Chapter 18

EARTH RETAINING STRUCTURES

GEOTECHNICAL DESIGN MANUAL

January 2022

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CHAPTER 18

EARTH RETAINING STRUCTURES

18.1 INTRODUCTION

ERSs are used to retain earth materials while maintaining a grade change between the front and rear of the wall (see Figure 18-1). ERSs transmit the loads (Q_1, Q_2, and p_1) to the base and to a possible internal stability reinforcement element (p_2 and p_3) to maintain stability. Typically, ERSs are expensive when compared to embankments; therefore, the need for an ERS should be carefully considered in preliminary design. An effort should be made to keep the retained soil height to a minimum. ERSs are used to support cut and fill slopes where space is not available for construction of flatter more stable slopes (see Chapter 17). Bridge abutments and foundation walls are designed as ERSs since these structures are used to support earth fills.

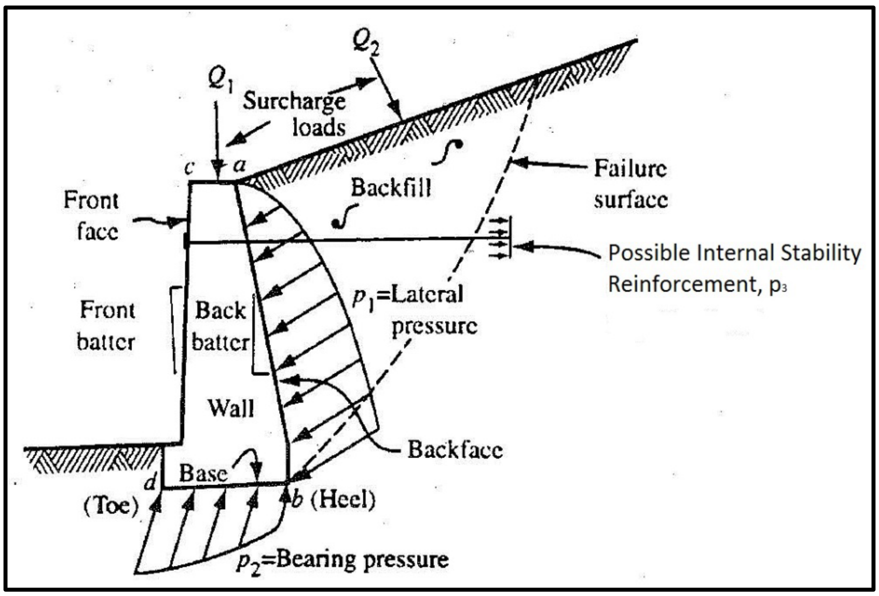


Figure 18-1, Retaining Wall Schematic
(modified Tanyu, Sabatini, and Berg (2008))

According to Tanyu, et al. (2008), ERSs are typically used in highway construction for the following applications:

- New or widened highways in developed areas
- New or widened highways at mountains or steep slopes
- Grade separations
- Bridge abutments, wing walls and approach embankments
- Culvert walls
- Tunnel portals and approaches
- Flood walls, bulkheads and waterfront structures
- Cofferdams for construction of bridge foundations
- Stabilization of new or existing slopes and protection against rockfalls
- Groundwater cut-off barriers for excavations or depressed roadways

18.2 EARTH RETAINING STRUCTURE CLASSIFICATION

There are 4 criteria for classifying an ERS:

- Load support mechanism (externally or internally stabilized walls)
- Construction concept (fill or cut)
- System rigidity (rigid or flexible)
- Service life (permanent or temporary)

All ERSs are classified using all 4 of the criteria listed above; however, the service life is not normally used since most ERSs are designed as permanent and are expected to have a minimum service life of 100 years. For example, a soldier pile and lagging wall is classified as an externally stabilized flexible cut wall, while a soil nail wall is an internally stabilized flexible cut wall. The design of temporary ERSs is discussed at the end of this Chapter. Therefore, the intermediate Sections are concerned with the design of permanent ERSs. Figure 18-2 provides a partial representation of the classification of permanent ERSs; this Figure is partial in that it does not include all of the possible types of walls available.

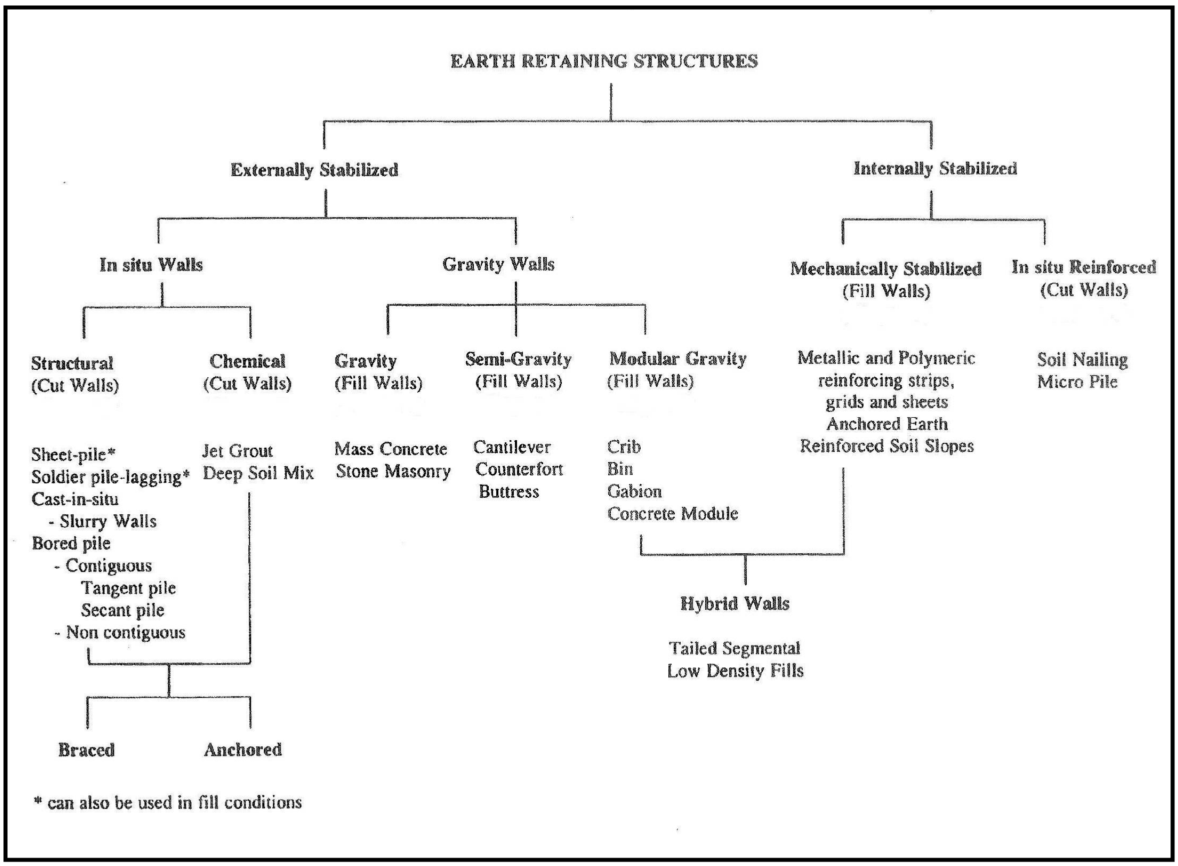


Figure 18-2, ERS Classification Chart (modified from Tanyu, et al. (2008))

18.2.1 Load Support Mechanism Classification

The load support mechanism classification is based on whether the ERS is stabilized externally or internally. Externally stabilized ERSs use an external structure against which the stabilizing forces are mobilized. Internally stabilized ERSs use reinforcements that are installed within the soil mass and extend beyond a potential failure surface to mobilize the stabilizing forces. A hybrid ERS may use both external and internal support mechanisms to achieve external stability. See Section 18.10 for more information regarding hybrid ERSs.

18.2.2 Construction Concept Classification

ERSs are also classified based on the construction method used. The construction methods consist of fill or cut. Fill construction refers to an ERS that is constructed from the base to the top of the ERS (i.e., bottom-up construction). Conversely, cut construction refers to an ERS that is constructed from the top to the base of the ERS (i.e., top-down construction). It is very important to realize the cut or fill designations refer to how the ERS is constructed, not the nature of the earthwork. For example, a prefabricated bin wall could be placed in front of a "cut" slope, but the wall would be classified as a "fill" wall since the construction is from the bottom-up.

18.2.3 System Rigidity Classification

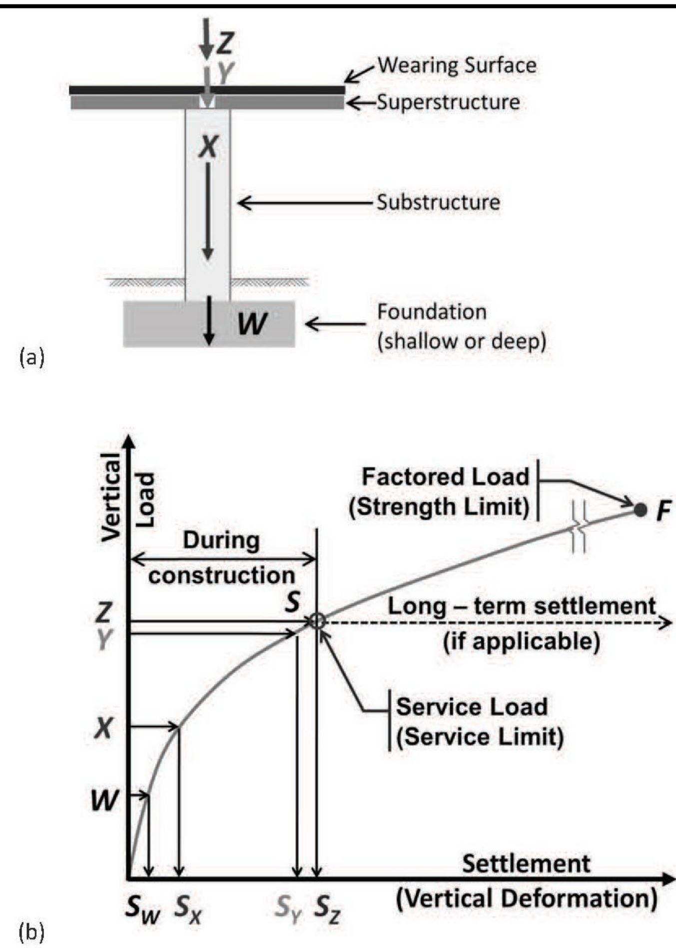
The rigidity of the ERS is fundamental to understanding the development of the earth pressures that develop behind and act on the ERS. A rigid ERS moves as a unit (i.e., rigid body rotation and/or translation) and does not experience bending deformations. A flexible ERS undergoes not only rigid body rotation and/or translation, but also experiences bending deformations. In flexible ERSs, the deformations allow for the redistribution of the lateral (earth) pressures from the more flexible portion of the wall to the more rigid portion of the wall. Most gravity type ERSs would be considered an example of a rigid wall. Almost all of the remaining ERS systems would be considered flexible.

18.2.4 Service Life Classification

The focus of this Chapter is on permanent ERS construction. According to Chapter 10, all geotechnical structures including ERS shall have a design life of 100 years. Temporary ERSs shall have a service life less than 5 years. Temporary ERSs that are to remain in service more than 5 years shall be designed as a permanent ERS. A more detailed explanation of temporary ERSs is provided at the end of this Chapter.

18.3 LRFD ERS DESIGN

The design of ERSs is comprised of 2 basic components: external and internal. External design handles overall stability, sliding, eccentricity, and bearing; while internal design handles pullout failure of soil anchors or reinforcement and structural failure of the ERS. The overall stability of an ERS is checked using the procedures outlined in Chapter 17. For ERSs supported by shallow foundations, sliding, eccentricity, and bearing are checked using Chapter 15, while those ERSs supported by deep foundations are checked using Chapter 16. All loads that affect the overall stability of an ERS shall be developed using Chapter 8, as well as the procedures outlined in AASHTO LRFD Specifications (Section 11.5 – Limit States and Resistance Factors). Where there is conflict, this Manual takes precedence over the AASHTO LRFD Specifications. According to Tanyu, et al. (2008); "In general, use minimum load factors if permanent loads increase stability and use maximum load factors if permanent loads reduce stability." The resistance factors shall be developed using Chapter 9 for Strength, Service, and Extreme Event limit states. Chapter 9 divides ERSs into three types of walls; Rigid Gravity, Flexible Gravity and Cantilever ERSs and provides examples of different types of common walls that fit within each group. In accordance with Chapter 8, the Strength and Service limit states are boundary conditions for performance of the structure under Strength and Service load conditions. The Strength limit state is evaluated to assure that the ERS will function if Strength loads are applied to the ERS. The Service limit state is evaluated for the movements induced by the Service load combinations (see Chapter 8). The movements induced by the Service loads are compared to the Performance Objectives established in Chapter 10. Depending on the requirements of a particular project, the use of the Construction-Point Concept may be used. Unlike traditional settlement calculations which assume the bridge or embankment is instantaneously placed, the Construction-Point Concept determines the settlement at specific critical construction points (see Figure 18-3). At the end of construction, the ERS shall have a front batter that either meets the Performance Objectives indicated in Chapter 10 or is vertically plumb.



Legend

W	Load after foundation construction
X	Load after pier column/wall construction
Y	Load after superstructure construction
Z	Load after wearing surface construction
S	Service Load (SLS)
F	Factored Load (Strength Limit State)

S_W	Settlement under load W
S_X	Settlement under load X
S_Y	Settlement under load Y
S_Z	Settlement under load Z

(a) Identification of critical construction points
(b) conceptual load-displacement pattern for a given foundation

Figure 18-3, Construction-Point Concept
(DeMarco, Bush, Samtani, Kulicki and Severns (2015))

All permanent ERSs shall have the external design performed by the GEOR regardless of the contracting method. If Procedural Based Construction is used, then the internal design shall be performed by the SEOR; however, if Performance-Based Construction is used, then the internal design shall be performed by the Contractor. According to Lazarte, et al. (2015),

> Procedural Based Construction – "…includes the development of a detailed set of plans and specifications to be provided in the bidding documents. In this approach, complete design details and specifications are developed so that each Contractor submitting a bid has a defined product to price, making it more straightforward … to compare pricing."
>
> Performance-Based Construction – "…*SCDOT*: (i) prepares drawings defining the geometric and aesthetic requirements for the structure, and material specifications for the components, (ii) defines performance requirements including LRFD resistance factors *(Chapter 9)*, … and deformation limits *(Chapter 10)*, and (iii) indicates the range of acceptable design and construction methods."

ERSs comprised of internal support elements use the internal resistance factors as presented in Chapter 9.

Temporary ERSs shall use the Performance Based Construction method, with the Contractor performing both the internal as well as external design. The GEOR is required to determine the feasibility (i.e., proof of concept) of particular temporary wall. The GEOR should consult the Standard Specifications to determine the types of temporary ERSs allowed.

All ERS designs must meet the requirements of the basic LRFD equation,

$$\boldsymbol{Q = \sum \gamma_i * Q_i \leq \varphi_n * R_n = R_r} \qquad \textbf{Equation 18-1}$$

Where,

Q = Factored Load
Q_i = Force Effect
γ_i = Load factor
R_r = Factored Resistance
R_n = Nominal Resistance (i.e., ultimate capacity)
φ_n = Resistance Factor

18.4 ERS SELECTION PHILOSOPHY

The selection of the type of ERS is based on numerous factors. It is possible for more than one ERS type to be applicable to a given site. Figure 18-4 provides a flow chart for determining the most appropriate type of wall for a specific location. Further, Tables 18-1 and 18-2 provide the most common cut and fill walls (see discussion above on ERS classification). The ERSs listed in Tables 18-1 and 18-2 contain walls that are typically used by SCDOT and walls that would be allowed. Written permission to use walls other than those indicated in these tables shall be obtained from the OES/GDS prior to designing the ERS. As indicated in Chapter 17 this same process shall be used to evaluate the applicability of reinforced embankments and RSSs at specific project site. Reinforced embankment or RSS may be substituted for ERS in following Subsections of this Section.

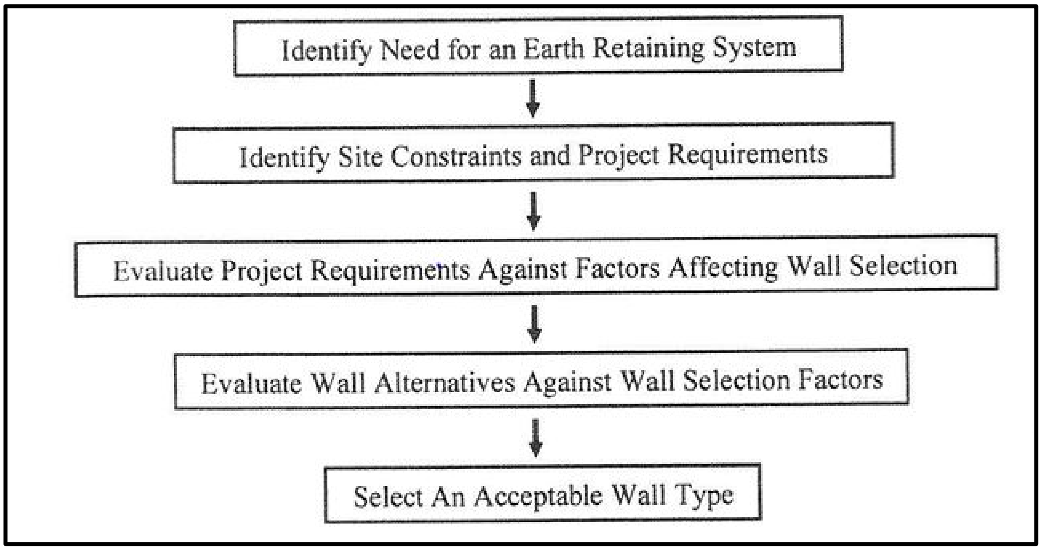


Figure 18-4, Wall Selection Flow Chart
(Tanyu, et al. (2008))

18.4.1 Necessity for ERS

As indicated in Figure 18-4, the first step in selecting an ERS type is to determine if a wall is needed. According to the SCDOT Roadway Design Manual (RDM) (2017), the need for ERSs is determined jointly by the design team which includes an experienced geo-structural engineer. Typically, ERSs are required in areas where additional ROW cannot be obtained or there are other factors (i.e., other roads, major utilities, etc.) that limit the development of stable slopes. The need for ERSs can often be determined during the DFR. It is critical to identify the need for an ERS early on in the project development process.

Table 18-1, Cut Wall Evaluation Factors
(Tanyu, et al. (2008))

	Wall Type	Application[1]	Height Range[2]	Required ROW[4]	Lateral Movements	Advantages	Disadvantages
CANTILEVERED	Sheet-pile	P/T	<16 ft	None	Large	- Rapid construction - Readily Available	- Difficult to construct in hard ground or penetrate obstructions
	Soldier Pile/Lagging	P/T	<16 ft	None	Medium	- Rapid construction - Soldier piles can be drilled or driven	- Difficult to maintain vertical tolerances in hard ground - Potential for ground loss at excavated face
	Anchored	P/T	15 - 70 ft	0.6H + abl[3]	Small-medium	- Can resist large horizontal pressures - Adaptable to varying site conditions	- Requires skilled labor and specialized equipment - Anchors may require permanent easements
IN-SITU REINFORCED	Soil-nailed	P/T	10 – 70 ft	1.0H	Small-medium	- Rapid construction - Adaptable to irregular wall alignment	- Nails may require permanent easements - Difficult to construct and design below water table
	Micropile	P	N/A	Varies	N/A	- Does not require excavation	- Requires specialty contractor

[1]P/T – Permanent and Temporary
[2]Height range based on cost effectiveness
[3]abl – Anchor Bond Length
[4]ROW requirements expressed as the distance (as a fraction of wall height, H) behind the wall face where anchorage components are installed

Table 18-2, Fill Wall Evaluation Factors
(Tanyu, et al. (2008))

	Wall Type	Application[1]	Height Range[2]	Required ROW[3]	Differential Settlement Tolerance	Advantages	Disadvantages
RIGID GRAVITY	Gravity[4]	P	3 – 10 ft	0.7H	1/500	- Durable - Requires smaller quantity of select backfill as compared to MSE walls - Can meet aesthetic requirements	- Deep foundation support may be necessary - Relatively long construction time
RIGID GRAVITY	Cantilever[4]	P	6 – 30 ft	0.7H	1/500	- Durable - Requires smaller quantity of select backfill as compared to MSE walls - Can meet aesthetic requirements	- Deep foundation support may be necessary - Relatively long construction time
RIGID GRAVITY	Counterfort[4]	P	30 – 60 ft	0.7H	1/500	- Durable - Requires smaller quantity of select backfill as compared to MSE walls - Can meet aesthetic requirements	- Deep foundation support may be necessary - Relatively long construction time
FLEXIBLE GRAVITY	Gabion	P/T	6 – 30 ft	0.7H	1/50	- Does not require skilled labor or equipment	- Need adequate source of stone - Construction of wall requires significant labor
FLEXIBLE GRAVITY	MSE Wall – precast facing	P/T	10 - 100 ft	1.0H	1/100	- Does not require skilled labor or equipment - Flexibility in choice of facing	- Requires use of select backfill - Subject to corrosion in aggressive environments (metallic reinforcement)
FLEXIBLE GRAVITY	MSE Wall – modular block facing	P/T	6 – 60 ft	1.0H	1/200	- Does not require skilled labor or equipment - Flexibility in choice of facing - Blocks are easily handled	- Requires use of select backfill - Subject to corrosion in aggressive environments (metallic reinforcement) - Positive reinforcement connection to blocks is difficult to achieve
FLEXIBLE GRAVITY	MSE Wall – geotextile / geogrid / welded wire facing	P/T	6 – 50 ft	1.0H	1/60	- Does not require skilled labor or equipment - Flexibility in choice of facing	- Facing may be unaesthetically pleasing -Geosynthetic reinforcement is subject to degradation in some environments
FLEXIBLE GRAVITY	MSE Wall – vegetated soil face	P/T	10 – 100 ft	1.0H	1/60	- Does not require skilled labor or equipment - Flexibility in choice of facing - Vegetation provides ultraviolet light protection to geosynthetic reinforcement	- Facing may be unaesthetically pleasing -Geosynthetic reinforcement is subject to degradation in some environments - Vegetated soil face requires significant maintenance

[1]P/T – Permanent and Temporary
[2]Height range based on cost effectiveness
[3]ROW requirements expressed as the distance (as a fraction of wall height, H) behind the wall face where anchorage components are installed
[4]These walls are all constructed of cast-in-place concrete and/or standard brick and mortar

18.4.2 Site Constraints and Project Requirements

Once the need for an ERS is identified, then specific site constraints and project requirements need to be identified. Listed below are some items that will affect ERS selection. This list is not all inclusive.

1. Site accessibility and space restrictions
    a. Limited ROW
    b. Limited headroom
    c. On-site material storage areas
    d. Access for specialized construction equipment
    e. Traffic disruption restrictions
2. Utility locations, both above and underground
3. Nearby structures
4. Aesthetic requirements
5. Environmental concerns
    a. Construction noise
    b. Construction vibration
    c. Construction dust
    d. On-site stockpiling, transport and disposal of excavated materials
    e. Discharge of large volumes of water
    f. Encroachment on existing waterways

6. Exposed wall face height

The relative importance of each of these items should be assessed by the design team for the specific project under consideration. This assessment should identify those items that should be given priority in the selection process.

18.4.3 Factors Affecting ERS Selection

Step 3 from Figure 18-4 establishes the process for evaluating project requirements against fairly common factors that affect the selection of an ERS. Twelve importance selection factors (ISFs) have been identified and indicated in Table 18-3. The ISFs are listed in no particular order. Additional factors may be considered based on the requirements of the design team. Each factor is evaluated based on its relevancy and importance to the project requirements and site constraints. Each ISF is assigned an importance rating (IR) from 1, the least important, to 3, the most important. The GEOR shall provide a written justification for the selection of the IRs by the project team. Table 18-4 depicts an example of the ISFs and IR for each factor.

Table 18-3, ERS Importance Selection Factors (ISF)
(modified from Tanyu, et al. (2008))

1	Ground type	7	Environmental concerns
2	Groundwater	8	Durability and maintenance
3	Construction considerations	9	Tradition
4	Speed of construction	10	Contracting practices
5	ROW	11	Cost
6	Aesthetics	12	Displacements (lateral and vertical)

Table 18-4, Weighted ERS Selection Factors (modified from Tanyu, et al. (2008))

ISF[1]	Ground Type	Groundwater	Construction Considerations	Speed of Construction	ROW	Aesthetics	Environmental Concerns	Durability and Maintenance	Tradition	Contracting Practice	Cost	Displace.
IR[2]	3	2	2	3	1	1	2	2	3	1	3	3

[1]Importance selection factor (ISF)
[2]Importance rating of each ERS selection factor based on project requirements and site constraints. Each factor should be rated between 1, least importance factor, and 3, most important factor.

18.4.4 Evaluate ERS Alternates

The fourth step in selecting an ERS type consists of reviewing specific ERS types versus the Weighted ERS ISFs presented in the previous Section. A logical first step in this process is the elimination of ERS types that would be inappropriate for the specific project site. This elimination process should focus on project constraints such as ERS geometry and performance; however, the project constraints related to costs should not be included as a reason to eliminate an ERS type. In addition, the factors affecting cut (top-down construction) or fill (bottom-up construction) ERS selection should also be evaluated.

The selection issues discussed in this Section apply to permanent ERSs, selection issues for temporary cut walls are discussed later in this Chapter. Typically, permanent cut walls are designed with greater corrosion protection or with higher strength materials. In addition, these types of ERSs have permanent facing elements that consist of either cast-in-place concrete or precast concrete panels. Cut ERSs are typically either cut or drilled into the existing geomaterials at a site and require specialty contractors. If ground anchors are not required, then little or no ROW is required. However, if anchors or soil nails are used, then either additional ROW or permanent easements will be required. The taller a cut ERS becomes, the higher the unit cost of the ERS becomes. Depending on the geotechnical conditions, for ERS heights ranging from 15 to 30 feet or greater, either anchors or soil nails will be required. Cut ERSs typically used by SCDOT are provided in Table 18-1.

Fill ERSs are constructed from the bottom-up and are typically used for permanent construction. However, temporary MSE walls can also be constructed using flexible facing elements. Fill ERSs typically require more ROW than cut ERSs. Typically, the soil used for fill ERSs is comprised of Sand-Like geomaterials. The requirements for high quality fill materials typically increase the cost of fill ERSs. Fill ERSs typically used by SCDOT are provided in Table 18-2.

Those ERS systems not eliminated earlier in this step should be evaluated using the ERS ISFs and IRs previously established (see Table 18-3). Each ISF is assigned a suitability factor (SF). The SF is based on how suitable a particular wall type is considering the ISF and the importance of each ISF. SF ranges from 4, most suitable, to 1, least suitable. The determination of SF is very subjective; every effort should be made to avoid making a specific type of ERS appear suitable. Any cost associated with a selection factor should be considered when developing the rating. A brief description of each selection factor is provided in the following sections.

18.4.4.1 Ground Type

According to Tanyu, et al. (2008), "An *ERS* is influenced by the earth it is designed to retain, and the one on which it rests." For example, ERSs that are internally supported (MSE walls and soil nail walls, etc.), the quality of the retained soil in which the reinforcement is placed is of great influence. For MSE walls, the pull-out force of the reinforcement is developed by the friction along the soil-reinforcement interface and any passive resistance that develops along transverse members of the reinforcement, if any are present. Typically, MSE walls require high quality granular fill materials with relatively high friction angles. Clay-Like soils are not used in MSE wall design or construction. For soil nail walls used to support excavations, the possible saturation and creep associated with Clay-Like soils can have a negative impact on the performance of the structure. For externally supported ERSs (gravity, semi-gravity, modular gravity and in-situ walls, etc.), the influence of the retained soil is less important. However, for soils that undergo large vertical and horizontal displacements, a flexible ERS (i.e., gabion) should be used in lieu of a more rigid ERS. A rigid ERS will attempt to resist the movements, thereby placing more stress on the structural members.

18.4.4.2 Groundwater

The groundwater table behind ERSs should be lowered for the following reasons:

1. To reduce the hydrostatic pressures on the structure
2. To reduce the potential for corrosion of metal reinforcing in the retained soil
3. To reduce the potential for corrosion of metal reinforcing in facing elements

4. To prevent saturation of the soil
5. To limit displacements that can be caused by saturated soils
6. To reduce the potential for soil migration through or from the ERS

Typically, fill ERSs are constructed with free-draining backfill, while the ERS face contains numerous weep holes or other means for water to be removed from behind the structure. Drainage media is also installed in cut walls. An SCDOT ERS shall never be designed to retain water/hydraulic forces. If the necessity for water/hydraulic forces retention is mandated on a project, the OES/GDS shall be contacted for instructions and guidance.

18.4.4.3 Construction Considerations

Construction considerations that need to be accounted for in the selection of an ERS are material availability, site accessibility, equipment availability and labor considerations. The availability of construction materials can affect selection of an ERS. For example, the use of a gabion wall in Charleston would be expensive since all stone for the gabion would have to be imported, while on the other hand a gabion wall in Cherokee County could be efficiently used. Limited site accessibility could limit the type of ERS that could be constructed. Another construction consideration is the requirement for specialized equipment and is the equipment locally or at least regionally available. The final construction consideration is the labor force to be used to build the wall (i.e., does the labor force require specialized training?).

18.4.4.4 Speed of Construction

Another factor to be considered is the speed at which the ERS can be constructed. The more rapidly an ERS can be constructed, the more rapidly the project can be completed.

18.4.4.5 Right-of-Way

The amount or need for additional ROW should be considered when selecting an ERS wall type. The question that needs to be asked is whether the ERS is being used to support the transportation facility or to support an adjacent owner. ERSs supporting the transportation facility should require limited to no additional ROW, while ERSs supporting an adjacent owner may require either additional ROW or an easement to install internally stabilizing reinforcements.

18.4.4.6 Aesthetics

Depending on the location of the ERS, the aesthetics of the wall can be of great importance in final selection. Typically, the aesthetics of wall is more important in populated areas than in non-, or limited, populated areas. In more environmentally sensitive areas, the ERS may need to blend in with the surrounding environment. This need for blending should be accounted for in ERS selection.

18.4.4.7 Environmental Concerns

ERSs can both cause, as well as alleviate, environmental concerns. ERSs cause environmental concerns if contaminated soil must be removed prior to or during the construction of the structure. In addition, noise and vibration from certain ERS wall installations can have a negative impact on the environment around the project. In addition, the fascia of some ERSs may allow for the bouncing or echoing of traffic noise; therefore, in cases where this may become a concern, an alternate fascia material may need to be selected. ERSs may alleviate environmental concerns by allowing for smaller footprints in environmentally sensitive areas; therefore, eliminating the need for environmental permits.

18.4.4.8 Durability and Maintenance

Depending on the environmental conditions (corrosiveness) of materials the ERS is founded on or is constructed of, certain ERS types may not be satisfactory. The ERS must meet design requirements and be durable for the life of the structure (100 years) or must have definitive maintenance procedures that will need to be identified. These maintenance procedures should also clearly indicate the time periods that maintenance should be performed.

18.4.4.9 Tradition

Tradition (i.e., what is normally done) can impact what type of ERS is selected. Traditionally, SCDOT uses the following wall types:

1. MSE
2. Cantilever (concrete)
3. Soil Nail
4. Sheetpile (cantilever or anchored)
5. Soldier pile and lagging (cantilever or anchored)
6. Gabion
7. Gravity

18.4.4.10 Contracting Practices

The use of sole source or patented ERSs should be avoided at all times. If sole source or patented ERSs cannot be avoided, a written justification is required. The written justification shall be maintained in the project file and shall include the endorsement (approval) of the RPE.

18.4.4.11 Cost

The total cost of the ERS should include the structure (structural elements; incidentals, including drainage items; and backfill materials, if any), ROW (acquisition or easement), excavation and disposal of unsuitable or contaminated materials, mitigation costs of environmental impacts (such as additional noise abatement) and the time value of construction delays. Credits for eliminating environmental permits or speeding up construction should also be factored into the decision.

18.4.4.12 Displacements

The amount of displacement (horizontal and vertical) that an ERS may be required to handle also affects the selection process. Some walls are more flexible than others. An idea of the amount of displacement that an ERS is anticipated to endure should also be known prior to making the final ERS selection.

18.4.5 Selection of Acceptable ERS Type

The final step in selecting an ERS is to determine the most acceptable type. This determination is made based on the IR and SF for each ISF. A weighted rating (WR) is developed as the product of IR and SF. A total weighted rating (WR_T) is determined. The ERS type with the highest WR_T should be selected for the specific project site. Other highly scored walls may be included in the Contract Documents as acceptable alternatives. Table 18-5 provides an example of this process. The Wall Selection Matrix is available on the Geotechnical page of the SCDOT website; https://www.scdot.org/business/geotech.aspx.

$$WR_T = \sum_{i=1}^{n}(IR_i * SF_i) = \sum_{i=1}^{n} WR_i \qquad \textbf{Equation 18-2}$$

Table 18-5, Wall Selection Matrix (modified Tanyu, et al. (2008))

ERS Type	ISF	Ground	Groundwater	Construction Considerations	Speed of Construction	ROW	Aesthetics	Environmental Concerns	Durability and Maintenance	Tradition	Contracting Practice	Cost	Displacement	**Total Weighted Rating (WR_T)**
	IR	3	2	2	3	1	1	2	2	3	1	3	3	
MSE Wall – Precast Facing[1]	SF	4	1	3	3	1	4	4	3	4	2	3	2	
	WR	**12**	**2**	**6**	**9**	**1**	**4**	**8**	**6**	**12**	**2**	**9**	**6**	**77**
Gabion Wall[1]	SF	3	1	3	1	4	1	4	4	1	3	1	4	
	WR	**9**	**2**	**6**	**3**	**4**	**1**	**8**	**8**	**3**	**3**	**3**	**12**	**62**
Cast-in-place Concrete Gravity Wall[1]	SF	4	1	1	1	1	4	2	4	3	4	1	2	
	WR	**12**	**2**	**2**	**3**	**1**	**4**	**4**	**8**	**9**	**4**	**3**	**6**	**58**
RSS[1]	SF	4	1	1	4	4	3	1	4	2	2	4	1	
	WR	**12**	**2**	**2**	**12**	**4**	**3**	**2**	**8**	**6**	**2**	**12**	**3**	**68**

[1]SF for each ERS, RSS or reinforced embankment are based on project requirements and site constraints.
Each SF should be rated between 1, least suitable, and 4, most suitable.

18.5 EARTH PRESSURE THEORY

Earth pressures act on the rear face of an ERS or an abutment wall, (ERS will used generically for the remainder of the Chapter and will include abutment walls as well as ERSs) and are caused by the weight of the soil (backfill or retained fill), seismic loads and various surcharge loads. The ERS is designed to resist these loads, as well as, any water (pore) pressures that may build up on the rear of the wall. There are 3 different lateral pressures used in the design of ERSs: active, at-rest and passive (see Chapter 2 for definitions).

The general horizontal earth pressure is expressed by the following equation.

$$\sigma_h = K * \sigma_v \qquad \textbf{Equation 18-3}$$

Where,

σ_h = Horizontal earth pressure at a specific depth on an ERS
K = Earth pressure coefficient
σ_v = Vertical earth pressure (overburden stress) at a specific depth on an ERS

The active and passive earth pressure coefficients (K_a and K_p, respectively) are a function of the soil shear strength, backfill geometry, the geometry of the rear face of the ERS and friction and cohesion that develop along the rear face as the wall moves relative to the retained backfill. The active earth pressure condition is developed by a relatively small movement of the ERS away from the retained backfill, while the movements required to develop the passive earth pressure condition are on the order to approximately 10 times larger than the movements required to develop active conditions (see Figure 18-5).

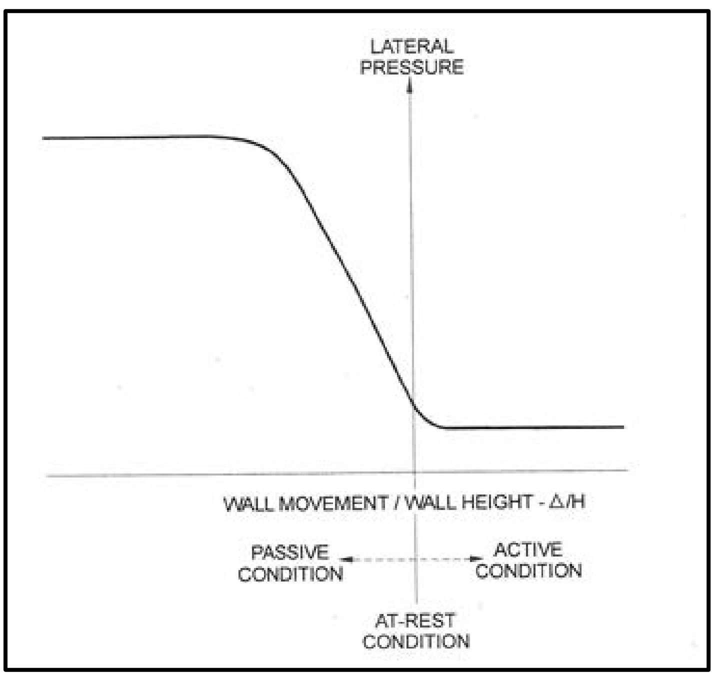


Figure 18-5, Relative Magnitude of Displace. Required to Develop Earth Pressures (Tanyu, et al. (2008))

Figure 18-6 presents a graphical relationship between displacement at the top of the wall and the earth pressure developed on the wall. Clough and Duncan (1991) developed a relationship between movement of the top of the wall and the wall height (Table 18-6).

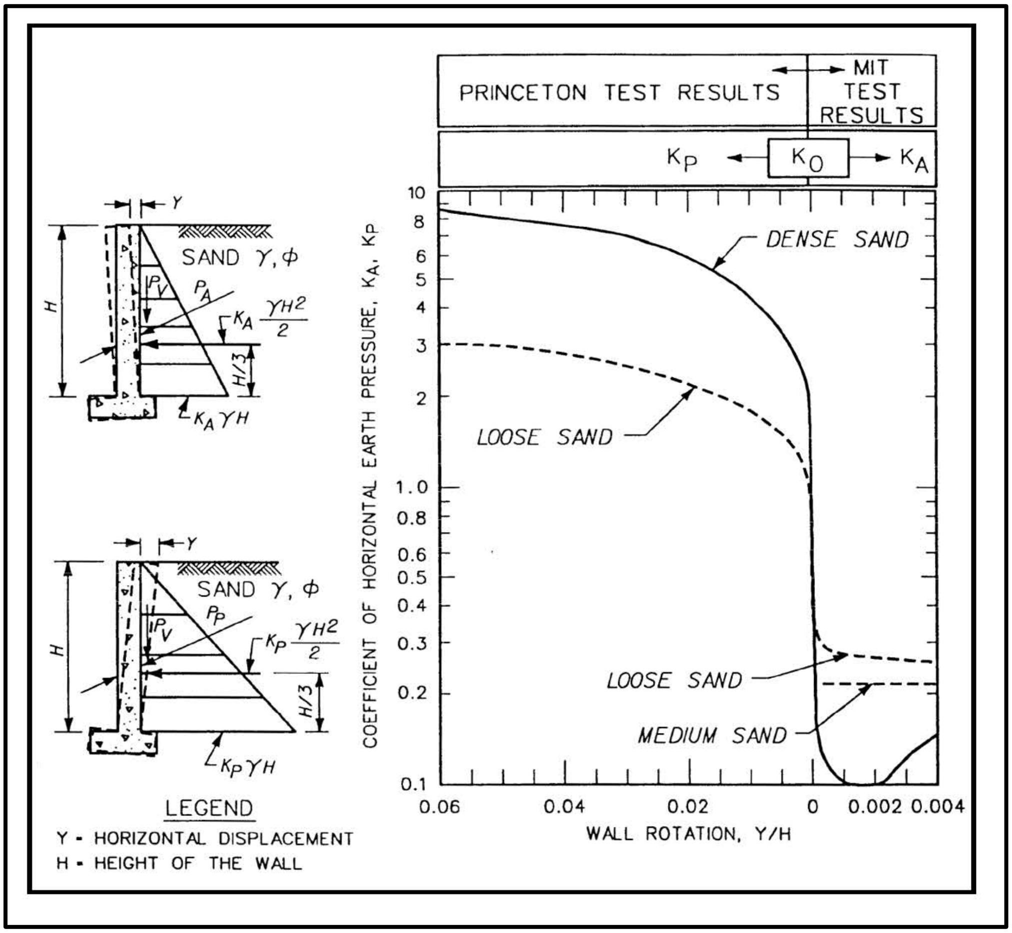


Figure 18-6, Effects of Wall Movement on Static Horizontal Earth Pressures (DOD (NAVFAC DM 7.2) (1986))

Table 18-6, Required Relative Movements To Reach P_A or P_P (Clough and Duncan, 1991)

Type of Backfill	Δ / H	
	Active[1]	**Passive[2]**
Dense Sand	0.001	0.010
Medium Dense Sand	0.002	0.020
Loose Sand	0.004	0.040
Compacted Silt	0.002	0.020
Compacted Lean Clay	0.010	0.050

Note: Δ = movement of top of wall (feet); H = height of wall (feet)
[1]At minimum active earth pressure
[2]At maximum passive earth pressure

18.5.1 Active Earth Pressure

The active earth pressure condition exists when an ERS is free to rotate or displace away from the retained backfill. There are 2 earth pressure theories available for determining the earth pressure coefficients; Rankine and Coulomb earth pressure theories. Rankine earth pressure makes several assumptions concerning the wall and the backfill. The first assumption is that the retained soil has a horizontal surface, secondly, that the failure surface is a plane and finally that the wall is smooth (i.e., no friction). Unlike Rankine earth pressure theory Coulomb earth pressure theory accounts for the friction between the wall and the soil, δ and allows for both a sloping backfill as well as a sloping back face of an ERS. Therefore, the use of Coulomb earth pressure theory is a better fit to most ERSs; however, the determination of the K_a is more rigorous.

18.5.1.1 Rankine Earth Pressure Coefficient

The use of Rankine earth pressure theory will cause a slight over estimation of K_a, therefore, increasing the pressure on the wall. The equations for developing the active earth pressure coefficients for Sand-Like soils ($\leq$ 20 percent fines) and Sand-Like (> 20 percent fines, PI $\leq$ 10) (see Chapter 7) are indicated below. For Clay-Like soils (> 20 percent fines, PI > 10) contact the OES/GDS to discuss how to handle these soils.

Sand-Like ($\leq$ 20 percent fines)

$$K_a = tan^2\left(45 - \frac{\phi'}{2}\right) \qquad \textbf{Equation 18-4}$$

Sand-Like (> 20 percent fines, PI $\leq$ 10)

$$K_a = tan^2\left(45 - \frac{\phi'}{2}\right) - \frac{2c'}{\sigma'_v} * \left[tan^2\left(45 - \frac{\phi'}{2}\right)\right] \qquad \textbf{Equation 18-5}$$

Where,

ϕ' = Effective friction angle

c' = Effective cohesion

σ'_v = Effective overburden pressure at bottom of wall

18.5.1.2 Coulomb Earth Pressure Coefficient

As indicated previously, the development of the Coulomb earth pressure coefficient is a more rigorous methodology that depends more on the geometry of the ERS and backfill. Unlike the Rankine earth pressure coefficient, Coulomb earth pressure theory is based on Sand-Like materials with cohesion being used to develop the pressures and resultants (see Section 18.5.4).

$$K_a = \frac{cos^2(\theta - \phi)}{cos^2\theta * cos(\theta + \delta) * [1 + \Gamma]^2} \qquad \textbf{Equation 18-6}$$

$$\Gamma = \sqrt{\frac{sin(\phi + \delta) * sin(\phi - \beta)}{cos(\theta + \delta) * cos(\theta - \beta)}} \qquad \textbf{Equation 18-7}$$

Where,

ϕ = Friction angle

δ = Wall friction (see Figure 18-8)

θ = Slope of back of ERS (see Figure 18-7)

β = Slope of backfill above horizontal (see Figure 18-7)

H = Height of ERS

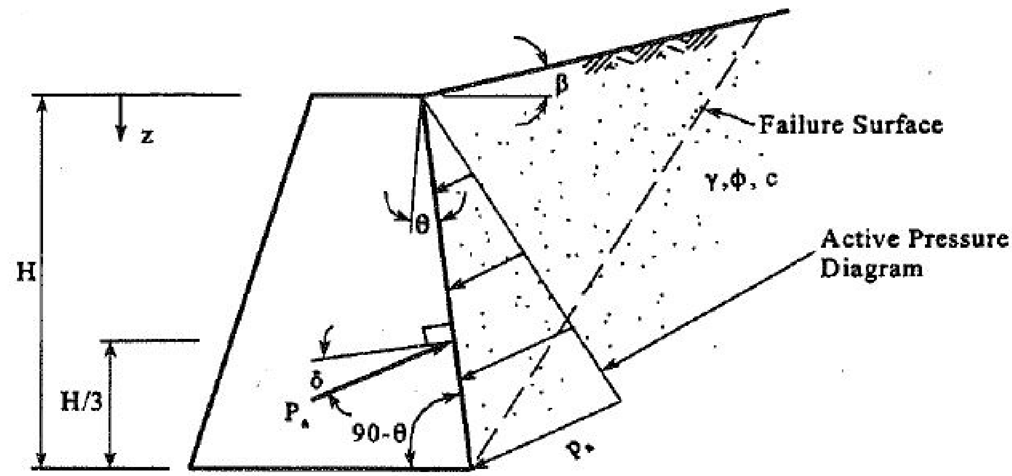


Figure 18-7, Coulomb Active Earth Pressures (Tanyu, et al. (2008))

Interface Materials	Friction factor, tan δ	Friction angle, δ degrees
Mass concrete on the following foundation materials:		
Clean sound rock..................................	0.70	35
Clean gravel, gravel-sand mixtures, coarse sand...	0.55 to 0.60	29 to 31
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel....................	0.45 to 0.55	24 to 29
Clean fine sand, silty or clayey fine to medium sand..	0.35 to 0.45	19 to 24
Fine sandy silt, nonplastic silt..................	0.30 to 0.35	17 to 19
Very stiff and hard residual or preconsolidated clay..	0.40 to 0.50	22 to 26
Medium stiff and stiff clay and silty clay........	0.30 to 0.35	17 to 19
(Masonry on foundation materials has same friction factors.)		
Steel sheet piles against the following soils:		
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls...........................	0.40	22
Clean sand, silty sand-gravel mixture, single size hard rock fill..................................	0.30	17
Silty sand, gravel or sand mixed with silt or clay	0.25	14
Fine sandy silt, nonplastic silt..................	0.20	11
Formed concrete or concrete sheet piling against the following soils:		
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls...........................	0.40 to 0.50	22 to 26
Clean sand, silty sand-gravel mixture, single size hard rock fill..................................	0.30 to 0.40	17 to 22
Silty sand, gravel or sand mixed with silt or clay	0.30	17
Fine sandy silt, nonplastic silt..................	0.25	14
Various structural materials:		
Masonry on masonry, igneous and metamorphic rocks:		
Dressed soft rock on dressed soft rock..........	0.70	35
Dressed hard rock on dressed soft rock..........	0.65	33
Dressed hard rock on dressed hard rock..........	0.55	29
Masonry on wood (cross grain).....................	0.50	26
Steel on steel at sheet pile interlocks...........	0.30	17

Figure 18-8, Coulomb Active Earth Pressures (DOD (NAVFAC DM 7.2) (1986))

18.5.2 At-Rest Earth Pressure

In the at-rest earth pressure (K_o) condition, the top of the ERS is not allowed to deflect or rotate; therefore, requiring the wall to support the full pressure of the soil behind the wall. The K_o coefficient is related to the OCR (Chapter 7) of the soil. The following equation is used to determine the at-rest earth pressure coefficient:

$$K_o = (1 - \sin\phi')(OCR)^{\Omega} \quad \text{Equation 18-8}$$

$$\Omega = \sin\phi' \quad \text{Equation 18-9}$$

While all soils can be overconsolidated, the ability to accurately determine the OCR for Sand-Like soil is not cost effective; therefore, the OCR for all Sand-Like materials shall be taken as 1.0. Therefore for Sand-Like materials, Equation 18-8 may be rewritten as:

$$K_o = 1 - \sin\phi' \quad \text{Equation 18-10}$$

For normally consolidated Clay-Like materials (i.e., c = X psf and ϕ = 0°) K_o shall be set equal to 1.0 (i.e., K_o = 1.0). Typically, cantilevered ERSs are not designed to withstand the at-rest earth pressure condition, since some movement is required for these types of walls to perform.

18.5.3 Passive Earth Pressure

The development of passive earth pressure requires the ERS to move into or toward the soil. As with the active earth pressure, there are 2 earth pressure theories available for determining the earth pressure coefficients; Rankine and Coulomb earth pressure theories. Rankine earth pressure makes several assumptions concerning the wall and the backfill. The first assumption is that the retained soil has a horizontal surface, secondly, that the failure surface is a plane and finally that the wall is smooth (i.e., no friction). Unlike Rankine earth pressure theory Coulomb earth pressure theory accounts for the friction between the wall and the soil, δ and allows for both a sloping backfill as well as a sloping back face of an ERS. Therefore, the use of Coulomb earth pressure theory is a better fit to most ERSs; however, the determination of the K_p is more rigorous.

18.5.3.1 Rankine Earth Pressure Coefficient

The use of Rankine earth pressure theory will cause an under estimation of K_p, therefore, decreasing the pressure on the wall. The equations for developing the passive earth pressure coefficients for Sand-Like soils (≤ 20 percent fines) and Sand-Like (> 20 percent fines, PI ≤ 10) (see Chapter 7) are indicated below. For Clay-Like soils (> 20 percent fines, PI > 10) contact the OES/GDS to discuss how to handle these soils.

Sand-Like (≤ 20 percent fines)

$$K_p = \tan^2\left(45 + \frac{\phi'}{2}\right) \quad \text{Equation 18-11}$$

Sand-Like (> 20 percent fines, PI ≤ 10)

$$K_p = tan^2\left(45+\frac{\phi'}{2}\right)+\frac{2c'}{\sigma'_v}*\left[tan^2\left(45+\frac{\phi'}{2}\right)\right]$$ **Equation 18-12**

Where,

ϕ' = Effective friction angle
c' = Effective cohesion
σ'_v = Effective overburden pressure at bottom of wall

18.5.3.2 Coulomb Earth Pressure Coefficient

As indicated previously, the development of the Coulomb earth pressure coefficient is a more rigorous methodology that depends more on the geometry of the ERS and backfill. Unlike the Rankine earth pressure coefficient, Coulomb earth pressure theory is based on cohesionless materials with cohesion being used to develop the pressures and resultants (see Section 18.5.4).

$$K_p = \frac{cos^2(\theta+\phi)}{cos^2\theta * cos(\theta-\delta) * [1-\Gamma]^2}$$ **Equation 18-13**

$$\Gamma = \sqrt{\frac{sin(\phi+\delta)*sin(\phi+\beta)}{cos(\theta-\delta)*cos(\theta-\beta)}}$$ **Equation 18-14**

Where,

φ = Friction angle
δ = Wall friction
θ = Slope of back of ERS (see Figure 18-9)
β = Slope of backfill above horizontal (see Figure 18-9)
H = Height of ERS

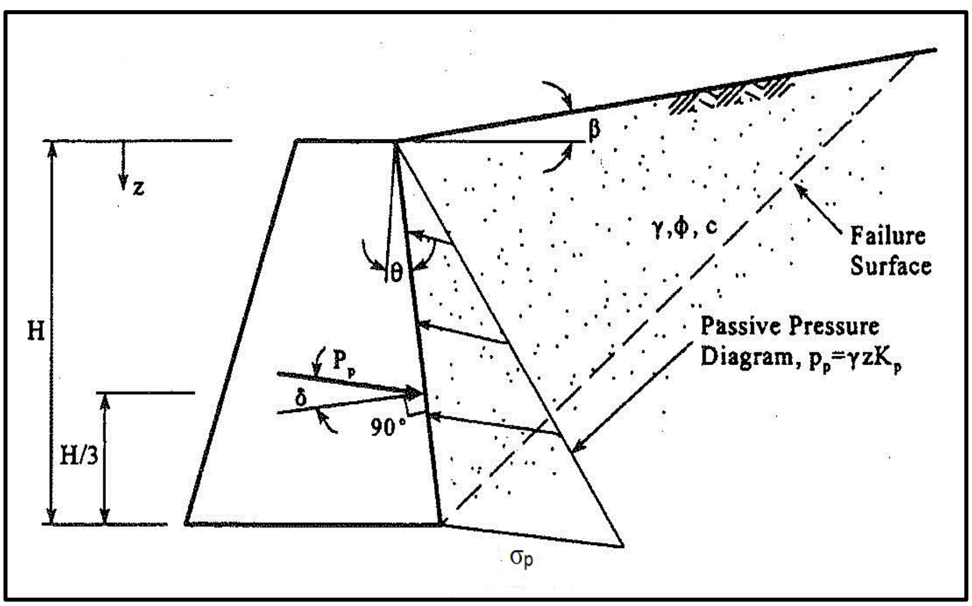


Figure 18-9, Coulomb Passive Earth Pressures (Tanyu, et al. (2008))

18.5.4 Determination of Earth Pressures

The active and passive earth stresses and pressures may be determined using either Rankine or Coulomb earth pressure theory. As indicated previously, ERSs used on SCDOT projects shall be designed to prevent the buildup of pore water pressures behind the wall. The effective earth stress at any depth along the ERS shall be determined using the following equations for Sand-Like soils (≤ 20 percent fines) and Sand-Like (> 20 percent fines, PI ≤ 10) (see Chapter 7) are indicated below. For Clay-Like soils (> 20 percent fines, PI > 10) contact the OES/GDS to discuss how to handle these soils.

Sand-Like (≤ 20 percent fines)

Active

$$\sigma_a' = K_a * [(\gamma_T * z) - u] \qquad \textbf{Equation 18-15}$$

At-Rest

$$\sigma_o' = K_o * [(\gamma_T * z) - u] \qquad \textbf{Equation 18-16}$$

Passive

$$\sigma_p' = K_p * [(\gamma_T * z) - u] \qquad \textbf{Equation 18-17}$$

Sand-Like (> 20 percent fines, PI ≤ 10)

Active

$$\sigma_a' = K_a * [(\gamma_T * z) - u] - 2c' * \sqrt{K_a} \qquad \textbf{Equation 18-18}$$

Passive

$$\sigma_p' = K_p * [(\gamma_T * z) - u] + 2c' * \sqrt{K_p} \qquad \textbf{Equation 18-19}$$

$$u = \gamma_w * z \qquad \textbf{Equation 18-20}$$

Where,

γ_T = Total unit weight of soil, pcf
γ_w = Unit weight of water, pcf
z = Depth of interest (see Figures 18-6 and 18-8), ft
u = Static pore water pressure (see Equation 18-9), psf
K_a = Active earth pressure coefficient, Rankine or Coulomb
K_o = At-Rest earth pressure coefficient
K_p = Passive earth pressure coefficient, Rankine or Coulomb
c' = Effective cohesion, psf

The resultant load, P_a or P_p, shown in Figures 18-7 or 18-9, respectively, are determined using the following equations.

Sand-Like (≤ 20 percent fines)

Active

$$P_a = \frac{\sigma'_a * H}{2} \qquad \textbf{Equation 18-21}$$

At-Rest

$$P_o = \frac{\sigma'_o * H}{2} \qquad \textbf{Equation 18-22}$$

Passive

$$P_p = \frac{\sigma'_p * H}{2} \qquad \textbf{Equation 18-23}$$

Where,

σ'_a = Effective active earth pressure at the base of the wall (i.e., z = H), psf
σ'_o = Effective at-rest earth pressure at the base of the wall (i.e., z = H), psf
σ'_p = Effective passive earth pressure at the base of the wall (i.e., z = H), psf
H = Height of wall, ft
P_a = Active resultant force per foot of wall width, pounds per foot of wall width
P_o = At-Rest resultant force per foot of wall width, pounds per foot of wall width
P_p = Passive resultant force per foot of wall width, pounds per foot of wall width

Sand-Like (> 20 percent fines, PI ≤ 10)

Active

$$P_a = \frac{\sigma'_a * H}{2} - 2c' * H * \sqrt{K_a} + \frac{2(c')^2}{[(\gamma_t * H) - u]} \qquad \textbf{Equation 18-24}$$

Passive

$$P_p = \frac{\sigma'_p * H}{2} + 2c' * H * \sqrt{K_p} \qquad \textbf{Equation 18-25}$$

For Clay-Like soils (> 20 percent fines, PI > 10) contact the OES/GDS to discuss how to handle these soils.

18.6 RIGID GRAVITY EARTH RETAINING STRUCTURES

Gravity ERSs are externally stabilized fill walls and consist of the wall types provided in Table 18-7. Gravity wall types can be subdivided into 3 categories; gravity, semi-gravity and modular gravity. The limited details of each wall type are discussed in the following Sections. The design of gravity retaining walls is also discussed.

Table 18-7, Gravity Wall Types

Gravity	Semi-Gravity	Modular Gravity
Mass Concrete	Cantilever	Gabion
Stone	Counterfort	Crib
Masonry	Buttress	Bin

18.6.1 Gravity Retaining Walls

Gravity walls are typically trapezoidal in shape; although for shorter walls, the walls are more rectangular (see Figure 18-10). Gravity walls are constructed of either mass concrete with little or no reinforcement or masonry or stone walls. These types of walls tend to behave rigidly and depend on the weight (mass) of concrete to resist eccentricity (overturning) and sliding.

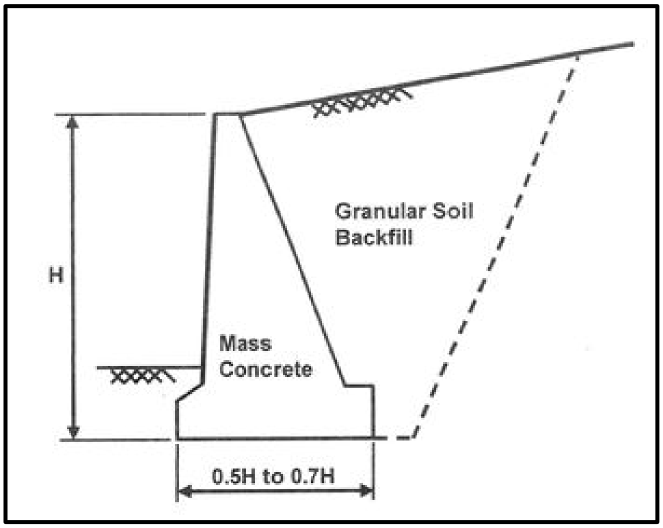


Figure 18-10, Gravity Retaining Wall (Tanyu, et al. (2008))

18.6.2 Semi-Gravity Retaining Walls

Semi-gravity walls are comprised of cantilevered, counterfort or buttress walls (see Figure 18-11). Semi-gravity walls are constructed of reinforced concrete, with the reinforcing in the stem designed to withstand the moments induced by the retained soil. Typically, cantilevered walls are limited to heights less than 30 feet. The counterforts (buttress within the retained soil mass) or buttresses (buttress on exposed face of the wall) are used when the moments are too large requiring a thicker stem and more reinforcing. Typically, these types of walls are used when the cantilevered wall height exceeds 30 feet.

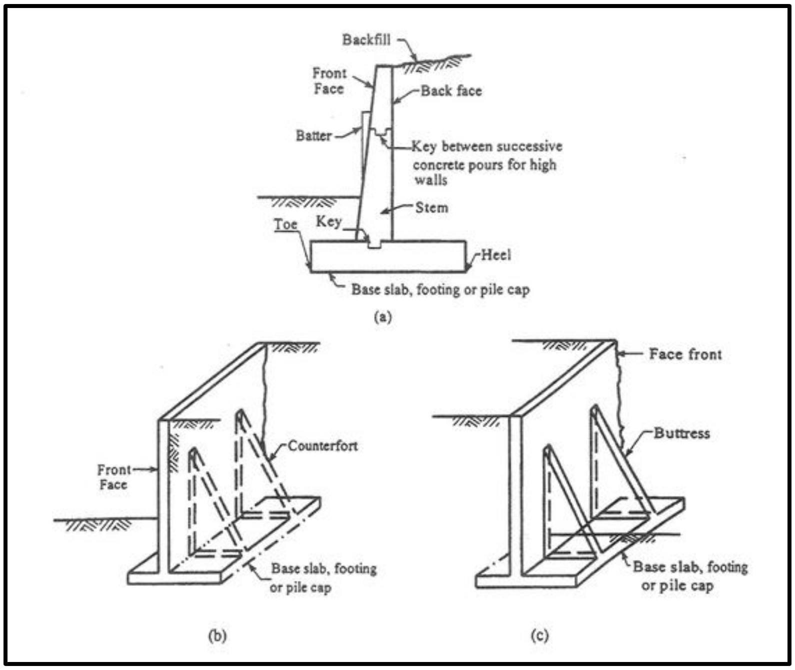


Figure 18-11, Semi-Gravity Retaining Wall
(Tanyu, et al. (2008))
(a) Cantilever; (b) Counterfort; (c) Buttress

18.6.3 Modular Gravity Walls

Modular gravity walls are comprised of gabion, crib or bin walls (see Figure 18-12). Gabion walls are rock filled wire baskets. Gabion walls are used in locations where rock is plentiful. These types of walls are labor intensive to construct. Gabion walls are often used in applications that will experience cycles of inundation from streams. Currently SCDOT does not use crib or bin walls. The use of crib or bin walls must be approved in writing by the OES/GDS prior to commencing design.

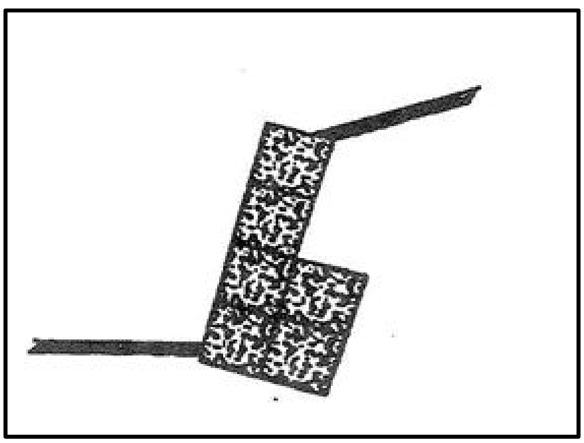


Figure 18-12, Gabion Retaining Wall
(Tanyu, et al. (2008))

18.6.4 Rigid Gravity Wall Design

The design of gravity ERSs includes the overall (global) stability, bearing and deformation, sliding and eccentricity (overturning). The overall (global) stability and deformation analyses are performed using the procedures presented in Chapter 17. The bearing, sliding and eccentricity (overturning) analyses are performed using the procedures discussed in Chapter 15, if shallow foundations are used. If deep foundations are required, then the procedures presented in Chapter 16 should be used. Table 18-8 provides the design steps for gravity walls. For additional details on the design of gravity walls refer to Tanyu, et al. (2008). The loads placed on gravity retaining walls should be developed in accordance with the AASHTO LRFD Specifications (Section 11 – Abutments, Piers and Walls) and Chapter 8 of this Manual. Resistance Factors and Performance Limits shall be developed in accordance with Chapters 9 and 10 of this Manual.

Table 18-8, Rigid Gravity Wall Design Steps
(Tanyu, et al. (2008))

Step	Action
1	Establish project requirements including all geometry, external loading conditions (transient and/or permanent, seismic, etc.), performance criteria and construction constraints.
2	Evaluate site subsurface conditions and relevant properties of in-situ soil and rock parameters and wall backfill parameters.
3	Evaluate soil and rock parameters for design and establish resistance factors.
4	Select initial base dimension of wall for Strength limit state (external stability) evaluation.
5	Select lateral earth pressure distribution. Evaluate water, surcharge, compaction and seismic pressures.
6	Evaluate factored loads for all appropriate loading groups and limit states.
7	Evaluate bearing resistance (Chapter 15).
8	Check eccentricity (see AASHTO LRFD Specification Section 11.6 – Abutments and Conventional Retaining Walls).
9	Check sliding (Chapter 15).
10	Check external stability at the Strength limit state and revise wall design if necessary (Chapter 17).
11	Estimate maximum lateral wall movement, tilt (rotation), and wall settlement at the Service limit state. Revise design if necessary.
12	Design wall drainage systems.

18.7 FLEXIBLE GRAVITY EARTH RETAINING STRUCTURES

Flexible gravity earth retaining structures consist of either Mechanically Stabilized Earth (MSE) Walls or gabion walls and are internally stabilized fill walls that are constructed using alternating layers of compacted soil and reinforcement (i.e., geosynthetics, metallic strips or metallic grids) (see Figure 18-13). As indicated in Table 18-2, there are 4 MSE Wall face alternatives that may be used. MSE Wall with precast panel facing shall be used at bridge end bent locations. However, other face options may be used with written permission of the OES/GDS. If a road embankment MSE Wall may be inundated, contact the OES/GDS to discuss design options. Table 18-9 provides the design steps that are used in the design of MSE Walls. Appendix C provides a detailed design procedure. The loads placed on in-situ structural retaining walls should be developed in accordance with the AASHTO LRFD Specifications (Section 11 – Abutments, Piers and Walls) and Chapter 8 of this Manual. Resistance Factors and Performance Limits shall be developed in accordance with Chapters 9 and 10 of this Manual. The external stability of the MSE Wall is the responsibility of the GEOR. The internal stability of the MSE Wall is the responsibility of the MSE Wall supplier.

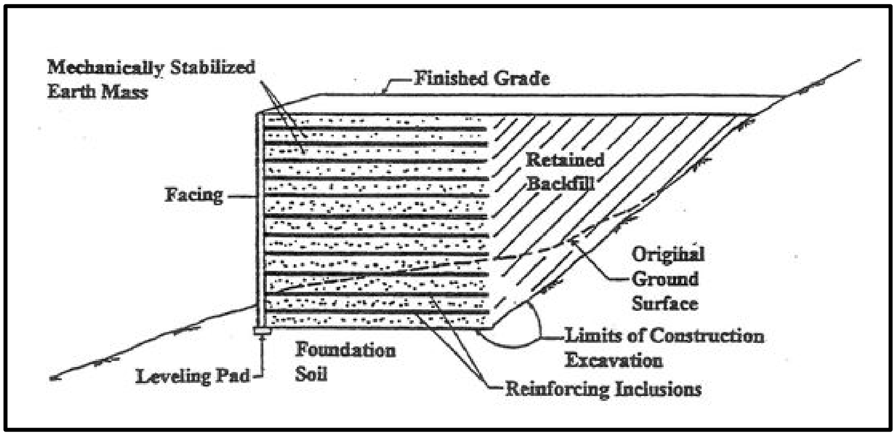


Figure 18-13, MSE Wall
(Tanyu, et al. (2008))

Table 18-9, MSE Wall Design Steps
(modified Berg, Christopher, and Samtani – Volume I (2009))

Step		Action
1	Establish project requirements including all geometry, external loading conditions (transient and/or permanent, seismic, etc.), performance criteria and construction constraints.	
2	Evaluate existing topography, site subsurface conditions, in-situ soil/rock parameters and wall backfill parameters.	
3	Based on initial wall geometry (including wall height), estimate wall embedment depth and length of reinforcement.	
4	Define nominal loads	
5	Summarize load combinations, load factors (γ), and resistance factors (φ)	
6	Evaluate external stability	
	a	Check eccentricity (Appendix C).
	b	Check sliding resistance (Appendix C).
	c	Check bearing resistance of foundation soil (Appendix C).
	d	Estimate vertical wall movements at the Service limit state
7	Evaluate Internal Stability	
	a	Select type of soil reinforcement
	b	Estimate critical failure surface based on reinforcement type (i.e., extensible or inextensible) for internal stability design at all appropriate Strength limit states.
	c	Define unfactored loads
	d	Establish vertical layout of soil reinforcements
	e	Calculate factored horizontal stress and maximum tension at each reinforcement level.
	f	Calculate nominal and factored long-term tensile resistance of soil reinforcements.
	g	Select grade (strength) of soil reinforcement and/or number of soil reinforcements, and check established layout.
	h	Calculate nominal and factored pullout resistance of soil reinforcements and check established layout
	i	Check connection resistance requirements at facing
	j	Estimate lateral wall movements at the Service limit state. Revise design if necessary.
	k	Check vertical movement and compression of pads
8	Design of facing elements.	
9	Check overall stability at the Service limit state (Chapter 17). Revise design if necessary.	
10	Assess Compound stability.	
11	Design wall drainage systems.	
	a	Subsurface drainage
	b	Surface drainage

18.8 CANTILEVER EARTH RETAINING STRUCTURES

Cantilever earth retaining structures have structural elements (i.e., sheetpile or soldier pile and lagging) installed to provide resistance of the applied lateral loads (see Figure 18-14). These types of walls are externally stabilized cut (top-down construction) walls. Cantilever earth retaining structures may develop resistance to the applied lateral loads through cantilever action, anchors or internal bracing (see Figure 18-15). In typical SCDOT applications, the use of exterior bracing is not normally used for permanent applications and will therefore not be discussed. Two different design methods are required for these walls depending if the wall is cantilevered or supported by anchors. Typically, cantilevered in-situ structural walls can have exposed heights of up to 15 feet. Cantilevered in-situ structural walls taller than this will require anchors to resist the bending moments induced by the soil on the structural elements. The anchors may be either deadman or tendon type, depending on the method of construction, the amount of ROW available, etc. Table 18-10 provides the design steps for a cantilevered in-situ structural wall. Anchored in-situ structural walls are designed using the steps provided in Table 18-11. For additional details on the design of in-situ structural walls refer to Tanyu, et al. (2008). The loads placed on in-situ structural retaining walls should be developed in accordance with the AASHTO LRFD Specifications (Section 11 – Abutments, Piers and Walls) and Chapter 8 of this Manual. Resistance Factors and Performance Limits shall be developed in accordance with Chapters 9 and 10 of this Manual.

Table 18-10, Cantilevered Wall Design Steps (Tanyu, et al. (2008))

Step	Action
1	Establish project requirements including all geometry, external loading conditions (transient and/or permanent, seismic, etc.), performance criteria and construction constraints.
2	Evaluate site subsurface conditions and profile, water profile, and relevant properties of in-situ soil and rock parameters.
3	Evaluate soil and rock parameters for design and establish resistance factors.
4	Select lateral earth pressure distribution. Evaluate water, surcharge, compaction and seismic pressures.
5	Evaluate factored total lateral pressure diagram for all appropriate limit states.
6	Evaluate embedment depth of vertical wall element and factored bending moment in the wall.
7	Check flexural resistance of vertical wall elements. Check combined flexural and axial resistance (if necessary).
8	Select temporary lagging (for soldier pile and lagging wall). For permanent lagging, lagging must be designed to resist earth pressures.
9	Design permanent facing (if required).
10	Estimate maximum lateral wall movements and ground surface settlement at the Service limit state. Revise design if necessary.

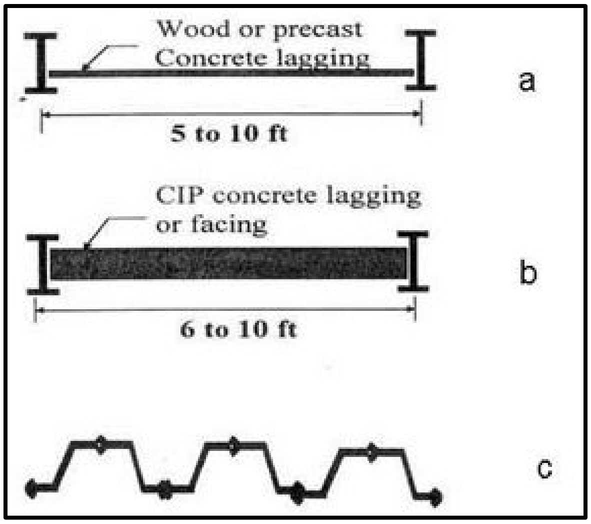


Figure 18-14, In-Situ Structural Walls (Modified from Tanyu, et al. (2008))
a and b Soldier pile and lagging; c Sheetpile

Table 18-11, Anchored Cantilevered Wall Design Steps (Tanyu, et al. (2008))

Step	Action
1	Establish project requirements including all geometry, external loading conditions (transient and/or permanent, seismic, etc.), performance criteria and construction constraints.
2	Evaluate site subsurface conditions and relevant properties of in-situ soil and rock parameters.
3	Evaluate soil and rock parameters for design and establish resistance factors and select level of corrosion project for the anchor.
4	Select lateral earth pressure distribution acting on back of wall for the final wall height. Evaluate water, surcharge, and seismic pressures.
5	Evaluate factored total loads for all appropriate limit states.
6	Calculate horizontal ground anchor loads and subgrade reaction force. Resolve each horizontal anchor load into a vertical force component and a force along the anchor. Evaluate horizontal spacing of anchors based on wall type and calculate individual factored anchor loads.
7	Evaluate required anchor inclination based on right-of-way limitations, location of appropriate anchoring strata, and location of underground structures.
8	Select tendon type and check tensile resistance.
9	Evaluate anchor bond length.
10	Evaluate factored bending moments and flexural resistance of wall.
11	Evaluate bearing resistance of wall below excavation subgrade. Revise wall section if necessary.

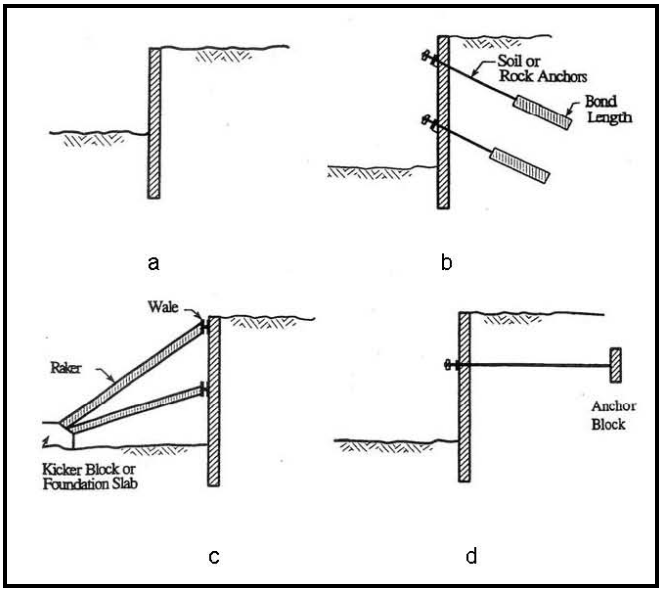


Figure 18-15, Wall Support Systems
(Modified from Tanyu, et al. (2008))
a Cantilever; b Anchored; c Braced; d Deadman Anchored

18.9 IN-SITU REINFORCED EARTH RETAINING STRUCTURES

In-situ reinforced ERSs are internally stabilized cut walls that involve the insertion of reinforcing elements into the in-situ soils to create a composite ERS (see Figure 18-16).

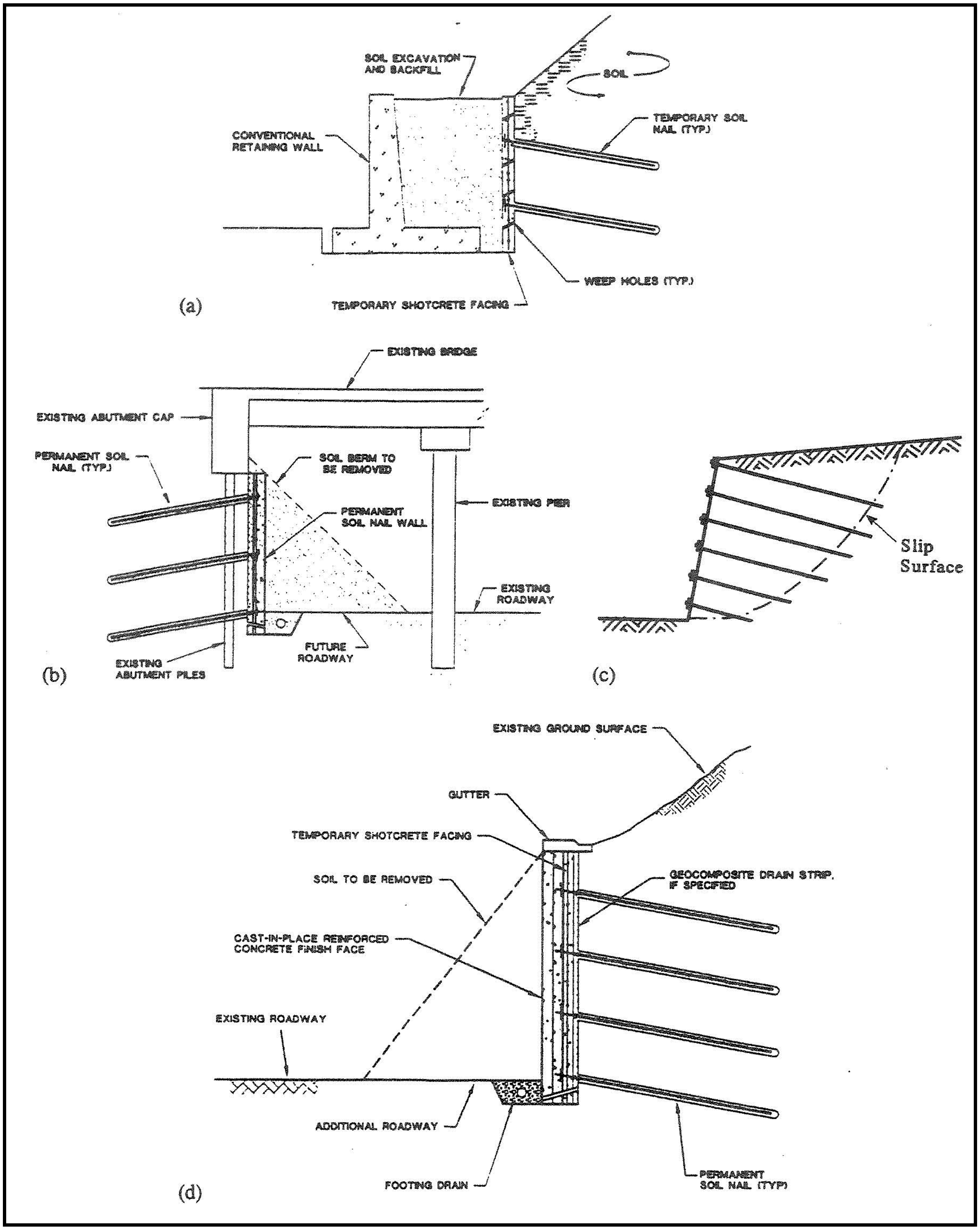


Figure 18-16, In-Situ Reinforced (Soil Nail) Walls (Tanyu, et al. (2008))

a Temporary shoring; b Roadway widening under existing bridge;
c Slope stabilization; d Roadway cut

The design steps for a soil nail wall are provided in Table 18-12. For detailed requirements of design, please refer Lazarte, et al. (2015). An alternate design source is Tanyu, et al. (2008). The loads placed on in-situ structural retaining walls should be developed in accordance with the AASHTO LRFD Specifications (Section 11 – Abutments, Piers and Walls) and Chapter 8 of this Manual. Resistance Factors and Performance Limits shall be developed in accordance with

Chapters 9 and 10 of this Manual. The external stability of the soil nail wall is the responsibility of the GEOR. The internal stability of the soil nail wall is the responsibility of either the SEOR or the soil nail wall contractor.

Table 18-12, Soil Nail Wall Design Steps (Tanyu, et al. (2008))

Step	Action
1	Establish project requirements including all geometry, external loading conditions (transient and/or permanent, seismic, etc.), performance criteria, aesthetic requirements, and construction constraints.
2	Evaluate site subsurface conditions and relevant properties of in-situ soil and rock.
3	Develop initial soil nail wall design criteria.
4	Perform preliminary design using simplified design chart solutions.
5	Evaluate external stability including global stability (Chapter 17), sliding and bearing capacity (Chapter 15).
6	Evaluate internal stability including nail pullout resistance and tensile resistance.
7	Perform facing design including: a) evaluation of nail head load; b) selection of temporary and permanent facing materials and thicknesses; c) evaluation of facing flexural resistance; d) evaluation of facing punching shear resistance; and, e) evaluation of facing stud tensile resistance.
8	Estimate maximum lateral wall movements.
9	Design wall subsurface and surface drainage systems

18.10 HYBRID WALLS

Hybrid walls are composed of 2 or more different types of walls (see Figure 18-17) or a combination of ERS and slope (see Figure 18-18) regardless of the slope angle or slope height. These kinds of walls allow a reduction in the ROW required for the construction of a project. The use of hybrid walls will require special attention from the design team. The various components of the hybrid wall may require different deformations to develop adequate resistance to the external loads. These differences can lead to incompatible deformations at the face of wall. The continuity of the drainage system must be maintained in both components of the hybrid wall. Finally, while the performance and design information for each component is known, the performance of the hybrid wall system is typically not known.

The combining of cut and fill walls should be performed with extreme care, since most cut walls require small strains to develop resistance, while most fill walls require larger strains to develop the same resistance. If the walls move (displace) different amounts to develop the required resistances, the face of the wall may display unaesthetic differential movements, even if the wall is structurally sound. The fact that the face shows displacement can cause the general public to consider the wall failing. In addition, the higher strains required to develop the resistance of 1 portion of the wall can induce higher loads in another portion of the wall causing failure of the wall.

In most cases, the hybrid wall consists of a stacked system (see Figure 18-17) with 1 wall or slope on top of another. The overall stability of the entire system must be checked in accordance with Chapter 17. Then, each individual wall component should be checked for stability. The lower wall should include the weight of the upper wall as a surcharge load. The design of the upper wall should include the movements (vertical and lateral) of the lower wall in design (see Chapter 17). The design engineer should have a clear understanding of how each different wall component will perform prior to selecting the use of a hybrid wall.

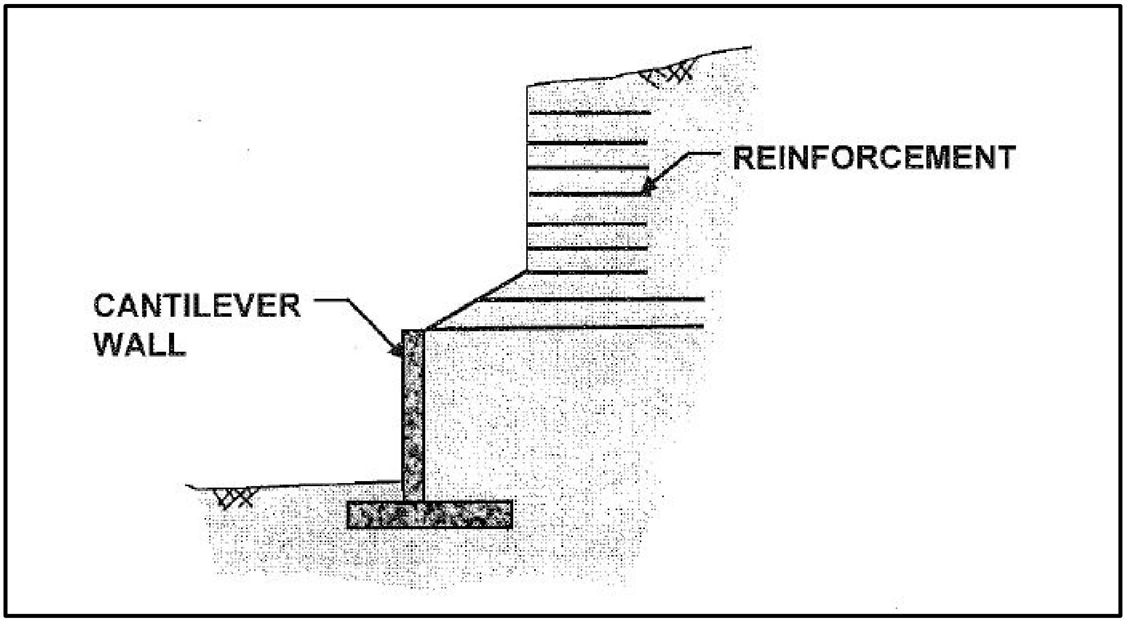


Figure 18-17, Hybrid Wall – Cantilever Concrete under MSE Wall

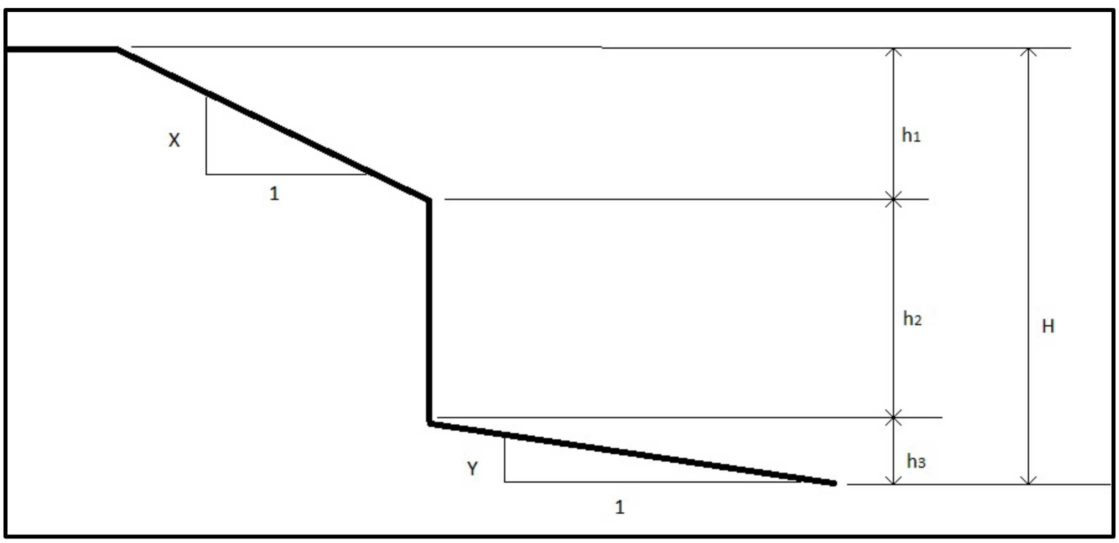


Figure 18-18, Compound Slope – Slope Above and Below ERS

18.11 UTILITIES

No utilities shall be placed directly behind or within the reinforced zone of any ERS without written permission of the OES/GDS. All utilities that conduct power shall be sufficiently insulated to prevent stray current from affecting the ERS. In addition, provide to SCDOT a stamped drawing prepared by a South Carolina licensed engineer providing the details of the power conduit installation and insulation. No force mains (water or wastewater) shall be permitted within either the active zone or the reinforced zone unless a secondary containment system is also provided, including a method to relieve pressure buildup in the secondary containment should the primary utility fail. The exception to this policy is the placement of storm water utilities that are required to permit drainage of the roadway surface. All storm water utilities shall be placed to avoid interference with the active zone or the reinforced zone except where details provided by SCDOT are applied. In addition, all storm water utilities should be designed to inhibit or prevent leaks. Please note that the use of reinforced concrete pipe (RCP) is required along all Interstate (including bridges that cross the Interstate) and SCDOT Evacuation Routes. Regardless of whether the storm water utility is located within the active zone, the reinforced zone or below the bottom of the wall footprint, the RCP shall meet the requirements of SC-M-714 – *Permanent Pipe Culverts*. A rubber gasket joint material meeting the requirements of ASTM C443 – *Standard Specification for Joints for Concrete Pile and Manholes, Using Rubber Gaskets* including a 13 psi pressure test. For ERSs located along non-interstate routes all pipe culvert types are allowed, however, non-concrete pipe is preferred, see SC-M-714. All pipes whether located in the active zone, the reinforced backfill or below the bottom of the wall footprint shall conform to requirements of SC-M-714. In addition, all joint materials shall include a 13 psi pressure test. Backfill all utility trenches located below the bottom of the reinforced backfill limits with flowable fill regardless of pipe culvert type in accordance with SC-M-714. The flowable fill shall meet the requirements of SC-M-210 – *Flowable Fill*.

18.12 TEMPORARY WALLS

Temporary shoring walls are used to support a temporary excavation that is required to allow construction to proceed. Temporary shoring walls have a service life of less than 5 years. Temporary shoring walls shall be designed for total stress conditions, including those walls that support normally consolidated Clay-Like materials (i.e., c = X psf and ϕ = 0°). Therefore, the equations provided in Section 18.5, shall be modified as required to use total stress soil parameters. Any shoring wall with a service life of greater than 5 years shall be designed as a permanent ERS. Another major distinction between permanent and temporary ERSs is an increase in the resistance factor allowed in design. Temporary walls may be subdivided into 2 classes "support of excavation" (SOE) and "critical." SOE walls typically support just the excavation while the critical temporary walls support critical structures (i.e., existing roadway and traffic, bridge end bent fill, utilities, etc.). The resistance factors and performance limits established (see Chapters 9 and 10) are for critical temporary walls. The OES/GDS should be contacted for the resistance factors and performance limits for SOE temporary walls. The design of temporary walls uses the same methodologies as the permanent walls.

18.13 REFERENCES

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