

## APPENDIX E

### Design and Construction Guidelines

## **E. Design and Construction Guidelines**

### ***E.1 Design Guidelines***

#### ***E.1.1 General***

The following guidelines are largely based upon recommendations included in the NCMA (1996), AASHTO (1996, 1997) and FHWA (1997) documents. These are intended as *general guidelines only*. For any specific retaining wall, an acceptable design will depend upon several factors, including:

- Wall height
- Slope of soil in front of and behind the wall
- Backfill soil properties
- Subsurface (foundation) soil properties
- Groundwater and surface water conditions
- Type & properties of reinforcing elements (geotextile, geogrid, timber deadman, etc.)

There is no generic retaining wall design that encompasses all the possible variations in these factors. Therefore, it is important that any individual wall design be checked to ensure that it satisfies both external stability (including bearing capacity, sliding, overturning, global stability, and total and differential settlement criteria) and internal stability (internal sliding, pullout and/or rupture of the reinforcing elements, and facing connection integrity). The final responsibility for the integrity of the wall rests with the owner. Local building codes should be checked, since many codes require that retaining wall designs be prepared and sealed by a Professional Civil Engineer licensed in the state where the wall is to be built.

#### ***E.1.2 Details at the Wall Base***

The base of the wall should be embedded below the ground surface. The recommended depth of embedment is one tenth (1/10) of the planned wall height, or a minimum of 6 inches. The embedment depth should be increased if any of the following special conditions exist: poor subgrade soil; a slope in front of the wall; scour from water applications; expansive subgrade soils; or seismically active locations.

The wall should be placed upon a leveling pad extending laterally at least 6 inches beyond the front and back faces of the timbers. The leveling pad should be constructed in accordance with the guidelines discussed in Section E.2.2. For an aggregate leveling pad, the leveling pad material should be at least 6 inches deep and should consist of coarse-grained, free draining sand and gravel, or crushed stone that allows water drainage. The recommended gradation limits for leveling pad material are presented in the table below.

**Table 1: Recommended Gradation for Leveling Pad Soil**

<b>Sieve Size</b>	<b>Percent Passing</b>
1 inch	100%
No. 4	35 – 80
No. 10	20 – 65
No. 40	10 – 35
No. 200	0 – 10

For walls which incorporate geosynthetic reinforcement, it is recommended that the leveling pad be constructed with a layer of lean concrete, at least 3 inches thick, with a strength of 200-300 psi. The concrete leveling pad should be angled slightly in order to provide an initial inward batter of the timber facing. Most retaining walls are constructed with an initial inward batter on the order of 2% to 10 %, to accommodate the invariable yielding which occurs.

***E.1.3 Drainage Aggregate***

It is recommended that drainage aggregate be placed within the first 12 inches behind the wall face. Vertically, it should not extend deeper than the final grade established for the front of the wall, and should be placed up to about 6 to 12 inches below the finished grade at the top of the wall. This drainage aggregate will help to prevent fine-grained backfill soils from washing through the face of the wall, and to prevent large hydrostatic pressures and ice lenses from forming immediately behind the wall face. It will also serve as a compaction aid during construction, since this type of soil can be fairly well compacted by hand tamping. The recommended gradation limits for drainage aggregate are presented in the table below.

**Table 2: Recommended Gradation for Drainage Aggregate**

<b>Sieve Size</b>	<b>Percent Passing</b>
1 inch	100%
¾ inch	75 – 100
No. 4	0 – 60
No. 40	0 – 50
No. 200	0 – 5

To collect and remove any water which accumulates in the drainage aggregate behind the wall face, a drainage pipe or weepholes should be provided. Weepholes may be installed by simply drilling holes through the timbers just above the finish grade at the base of the wall. Alternately, perforated or slotted PVC, or corrugated HDPE pipe may be placed in the drainage aggregate behind the face, and allowed to exit either through the face or out through the soil at the ends of the wall. If perforated pipe is used, it should be sloped at a minimum grade of 1/8 inch per foot, and should be provided with outlets spaced at a maximum distance of 40 feet apart.

It is important that the drainage aggregate satisfies required flow and retention criteria. The flow capacity of the drainage aggregate may be impeded if fines from the surrounding backfill soil migrate into the drainage fill. The following criteria (Terzaghi and Peck, 1967) are recommended for aggregate drainage systems:

$$\frac{D_{15} \text{ aggregate}}{D_{85} \text{ soil}} < 5$$

$$4 < \frac{D_{15} \text{ aggregate}}{D_{15} \text{ soil}} < 20$$

$$\frac{D_{50} \text{ aggregate}}{D_{50} \text{ soil}} < 25$$

$D_{15}$ ,  $D_{50}$ , and  $D_{85}$  denote the particle diameters corresponding to 15%, 50%, and 85% passing on the grain size distribution curves for the drainage aggregate (“*aggregate*”) and backfill soil (“*soil*”).

For applications where the recommended soil filtration criteria are not met, it may be necessary to provide a geotextile filter fabric between the drainage aggregate and the backfill soil. The filter fabric will prevent soil fines from migrating into the drainage aggregate. For geotextile filters, the following filtration criteria are recommended by AASHTO (1997):

- For soils with < 15% fines:      AOS < 0.43 mm,  $\psi \geq 0.5 \text{ sec}^{-1}$
- For 15 to 50% fines:            AOS < 0.25 mm,  $\psi \geq 0.2 \text{ sec}^{-1}$
- For soils with > 50% fines:    AOS < 0.22 mm,  $\psi \geq 0.1 \text{ sec}^{-1}$

“Fines” denote soil particles with diameters smaller than 0.075 mm (#200 sieve), and AOS and  $\psi$  denote the apparent opening size and the permittivity of the geotextile, respectively.

It should be noted that in cases where a groundwater table and/or significant seepage is anticipated behind the wall, a more comprehensive drainage system than that described herein may be required.

#### ***E.1.4 Backfill Soil***

The design and performance of an MSE wall is highly dependent upon the nature of the backfill soil. Currently accepted standards (NCMA (1996), FHWA (1997), AASHTO (1996)) indicate that the soil used as backfill should ideally consist of the inorganic USCS soil types GP, GW, SW, SP, SM (sandy and gravelly soils), and should meet the following gradation limits:

**Table 3: Recommended Gradation for Backfill Soil**

<b>Sieve Size</b>	<b>Percent Passing</b>
4 inch	75 – 100
No. 4	20 – 100
No. 40	0 – 60
No. 200	0 – 35

In addition, the plasticity index of the fine fraction should be less than 20. If geosynthetic reinforcement is to be used, the maximum particle size should not exceed  $\frac{3}{4}$  inch, unless the geosynthetic strength value used for design is reduced to account for potential installation damage from particles larger than this maximum.

A recent trend in design and construction of retaining walls is to use on-site soils which do not fall strictly within the gradation limits stated above. This usually results in significant cost savings, since it minimizes the costs associated with importing fill and/or removing excavated materials. The potential drawbacks associated with using poorer quality soils for backfill are:

- The soils may be harder to place and compact.
- They generally exhibit lower shear strength, and thus may require more substantial reinforcement than higher quality backfill soils.
- They are more susceptible to creep.
- They are not as free-draining.

In the UMass Dartmouth project, on site soils with a high percentage of fines were used fairly successfully as backfill. Caution should be exercised, however, when using fine grained soils as backfill. Compaction control is extremely important with these soils; they should be compacted at their optimum moisture content, or just slightly dry of optimum. For wall geometry and/or site conditions which differ from those encountered in the UMass Dartmouth project, performance of the wall may be adversely affected by the use of poor quality backfill soils. Any questionable use of such soils should be evaluated on a project-specific basis by a qualified geotechnical engineer.

### ***E.1.5 Reinforcing Elements***

#### ***E.1.5.1 General***

For a given wall height and geometry, the properties of the backfill soil will significantly affect the amount of reinforcement required for stability of the wall. The recommendations provided herein are based upon the use of backfill soil with the following characteristics:

- Fines content between 20% to 40% by weight
- Relatively low plasticity (plasticity index = 2.6)

- Minimum angle of internal friction = 30 degrees
- Moist unit weight of approximately 120 lb./ft<sup>3</sup>

If higher quality backfill is used, the recommendations provided herein would result in very conservative reinforcement designs. In contrast, if poorer quality backfill is used, the recommendations provided herein would result in non-conservative designs.

These recommendations are also based upon the assumption that there are no significant surcharge loads, that there is negligible seepage behind the wall, and that the wall is placed upon a competent subgrade (foundation) soil. If any of these conditions fail to exist, the recommended reinforcement patterns may be inadequate, and the design should be checked by a qualified geotechnical engineer.

#### *E.1.5.2 Geotextile Reinforcement*

The reinforcement design provided in this section is based specifically upon use of Mirafi HP 370 geotextile. For a wall with a total height of 4.58 feet (10 courses of timbers), a backslope not exceeding 9 degrees, and a frontslope which is approximately horizontal, three layers of Mirafi HP 370 geotextile should be placed as reinforcement. The layers should be placed between timber courses 2-3, 5-6, and 8-9 (starting with course #1 at the base of the wall and course #10 at the top). The geotextile sheets should extend 4.0 feet, 5.0 feet, and 6.0 feet, respectively, behind the wall. For a wall which is approximately 6 feet high (13 to 14 courses of timbers) with a level back slope, the design would be the same as for the 4.58 foot wall, except that an additional layer of geotextile should be placed between courses 11-12. The length of this layer should be 6 feet. All geotextile layers should be attached to the facing as described in section E.2.4.

For lower walls, shallower backslopes, or higher quality backfill, it is likely that fewer and/or shorter lengths of geotextile would be required. Conversely, for higher walls, steeper backslopes, or poorer quality backfill, additional sheets of geotextile with increased lengths may be required.

#### *E.1.5.3 Timber Deadman Reinforcement*

Timber deadman anchors can be constructed by placing two timbers perpendicular to the face of the wall, and then connecting them at their ends (behind the wall) with timbers running parallel to the face. Two types of deadmen were designed for the UMass Dartmouth project; schematics of both designs (Detail “A” and Detail “B”) are shown in Appendix C of this report.

For walls on the order of 4 to 6 feet in height, with relatively level front and back slopes, and soil conditions typical of those described in Section E.1.5.1, deadmen should be spaced horizontally behind every other eight foot timber, and spaced vertically at every other row. The two lowest levels of deadmen should be constructed in accordance with Detail “A”. If a third level of anchors is required, the uppermost level could be constructed in accordance with Detail “B”. The uppermost level of deadmen should be located such that about a foot of backfill [↪](#)

~~courses of timbers~~) is placed above the top of the anchor, since negligible resistance is provided by anchors with minimal embedment. ~~{~~For retaining walls with ~~better~~ higher quality backfill soils, it may be possible to increase the vertical spacing to every third row of timbers. ~~This will be evaluated pending the~~ The reader should consult the results of the UMass Amherst study in this regard.~~}~~

### ***E.1.6 Final Grading and Surface Water Drainage***

As a final design detail, plans for finish grading should provide positive drainage away from the wall face. This will help prevent increases in lateral pressures on the structure due to infiltration of water into the backfill soils. It is generally recommended that soils be sloped at a minimum gradient of about 2% to provide for drainage away from the wall. A final cover of 4 to 6 inches of topsoil with surface vegetation is also recommended to provide erosion protection.

## ***E.2 Construction Guidelines***

### ***E.2.1 Preliminary Reconnaissance***

Prior to construction of any retaining wall, a thorough review of existing site and soil conditions should be completed. A retaining wall placed on an incompetent subgrade will not perform well. In general, dense sand and gravel, or firm clay is considered to be acceptable as a foundation for a retaining wall. Soft and compressible clay, organic soils or loose sands are usually considered to be unacceptable. Any questionable foundation soils should be removed and replaced with properly compacted granular soils and/or should be evaluated by a qualified geotechnical engineer.

### ***E.2.2 Excavation and Leveling Pad Construction***

The first step in construction is to excavate a trench for the leveling pad. At some sites, excavation back into a slope may also be required for the geosynthetic or timber reinforcing elements. Prior to excavation, it is important to verify the location of any existing structures and utilities in the area, and to take any necessary precautions. For the leveling pad, excavate a trench deep enough for placement of a minimum of 6 inches of aggregate (or 3 inches of concrete) plus the number of buried timbers to be embedded below grade. In general, the depth of embedment should be one tenth (1/10) of the planned wall height, or a minimum of 6 inches. The pad should be at least 6 inches thick and should extend laterally at least 6 inches on each side of the timbers.

Prior to placement of the leveling pad, any loose soil in the bottom of the trench should be compacted with a mechanical plate compactor. Use of screed boards is recommended for leveling pad construction. Steel or aluminum tubing, channels, or angle is recommended for this purpose, since these materials will not warp. For a concrete leveling pad, place and secure the screed boards on the compacted subgrade. For an aggregate leveling pad, set up the screed

boards after placing and compacting about 4" of the leveling pad aggregate. Level the screed boards along their length. The rear boards may be set down slightly lower than the front boards, to create an initial inward batter of the wall. For aggregate leveling pads, place additional soil up to approximately ½" of the top of the boards, and compact using a hand tamper. Place additional soil so that it is just slightly above the screed boards, and then screed off excess material. Well-graded sand can be used to smooth the top 1/2 to 1/4 inch of the leveling pad if the leveling pad aggregate contains large angular particles which can not easily be leveled.

For a concrete leveling pad, place the concrete between the boards and screed off excess material. Carefully set the first course of timbers in place, and install the rebar as described in Section E.2.3. Check to ensure that the timbers are still level (end-to-end) and that desired inward batter is maintained. The concrete should then be cured a minimum of 24 hours before placing the remaining timbers.

### ***E.2.3 Placement and Backfilling of Timbers***

After completing the leveling the pad, place the first course of timbers in the center of the leveling pad. Alignment of the timbers can be aided by using a string line hung just above the timbers, or by sighting down the holes in the timbers with a transit. Any timbers which appear to be warped or bowed should not be used. Level adjacent timbers using a 4" or longer level. When setting the base course timbers, make sure there is complete contact between the bottom of the timbers and the leveling pad. Then tap the top edge of the timbers with a mallet so that the lip on the back of the timber becomes embedded in the leveling pad. Be sure that the first course of timbers is battered so that the back edge is at least ¼ inch lower than the front edge of the timber. For the long-term appearance of the wall, it is important that this initial course of timbers is battered slightly inward.

Confirm that adjacent timbers are still level, and then anchor the timbers to the underlying soil using 36 inch lengths of rebar. One rebar should be placed at each end of each timber, and the rebar should extend at least a foot or two into the underlying soil if possible. Clean any excess debris from the top of the timbers and install the next course(s). Timbers should be staggered so that the joints between ends of adjacent timbers do not all line up with one another on successive courses. Steel rebar should be placed in all holes, and rebar lengths should also be staggered so that the rebar ends do not all fall along an individual course of timbers. When placing additional courses of timbers, it will be necessary to knock the timbers down over the rebar using a mallet and a wood block.

After installing the initial course(s) of timbers, place and compact soil backfill in front of and behind the units until you have buried the entire base course(s) up to the required embedment depth. Do not place drainage fill behind the embedded base units. The drainage fill should not extend deeper than the final grade established for the front of the wall. When this grade is reached, begin placing the drainage aggregate behind the timber facing. It should extend laterally about 12 inches behind the face. If drainage pipe is to be installed, it should be placed near the base of the wall, and should have a few inches of aggregate beneath it. It should be

sloped at a minimum grade of 1/8 inch per foot, and should be provided with outlets spaced at a maximum distance of 40 feet apart.

Backfill soils should be placed and compacted in lifts behind the wall. If geosynthetic reinforcement is used, the backfill should be placed and spread in such a manner as to eliminate wrinkles and/or damage of the geosynthetic reinforcement. The backfill should be placed and compacted in lifts which range from about 6 to 10 inches thick, after compaction. Larger lift thicknesses may be used when heavy compaction equipment is available, however, for small plate compactors typically used in landscape work, lift thicknesses should be limited to 6 to 8 inches.

It is generally recommended that only hand-operated compaction equipment (lightweight mechanical tamper, plate, or roller) be used within 3 feet of the front of the wall face. [However, for the recycled plastic timber walls, ~~reinforced with geosynthetics~~, it is recommended that a non-mechanical tamper be used within 2 to 3 feet of the wall face, to limit outward movement of the facing during construction. For walls anchored with timber deadmen, compaction should first be performed on the fill directly in front of the deadmen, followed by compaction of the material behind the wall face and behind the deadmen.](#)

For adequate wall performance, the backfill soil must be properly compacted. Most construction specifications require that soil be compacted to at least 95% of its maximum density determined by a Standard Proctor compaction test (ASTM D 698). Generally, properly compacted soil will not compress further with additional force from standard compaction equipment. Placement moisture content is very important for proper compaction and wall performance, especially for soils with a high percentage of fines. It is usually recommended that soils be compacted within 2% of the optimum moisture content determined from the Standard Proctor compaction test. One can very roughly estimate if a soil is near its optimum moisture content by taking a handful of the soil and squeezing it. If it essentially holds its shape without falling apart, and can be slightly deformed with light finger pressure, then it is probably fairly close to its optimum moisture content.

When backfilling operations take more than one day, attempts should be made at the end of the day to slope the last lift of backfill away from the wall facing to direct water runoff away from the face. At completion of wall construction, finish grading should provide positive drainage away from the wall face. It is generally recommended that soils be sloped at a minimum gradient of about 2% to provide for drainage away from the wall.

#### ***E.2.4 Placement of Reinforcing Elements***

Reinforcing elements should be placed in accordance with the design guidelines presented in Section E.1.5. When anchoring a wall with timber deadmen, the 8-foot section of timber facing in front of the deadman will need to have 5.5 inches cut off each end to accommodate the perpendicular members. The two perpendicular members should be set in place, and connected to the facing with rebar placed through the holes at their ends. For deadmen constructed in accordance with Detail "A", another timber must also have 5.5 inches

cut off each end. This timber should be placed between the perpendicular members, eight feet behind the wall facing. A full eight-foot length of timber should then be placed over that cut piece. Rebar should be placed through all holes, so that the two timbers comprising the anchor are connected. The ends of the upper timber should also be connected to the two perpendicular members with rebar. For deadmen constructed in accordance with Detail "B", the perpendicular members are simply connected at their ends with only one timber. (Schematics of Detail "A" and Detail "B" are included in Appendix C of this report.)

When using geotextile reinforcement, the geotextile should be cut to the proper length, and laid horizontally on the compacted backfill soil. The highest strength direction of the geosynthetic must be perpendicular to the wall face. The reinforcement layers should be one continuous piece for their entire embedment length. The geotextile should not be overlapped in the design strength direction (perpendicular to the wall face).

The geotextile should be attached to the timber facing using plumber's strap (which is supplied with pre-drilled holes) and 1 ¼ inch galvanized roofing nails as follows. The geotextile is extended over the lower course of timbers and attached to the timber using a length of plumber's strap tacked down about ¾ of an inch from the back edge of the timber. Tacks should be placed at a 2 ¼ inch spacing (every third hole) along this strap. The geotextile is then wrapped back over the strap and out behind the back of the timbers. A length of about 8 to 12 inches of geotextile should be extended out the back of the timbers and should be embedded in the drainage aggregate when it is placed behind the face of the wall. Before placing the upper course of timbers, a second length of plumber's strap should be tacked down ¾ of an inch from the front edge of the timber, to serve as a spacer to prevent outward batter of the facing. For this strap, tacks only need to be placed about every 18 to 24 inches.

After the next course of timbers is placed above the geotextile, the geotextile should be pulled in tension so that it is free of wrinkles prior to placement of backfill soil. The tension should be maintained by securing the geotextile in place with stakes or by hand tensioning until the reinforcement is covered by the backfill. The backfill soil should be end-dumped or bladed ahead of construction equipment. Construction equipment should not be operated directly on the geosynthetic reinforcement. If vehicles are operated behind the wall face, a minimum of 6 inches of backfill should be placed over the geotextile prior to operation of the vehicles, and turning should always be kept to a minimum.