5.3 DRAINAGE

Good drainage is essential to the proper performance of an MSE wall. There are two types of drainage considerations for an MSE wall, internal and external. Internal drainage considerations are related to control of surface or subgrade water that may infiltrate the reinforced soil mass. The internal drainage of an MSE wall depends on the characteristics of the backfill used in the reinforced soil mass. External drainage considerations deal with water that may flow externally over and/or around the wall surface taxing the internal drainage and/or creating external erosion issues. The external drainage depends on the location of the MSE wall with respect to local hydrogeological factors and generally deals with diverting water flow away from the reinforced soil structure.

Regardless of the source of the water, i.e., internal or external, the cardinal rule in the design of MSE walls, as with any other wall type, is to allow unimpeded flow of water through the wall and/or collect and remove water before it enters the zone of influence of the wall to prevent the following:

- build-up of hydrostatic forces that increase lateral pressures,
- piping, i.e., erosion of one soil into another, which creates paths for additional water flow or clogging of drainage aggregate, and
- external soil erosion from the toe, around the edges or at the top of the wall.

It is recommended that adequate drainage features be required for all walls unless the engineer determines that such features are not needed for a specific project. During a determination of the need for drainage features, the engineer must include consideration for both subsurface (e.g., ground water, perched water, flooding and tidal action) and surface infiltration water (e.g., rain, runoff, and snow melt).

Effect of Fines on Drainage

Soil particles with sizes smaller than the U.S. No. 200 (0.075 mm) sieve are referred to as "fines." The permeability of an overall soil mass is affected significantly by the amount of fines. In general, soils with less than 3 to 5% non-plastic fines by weight are considered to be free draining and water can readily flow through the soil mass even under low hydraulic gradients. In the case of MSE walls, a reinforced soil mass with less than 3 to 5% non-plastic fines will allow unimpeded flow provided the permeability of the reinforced fill is greater than the permeability of the retained fill and the wall is not exposed to significant water events such as flooding, tidal action or significant snow melt.

When the amount of the fines is more than 3 to 5%, the permeability is significantly reduced and drainage requirements must be carefully evaluated as groundwater and/or infiltration of surface water can result in build-up of seepage/hydrostatic forces within the reinforced soil mass. Surface water that infiltrates into the reinforced soil mass will tend to move toward the permeable face of an MSE wall and can have a destabilizing effect due to a potential increase in seepage forces (Terzaghi et al., 1996; Cedergren, 1989). Such a condition can occur during severe rainstorms, if the permeability of the fill is equal to or less than about 0.002 cm/sec (Terzaghi et al., 1996; Cedergren, 1989). Therefore, good drainage features should be incorporated into the design if low permeability reinforced fill is used, i.e., if the reinforced fill has more than 3 to 5% non plastic fines. Special precaution is also advised for hillside construction due to the potential for seepage to occur through retained soil and rock seams, faults and joints during rain events that may not be apparent during subsurface exploration and construction.

Internal and external drainage details, which represent good drainage, are presented in the following Sections 5.3.1 and 5.3.2, respectively. Good design of drainage features requires proper consideration of the filtration properties of various geomaterials within and external to the MSE wall as well as drains that are adequately sized to effectively remove any seepage water. The drainage components including filtration criteria and drain component requirements are presented in Section 5.3.3.

5.3.1 Internal Drainage Systems

There are two specific forms of internal drainage as shown in Figure 5-4, (a) drainage near wall face due to infiltration of surface water near the wall face, and (b) drainage behind and under reinforced soil mass from groundwater. Groundwater may be present at an elevation above the bottom of the wall and would flow to the MSE walls from an excavation backcut; or it may be present beneath the bottom of the MSE wall. A groundwater surface beneath a MSE wall may rise into the reinforced soil mass, depending on the hydrogeology of the site. Surface water may infiltrate into the reinforced soil mass from above or from the front face of the wall, for the case of flowing water in front of the structure.

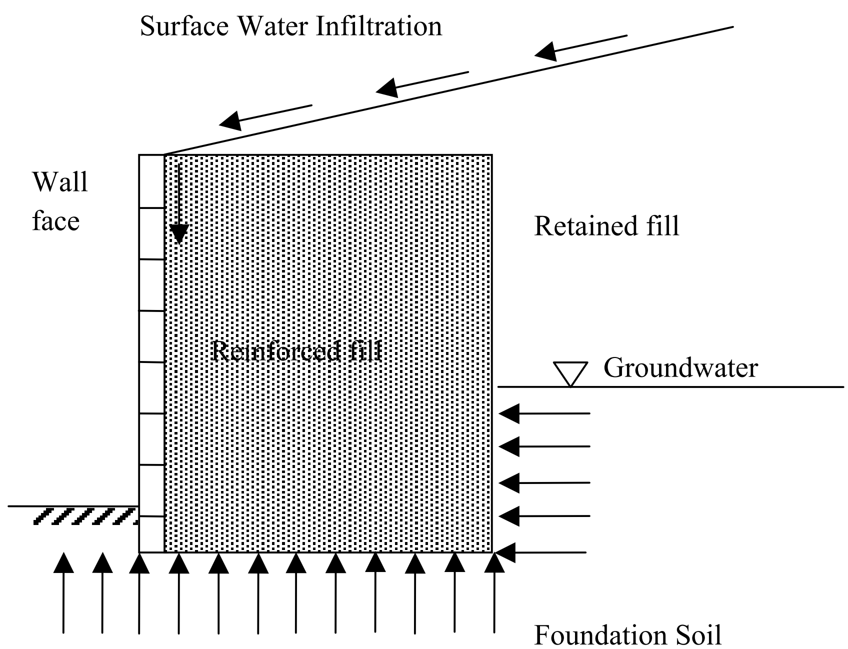


Figure 5-4. Potential sources and flowpaths of water.

Internal Drainage Near Wall Face

A filter is provided at all vertical and horizontal joints in the wall face to prevent the migration of fines from the reinforced soil mass through the joints. The location and configuration of the filter is a function of the type of wall facing units as follows:

- For segmental precast wall facing units, the filter is commonly in the form of geotextile fabric that is placed across all horizontal and vertical joints as shown in Figure 5-5. The geotextile should extend a minimum of 4 in. (100 mm) on either side of the joint and up into the coping to prevent soil from moving around the geotextile. The geotextile filter characteristics should be such that it is compatible with the backfill in the reinforced soil mass as discussed in Section 5.3.3.

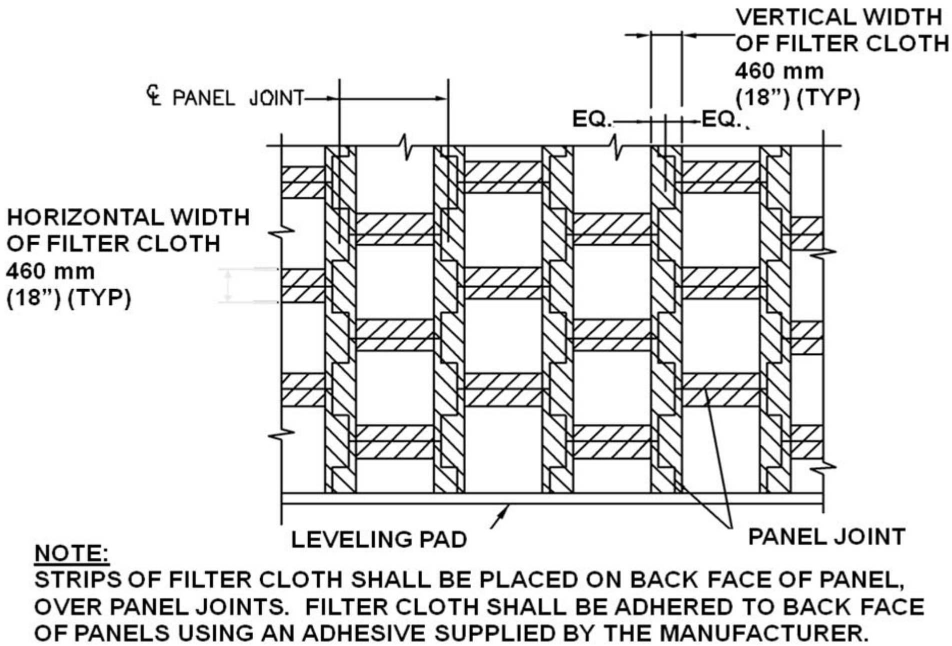
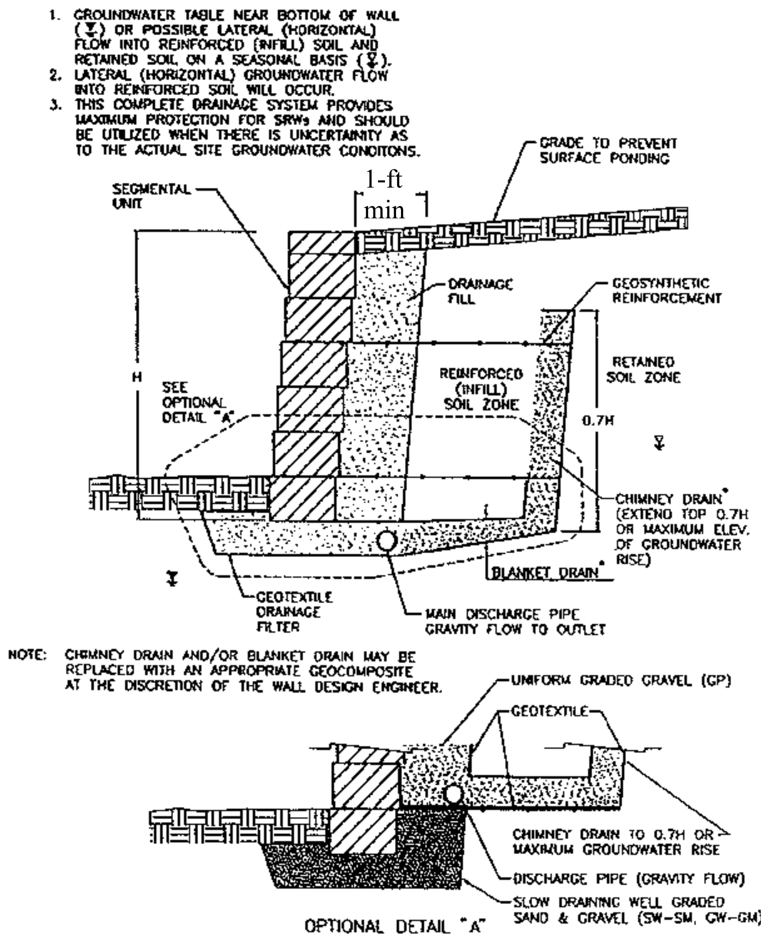


Figure 5-5. Example layout of filter at joints between segmental precast facing units.

- Modular block wall (MBW) facing units are typically constructed with a zone of free drainage aggregate adjacent to the back face of the units. The minimum width of this aggregate zone is typically 1 ft (300 mm). In addition to serving as a back face drain, this aggregate is required for stiffness of the wall face and constructability, i.e., placement and compaction of wall fill may be difficult based on the configuration of the MBW units. This column of aggregate is often a high permeability well graded gravel as discussed in Section 5.3.3. The gradation of the aggregate should be used to determine the maximum allowable vertical joint opening between MBW units, using slot criterion given by Equation 5-8 in Section 5.3.3. The configuration of the gravel filter is a function of whether the modular block unit is solid or with a hollow-core. For solid modular block units, the well graded gravel should be at least 1 ft (300 mm) wide as shown in Figure 5-6a. For hollow-core modular block units, the well graded gravel should be at least 1 ft (300 mm) wide with a minimum volume of 1 ft^3 per ft^2 (0.3 m^3/m^2) of wall face as illustrated in Figure 5-6b. The gradation of the gravel should be sized to be compatible with the reinforced wall fill gradation in the reinforced soil mass, i.e. meet soil filter criteria as discussed in Section 5.3.3. Alternatively, a geotextile may be used between the gravel and reinforced wall fill to meet filtration requirements, as illustrated in Figure 5-6b. Finally, the construction sequence should be specified to ensure a workable drain system.

(a)



(b)

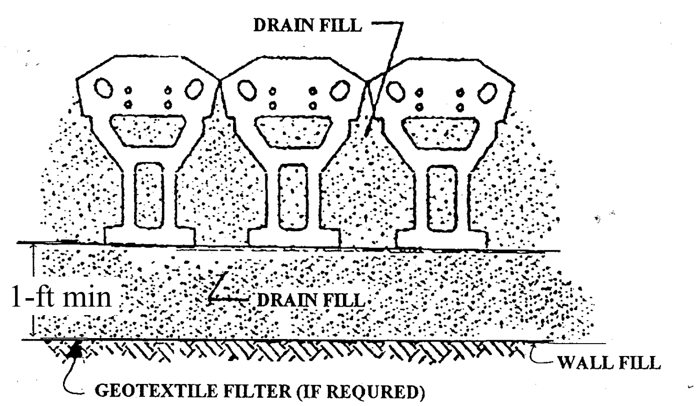


Figure 5-6. Layout of drainage fabric and drainage fill at the face for modular block units. (Collin et al., 2002).

- Figure 5-7 provides a common detail for face drainage in the case of wire-faced walls. In this case, the geotextile filter is placed between the facing stones and the reinforced soil mass.

<u>Internal Drainage Under and Behind the MSE Wall</u>

For walls in locations where groundwater can result in build-up of seepage/hydrostatic forces within the height of the reinforced soil mass and/or surface water infiltration is anticipated, a base drain that provides drainage beneath the MSE wall and a back or chimney drain that provides drainage behind the reinforced soil mass is strongly recommended to ensure proper long-term functionality of the MSE wall. This is because, as noted earlier, a reinforced fill with more than 3 to 5% non plastic fines is not "free draining."

The base drain and back drain should be designed to collect and remove groundwater before it enters the reinforced mass and allows infiltration water to preferentially flow downward and toward the back of the wall, away from the face. An example of such a drainage system is illustrated in Figure 5-8 for segmental precast facing unit structure. Figure 5-6a shows a common detail for modular block unit faced structures. Figures 5-9 and 5-10 show alternative drainage systems that include geocomposite drains and blanket drains in lieu of open graded gravel drains with a geotextile or well-graded soil filter. Information on the various drains to relieve hydrostatic pressures is provided below. Design of the base drain and backdrain and the drainage system components is covered in Section 5.3.3.

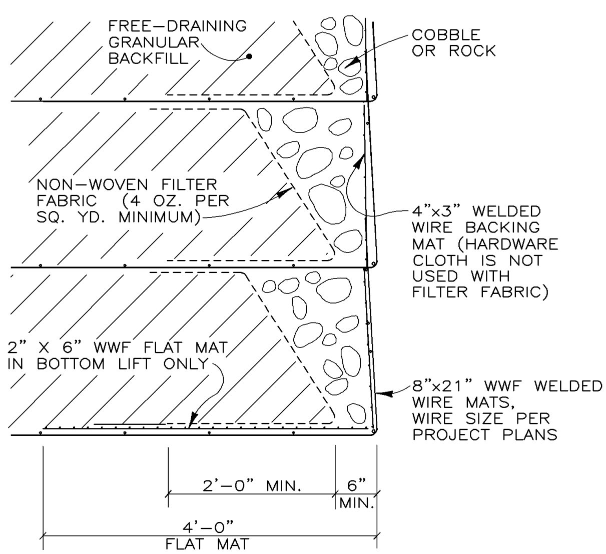


Figure 5-7. Example layout of geotextile filter near the face for welded wire facing units.

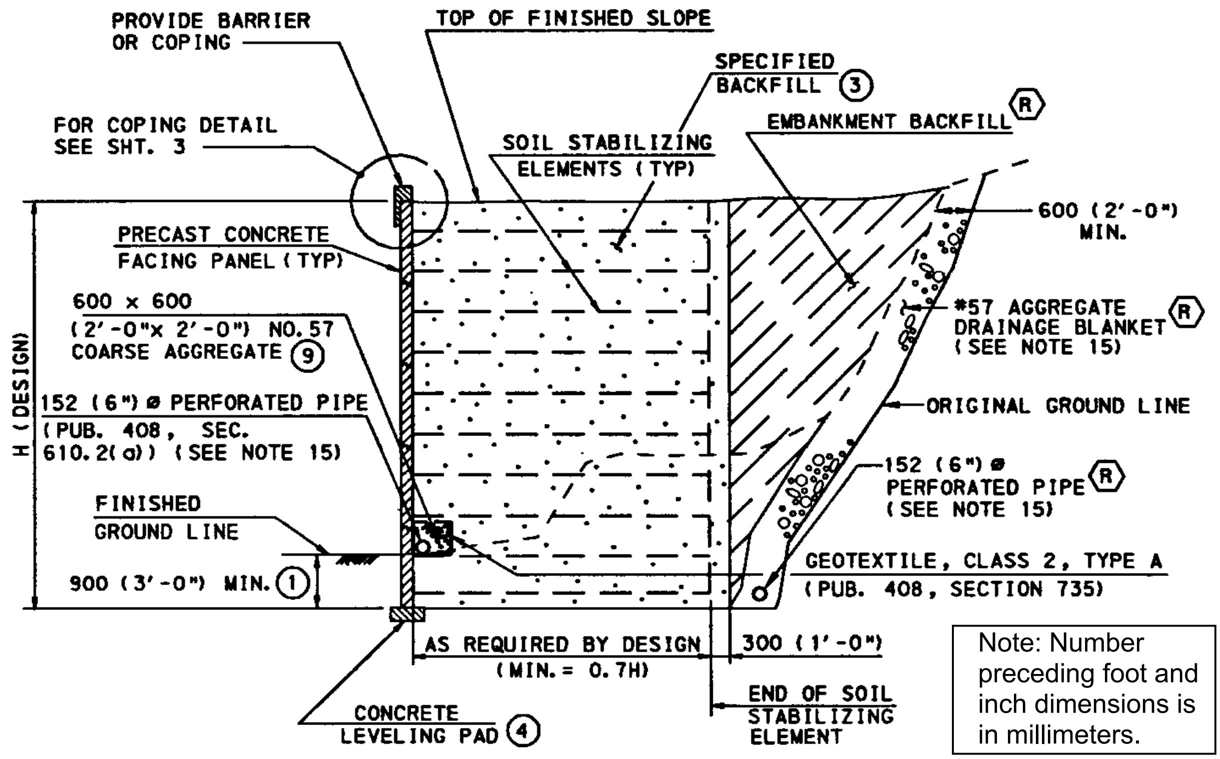


Figure 5-8. Example drainage blanket detail behind the retained backfill.

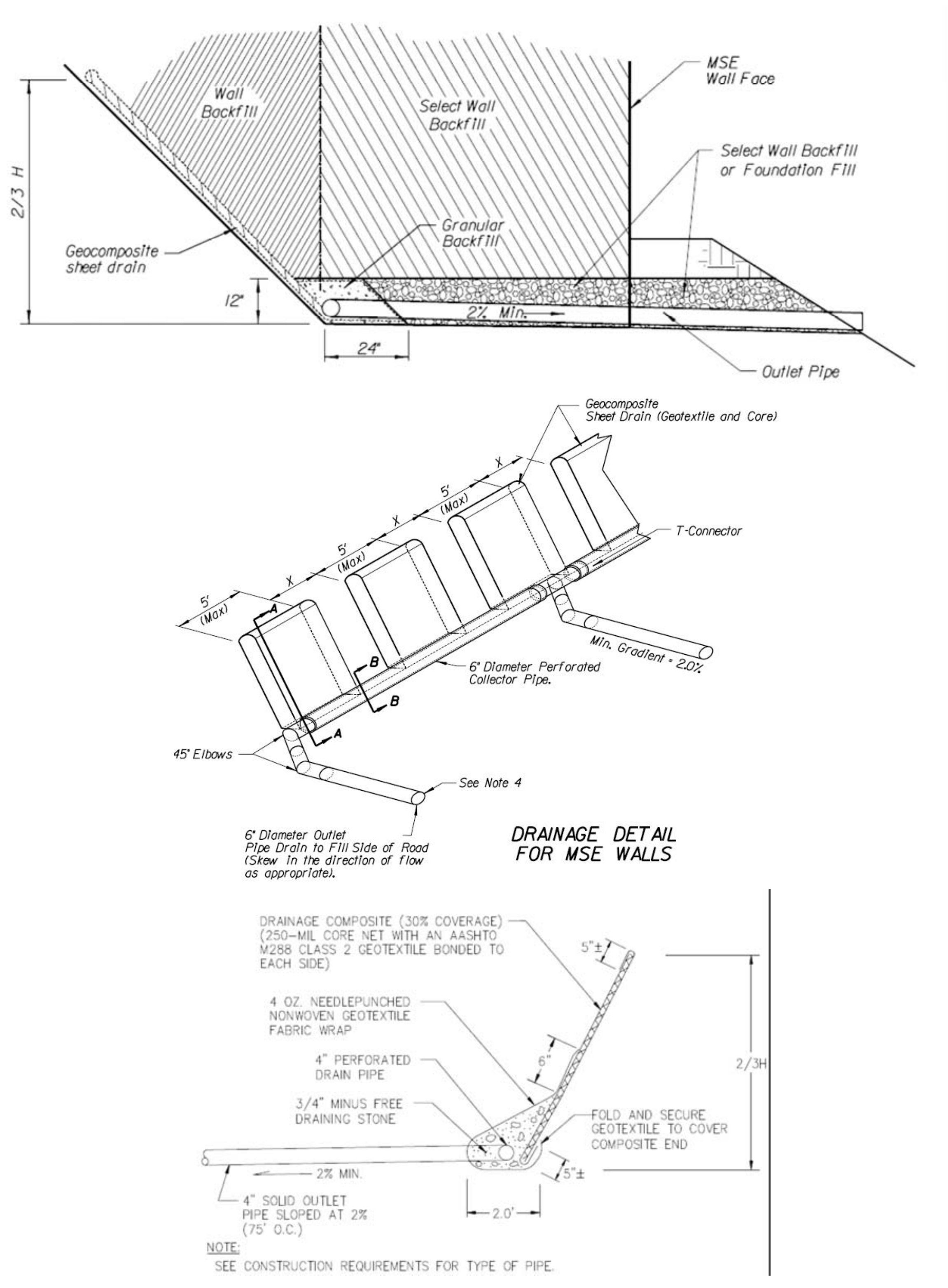


Figure 5-9. Example drainage detail using a geocomposite sheet drain.

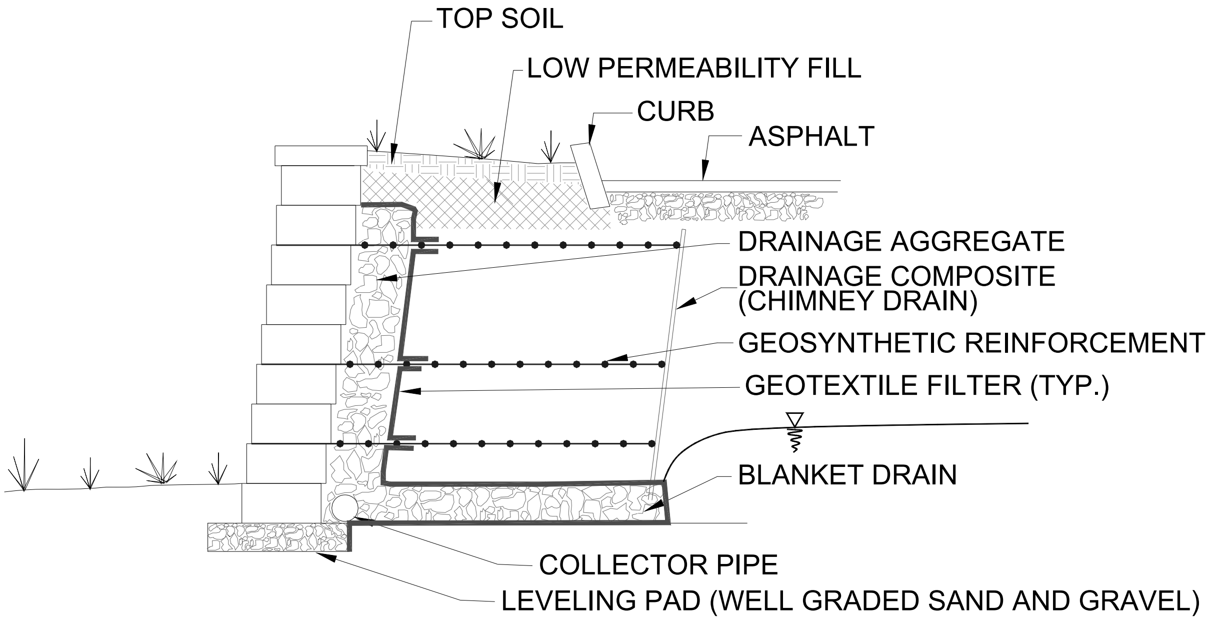


Figure 5-10. Example drainage detail using a blanket drain with chimney drain (Collin et al., 2002).

Walls with Possibility of Inundation

For walls potentially subject to inundation, such as those located adjacent to rivers, canals, detention basins or retention basins, a minimum hydrostatic pressure equal to 3 ft (1 m) should be applied at the high-water level for the design flood event. Effective unit weights should be used in the calculations for internal and external stability beginning at levels just below the equivalent surface of the pressure head line. Where the wall is influenced by water fluctuations, the wall should be designed for rapid drawdown conditions which could result in differential hydrostatic pressure greater than 3 ft (1 m). As an alternative to designing for rapid drawdown conditions, No. 57 coarse aggregate, as specified in AASHTO M 43, could be provided as reinforced backfill for the full reinforced zone of the wall and to the maximum height of submergence of the wall. A geotextile filter should be provided at the interface of the No. 57 coarse aggregate and reinforced backfill above it, at the interface of the retained backfill behind it, and at the interface of the coarse gravel and subgrade beneath it, unless the coarse aggregate meets the soil filtration criteria for the adjacent soils (see Section 5.3.3). The geotextile should meet the filtration and survivability criteria in Section 5.3.3. Adjoining sections of geotextile filter/separator shall be overlapped by a minimum of 1 ft (0.3 m). An example detail is shown in Figure 5-11.

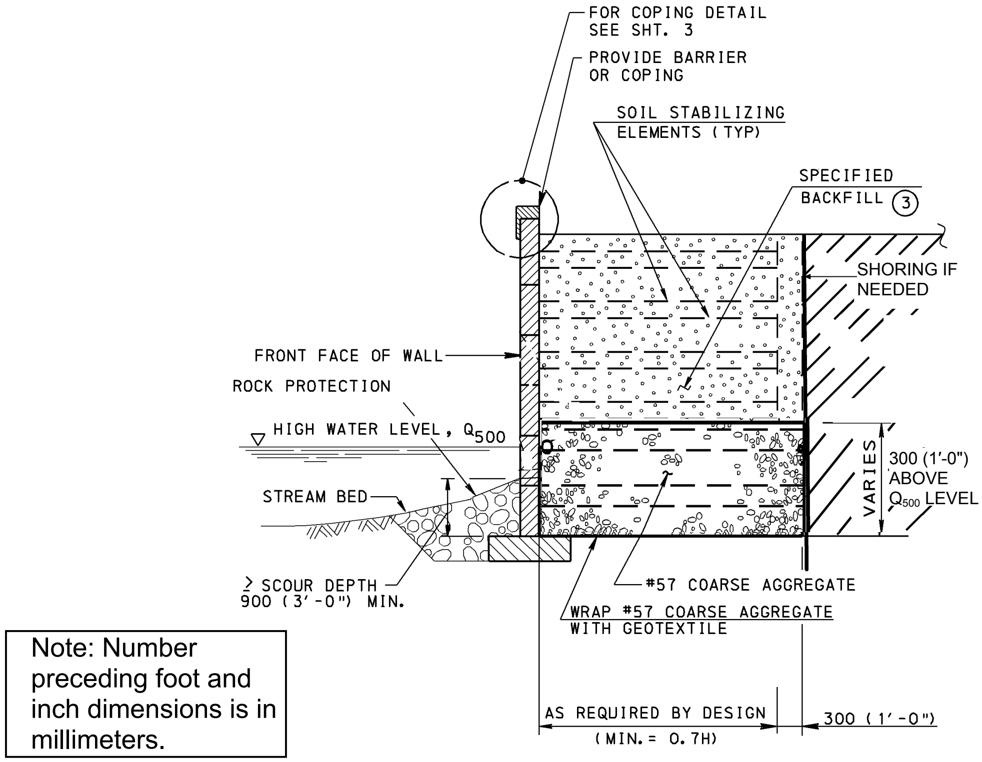


Figure 5-11. Example detail for wall that may experience inundation.

5.3.2 External Drainage

Surface drainage is an important aspect of ensuring MSE wall performance and must be addressed during design. Appropriate measures to prevent surface water from infiltrating into the wall backfill should be included in the design of all MSE walls. This typically requires coordination with designers of other project elements.

During construction of an MSE wall, the Contractor should grade the wall fill surface away from the wall face at the end of each day of construction to prevent water from ponding behind the wall and saturating the soil. In addition to softening the subgrade, surface water running onto a partially completed wall fill can carry fine-grained soils into the backfill work area and locally contaminate a free-draining granular backfill with fines. If finer grained backfill is being utilized for the reinforced wall fill, saturation can cause movements of the partially constructed wall.

When possible, finished grading at the top of a wall structure should provide positive drainage away from the wall to prevent or minimize infiltration of surface water into the reinforced wall fill. If the area above the wall is paved, a curb and gutter is typically used to direct the flow away from the wall. Drainage swales lined with concrete or asphalt can be used to collect and discharge surface water. Vegetation lined swales may be used where a vegetated finished grade slopes to the wall. Water runoff over the top of a wall where the backfill slopes towards it can lead to erosion behind the top of the wall and underming of the wall. Such runoff can also cause staining of the wall face as soil is carried with the water. Construction of a collection swale close to the wall will help to prevent runoff from going over the top of the wall. Runoff flow will concentrate at grading low points behind the face and cause ponding which leads to undesirable infiltration of water into the backfill and increased compressibility due to softening of the backfill.

Collection and conveyance swales should prevent overtopping of the wall for the design storm event. Extreme events such as heavy rainfalls of short duration have been known to cause substantial damage to earth retaining structures due to erosion and undermining, flooding, and/or increased hydrostatic pressures both during and after construction. This is particularly true for sites where surface drainage flows toward the wall structure and where finer-grained backfills are used.

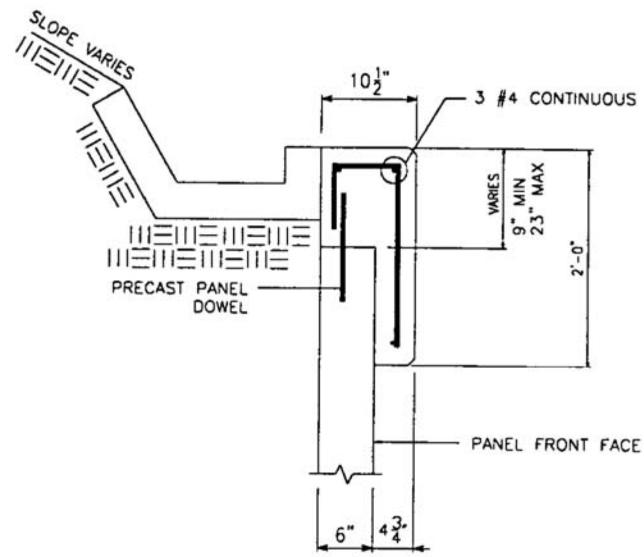
If the surface grading is such that there is likelihood of surface water flowing towards an MSE structure, then the water should be collected in a gutter or other collection feature that is part of the site drainage features. Such site drainage features are designed for an assumed or prescribed design storm event. For MSE walls, the design storm event should be based on a minimum 100 year event. However, extreme events can occur that result in short duration flows, e.g., 1 to 3 hours, which significantly exceed the design capacity of the stormwater management system. When such events occur, site flooding can cause overtopping of the wall, erosion and undermining, and an increase in hydrostatic forces within and behind the reinforced soil mass. Therefore, the site layout and wall structure should include features for handling flows greater than the design event as is typically done in the design of an overflow spillway for a dam. The project civil engineer should address potential excess flows and coordinate work with the wall designer. Consideration should be given to incorporating details of overflow features, such as a spillway, into the wall design for sites where surface water flows towards the wall structure. An example of an overflow feature is shown in Figure 5-12. Maintenance issues included in Section 5.3.4 should be addressed to ensure that all site drainage features are performing adequately.

Figure 5-12. Example MSE wall overflow sill at top of wall.

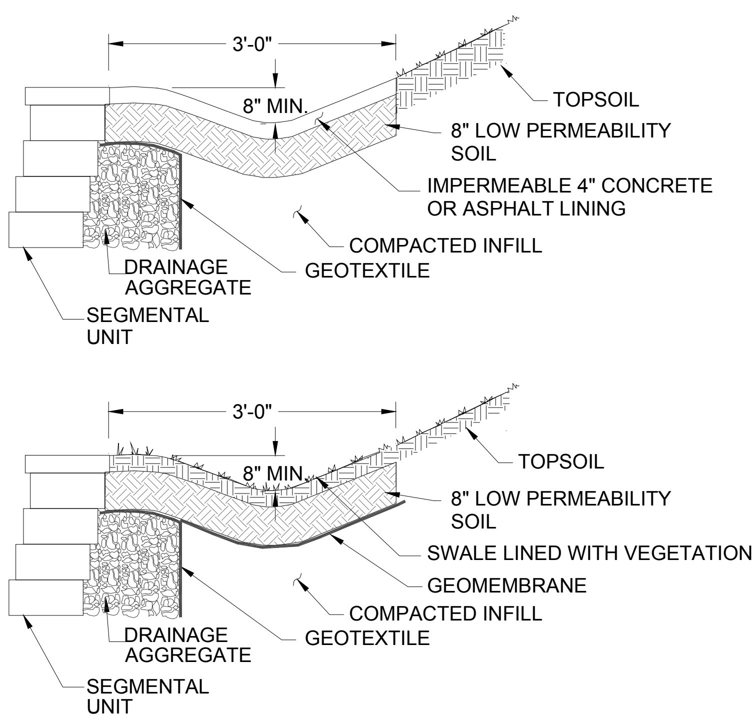
Drainage Swale at Top of Wall

A drainage swale is a man-made depression in the ground surface used to intercept surface water and direct it in a controlled manner to an outlet. Drainage swale can also be used to reduce the potential for surface water from overtopping the wall. Figure 5-13 shows typical drainage swale details for segmental precast concrete facing and modular block wall facing units. When a drainage swale is used, the project civil engineer and the wall designer should address and detail the outlet(s) for the swale. For example, the swale can be detailed to discharge water at the end of the wall structure or to low overflow points along the wall length. Overflow points should be detailed on the construction drawings. The designer should anticipate and address in design and detailing the possibility of water runoff from extreme events which will overtop the drainage swale and run down the wall face, unless the swales are specifically sized for such events. For sloping backfills, the wall designer should also address collection and diversion of water at the top of the slope. Site water runoff from above the backslope should not be directed toward the MSE wall backslope.

Vegetated swales as shown in Figure 5-13b can provide an aesthetically pleasing appearance. However, the effectiveness of the low permeability soil in preventing water from migrating into the reinforced soil mass and drainage aggregate should be evaluated. Shrinkage cracks in the low permeability soil during periods of extended dry weather may increase the permeability of the layer to the extent that it is no longer an effective barrier layer. Therefore, a geomembrane should be used beneath any vegetated swale.



(a)



(b)

Figure 5-13. Example drainage swale near top of wall. ((b) Collin et al., 2002).

Geomembrane Barriers

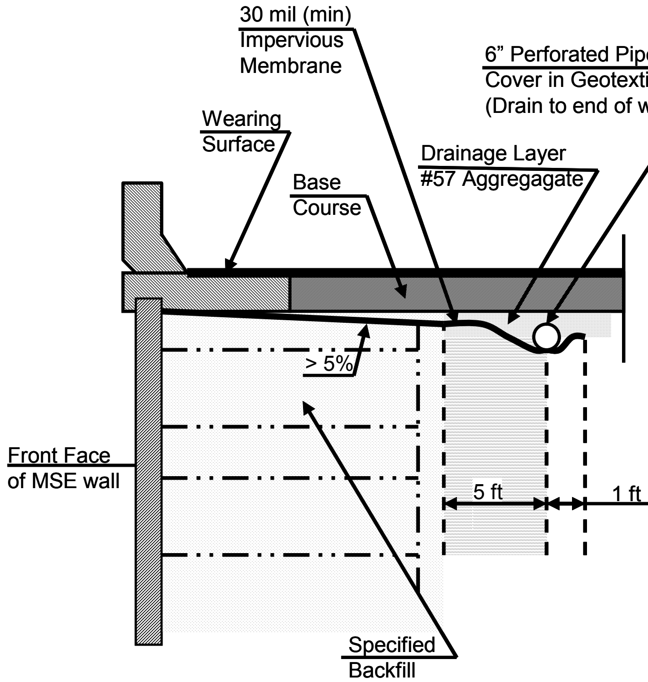
A geomembrane barrier can be used to prevent surface water infiltration and associated seepage forces that can occur when using poorly draining reinforced fill. In addition steel soil reinforcements in the upper portion of MSE walls exposed to runoff containing deicing salts are affected by higher corrosion rates than defined by current corrosion rate models. Therefore, a geomembrane barrier should be placed below the road base and just above the first layer of soil reinforcement. The geomembrane should be tied into a drainage system to collect and discharge the runoff. As per Article 11.10.8 of AASHTO (2007), a roughened surface PVC, HDPE or LLDPE geomembrane with a minimum thickness of 30 mils (0.75 mm) should be used. All seams in the membrane should be glued or welded to prevent leakage.

An example detail for use of geomembrane barrier to prevent infiltration of runoff into the reinforced soil mass is illustrated in Figure 5-14a. As shown in Figure 5-14a, the geomembrane should be sloped to drain away from the facing to an intercepting longitudinal drain outletted beyond the reinforced mass. Installation of a geomembrane infiltration barrier is shown in Figure 5-14b and 5-14c. Design requirements for the geomembrane are covered in Section 5.3.3.

Pavement Permeability and Runoff

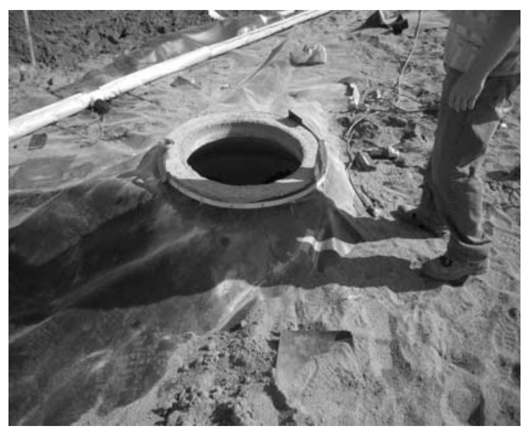
Pavements are porous structures. Surface water flows through asphalt pavement cracks and concrete joints and cracks into the pavement base material(s). The flow into the base aggregates can be significant, with up to 50% of the water falling on the pavement finding its way to the base course, and much more if there are cracks in the pavement, e.g., upwards of 97% will flow though a 1/8 in. (3 mm) crack according to AASHTO (1986). This water then saturates the subgrade because the relatively high permeability base aggregate ponds the water above the MSE wall. The situation is compounded if the site and pavement grades toward a low spot as shown in Figure 5-15. The MSE wall designer should interact with the project civil engineer to ensure that such a condition is mitigated and positive drainage measures are provided to capture the pavement drainage in the form of proper grading away from the wall and edge drains. Consideration should also be given to using the geomembrane detail shown in Figure 5-14, to intercept and discharge the water seeping through cracks in the pavement.

Surface runoff on the pavements that overtops the wall can cause undermining of the wall. Sloping the roadway towards a ditch is a common way to guard against wall overtopping. This is also sometimes referred to as roadway "in sloping."



(a)

(b)



(c)

Figure 5-14. (a) Example geomembrane barrier details, (b) Installation of geomembrane deicing salt runoff barrier, (c) Geomembrane installation around manhole penetration.

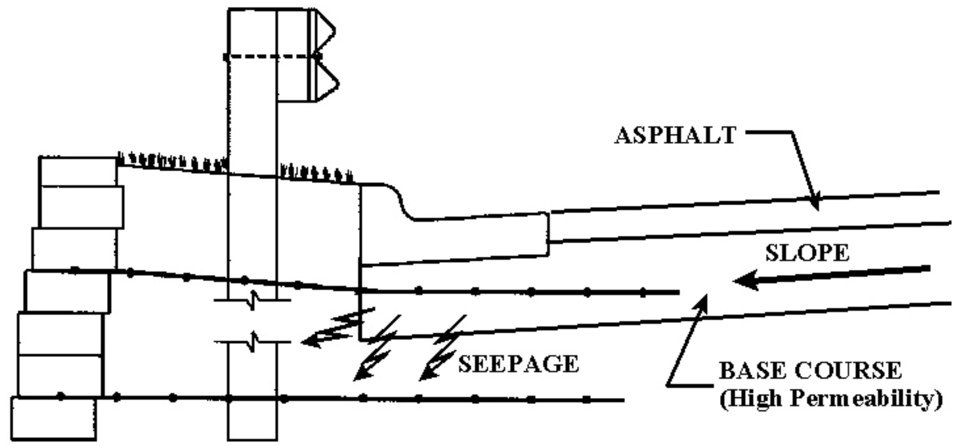


Figure 5-15. Example of undesirable water seepage through pavement due to deficient grades (Collin et al., 2002)

Grade at Toe and Ends of the Wall

The final grade at the toe and ends of the wall, both as designed and as constructed, is an important consideration for water flow conditions. Surface water flow along the toe of a MSE wall may occur around the ends or along the face of the structure and has the potential to erode the soil. An example of water damage is shown in Figure 5-16. Erosion of soil at the toe of a wall eventually may undermine the MSE wall facing units. Thus, design and construction details normally should direct flow away from the toe of wall structures. This can be accomplished with site grading and with a soil berm or slope at the toe of the wall.

Erosion control details are required where water will flow adjacent to the wall toe. Geotextile lined riprap stone or other means should be used to prevent scour. The designer also may elect to embed the wall deeper (i.e., lower foundation level) where the potential for erosion of the wall toe exists. Consideration should be given to turning the wall 90 degrees inward from the face.

The ends of the wall that terminate in or intercept embankment slopes should also be protected from erosion. Walls that terminate in slopes should be adequately keyed into the slope and a swale used to divert water away from the ends of the wall to mitigate erosion. Wing walls for approach fills should also be design such that water does not flow down the slope along the back of the wall face. Again a swale can be used to divert water and the surface of the slope should be graded to promote water flows away from the wall.

Figure 5-16. Example of surface flow erosion at the bottom of an MSE wall.

5.3.3 Filtration and Drainage System Component Requirements

Construction of an MSE wall may involve several types of soils. Groundwater flow from one soil type to another, and then to a drain and outlet feature, should be unimpeded. Soil filtration and permeability requirements must be met between adjacent zones of different soils to prevent impeded flow or piping. Adjacent soils of interest in an MSE wall system are as follows:

- the reinforced fill and any drainage layers,
- the reinforced fill, facing elements such as joints and/or face drainage aggregate and geotextile covering the joints,
- the reinforced fill and retained fill,
- the reinforced fill and foundation soil, and
- the reinforced fill and embankment fill above the wall and low permeable surface fill that may be used to reduce infiltration.

Filters may be in the form of a graded granular soil or a geotextile. Design of both soil filters and geotextile filters are discussed below. Design of geocomposite drains, drainage inflow and outflow, drain collection and outlet pipes and geomembrane barriers are also discussed.

Soil Filters

As water flows from one soil zone to another, the downstream soil must meet filter criteria to prevent piping of the upstream soil. Furthermore, the downstream soil must have adequate permeability relative to the adjacent, upstream soil. Therefore, the downstream soil must have the correct gradation range to function properly as a filter. The gradation requirements of the filter are also a function of the upstream soil gradation because the design flow capacity of the filter cannot be realized if the upstream soil pipes into the downstream soil. The pore sizes in the filter soil must be small enough to retain the larger size particles of the soil, which in turn retain the smaller sizes of the retained soil. The filter pore size is mathematically a function of its controlling particle size.

Design criteria for soil filters are summarized below and are based upon gradations of two adjacent soils. The particle sizes used in design are the D_{15}, D_{50}, and D_{85} sizes (subscript denotes the percentage of material, by weight, which has a smaller diameter). These criteria are applicable to adjacent soils with gradation curves that are approximately parallel. The equations are <u>not</u> applicable to gap-graded soils, soil-rock mixtures, non steady-state flow and soils with gradation curves that are not approximately parallel. When criteria are not applicable, filter design should be based upon laboratory filtration tests. The reader is referred to Cedergren (1989) for a comprehensive discussion on soil filtration.

The soil filtration criterion to prevent piping (i.e., retention) of the upstream soil into the filter is:

$$\frac{D_{15(\text{filter})}}{D_{85(\text{soil})}} < 5 \qquad (5\text{-}1)$$

To ensure sufficient permeability of the filter material, the ratio of the filter D_{15} to the upstream soil D_{15} should be as shown in Equation 5-2.

$$4 < \frac{D_{15(\text{filter})}}{D_{15(\text{soil})}} < 20 \qquad (5\text{-}2)$$

An additional criterion to prevent movement of soil particles into or through filters is presented in Equation 5-3. For CL and CH soils without sand or silt particles, the D_{15} size of the filter in Equation 5-2 may be as great as 0.016 in, and Equation 5-3 may be disregarded. However, if the upstream soil, i.e., retained fill or backcut soils, contains particles of uniform non-plastic fine sand and silt sizes, the filter must be designed to meet these criteria.

$$\frac{D_{50(\text{filter})}}{D_{50(\text{soil})}} < 25 \qquad (5\text{-}3)$$

Geotextile Filters

A geotextile is often used as a filter between a finer-grained and a more permeable soil. The geotextile must retain the finer-grained soil, while allowing water to readily pass into the more permeable soil, and function throughout the life of the earth retaining structure. Thus, geotextile design must address retention, permeability, and clogging. The geotextile must also survive the installation process.

The following design steps are from the FHWA Geosynthetic Design and Construction Guidelines Manual (Holtz et al. 2008).

Step 1. Determine the gradation of the material to be separated/filtered. The filtered material is directly upstream or downstream of the geotextile filter for the drainage layer. Determine D_{85}, D_{15}, $C_u = D_{60}/D_{10}$ and the percent passing a No. 200 (0.075 mm) sieve. When the soil contains particles 1 in. (25 mm) and larger, use only the gradation of soil passing the No.4 (4.75 mm) sieve in selecting the geotextile (*i.e.*, scalp off the + No.4 (+4.75 mm) material).

Step 2. Determine the permeability of the upstream or downstream material to be filtered. These include the reinforced fill, foundation soil, retained fill and the natural soil in cut slope.

Step 3. Apply design criteria for retention, permeability and clogging resistance to determine apparent open size (AOS), permeability (k), and permittivity (ψ) requirements for the geotextile (after Holtz et al., 2008). AOS, k and ψ of the candidate geotextile are determined from standard ASTM tests and is typically the value published by the geotextile manufacturers/suppliers. Use only needlepunched nonwoven or monofilament woven geotextiles (i.e., slit film woven geotextiles shall not be used).

A. *Retention Criteria – Steady State Flow*

Using the D_{85} and C_u values from Step 1, determine the largest allowable pore size as follows:

$$AOS \leq B\ D_{85} \qquad (5\text{-}4)$$

where:

AOS = apparent opening size of the geotextile

B = dimensionless coefficient
D_{85} = soil particle size for which 85% are smaller

The AOS value of the candidate geotextile is determined from the results of the ASTM D4751 test method, and is typically the value published by the geotextile manufacturers/suppliers. The B coefficient ranges from 0.5 to 2 and is a function of the upstream finer-grained soil, type of geotextile, and/or the flow conditions. For sands, gravelly sands, silty sands and clayey sands (i.e., sands with less than 50% passing the No. 200 sieve), B is a function of the uniformity coefficient, C_u ($C_u = D_{60}/D_{10}$), of the upstream soil. Table 5-1 presents values of B for various values of C_u.

If the upstream soil contains any fines, only the portion passing the No. 200 sieve should be used for selecting the geotextile. For silts and clays (more than 50% passing the No. 200 sieve), B is a function of the type of geotextile as given in Table 5-2.

These retention criteria are for internally stable soils and steady-state seepage conditions. Laboratory performance tests should be conducted for unstable soils. For soils with a $C_u > 20$, unsteady seepage may occur. For dynamic and cyclic flow condition use AOS < $0.5D_{85}$. See Holtz et al. (2008) for further information on dynamic flow conditions such as wave action.

Table 5-1. Values of B for Various C_u Values for Soils with Less than 50% Passing the No. 200 Sieve.

C_u	B
$C_u \leq 2$	1
$2 \leq C_u \leq 4$	$0.5\ C_u$
$4 < C_u < 8$	$8 / C_u$
$C_u \geq 8$	1

Table 5-2. Values of B and AOS for Soils with More than 50% Passing the No. 200 Sieve Based on Type of Geotextile.

Type of Geotextile	B	AOS
Woven monofilament	B = 1	AOS $\leq D_{85}$
Nonwoven	B = 1.8	AOS $\leq 1.8D_{85}$
Both woven and nonwoven	-	AOS $\leq$ 0.012 in. (0.3 mm)

B. *Permeability/Permittivity Criteria*

For steady-state flow, low hydraulic gradient and well graded or uniform upstream soil, the permeability and permittivity criteria are:

- For permeability
  $k_{geotextile} \geq k_{soil}$ (Less Critical / Less Severe) (5-5a)
  $k_{geotextile} \geq 10\ k_{soil}$ (Critical / Severe)

- For permittivity
  $\Psi \geq 0.5\ sec^{-1}$ for < 15% passing No. 200 sieve (5-5b)
  $\Psi \geq 0.2\ sec^{-1}$ for 15% to 50% passing No. 200 sieve (5-5c)
  $\Psi \geq 0.1\ sec^{-1}$ for > 50% passing No. 200 sieve (5-5d)

where:

k = coefficient of permeability (or hydraulic conductivity) and

Ψ = geotextile permittivity, which is equal to $k_{geotextile}/t_{geotextile}$.

Critical or severe applications are described in Holtz et al. (2008) and, as indicated in Equation 5-5a, a geotextile permeability of 10 times the soil permeability should be used. The geotextile permittivity is determined from the results of the ASTM D4491 test method.

C. *Clogging Criteria*

a. For steady state flow, low hydraulic gradient and well graded or uniform upstream soil, the clogging criterion is:

$$AOS \geq 3\ D_{15(upstream\ soil)} \quad (5\text{-}6)$$

This equation applies to soils with $C_u > 3$. For soils with $C_u \leq 3$, a geotextile with the maximum AOS value from the retention criteria should be used.

b. Other qualifiers

Nonwoven geotextiles: Porosity (geotextile) ≥ 50%
Woven geotextiles: Percent open area ≥ 4%

c. Alternative: Run filtration tests, especially for critical and severe applications

Step 4. In order to perform effectively, the geotextile must also survive the installation process. AASHTO M288 (2006) provides the criteria for geotextile strength required to survive construction of roads, as shown in Table 5-3. Use geotextile Class 2 where a moderate level of survivability is required (e.g., for geotextile filters at the wall face and on back drains). Class 1 geotextiles are recommended when heavy construction equipment is used and/or angular fill will be placed directly above or below the geotextile (e.g., geotextile filters for base drains). A minimum of 6 in. (150 mm) of base/subbase should be maintained between the wheel and geotextile at all times.

Table 5-3. Geotextile Survivability Requirements (AASHTO M 288, 2006).

Test	Test Method	Units	Geotextile Class			
			Class 1		Class 2	
			< 50%*	≥ 50%*	< 50%*	≥ 50%*
Grab Strength	ASTM D4632	N (lb)	1400 (315)	900 (200)	1100 (250)	700 (157)
Seam Strength	ASTM D4632	N (lb)	1200 (260)	810 (180)	990 (220)	630 (140)
Tear Strength	ASTM D4533	N (lb)	500 (110)	350 (80)	400 (90)	250 (56)
Puncture Strength	ASTM D6241	N (lb)	2750 (620)	1925 (433)	2200 (495)	1375 (309)
Ultraviolet Stability (Retained Strength)	ASTM D4355	%	At face joints - 70% after 500 hours of exposure Buried in wall - 50% after 500 hours of exposure			
*Note: Elongation measured in accordance with ASTM D4632 with < 50% typical of woven geotextiles and ≥ 50% typical of nonwoven geotextiles. (1 N = 0.22 lbs, 1 kPa = 0.145 psi)						

Step 5. Collect samples of geotextile, reinforced fill and retained fill at time of construction to confirm acceptance.

Step 6. Monitor installation during construction.

Step 7. Observe effectiveness of drainage system during and after storm events.

For a more thorough treatment of geotextile drains see Holtz et al. (2008).

Geocomposite Drain

A geocomposite, or prefabricated, drain consists of a geotextile filter and a water collection and conveyance core. The cores convey the water and are generally made of plastic waffles, three-dimensional meshes or mats, extruded and fluted plastic sheets, or nets. A wide variety of geocomposites are readily available. For MSE wall design, only geocomposites that allow two-sided flow (i.e., flow into the drains from both sides) should be used. However, the filtration and flow properties, detailing requirements, and installation recommendations vary and may be poorly defined for some products. The geotextile of the geocomposite should be designed to meet filter and permeability requirements discussed previously in this section. The flow capacity of geocomposite drains can be determined by using the procedures described in ASTM D4716. Long-term compressive stresses and eccentric loadings on the geocomposite core should be considered during design and selection.

MSE walls can place a significant stress on the geocomposite. Hence, the design pressure on a geocomposite core should be limited to either of the following:

- the maximum pressure sustained on the core in a test of 10,000 hr minimum duration; or
- the crushing pressure of a core, as defined with a quick loading test, divided by a safety factor of five.

Finally, as with in drain system, consideration should be given to system performance factors such as distance between drain outlets, hydraulic gradient of the drains, potential for blockage due to small animals, freezing, etc. Other design aspects of geocomposite drains are addressed in Holtz et al. (2008).

Installation details, such as joining adjacent sections of the geocomposite and connections to outlets, are usually product-specific. Product-specific variances should be considered and addressed in the design, specification, detailing and construction phases of a project. General construction specification requirements will be review in Chapter 10. Post installation examination of the drainage core/path with a camera scope should be considered for critical applications.

Drainage Inflow and Outflow Design Requirements

For proper design of the drains at the back or base of the reinforced soil mass, the flow into the system and the flow in the drain must be evaluated. These flow conditions are discussed below and apply to either gravel or geocomposite drains. Cedergren (1989) and Huntington (1957) present a more thorough treatment of pressures induced by the influence of ground water and seepage acting on retaining walls as well as drainage design.

Flow into the System. Anticipated flow into the drain system may be estimated using Darcy's Law. Flow is equal to:

$$q = k\,i\,A \qquad (5\text{-}7)$$

where:

- q = infiltration rate
- k = effective permeability of retained backfill soil
- i = average hydraulic gradient in retained backfill soil
- A = area of soil normal to the direction of flow

Conventional flow net analysis can be used to calculate the hydraulic gradient.

Some drains consist of drainage aggregate surrounding a perforated pipe with a filter (usually a geotextile) surrounding the drainage aggregate. Flow into the drainage aggregate may be calculated with Equation 5-7. Flow from the drainage aggregate into the pipe is through the circular or slot perforations. Perforated, corrugated HDPE pipe is manufactured with minimum inlet openings of approximately 1 square inch per 1 foot length (20 cm^2 per meter length) for standard pipe (AASHTO M252, 2006). Standard pipe is generally adequate for most subsurface drainage applications. Hole diameter or slot width must be checked relative to the size of the surrounding drainage aggregate, to ensure soil retention. For slots, Equation 5-8 may be used to check retention.

$$\frac{D_{85(\text{drain fill})}}{\text{Slot Width}} > 1.2 \text{ to } 1.4 \qquad (5\text{-}8)$$

For circular perforations, Equation 5-9 may be used to check retention.

$$\frac{D_{85(\text{drain fill})}}{\text{Hole Diameter}} > 1.0 \qquad (5\text{-}9)$$

Flow Capacity of the Drain. Flow capacity within aggregate drains can be estimated with Equation 5-7, using k and i for the soil drain material. Flow capacity within geocomposite drains is expressed in term of unit width using the following form of Darcy's Law.

$$q = \lambda\,i\,B \qquad (5\text{-}10)$$

where:

q	=	flow rate
λ	=	transmissivity of geocomposite drain
i	=	hydraulic gradient in drain
B	=	width of geocomposite drain

The geocomposite transmissivity should be evaluated with an appropriate laboratory model test. Product long-term transmissivity should be quantified at anticipated (or greater) design pressure and over time to evaluate potential decrease of flow capacity due to creep (i.e., creep of geotextile into flow channel).

Flow Capacity of the Drain Pipe. Flow capacity within drain pipes, flowing full, can be computed with the Manning's equation. Flow is equal to:

$$q = \frac{0.463}{n} d^{8/3} s^{1/2} \quad (5\text{-}11)$$

where:

q	=	flow rate (cfs)
n	=	roughness coefficient, or Manning's value
d	=	diameter of pipe (feet)
s	=	slope of energy grade line (ft per ft)

Drain Collection and Outlet Pipes

Collection and outlet pipes are often used with the drain directly behind the facing units and with the drain at the back of the reinforced soil mass. Examples of such drains are shown in Figures 5-8 and 5-10. Pipes are generally laid at required slopes, with a minimum of 2% for constructability and to ensure positive flow. Outlets are generally spaced based on the flow capacity of the pipes or alternatively at 20 ft (6 m) to 50 ft (15 m) maximum lateral spacing, and protected as noted in a later discussion on maintenance. The outlet pipes should be solid and gravity flow (e.g., 2% minimum grade) to daylight or the storm drain system.

Geomembrane Barriers

Design and specification of a geomembrane as a deicing salt barrier must address installation requirements. A geomembrane must be capable of withstanding the rigors of installation to ensure the integrity of the barrier. The subgrade material, subgrade preparation, geomembrane placement method, overlying soil fill type, and placement and compaction of overlying fill soil all affect the geosynthetic barrier's survivability. Recommended properties of geomembrane barriers (Koerner, 1998) are presented in Table 5-4. A minimum thickness of 30 mils (0.75 mm) is recommended for geomembranes above MSE walls.

Three areas of construction which are critical to a successful installation are:

- subgrade preparation;
- handling/installation including field seaming; and
- sealing around penetrations and adjacent structures.

The subgrade must provide support to the geosynthetic barrier and minimal point loadings. The subgrade must be well-compacted and devoid of large stones, sharp stones, grade stakes, etc., that could puncture the geosynthetic barrier. In general, no objects greater than ½ in. (12 mm) should be protruding above the prepared subgrade (Daniel and Koerner, 1993).

Handling and installation specifications for geomembrane and other geosynthetic barriers should, as a minimum, conform to the manufacturer's recommendations. All seams in the membrane should be glued or welded to prevent leakage. Special project requirements for geomembranes should be noted in the construction specifications and plans.

Table 5-4. Recommended Minimum Properties for General Geomembrane Installation Survivability (after Koerner, 1998).

Property and test method	Required degree of survivability	
	Medium[1]	Very high[2]
Thickness, mils (mm) – ASTM D5199 or ASTM D5994 for Textured	30 (0.75)	40 (1.00)
Tear (Die C), lbf (N) - ASTM D1004	10 (45)	20 (90)
Puncture, lbf (N) - ASTM D4833	32 (140)	45 (200)

NOTES:

1. *Medium* refers to placement on machine-graded subgrade with medium loads. Soil fill should have a maximum size of ¾-inch.
2. *Very high* refers to placement on machine-graded subgrade of very poor texture. Soil fill with maximum size greater than ¾-inch.

Geomembrane selection should also consider installation details of attachment to the MSE wall facing and details around penetrations. Construction details around penetrations and adjacent structures depend upon the chosen geosynthetic material and the project design. As such, they must be individually designed and detailed. For example, batten strips and mechanical fasteners were used with the 30 mil (0.75 mm) thick HDPE geomembrane shown in Figure 5-14c. Geosynthetic manufacturers and waste containment manuals can provide design guidance.

Another design consideration may be the frictional resistance of the geomembrane. As per Article 11.10.8 of AASHTO (2007), typically, a roughened surface PVC, HDPE or LLDPE geomembrane with a minimum thickness of 30 mils (0.75 mm) should be used. Such roughened geomembranes are readily available in the marketplace.

5.3.4 Maintenance of Drainage

Features that minimize water flow into an MSE wall and features that preserve MSE wall drainage should be maintained over the life of the structure. For example, cracks in pavement above MSE walls should be sealed. Differential settlements and pavement cracks around catch basins should be corrected to minimize potential inflow into the reinforced soil or retained soil mass. These maintenance items are for non-wall features and the wall designer may have little influence on these items. However, in interacting with designers of other project features, the need to maintain items that potentially could affect the wall should be discussed.

One of the maintenance items that the wall designer has control over is the drain outlet(s). Screens should be installed and maintained on drainpipe outlets. Screening is used to prevent small animals from nesting in and clogging the pipe. Outlet screens and cleanouts to provide access to clogged drainage should be detailed on the retaining wall construction drawings.

Additional items should be detailed when outlets are located in a soil embankment beneath the MSE walls. Drains are not effective unless the outlets are maintained, i.e., not clogged. Outlets in soil embankments should drain onto a concrete (usually precast) apron and should be marked with a permanent metal fence post. The apron and post minimize the chance of the outlet being run over and crushed by mowers or covered in subsequent construction activities. The apron and post should be detailed on the wall construction drawings.