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Chapter 17
EARTH RETAINING SYSTEMS

17.1 GENERAL

17.1.1 Overview

MDT uses earth retaining systems to provide lateral support for a variety of applications:

- cuts in slopes for roadway alignments;
- roadway widening where right-of-way is limited;
- grade separations;
- proximity to live-load surcharge from buildings, highways, etc., that must remain in place;
- stabilization of slopes where instabilities have occurred;
- protection of environmentally sensitive areas;
- bridge abutments; and
- excavation support.

Earth retaining systems are classified according to their construction method and the mechanism used to develop lateral support:

1. Construction Method. This may be either a "fill-wall" construction or "cut-wall" construction. Fill-wall construction is where the wall is constructed from the base of the wall to the top (i.e., "bottom-up" construction). Cut-wall construction is where the wall is constructed from the top of the wall to the base (i.e., "top-down" construction). Note that the "cut" and "fill" designations refer to how the wall is constructed, not the nature of the earthwork (i.e., cut or fill) associated with the project.

2. Lateral Load Support. The basic mechanism of lateral load support may be either "externally stabilized" or "internally stabilized." Externally stabilized wall systems use an external structural wall, against which stabilizing forces are mobilized. Internally stabilized wall systems employ reinforcement that extends within and beyond the potential failure mass.

The NHI training course manual, *Earth Retaining Structures – Participant Manual*, presents the types of walls in each of these categories. Section 17.2 of this Chapter discusses the process to use when selecting the type of earth retaining systems.

Some of the walls identified in the NHI *Earth Retaining Structures Manual* are proprietary. The most common types of proprietary walls include MSE, modular block, gabion and crib walls. MDT currently has no pre-approved proprietary walls, but may have some approved proprietary walls in the future; consequently, the use of these wall systems is determined on a case-by-case base.

17.1.2 Responsibilities

The following identifies the basic responsibilities of the respective MDT Units for the selection and design of earth retaining systems. Close communication among the Units is important, because any constraints identified by one Unit could have significant construction cost and schedule implications, that may impact the overall suitability of the wall selection.

17.1.2.1 Geotechnical Section

For all permanent earth retaining systems except MSE walls, the Geotechnical Section:

- performs the geotechnical investigations;
- selects the wall type;
- recommends allowable soil bearing and lateral earth pressures for gravity, surcharge and seismic loading;
- performs the global and external stability checks; and
- determines the drainage design for the wall.

Note: MDT currently uses allowable stress design (ASD) methods for the design of retaining walls. See Section 17.3.2 for further discussion of MDT's policy and the use of ASD versus Load and Resistance Factor Design (LRFD) for retaining walls.

The wall supplier will usually design MSE walls due to the proprietary nature of these wall types. However, for this wall type, the Geotechnical Section must perform all of the tasks as described above, except for internal stability checks. The wall supplier is responsible for both the internal stability (e.g., reinforcing system design, wall connections, wall facing), as well as checking the external stability design (i.e., sliding, overturning, bearing checks). The wall supplier also evaluates internal and external stability during seismic loading using the design earthquake information provided by the Geotechnical Section.

The Geotechnical Section will also provide (1) allowable bearing capacities and estimates of settlement for gravity walls (e.g., CIP concrete cantilever walls, MSE walls, prefabricated modular walls); (2) testing requirements for anchored and soil nail walls; and (3) special construction requirements for all walls. The construction requirements could include sheet pile driving criteria, methods of installing soldier piles and anchors for anchored walls, and backfill specifications for fill walls.

17.1.2.2 Road Design Section

For all permanent earth retaining systems, the Road Design Section determines the height and location of the wall based on the roadway alignment and right-of-way requirements. This often involves a trade-off between the height of the wall and the suitable steepness of the roadway slope and, therefore, alignment selection in sloping areas should not be made without discussions between the Road Design Section and Geotechnical Section.

The Geotechnical Section assists the Road Design Section in the preparation of the roadway plans to ensure that the required information is accurately presented in the plans. Figure 17.1-A lists the primary information that should be checked by the project geotechnical specialist in the plans for earth retaining systems. In some cases, plan preparation also includes providing cross-sections of the wall at appropriate intervals and most walls require inclusion of a special provision.

17.1.2.3 Bridge Bureau

The role of the Bridge Bureau in the design of earth retaining systems will depend on the type of wall:

1. CIP Concrete Cantilever Walls. The Bridge Bureau is responsible for the design of this wall type based on the following information provided by the Geotechnical Section:

    - earth pressure coefficients (k_a, k_o, k_p). Include a statement with the values indicating the estimated amount of deformation to develop the active and passive earth pressures and any recommendations on factors of safety;
    - unit weight of the backfill material;
    - allowable interface friction between cast-in-place concrete footing and soil;
    - allowable bearing capacity;
    - expected settlement; and
    - requirements for drainage control.

Plan View	Elevation	Details
• Alignment at top of wall and width of footing • Start and end stationing • Location of soil explorations • Ground surface contours • Location of utilities • Right-of-way and easement limits • Physical features (e.g., wetlands, restricted property)	• Original and finished grade • Bottom of foundation location • Locations of anchors or soil nails • Top and bottom of wall elevations • Drainage location and grades • Facing • Luminaires and barriers	• Surface drainage • Slope above and below wall • Anchor details (grout length, free stressing zone, head details, facing design) • Soil nail and wall facing details (nail head, test nail, facing design) • Wall drainage details • Wall sections, including batter • Limits of excavation and fill

Figure 17.1-A — CHECKLIST FOR EARTH RETAINING SYSTEM CONTRACT PLANS

2. Non-Gravity Cantilever (Sheet Pile) Walls and Anchored Walls. Where applicable, the Bridge Bureau will normally perform the internal stability design for these walls (e.g., size and spacing of reinforcing steel, details for reinforcing elements, facing). The Geotechnical Section will perform overturning, sliding and bearing checks, where applicable.

3. MSE, Gabion or Modular Block Walls. The Bridge Bureau has minimal involvement in the design. However, during construction the Bridge Bureau may be requested to review contractor submittals for walls that have structural facing.

4. Soil Nail Walls. The Bridge Bureau will normally design the reinforcing for the structural facing of the wall. This facing is placed over the shotcrete facing after all soil nails have been installed.

17.1.2.4 Other MDT Units

Depending on the site, other MDT Units may participate in the design and selection process for earth retaining systems. These include:

- Hydraulics Section, if the wall is located near flowing water or if it could be inundated during floods and there is scour potential at the base of the wall;
- Resources Section, Environment Services Bureau, if the wall will be located in or adjacent to wetlands or other environmentally sensitive areas; and/or
- Hazardous Waste Section, Environment Services Bureau, if the wall requires excavations in contaminated soils.

17.1.2.5 Contractor and Supplier-Designed Walls

Temporary retaining walls used during construction are normally the responsibility of the contractor. The contract documents will usually require that the contractor provides submittals for the design of these temporary walls. These designs are reviewed by the Geotechnical Section for completeness; however, the contractor is responsible for the function and structural safety of all temporary walls.

The wall supplier normally designs proprietary wall systems (e.g., gabion, MSE/modular block, crib walls). The Geotechnical Section's role will depend on the wall type. Usually, the Geotechnical Section will evaluate the global (slope) stability and then identify engineering parameters and design criteria (e.g., minimum factors of safety, seismic criteria, earth pressure coefficients, surcharge loads, allowable bearing values, values of sliding resistance coefficients, angle of internal friction of backfill and retained soil) that should be used by the wall supplier during design. The wall supplier will size the wall to meet internal and external stability requirements. The external stability checks include sliding, bearing and overturning. The Geotechnical Section will review submittals provided by the contractor for the project. If the wall supplier's submittals do not provide an adequate description of the analyses or do not conform with the engineering design criteria, the project geotechnical specialist should require a re-submittal of the design information.

17.1.3 References

For further guidance on earth retaining systems, the project geotechnical specialist should review the following documents:

- Geotechnical Engineering Circular No. 2, *Earth Retaining Systems*, FHWA-SA-96-038;
- FHWA *Manual for Design and Construction Monitoring of Soil Nail Walls*, FHWA-SA-96-069R, Revised 1998;
- Geotechnical Engineering Circular No. 4, *Ground Anchors and Anchored Systems*, FHWA-IF-99-015;
- *Training Course in Geotechnical and Foundation Engineering: Earth Retaining Structures — Participant Manual*, FHWA-NHI-99-025;
- *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*, FHWA-NHI-00-043;
- Geotechnical Engineering Circular No. 7, *Soil Nail Walls,* FHWA-IF-03-017;
- ASCE *Journal of Geotechnical Engineering*, "Estimation of Earth Pressures Due to Compaction," Duncan et al., December 1991; and
- *Foundations and Earth Structures,* Department of the Navy, Naval Facilities Engineering, NAVFAC DM 7.2, May 1982.

17.2 SELECTION OF EARTH RETAINING SYSTEM

Figure 17.2-A summarizes the characteristics for the various types of fill and cut walls, respectively, that are normally considered during the selection process.

17.2.1 Typical MDT Practices

Although each site must be analyzed individually to identify the most appropriate earth retaining system, MDT has established preferences for certain wall types based on the ease of construction, costs and past performance.

For fill walls, a MSE wall is most often the preferred choice. Where an MSE wall is not suitable, a selection is usually made among:

- a CIP concrete cantilever wall,
- a gabion wall, or
- a metal bin wall.

For cut walls of moderate height, a sheet pile wall is most often the most economical choice. However, these walls have significant height limitations, and they are difficult to install in some geologic conditions. For high cuts, a soldier pile with lagging and tiebacks is most often the preferred choice. Soil nail walls should also be seriously considered if soils are suitable.

17.2.2 Fill Walls

17.2.2.1 MSE Walls

MSE walls are constructed using earth fill with metallic or polymeric reinforcing in the soil mass. The facing for the walls can be concrete panels, modular blocks or exposed welded wire. The heights of these walls can extend to over 100 ft (30 m). Advantages of MSE walls include:

- They tolerate larger settlements than a CIP concrete cantilever wall.
- They are relatively fast to build.
- They are relatively low in cost.
- They perform well during earthquakes.

If the MSE wall is less than 10 ft (3 m) in height and 100 ft (30 m) in length, an alternative wall type is often more desirable because of the mobilization costs of the contractor.

Figure 17.2-A identifies the required right-of-way and settlement tolerances for this wall type. For permanent walls, MDT prefers the use of metallic (inextensible) rather than geosynthetics (extensible) reinforcing, although extensible reinforcing may be allowed.

Figure 17.2-A — SYSTEM SELECTION FOR FILL APPLICATIONS

System Type	Perm.	Temp.	Cost Effective Height Range	Required ROW[1]	Differential Settlement Tolerance[2]	Advantages	Disadvantages
Concrete gravity wall	✓		3 ft – 10 ft (1 m – 3 m)	0.5H – 0.7H[3]	1/500	• durable • requires smaller quantity of select backfill as compared to MSE walls • concrete can meet aesthetic requirements	• deep foundation support may be necessary • relatively long construction time
Concrete cantilever wall	✓		6 ft – 30 ft (2 m – 9 m)	0.4H – 0.7H[3]	1/500	• durable • requires smaller quantity of select backfill as compared to MSE walls • concrete can meet aesthetic requirements	• deep foundation support may be necessary • relatively long construction time
Concrete counterfort wall	✓		30 ft – 60 ft (9 m – 18 m)	0.4H – 0.7H[3]	1/500	• durable • requires smaller quantity of select backfill as compared to MSE walls • concrete can meet aesthetic requirements	• deep foundation support may be necessary • relatively long construction time
Concrete crib wall	✓		6 ft – 35 ft (2 m – 11 m)	0.5H – 0.7H	1/300	• does not require skilled labor or specialized equipment • rapid construction	• difficult to make height adjustments in field
Metal bin wall	✓		6 ft – 35 ft (2 m – 11 m)	0.5H – 0.7H	1/300	• does not require skilled labor or specialized equipment • rapid construction	• difficult to make height adjustments in field • subject to corrosion in aggressive environment
Gabion wall	✓		6 ft – 25 ft (2 m – 8 m)	0.5H – 0.7H	1/50	• does not require skilled labor or specialized equipment	• need adequate source of stone • construction of wall requires significant labor
MSE wall (precast facing)	✓		10 ft – 65 ft (3 m – 20 m)	0.7H – 1.0H	1/100	• does not require skilled labor or specialized equipment • flexibility in choice of facing	• requires use of select backfill • subject to corrosion in aggressive environment (metallic reinforcement)
MSE wall (modular block facing)	✓		6 ft – 20 ft (2 m – 7 m)	0.7H – 1.0H	1/200	• does not require skilled labor or specialized equipment • flexibility in choice of facing • blocks are easily handled	• requires use of select backfill • subject to corrosion in aggressive environment (metallic reinforcement) • positive reinforcement connection to blocks is difficult to achieve
MSE wall (geotextile/geogrid/ welded wire facing)	✓	✓	6 ft – 50 ft (2 m – 15 m)	0.7H – 1.0H	1/60	• does not require skilled labor or specialized equipment • flexibility in choice of facing	• facing may not be aesthetically pleasing • geosynthetic reinforcement is subject to degradation in some environments

Notes:

(1) ROW requirements expressed as the distance (as a fraction of wall height, H) behind the wall face where fill placement is generally required for flat backfill conditions, except where noted.
(2) Ratio of the difference in vertical settlement between two points along the wall to the horizontal distance between the points.
(3) ROW requirement given is the typical wall base width as a fraction of wall height, H.

System Type	Perm.	Temp.	Cost Effective Height Range	Required ROW[3]	Lateral Movements	Water Tightness	Advantages	Disadvantages
Sheet pile wall	✓	✓	up to 15 ft (5 m)	None	large	fair	• rapid construction • readily available	• difficult to construct in hard ground or through obstructions
Soldier pile/ lagging wall	✓	✓	up to 15 ft (5 m)	None	medium	poor	• rapid construction • soldier beams can be drilled or driven	• difficult to maintain vertical tolerances in hard ground • potential for ground loss at excavated face
Slurry (diaphragm) wall	✓	✓	10 ft to 80 ft (6 m – 24 m)[1]	None[4]	small	good	• can be constructed in all soil types or weathered rock • watertight • wide range of wall stiffness	• requires specialty contractor • significant spoil for disposal • requires specialized equipment
Tangent pile wall	✓	✓	10 ft to 30 ft (3 m – 9 m) 20 ft to 80 ft (6 m – 24 m)[1]	None[4]	small	fair	• adaptable to irregular layout • can control wall stiffness	• difficult to maintain vertical tolerances in hard ground • requires specialized equipment • significant spoil for disposal
Secant pile wall	✓	✓	10 ft to 30 ft (3 m – 9 m) 20 ft to 80 ft (6 m – 24 m)[1]	None[4]	small	fair	• adaptable to irregular layout • can control wall stiffness	• requires specialized equipment • significant spoil for disposal
Soil mixed wall	✓	✓	20 ft to 80 ft (6 m – 24 m)[1]	None[4]	small	fair	• adaptable to irregular layout	• requires specialized equipment • relatively small bending capacity
Anchored wall	✓	✓	15 ft to 65 ft (5 m – 20 m)[2]	0.6H + anchor bond length	small to medium	N/A	• can resist large horizontal pressures • adaptable to varying site conditions	• requires skilled labor and specialized equipment • anchors may require permanent easements
Soil nail wall	✓	✓	10 ft to 65 ft (3 m – 20 m)	0.6H – 1.0H	small to medium	N/A	• rapid construction • adaptable to irregular wall alignment	• nails may require permanent easements • difficult to construct and design below water table
Micropile wall	✓		N/A	Varies	N/A	N/A	• does not require excavation	• requires specialty contractor

Notes:

(1) Height range given is for wall with anchors.
(2) For soldier pile and lagging wall only.
(3) ROW requirements expressed as the distance (as a fraction of wall height, H) behind the wall face where wall anchorage components (i.e., ground anchors and soil nails) are installed.
(4) ROW required if wall includes anchors.

Figure 17.2-A — SYSTEM SELECTION FOR FILL APPLICATIONS
(Continued)

17.2.2.2 CIP Concrete Cantilever Walls

CIP concrete cantilever walls are best-suited for sites characterized by good bearing material and small anticipated long-term total and differential settlement. If bearing or settlement may be a problem, the semi-gravity walls can be pile supported. This adds to the cost, especially relative to a MSE wall. However, for short wall lengths, the CIP concrete cantilever wall may be the most cost-effective selection.

An important advantage is that these walls do not require special construction equipment, wall components or specialty contractors. They can be up to 30 ft (9 m) in height, although most are less than 20 ft (6 m) in height. The footing for these walls is normally ½ to ⅔ the wall height.

CIP concrete cantilever walls can be used in cut slope locations. In this case, the slope behind the face of the wall requires excavation to provide clearance for the construction of the wall footing. Typically, excavation slopes are no steeper than 1H:1V, which can result in significant excavations in sloped areas. In this case, either shoring systems could be required to minimize slope cuts or alternative wall types may be more suitable.

17.2.2.3 Gabion Wall

Gabion walls are constructed by hand or machine placing rock in galvanized wire baskets. This labor-intensive construction method is most cost effective where the size of the wall is relatively small, the length is limited and rock is locally available. Maximum heights are normally less than 15 ft (4.5 m).

Gabion walls can be desirable where equipment access is limited (e.g., along a stream at the bottom of a roadway slope). This wall type can also be used for emergency repairs where slope failures have occurred, until a more permanent wall systems can be designed and constructed.

Corrosion of the wire baskets is an important design consideration. Either polyvinyl chloride (PVC) coatings or increasing the basket wire size can be used to mitigate the corrosion potential.

17.2.2.4 Rockery Walls

Rockeries are typically constructed by stacking large individual rocks to create a wall. Rockery walls are normally limited to 10 ft (3 m) in height and are relatively inexpensive if large rock is locally available. The wall is constructed as the fill is raised behind the wall. A granular filter is used between the rock and the fill to prevent migration of fill through the rock. Rockeries can also be used in cut slope locations. In this case, the rockery often serves as an erosion protection layer.

The FHWA *Rockery Design and Construction Guidelines* provides methods for design rockery walls for static and seismic loading. This FHWA Manual includes construction and construction inspection guidelines, as well as a guide specification.

17.2.2.5 Prefabricated Modular Walls

Prefabricated modular walls include concrete and metal bin walls and concrete crib walls. At this time, these types of walls are not commonly used by MDT but may occasionally be advantageous. Because the components are prefabricated before delivery to the field, prefabricated modular walls may be desirable where the time to build the wall is limited.

17.2.2.6 Other Types

MDT has used other fill wall types. These may merit consideration where the more common wall types are not feasible because of technical, cost or scheduling reasons.

17.2.3 Cut Walls

17.2.3.1 Nongravity Cantilever (Sheet Pile) Walls

Sheet pile walls are normally driven or vibrated into the ground with a pile driving hammer and, therefore, are most suitable at sites where driving conditions are amenable to pile driving. If there is uncertainty whether the sheet pile can be driven into the ground, part of the design process may require performing a driveability analysis. Sites with shallow rock or consisting of significant amounts of cobbles and boulders are not suitable for sheet pile driving.

Generally, the sheet pile is driven to a depth of 2 times the exposed height to meet stability requirements. Most sheet pile walls are 10 ft to 15 ft (3.0 m to 4.5 m) or less in height. Although higher walls are possible, the structural design and installation requirements increase significantly.

17.2.3.2 Soldier Pile Walls

Soldier pile walls involve installing H-piles every 8 ft to 10 ft (2.4 m to 3 m) and spanning the space between the H-piles with lagging. The H-piles are usually installed by grouting the H-pile into a drilled hole; however, they can also be installed by driving. There are several advantages of installing the H-pile by drilling rather than vibrating or impact driving:

- wall alignment tolerances are easier to meet,
- the potential for driving refusal is avoided, and
- the vibrations associated with vibratory or impact driving are avoided.

However, for temporary application, driven soldier piles are sometimes used.

The depth of the soldier pile is similar to the sheet pile wall (i.e., about two times the exposed height). Lagging can be either timber or concrete panels. For temporary applications, Contractors will often use steel plates for lagging. For most permanent soldier pile walls, a concrete facing is cast in front of the soldier piles and lagging after the wall is at full height. Various architectural finishes can be used for the facing.

17.2.3.3 Anchored Walls

Anchored walls are essentially the same as a sheet pile or soldier pile wall but extend beyond the normal height limits of a cantilever wall through the use of ground anchors. Ground anchors consist of a bar, wire or strand that is grouted into a nearly horizontal borehole and then tensioned to provide a reaction force at the wall face. These anchors are typically located at 8-ft to 10-ft (2.4-m to 3-m) vertical spacing at each H-pile for soldier pile walls. The anchor for a sheet pile wall is usually attached to a waler at the face of the wall and, therefore, vertical and horizontal spacing is more flexible. Each anchor is normally tested to confirm its capacity. Specialized equipment is required to install and test the anchors, resulting in a higher cost relative to soldier pile walls without anchors.

Anchored walls can be built to heights of over 100 ft (30 m). An important consideration for this wall type can be the subsurface easement requirements for the anchoring system. The upper row of anchors can extend a distance equal to the wall height plus up to 40 ft (12 m) behind the face of the wall. In some cases, deadman anchor blocks or an embedded wall can be used in lieu of grouted anchors.

17.2.3.4 Soil Nail Walls

A soil nail wall involves grouting large diameter rebar (e.g., #10 (#32M) or larger) into the soil at 4-ft to 6-ft (1.2-m to 2-m) spacing vertically and horizontally. The length of the rebar will typically range from 0.7 times the wall height to 1.0 times the wall height or more. This wall type has been installed to heights of 60 ft (18 m) or more. The facing for the soil nail wall is typically covered with vertical drainage strips located between the nails and then covered with shotcrete. A permanent facing is often cast in front of the shotcrete wall. A recent trend has been to use "sculpted" shotcrete walls formed to look like rock in areas where aesthetics are critical.

Specialty contractors are required when constructing this wall type. Soil nail walls can be difficult to construct in certain soil and groundwater conditions. For example, where seeps occur within the wall profile or in relatively clean sands and gravels, the soil may not stand at an exposed height for a sufficient time to install nails and apply shotcrete.

17.2.3.5 Other Types

MDT has used other cut wall types. These may merit consideration where the more common wall types are not feasible because of technical, cost or scheduling reasons.

17.2.4 <u>Factors to Consider in Wall-Type Selection</u>

In addition to the wall-specific characteristics discussed in Sections 17.2.2 and 17.2.3, the selection of the optimum type of earth retaining system depends on a number of factors involving both design and construction considerations. The FHWA *Earth Retaining Structures Manual* provides additional information related to considered factors. The final selection may require coordination with the Bridge Bureau, Road Design Section and/or Environmental Services Bureau. These discussions should occur early in the project development process.

17.3 GEOTECHNICAL DESIGN

17.3.1 General

The basic design of earth retaining systems involves determining earth pressures that will be imposed on the wall, and then evaluating the response of the wall to these pressures. For most walls, the evaluation of response to pressure must consider the external stability of the wall (e.g., sliding, overturning and bearing stability). Internal stability checks also must be performed to confirm that the wall will meet force demands. The internal stability check can range from evaluating the pullout capacity of soil nails and MSE wall reinforcing to the evaluation of bending stresses in CIP cantilever walls. As part of the design process, the global stability of the retaining wall is assessed by evaluating the potential for the sliding of the slope beneath or through the wall.

The FHWA *Earth Retaining Structures Manual*, plus other FHWA manuals on the design of MSE, soil-nail and anchored walls, provide guidance for the geotechnical design of earth retaining systems. Another reference for the geotechnical design of earth retaining systems is the current edition of the AASHTO *LRFD Bridge Design Specifications*. Section 3 of the *AASHTO LRFD Specifications* provides guidance on the determination of earth pressures on retaining walls; Section 11 summarizes design requirements for gravity and semi-gravity, non-gravity cantilever, anchored, MSE and prefabricated modular walls. The guidance in the *AASHTO Specifications* can be applied within the context of Allowable Stress Design (ASD) methods currently used by the Geotechnical Section.

Figure 17.3-A provides a summary of the engineering evaluations that are typically conducted for fill and cut walls. This summary presents the data required for analysis. Chapters 8 and 9 present the MDT methods for conducting field explorations and laboratory testing.

17.3.2 Design Methodology

The design methodology used for earth retaining structures is in a state of transition as State Highway Departments change from the Allowable Stress Design Methods they have historically used to the Load and Resistance Factor Design (LRFD) methods given in the current *AASHTO Specifications*. The transition from ASD to LRFD has been somewhat difficult for walls because of the confusion that often occurs between load and resistance components of the wall. At the current time, FHWA in their letter dated June 28, 2000, has indicated *"All new culverts, retaining walls, and other standard structures on which States initiate preliminary engineering after October 1, 2010, shall be designed by LRFD Specifications, with the assumption that the specifications and software for these structures are "mature" at this time."*

17.3.2.1 MDT Policy

MDT has adopted a policy based on the FHWA directive to postpone implementation of LRFD methods for all new earth retaining systems until after the October 1, 2010 date. For designs initiated before October 1, 2010, the geotechnical designer may complete the geotechnical wall design process based on the Allowable Stress Design (ASD) methodology in the current version of the AASHTO *Standard Specifications for Highway Bridges.*

Fill Walls	
Engineering Evaluations	**Required Data for Analysis**
• internal stability • external stability • limitations on rate of construction • settlement • horizontal deformation • lateral earth pressures • bearing capacity • chemical compatibility with soil, groundwater and wall materials • pore pressures behind wall • borrow source evaluation (available quantity and quality of borrow soil) • liquefaction • potential for subsidence (karst, mining, etc.) • constructibility • scour	• subsurface profile (soil, ground water, rock) • horizontal earth pressure coefficients • interface shear strengths • foundation soil/wall fill shear strengths • compressibility parameters (including consolidation, shrink/swell potential and elastic modulus • chemical composition of fill/foundation soils • hydraulic conductivity of soils directly behind wall • rate of consolidation parameters • geologic mapping including orientation and characteristics of rock discontinuities • design flood elevations • seismicity
Cut Walls	
Engineering Evaluations	**Required Data for Analysis**
• internal stability • external stability • excavation stability • dewatering • chemical compatibility of wall/soil • lateral earth pressure • down-drag on wall • pore pressures behind wall • obstructions in retained soil • liquefaction • seepage • potential for subsidence (karst, mining, etc.) • constructibility	• subsurface profile (soil, ground water, rock) • shear strength of soil • horizontal earth pressure coefficients • interface shear strength (soil and reinforcement) • hydraulic conductivity of soil • geologic mapping including orientation and characteristics of rock discontinuities • seismicity

Figure 17.3-A — ENGINEERING EVALUATIONS/GEOTECHNICAL DATA FOR EARTH RETAINING SYSTEMS

17.3.2.2 LRFD vs ASD

Although MDT policy is to use ASD methodologies for the immediate future, the project geotechnical specialist is permitted to use LRFD methods for retaining wall design on a case-by-case basis. The LRFD methodology involves the separation of load-and-resistance factors, rather than the use of composite factor-of-safety values in ASD. Although the load-and-resistance factors are identified in the *AASHTO LRFD Specifications*, the derivation of these factors is not always intuitive. Given the uncertainties associated with the use of LRFD methods for retaining wall design, it will be necessary to check the initial LRFD design results using allowable stress design methods. In principle, these two design methods should yield consistent designs.

17.3.3 Design Steps

The design of an earth retaining system should follow a systematic sequence of steps, as summarized below. Refer to the FHWA *Earth Retaining Systems Manual* for specific discussions for each Step:

1. Basic Requirements. Determine the wall geometry, aesthetics, project constraints (e.g., right-of-way, environmental, utilities) and wall function.

2. Investigation and Testing. Conduct geotechnical investigation and laboratory testing as discussed in Chapters 8 and 9 of this *Manual*. Exploration depths and locations will change for different walls; therefore, it is useful to have a preliminary estimate of possible wall-types when the geotechnical explorations are planned. If the wall type changes during later phases of design, it may be necessary to conduct additional field explorations and laboratory testing.

3. Preliminary Selections. Make a preliminary selection of the wall type and geometry.

4. Earth Pressure. Evaluate the earth pressure following the recommendations in FHWA *Earth Retaining Structures Manual* and in consideration of the discussions in Section 17.3.4 of this *Manual*.

5. Stability Checks. Perform global and external stability checks for slope stability below or through the walls and for sliding, overturning and bearing of the wall as discussed in Section 17.3.5 of this *Manual*.

6. Internal Stability Checks. Perform internal stability check for components including bending stress in structural components, pullout of MSE reinforcing and anchor support system components.

7. Settlement/Movement. Check settlement and wall movements to develop earth pressures and resulting from imposed loads of the wall system.

8. Drainage. Design the wall drainage as discussed in Section 17.3.4.2.7 of this *Manual*.

17.3.4 Earth Pressure Computations

The earth pressure that will develop on the wall includes both active and passive pressures. The determination of these pressures will differ according to soil and groundwater conditions and the wall movement, configuration and response to load. The following Sections summarize the soil and groundwater considerations during earth pressure evaluations. This summary is followed by a discussion of other factors affecting earth pressure determination. Equations for estimating the active, at-rest and passive earth pressures are found in the FHWA *Earth Retaining Systems Manual*.

17.3.4.1 Geotechnical Properties and Groundwater Conditions

Determining soil strength parameters and groundwater conditions will be one of the first important tasks. These are used to estimate earth pressures and to evaluate global and external (i.e., sliding, overturning, bearing) stability. The potential for both short- and long-term loading must be evaluated. Consider the following factors in this process:

1. Loading. Under most loading conditions, use the long-term, drained strength parameters to determine earth pressures and to evaluate global and external stability. Exceptions are for earthquake loading and for end-of-construction conditions, in which short-term, undrained conditions are appropriate. Conduct global stability evaluations for both short- and long-term conditions.

2. Fill Walls. For fill walls, the backfill will often consist of granular materials with a low fines content (e.g., < 15%). The friction angle for granular backfill can be estimated using grain-size characteristics and relative density correlations, based on the requirements of the backfill material as specified in the *MDT Standard Specifications*. Friction angles range from 33° to 37° for backfills typically used by MDT. If materials with greater than 30% fines will be used for backfill, then conduct laboratory tests to determine the short- and long-term strength parameters, including the friction angle and the cohesion intercept.

3. Cut Walls. Soil conditions for cut walls will be determined by the geology of the site. Soil strengths should be characterized for each primary soil layer. Generally, the long-term effective stress friction angle and cohesion value are used in design. The exceptions are the same as described in Item #1 for short-term earthquake loading and end-of-construction conditions. Normally, the undrained strength of the soil can be used for seismic design. For temporary walls in stiff, over-consolidated clays, it is normally best to evaluate earth pressures using both drained and undrained strength parameters. The design is then based on the largest wall pressure, because of the difficulties in selecting engineering strength parameters to use for design.

4. Drainage. Nearly all walls need to include provisions for drainage, which can range from geo-composite drainage materials located directly behind the face of the wall to the use of highly permeable backfill with underdrain systems. Identify the location of the phreatic surface at equilibrium, because the location of the water table for long-term conditions will affect both the loading on the wall and the strength of the soil. Also, address the potential for changes in groundwater elevation.

17.3.4.2 Other Factors Affecting Earth Pressure Determination

The earth pressures used in the design of earth retaining systems are impacted by several factors in addition to strength parameters and groundwater conditions. The following Sections summarizes these factors.

17.3.4.2.1 *Wall Deformation*

Determination of the wall movement is necessary to develop the active pressure behind the wall or passive earth pressure in front of the wall. Walls that are constrained from movement are designed to resist the at-rest earth pressure. The following apply:

1. Active Earth Pressure Conditions. Active earth pressures develop when the wall rotates or translates outward from the supported soil. Walls that move outward are generally referred to as flexible walls. The amount of movement to develop this condition is very small, typically 0.001 to 0.01 times the exposed height of the wall. The FHWA *Earth Retaining Structures Manual* provides a summary of the movement required for different soil types.

2. At-Rest Pressure Conditions. At-rest earth pressure conditions develop when the wall is restrained from movement. This condition can develop for integral abutment walls, cut-and-cover tunnel walls and braced walls. Walls that are constructed at sites with cohesive soil will often be designed for at-rest pressures, or greater if there are slopes above the wall and there is concern with long-term creep of the soil.

3. Passive Earth Pressure Condition. Passive earth pressure develops when the wall moves into the soil or at bridge abutments during temperature loading on the structure or during seismic loading. The deformation necessary to develop passive earth pressures (0.01 to 0.05 times the wall height) is generally an order of magnitude higher than the deformation to mobilize active earth pressure. The FHWA *Earth Retaining Structures Manual* provides a summary of wall movements for a range of soil types. The method of wall construction also has some effect on the amount of movement. For example, a driven sheet pile wall requires smaller amounts of deformation to mobilize passive pressures than a slurry wall or secant pile wall. An approximate approach commonly used in design is to reduce the passive earth pressure by a factor of 1.5 to 2, in recognition of the larger deformations required to develop the full passive earth pressure resistance.

17.3.4.2.2 *Ground Slope*

The slope above and below the wall will significantly affect static earth pressures. Slopes above the wall will increase active earth pressures; slopes at the toe of the wall will decrease passive earth pressures. Equations and charts in the FHWA *Earth Retaining Structures Manual* can be used to determine the effects of slope angle on earth pressures. As a general rule, the slope behind or in front of the wall should be no steeper than 2H:1V.

17.3.4.2.3 *Wall Friction*

Frictional resistance will develop at the interface between the soil and retaining wall This friction can influence the earth pressure determination. The effect is significant for passive earth pressure computations, but can be generally ignored for active pressure determination. The FHWA *Earth Retaining Structure Manual* provides further guidance on wall friction.

17.3.4.2.4 *Tension Cracks*

Earth pressures in cohesive soils are initially reduced by the undrained strength of the soil, potentially resulting in very low, active earth pressures. These low pressures should not normally be used in design except for temporary loading conditions. For these cases, consider the potential development of tension cracks filled with water. Tension cracks that fill with water will soften the surrounding soil and result in an increase in active earth pressures. It is difficult to anticipate when the tension crack will form and fill with water and, therefore, it is generally best to design for long-term (drained) strength conditions.

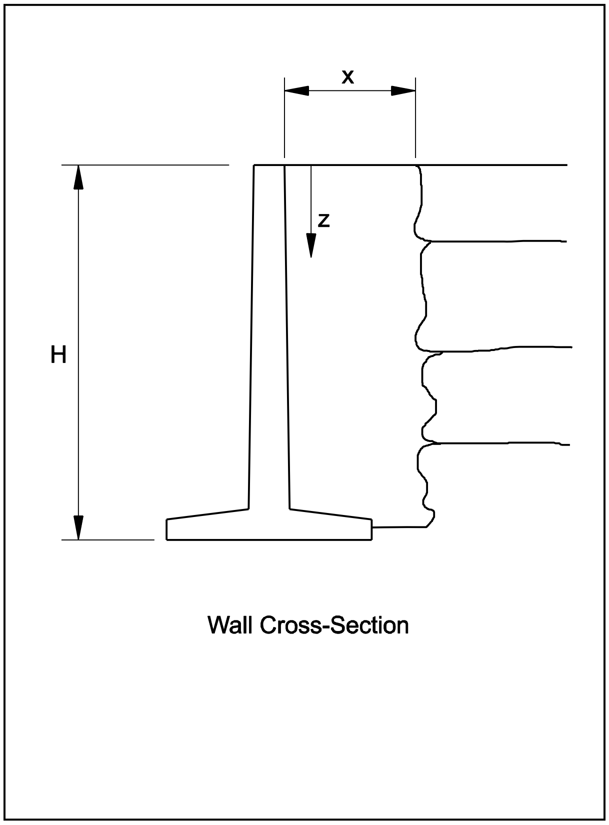
17.3.4.2.5 *Silo Effect*

If a retaining wall is constructed in front of a stable rock face or an existing wall (with granular fill placed between the new wall and the existing structure or rock face (see Figure 17.3-B)), the wall may not develop active earth pressures because of the effects of the adjacent wall or rock face. Using conventional earth pressure design could result in an overly conservative design. Methods provided in Figure 17.3-B can be used to estimate the lateral "silo" pressures on these retaining walls.

17.3.4.2.6 *Backfill Compaction and Surcharge Loads*

Large increases in active earth pressure can occur near the top of retaining walls from compaction equipment or the placement of surcharge loads. If a temporary or permanent load is located within a distance of one-half the wall height, consider the effects of surcharge loading. Loads from existing buildings must be considered if they are within a horizontal distance from the wall equal to the wall height. The *FHWA Earth Retaining Structures Manual* provides equations for estimating the effects of pressure and line loads. In most cases, traffic surcharge can be represented by assuming 2 ft (0.6 m) of fill weighing 125 pcf (2000 kg/m^3).

Pressures induced by compaction equipment can extend to depths of 20 ft (6 m) or more. The depth of influence is determined by the total static and dynamic forces exerted by the roller drum and the stiffness of the wall. Normally, this potential issue can be avoided by requiring small walk-behind compaction equipment within 5 ft (1.5 m) of the wall. Procedures described in NAVFAC (1982) and in the ASCE *Journal of Geotechnical Engineering* article "Estimation of Earth Pressures Due to Compaction" (Duncan et al., 1991) can be used to determine compaction forces for sands and clays, where more specific pressure estimates are required.

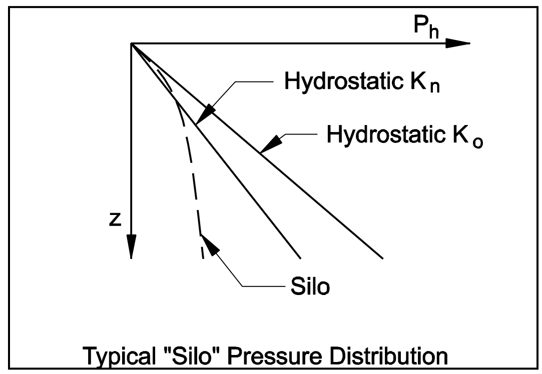


Use the following equation to estimate P_{sh} (Spangler and Handy, 1984):

$$p_{sh} = \frac{\gamma x}{2 \tan \delta}\left[1 - \exp\left(-2K\frac{z}{x}\tan\delta\right)\right]$$

where:

- P_{sh} = horizontal silo pressure
- x = distance between the walls
- z = depth at which P_{sh} is calculated
- K = coefficient of lateral earth pressure
- γ = unit weight of the fill
- δ = angle of friction between the wall and fill



In the absence of specific test data, estimate the wall friction angle, δ.

Use $K = K_o = 1\text{-}\sin\phi'$ for walls with no-movement criterion where ϕ' is the backfill friction angle. In this case, small variations in placement procedures such as localized compaction effects and slight variations in density may induce significant variations from the estimated "silo" pressure. A conservative approach could be to use a smaller ϕ' value in calculating K so as to obtain an upper envelope to the expected pressure values (Frydman and Keissar, 1987).

Use $K = K_n$ values in the following table (after Frydman and Keissar, 1987) for walls expected to mobilize active state. Under active conditions, the estimated "silo" pressure are less sensitive to small variations in placement procedures. Progressive failure, which occurs within the soil mass adjacent to the wall during its movement, may resulting a decrease in ϕ', and this decreased value should be used in estimating the pressure acting on the wall.

Value of K_n

Wall Friction Angle δ (deg)	**Backfill Friction Angle, ϕ' (degrees)**						
	28	**30**	**32**	**34**	**36**	**38**	**40**
0	0.3610	0.3333	0.3073	0.2827	0.2596	0.2379	0.2174
5	0.3632	0.3351	0.3086	0.2838	0.2605	0.2386	0.2180
10	0.3701	0.3406	0.3130	0.2873	0.2633	0.2408	0.2198
15	0.3838	0.3512	0.3213	0.2938	0.2684	0.2449	0.2230
20	0.4093	0.3701	0.3357	0.3049	0.2770	0.2515	0.2282
25	0.4664	0.4077	0.3621	0.3241	0.2913	0.2623	0.2364
30	—	—	0.4265	0.3635	0.3179	0.2812	0.2501

Figure 17.3-B — ESTIMATION OF "SILO" PRESSURES

17.3.4.2.7 *Wall Drainage*

Drainage systems for fill and cut wall systems are typically designed using one or more of the following components:

- free-draining granular soil backfill,
- sloping or horizontal drains, and/or
- vertical drains.

The drainage system design depends on wall type, backfill and/or retained soil type and groundwater conditions. Drainage system components (e.g., granular soils, prefabricated drainage elements, filters) are usually sized and selected based on local experience, site geometry and estimated flows, although detailed design is occasionally warranted. Drainage systems are also occasionally used to maintain reasonably constant moisture conditions in soils near the wall that are susceptible to volume change upon wetting/drying (i.e., expansive or collapsible soils).

Drainage systems may be omitted if the wall is designed to resist full water pressure. Designs to resist full water pressure can significantly increase the cost of the wall. This approach is used primarily where the project requires that the wall system be watertight (e.g., where groundwater drawdown in the retained soil is prohibited or undesirable).

The following applies to the drainage for specific wall types:

1. <u>CIP Concrete Cantilever Walls</u>. CIP concrete cantilever walls and fill used behind MSE walls should be constructed with free-draining backfill. It may be necessary to use a geotextile on the exposed surface of cut slopes to prevent fines from migrating into the backfill and potentially clogging the voids and negatively impacting the drainage characteristics of the fill.

2. <u>Gabion/Rock Walls</u>. Gabion walls and rock walls are generally considered permeable and do not typically require wall drains. However, a geotextile should be considered for locations where fines could migrate through the rock.

3. <u>Soil Nail Walls</u>. Soil nail walls should have composite drain material at the face of the wall between the nails. The drain material should be connected to weep holes or to an underdrain system.

4. <u>Cantilever/Anchored Walls</u>. Cantilever and anchored walls using lagging should have composite drainage material attached to the lagging facing prior to casting permanent facing. Walls without facing or walls using precast panels do not typically require composite drainage materials, provided that water can pass through the lagging.

17.3.4.2.8 *Utilities*

The effects of new utilities, utility repairs (excavation) and/or failures may place on the wall is an important design consideration. The impacts of water line failure are of special concern. For this reason and as practical, do not locate utilities or surface drainage structures within the retaining wall backfill. The following apply:

1. Do not use MSE, soil nail and anchored walls where utilities must remain in the reinforced zone. Utilities that are located within the reinforced zone should be considered inaccessible for replacement or maintenance, unless studies confirm that exposing the utility will not affect the stability of the retaining wall.

2. Before allowing utilities to be located at the toe of the wall, conduct design checks to confirm that the wall will not be adversely affected if the soil at the toe of the wall is removed to expose the utility. If the utility will affect the wall, either do not locate the utility at the toe of the wall or select an alternative wall type (e.g., non-gravity cantilever, anchored wall).

17.3.4.2.9 *Walls on Slopes*

Walls located on slopes should usually include a horizontal bench at the wall face at least 4 ft (1.2 m) wide to provide access for maintenance. Consider the effects of the slope in the bearing capacity analyses of gravity walls. Significant reductions in bearing capacity will usually occur if there is a slope on the downside of the wall.

Likewise, both active and passive pressures are affected by the slope above and below the wall. Active pressures resulting from slopes above a wall can be significantly higher than would occur for level ground conditions. Passive pressures on a slope will be much lower than those for level ground conditions. The FHWA *Earth Retaining Structures Manual* provides guidance on these effects.

17.3.4.2.10 *Minimum Embedment*

All retaining walls should be embedded so that the bottom of the wall is below the maximum depth of the anticipated frost penetration. Also, consider the following requirements:

- Walls located near streams or rivers should be designed for potential scour.
- Embedment depth should consider the potential for utility excavations in the future.
- MSE walls should meet the provisions in the FHWA *Mechanically Stabilized Earth Walls Manual*.

17.3.4.2.11 *Seismic Loading*

See Chapter 19 for a discussion on seismic earth pressures.

17.3.5 Stability Check During Wall Design

The project geotechnical specialist must check the stability of the wall for global stability and may need to evaluate external stability. External stability analyses are used in design to evaluate the ability of the wall to resist lateral pressures applied by surcharges, the backfill and the retained soil. The possible modes of external instability that are generally considered include:

1. Sliding. Sliding may occur when the lateral pressure on the wall exceeds the available lateral resistance along the base of the wall. The lateral resistance may have several components including frictional resistance and adhesion that can be mobilized between the base of the wall and the underlying wall foundation soil or rock and passive resistance from the soil in front of the wall or adjacent to any foundation. Sliding stability is typically a concern for standard cantilever walls, MSE walls and soil nail walls.

2. Overturning. Overturning may occur when the driving moments (generated by the lateral pressure against the wall) are in excess of the resisting moments (generated by the self-weight of the wall and wall/soil interface friction). These checks are also conducted for standard cantilever walls, MSE walls and soil nail walls. The flexibility of the MSE wall and soil nail wall likely prevents an overturning failure; however, an MSE or nail wall designed to meet overturning requirements will normally avoid the potential for localized distortions.

3. Bearing Capacity. Bearing capacity failure may occur when the maximum bearing pressure along the wall base exceeds the allowable bearing pressure of the wall foundation soil or rock. Checks are made for standard cantilever walls, MSE walls and soil nail walls.

4. Global Stability. Global instability may occur if the shear stresses along a deep-seated surface under the wall exceed the soil shear strength along the same surface. Both circular and non-circular surfaces should be considered. This type of check applies for all wall types.

During the transition from Allowable Stress Design to LRFD methods, factors of safety will still be used as a basis for design or as a check on the LRFD methodology. Figure 17.3-C summarizes factors of safety that must be satisfied to meet global and external stability requirements for wall designs.

After the LRFD design method has been fully implemented, the resulting capacity-to-demand ratio, after load-and-resistance factors have been applied, must be greater than 1.0 for the stability checks. For overall global stability, use a load factor of 1.0. The composite resistance factor should be 0.75 (i.e., factor of safety of 1.3). If the abutment or retaining wall is considered critical, reduce the resistance factor to 0.65 (i.e., factor of safety of 1.5).

17.3.6 Settlement Evaluations

Settlement checks will be required for some wall types (e.g., CIP concrete cantilever walls, MSE, prefabricated modular walls). Also conduct settlement checks for nongravity cantilever, anchored and soil nail walls if changes in grade occur as part of wall construction.

Figure 17.3-D summarizes the typical allowable settlement guidelines. More stringent settlement tolerances may be required to meet engineering and aesthetic objectives.

Stability	Factor of Safety in Allowable Stress Design	Comments
Global Stability (Fill Walls)	1.5	These analyses involve stability for failure surfaces below the base of the wall.
Global Stability (Cut Walls)	1.5	Selection of factor of safety based on risk and consequences of failure.
Sliding	1.5	Appropriate for CIP concrete cantilever, MSE and soil nail walls.
Overturning	2.0	Appropriate for standard cantilever, MSE and soil nail walls.
Bearing Capacity	2.5 to 3	Appropriate for standard cantilever, MSE and soil nail walls.

Figure 17.3-C — FACTORS OF SAFETY TO USE FOR ALLOWABLE STRESS DESIGN

17.3.7 Wall-Specific Design Requirements

Each wall type involves several wall-specific considerations during design and construction, as discussed in the following Sections.

17.3.7.1 CIP Concrete Cantilever Walls

MDT does not recommend using shear keys for CIP walls, because the effectiveness of shear keys is not reliable. For CIP walls on rock, the wall should be embedded at least 6 in (150 mm) into competent rock to develop sliding resistance. Dowels or rock bolts can also be used to increase the base shear of CIP walls located on rock.

17.3.7.2 Abutment Walls, Wing Walls and Curtain Walls

Design these wall for active earth pressures if the wall is backfilled before the superstructure is constructed. If the backfill is placed after the superstructure is constructed, consider using at-rest earth pressures, unless the design of the structure will allow enough movement of the wall to develop active earth pressures.

17.3.7.3 Nongravity Cantilever Walls

For permanent soldier pile walls, install H-piles in drilled holes, instead of driving or vibrating the soldier piles in place. If conditions are favorable, H-piles for temporary walls can be driven or vibrated. For permanent installations where water is present, use special care in grouting the pile in place. If controlled-density fill (CDF) is used, use the width of the H-pile in the design

Total Settlement	Differential Settlement Over 100 ft (30 m)	Action
CIP Concrete Cantilever Walls		
$\Delta H \leq$ 1 in (25 mm)	$\Delta H_{100} \leq$ ¾ in (20 mm)	Acceptable for design.
1 in (25 mm) < $\Delta H \leq$ 2½ in (65 mm)	¾ in (20 mm) < $\Delta H_{100} \leq$ 2 in (50 mm)	Ensure structure can tolerate settlement.
$\Delta H >$ 2½ in (65 mm)	$\Delta H_{100} >$ 2 in (50 mm)	Obtain approval prior to proceeding with design and construction.
Reinforced Concrete Walls, Nongravity Cantilever Walls, Anchored/Braced Walls and MSE Walls with Full-Height Precast Panels		
$\Delta H \leq$ 2 in (50 mm)	$\Delta H_{100} \leq$ 1½ in (40 mm)	Acceptable for design.
2 in (50 mm) < $\Delta H \leq$ 4 in (100 mm)	1½ in (40 mm) < $\Delta H_{100} \leq$ 3 in (75 mm)	Ensure structure can tolerate settlement.
$\Delta H >$ 4 in (100 mm)	$\Delta H_{100} >$ 3 in (75 mm)	Obtain approval prior to proceeding with design and construction.
MSE Walls with Modular (Segmental) Block Facings, Prefabricated Modular Walls and Rock Walls		
$\Delta H \leq$ 4 in (100 mm)	$\Delta H_{50} \leq$ 3 in (75 mm)	Acceptable for design.
4 in (100 mm) < $\Delta H \leq$ 12 in (300 mm)	3 in (75 mm) < $\Delta H_{100} \leq$ 9 in (225 mm)	Ensure structure can tolerate settlement.
$\Delta H >$ 12 in (300 mm)	$\Delta H_{100} >$ 9 in (225 mm)	Obtain approval prior to proceeding with design and construction.

Figure 17.3-D — SETTLEMENT GUIDELINES FOR EARTH RETAINING SYSTEMS

calculations rather than the width of the drill hole. This reduction is used because of the potential for washout of cement. For below-water installations, it may be desirable to use high-strength concrete designed for tremie applications. Full-strength concrete should be considered if the wall is being used for landslide stabilization.

17.3.7.4 Anchored Walls

Similar to nongravity cantilever walls, install H-piles in drilled holes for permanent walls, instead of driving or vibrating the soldier piles in place. Because kickout at the toe of the wall is not as critical, CDF is usually a suitable grout for dry holes or high groundwater conditions.

Install anchors at an angle of 15° to 45°. Evaluate the response of the H-pile to the vertical component of the anchor loads to confirm that the H-piles will not settle. If capacity or settlement analyses suggest that downward movement of the H-piles could occur under the anchor load, either increase the length of the H-pile or decrease the anchor load.

Permanent anchors must be tested. The FHWA *Soil Nail Walls Manual* provides a complete description of appropriate testing procedures. Typical anchor capacities range between 40 k (180 kN) and 240 k (1070 kN). Research has found that bond lengths greater than 40 ft (12 m) are not fully effective. For this reason, anchor lengths greater than 50 ft (15 m) must be approved by the Geotechnical Engineer before use. Procedures given in NAVFAC (1982) can be used to design deadman anchors.

17.3.7.5 MSE Walls

The wall supplier typically designs MSE walls. To properly design the wall, the project geotechnical specialist should evaluate the global stability of the wall and provide static and seismic active earth pressure coefficients, nominal bearing pressure and sliding resistance at the base of the wall. Also provide estimates of short- and long-term settlements of the wall under the anticipated gravity loads. When evaluating settlements, consider using a composite unit weight higher than the soil unit weight due to the reinforcing. The length of the reinforced zone can be assumed to be 0.7H for initial global stability evaluations, where H is the height of the wall. If a slope exists above the wall, increase the length of the reinforced zone to 1.0H.

The Geotechnical Section typically reviews contractor submittals demonstrating that the internal stability and external (e.g., sliding, overturning, bearing) stability are met. It is important to note that the Geotechnical Section performs a “review and comment” task (i.e., it does not have an “approval” role). Basically, this review is focused on the completeness and reasonableness of the wall supplier’s analysis (e.g., a review of the design calculations to ensure that the stability checks were in fact performed) and to ensure the analysis satisfies contract requirements (i.e. special provisions)

If piles will be located through the MSE wall, they should be installed before the MSE wall construction. For back-to-back MSE walls, the face-to-face dimension should be 1.1 times the average height of the MSE, or greater. Reinforcement can be connected at each face if the reinforcing is designed for double the load. Reinforcement from one wall can also overlap with reinforcement from the other wall if the reinforcement is not in contact.

The MSE wall supplier must provide a field demonstration that it can properly construct the wall. The supplier must be on-site during construction. For large MSE walls, the project geotechnical specialist may also be present during construction.

17.3.7.6 Prefabricated Modular Walls

These walls should normally meet internal and external stability requirements following the same approach as described for MSE walls. Because many of these walls are designed by the wall supplier, most of the same geotechnical information for MSE walls must be provided to the wall supplier.

Typically, gabion walls should be less than 15 ft (4.5 m) in height, and baskets should be positioned so that the seams are not aligned. The unit weight within the bins should normally be assumed to be no more than 80% of the effective unit weight to account for void space. Ensure the base of these walls is located below the maximum depth of frost penetration.

17.3.7.7 Soil Nail Walls

Design and construct these walls using the methods provided in the FHWA *Soil Nail Walls Manual*. Consider the following:

- When using the SNAIL software, the project geotechnical specialist should use the “allowable option” and should pre-factor the yield strength of the nails, punching shear of the shotcrete and nail adhesion. Use the unfactored cohesion and friction angle to determine the overall stability.

- When using the GOLDNAIL software, the project geotechnical specialist should use the design mode and the safety factor mode of the program with the partial safety factors identified in the FHWA *Manual for Design and Construction Monitoring of Soil Nail Walls*.

Each critical wall section should be analyzed for construction of the lift (before the nail is installed). Factors of safety should be 1.2 for noncritical walls and 1.35 for critical walls under this construction case. Typical nail spacing should range between 4 ft (1.2 m) minimum to approximately 8 ft (2.4 m) maximum.