cooled, the sheet must be turned over and the process repeated on the opposite side. Adherence of the polymer to the fabric is essential.

Geomembranes produced by the spread coating method are indeed multiple-ply reinforced materials, but produced by a method other than calendering. MQC and MQA plans and specifications should be framed in a similar manner as described previously for CSPE-R geomembranes.

3.3 Handling

While there should be great concern and care focused on the manufacturers and installers of geomembranes, it is also incumbent that they are packaged, handled, stored, transported, re-stored, re-handled and deployed in a manner so as not to cause any damage. This section is written with these many ancillary considerations in mind.

3.3.1 Packaging

Different types of geomembranes require different types of packaging after they are manufactured. Generally HDPE and VLDPE are packaged around a core in roll form, while PVC and CSPE-R are accordion folded in two directions and packaged onto pallets.

3.3.1.1 Rolls

Both HDPE and VLDPE geomembranes are manufactured and fed directly to a wind-up core in full-width rolls. No external wrapping or covering is generally needed, nor provided. These rolls, which weigh up to 22 kN (5000 pounds), are either moved by fork-lifts using a long rod inserted into the core (called a “stinger”) or they are picked up by fabric slings with a crane or hoist. Note that the slings are often dedicated to each particular roll and follow along with it until its actual deployment. The rolls are usually stored in an outdoor area. They are stacked such that one roll is nested into the valley of the two underlying rolls, see Fig. 3.14.

Regarding a specification or MQA document for finished rolls of HDPE geomembranes the following applies.

1. The cores on which the rolls of geomembranes are wound should be at least 150 mm (6.0 in.) outside diameter.

2. The cores should have a sufficient inside diameter such that fork lift stingers can be used for lifting and movement.

3. The cores should be sufficiently strong that the roll can be lifted by a stinger or with slings without excessively deflecting, nor structurally buckling the roll.

4. The stacking of rolls at the manufacturing facility should not cause buckling of the cores nor flattening of the rolls. In general, the maximum stacking limit is 5 rolls high.

5. If storage at the manufacturer’s facility is for longer than 6 months, the rolls should be covered by a sacrificial covering, or placed within a temporary or permanent enclosure.

6. The manufacturer should identify all rolls with the manufacturer’s name, product identification, thickness, roller number, roll dimensions and date manufactured.
3.3.1.2 **Accordion Folded**

PVC and CSPE-R geomembranes are initially manufactured in rolls and are then sent to a fabricator for factory seaming into panels. At the fabrication facility they are unrolled directly on top of one another, factory seamed along alternate edges of the rolls and are then accordion folded both width-wise and length-wise and placed onto wooden pallets for packaging and shipment. PVC and CSPE-R geomembranes are generally not stored longer than a few weeks at the fabrication facility.

Regarding items for a specification or MQA document, the following applies.

1. The wooden pallets on which the accordion folded geomembranes are placed should be structurally sound and of good workmanship so that fork lifts or cranes can transport and maneuver them without structurally failing or causing damage to the geomembrane.

2. The wooden pallets should extend at least 75 mm (3 in.) beyond the edge of the folded geomembrane panel on all four sides.

3. The folded geomembrane panel should be packaged in treated cardboard or plastic wrapping for protection from precipitation and direct ultraviolet exposure.

4. Banding straps around the geomembrane and pallet should be properly cushioned so as not to cause damage to any part of the geomembrane panel.
5. Palleted geomembranes should be stored only on level surfaces since the folded material is susceptible to shifting and possible damage.

6. The stacking of palleted geomembrane panels on top of one another should not be permitted.

7. If storage at the fabricator's facility is for longer than 6 months, the pallered panels should be covered with a sacrificial covering, temporary shelter or placed within a permanent enclosure.

8. The fabricator should identify all panels with the manufacturers name, product information, thickness, panel number, panel dimensions and date manufactured.

3.3.2 Shipment, Handling and Site Storage

The geomembrane rolls or pallets are shipped to the job site, offloaded, and temporarily stored at a remote location on the job site, see Fig. 3.15.

Regarding items for a specification or CQA document*, the following applies:

1. Unloading of rolls or pallets at the job site's temporary storage location should be such that no damage to the geomembrane occurs.

2. Pushing, sliding or dragging of rolls or pallets of geomembranes should not be permitted.

3. Offloading at the job site should be performed with cranes or fork lifts in a workmanlike manner such that damage does not occur to any part of the geomembrane.

4. Temporary storage at the job site should be in an area where standing water cannot accumulate at any time.

5. The ground surface should be suitably prepared such that no stones or other rough objects which could damage the geomembranes are present.

6. Temporary storage of rolls of HDPE or VLDPE geomembranes in the field should not be so high that crushing of the core or flattening of the rolls occur. This limit is typically 5 rolls high.

7. Temporary storage of pallets of PVC or CSPE-R geomembranes by stacking should not be permitted.

8. Suitable means of securing the rolls or pallets should be used such that shifting, abrasion or other adverse movement does not occur.

9. If storage of rolls or pallets of geomembranes at the job site is longer than 6 months, a sacrificial covering or temporary shelter should be provided for protection against precipitation, ultraviolet exposure and accidental damage.

* Note that the designations of MQC and MQA will now shift to CQC and CQA since field construction personnel are involved. These designations will carry forward throughout the remainder of this Chapter.
3.3.3 Acceptance and Conformance Testing

It is the primary duty of the installation contractor, via the CQC personnel, to see that the geomembrane supplied to the job site is the proper material that was called for in the contract, as specified by the Plans and Specifications. It is also the duty of the CQA Engineer to verify this material to be appropriate. Clear marking should identify all rolls or pallets with the information described in Section 3.3.1. A complete list of roll numbers should be prepared for each material type.

Upon delivery of the rolls or pallets of geomembrane, the CQA Engineer should ensure that conformance test samples are obtained and sent to the proper laboratory for testing. This will generally be the laboratory of the CQA firm, but may be that of the CQC firm if so designated in the CQA documents. Alternatively, conformance testing could be performed at the manufacturers facility and when completed the particular lot should be marked for the particular site under investigation.

The following items should be considered for a specification or CQA document with regard to acceptance and conformance testing.

1. The particular tests selected for acceptance and conformance testing can be all of those listed previously, but this is rarely the case since MQC and MQA testing should have preceded the field operations. However, at a minimum, the following tests are recommended for field acceptance and conformance testing for the particular
geomembrane type.

(a) HDPE: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-638) and possibly puncture (FTM Std 101C) and tear resistance (ASTM D-1004, Die C)

(b) VLDPE: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-638), and possibly puncture (FTM Std 101C) and tear resistance (ASTM D-1004, Die C)

(c) PVC: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-882), tear resistance (ASTM D-1004, Die C)

(d) CSPE-R: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-751), ply adhesion (ASTM D-413, Machine Method, Type A)

2. The method of geomembrane sampling should be prescribed. For geomembranes on rolls, 1 m (3 ft.) from the entire width of the roll on the outermost wrap is usually cut and removed. For geomembranes folded on pallets, the protective covering must be removed, the uppermost accordion folded section opened and an appropriate size sample taken. Alternatively, factory seam retains can be shipped on top of fabricated panels for easy access and use in conformance testing.

3. The machine direction must be indicated with an arrow on all samples using a permanent marker.

4. Samples are usually taken on the basis of a stipulated area of geomembrane, e.g., one sample per 10,000 m² (100,000 ft²). Alternatively, one could take samples at the rate of one per lot, however, a lot must be clearly defined. One possible definition could be that a lot is a group of consecutively numbered rolls or panels from the same manufacturing line.

5. All conformance test results should be reviewed, accepted and reported by the CQA Engineer before deployment of the geomembrane.

6. Any nonconformance of test results should be reported to the Owner/Operator. The method of a resolution of such differences should be clearly stated in the CQA document. One possible guidance document for failing conformance tests could be ASTM D-4759 titled "Determining the Specification Conformance of Geosynthetics".

3.3.4 Placement

When the subgrade or subbase (either soil or some other geosynthetic) is approved as being acceptable, the rolls or pallets of the temporarily stored geomembranes are brought to their intended location, unrolled or unfolded, and accurately spotted for field seaming, see Fig. 3.16.

3.3.4.1 Subgrade (Subbase) Conditions

Before beginning to move the geomembrane rolls or pallets from their temporary storage location at the job site, the soil subgrade (or other subbase material) should be checked for its preparedness.
Figure 3.16 - Photographs Showing the Unrolling (Upper) and Unfolding (Lower) of Geomembranes
Some items recommended for a specification or CQA document include the following:

1. The soil subgrade shall be of the specified grading, moisture content and density as required by the installer and as approved by the CQA engineer for placement of the geomembrane. See Chapter 2 for these details for compacted clay liner subgrades.

2. Construction equipment deploying the rolls or pallets shall not deform or rut the soil subgrade excessively. Tire or track deformations beneath the geomembrane should not be greater than 25 mm (1.0 in.) in depth.

3. The geomembrane shall not be deployed on frozen subgrade where ruts are greater than 12 mm (0.5 in.) in depth.

4. When placing the geomembrane on another geosynthetic material (geotextile, geonet, etc.), construction equipment should not be permitted to ride directly on the lower geosynthetic material. In cases where rolls must be moved over previously placed geosynthetics it is necessary to move materials by hand or by using small pneumatic tired lifting units. Tire inflation pressures should be limited to a maximum value of 40 kPa (6 lb/in^2).

5. Underlying geosynthetic materials (such as geotextiles or geonets) should have all folds, wrinkles and other undulations removed before placement of the geomembrane.

6. Care, and planning, should be taken to unroll or unfold the geomembrane close to its intended, and final, position.

3.3.4.2 Temperature Effects - Sticking/Cracking

High temperatures can cause geomembrane surfaces on rolls, or accordion folded on pallets, to stick together, a process commonly called “blocking”. At the other extreme, low temperatures can cause geomembrane sheets to crack when unrolled or unfolded. Comments on unrolling, or unfolding of geoinembranes at each of these temperature extremes follow.

For example, a specification or CQA document should have included in it the following items.

1. Geomembranes when unrolled or unfolded should not stick together to the extent where tearing, or visually observed straining of the geomembrane, occurs. The upper temperature limit is very specific to the particular type of geomembrane. A sheet temperature of 50°C (122°F) is the upper limit that a geomembrane should be unrolled or unfolded unless it is shown otherwise to the satisfaction of the CQA engineer.

2. Geomembranes which have torn or have been excessively deformed should be rejected, or shall be repaired per the CQA Document.

3. Geomembranes when unrolled or unfolded in cold weather should not crack, craze, or distort in texture. A sheet temperature of 0°C (32°F) is the lower limit that a geomembrane should be unrolled or unfolded unless it is shown otherwise to the satisfaction of the CQA engineer.
3.3.4.3 Temperature Effects - Expansion/Contraction

Polyethylene geomembranes expand when they are heated and contract when they are cooled. Other types of geomembranes may slightly contract when heated. This expansion and contraction must be considered when placing, seaming and backfilling geomembranes in the field. Fig. 3.17 shows a wrinkled polyethylene liner which has expanded due to thermal warming from the sun.

![Figure 3.17 - HDPE Geomembrane Showing Sun Induced Wrinkles](image)

Either the contract plans and specifications, or the CQA documents should cover the expansion/contraction situation on the basis of site specific and geomembrane specific conditions. Some items to consider include the following:

1. Sufficient slack shall be placed in the geomembrane to compensate for the coldest temperatures envisioned so that no tensile stresses are generated in the geomembrane or in its seams either during installation or subsequently after the geomembrane is covered.

2. The geomembrane shall have adequate slack such that it does not lift up off of the subgrade or substrate material at any location within the facility, i.e., no “trampolining” of the geomembrane shall be allowed to occur at any time.
3. The geomembrane shall not have excessive slack to the point where creases fold over upon themselves either during placement and seaming, or when the protective soil or drainage materials are placed on the geomembrane.

4. Permanent (fold-over type) creases in the covered geomembrane should not be permitted at any time.

5. The amount of slack to be added to the deployed and seamed geomembrane should be carefully considered and calculated, taking into account the type of geomembrane and the geomembrane’s temperature during installation versus its final temperature in the completed facility.

3.3.4.4 Spotting

When a geomembrane roll or panel is deployed it is generally required that some shifting will be necessary before field seaming begins. This is called “spotting” by many installers.

Some items for a specification or CQA document should include the following:

1. Spotting of deployed geomembranes should be done with no disturbance to the soil subgrade or geosynthetic materials upon which they are placed.

2. Spotting should be done with a minimum amount of dragging of the geomembrane on soil subgrades.

3. Temporary tack welding (usually with a hand held hot air gun) of all types of thermoplastic geomembranes should be allowed at the installers discretion.

4. When temporary tack welds of geomembranes are utilized, the welds should not interfere with the primary seaming method, or with the ability to perform subsequent destructive seam tests.

3.3.4.5 Wind Considerations

Wind damage to geomembranes, unfortunately, is not an uncommon occurrence, see Fig. 3.18. Many deployed geomembranes have been uplifted by wind and have been damaged. In some cases the geomembranes have even been torn out of anchor trenches. This is sometimes referred to as “blow-out” by field personnel. Generally, but not always, the unseamed geomembrane rolls or panels acting individually are most vulnerable to wind uplift and damage.

The contract plans and specification, or at least the CQA documents, must be very specific as to resolutions regarding geomembranes that have been damaged due to shifting by wind. Some suggestions follow.

1. Geomembrane rolls or panels which have been displaced by wind should be inspected and approved by the CQA engineer before any further field operations commence.

2. Geomembrane rolls or panels which have been damaged (torn, punctured, or deformed excessively and permanently) shall be rejected and/or repaired as directed in the contract plans, specifications or CQA documents.

3. Permanent crease marks, or severely folded (crimped) locations, in geomembranes
should not be permitted unless it can be shown that such distortions have no adverse
effect on the properties of the geomembrane. If this cannot be done, these areas should
be cut out and properly patched as per the contract documents and approved by the CQA
Engineer.

4. If patching of wind damaged geomembranes becomes excessive (to the limit set forth in
the specifications or CQA plan), the entire roll or panel should be rejected.

Figure 3.18 - Wind Damage to Deployed Geomembrane

3.4 Seaming and Joining

The field seaming of the deployed geomembrane rolls or panels is a critical aspect of their
successful functioning as a barrier to liquid (and sometimes vapor) flow. This section describes
the various seaming methods in current use, references a recently published EPA Technical
Guidance Document on seam fabrication techniques (EPA, 1991), and describes the concept and
importance of test strips (or trial seams).

3.4.1 Overview of Field Seaming Methods

The fundamental mechanism of seaming polymeric geomembrane sheets together is to
temporarily reorganize, i.e., melt, the polymer structure of the two surfaces to be joined in a
controlled manner that, after the application of pressure and after the passage of a certain amount of
time, results in the two sheets being bonded together. This reorganization results from an input of
energy that originates from either thermal or chemical processes. These processes may involve the
addition of extra polymer in the bonded area.

Ideally, seaming two geomembrane sheets would result in no net loss of tensile strength
across the two sheets and the joined sheets would perform as one single geomembrane sheet.
However, due to stress concentrations resulting from the seam geometry, current seaming
techniques may result in minor tensile strength loss relative to the parent geomembrane sheet. The
characteristics of the seamed area are a function of the type of geomembrane and the seaming
technique used. These characteristics, such as residual strength, geomembrane type, and seaming
type, should be recognized by the designer when applying the appropriate design factors-of-safety
for the overall geomembrane function and facility performance.

It should be noted that the seam can be the location of the lowest tensile strength in a
geomembrane liner. Designers and inspectors should be aware of the importance of seeking only
the highest quality geomembrane seams. The minimum seam tensile strengths (as determined by
design) for various geomembranes must be predetermined by laboratory testing, knowledge of past
field performance, manufacturers literature, various trade journals or other standards setting
organizations that maintain current information on seaming techniques and technologies.

The methods of seaming at the time of the printing of this document and discussed herein
are given in Table 3.2 and shown schematically in Fig. 3.19.

Table 3.2. Fundamental Methods Of Joining Polymeric Geomembranes

<table>
<thead>
<tr>
<th>Thermal Processes</th>
<th>Chemical Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrusion:</td>
<td>Chemical:</td>
</tr>
<tr>
<td>• Fillet</td>
<td>• Chemical Fusion</td>
</tr>
<tr>
<td>• Flat</td>
<td>• Bodied Chemical Fusion</td>
</tr>
<tr>
<td>Fusion:</td>
<td>Adhesive:</td>
</tr>
<tr>
<td>• Hot Wedge</td>
<td>• Chemical Adhesive</td>
</tr>
<tr>
<td>• Hot Air</td>
<td>• Contact Adhesive</td>
</tr>
</tbody>
</table>

Within the entire group of thermoplastic geomembranes that will be discussed in this
manual, there are four general categories of seaming methods: extrusion welding, thermal fusion or
melt bonding, chemical fusion and adhesive seaming. Each will be explained along with their
specific variations so as to give an overview of field seaming technology.
Figure 3.19 - Various Methods Available to Fabricate Geomembrane Seams

(a) Extrusion Seams
- Flat - Type Fillet
- (a) Extrusion Seams

(b) Fusion Seams
- Dual Hot Wedge
  (Single Track is Also Possible)
- Single Hot Air
  (Dual Track is Also Possible)

(c) Chemical Seams
- Chemical
- Bodied Chemical

(d) Adhesive Seams
- Chemical Adhesive
- Contact Adhesive

Figure 3.19 - Various Methods Available to Fabricate Geomembrane Seams
Extrusion welding is presently used exclusively on geomembranes made from polyethylene. A ribbon of molten polymer is extruded over the edge of, or in between, the two surfaces to be joined. The molten extrudate causes the surfaces of the sheets to become hot and melt, after which the entire mass cools and bonds together. The technique is called extrusion fillet seaming when the extrudate is placed over the leading edge of the seam, and is called extrusion flat seaming when the extrudate is placed between the two sheets to be joined. It should be noted that extrusion fillet seaming is essentially the only practical method for seaming polyethylene geomembrane patches, for seaming in poorly accessible areas such as sump bottoms and around pipes and for seaming of extremely short seam lengths. Temperature and seaming rate both play important roles in obtaining an acceptable bond; excessive melting weakens the geomembrane and inadequate melting results in poor extrudate flow across the seam interface and low seam strength. The polymer used for the extrudate is also very important and should generally be the same polyethylene compound used to make the geomembrane. The designer should specify acceptable extrusion compounds and how to evaluate them in the specifications and CQA documents.

There are two thermal fusion or melt-bonding methods that can be used on all thermoplastic geomembranes. In both of them, portions of the opposing surfaces are truly melted. This being the case, temperature, pressure, and seaming rate all play important roles in that excessive melting weakens the geomembrane and inadequate melting results in low seam strength. The hot wedge, or hot shoe, method consists of an electrically heated resistance element in the shape of a wedge that travels between the two sheets to be seamed. As it melts the surface of the two sheets being seamed, a shear flow occurs across the upper and lower surfaces of the wedge. Roller pressure is applied as the two sheets converge at the tip of the wedge to form the final seam. Hot wedge units are controllable as far as temperature, amount of pressure applied and travel rate. A standard hot wedge creates a single uniform width seam, while a dual hot wedge (or “split” wedge) forms two parallel seams with a uniform unbonded space between them. This space can be used to evaluate seam quality and continuity of the seam by pressurizing the unbonded space with air and monitoring any drop in pressure that may signify a leak in the seam.

The hot air method makes use of a device consisting of a resistance heater, a blower, and temperature controls to force hot air between two sheets to melt the opposing surfaces. Immediately following the melting of the surfaces, pressure is applied to the seamed area to bond the two sheets. As with the hot wedge method, both single and dual seams can be produced. In selected situations, this technique may also be used to temporarily “tack” weld two sheets together until the final seam or weld is made and accepted.

Regarding the chemical fusion seam types; chemical fusion seams make use of a liquid chemical applied between the two geomembrane sheets to be joined. After a few seconds, required to soften the surface, pressure is applied to make complete contact and bond the sheets together. As with any of the chemical seaming processes to be described, the two adjacent materials to be bonded are transformed into a viscous phase. Care must be used to see that the proper amount of chemical is applied in order to achieve the desired results. Bodied chemical fusion seams are similar to chemical fusion seams except that 1% to 20% of the parent lining resin or compound is dissolved in the chemical and then is used to make the seam. The purpose of adding the resin or compound is to increase the viscosity of the liquid for slope work and/or adjust the evaporation rate of the chemical. This viscous liquid is applied between the two opposing surfaces to be bonded. After a few seconds, pressure is applied to make complete contact. Chemical adhesive seams make use of a dissolved bonding agent (an adherent) in the chemical or bodied chemical which is left after the seam has been completed and cured. The adherent thus becomes an additional element in the system. Contact adhesives are applied to both mating surfaces. After reaching the proper degree of tackiness, the two sheets are placed on top of one another, followed by application of roller pressure. The adhesive forms the bond and is an additional element in the system.
Other emerging seaming methods use ultrasonic, electrical conduction and magnetic induction energy sources. Since these methods are in the developmental stage, they will not be described further in this document. See EPA (1991) for further details.

In order to gain an overview as to which seaming methods are used for the various thermoplastic geomembranes described in this document, Table 3.3 is offered. It is generalized, but it is used to introduce the primary seaming methods versus the type of geomembrane that is customarily seamed by that method.

Table 3.3 Possible Field Seaming Methods for Various Geomembranes Listed in this Manual

<table>
<thead>
<tr>
<th>Type of Seaming Method</th>
<th>Type of Geomembrane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HDPE</td>
</tr>
<tr>
<td>extrusion (fillet and flat)</td>
<td>A</td>
</tr>
<tr>
<td>thermal fusion (hot wedge and hot air)</td>
<td>A</td>
</tr>
<tr>
<td>chemical (chemical and bodied chemical)</td>
<td>n/a</td>
</tr>
<tr>
<td>adhesive (chemical and contact)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Note: A = method is applicable
n/a = method is “not applicable”

3.4.2 Details of Field Seaming Methods

Full details of field seaming methods for the edges and ends of geomembrane rolls or panels has recently been described in EPA Technical Guidance Document, EPA/530/SW-91/051, entitled: “Inspection Techniques for the Fabrication of Geomembrane Seams”. In this document (EPA, 1991) are separate chapters devoted to the following field seaming methods.

- extrusion fillet seams
- extrusion flat seams
- hot wedge seams
- hot air seams
- chemical and bodied chemical fused seams
- chemical adhesive seams

There is also a section on emerging technologies for geomembrane seaming. The interested reader should consult this document for details regarding all of these seaming methods.

Whenever the plans and specifications are not written around a particular seaming method the actual method which is used becomes a matter of choice for the installation contractor. As seen in Table 3.3, there are a number of available choices for each geomembrane type. Furthermore, even when the installation contractor selects the particular seaming method to be used, its specific details are rarely stipulated even in the specification or CQA documents. This is to give the installation contractor complete latitude in selecting seaming temperatures, travel rates, mechanical roller pressures, chemical type, tack time, hand rolling pressure, etc. The role of the plans, specifications and CQA documents is to adequately provide for destructive tests (on test strips and on production seams) and nondestructive tests (on production seams) to assure that the seams are fabricated to the highest quality and uniformity and are in compliance with the project’s documents.

This is not to say that the specification never influences the type of seaming method. For example, if the specifications call for a nondestructive constant air pressure test to be conducted, the installation contractor must use a thermal fusion technique like the dual hot wedge or dual hot air methods since they are the only methods that can produce such a seam.

3.4.3 Test Strips and Trial Seams

Test strips and trial seams, also called qualifying seams, are considered to be an important aspect of CQC/CQA procedures. They are meant to serve as a prequalifying experience for personnel, equipment and procedures for making seams on the identical geomembrane material under the same climatic conditions as the actual field production seams will be made. The test strips are usually made on two narrow pieces of excess geomembrane varying in length between 1.0 to 3.0 m (3 to 10 ft.), see Fig. 3.20. The test strips should be made in sufficient lengths, preferably as a single continuous seam, for all required testing purposes.

The goal of these test strips is to reproduce all aspects of the actual production field seaming activities intended to be performed in the immediately upcoming work session so as to determine equipment and operator proficiency. Ideally, test strips can be used to estimate the quality of the production seams while minimizing damage to the installed geomembrane through destructive mechanical testing. Test strips are typically made every 4 hours (for example, at the beginning of the work shift and after the lunch break). They are also made whenever personnel or equipment are changed and when climatic conditions reflect wide changes in geomembrane temperature or when other conditions occur that could affect seam quality. These details should be stipulated in the contract specifications or CQA documents.

The destructive testing of the test strips should be done as soon as the installation contractor feels that the strength requirements of the contract specification or CQA documents can be met. Thus it behooves the contractor to have all aspects of the test strip seam fabrication in complete
working order just as would be done in the case of fabricating production field seams. For extrusion and thermal fusion seams, destructive testing can be done as soon as the seam cools. For chemical fusion and adhesive seams this could take several days and the use of a field oven to accelerate the curing of the seam is advisable.

Figure 3.20 - Fabrication of a Geomembrane Test Strip

From two to six test specimens are cut from the test strip using a 25 mm (1.0 in. wide die). They are selected at random by the CQA inspector. The specimens are then tested in both peel and shear using a field tensiometer, see Fig. 3.21. (Generally peel tests are more informative in assessing the quality of the seam). If any of the test specimens fail, a new test strip is fabricated. If additional specimens fail, the seaming apparatus and seamer should not be accepted and should not be used for seaming until the deficiencies are corrected and successful trial welds are achieved. The CQA inspector should observe all trial seam procedures and tests. If the specimens pass, seaming operations can move directly to production seams in the field. Pass/fail criteria for destructive seam tests will be described in Section 3.5.
The flow chart illustrated in Fig. 3.22 gives an idea of the various decisions that can be reached depending upon the outcome of destructive tests on test strip specimens. Here it is seen that failed test strips are linked to an increased frequency of destructive tests to be taken on production field seams made during the time interval between making the test strip and its testing. Furthermore, it is seen that there are only two chances at making adequate test strips before production field seaming is stopped and repairs are initiated. These details should be covered in either the project specification or the CQA documents.

Some specification or CQA document items regarding the fabrication of geomembrane seam test strips include the following:

1. The frequency of making test strips should be clearly stated. Typically this is at the beginning of the day, after the noon break and whenever changed conditions are encountered, e.g., changes in weather, equipment, personnel.

2. The CQA Engineer should have the option of requesting test strips of any field seaming crew or device at any time.
3. The procedure for sampling and evaluating the field test strip samples should be clearly outlined, i.e., the number of peel and shear test specimens to be cut and tested from the test strip sample, the rate of testing and what the required strength values are in these two different modes of testing.

4. The fabrication of the field test strip and testing of test specimens should be observed by the CQA personnel.
5. The time for testing after the test strip is fabricated varies between seam types. For extrusion and fusion fabricated seams, the testing can commence immediately after the polymer cools to ambient temperature. For chemical fusion and adhesive fabricated seams, the testing must wait until adequate curing of the seam occurs. This can take as long as 1 to 7 days. During this time all production seaming must be tracked and documented.

6. Accelerated oven curing of chemical and adhesive fabricated seams is acceptable so as to hasten the curing process and obtain test results as soon as possible. GRI Test Method GM-7 can be used for this purpose.

7. The required inspection protocol and implications of failed test specimens from the test strips must be clearly stated. The protocol outlined in Fig. 3.22 is suggested.

8. Field test strips are usually discarded after the destructive test specimens are removed and tested. If this is not the case, it should be clearly indicated who receives the test strip samples and what should be the utilization (if any) of these samples.

3.5 Destructive Test Methods for Seams

The major reason that plans and specifications do not have to be specific about the type of seaming methods and their particular details is that geomembrane seams can be readily evaluated for their quality by taking samples and destructively testing them either at the job site or in a timely manner at a testing laboratory thereafter.

3.5.1 Overview

By destructively testing geomembrane seams it is meant to actually cut out (i.e., to sample) and remove a portion of the completed production seam, and then to further cut the sample into appropriately sized test specimens. These specimens are then tested according to a specified procedure to failure or to yield depending upon the type of geomembrane.

A possible procedure is to select the sampling location and cut two closely spaced 25 mm (1.0 in.) wide test specimens from the seam. The distance between these two test specimens is defined later. The individual specimens are then tested in a peel mode using a field tensiometer (recall Fig. 3.21). If the results are acceptable, the complete seam between the two field test specimens is removed and properly identified and distributed. If either test specimen fails, two new locations on either side of the failed specimen(s) are selected until acceptable seams are located. The seam distance between acceptable seams is usually repaired by cap-stripping but other techniques are also possible. The exact procedure must be stipulated in the specifications or CQA document.

The length dimension of the field seam sample between the two test specimens just described varies according to whatever is stipulated in the plans and specifications, or in accordance with the CQA documents. Some common options are to sample the seam for a distance of either 36 cm (14 in.), 71 cm (28 in.) or 106 cm (42 in.) along its length. Since the usual destructive seam tests are either shear or peel tests and both types are 25 mm (1.0 in.) wide test specimens, this allows for approximately 10, 20 or 30 tests (half shear and half peel) to be conducted on the respective lengths cited above. The sample width perpendicular to the seam is usually 30 cm (12 in.) with the seam being centrally located within this dimension.
The options of seam sample length between the two peel test specimens mentioned above that are seen in various plans, specifications, and CQA documents, are as follows:

- A 36 cm (14 in.) sample is taken from the seam and cut into 5 shear and 5 peel specimens. The tests are conducted in the field or at a remote laboratory by, or under the direction of, the responsible CQA organization.

- A 71 cm (28 in.) long sample is taken from the seam and cut in half. One half is further cut into 5 shear and 5 peel test specimens which are tested in the field or at a remote laboratory by the CQC organization (usually the installation contractor). The other half is sent to a remote laboratory for testing by the CQA organization who also does 5 shear and 5 peel tests. Alternatively, sometimes only the CQA organization does the testing and the second half of the sample is left intact and archived by the owner/operator.

- A 106 cm (42 in.) long sample is taken from the seam and cut into three individual 36 cm (14 in.) samples. Individual samples go to the CQC organization, the CQA organization and the owner/operator. The CQC and CQA organizations each cut their respective samples into 5 shear and 5 peel test specimens and conduct the appropriate tests immediately. The remaining sample is archived by the owner/operator.

Whatever is the strategy for taking samples from the production seams for destructive testing it must be clearly outlined in the contract plans and specifications and further defined and/or corroborated in the CQA documents.

Obviously, the hole created in the production seam from which the test sample was originally taken must be patched in an appropriate manner. See Fig. 3.23 for such a patched sampling location. Recognize that the seams of such patches are themselves candidates for field sampling and testing. If this is done, one would have the end result of patch on a patch, which is a rather unsightly and undesirable condition.

3.5.2 Sampling Strategies

The sampling of production seams of installed geomembranes represents a dilemma of major proportions. Too few samples results in a poor statistical representation of the strength of the seam, and too many samples requires an additional cost and a risk of having the necessary repair patches being problems in themselves. Unfortunately, there is no clear strategy for all cases, but the following are some of the choices that one has in formulating a specification or CQA plan.

Note also that in selecting a sampling strategy the sampling frequency is tied directly into the performance of the test strips described in Section 3.4.3. If the test strips fail during the time that production seaming is ongoing, the frequency of destructive sampling and testing must be increased. The following strategies, however, are for situations where geomembrane seam test strips are being made in an acceptable manner.

3.5.2.1 Fixed Increment Sampling

By far the most commonly used sampling strategy is the “fixed increment sampling” method. In this method, a seam sample is taken at fixed increments along the total length of the seams. Increments usually range from 75 to 225 m (250 to 750 ft) with a commonly specified value being one destructive test sample every 150 m (500 ft). Note that this value can be applied either directly to the record drawings during layout of the seams, to each seaming crew as they progress during the work period, or to each individual seaming device. Once the increment is
decided upon, it should be held regardless of the location upon which it falls, e.g., along side slopes, in sumps, etc. Of course, if the CQA documents allow otherwise, exceptions such as avoiding sumps, connections, protrusions, etc. can be made.

Figure 3.23 - Completed Patch on a Geomembrane Seam Which had Previously Been Sampled for Destructive Tests

3.5.2.2 Randomly Selected Sampling

In random selection of destructive seam sample locations it is first necessary to preselect a preliminary estimate of the total number of samples to be taken. This is done by taking the total seam length of the facility and dividing it by an arbitrary interval, e.g., 150 m (500 ft), to obtain the total number of samples that are required. Two choices to define the actual sampling locations
are now available: "stratified" random sampling, or "strict" random sampling. The stratified method takes each pre-selected interval (e.g., a 150 m (500 ft) length) and randomly selects a single sample location within this interval. Thus with stratified random sampling one has location variability within a fixed increment (unlike fixed frequency sampling which is always at the exact end of the increment). The strict method uses the total seam length of the facility (or cell) and randomly selects sample locations throughout the facility up to the desired number of samples. Thus with strict random sampling a group of samples may be taken in close proximity to one another, which necessarily leaves other areas with sparse sampling.

There are various ways of randomly selecting the specific location within an interval, e.g., in a specific region of great concern, or within the total project seam length. These are as follows:

- Use a random number generator from statistical tables to predetermine the sampling locations within each interval or for the entire project.
- Use a programmable pocket calculator with a random number generator program to select the sampling location in the field for each interval or for the entire project.
- Use a random number obtained by simply multiplying two large numbers together to form an 8-digit result. A pocket calculator with an adequate register will be necessary. The center two digits in such a procedure are quite randomly distributed and can be used to obtain the sampling location. For example, multiplication of the following two numbers “4567” by 4567” gives 20857489 where the central two digits, i.e., the “57”, are used to select the location within the designated sampling interval. If this interval were 500 ft., the sampling location within it would be at \(0.57 \times 500 = 285\) ft. from the beginning of the interval. The next location of the sample would require a new calculation resulting in a different central two-digit number somewhere within the next 500 ft. sampling interval and would be located in a similar fashion.

3.5.2.3 Other Sampling Strategies

There are two other sampling strategies which might be selected in determining how many destructive seam samples should be taken. Both are variable strategies in that repeated acceptable seam tests are rewarded by requiring fewer samples and repeated failures are penalized by requiring more frequent samples. These two strategies are called the “method of attributes” and the use of “control charts”. Both set upper and lower bounds which require either fewer or more frequent testing than the initially prescribed sampling frequency. Each of these methods are described fully in Richardson (1992).

Whatever the sampling strategy used, it should never limit or prohibit the ability to select a destructive seam sample from a suspect area. This should ultimately be an option left to the CQA engineer.

3.5.3 Shear Testing of Geomembrane Seams

Shear testing of specimens taken from field fabricated geomembrane seams represents a reasonably simulated performance test. The possible exception is that a normal stress is not applied to the surfaces of the test specimen thus it is an “unconfined” tension test. A slight rotation may be induced during tensioning of the specimen, making the actual test results tend toward conservative values. The configuration of a shear test in a tension testing machine is shown in Fig. 3.24.
Commonly recommended shear tests for HDPE, PVC, CSPE-R and EIA-R seams, along with the methods of testing the unseamed sheet material in tension, are given in Table 3.4. The VLDPE data presented was included in a way so as to parallel the HDPE testing protocol except for the strain rate values which are faster since breaking values, rather than yield values are required. There is no pronounced yield value when tensile testing VLDPE geomembranes.
Table 3.4  Recommended Test Method Details for Geomembrane Seams in Shear and in Peel and for Unseamed Sheet

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>HDPE</th>
<th>VLDPE</th>
<th>PVC</th>
<th>CSPE-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear Test on Seams</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM Test Method</td>
<td>D4437</td>
<td>D4437</td>
<td>D3083</td>
<td>D751</td>
</tr>
<tr>
<td>Specimen Shape</td>
<td>Strip</td>
<td>Strip</td>
<td>Strip</td>
<td>Grab</td>
</tr>
<tr>
<td>Specimen Width (in.)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>4.00 (1.00 grab)</td>
</tr>
<tr>
<td>Specimen Length (in.)</td>
<td>6.00 + seam</td>
<td>6.00 + seam</td>
<td>6.00 + seam</td>
<td>9.00 + seam</td>
</tr>
<tr>
<td>Gage Length (in.)</td>
<td>4.00 + seam</td>
<td>4.00 + seam</td>
<td>4.00 + seam</td>
<td>6.00 + seam</td>
</tr>
<tr>
<td>Strain Rate (ipm)</td>
<td>2.0</td>
<td>20</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>Strength (psi) or (ppi)</td>
<td>Force/(1.00xt)</td>
<td>Force/(1.00xt)</td>
<td>Force/(1.00xt)</td>
<td>Force</td>
</tr>
<tr>
<td>Peel Test on Seams</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM Test Method</td>
<td>D4437</td>
<td>D4437</td>
<td>D413</td>
<td>D413</td>
</tr>
<tr>
<td>Specimen Shape</td>
<td>Strip</td>
<td>Strip</td>
<td>Strip</td>
<td>Strip</td>
</tr>
<tr>
<td>Specimen Width (in.)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Specimen Length (in.)</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Gage Length (in.)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Strain Rate (ipm)</td>
<td>2.0</td>
<td>20</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Strength (psi) or (ppi)</td>
<td>Force/(1.00xt)</td>
<td>Force/(1.00xt)</td>
<td>Force/1.00</td>
<td>Force/1.00</td>
</tr>
<tr>
<td>Tensile Test on Sheet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM Test Method</td>
<td>D638</td>
<td>D638</td>
<td>D882</td>
<td>D751</td>
</tr>
<tr>
<td>Specimen Shape</td>
<td>Dumbbell</td>
<td>Dumbbell</td>
<td>Strip</td>
<td>Grab</td>
</tr>
<tr>
<td>Specimen Width (in.)</td>
<td>0.25</td>
<td>0.25</td>
<td>1.00</td>
<td>4.00 (1.00 Grab)</td>
</tr>
<tr>
<td>Specimen Length (in.)</td>
<td>4.50</td>
<td>4.50</td>
<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Gage Length (in.)</td>
<td>1.30</td>
<td>1.30</td>
<td>2.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Strain Rate (ipm)</td>
<td>2.0</td>
<td>20</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>Strength (psi) or (lb)</td>
<td>Force/(0.25xt)</td>
<td>Force/(0.25xt)</td>
<td>Force/(1.00xt)</td>
<td>Force</td>
</tr>
<tr>
<td>Strain (in./in.)</td>
<td>Elong./1.30</td>
<td>Elong./1.30</td>
<td>Elong./2.00</td>
<td>Elong./3.00</td>
</tr>
<tr>
<td>Modulus (psi)</td>
<td>From Graph</td>
<td>From Graph</td>
<td>From Graph</td>
<td>n/a</td>
</tr>
</tbody>
</table>

where  
\( n/a \) = not applicable  
\( t \) = geomembrane thickness  
\( \text{psi} \) = pounds/square inch of specimen cross section  
\( \text{ppi} \) = pounds/linear inch width of specimen  
\( \text{ipm} \) = inches/minute  
Force = maximum force attained at specimen failure (yield or break)
Insofar as the shear testing of nonreinforced geomembrane seams (HDPE, VLDPE and PVC), all use a 25 mm (1.0 in.) wide test specimen with the seam being centrally located within the testing grips. For the reinforced geomembranes (CSPE-R and EIA-R) a “grab” test specimen is used. In a grab tension test the specimen is 200 mm (4.0 in.) wide but is only gripped in the central 25 mm (1.0 in.). The test specimen is tensioned, at its appropriate strain rate, until failure occurs. If the seam delaminates (i.e., pulls apart in a seam separation mode), the seam fails in what is called a “non-film tear bond”, or non-FTB. In this case, it is rejected as a failed seam. Details on various types of seam failures and on the interpretation of FTB are found in Haxo (1988). Conversely, if the seam does not delaminate, but fails in the adjacent sheet material on either side of the seam, it is an acceptable failure mode, i.e., called a “film tear bond”, or FTB, and the seam strength is then calculated.

The seam strength (for HDPE, VLDPE and PVC) is the maximum force attained divided by either the original specimen width (resulting in units of force per unit width), or the original specimen cross sectional area (resulting in units of stress). It is general procedure to use force per unit width as it is an absolute strength value which can be readily compared to other test results. If stress units are desired, one can use the nominal thickness of the geomembrane, or continuously measure the actual thickness of each test specimen. This latter alternative requires considerable time and effort and is generally not recommended. The procedure is slightly different for the reinforced geomembranes (CSPE-R and EIA-R) which use a grab test method. Here the strength is based on the maximum tensile force that can be mobilized and a stress value is not calculated.

The resulting value of seam shear strength is then compared to the required seam strength (which is the usual case) or to the strength of the unseamed geomembrane sheet. If the latter, the procedures for obtaining this value are listed in Table 3.4. In each case the test protocol for seam and sheet are the same, except for HDPE and VLDPE. The sheet strength value for these polyethylene geomembranes are based on a ASTM D-638 “dumbbell-shaped” specimens, although the strength is calculated on the reduced section width. With all of these sheet tension tests, the nominal thickness of the unseamed geomembrane sheet is used for the comparison value. If actual thickness of the sheet is considered, the results will be reflected accordingly. Note, however, that this will require a large amount of additional testing (to get average strength values) and is not a recommended approach.

Knowing the seam shear strength and the unseamed sheet strength (ether by a specified value or by testing), allows for a seam shear efficiency calculation to be made as follows:

$$E_{\text{shear}} = \frac{T_{\text{seam in shear}}}{T_{\text{unseamed sheet}}}$$  \hspace{1cm} (3.1)

where

- $E_{\text{shear}}$ = seam efficiency in shear (%)
- $T_{\text{seam}}$ = seam shear strength (force or stress units)
- $T_{\text{sheet}}$ = sheet tensile strength (force or stress units)

The contract plans, specifications or CQA documents should give the minimum allowable seam shear strength efficiency. As a minimum, the guidance listed below can be used whereby
percentages of seam shear efficiencies (or values) are listed:

\[
\text{HDPE} = 95\% \text{ of specified minimum yield strength} \\
\text{VLDPE} = \text{typically 1200 } \text{lb/in}^2 \\
\text{PVC} = 80\% \\
\text{CSPE-R} = 80\% \text{ (for 3-ply reinforced)} \\
\text{EIA-R} = 80\%
\]

Generally an additional requirement of a film tear bond, or FTB, will also be required in addition to a minimum strength value. This means that the failure must be located in the sheet material on either side of the seam and not within the seam itself. Thus the seam cannot delaminate.

Lastly, the number of failures allowed per number of tests conducted should be addressed. If sets of 5 test specimens are performed for each field sample, many specifications allow for one failure out of the five tested. If the failure number is larger, then the plans, specifications or CQA documents must be clear on the implications.

When a destructive seam test sample fails, many specifications and CQA documents require two additional samples to be taken, one on each side of the original sample each spaced 3 m (10 ft) from it. If either one of these samples fail, the iterative process of sampling every 3 m (10 ft) is repeated until passing test results are observed. In this case the entire seam between the two successful test samples must be questioned. For example, remedies for polyethylene geomembranes are to cap strip the entire seam or if the seam is made with a thermal fusion method (hot air or hot wedge) to extrude a fillet weld over the outer seam edge. When such repairs are concluded the seams on the cap strip or extrusion fillet weld should be sampled and tested as just described.

Note that elongation of the specimens during shear testing is usually not monitored (although current testing trends are in this direction), the only value under consideration is the maximum force that the seam can sustain. It should also be mentioned that the test is difficult to perform on the inside of the tracks facing the air channel of a dual channel thermal fusion seam. For small air channels the tab available for gripping will be considerably less than that required in test methods as given in Table 3.4. Regarding the testing of the inside or outside tracks (away from the air channel) of a dual channel thermal fusion seam, or even both tracks, the specification or CQA document should be very specific.

3.5.4 Peel Testing of Geomembrane Seams

Peel testing of specimens taken from field fabricated geomembrane seams represent a quality control type of index test. Such tests are not meant to simulate in-situ performance but are very important indicators of the overall quality of the seam. The configuration of a peel test in a tension testing machine is shown in Fig. 3.25.

The recommended peel tests for HDPE, PVC, CSPE-R and EIA-R seams, along with the unseamed sheet material in tension are given in Table 3.4. The VLDPE data was included in a way so as to parallel the HDPE testing protocol.

Insofar as the peel testing of geomembrane seams is concerned, it is seen that all of the geomembranes listed have a 25 mm (1.0 in.) width test specimen. Furthermore, the specimen lengths and strain rate are also equal for all geomembrane types. The only difference is that HDPE and VLDPE use the thickness of the geomembrane to calculate a tensile strength value in stress.
units, whereas PVC, CSPE-R and EIA-R calculate the tensile strength value in units of force per unit width, i.e., in units of pounds per linear inch of seam.

In a peel test the test specimen is tensioned, at its appropriate strain rate, until failure occurs. If the seam delaminates (i.e., pulls apart in a seam separation mode), it is called a "non-film tear bond or non-FTB", and is recorded accordingly. Conversely, if the seam does not delaminate, but fails in the adjacent sheet material on either side of the seam it is called a "film tear bond or FTB" and the seam strength is calculated. Details on various types of seam failures and on the interpretation of FTB are found in Haxo (1988). The seam strength is the maximum force attained divided by the specimen width (resulting in units of force per unit width), or by the specimen cross sectional area (resulting in units of stress). The former procedure is the most common, i.e., peel strengths are measured in force per unit width units. If stress units are desired the thickness of the

Fig. 3.25 - Peel Test of a Geomembrane Seam Evaluated in a CQC/CQA Laboratory Environment
geomembrane sheet must be included. The nominal sheet thickness is usually used. If the actual sheet thickness is used, a large amount of thickness measurements will be required to obtain a statistically reliable value. It is not a recommended procedure.

The resulting value of seam peel strength is then compared to a specified value (the usual case) or to the strength of the unseamed geomembrane sheet. The testing procedures for obtaining these values are listed in Table 3.4. It can be seen, however, that only with PVC is the same width test specimen used for peel and sheet testing. For HDPE and VLDPE one is comparing a 1.0 in. uniform width peel test with a dumbbell shaped specimen, while for CSPE-R and EIA-R one is comparing a uniform width peel test with the strength from a grab shaped test specimen. If, however, one does have a specified sheet strength value or a measured value, a seam peel strength efficiency calculation can be made as follows:

$$E_{\text{peel}} = \frac{T_{\text{seam in peel}}}{T_{\text{unseamed sheet}}} \quad (100)$$

where

- $E_{\text{peel}}$ = seam efficiency in peel (%)
- $T_{\text{seam}}$ = seam peel strength (force or stress units)
- $T_{\text{sheet}}$ = sheet tensile strength (force or stress units)

The contract plans, specifications or CQA documents should give the minimum allowable seam peel strength efficiency. As a minimum, the guidance listed below can be used whereby percentage peel efficiencies (or values) are listed as follows:

- HDPE = 62% of specified minimum yield strength and FTB
- VLDPE = typically 1000 lb/in²
- PVC = 10 lb/in.
- CSPE-R = 10 lb/in. or FTB
- EIA-R = 10 lb/in.

Lastly, the number of failures allowed per number of tests conducted should be addressed. If sets of 5 test specimens are performed for each field sample, many specifications allow for one failure out of the five tested. If the failure number is larger, then the plans, specifications or CQA documents must be clear on the implications.

When a destructive seam test sample fails, many specifications require an additional two samples to be taken, one on each side of the original spaced 3 m (10 ft) from it. If either one of these samples fail the iterative process of sampling every 3 m (10 ft) is repeated until successful samples result. In this case, the entire seam between the last successful test samples must be questioned. Remedies are to cap strip the entire seam or if the seam is HDPE or VLDPE made with a thermal fusion method (hot air or hot wedge) to extrude a fillet weld over the outer seam edge. When this is done the seams on the cap strip or extrusion fillet weld may be sampled and tested as just described.

Note that neither elongation of the specimen nor peel separation, during the test is usually monitored (although current testing trends are in this direction), the only value under consideration is the maximum tensile force that the seam can sustain. It should also be mentioned that both frontward and backward peel tests can be performed thereby challenging both sides of a seam. For
dual channel seams, both insides of the tracks facing the air channel can be tested, but due to the narrow width of most air channels the tab available for gripping will be considerably less than that given in Table 3.4. Regarding the testing of the inside or outside tracks (away from the air channel) of a dual channel seam, or even both tracks, the specification or CQA document should be very specific.

3.5.5 General Specification Items

Regarding field sampling of geomembrane seams and their subsequent destructive testing, a specification or CQA document should consider the following items.

1. CQA personnel should observe all production seam sample cutting.
2. All samples should be adequately numbered and marked with permanent identification.
3. All sample locations should be indicated on the geomembrane layout (and record) drawings.
4. The reason for taking the sample should be indicated, e.g., statistical routine, suspicious feature, change in sheet temperature, etc.
5. The sample dimensions should be given insofar as the length of sample and its width. The seam will generally be located along the center of the length of the sample.
6. The distribution of various portions of the sample (if more than one) should be specified.
7. The number of shear and peel tests to be conducted on each sample (field tests and laboratory tests) should be specified.
8. The specifics of conducting the shear and peel tests should be specified, e.g., use of actual sheet thickness, or of nominal sheet thickness. The following are suggested ASTM test methods for each geomembrane type:

<table>
<thead>
<tr>
<th>Geomembrane</th>
<th>Seam Shear Test</th>
<th>Seam Peel Test</th>
<th>Sheet Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>D-4437</td>
<td>D-4437</td>
<td>D-638</td>
</tr>
<tr>
<td>VLDPE</td>
<td>D-4437</td>
<td>D-4437</td>
<td>D-638</td>
</tr>
<tr>
<td>PVC</td>
<td>D-3083</td>
<td>D-413</td>
<td>D-882</td>
</tr>
<tr>
<td>CSPE-R</td>
<td>D-751</td>
<td>D-413</td>
<td>D-751</td>
</tr>
<tr>
<td>EIA-R</td>
<td>D-751</td>
<td>D-751</td>
<td>D-751</td>
</tr>
</tbody>
</table>

9. The CQA personnel should witness all field tests and see that proper identification and details accompany the test results. Details should be provided in the CQA documents. Such details as follows are often required.
• date and time
• ambient temperature
• identification of seaming unit, group or machine
• name of master seamer
• welding apparatus temperature and pressure, or chemical type and mixture
• pass or fail description
• a copy of the report should be attached to the remaining portion of the sample

10. The CQA personnel should verify that samples sent to the testing laboratory are properly marked, packaged and shipped so as not to cause damage.

11. Results of the laboratory tests should come to the CQA Engineer in a stipulated time. For extrusion and thermally bonded seams, verbal test results are sometimes required with 24 to 72 hours after the laboratory receives the samples. For chemically bonded seams, the time frame is longer and depends on whether or not accelerated heat curing of the seams is required. In all cases, the CQA Engineer must inform the Owner's representative of the results and make appropriate recommendations.

12. The procedures for seam remediation in the event of failed destructive tests should be clear and unequivocal. Options usually are (a) to repair the entire seam between acceptable sampling locations, or (b) to retest the seam on both sides in the vicinity of the failed sample. If they are acceptable only this section of the seam is repaired. If they are not, a wider spaced set of samples are taken and tested.

13. Repairs to locations where destructive samples were removed should be stipulated. These repairs are specific to the type of geomembrane and to the seaming method. Guidance in this regard is available in EPA (1991).

14. Each repair of a patched seam where a test sample had been removed should be verified. This is usually done by an appropriate nondestructive test. If, however, the sampling strategy selected calls for a destructive test to be made at the exact location of a patch it should be accommodated. Thus the final situation will require a patch to be placed on an earlier patch. If this (unsightly) detail is to be avoided, it should be stated outright in the specifications or CQA document.

15. The time required to retain and store destructive test samples on the part of the CQC and CQA organizations should be stipulated.

3.6 Nondestructive Test Methods for Seams

3.6.1 Overview

Although it is obviously important to conduct destructive tests on the fabricated seams, such tests do not give adequate information on the continuity and completeness of the entire seam between sampling locations. It does little good if one section of a seam meets the specification requirements, only to have the section next to it missed completely by the field-seaming crew.
Thus continuous methods of a nondestructive testing (NDT) nature will be discussed here. In each of these methods the goal is to validate 100% of the seams or, at minimum, a major percentage of them.

3.6.2 Currently Available Methods

The currently available NDT methods for evaluating the adequacy of geomembrane field seams are listed in Table 3.5 in the order that they will be discussed.

The **air lance** method uses a jet of air at approximately 350 kPa (50 lb/in.\(^2\)) pressure coming through an orifice of 5 mm (3/16 in.) diameter. It is directed beneath the upper edge of the overlapped seam and is held within 100 mm (4.0 in.) from the edge of the seamed area in order to detect unbonded areas. When such an area is located, the air passes through the opening in the seam causing an inflation and fluttering in the localized area. A distinct change in sound emitted can generally be heard. The method works best on relatively thin, less than 1.1 mm (45 mils), flexible geomembranes, but works only if the defect is open at the front edge of the seam, where the air jet is directed. It is essentially a geomembrane installer’s method to be used in a construction quality control (CQC) manner.

The **mechanical point stress or “pick” test** uses a dull tool, such as a blunt screw-driver, under the top edge of a seam. With care, an individual can detect an unbonded area, which would be easier to separate than a properly bonded area. It is a rapid test that obviously depends completely on the care and sensitivity of the person doing it. Detectability is similar to that of using the air lance, but both are very operator-dependent. This test is to be performed only by the geomembrane installer as a CQC method. Design or inspection engineers should not use the pick test but rather one or more of the techniques to be discussed later.

The **pressurized dual seam** method was mentioned earlier in connection with the dual hot wedge or dual hot air thermal seaming methods. The air channel that results between the dual bonded tracks is inflated using a hypodermic needle and pressurized to approximately 200 kPa (30 lb/in.\(^2\)). There is no limit as to the length of the seam that is tested. If the pressure drop is within an allowable amount in the designated time period (usually 5 minutes), the seam is acceptable; if an unacceptable drop occurs, a number of actions can be taken:

- The distance can be systematically halved until the leak is located.
- The section can be tested by some other leak detection method.
- An extrusion fillet weld can be placed over the entire edge.
- A cap strip can be seamed over the entire edge.

Details of the test can be found in GRI Test Method GM6. The test is an excellent one for long, straight-seam lengths. It is generally performed by the installation contractor, but usually with CQA personnel viewing the procedure and documenting the results.
Table 3.5 - Nondestructive Geomembrane Seam Testing Methods, Modified from Richardson and Koerner (1988)

<table>
<thead>
<tr>
<th>Nondestructive Test Method</th>
<th>Primary User</th>
<th>CQC</th>
<th>CQA</th>
<th>Cost of Equipment</th>
<th>Speed of Tests</th>
<th>Cost of Tests</th>
<th>Type of Result</th>
<th>Recording Method</th>
<th>Operator Dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. air lance</td>
<td>yes</td>
<td>---</td>
<td>200</td>
<td>fast</td>
<td>low</td>
<td>yes-no</td>
<td>manual</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>2. mechanical point (pick) stress</td>
<td>yes</td>
<td>---</td>
<td>nil</td>
<td>fast</td>
<td>nil</td>
<td>yes-no</td>
<td>manual</td>
<td>very high</td>
<td></td>
</tr>
<tr>
<td>3. dual seam (positive pressure)</td>
<td>yes</td>
<td>---</td>
<td>200</td>
<td>fast</td>
<td>moderate</td>
<td>yes-no</td>
<td>manual</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>4. vacuum chamber (negative pressure)</td>
<td>yes</td>
<td>yes</td>
<td>1000</td>
<td>slow</td>
<td>very high</td>
<td>yes-no</td>
<td>manual</td>
<td>moderate</td>
<td></td>
</tr>
<tr>
<td>5. electric wire</td>
<td>yes</td>
<td>yes</td>
<td>500</td>
<td>fast</td>
<td>nil</td>
<td>yes-no</td>
<td>manual</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>6. electric field</td>
<td>yes</td>
<td>yes</td>
<td>20,000</td>
<td>slow</td>
<td>high</td>
<td>yes-no</td>
<td>manual and automatic</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>7. ultrasonic pulse echo</td>
<td>---</td>
<td>yes</td>
<td>5000</td>
<td>moderate</td>
<td>high</td>
<td>yes-no</td>
<td>automatic</td>
<td>moderate</td>
<td></td>
</tr>
<tr>
<td>8. ultrasonic impedance</td>
<td>---</td>
<td>yes</td>
<td>7000</td>
<td>moderate</td>
<td>high</td>
<td>qualitative</td>
<td>automatic</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>9. ultrasonic shadow</td>
<td>---</td>
<td>yes</td>
<td>5000</td>
<td>moderate</td>
<td>high</td>
<td>qualitative</td>
<td>automatic</td>
<td>moderate</td>
<td></td>
</tr>
</tbody>
</table>
The vacuum chamber (box) method uses a box up to 1.0 m (3 ft) long with a transparent top that is placed over the seam; a vacuum of approximately 20 kPa (3 lb/in.²) is applied. When a leak is encountered the soapy solution originally placed over the seam shows bubbles thereby reducing the vacuum. This is due to air entering from beneath the geomembrane and passing through the unbonded zone. The test is slow to perform (a 10 sec dwell time is currently recommended) and is often difficult to make a vacuum-tight joint at the bottom of the box where it passes over the seam edges. Due to upward deformations of the liner into the vacuum box, only geomembrane thickness greater than 1.0 mm (40 mils) should be tested in this manner. For thinner, more flexible geomembranes an open grid wire mesh can be used along the bottom of the box to prevent uplift. It should also be noted that vacuum boxes are the most common form of nondestructive test currently used by design engineers and CQA inspectors for polyethylene geomembranes. It should be recognized that 100% of the field seams cannot be inspected by this method. The test cannot cover portions of sumps, anchor trenches, and pipe penetrations with any degree of assurance. The method is also very awkward to use on side slopes. The adequate downward pressure required to make a good seal is difficult to mobilize since it is usually done by standing on top of the box.

Electric sparking (not mentioned in Table 3.5) is a technique used to detect pinholes in thermoplastic liners. The method uses a high-voltage (15 to 30 kV) current, and any leakage to ground (through an opening or hole) results in sparking. The method is being investigated for possible field use. The electric wire method places a copper or stainless steel wire between the overlapped geomembrane region and actually embeds it into the completed seam. After seaming, a charged probe of about 20,000 volts is connected to one end of the wire and slowly moved over the length of the seam. A seam defect between the probe and the embedded wire results in an audible alarm from the unit.

The electric field test utilizes a potential which is applied across the geomembrane by placing a positive electrode in water within the geomembrane and a ground electrode in the subgrade or in the sump of the leak detection system. A current will only flow between the electrodes through a hole (leak) in the geomembrane. The potential gradients in the ponded water are measured by “walking” the area with a previously calibrated probe. The operator walks along a calibration grid layout and identifies where anomalies exist. Holes less than 1 mm diameter can be identified. These locations can be rechecked after the survey is completed by other methods, such as the vacuum box. In deep water, or for hazardous liquids, a remote probe can be dragged from one side of the impoundment to the other across the surface of the geomembrane. On side slopes that are not covered by water, a positively charged stream of water can be directed onto the surface of the geomembrane. When the water stream encounters and penetrates a hole, contact with the subgrade is made. At this point current flow is indicated, thus locating the hole. Pipe penetrations through the geomembrane and soil cover that goes up the side slope and contacts the subgrade reduce the sensitivity of the method.

The last group of nondestructive test methods noted in Table 3.5 can collectively be called ultrasonic methods. A number of ultrasonic methods are available for seam testing and evaluation. The ultrasonic pulse echo technique is basically a thickness measurement technique and is only for use with nonreinforced geomembranes. Here a high-frequency pulse is sent into the upper geomembrane and (in the case of good acoustic coupling and good contact between the upper and lower sheets) reflects off of the bottom of the lower one. If, however, an unbonded area is present, the reflection will occur at the unbonded interface. The use of two transducers, a pulse generator, and a CRT monitor are required. It cannot be used for extrusion fillet seams, because of their nonuniform thickness. The ultrasonic impedance plane method works on the principle of acoustic impedance. A continuous wave of 160 to 185 kHz is sent through the seamed geomembrane, and a characteristic dot pattern is displayed on a CRT screen. Calibration of the dot
A pattern is required to signify a good seam; otherwise, it is not. The method has potential for all types of geomembranes but still needs additional developmental work. The ultrasonic shadow method uses two roller transducers: one sends a signal into the upper geomembrane and the other receives the signal from the lower geomembrane on the other side of the seam (Richardson and Koerner, 1988). The technique can be used for all types of seams, even those in difficult locations, such as around manholes, sumps, appurtenances, etc. It is best suited for semicrystalline geomembranes, including HDPE, and will not work for scrim-reinforced liners.

3.6.3 Recommendations for Various Seam Types

The various NDT methods listed in Table 3.5 have certain uniqueness and applicability to specific seam and geomembrane types. Thus a specification should only be framed around the particular seam type and geomembrane type for which it has been developed. Table 3.6 gives guidance in this regard. Even within Table 3.6, there are certain historical developments. For example, the air lance method is used routinely on the flexible geomembranes seamed by chemical methods, whereas the vacuum chamber method is used routinely on the relatively stiff HDPE geomembranes. Also to be noted is that the dual seam can technically be used on all geomembranes, but only when they are seamed by a dual track thermal fusion method, i.e., by hot wedge or hot air seaming methods. Thus by requiring such a dual seam pressure test method one mandates the type of seam which is to be used by the installation contractor.

Lastly, it should be mentioned that only three of the nine methods listed in Table 3.5 are used routinely at this point in time. They are the air lance, dual seam and vacuum chamber methods. The others are either uniquely used by the installation contractor (pick test and electric wire), or are in the research and development stage (electric current and the various ultrasonic test methods).

3.6.4 General Specification Items

Regarding field evaluation of geomembrane seams and their nondestructive testing, a specification or CQA document should consider the following items:

1. The purpose of nondestructive testing should be clearly stated. For example, nondestructive testing is meant to verify the continuity of field seams and not to quantify seam strength.

2. Generally nondestructive testing is conducted as the seaming work progresses or as soon as a suitable length of seam is available.

3. Generally nondestructive testing of some type is required for 100% of the field seams. For geomembranes supplied in factory fabricated panels, the factory seams may, or may not, be specified to be nondestructively tested in the field. This decision depends on the degree of MQC (and MQA) required on factory fabricated seams.

4. The specification should recognize that the same type of nondestructive test cannot be used in every location. For example, in sumps and at pipe penetrations the dual air channel and vacuum box methods may not be usable.

5. It must be recognized that there are no current ASTM Standards on any of the NDT methods presented in Table 3.5 although many are in progress. Thus referencing to such consensus documents is not possible. For temporary guidance, there is a GRI Standard available for dual seam air pressure test method, GRI GM-6.
6. CQA personnel should observe all nondestructive testing procedures.

7. The location, data, test number, name of test person and outcome of tests must be recorded.

8. The Owner's representative should be informed of any deficiencies.

9. The method of repair of deficiencies found by nondestructive testing should be clearly outlined in the specifications or CQA documents, as should the retesting procedure.

Table 3.6 Applicability Of Various Nondestructive Test Methods To Different Seam Types And Geomembrane Types

<table>
<thead>
<tr>
<th>NDT Method</th>
<th>Seam Types*</th>
<th>Geomembrane Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. air lance</td>
<td>C, BC, Chem A, Cont. A</td>
<td>all except HDPE</td>
</tr>
<tr>
<td>2. mechanical point stress</td>
<td>all</td>
<td>all</td>
</tr>
<tr>
<td>3. dual seam</td>
<td>HW, HA</td>
<td>all</td>
</tr>
<tr>
<td>4. vacuum chamber</td>
<td>all</td>
<td>all</td>
</tr>
<tr>
<td>5. electric wire</td>
<td>all</td>
<td>all</td>
</tr>
<tr>
<td>6. electric current</td>
<td>all</td>
<td>all</td>
</tr>
<tr>
<td>7. ultrasonic pulse echo</td>
<td>HW, HA</td>
<td>HDPE, VLDPE, PVC</td>
</tr>
<tr>
<td></td>
<td>C, BC, Chem. A, Cont. A</td>
<td></td>
</tr>
<tr>
<td>8. ultrasonic impedance</td>
<td>HW, HA</td>
<td>HDPE, VLDPE, PVC</td>
</tr>
<tr>
<td></td>
<td>C, BC, Chem. A, Cont. A</td>
<td></td>
</tr>
<tr>
<td>9. ultrasonic shadow</td>
<td>E Fil., E Flt., HW, HA</td>
<td>HDPE, VLDPE</td>
</tr>
</tbody>
</table>

* E Fil. = extrusion fillet
E Flt. = extrusion flat
HW = hot wedge
HA = hot air
C = chemical
BC = bodied chemical
Chem. A = chemical adhesive
Cont. A = contact adhesive
3.7 Protection and Backfilling

The field deployed and seamed geomembrane must be backfilled with soil or covered with a subsequent layer of geosynthetics in a timely manner after its acceptance by the CQA personnel. If the covering layer is soil, it will generally be a drainage material like sand or gravel depending upon the required permeability of the overlying layer. Depending upon the particle size, hardness and angularity of this soil, a geotextile or other type of protection layer may be necessary. If the covering layer is a geosynthetic, it will generally be a geonet or geocomposite drain, which is usually placed directly upon the geomembrane. This is obviously a critical step since geomembranes are relatively thin materials with puncture and tear strengths of finite proportions. Specifications should be very clear and unequivocal regarding this final step in the installation survivability of geomembranes.

3.7.1 Soil Backfilling of Geomembranes

There are at least three important considerations concerning soil backfilling of geomembranes: type of soil backfill material, type of placement equipment and considerations of slack in the geomembrane.

Concerning the type of soil backfilling material; its particle size characteristics, hardness and angularity are important with regard to the puncture and tear resistance of the geomembrane. In general, the maximum soil particle size is very important, with additional concerns over poorly graded soils, increased angularity and increased hardness being of significance. Past research on puncture resistance of geomembranes has shown that HDPE and CSPE-R geomembranes are more sensitive to puncture than are VLDPE and PVC geomembranes for conventional thicknesses of the respective types of geomembranes. Using truncated cones in laboratory tests to simulate the puncturing phenomenon (Hullings and Koerner, 1991), the critical cone height values which were obtained are listed in Table 3.7. It should be cautioned, however, that these values are not based on actual soil subgrades, nor on geostatic type stresses. The values are meant to give relative performance between the different geomembrane types.

Table 3.7. Critical Cone Heights For Selected Geomembranes In Simulated Laboratory Puncture Studies (Richardson and Koerner, 1988)

<table>
<thead>
<tr>
<th>Geomembrane Type</th>
<th>Geomembrane Thickness mm</th>
<th>Critical Cone Height mm</th>
<th>Geomembrane Thickness mil</th>
<th>Critical Cone Height inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>1.5</td>
<td>12</td>
<td>60</td>
<td>0.50</td>
</tr>
<tr>
<td>VLDPE</td>
<td>1.0</td>
<td>89</td>
<td>40</td>
<td>3.50</td>
</tr>
<tr>
<td>PVC</td>
<td>0.5</td>
<td>70</td>
<td>20</td>
<td>2.75</td>
</tr>
<tr>
<td>CSPE-R</td>
<td>0.9</td>
<td>15</td>
<td>36</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Although the truncated cone hydrostatic test is an extremely challenging index-type test, the data of Table 3.7 does not reflect creep and/or stress relaxation of the geomembrane. In reviewing numerous CQA documents it appears that the maximum backfill particle size for use with HDPE and CSPE-R geomembranes should not exceed 12-25 mm (0.5-1.0 in.). VLDPE and PVC geomembranes appear to be able to accommodate larger soil backfill particle sizes. If the soil
particle size must exceed the approximate limits given (e.g., for reasons of providing high permeability in a drainage layer), then a protection material must be placed on top of the geomembrane and beneath the soil. Geotextiles, as well as other protection materials, have been used in this regard. New materials, e.g., recycled fiber geotextiles and rubber matting, are being evaluated.

Concerning the type of placement equipment, the initial lift height of the backfill soil is very important. (Note that construction equipment should never be allowed to move directly on any deployed geomembrane. This includes rubber tired vehicles such as automobiles and pickup trucks but does not include light weight equipment like all-terrain vehicles (ATV’s). The minimum initial lift height should be determined for the type of placement equipment and soil under consideration, however, 150 mm (6 in.) is usually considered to be a minimum. Between this value and approximately 300 mm (12.0 in.), low ground pressure placement equipment should be specified. Ground contact pressure equipment of less than 35 kPa (5.0 lb/in²) is recommended. For lift heights of greater than 300 mm (12.0 in.), proportionately heavier placement equipment can be used.

Placement of soil backfilling should proceed from a stable working area adjacent to the deployed geomembrane and gradually progress outward. Soil is never to be dropped from dump trucks or front end loaders directly onto the geomembrane. The soil should be pushed forward in an upward tumbling action so as not to impact directly on the geomembrane. It should be placed by a bulldozer or front end loader, never by a motor grader which would necessarily have its front wheels riding directly on the geomembrane. Sometimes “fingers” of backfill are pushed out over the geomembrane with controlled amounts of slack between them. Figure 3.26 shows a sketch and photograph of this type of soil covering placement. Backfill is then widened so as to connect the “fingers”, with the controlled slack being induced into the geomembrane. This procedure is at the discretion of the design engineer and depends on site specific materials and conditions.

If a predetermined amount of slack is to be placed in the geomembrane, the temperature of the geomembrane itself during backfilling is important and should be contrasted against the minimum service temperature that the geomembrane will eventually experience. This difference in temperature, assuming the geomembrane temperature at the time of backfilling is higher than the minimum service temperature, is multiplied by the distance between backfilling “fingers” and by the coefficient of thermal expansion/contraction of the particular geomembrane. Coefficients of thermal expansion/contraction found in the literature are given in Table 3.8. Note, however, that the coefficient of expansion/contraction of the site specific geomembrane should be available for such calculations.

While many geomembrane polymers fall in the same general range of coefficient of thermal expansion/contraction (as seen in Table 3.8), it is the stiff and relatively thick geomembranes, which are troublesome during backfilling. Here the slack accumulates in a wave which should not be allowed to crest over on itself, lest a fold is trapped beneath the backfill. In such cases, the “fingers” of backfilling must be relatively close together. If the situation becomes unwieldy due to very high geomembrane temperature, the backfilling should temporarily cease until the ambient temperature decreases. This will have the effect of requiring less slack to be placed in the geomembrane.
Figure 3.26 - Advancing Primary Leachate Collection Gravel in “Fingers” Over the Deployed Geomembrane
Table 3.8 - Coefficients Of Thermal Expansion/Contraction Of Various Nonreinforced Geomembrane Polymers (Various References)*

<table>
<thead>
<tr>
<th>Polymer Type</th>
<th>Thermal linear expansivity x $10^{-5}$ per 1°F</th>
<th>per 1°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>high density</td>
<td>7-12</td>
<td>12-22</td>
</tr>
<tr>
<td>medium density</td>
<td>6-8</td>
<td>11-15</td>
</tr>
<tr>
<td>low density</td>
<td>5-7</td>
<td>9-13</td>
</tr>
<tr>
<td>very low density</td>
<td>11-16</td>
<td>20-30</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>3-5</td>
<td>5-9</td>
</tr>
<tr>
<td>Polyvinyl chloride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unplasticized</td>
<td>3-10</td>
<td>5-18</td>
</tr>
<tr>
<td>plasticized</td>
<td>4-14</td>
<td>7-25</td>
</tr>
</tbody>
</table>

*Values are approximate and change somewhat with the particular formulation and with the actual temperature range over which the values are measured.

3.7.2 Geosynthetic Covering of Geomembranes

Various geosynthetic materials may be called upon to cover the deployed and seamed geomembrane. Often a geotextile or a geonet will be the covering material. Sometimes, however, it will be a geogrid (for cover soil reinforcement on slopes) or even a drainage geocomposite (again on slopes to avoid instability of natural drainage soils). As with the previous discussion on soil covering, no construction vehicles of any type should be allowed to move directly on the geomembrane (or any other geosynthetic for that matter). Generators, low tire inflation ATV's, and other seaming related equipment are allowed as long as they do not damage the geomembrane. As a result, the movement of large rolls of geotextile or geonet becomes very labor intensive. Proper planning and sequencing of the operations is important for logistical control. The geosynthetic materials are laid directly on the geomembrane with no bonding of any type to the geomembrane being allowed. For example, thermally fusing of a geonet to a geomembrane should not be permitted. Temperature compensation (as described earlier) should be added based on material characteristics.

The geosynthetics placed above the geomembrane will either be overlapped (as with some geotextiles), sewn (as with other geotextiles), connected with plastic ties (as with geonets), mechanically joined with rods or bars (as with geogrids), or male/female joined (as with drainage composites). These details will be described in Chapter 6 on geosynthetic materials other than geomembranes.
3.7.3 General Specification Items

The specification or CQA document for backfilling should be written around the concept that the geomembrane must be protected against damage by the overlying material. Since soil, usually sand or gravel, is the most common backfilling material, the items that follow should be considered.

1. The temperature during soil backfilling should be considered. Expansion, contraction, puncture, tear and other properties vary in accordance with the geomembrane temperature.

2. In general, backfilling in warm climates or during summer months should be performed at the coolest part of the day.

3. In extreme cases of excessively high temperatures, backfilling may be required during non-typical work hours, e.g., sunrise to 10:00 AM or 5:00 PM to sunset.

4. If soil backfilling is to be done between sunset and sunrise, i.e., at night, the work area should be suitably lit for safety, constructability and inspection considerations.

5. If soil backfilling is to be done at night, excessive equipment noise may not be tolerated by people in the local neighborhood. This is an important and obviously site specific condition which should be properly addressed.

6. When a geotextile or other protection layer is to be placed above the geomembrane it should be done so according to the plans and specifications.

7. Soil placement equipment should never move, or drive, directly on the geomembrane.

8. Personnel or materials vehicles (automobiles, pickup trucks, etc.) should never drive directly on the geomembrane.

9. The soil particle size characteristics should be stipulated as part of the design requirements.

10. The minimum soil lift thickness should be stipulated in the design requirements. Furthermore, the thickness should be clear as to whether it is loose or compacted thickness.

11. The maximum ground contact pressure of the placement equipment should be stipulated in the design requirements.

12. For areas regularly traversed by heavy equipment, e.g., the access route for loaded dump trucks, a larger than usual fill height should be required.

13. The CQA personnel should be available at all times during backfilling of the geomembrane. It is the last time when anyone will see the completely installed material.

14. Documentation should include the soil type, lift thickness, total thickness, density and moisture conditions (as appropriate).
3.8 References

ASTM D-413, “Rubber Property-Adhesion to Flexible Substrate”
ASTM D-638, “Tensile Properties of Plastics”
ASTM D-751, “Test Methods for Coated Fabrics”
ASTM D-792, “Specific Gravity and Density of Plastics by Displacement”
ASTM D-882, “Test Methods for Tensile Properties of Thin Plastic Sheeting”
ASTM D-1004, “Initial Tear Resistance of Plastic Film and Sheeting”
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-1765, “Classification System for Carbon Black Used in Rubber Products”
ASTM D-2663, “Rubber Compounds - Dispersion of Carbon Black”
ASTM D-3015, “Recommended Practice for Microscopical Examination of Pigment Dispersion in Plastic Compounds”
ASTM D-4437, “Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes”
ASTM D-4545, “Practice for Determining the Integrity of Factory Seams Used in Joining Manufactured Flexible Sheet Geomembranes”
ASTM D-5199, “Measuring Nominal Thickness of Geotextiles and Geomembranes”
ASTM D-5321 “Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method”
ASTM D-5397, “Notched Constant Tensile Load Test for Polyolefin Geomembranes”

GRI GM-6, “Pressurized Air Channel Test for Dual Seamed Geomembranes”

GRI GM-7, “Accelerated Curing of Geomembrane Test Strips Made by Chemical Fusion Methods”

GRI GS-7, “Determining the Index Friction Properties of Geosynthetics”


