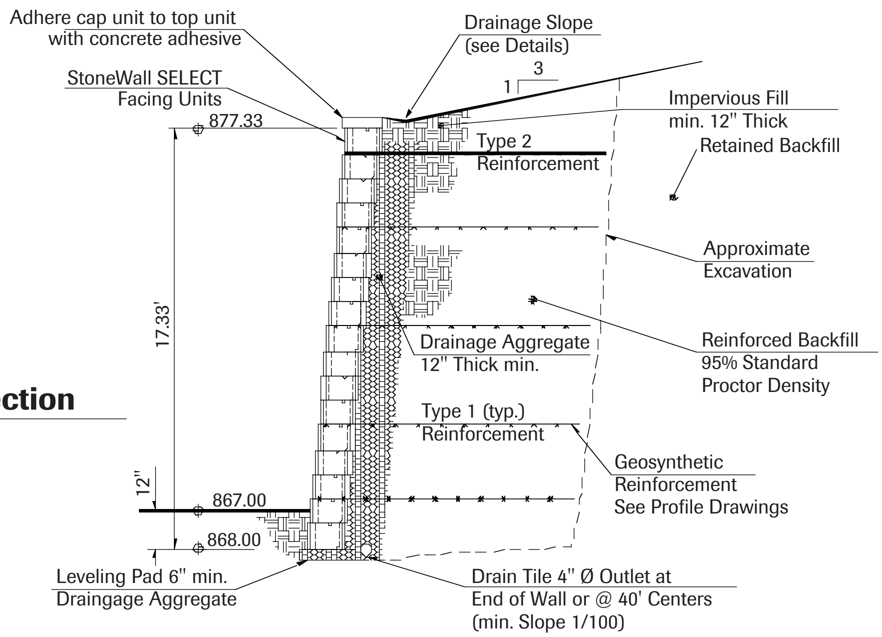
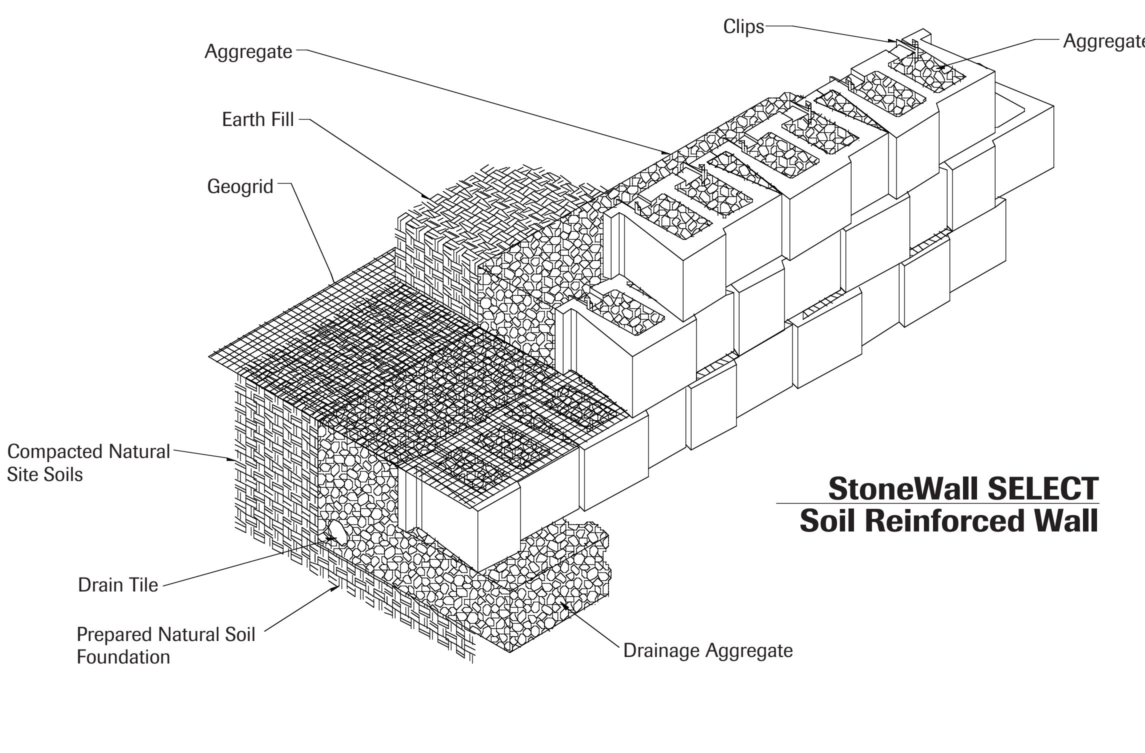
StoneWall® SELECT®

Segmental Retaining Wall System

Engineering Design Basics



Typical Section



StoneWall SELECT
Soil Reinforced Wall

INTRODUCTION

The use of retaining structures has expanded in recent years as increasingly transportation/highway upgrades are constructed within existing rights-of-way and the development of prime industrial, residential, and commercial property has spilled on to sites requiring more improvement. The StoneWall SELECT Segmental Retaining Wall (SRW) system has been specifically developed to meet the challenges that *change in grade* construction present, particularly when foundation conditions are predominated by compressible soils. This brochure will explain the engineering concepts for selection of a StoneWall SELECT SRW for your project and a synopsis of the methodology used to design the structure.

The basic StoneWall SELECT SRW system, as depicted on the front cover, can be readily adapted to a wide range of design requirements and site conditions. The extreme versatility of StoneWall SELECT results from its inherent flexibility and suitability with a wide range of infill materials and foundation soils. This permits StoneWall SELECT SRWs to cost-effectively replace conventional retaining walls constructed as:

- Concrete cantilever
- Concrete gravity
- MSE or Earth-anchored
- Concrete crib
- Timber crib
- Sheet pile
- Soldier pile & lagging with or without tiebacks

Earth retaining structures are commonly incorporated into civil construction work to accommodate irregular topography and facilitate grade separation. In lieu of simple earth slopes, their use is generally dictated by severity of the grade change and availability or cost of land within a project site. Typical applications are:

- Widening within existing rights-of-way
- Adding a lane of traffic or parking
- Grading development sites to boundary limits
- Providing truck or emergency vehicle access
- Expanding sports fields & storage yards
- Reshaping & stabilizing storm water channels
- Building storm water detention structures
- Repair of failed slopes and retaining structures

The primary function of an earth structure is to provide a very steep, or in some cases vertical surface, which is erosion resistant and structurally stable under its self-weight and externally imposed loads. The near vertical *change in grade* requires that earth materials be stacked higher and steeper than their internal shear strength properties will permit. Consequently, the magnitude of lateral earth pressure which these earth structures must resist is directly related to:

- Height of the change in grade,
- Internal shear strength of the earth materials,
- Geometry of slope above the structure, and
- Magnitude of any imposed surcharge loadings.

The following is a basic engineering approach and design methodology to address those issues, plus availability of suitable backfill materials, economics and the aesthetics which govern StoneWall SELECT SRWs.

StoneWall SELECT Advantages

Aesthetics: The split face concrete block facing that is an integral part of the StoneWall SELECT SRW system provides an instantaneous and enduring beauty in a variety of colors, shapes and finishes.

Performance: The "dry-stack" construction of the StoneWall SELECT SRW system provides a retaining structure which "breathes." The joints between adjacent SRW units are free to move relative to each other, allowing the wall to accommodate differential settlement and conditions. The "dry-stack" facing and typical wall face drain also prevent the buildup of hydrostatic pressures behind the wall.

Infill Materials: The StoneWall SELECT SRW units are filled with a select granular (AASHTO 57 or 67 stone) to promote good shear capacity between units, connection strength with geosynthetic reinforcement, and free draining paths for water to exit the system. Generally, the reinforced soil volume performs best when free-draining granular soils are utilized, as recommended by design guidelines.

Economics: StoneWall SELECT SRWs are cost competitive with other conventional retaining wall systems even though the installed cost for all retaining wall systems varies with site specific conditions such as accessibility, soil conditions, cost of infill, labor rates, surcharge loadings, length of wall, etc. **Fig. 1** illustrates that depending upon wall height, StoneWall SELECT SRWs offer a 25 to 50 % cost savings over conventional cast-in-place concrete retaining walls. This installed cost graph **(Fig. 1)**, indicates relative cost competitiveness by comparing StoneWall SELECT SRWs built in 1990-92, with the cost of more conventional retaining wall construction methods compiled by the California DOT in 1986.

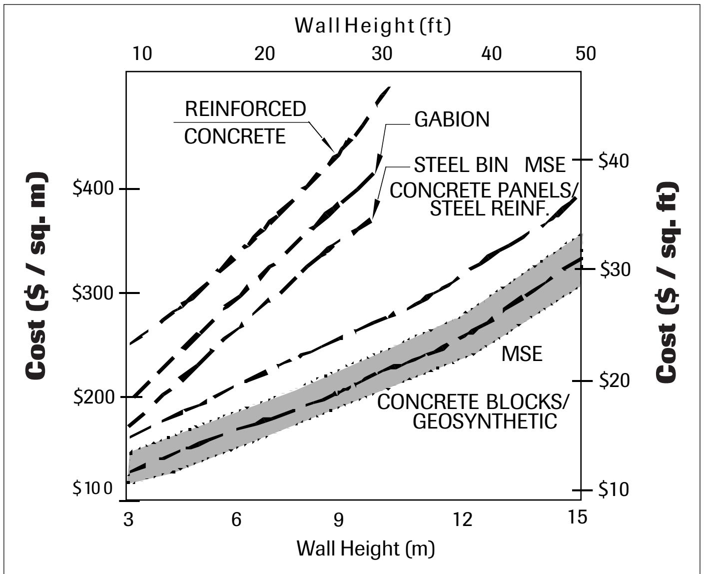


Fig. 1: Installed Cost Comparison

Ease of Construction: StoneWall SELECT SRWs can be assembled with commonly available construction equipment and by workers with little masonry experience. The simplicity of installation aids both quality control and speed of construction, as workers become familiar with the repetitive procedure. Geosynthetic reinforcement is easily integrated between courses of facing and the fill placement / compaction procedures. The versatility of the SRW system accommodates curves, corners, and steps. Typically a crew of four with appropriate equipment can install 300 to 400 square feet per day depending on availability and haul distance of the backfill.

Durability: The components used in StoneWall SELECT SRWs are well known for their durability. The concrete block facing units have higher compression strength than those commonly used in building construction. The longevity of naturally occurring aggregate and other soils utilized has been well documented in the engineering literature. The backfill soils are stabilized using geosynthetic reinforcement manufactured from specially formulated polymers engineered to resist creep and environmental degradation for service lives of 5 to 120 years according to the geosynthetic industry standards referenced herein.

GENERAL DESIGN GUIDELINES

The design methodology for StoneWall SELECT SRWs follows those established in the second edition NCMA "Design Manual for SRWs." The Following is a summary of the engineering calculations used to analyze **gravity (A)** SRWs, as shown in **Fig. 3**, and **soil reinforced (B)** SRWs as shown in **Fig.4**. The generalized geometric and soil properties for these two types of SRWs are shown in **Figs. 3 & 4**.

NOTE: The more complex calculations for soil reinforced SRWs are easily adapted to a computer program available from NCMA. See references.

The site specific information necessary to execute a design are: wall geometry, surcharge loadings, excavation limits, and soil/groundwater conditions at the wall location. This is facilitated by generating a plan and profile drawing of the wall to understand its relationship to existing and proposed finish grades. The drawing should contain the location of any proposed or existing structures including underground utilities and property boundaries that may affect wall construction.

Based upon these project criteria the engineering design of the StoneWall SELECT retaining structure should address the major modes of potential failure: external, internal, local, and global stability. *Global stability* (**Fig. 2**) *of the retaining walls should be addressed by the site geotechnical or civil engineer* and is therefore not included as part of this summary.

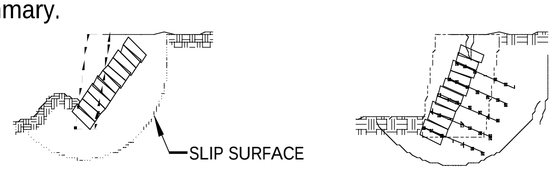


Fig. 2: Global Slope Stability

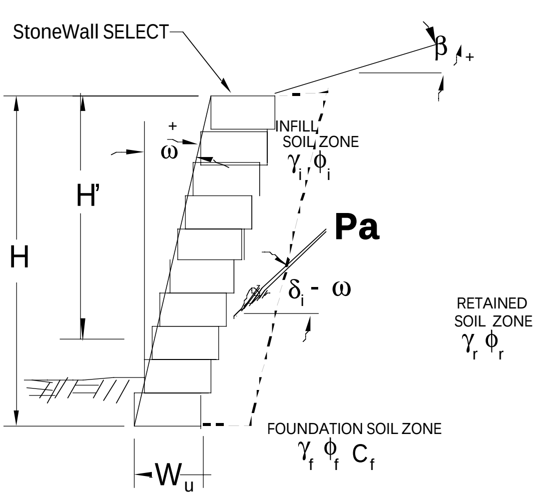
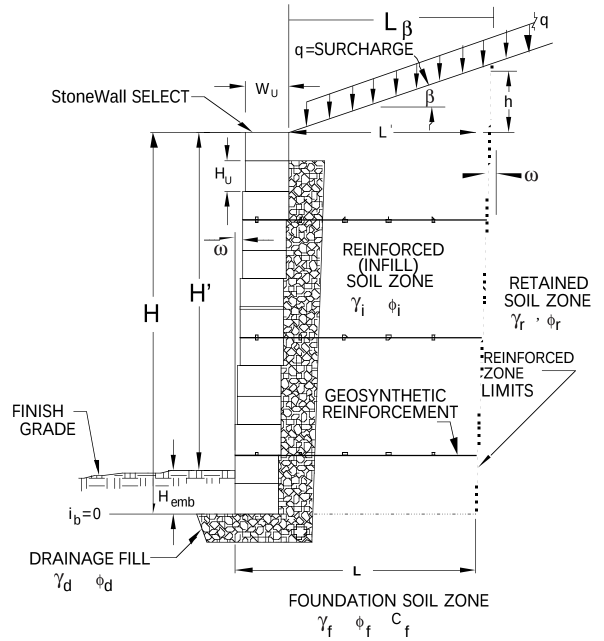


Fig. 3: Gravity SRW (A)



H = Total Height of Wall (Design Height)
H' = Exposed Height of Wall
H_{emb} = Wall Embedment (min 0.5ft., more if Sloping Toe)
L = Total Length of Reinforcement, with Facing Connection
H_u = Height of StoneWall SELECT
W_u = Width of StoneWall SELECT

Fig. 4: Soil Reinforced SRW (B)

EXTERNAL STABILITY

The general failure modes for external stability are shown in **Fig. 5**.

Step 1: Determine the earth pressure coefficient, $\mathbf{K_a}$, for both gravity, (**A**), and soil reinforced, (**B**), SRWs by Coulomb earth pressure theory (after Jumikis) using ϕ_r and δ_i (**A**) or δ_e (**B**):

$$K_a = \frac{\cos^2(\phi+\omega)}{\cos^2\omega \quad \cos(\omega-\delta) \quad \left[1+\sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi-\beta)}{\cos(\omega-\delta)\cos(\omega+\beta)}}\right]^2}$$

Step 2: Determine general and geometric quantities necessary for performing calculations:

Wall friction: $\delta_i = 0.667\ \phi_i$

δ_e = smaller of ϕ_i or ϕ_r

Determine the live, q_l, and dead, q_d, load surcharge:

$q = q_d + q_l$

B. For analysis determine **L**, for design select **L** :

(note: minimum L = 0.6 H)

Calculate other quantities

$L' = L - W_u$
$L'' = [L' (\tan\beta \tan\omega)] / [1-(\tan\beta \tan\omega)]$
$L_\beta = L' + L''$
$h = L_\beta \tan\beta$

Step 3: Determine the earth forces acting for external stability:

A. For gravity walls use total height of stacked StoneWall Select courses, H, and $K_{a'}$ based upon ϕ_i and δ_i:

$P_{sh'} = 0.5\ K_{a'}\ \gamma_r\ H^2 \cos(\delta_i - \omega)$

$P_{qh'} = K_{a'}\ q\ H \cos(\delta_i - \omega)$

B. For soil reinforced walls use height (H+h) at the back of the reinforced soil mass and Ka based upon ϕ_r and δ_e:

$P_{sh} = 0.5\ K_a\ \gamma_r\ (H+h)^2 \cos(\delta_e - \omega)$

$P_{qh} = K_a\ q\ (H+h) \cos(\delta_e - \omega)$

Step 4: Determine the weight of the wall for sliding resistance:

A. For gravity walls use total height of stacked StoneWall SELECT courses, H:

$W' = Hm\ W_u\ \gamma_i$

Calculate limiting Height (Hm) for analysis:

$Hm = Hh$, if $Hh < H$

$Hm = H$, if $Hh \geq H$

where: Hh = hinge Height

$Hh = [\ 2\ (W_u - G_u)\ ] / \tan\omega$

G_u = Center of Gravity, good estimate $W_u/2$

B. For soil reinforced walls use entire width of the reinforced zone, L, to resist sliding:

$W_r = W_{ri} + W_{r\beta} + W_{rq}$

where: $W_{ri} = \gamma_i\ H\ L$

$W_{r\beta} = \gamma_i\ [\ 0.5\ h\ (0.5\ (L' + L_\beta))]$

$W_{rq} = q_d\ L_\beta$

Step 5: Determine the Factor of Safety against sliding, $\mathbf{FS_{sl}}$. Conceptually this is the sliding resistance generated at the base of the structure due to self weight, divided by the lateral forces trying to move the structure outward, as shown in **Fig. 5**. Generally, a $\mathbf{FS_{sl}}$ greater than 1.5 is acceptable for design.

Note: ϕ_f shown in Fig. 4, for illustrative purposes, if ϕ_i or ϕ_d provide lower sliding resistance they control, in those cases $c_f = 0$. C_{ds} used when a geosynthetic is present at base, otherwise = 1.0.

A. For gravity walls determine sliding ristance along base width, W_u,.

$FS_{sl} = [\ c_f + (\ W'\ ) \tan\phi_f\ ] / (\ P_{sh'} + P_{qh'}\ )$

B. For soil reinforcement walls determine sliding along base length of reinforcement, i.e. the width of the reinforced zone, L,

$FS_{sl} = C_{ds}\ [\ c_f + (\ W_r \tan\phi_f\ )\ ] / (\ P_{sh} + P_{qh}\ )$

Step 6: Determine the Factor of Safety against overturning, $\mathbf{FS_{ot}}$. The tendency for the structure to rotate is evaluated by comparing the moments resisting rotation, $\mathbf{M_r}$, generated by the self weight of the structure, to loads, $\mathbf{M_d}$. Overturning about the toe of the structure is analyzed to protect against excessive outward tilting and distortion. A $\mathbf{FS_{ot}}$ greater than 1.5 (A) and 2.0 (B) indicates suitable performance.

$FS_{ot} = M_r / M_d$

A. For gravity walls determine the moments resisting overturning about the toe of base width, $\mathbf{W_u}$, as shown in **Fig. 3**.

$M_{d'} = P_{sh'}\ (H)\ 0.333 + P_{qh'}\ (H)\ 0.5$

$M_{r'} = W'\ X_w$

where: $X_w = G_u + [\ 0.5\ (Hh - H_u\ ) \tan\omega\ ]$

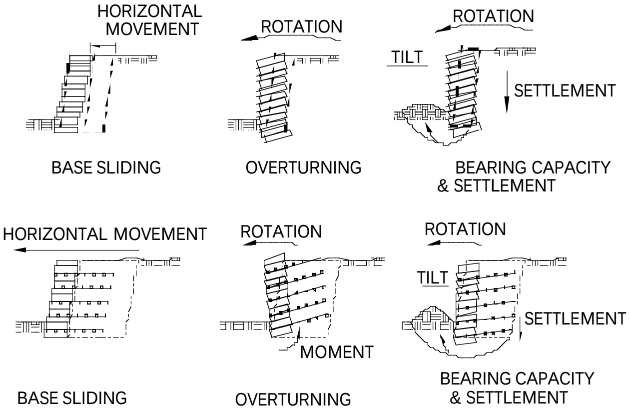


Fig. 5: External Stability Modes of Failure

B. For soil reinforced walls sum moments about the toe of the structure, along the base length of geosynthetic reinforcement, **L**, as shown in **Fig. 4**.

$M_d = P_{sh}\ (H+h)\ 0.333 + P_{qh}\ (H+h)\ 0.5$

$M_r = W_{ri}\ X_{ri} + W_{r\beta}\ X_{r\beta} + W_{rq}\ X_{rq}$

where: $X_{ri} = 0.5\ (\ H \tan\omega + L\ )$

$X_{r\beta} = L + H \tan\omega - 0.333\ [0.5\ (L' + L_\beta)]$

$X_{rq} = L + H \tan\omega - 0.5\ L_\beta$

Step 7: Determine the Factor of Safety against bearing capacity failure, $\mathbf{FS_{bc}}$. A conventional bearing capacity analysis is performed by comparing the design bearing pressure, $\mathbf{Qd_{sg}}$, determined from soils testing and analysis to the calculated applied bearing stress, $\mathbf{Q_{apd}}$, using a conservative Meyerhof stress distribution. Generally, a $\mathbf{FS_{bc}}$ greater than 2.0 is acceptable.

Note: $\mathbf{Q_{dsg}}$ may be either an ultimate bearing capacity, $\mathbf{Q_{ult}}$, calculated based upon the shear strength of the soil or an allowable bearing pressure, $\mathbf{Q_{alw}}$, provided by a geotechnical engineer based upon settlement analysis.

$FS_{bc} = Q_{dsg} / Q_{apd}$

A. For gravity walls determine the applied bearing pressure for the base width, $\mathbf{H_u}$, plus the distribution through the gravel leveling pad, $\mathbf{G_p}$ (0.5 ft., min), as shown in **Fig. 3**.

$Q_{ult} = c_f\ N_c + 0.5\gamma_f\ B'_f\ N\gamma + \gamma_f\ H_{emb}\ N_q$

where: $B'_f = B_f - 2e'$

$N_c, N\gamma, N_q$ = bearing capacity factors

$B_f = W_u + G_p$

$e' = [M_{d'} - W'\ e_w] / W'$

$e_w = X_w - W_u$

$Q_{apd} = W' / B'_f$

B. For soil reinforced walls determine the applied bearing pressure along the base length of geosynthetic reinforcement, **L**, as shown in **Fig. 4**.

$Q_{ult} = c_f\ N_c + 0.5\ \gamma_f\ B\ N_\gamma + \gamma_f\ H_{emb}\ N_q$

where: $B = L - 2e$

N_c, N_γ, N_q = bearing capacity factors

$e = [M_d - Z_1] / W_r$

$Z_1 = W_{ri}\ (X_{ri} - L/2) + W_{r\beta}\ (X_{r\beta} - L/2) + W_{rq}\ (X_{rq} - L/2)$

$Q_{apd} = [\ W_{ri} + W_{r\beta} + (\ q_l + q_d\ )\ L_\beta\ ] / B$

Internal Stability

The general modes of failure for internal stability are shown in **Fig. 6**.

Step 8: Determine the Factor of Safety against an internal sliding failure, $\mathbf{FS_{sl}}$. This analysis is very similar to the earlier external sliding analysis, except the sliding surface exits through the StoneWall SELECT facing at some point less than the full wall height, H, see Fig. 6. It ensures that the shear capacity between StoneWall SELECT SRW units is sufficient for a stable wall at intermediate heights for gravity walls, and between vertical spacing of geosynthetic reinforcement layers for soil-reinforced walls. This may, in some scenarios, create a more critical sliding surface than the full height structure (see external stability, Step 5). Generally, a $\mathbf{FS_{sl}}$ greater than 1.5 is acceptable for design.

Note: The shear capacity of StoneWall SELECT SRW units has been determined through laboratory testing according to the NCMA test method SRWU-2 "Determination of Shear Strength between Segmental Concrete Units." This data is available upon request.

FS_{sl} = Sliding Resistance / Lateral $Forces_{applied}$

A. For gravity walls determine the external applied lateral forces for each incremental height of wall, Hi, as measured from the top of wall to the bottom of each StoneWall SELECT course using the procedures outlined in steps 2 & 3. Compute the available sliding resistance, which is just the shear capacity of the StoneWall SELECT unit, using the procedure in step 4 for Hm and the prediction model for StoneWall SELECT based on laboratory test results.

B. For soil reinforced walls determine the external applied lateral forces for each incremental height of wall where a geosynthetic reinforcement layer is present using the procedures outlined in steps 2 & 3. Compare that to the resistance for sliding on the geosynthetic reinforcement using the procedure described in steps 4 & 5, plus shear resistance of the StoneWall SELECT unit width, $\mathbf{W_u}$, based on the prediction model for StoneWallSELECT from laboratory test results.

Note: The critical wedge failure surface, α, may initiate at any horizontal location along the geosynthetic reinforcement layer. Since reduced base width greatly affects sliding resistance, check several locations along the reinforcement, such as; 0.33L, 0.5L, 0.67L, and 1.0L - (less) vertical spacing to next reinforcement layer.

Step 9: Determine the Factor of Safety against overturning, $\mathbf{FS_{ot}}$. for every incremental height Hi, created by each course of StoneWall SELECT down to the bottom most course for gravity walls, see **Fig. 6**. This analysis is also performed for soil reinforced SRWs as part of local stability of the facia down to the upper-most layer of geosynthetic reinforcement, se step 17. A $\mathbf{FS_{ot}}$ greater than 1.5 indicates suitable performance.

$FS_{ot} = Moments_{resisting} / Moments_{driving}$

A. For gravity walls determine the moments driving overturning about the toe of the unit width, Wu, for each incremental height, Hi, as measured from the top of wall to the bottom of each StoneWall SELECT course using the procedures outlined in steps 2, 3 & 6. Compute the available moments resisting, using the procedure in step 4 & 6 for each corresponding incremental height, Hi.

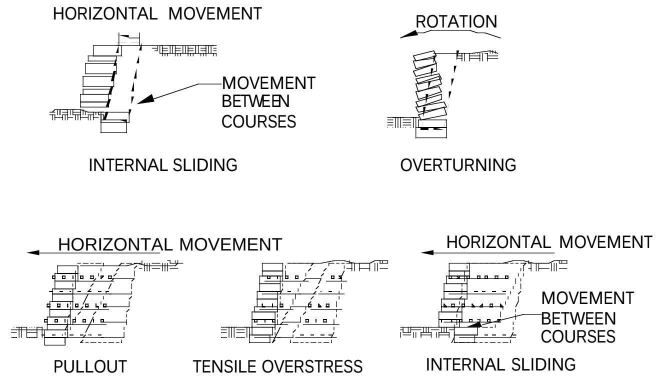


Fig. 6 Internal Stability Modes of Failure

Note: This concludes engineering anayses required for the design of gravity StoneWall SELECT walls, except for step 18. The following analytical steps refer to soil reinforced SRWs only.

Step 10: Determine the design properties of the geosynthetic reinforcement, consisting of a Long Term Design Strength LTDS and coefficient of interaction, $\mathbf{C_i}$. Manufacturers of geosynthetic reinforcement products routinely provide these properties to their customers, along with test data that supports their interpretation. Guidelines for interpreting manufacturer supplied test data on geosythetic reinforcement and determining design properties are provided in industry standards for geosynthetic reinforcement (NCMA design manual, Task Force 27, Christopher et. al. & Simac et. al.). LTDS is a working or allowable stress for the material calculated as follows:

$LTDS = T_{ult} / [RF_d \; RF_{id} \; RF_{cr} \; FS_{unc}]$

T_{ult} = Ultimate Tensile Strength

RF_d = Durability reduction factor (typical range: min. 1.1 to 2.0)

RF_{id} = Installation Damage Reduction Factor (typical range: min. 1.05 to 3.0)

RF_{cr} = Creep Reduction Factor (typical range: min. 1.5 to 5.0)

FS_{unc} = Safety Factor for Uncertainties (typical range: min. 1.5 to 3.0)

Step 11: Determine the number of reinforcement layers to be analyzed. For internal stability Ka' is based upon ϕ_i and δ_i:

B. For analysis determine the total number, $_{(N)}$, and placement elevation, $E_{(n)}$, of each geosynthetic reinforcement layer (i.e., selected vertical spacing). For design estimate the total number, $_{(N)}$, and select placement elevation, $E_{(n)}$ for each geosynthetic reinforcement:

Note: $_{(n)}$ denotes any layer from $_{(1 \text{ to } N)}$ 1 bottom, N top.

min $_{(N)}$ = $P'_a / LTDS$ (round up)

$P'_a = P'_{sh} + P'_{qh}$

$P'_{sh} = 0.5 \, K_a' \, \gamma_r \, H^2 \cos(\delta_i - \omega)$

$P'_{qh} = K_{a'} \, q \, H \cos(\delta_i - \omega)$

Step 12: Determine the load applied to each geosynthetic reinforcement layer, **(n)**, used to maintain stability (i.e., resisting the stress applied laterally to the back of the facing units). For internal stability $K_{a'}$ is based upon ϕ_i and δ_i:

B. Calculate the applied force to each geosynthetic layer, $\mathbf{Fg_{(n)}}$, from the midpoints between layers above and below it. This will be equal to the average lateral stress at the midpoint depth, $\mathbf{D_n}$, of contributory area, $\mathbf{A_{c(n)}}$, as shown in this equation:

$$F_{g(n)} = (\gamma_i D_{(n)} + q_l + q_d) K_{a'} A_{c(n)} \cos (\delta_i - \omega)$$

For the selected vertical spacing of geosynthetic reinforcement, calculate contributory area, $\mathbf{A_{c(n)}}$:

$$A_{c(1)} = [(E_{(2)} + E_{(1)}) / 2] - E_{(0)}$$
$$A_{c(n)} = [(E_{(n+1)} - E_{(n-1)}) / 2]$$
$$A_{c(N)} = H - [(E_N + E_{(n-1)}) / 2] - E_{(0)}$$

Note: If base of wall elevation, $E_{(0)} = 0$, the $E_{(0)}$ may be dropped from the above equations.

For the selected vertical spacing of geosynthetic reinforement calculate the depth, $\mathbf{D_{(n)}}$, to the midpoint of the contributory area, $\mathbf{A_{c(n)}}$:

$$D_1 = H - (A_{c1} / 2)$$
$$D_{(n)} = H - (\Sigma A_{c1} \text{ to } A_{c(n-1)}) - A_{c(n)} / 2)$$
$$D_{(N)} = (Ac_{(N)} / 2)$$

Step 13: Determine the Factor of Safety against tensile overstress, $\mathbf{FS_{tos}}$. This safety factor ensures there is sufficient allowable tensile capacity, **LTDS**, in the geosynthetic reinforcement to resist the applied force, **Fg**. The FS_{tos} is calculated as:

$$FS_{tos\ (n)} = LTDS_{(n)} / Fg_{(n)}$$

B. The FS_{tos} is calculated for each geosynthetic reinforcement layer in the structure to ensure it is greater than 1.0. Remember, LTDS is a working stress with the overall safety factor, FS_{unc} included in step 10. Reinforcement layers with FS_{tos} less than 1.0 indicate portions of the structure that require adjustment of reinforcement vertical spacing, more layers of reinforcement added, or replaced with stronger reinforcement.

Step 14: Determine the Factor of Safety against pullout of the geosynthetic reinforcement $\mathbf{FS_{po}}$ for each reinforcement layer. This safety factor ensures that the load applied to the geosynthetic reinforcement is transferred to the soil in the anchorage zone, i.e., beyond the internal failure plane at α degrees. The minimum FS_{po} generally used in design is 1.5. The FS_{po} is calculated as follows:

$$FS_{po(n)} = AC_{(n)} / Fg_{(n)}$$

B. The anchorage capacity, **AC**, for any geosynthetic reinforcement, may be calculated using its pullout properties, $\mathbf{C_i}$, available anchorage length, $\mathbf{L_a}$, and depth to the midpoint, d, of the anchorage length as shown in the following equation:

$$AC_{(n)} = 2 L_{a(n)} C_i (\gamma_i d_{(n)} + q_d) \tan \phi_i$$

Determine the anchorage length, $\mathbf{L_a}$, as that reinvorecement length behind the internal failure plane at a horizontal orientation of , α,:

$$L_{a(n)} = L - W_u - Z_{2(n)} \tan(90-\alpha_i) + Z_{2(n)} \tan \omega$$

where: $Z_{2(n)} = [E_{(n)} - E_{(0)}]$

The horizontal orientation of the internal failure plane, α, may be calculated by Coulomb earth pressure theory (after Jumikis) using ϕ_i and δ_i:

$$\tan(\alpha - \phi) = \frac{- \tan(\phi - \beta) + \sqrt{ZY}}{1 + \tan(\delta - \omega) [\tan(\phi - \beta) + \cot(\phi + \omega)]}$$

where: $Z = \tan(\phi - \beta) [\tan(\phi - \beta) + \cot(\phi + \omega)]$
$Y = [1 + \tan(\delta - \omega) \cot(\phi + \omega)]$

Determine the depth of overburden, $\mathbf{d_{(n)}}$, on anchorage length, $\mathbf{L_{a(n)}}$,:

$$d_{(n)} = [H - Z_{2(n)}] + Z_{3(n)}$$
$$Z_{3(n)} = [Z_{2(n)} / \tan\alpha_i - H \tan \omega + L_{a(n)}/2] \tan \beta$$

Local Stability

Local stability analyses for the specific modes of failure shown in **Fig. 7**, ensure that the StoneWall SELECT facia and soil reinforcement function together as one composite structure.

Step 15: Determine the Factor of Safety against failure of the connection between the geosynthetic reinforcement and the StoneWall SELECT facing, $\mathbf{FS_{cs}}$. The connection strength CS is determined through full-scale laboratory testing of the specific geosynthetic reinforcement with StoneWall SELECT (Bathurst & Simac). Based on the granular fills normally used with StoneWall SELECT, the connection will have a significant frictional component and thus vary with wall height. Acceptable connection performance is evaluated for both the peak connection strength, $\mathbf{CS_p}$, and service state connection strength, $\mathbf{CS_s}$. The typical service state deformation is 0.75 inches. The minimum connection strength safety factors, $\mathbf{FS_{cs}}$ are 1.5 for peak and 1.0 for service.

Note: The connection strength of StoneWall SELECT SRW units with several types of geosynthetic reinforcement has been determined through laboratory testing by the NCMA test method SRWU-1 "Determination of Connection Strength between Geosynthetics and Segmental Concrete Units." This data is available upon request.

FACING CONNECTION BULGING

Fig. 7: Local Stability Modes of Failure

B. The connection strength, **CS**, shall be determined based on the laboratory test results for each geosynthetic type in the reinforement layout using the height of facing above it, **Hf**, subjected to the hinge height imitation (see Step 4). Calculate the connection strength safety factor, $\mathbf{FS_{cs}}$, for each layer using both the peak and service state conditions to ensure acceptable performance:

$$FS_{cs(n)} = CS_{p(n)} / F_{g(n)} \text{ and } CS_{s(n)} / F_{g(n)}$$

Insufficient connection strength requires adjustment of reinforcement spacing, adding more reinforcement layers, or switching to reinforcement with a more efficient connection.

Step 16: The probability of bulging between layers of geosynthetic reinforcement is determined by analyzing the shear capacity, $\mathbf{V_u}$, between StoneWall SELECT courses relative to the applied shear force. The applied shear force at the bottom of any course is determined as the total lateral earth force, less the calculated applied force in the geosynthetic layers above that course. This means that the largest shear forces occur at the courses where geosynthetic reinforcement is present.

Note: The shear capacity of StoneWall SELECT SRW units has been determined through laboratory testing according to the NCMA test method SRWU-2, "Determination of Shear Strength between Segmental Concrete Units." The tests have been performed both with and without geosynthetic reinforcement on the interface. This data is available upon request.

B. The critical shear capacity, $\mathbf{V_{u(n)}}$, occurs at the geosynthetic reinforcement elevations, $\mathbf{E_{(1\ to\ N)}}$. Calculate the safety factor for shear capacity, $\mathbf{FS_{sc(n)}}$, for each StoneWall SELECT course where there is a reinforcement layer as shown:

$$FS_{sc(n)} = V_{u(n)} / (P'_{a(n)} - \Sigma F_{g\ (n+1\ to\ N)})$$

Inadequate shear capacity requires adjusting the reinforcement spacing, adding more layers of reinforcement, or switching to reinforcement with less impact on shear capacity.

Step 17: Maximum Unreinforced Height

B. The height of StoneWall SELECT walls above the upper-most geosynthetic reinforcement layer should be analyzed as a gravity structure to ensure adequate stability against sliding and overturning as described in calculation steps 8A and 9A. Instability can be corrected by raising the upper-most reinforcement layer to a higher elevation, or limiting the loading near the top of the wall with geometric design constraints, such as the curb and gutter or guard rail locations.

Step 18: A properly designed drainage system is essential to good performance of StoneWall SELECT retaining walls. Generally, the granular infill used with StoneWall SELECT walls provides a good drainage media for relief of hydrostatic pressure and should be extended 200 to 300mm (8 to 12 in) behind the StoneWall SELECT units as shown in Fig. 4. If the retained soil has a finer gradation than the infill soil it should be protected by a geotextile filter. For submerged walls, coastal structures, or sites with significant groundwater flow, a more comprehensive drainage design may be required.

References

AASHTO, "Standard Specifications for Highway Bridges", AASHTO, Washington, DC, 15 ed., (1992)

Bathurst, R.J. & Simac, M.R., "Laboratory Testing of Modular Masonry Concrete Block-Geogrid Facing Connections", ASTM Symposium on Geosynthetic Soil Reinforcement Testing, STP 1190, Jan (1993).

Berg, R.R., "Guidelines for Design, Specification, & Contracting of Geosynthetic Mechanically Stabilized Earth Slopes on Firm Foundations", publication of the US DOT - FHWA, Washington, DC (1993).

CalTrans, "Alternative Earth Retaining Systems in California Highway Practice," (June 1986).

Christopher, B.R., et.al., "Reinforced Soil Structures: Volume 1, Design and Construction Guidelines," Report No. FHWA-RD-89-043, FHWA, (Nov. 1989).

Jumikis, A.R., "Soil Mechanics", D. Van Nostrand Company Inc., New York, NY (1962).

NCMA, "Design Manual for Segmental Retaining Walls", NCMA, Herndon, VA, Second Edition (1997).

NCMA, "Design Software for Segmental Retaining Walls", program SRWall1 & Users manual, National Concrete Masonry Assoc., Herndon, VA, (1995).

Simac, M.R., Bathurst, R.J., Berg, R.R., Lothspeich, S.E., "Design Manual for Segmental Retaining Walls", NCMA, Herndon, VA, First Edition (1993).

Task Force 27, AASHTO-AGC-ARTBA Joint Committee on In Situ Soil Improvement Techniques: "Guidelines for the Design of Mechanically Stabilized Earth Walls" AASHTO, Washington, DC, (1990)

Assistance

Through its network of local suppliers and licensees, ICD Corporation offers many services to assist anyone interested in designing, building or owning a StoneWall SELECT retaining wall system. The best contact is the local supplier listed at the bottom of this brochure, since they provide the most personalized service and have the best knowledge of site conditions and materials in your area. To obtain product information, assistance, or location of your closest supplier contact ICD directly at: (800) 394-4066 or (414) 962-4065 Monday through Friday from 8:00 AM to 5:00 PM central time or visit our web site anytime.

Listed below are the customer services available:

- Sales support staff are available to answer questions on product specifications, product availability, distribution outlets and shipping status.
- StoneWall Select suppliers have an ICD trained technical specialist available to answer any questions on the design, construction/installation, or performance issues for a particular application.
- Many standard detail drawings and typical designs are available on computer disk or hard copy to assist the designer in understanding significant construction issues in using StoneWall SELECT.
- For complex or unusual installations, StoneWall SELECT suppliers can directly assist the design team in developing the safest and most cost-effective solution to soil retention applications.
- In an effort to equip and educate today's design professional on using the StoneWall SELECT SRW system for site/civil engineering applications, ICD has developed the following product data and technical literature that is available upon request:

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GENERAL: Product data, engineering concepts, and pre-engineered design tables for general applications.

CAD DETAILS: Detail drawings on computer diskette.

CONNECTION & SHEAR TESTING: Laboratory test results of connection strength and shear testing with several geosynthetic reinforcements.

GUIDE SPEC: Comprehensive guide specification in standard CSI format including a product description of StoneWall SELECT SRW system

StoneWall SELECT WALLS: Illustrative example projects using the StoneWall SELECT system for retaining structures and special features/options.

INSTALLATION: An illustrated set of installation guidelines for StoneWall SELECT retaining structures.

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