SEGMENTAL RETAINING WALL DESIGN

INTRODUCTION

Segmental retaining walls (SRWs) function as gravity structures by relying on self-weight to resist the destabilizing forces due to retained soil (backfill) and surcharge loads. The self-weight of the SRW system is either the weight of the SRW units themselves including aggregate core fill if used (in the case of conventional SRWs) or the combined weight of the units, aggregate core fill if used and the reinforced soil mass (in the case of soil-reinforced SRWs).

Stability is provided by a coherent mass with sufficient width to prevent both sliding at the base and overturning about the toe of the structure under the action of lateral earth forces.

SRWs are durable and long lasting retaining wall systems. The typical size of SRW units, placed without mortar (dry-stacked), permits the construction of walls in locations with difficult access and allows the construction of tight curves or other complex architectural layouts. Segmental retaining walls are used in many applications, including landscaping walls, structural walls for changes in grade, bridge abutments, stream channelization, waterfront structures, tunnel access walls, wing walls and parking area support. This Tech Note provides a general overview of design considerations and the influences that height, soil, loads and geometry have on structural stability, based on *Design Manual for Segmental Retaining Walls* (ref. 1).

It is recommended that users of this Tech Note consult local building codes to determine additional SRW requirements and the engineering needs of their project. Where such specific requirements do not exist, CMHA recommends an engineered design performed by a registered professional on walls with a total (design) height, *H*, exceeding 4 ft (1.21 m) (for further detail, refer to SRW-TEC-008-12, *Inspection Guide for Segmental Retaining Walls* (ref. 3).

TYPES OF SEGMENTAL RETAINING WALLS

Conventional (Gravity) Segmental Retaining Walls

Conventional (gravity) SRWs retain soils solely through the self-weight of the SRW units. They can be constructed with either a single depth of unit or with multiple depths. The maximum wall height achievable using a conventional SRW is directly proportional to the unit's weight, width, site geometry, surcharge load and retained soil type. Table 1 illustrates the effect of increasing the wall batter, unit width, unit's in-place density (using either a solid unit or unit with aggregate core fill), and better quality backfill on the maximum height of a gravity wall.

Soil-Reinforced Segmental Retaining Walls

Soil-reinforced SRWs are composite systems consisting of SRW units in combination with a mass of reinforced soil. The soil is stabilized by horizontal layers of reinforcement, typically a geosynthetic material. The reinforcement increases the effective width and weight of the gravity system.

Geosynthetic reinforcement materials are high-tensile-strength polymeric materials. They may be geogrids or geotextiles, although current SRW construction typically uses geogrids. Figure 2 illustrates a typical soil-reinforced segmental retaining wall and current design terminology.

The geosynthetic reinforcement is placed between the units and extended into the soil to create a composite gravity mass structure. This mechanically stabilized wall system, comprised of the SRW units and a reinforced soil mass, is designed to offer the required resistance to external forces associated with taller walls, surcharged structures, or more difficult soil conditions. Soil-reinforced SRWs may also be referred to as mechanically stabilized earth (MSE) walls, the generic term used to describe all forms of reinforced soil structures.

DESIGN CONSIDERATIONS

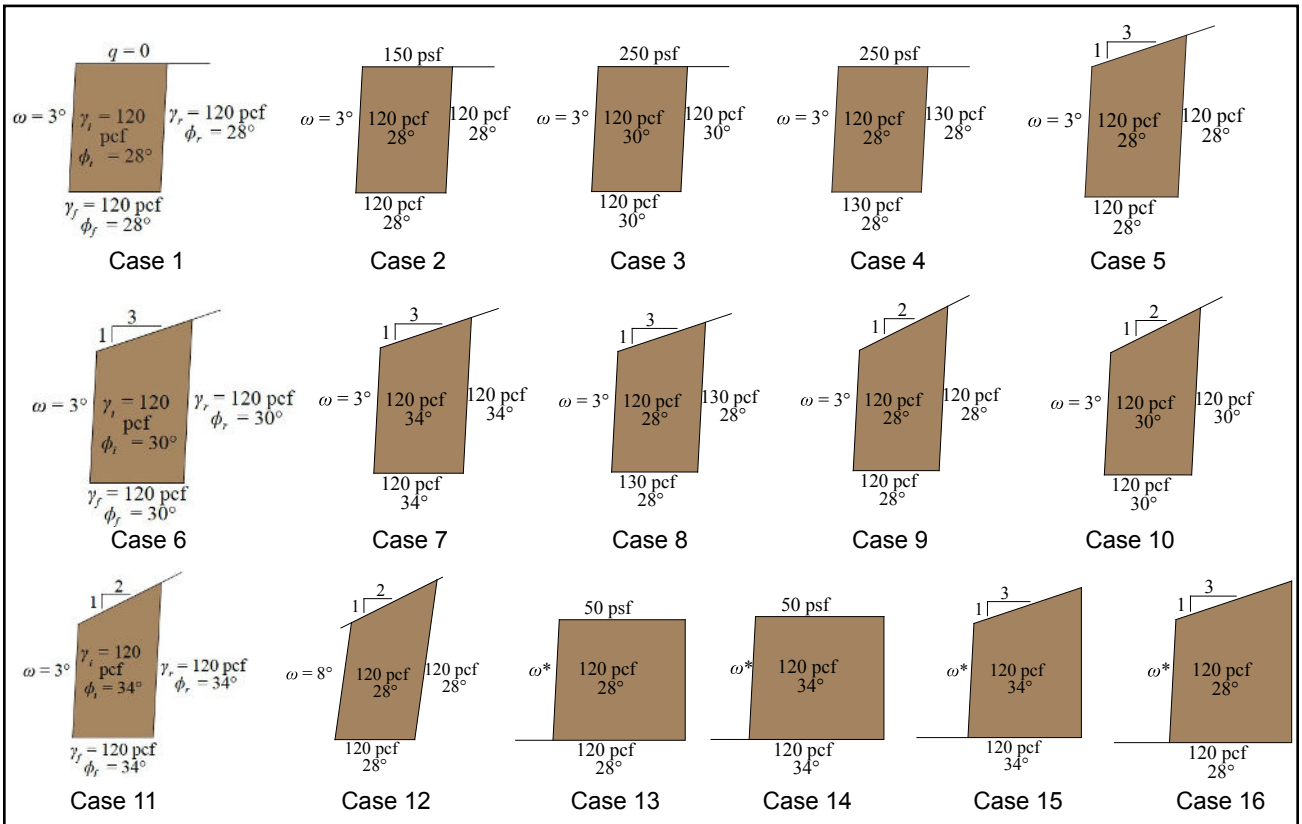
Geosynthetic Length and Spacing

For soil-reinforced segmental retaining walls, geosynthetic reinforcement increases the mass of the composite SRW structure, and therefore increases its resistance to destabilizing forces. Geosynthetic length (*L*) is typically controlled by external stability or internal pullout capacity calculations. Increasing the length of the geosynthetic layers increases the SRW's resistance to overturning, base sliding, bearing failure

Table 1—Gravity SRW Design Heights for Various Unit, Soil and Wall Properties (refer to cases on Figure 1 and design parameters on next page)

Level conditions w/50 psf surcharge—Cases 13 and 14							
Unit width, in. (mm)	ϕ (deg)	Retained unit weight = 110 pcf (1,762 kg/m³)			Retained unit weight = 120 pcf (1,922 kg/m³)		
		Max. wall height, ft (m), for wall batter of:			Max. wall height, ft (m), for wall batter of:		
		5°	10°	15°	5°	10°	15°
12 (305)	28	2.0 (0.60)	2.0 (0.60)	2.6 (0.79)	1.3 (0.39)	2.0 (0.60)	2.0 (0.60)
24 (610)	28	4.6 (1.40)	5.3 (1.61)	6.6 (2.01)	4.6 (1.40)	5.3 (1.61)	6.0 (1.82)
12 (305)	34	2.6 (0.79)	3.3 (1.00)	4.0 (1.21)	2.6 (0.79)	3.3 (1.00)	4.0 (1.21)
24 (610)	34	6.0 (1.82)	7.3 (2.22)	8.0 (2.43)	6.0 (1.82)	7.3 (2.22)	8.0 (2.43)

Slope 3:1—Cases 15 and 16							
Unit width, in. (mm)	ϕ (deg)	Retained unit weight = 110 pcf (1,762 kg/m³)			Retained unit weight = 120 pcf (1,922 kg/m³)		
		Max. wall height, ft (m), for wall batter of:			Max. wall height, ft (m), for wall batter of:		
		5°	10°	15°	5°	10°	15°
12 (305)	28	2.0 (0.60)	2.0 (0.60)	2.6 (0.79)	2.0 (0.60)	2.0 (0.60)	2.0 (0.60)
24 (610)	28	4.0 (1.21)	4.6 (1.40)	5.3 (1.61)	4.0 (1.21)	4.0 (1.21)	4.6 (1.40)
12 (305)	34	2.6 (0.79)	3.3 (1.00)	4.0 (1.21)	2.6 (0.79)	3.3 (1.00)	3.3 (1.00)
24 (610)	34	6.0 (1.82)	7.3 (2.22)	8.0 (2.43)	5.3 (1.61)	6.6 (2.01)	7.3 (2.22)



* Cases 1 through 12 represent soil-reinforced SRW design cases. Cases 13 through 16 represent conventional SRW design cases, where wall batter, ω, varies: 5°, 10° or 15°

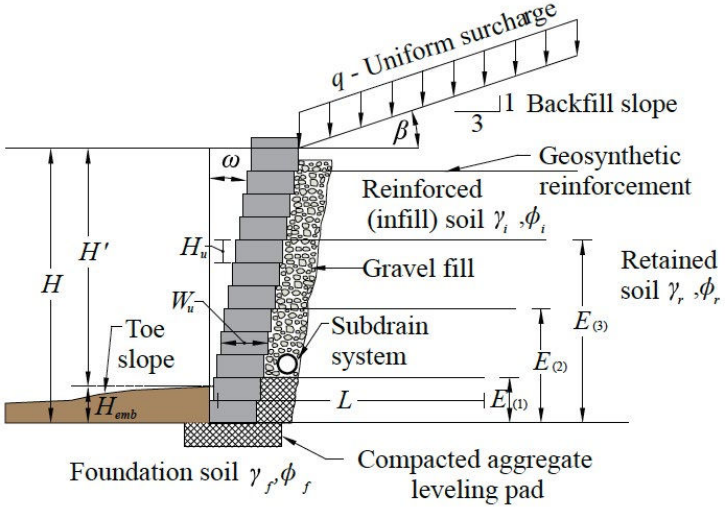
Figure 1—Design Cases Corresponding to Table 1 and Figures 3 through 5

Design Parameters for Table 1:

- Minimum factor of safety for base sliding, overturning and internal shear, 1.5
- Toe slope 0°
- Minimum masonry friction reduction factor, μ_b, between SRW unit and aggregate leveling pad, 0.7
- Minimum shear capacity between SRW units, 400 lb/ft (5.8 kN/m)
- Angle of friction between SRW units, 30°
- Live surcharge is initiated behind the face of the wall
- Required minimum embedment at toe, H_{emb}, 6 in. (152 mm)
- SRW unit weight, 120 pcf (1,922 kg/m³), includes aggregate core fill when used
- See Reference 1 for typical values of ϕ for various soil types

and geosynthetic pullout. In some cases, the length of the uppermost layer(s) is locally extended to provide adequate anchorage (pullout capacity) for the geosynthetic layers. The strength of the geosynthetic and the frictional interaction with the surrounding soil may also affect the geosynthetic length necessary to provide adequate pullout capacity. In addition, the required length to achieve minimum pullout capacity is affected by soil shear strength, backslope geometry and surcharge load (dead or live).

The minimum geosynthetic length required to satisfy external stability criteria is also a function of the soil shear strength and structure geometry (including wall batter, backslope, toe slope and surcharge). As the external driving force increases (as occurs with an increase in backslope angle, reduction in soil shear strength, or increase in external surcharge load (dead or live)), the length of the geosynthetic increases to satisfy minimum external stability requirements. Figures 3 through 5 illustrate the effect of backslope geometry, surcharge, soil unit weight and soil shear strength on the minimum required geosynthetic length to satisfy base sliding (*FS* = 1.5), overturning (*FS* = 1.5) and pullout (*FS* = 1.5). Regardless of the results of external stability analyses for sliding and overturning, the geogrid length (*L*) should not be less than 0.6*H*. The purpose of this empirical constraint is to prevent the construction of unusually narrow reinforced retaining walls. In addition, it is recommended that the absolute minimum value for *L* be 4 ft (1.2 m).



$E_{(n)}$ = elevation of geosynthetic reinforcement above top of leveling pad, ft (m)
H = total (design) height of wall, ft (m)
H' = exposed height of wall, ft (m)
H_{emb} = wall embedment depth, ft (m)
H_u = height of segmental retaining wall unit, ft (m)
L = minimum length of geosynthetic reinforcement, including facing connection, ft (m)
W_u = width of segmental retaining wall unit, ft (m)
β = backslope angle from horizontal, degrees
γ = soil unit weight, pcf (kg/m³)
ϕ = friction angle of soil, degrees
ω = wall batter, degrees

Figure 2—Soil Reinforced Segmental Retaining Wall Components

A sufficient number and strength of geosynthetic layers must be used to satisfy horizontal equilibrium with soil forces behind the wall and to maintain internal stability. In addition, the tension forces in the geosynthetic layers must be less than the design strength of the geosynthetic and within the allowable connection strength between the geosynthetic and the SRW unit. The optimum spacing of these layers is typically determined iteratively, usually with the aid of a computer program. Typically, the vertical spacing decreases with depth below the top of the wall because earth pressures increase linearly with depth.

Vertical spacing between geosynthetic layers should be limited to prevent bulging of the wall face between geosynthetic connection points, to prevent exceeding the shear capacity between SRW units, to decrease the load in the soil reinforcement and at the geosynthetic-SRW unit connection interface. Figure 6 shows that smaller vertical reinforcement spacings reduce the geosynthetic reinforcement tensile load. Even when all internal and facial stability failure modes can be satisfied with larger spacings, however, a maximum vertical

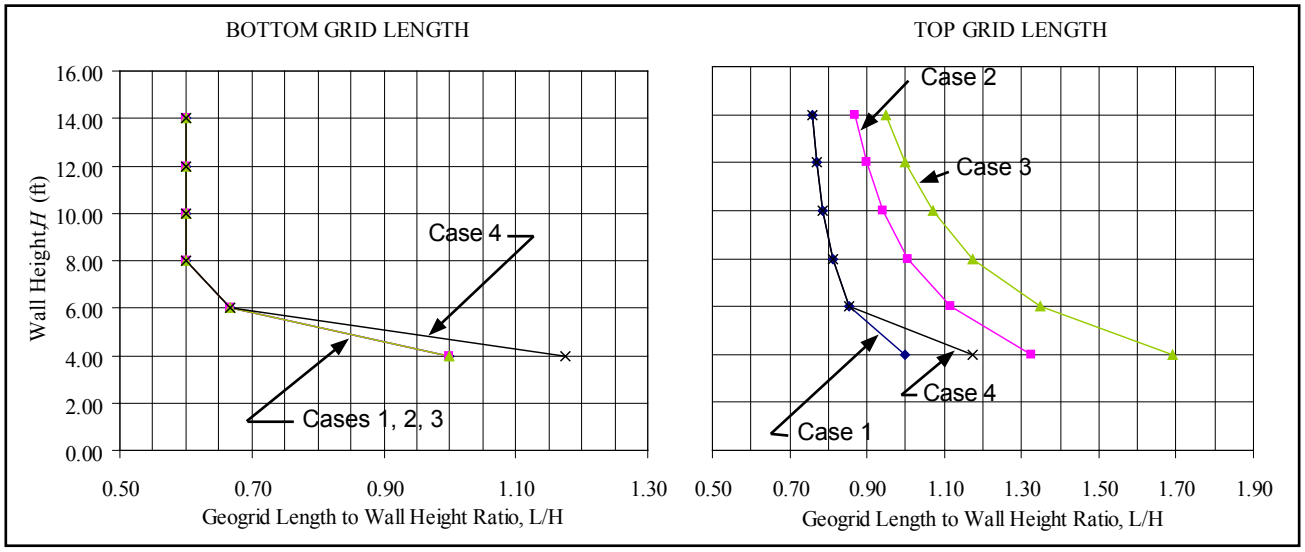
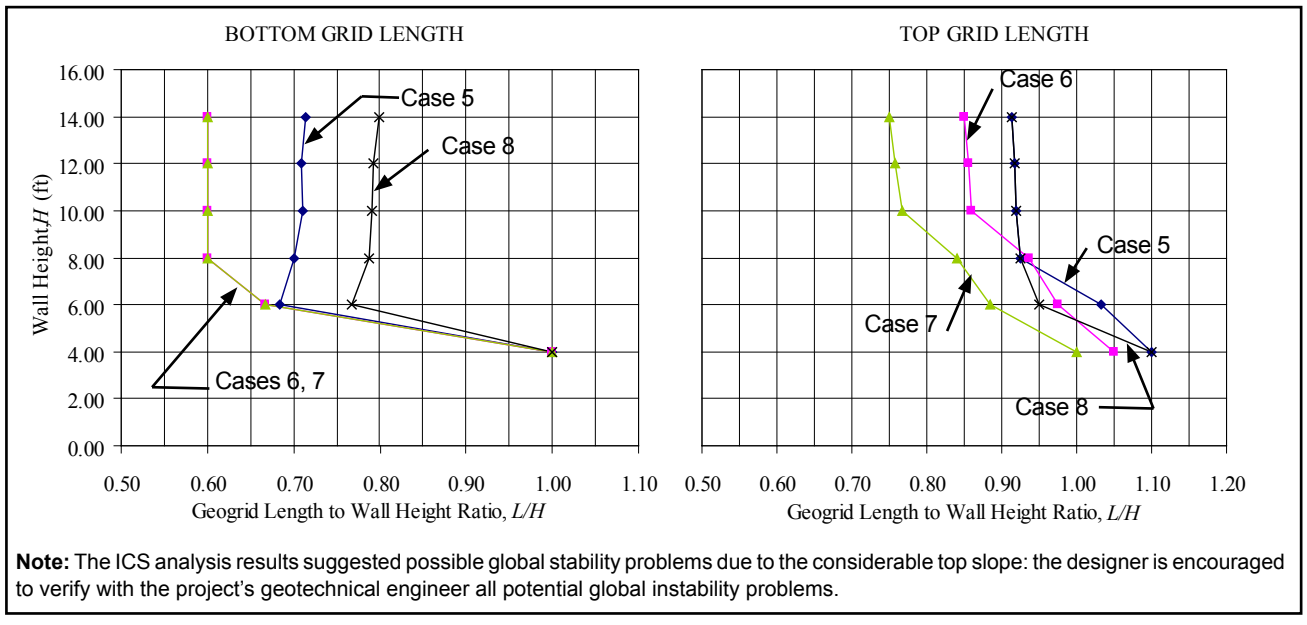


Figure 3—Flat Slope Cases, Varying ϕ, γ and *q*—Cases 1, 2, 3 and 4

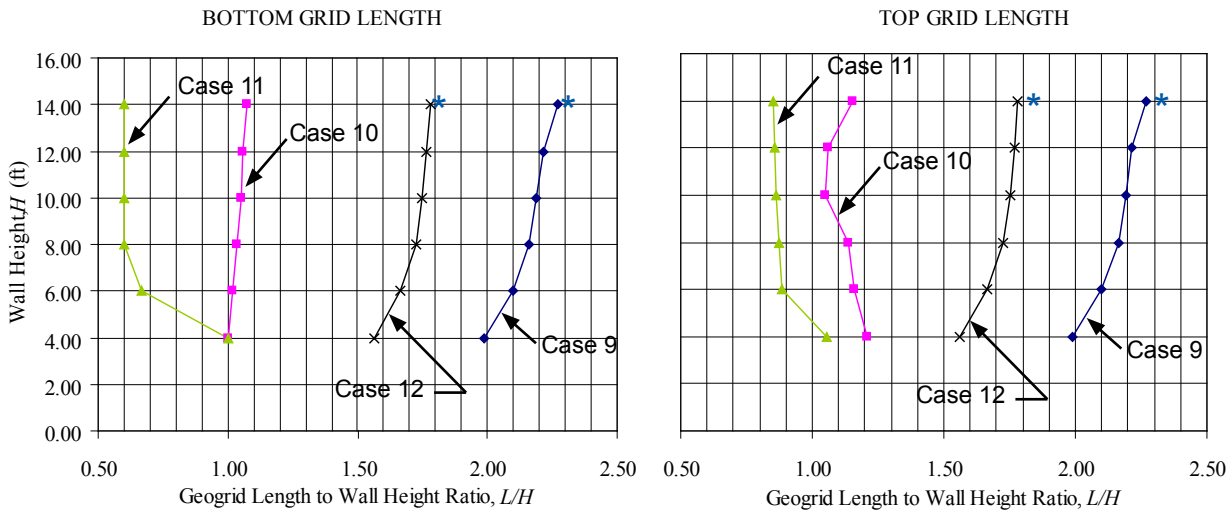


Note: The ICS analysis results suggested possible global stability problems due to the considerable top slope: the designer is encouraged to verify with the project's geotechnical engineer all potential global instability problems.

Figure 4—3:1 Top Slope Cases, Varying ϕ and γ—Cases 5, 6, 7 and 8

spacing between reinforcement layers of 24 in. (609 mm) is suggested to reduce construction stability issues. Note that some proprietary systems may be capable of supporting larger spacings: a 32 in. (813 mm) maximum spacing is suggested for these systems. This maximum spacing limits construction issues and also ensures that the reinforced soil mass behaves as a composite material, as intended by this design methodology. For SRW units less than or equal to 10 in. (254 mm) in depth, it is recommended that the maximum vertical spacing of the reinforcement layers be no more than twice the depth of the unit. For example, the maximum vertical spacing for a 9 in. (229 mm) deep modular block would be 18 in. (457 mm). Within these limits, the wall designer should choose an appropriate maximum reinforcement spacing for the proprietary system used.

Regardless of the reinforcement spacing, compaction of the reinforced fill zone is generally limited to 6 to 8 in. (152 to 203 mm) (compacted height) in order to achieve the necessary density and construction quality control. Compaction lift thickness in the retained zone is typically limited to the same



Note: The ICS analysis results suggested possible global stability problems due to the considerable top slope: the designer is encouraged to verify with the project's geotechnical engineer all potential global instability problems.

* The ICS factor of safety cannot be satisfied for this wall height due to the combination of slope and soil conditions. The failure is caused by instability of the slope above the wall that may require further investigation in coordination with the project's geotechnical engineer.

Figure 5—2:1 Top Slope Cases, Varying ϕ and ω—Cases 9, 10, 11 and 12

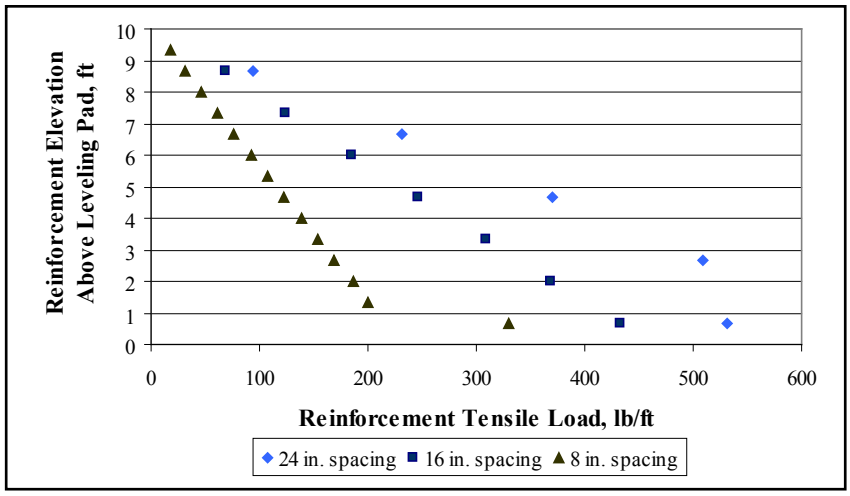


Figure 6—Influence of Reinforcement Vertical Spacing on Calculated Reinforcement Tensile Load

Design Parameters for Figures 3 through 6:

- Width of SRW unit, W_u, 12 in. (305 mm)
- SRW unit weight, 120 pcf (1,922 kg/m³), includes aggregate core fill when used
- Wall batter, ω, 3° or 8°, as designated; toe slope 0°
- Angle of friction between SRW units and geosynthetic, 40°
- Direct sliding coefficient, C_{ds}, 0.95 (min.)
- Interaction coefficient, C_i, 0.7 (min.)
- Minimum shear capacity between SRW units, 400 lb/ft (5.8 kN/m)
- Angle of friction between SRW units, 30°
- Soil properties as designated. When different soil unit weights (γ) are considered, g_r refers to the united weight of the retained soil
- Live surcharge is initiated behind the face of the wall
- Required minimum embedment at toe, H_{emb}, 6 in. (152 mm)
- See Reference 1 for typical values of f for various soil types

height; however, thicker lifts can be accomplished if the specified density can be achieved throughout the entire lift thickness and it can be demonstrated that there are no adverse affects to the wall system performance or aesthetics. Regardless of the compaction method or equipment, the specified densities should be met and any variation from the approved specifications must be authorized by the SRW design engineer of the project.

Gravel Fill and Drainage Materials

Whenever possible, water should be directed away from SRWs. However, when water does reach an SRW, proper drainage components should be provided to avoid erosion, migration of fines, and hydrostatic pressure on the wall. Drainage features of the SRW will depend on site-specific groundwater conditions. The wall designer should provide adequate drainage features to collect and evacuate water that may potentially seep at the wall. The civil site engineer is typically responsible for the design of surface drainage structures above, below and behind the wall and the geotechnical engineer is typically responsible for foundation preparation and subsurface drainage beneath a wall. Reference 1 addresses in detail the drainage features and materials required for various ground water conditions on SRWs.

The gravel fill (formerly known as the drainage aggregate) and drain pipe shown on Figure 2 should only be relied on to remove incidental water—they are not meant to be the primary drainage path of the system. The gravel fill acts mainly as a compaction aid to reduce horizontal compaction stresses on the back of the SRW units during construction. It also prevents retained soils from washing through the face of the wall when designed as a soil filter, and facilitates drainage of incidental water, thereby relieving hydrostatic pressure or seepage forces.

The drain pipe collects and evacuates any water in the system through weep holes (maximum 50 ft (15.2 m) o.c. spacing) or directly to a drainage collection system. The elevation and diameter of the drain pipe should be determined by the wall designer depending on the specific site conditions.

The gravel fill should consist of at least 12 in. (305 mm) of a free-draining aggregate installed behind of the SRW units, and the drain pipe have a minimum diameter of 3 in. (75 mm).

Wall Batter

Segmental retaining walls are generally installed with a small horizontal setback between units, creating a wall batter into the retained soil (ω in Figure 2). The wall batter compensates for any slight lateral movement of the SRW face due to earth pressure and complements the aesthetic attributes of the SRW system. For conventional (gravity) SRWs, increasing the wall batter increases the wall system stability.

Unit Size and Shear Capacity

All SRW units provide a means of transferring lateral forces from one course to the next. Shear capacity provides lateral stability for the mortarless SRW system. SRW units can develop shear capacity by shear keys, leading lips, trailing lips, clips, pins or compacted columns of aggregate in open cores. In conventional (gravity) SRWs, the stability of the system depends primarily on the mass and shear capacity of the SRW units: increasing the SRW unit width or weight provides greater stability, larger frictional resistance, and larger resisting moments. In soil-reinforced SRWs, heavier and wider units may permit a greater vertical spacing between layers of geosynthetic, minimize the potential for bulging of the wall face. For design purposes, the unit weight of the SRW units includes the gravel fill in the cores if it is used.

Wall Embedment

Wall embedment is the depth of the wall face below grade (H_{emb} in Figure 2). The primary benefit of wall embedment is to ensure the SRW is not undermined by soil erosion in front of the wall. Increasing the depth of embedment also provides greater stability when site conditions include weak bearing capacity of underlying soils, steep slopes near the toe of the wall, potential scour at the toe (particularly in waterfront or submerged applications), seasonal soil volume changes or seismic loads.

The embedment depth is determined based on the wall height and toe slope conditions (see Table 2), although the absolute minimum suggested H_{emb} is 6 in. (152 mm).

Surcharge Loadings

Often, vertical surcharge loadings (q in Figure 2) are imposed behind the top of the wall in addition to load due to the retained earth. These surcharges add to the lateral pressure on the SRW structure and are classified as dead or live load surcharges.

Live load surcharges are considered to be transient loadings that may change in magnitude and may not be continuously present over the service life of the structure. In this design methodology, live load surcharges are considered to contribute to destabilizing forces only, with no contribution to stabilizing the structure against external or internal failure modes. Examples of live load surcharges are vehicular traffic and bulk material storage facilities.

Dead load surcharges, on the other hand, are considered to contribute to both destabilizing and stabilizing forces since they are usually of constant magnitude and are present for the life of the structure. The weight of a building or another retaining wall (above and set back from the top of the wall) are examples of dead load surcharges.

DESIGN RELATIONSHIPS

Table 1 summarizes the influence of increasing the wall batter, increasing the unit width, increasing the unit's in-place density, and using better quality backfill on the maximum constructible height of a gravity SRW to satisfy sliding and overturning.

Figures 3 through 5 summarize the influences wall geometry, backslope and soil shear strength have on the minimum required reinforcement length to satisfy base sliding, overturning and pullout for a reinforced SRW.

These design relationships were generated using conservative, generic properties of SRW units. They are not a substitute for project-specific design, since differences between properties assumed in the tables and project-specific parameters can result in large differences in final design dimensions or factors of

safety. Although wall heights up to 8 ft (2.44 m) for conventional (gravity) walls and 14 ft (4.28 m) for soil-reinforced walls are presented, properly engineered walls can exceed these heights.

For a detailed discussion of design and analysis parameters, the *Design Manual for Segmental Retaining Walls* (ref. 1) should be consulted. Design cases 1 through 16 are illustrated in Figure 1. All results shown were calculated using the software SRWall 4.0 (ref. 2) providing the appropriate geosynthetic lengths to satisfy sliding, overturning, and pullout (reinforced walls only) safety factors; or the maximum gravity wall height to satisfy sliding, overturning and internal shear. The final number, distribution and strength of the geogrids can only be determined by a designer for each specific SRW unit-geogrid combination to guarantee the appropriate safety factors for internal, facial stability and Internal Compound Stability (ICS) are met (for more detailed information, see Reference 1). The ICS can be met by reducing the geogrid spacing or increasing the grid length or strength: the examples presented here were calculated by reducing the geogrid spacing and maintaining the maximum and minimum geogrid lengths for convenience. See SRW-TEC-003-10, *Segmental Retaining Wall Global Stability,* (ref. 4) for more detailed information.

Large or commercial SRWs might also require foundation soil competency, settlement, and global stability analyses for a final design in coordination with other professionals in the project that are not addressed here (for more details on roles and responsibilities see SRW-TEC-002-10, *Roles and Responsibilities on Segmental Retaining Wall Projects* (ref. 5)). If the foundation and global analyses ultimately require a modification to the wall design, this must be done in coordination with the SRW designer.

EXAMPLE

A reinforced SRW is specified for a project that has the following characteristics:

H= 10 ft (3.0 m)

Backslope 3:1

Live surcharge= 0 psf

All soils ϕ = 28° and γ = 120 pcf (1,922 kg/m^3)

Table 2—Minimum Wall Embedment Depth

Slope in front of wall	Minimum H_{emb}, to top of leveling pad[A]
Horizontal (walls)	H'/20, 6 in. (152 mm) min.
Horizontal (abutments)	H'/10, 6 in. (152 mm) min.
3H : 1V	H'/10, 6 in. (152 mm) min.
2H : 1V	H'/7, 6 in. (152 mm) min.

[A] H' is the exposed height of the SRW, see Figure 2

Determine the approximate geogrid lengths (L) at the bottom and top of the retaining wall.

Solution

Determine the case that applies to this problem using Figure 1: Case 5 for this example. Using Figure 4 (3:1 backslope), find L/H for the given soil conditions and for the design height of 10 ft (3.0 m).

Bottom geogrid:

L/H= 0.71; L_{bottom} = 0.71 x 10 ft = 7.1 ft (2.2 m)

Top geogrid:

L/H= 0.92; L_{top} = 0.92 x 10 ft = 9.2 ft (2.8 m)

For estimating purposes, the volume of excavation and reinforced fill could be determined from the obtained data. The number, strength and distribution of the geogrids can only be determined by a designer for the specific SRW unit-geogrid combination to comply with the appropriate safety factors for internal, facial stability and ICS. The ICS is dependent on the spacing, length and strength of the geogrids: the designer is encouraged to perform the appropriate calculations to verify the distribution of the geosynthetics.

NOTATIONS:

C_{ds} = direct sliding coefficient
C_i = interaction coefficient
$E_{(n)}$ = elevation of geosynthetic reinforcement above top of leveling pad, ft (m)
FS = factor of safety
H = total (design) height of wall, ft (m)
H' = exposed height of wall, ft (m)
H_{emb} = wall embedment depth, ft (m)
H_u = height of segmental retaining wall unit, ft (m)
L = minimum length of geosynthetic reinforcement, including facing connection, ft (m)
q = vertical uniform surcharge load, lb/ft
W_u = width of segmental retaining wall unit, ft (m)
β = backslope angle from horizontal, degrees
γ = soil unit weight, pcf (kg/m^3)
γ_f = weight of foundation soil, pcf (kg/m^3)
γ_i = weight of infill soil, pcf (kg/m^3)
γ_r = weight of retained soil, pcf (kg/m^3)
μ_b = minimum masonry friction reduction factor
ϕ = friction angle of soil, degrees
ϕ_f = friction angle of foundation soil, degrees
ϕ_i = friction angle of infill soil, degrees
ϕ_r = friction angle of retained soil, degrees
ω = wall batter, degrees

REFERENCES

1. *Design Manual for Segmental Retaining Walls*, 3rd edition. Concrete Masonry & Hardscapes Association, 2009.
2. *Design Software for Segmental Retaining Walls*, SRWall 4.0. Concrete Masonry & Hardscapes Association, 2009.
3. *Inspection Guide for Segmental Retaining Walls*, SRW-TEC-008-12, Concrete Masonry & Hardscapes Association, 2010.
4. *Segmental Retaining Wall Global Stability*, SRW-TEC-003-10, Concrete Masonry & Hardscapes Association, 2010.
5. *Roles and Responsibilities on Segmental Retaining Wall Projects,* SRW-TEC-002-10, Concrete Masonry & Hardscapes Association, 2010.

ABOUT CMHA

The Concrete Masonry & Hardscapes Association (CMHA) represents a unification of the Interlocking Concrete Pavement Institute (ICPI) and National Concrete Masonry Association (NCMA). CMHA is a trade association representing US and Canadian producers and suppliers in the concrete masonry and hardscape industry, as well as contractors of interlocking concrete pavement and segmental retaining walls. CMHA is the authority for segmental concrete products and systems, which are the best value and preferred choice for resilient pavement, structures, and living spaces. CMHA is dedicated to the advancement of these building systems through research, promotion, education, and the development of manufacturing guides, design codes and resources, testing standards, and construction practices.

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