hamper subsequent seaming.

3. On side slopes, the geotextiles should be anchored at the top and then unrolled so as to keep the geotextile free of wrinkles and folds.

4. Trimming of the geotextiles should be performed using only an upward cutting hook blade.

5. Nonwoven geotextiles placed on textured geomembranes can be troublesome due to sticking and are difficult to align or even separate after they are placed on one another. A thin sheet of plastic on the geomembrane during deployment of the geotextile can be very helpful in this regard. Of course, it is removed after correct positioning of the geotextile.

6. The geotextile should be weighted with sandbags, or the equivalent, to provide resistance against wind uplift. This is a site-specific procedure and completely the installer’s decision. Uplifted and moved geotextiles can generally be reused but only after approval by the owner and observation by the CQA personnel.

7. A visual examination of the deployed geotextile should be carried out to ensure that no potentially harmful objects are present, e.g., stones, sharp objects, small tools, sandbags, etc.

6.2.3 **Seaming**

Seaming of geotextiles, by sewing, is sometimes required (versus overlapping with no sewn seams) of all geotextiles placed in waste facilities. This generally should be the case for geotextiles used in filtration, but may be waived for geotextiles used in separation (e.g., as gas collection layers above the waste or as protective layers for geomembranes) as per the plans and specifications. In such cases, heat bonding is also an acceptable alternate method of joining separation geotextiles. In cases where overlapping is permitted, the overlapped distance requirements should be clearly stated in the specification and CQA documents. Geotextile seam types and procedures, seam tests and geotextile repairs are covered in this section.

6.2.3.1 **Seam Types and Procedures**

The three types of sewn geotextile seams are shown in Fig. 6.6. They are the “flat” or “prayer” seam, the “J” seam and the “butterfly” seam. While each can be made by a single thread, or by a two-thread chain stitch, as illustrated, the latter stitch is recommended. Furthermore, a single, double, or even triple, row of stitches can be made as illustrated by the dashed lines in the
figures. Figure 6.7 shows a photograph of the fabrication of a flat seam and see Diaz (1990) for further details regarding geotextile seaming.

Figure 6.6 - Various Types of Sewn Seams for Joining Geotextiles (after Diaz, 1990)
The project specification or CQA documents should address the following considerations.

1. The type of seam, type of stitch, stitch count or number of stitches per inch and number of rows should be specified based on the tendency of the fabric to fray, strength need and toughness of the fabric. For filtration and separation geotextiles a flat seam using a two-thread chain stitch and one row is usually specified. For reinforcement geotextiles, stronger and more complex seams are utilized. Alternatively, a minimum seam strength, per ASTM D-4884, could be specified.

2. The seams should be continuous, i.e., spot sewing is generally not allowed.

3. On slopes greater than approximately 5 (horiz.) to 1 (vert.), seams should be constructed parallel to the slope gradient. Exceptions are permitted for small patches and repairs.

4. The thread type must be polymeric with chemical and ultraviolet light resistant properties equal or greater than that of the geotextile itself.
5. The color of the sewing thread should contrast that of the color of the geotextile for ease in visual inspection. This may not be possible due to polymer composition in some cases.

6. Heat seaming of geotextiles may be permitted for certain seams. A number of methods are available such as hot plate, hot knife and ultrasonic devices.

7. Overlapped seams of geotextiles may be permitted for certain seams. The overlap distance should be stated depending on the site specific conditions.

6.2.3.2 Seam Tests

For geotextiles used in filtration and separation, seam samples and subsequent strength testing are not generally required. If they are, however, they should be stipulated in the specifications or CQA documents. Also, the sampling and testing frequency should be noted accordingly. The test method to evaluate sewn seam test specimens is ASTM D-4884.

6.2.3.3 Repairs

Holes, or tears, in geotextiles made during placement or anytime before backfilling should be repaired by patching. Some relevant specifications and CQA document items follow.

1. The patch material used for repair of a hole or tear should be the same type of polymeric material as the damaged geotextile, or as approved by the CQA engineer.

2. The patch should extend at least 30 cm (12 in.) beyond any portion of the damaged geotextile.

3. The patch should be sewn in place by hand or machine so as not to accidentally shift out of position or be moved during backfilling or covering operations.

4. The machine direction of the patch should be aligned with the machine direction of the geotextile being repaired.

5. The thread should be of contrasting color to the geotextile and of chemical and ultraviolet light resistance properties equal or greater than that of the geotextile itself.

6. The repair should be made to the satisfaction of the specification and CQA documents.

6.2.4 Backfilling or Covering

The layer of material placed above the deployed geotextile will be either soil, waste or another geosynthetic. Soils will vary from compacted clay layers to coarse aggregate drainage layers. Waste should be what is referred to as “select” waste, i.e., carefully separated and placed so as not to cause damage. Geosynthetics will vary from geomembranes to geosynthetic clay liners. Some considerations for a specification and CQA document to follow:

1. If soil is to cover the geotextile it should be done such that the geotextile is not shifted from its intended position and underlying materials are not exposed or damaged.

2. If a geosynthetic is to cover the geotextile, both the underlying geotextile and the newly deployed material should not be damaged during the process.
3. If solid waste is to cover the geotextile, the type of waste should be specified and visual observation by CQA personnel should be required.

4. The overlying material should not be deployed such that excess tensile stress is mobilized in the geotextile. On side slopes, this requires soil backfill to proceed from the bottom of the slope upward.

5. Soil backfilling or covering by another geosynthetic, should be done within the time frame stipulated for the particular type of geotextile. Typical time frames for geotextiles are within 14 days for polypropylene and 28 days for polyester geotextiles.

6.3 **Geonets and Geonet/Geotextile Geocomposites**

Geonets are unitized sets of parallel ribs positioned in layers such that liquid can be transmitted within their open spaces. Thus their primary function is drainage; recall Fig. 6.1. Figure 6.8(a) shows a photograph of rolls of geonets, while Fig. 6.8(b) shows a closeup of the intersection of a typical set of geonet ribs. Note that open space exists both in the plane of the geonet (above or under the parallel sets of ribs) and cross plane to the geonet (within the apertures between adjacent sets of ribs). In all cases, the apertures must be protected against migration and clogging by adjacent soil materials. Thus geonets always function with either geomembranes and/or geotextiles on their two planar surfaces. Whenever the geonet comes supplied with a geotextile on one or both of its surfaces, it is called a geocomposite. The geotextile(s) is usually bonded on the surface by heat fusing or by using an adhesive.

This section will describe the manufacturing and handling of geonets for waste containment facilities. Since continuity of liquid flow is necessary at the sides and ends of the rolls, joining methods will also be addressed, as will the placement of the covering layer. Also covered will be the bonding of geotextiles to geonets in the form of drainage geocomposites.

6.3.1 **Manufacturing of Geonets**

Geonets currently used in waste containment applications are formed using an extruder which accepts the intended polymer formulation and then melts, mixes, filters and feeds the molten material directly into a counter-rotating die. This die imparts parallel sets of ribs into the preform. Upon exiting the die, the ribs of the preform are opened by being forced over a steel spreading mandrel. Figure 6.9 shows a small laboratory size geonet as it is formed and expands into its final shape. The fully formed geonet is then water quenched, longitudinally cut in the machine direction, spread open as it exits the quench tank and rolled onto a handling core. The width of the rolls are determined by the maximum circumference of the spreading mandrel. Since the process is continuous in its operation, the roll length is determined on the basis of the manageable weight of a roll. The thickness of the geonet is based on the slot dimensions of the opposing halves of the counter-rotating mold. Thicknesses of commercially available geonets vary between 4.0 and 6.9 mm (160 - 270 mils).

Most of the commercially available resins used for geonets are polyethylene in the natural density range of 0.934 to 0.940 g/cc. Thus they are classified as medium density polyethylene according to ASTM D-1248. The final compound is approximately 97% polyethylene. An additional 2 to 3% is carbon black, added as a powder or as a concentrate, and the remaining 0.5 to 1.0% are additives. The additives are added as a powder as are antioxidants and processing aids, both of which are proprietary to the various geonet manufacturers. Formulations are often the same as for HDPE geomembranes (recall Chapter 3), or slight variations thereof.
Figure 6.8 - Typical Geonets Used in Waste Containment Facilities
Figure 6.9 - Counter Rotating Die Technique (Left Sketch) for Manufacturing Drainage Geonets
and Example of Laboratory Prototype (Right Photograph)
Regarding the preparation of a specification or MQA document for the resin component of HDPE geonets, the following items should be considered:

1. Specifications may call for the polyethylene resin to be made from virgin, uncontaminated ingredients. Alternatively, geonets can be made with off-spec geomembrane material as a large, or even major part, of their total composition provided this material is of the same formulation as the intended geonet and does not consist of recycled and/or reclaimed material. Recycled and/or reclaimed material is generally not allowed. It is acceptable, and is almost always the case, that the density of the resin is in the medium density range for polyethylene, i.e., that its density is equal to or less than 0.940 g/cc.

2. Typical quality control tests on the resin are density, via ASTM D-1505 or D-792 and melt flow index via ASTM D-1238.

3. An HDPE geonet formulation should consist of at least 97% of polyethylene resin, with the balance being carbon black and additives. No fillers, extenders, or other materials should be mixed into the formulation.

4. It should be noted that by adding carbon black and additives to the resin, the density of the final formulation is generally over 0.941 g/cc. Since this value is in the high density polyethylene category, according to ASTM D-1248, geonets of this type are customarily referred to as high density polyethylene (HDPE).

5. Regrind or reworked polymer which is previously processed HDPE geonet in chip form, is often added to the extruder during processing. It is acceptable if it is the same formulation as the geonet being produced.

6. No amount of “recycled” or “reclaimed” material, which has seen prior use in another product should be added to the formulation.

7. An acceptable variation of the process just described is to add a foaming agent into the extruder which then is processed in the standard manner. As the geonet is formed and is subsequently quenched, the foaming agent expands within the ribs creating innumerable small spherical voids. The voids are approximately 0.01 mm (0.5 mil) in diameter. This type of geonet is called a “foamed rib” geonet, in contrast to the standard type which is a “solid rib” geonet. Foamed rib geonets are currently seen less frequently in drainage systems than previously.

8. Quality control certificates from the manufacturer should include proper identification of the product and style and results of quality control tests.

9. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

6.3.2 Handling of Geonets

A number of activities occur between the manufacture of geonets and their final positioning where intended at the waste facility. These activities involve packaging, storage at the manufacturing facility, shipment, storage at the site, acceptance and conformance testing and final placement at the facility. Each of these topics will be described in this section.
6.3.2.1 Packaging

As geonets come from the quenching tank they are wound on a core until the desired length is reached. The geonet is then cut along its width and the entire roll contained by polymer straps so as not to unwind during subsequent handling. There is generally no protective wrapping placed around geonets, however, a plastic wrapping can be provided if necessary.

Specifications or a MQA document should be formed around a few important points.

1. The core must be stable enough to support the geonet roll while it is handled by either slings around it, or from a fork lift “stinger” inserted in it.

2. The core should have a minimum 100 mm (4.0 in.) inside diameter.

3. The banding straps around the outside of the roll should be made from materials with adequate strength yet should not damage the outer wrap(s) of the roll.

6.3.2.2 Storage at Manufacturing Facility

The storage of geonet rolls at the manufacturer’s facility is similar to that described for HDPE geomembranes. Refer to Section 3.3.1 for a complete description.

6.3.2.3 Shipment

The shipment of geonet rolls from the manufacturer’s facility to the project site is similar to that described for HDPE geomembranes. Refer to Section 3.3.2 for a complete description.

6.3.2.4 Storage at the Site

The storage of geonet rolls at the project site is similar to that described with HDPE geomembranes. Refer to section 3.3.2 for a complete description, see Fig. 6.10. An important exception is that a ground cloth should be placed under the geonets if they are stored on soil for any time longer than one month. This is to prevent weeds from growing into the lower rolls of the geonet. If weeds do grow in the geonet during storage, the broken pieces must be removed by hand on the job when the geonet is deployed.

6.3.2.5 Acceptance and Conformance Testing

The acceptance and conformance testing of geonets is similar to that described for HDPE geomembranes. Refer to Section 3.3.3 for a complete description. For geonets, the usual conformance tests are the following:

- density, per ASTM D-1505 or D-792
- mass per unit area, per ASTM D-5261
- thickness, per ASTM D-5199

Additional conformance tests such as compression per ASTM D-1621 and transmissivity per ASTM D-4716 may also be stipulated.
6.3.2.6 Placement

The placement of geonets in the field is similar to that described for geotextiles. Refer to Section 6.2.2.6 for a complete description.

6.3.3 Joining of Geonets

Geonets are generally joined together by providing a stipulated overlap and using plastic fasteners or polymer braid to tie adjacent ribs together at minimum intervals, see Fig. 6.11.

Recommended items for a specification or CQA document on the joining of geonets include the following:

1. Adjacent roll edges of geonets should be overlapped a minimum distance. This is typically 75-100 mm (3-4 in.).

2. The roll ends of geonets should be overlapped 150-200 mm (6-8 in.) since flow is usually in the machine direction.
3. All overlaps should be joined by tying with plastic fasteners or polymeric braid. Metallic ties or fasteners are not allowed.

4. The tying devices should be white or yellow, as contrasted to the black geonet, for ease of visual inspection.

5. The tying interval should be specified. Typically tie intervals are every 1.5 m (5.0 ft) along the edges and every 0.15 m (6.0 in.) along the ends and in anchor trenches.

6. Horizontal seams should not be allowed on side slopes. This requires that the length of the geonet should be at least as long as the side slope, anchor trench and a minimum run out at the bottom of the facility. If horizontal seams are allowed, they should be staggered from one roll to the adjacent roll.

7. In difficult areas, such as corners of side slopes, double layers of geonets are sometimes used. This should be stipulated in the plans and specifications.

8. If double geonets are used, they should be layered on top of one another such that interlocking does not occur.
9. If double geonets are used, roll edges and ends should be staggered so that the joints do not lie above one another.

10. Holes or tears in the geonet should be repaired by placing a geonet patch extending a minimum of 0.3 m (12 in.) beyond the edges of the hole or tear. The patch should be tied to the underlying geonet at 0.15 m (6.0 in.) spacings.

11. Holes or tears along more than 50% of the width of the geonet on side slopes should require the entire length of geonet to be removed and replaced.

6.3.4 Geonet/Geotextile Geocomposites

Geonets are always covered with either a geomembrane or a geotextile, i.e., they are never directly soil covered since the soil particles would fill the apertures of the geonet rendering it useless. Many geonets have a geotextile bonded to one, or both, surfaces. These are then referred to as geocomposites in the geonet manufacturer's literature. In this document, however, geocomposites will refer to many different types of drainage core structures. Clearly, covered geonets are included in this group. However, geocomposites also consist of fluted, nubbed and cuspated cores, covered with geotextiles and/or geomembranes and will be described separately in section 6.4. Still further, some manufacturers refer to the entire group of geosynthetic drainage materials as “geospacers”.

Regarding a specification or CQA document for geonet/geotextile drainage geocomposites, a few comments are offered:

1. The geotextile(s) covering a geonet should be bonded together in such a way that neither component is compromised to the point where proper functioning is impeded. Thus adequate, but not excessive, bonding of the geotextile(s) to the geonet is necessary.

2. If bonding is by heating, the geotextile(s) strength cannot be compromised to the point where failure could occur. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product.

3. If bonding is by adhesives, the type of adhesive must be identified, including its water solubility and organic content. Excessive adhesive cannot be used since it could fill up some of the geonet’s void space. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product. The geotextile’s permittivity could be evaluated using ASTM D-4491.

4. If the shear strength of the geotextile(s) to the geonet is of concern an adapted form of an interface shear test, e.g., ASTM D-5321, can be performed with the geotextile firmly attached to a wooden substrate, or other satisfactory arrangement. Alternatively, a ply adhesion test may be adequate, see ASTM D-413 which might be suitably modified for geotextile-to-geonet adhesion.

5. For factory fabricated geocomposites with geotextiles placed on both sides of a geonet, the geonet must be free from all dirt, dust and accumulated debris before covering.
6. For field placed geotextiles, the geonet should be free of all soil, dust and accumulated debris before covering with a geomembrane or geotextile. In extreme cases this may require washing of the geonet to accumulate the particulate material at the low end (sump) area where it is subsequently removed by hand.

7. When placing geosynthetic clay liners (GCLs) above geocomposites, cleanliness is particularly important in assuring that fugitive bentonite clay particles do not find their way into the geonet.

8. Placement of a covering geomembrane should not shift the geotextile or geocomposite out of position nor damage the underlying geonet.

9. An overlying geomembrane or geotextile should not be deployed such that excess tensile stress is mobilized in the geocomposite.

6.4 Other Types of Geocomposites

Geocomposite drainage systems consist of a polymer drainage core protected by a geotextile acting as both a filter and a separator to the adjacent material. Thus a geonet, with a geotextile attached to one surface or to both surfaces as described in section 6.3.4, is indeed a drainage geocomposite. However, for the drainage geocomposites discussed in this section the geotextile filter is always attached to the drainage core and the core can take a wide variety of non-geonet shapes and configurations. In some cases, the geotextile is only on one side of the core (the side oriented toward the inflowing liquid), in other cases it is wrapped completely around the drainage core.

There are three different types of drainage geocomposites referred to in this document; sheet drains, edge drains and strip (or wick) drains. Typical variations are shown in Fig. 6.12. For drainage systems associated with waste containment facilities, sheet drains, Fig. 6.12a, are sometimes used as surface water collectors and drains in cover systems of closed landfills and waste piles, refer to Fig. 6.1. Infiltration water that moves within the cover soil enters the sheet drain and flows gravitationally to the edge of the site (or cell) where it is generally collected by a perforated pipe, or edge drain. Pipes will be discussed separately in Chapter 8. The other possible use for sheet drains is for primary leachate collection systems in landfills. The required flow rate in some landfills is too great for a geonet, hence the greater drainage capacity of a geocomposite is sometimes required. Of course, when used in this application the drainage geocomposite must resist the compressive and shear stresses imposed by the waste and it must be chemically resistant to the leachate, but these are design considerations. The use of strip (wick) drains, Fig. 6.12b, in waste containment has been as vertical drains within a solid waste landfill to promote leachate communication between individual lifts. The edge drains, shown in Fig. 6.12(c), have potential applicability around the perimeter of a closed landfill facility to accumulate the surface water coming from a cap/closure system. A variety of perimeter drains could utilize such geocomposite edge drains.

Of the different types of drainage geocomposites shown in Fig. 6.12, only sheet drains will be described since they have the greatest applicability in waste containment systems.
Figure 6.12 - Various Types of Drainage Geocomposites (Continued on Next Page)
6.4.1 Manufacturing of Drainage Composites

The manufacture of the drainage core of a geocomposite sheet drain is generally accomplished by taking the desired type of polymer sheet and then vacuum forming dimples, protrusions or cuspatations which give rise to the protrusions. The polymer sheets of drainage geocomposites have been made from a wide variety of polymers. Commercial products that are currently available consist of the following polymer formulations:

- polystyrene
- nylon
- polypropylene
- polyvinyl chloride
- polyethylene
- polyethylene/polystyrene/polyethylene (coextrusion)
With coextrusion there exists a variety of possibilities in addition to those listed above. Recognize, however, that coarse fibers, entangled webs, filament mattings, and many other variations are also possible.

Upon deciding on the proper type and thickness of polymer sheet, a geocomposite core usually goes through a vacuum forming step. In this step a vacuum draws portions of the polymer sheet into cusps at prescribed locations. Depending on the particular product, the protrusions are at 12 to 25 mm (0.5 to 1.0 in.) centers and are of a controlled depth and shape. Figure 6.13 shows a sketch of a vacuum forming system. In many of the systems the protrusions are tapered for ease in manufacturing during release of the vacuum and for a convenient male-to-female coupling of the edges and/or ends of the product in the field. The different types of drainage geocomposites are made in either continuous rolls or in discrete panels.

The geotextile, which acts as both a filter to allow liquid into the drainage core and as a separator to keep soil out of the core by spanning from cusp to cusp is put onto the core as a secondary operation. Quite often an adhesive is placed on the tops of the cusps to adhere the geotextile to the core. Alternatively, heat bonding can be utilized. A variety of geotextiles can be
used and the site specific design will dictate the actual selection. As far as the MQA/CQA of the geotextile it is the same as was described in Section 6.2.

There are several items which should be included in a specification or MQA document for drainage geocomposite cores.

1. There should be verification and certification that the actual geocomposite core properties meet the manufacturers specification for that particular type and style.

2. Quality control certificates should include at a minimum, polymer composition, thickness of sheet per ASTM D-5199, height of raised cusps, spacing of cusps, compressive strength behavior (both strength and deformation values at core failure) per ASTM D-1621, and transmissivity using site specific conditions per ASTM D-4716.

3. For drainage systems consisting of coarse fibers, entangled webs and/or filament mattings the thickness under load per ASTM D-5199 and transmissivity under load per ASTM D-4716 are the main tests for QC purposes.

4. Values for each property should meet, or exceed, the manufacturers listed values or the project specification values, whichever are higher.

5. A statement indicating if, and to what extent, regrind polymer was added during manufacturing. No amount of reclaimed polymer should be allowed.

6. The frequency of performing each of the preceding tests should be covered in the MQC plans and it should be implemented and followed.

Additionally, there are several items which should be included in a specification or MQA document for the geotextile(s)/drainage core geocomposite.

1. The type of geotextile(s) should be identified and properly evaluated. See section 6.2 for these details.

2. For strip (wick) drains and edge drains, see Figs. 6.12(b) and (c) respectively, the geotextile complete surrounds the drainage core and generally no fixity is required. For sheet drains, Fig. 6.12(a), this is not the case.

3. The geotextile(s) covering of a drainage core should be bonded in such a way that neither component is compromised to the point where proper functioning is impeded. Thus adequate, but not excessive, bonding of the geotextile(s) to the drainage core is necessary.

4. If bonding is by heating, the geotextile(s) strength cannot be compromised to the point where failure could occur. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product.

5. If bonding is by adhesives, the type of adhesive must be identified, including its water solubility and organic content. Excessive adhesive cannot be used since it could fill up some of the drainage core's void space. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product. The geotextile’s permittivity could be evaluated using ASTM D-4491.

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6. If the shear strength of the geotextile(s) to the core is of concern an adapted form of an interface shear test, e.g., ASTM D-5321, can be performed with a wooden substrate, or other satisfactory arrangement. Alternatively, a ply adhesion test may be adequate, see ASTM D-413 which might be suitably modified for geotextile-to-core adhesion.

7. For factory fabricated geocomposites with geotextiles placed on both sides of the drainage core, the core must be free from all dirt, dust and accumulated debris before covering.

6.4.2 Handling of Drainage Geocomposites

A number of activities occur between the manufacture of drainage geocomposites and their final positioning where intended at the waste facility. These activities involve packaging, storage at the manufacturing facility, shipment, storage at the site, acceptance and conformance testing, and final placement at the facility. Each of these topics will be described although most will be by reference to the appropriate geotextile section.

6.4.2.1 Packaging

Usually a manufacturer will not attach the geotextile to the core until an order is received and shipment is imminent. Thus warehousing is not a major issue. The cores are either rolled onto themselves or are laid flat if they are in panel form. When an order is received, the geotextile is bonded to the core, the rolls are banded together with polymer straps and, if panels, they are banded in a similar manner.

6.4.2.2 Storage at Manufacturing Facility

Storage of the drainage cores at the manufacturing facility is usually not a major issue. The cores are generally stored indoors and are thus protected from atmospheric conditions.

6.4.2.3 Shipment

Shipment of drainage geocomposites (with the geotextile attached) is quite simple due to the light weight of these geosynthetics compared to other types. The text in Section 6.2.2.3 should be utilized, however, since accidental damage can always occur.

6.4.2.4 Storage at Field Site

The storage of drainage geocomposites at the project site is similar to that described for geotextiles, recall Section 6.2.2.4.

6.4.2.5 Acceptance and Conformance Testing

The acceptance and conformance testing of the geotextile portion of a drainage geocomposite is the same as described in Section 6.2.2.5. The acceptance and conformance testing of the core portion of a drainage geocomposite is project specific with the exception of the conformance tests themselves which are different. The recommended conformance tests for geocomposite drainage cores are the following:

- thickness of sheet per ASTM D-5199 or thickness of the geocomposite per ASTM D-5199
• thickness of raised cusps per ASTM D-1621
• spacing of raised cusps per ASTM D-1621

Optional conformance tests such as compression per ASTM D-1621 and transmissivity per ASTM D-4716 may also be stipulated. The frequency of conformance tests of the drainage core must be stipulated. In general, one test per 5,000 m² (50,000 ft²) should be the minimum test frequency.

6.4.2.6 Placement

The placement of drainage geocomposites in the field is similar to that described for geotextiles. Refer to Section 6.2.2.6 for details.

6.4.3 Joining of Drainage Geocomposites

Drainage geocomposites are usually joined together by folding back the geotextile from the lower core and inserting it into the bottom void space of the upper core, see Fig. 6.14. Where this is not possible a tab should be available at the edges of the core material for the purpose of overlapping. The geotextile must be refolded over the connection area assuring a complete covering of the core surface.

Figure 6.14 - Photograph of Drainage Core Joining via Male-to-Female Interlock
Recommended items for a specification or CQA document on the joining of drainage geocomposites include the following:

1. Adjacent edges of drainage cores should be overlapped for at least two rows of cusps.
2. The ends of drainage cores (in the direction of flow) should be overlapped for at least four rows of cusps.
3. The geotextiles covering the joined cores must provide a complete seal against backfill soil entering into the core.
4. Horizontal seams should not be allowed on sideslopes. This requires that the drainage geocomposite be provided in rolls which are at least as long as the side slope.
5. Holes or tears in drainage cores are repaired by placing a patch of the same type of material over the damaged area. The patch should extend at least four cusps beyond the edges of the hole or tear.
6. Holes or tears of more than 50% of the width of the drainage core on side slopes should require the entire length of the drainage core to be removed and replaced.
7. Holes or tears in the geotextile covering the drainage core should be repaired as described in Section 6.2.3.3.

6.4.4 Covering

Drainage geocomposites, with an attached geotextile, are covered with either soil, waste or in some cases a geomembrane. Regarding a specification or CQA document some comments should be included.

1. The core of the drainage geocomposite should be free of soil, dust and accumulated debris before backfilling or covering with a geomembrane. In extreme cases this may require washing of the core to accumulate the particulate material to the low end (sump) area for removal.
2. Placement of the backfilling soil, waste or geomembrane should not shift the position of the drainage geocomposite nor damage the underlying drainage geocomposite, geotextile or core.
3. When using soil or waste as backfill on side slopes, the work progress should begin at the toe of the slope and work upward.

6.5 References

ASTM D-413, “Rubber Property-Adhesion to Flexible Substrate”
ASTM D-792, “Specific Gravity and Density of Plastics by Displacement”
ASTM D-1238, “Flow Rates of Thermoplastics by Extrusion Plastometer”
ASTM D-1248, “Polyethylene Plastics and Extrusion Materials”
ASTM D-1505, "Density of Plastics by the Density-Gradient Technique"

ASTM D-1603, "Carbon Black in Olefin Plastics"

ASTM D-1621, "Compressive Properties of Rapid Cellular Plastics"

ASTM D-3786, "Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics: Diaphragm Bursting Strength Tester Method"

ASTM D-4354, "Sampling of Geosynthetics for Testing"

ASTM D-4355, "Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus)"

ASTM D-4491, "Water Permeability of Geotextiles by Permittivity"

ASTM D-4533, "Trapezoidal Tearing Strength of Geotextiles"

ASTM D-4632, "Breaking Load and Elongation of Geotextiles (Grab Method)"

ASTM D-4716, "Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products"

ASTM D-4751, "Determining the Apparent Opening Size of a Geotextile"

ASTM D-4759, "Determining the Specification Conformance of Geosynthetics"

ASTM D-4833, "Index Puncture Resistance of Geotextiles, Geomembranes and Related Products"

ASTM D-4873, "Identification, Storage and Handling of Geosynthetics"

ASTM D-4884, "Seam Strength of Sewn Geotextiles"

ASTM D-5199, "Measuring Nominal Thickness of Geotextiles and Geomembranes"

ASTM D-5261, "Measuring Mass Per Unit Area of Geotextiles"

ASTM D-5321, "Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"
