A SunCam online continuing education course

Mechanically Stabilized Earth Structures – Part 2

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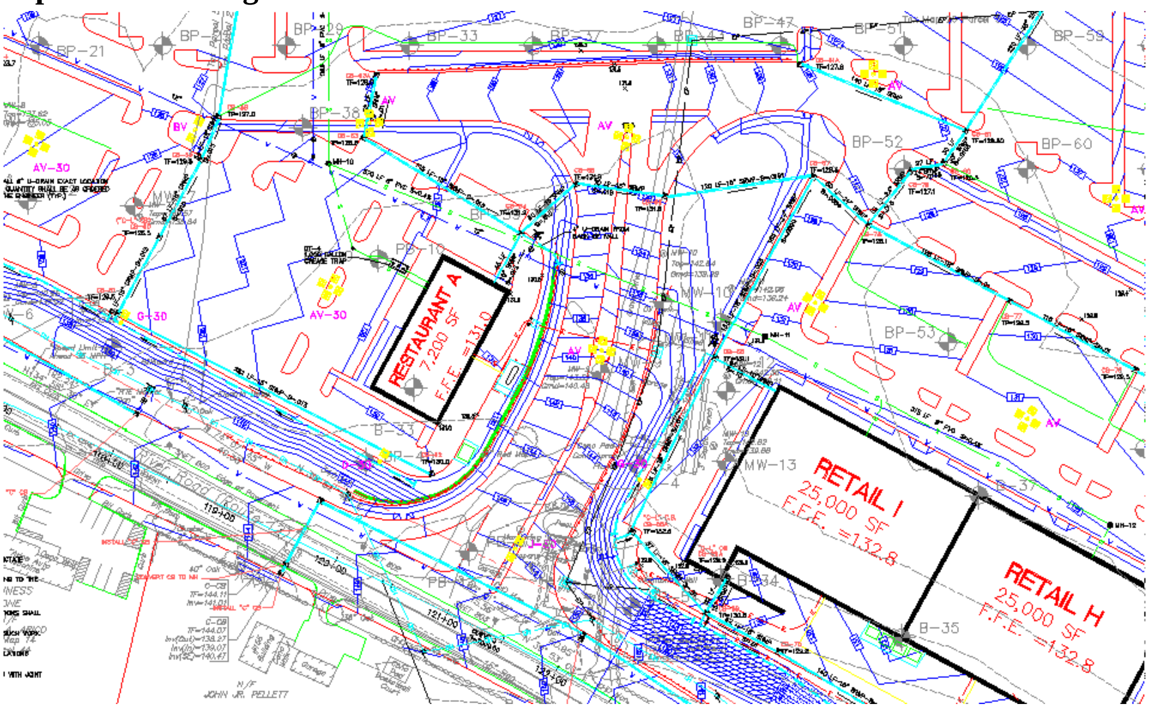
IV. Design Procedure

Defining the Wall Geometry from Civil Engineers Grading Plan

- Establish wall profile (top and bottom of wall elevations).
- Determine crest and toe slopes.
- Identify surcharge loads (traffic & structural).
- Consider drainage issues.
- Usually, this information can be obtained from the site grading plan.

Example of a Grading Plan



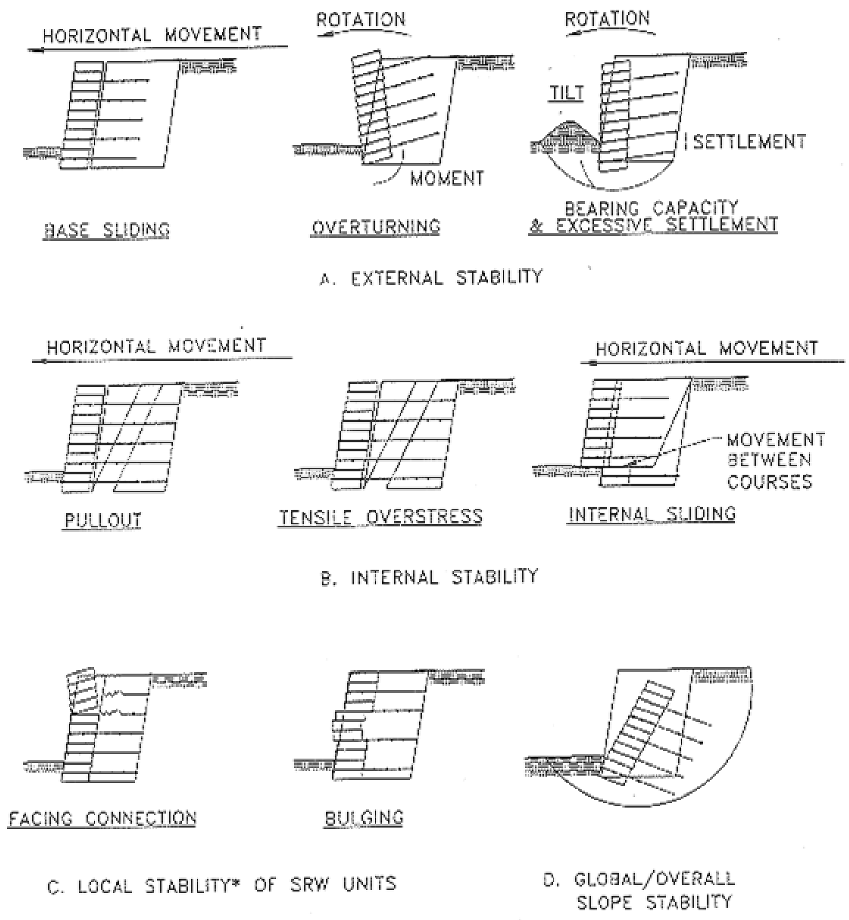
A grading and drainage plan must be designed by a qualified civil engineering consultant clearly showing the MSE wall location with respect to line and grade.

<u>Wall Design Analysis</u>

MSE wall stability must be analyzed with respect to several failure modes including…

- External Stability – performed by MSE wall engineer
- Internal Stability – performed by MSE wall engineer
- Facing Connection – performed by MSE wall engineer
- Seismic Analysis – performed by MSE wall engineer
- Global Stability (*see discussion on Page 6*)
    - Internal
    - Compound Internal
    - Deep Seated

Main Modes of Failure for Reinforced Soil SRWs (NCMA, 1997)



Recommended Minimum Factors of Safety for MSE Walls

Mode	Design Parameters	Required FS
External	FS - Base Sliding	≥ 1.5
External	FS - Overturning	≥ 2.0
External	FS - Bearing Capacity	≥ 2.0
Internal	FS - Sliding Along Reinforcement Layers	≥ 1.5
Internal	FS - Reinforcement Pullout	≥ 1.5
Internal	FS - Reinforcement Tensile Overstress	≥ 1.5
Internal	FS - Facing Connection Break and Pullout	≥ 1.5
Internal	FS - Material Uncertainty	≥ 1.5
Global	FS - Rotational Failure (Bishop's Modified Method)	≥ 1.3
Global	FS - 2 Part Wedge Translational Failure (Spencer's Method)	≥ 1.3
Global	FS - 3 Part Wedge (Spencer's Method)	≥ 1.3

General Overview of External Stability

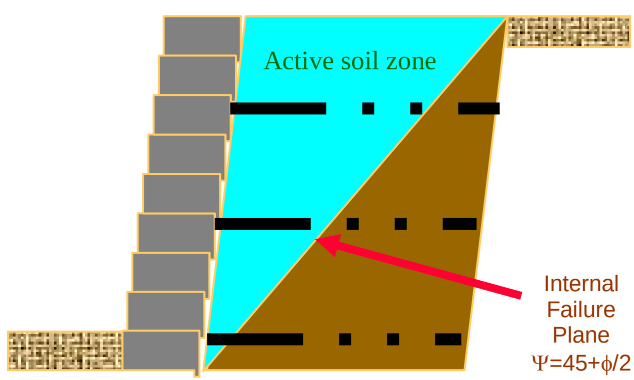
Sliding (FS_{SL}) - Base sliding consists of horizontal movement of the entire reinforced soil mass sliding on the reinforced or foundation zone, whichever zone is weaker. Sliding failure can occur if the bottom reinforcement length (lowest reinforcement layer) is not long enough to withstand external forces. The NCMA method defines the minimum reinforcement length to be 60 percent of the total wall height regardless of block, reinforcement or soil type whereas FHWA defines the minimum reinforcement length to be 70 percent of the total wall height. The bottom reinforcement length in many cases can be longer than the minimum values required by NCMA or FHWA.

Overturning (FS_{OT}) - Theoretically if the bottom reinforcement is not long enough an overturning failure could occur, however failure due to overturning is likely to not occur as moments within a reinforced soil mass cannot be developed. The main purpose of calculating stability due to overturning is to determine eccentricity values used in bearing capacity analyses.

Bearing Capacity (FS_{BC}) - Failures occur in foundation soils below the MSE wall system if they are not strong enough to support the additional weight. A typical question asked regarding the "footing" of a MSE wall is….*What is the footing below the MSE wall system*? On a per cubic foot basis, the block weighs fairly close to what the soil does, 110 pcf to 130 pcf. The actual footing for a MSE wall system is not the width of the leveling pad. The footing or bearing width is measured from the face of the block to the back of the reinforced earth zone, i.e. the bottom reinforcement length (L). A particle of soil below the MSE wall does not feel the weight difference between the block and the reinforced earth.

General Overview of Internal Stability

The key point in proceeding with an Internal Stability Analysis is to define the internal failure plane. MSE walls are design using "active" earth pressure theory, i.e. NCMA uses Coulomb and FHWA uses Rankine. The soils between the back of the block and the failure plane are active soils. These soils will have some movement in order to mobilize the reinforced soil shear strength and tension the reinforcement, which means the wall, will rotate forward. If zero set back is specified (no batter), the wall will eventually end up negative due to this "mobilization" of forces. A properly designed and constructed MSE wall may experience a forward rotation between 2 and 3 degrees. In estimating this rotation one could use the "2 + 1" rule, i.e. two degrees of rotation during construction, with an additional 1 degree after.



Pullout (FS_{PO}) - The design engineer needs to determine how far the reinforcement must extend past this theoretical failure plane. The NCMA requires a one foot extension beyond the failure plane based on Coulomb theory whereas FHWA requires a three foot extension beyond the failure plane based on Rankine theory. The 60% minimum requirement in NCMA typically needs to be surpassed in order to achieve an acceptable factor of safety regarding pullout (FS_{po}). In a NCMA design the top two or three layers are typically longer than 60% whereas using a minimum length of 70% in FHWA design typically satisfies pullout criteria. It should be noted that pullout only controls length for the upper two or three layers of reinforcement.

The Soil/Geosynthetic Interaction Coefficient, C_i value is determined from pullout tests per GRI:GG-5. The maximum pullout force used to determine C_i is limited to the lesser of the allowable reinforcement strength (T_a) or the force that yields 1.5 inches displacement. The value of C_i is determined as follows:

$$C_i = \frac{F}{2\,Le\,\sigma_N \tan\phi}$$ Where

F	=	Pullout force (lb/ft), per GRI:GG-5
L_e	=	Geosynthetic Embedment Length in the Anchorage Zone in Test (ft)
σ_N	=	Effective Normal Stress (psf) at range from 500 to 1,000 psf
ϕ'	=	Effective Soil Friction Angle, Degrees

The interaction coefficient is a function of the soil type (strength) and reinforcement. In most cases the value of C_i will range between 0.75 and 0.90.

Soil Type	Geotextile Ci	Flexible Geogrid Ci	Stiff Geogrid Ci
GP, GW	0.75-0.85	0.75-0.85	0.85-0.95
SP, SW	0.80-0.90	0.75-0.85	0.85-0.95
SM, SC	0.70-0.90	0.70-0.80	0.50-0.65

Manufacturers will typically provide pullout tests and Ci values for design. Pullout design based on NCMA criteria uses the value of C_i directly. Pullout design based on FHWA criteria uses the pullout resistance factor ($F^* = C_i \tan\phi$) and scale correction factor from manufacturer (α).

Tensile Overstress (FS_{OS}) - The highest point of stress in the reinforcement occurs at the location where reinforcement layers cross the theoretical internal failure plane. This is typically not a mode of failure seen in the field due to all the reduction factors applied to the reinforcement. A MSE wall would have to be severely under designed in order for the reinforcement to overstress or rupture, and if that was the case, something else in the system would likely fail before the reinforcement tears.

Internal Sliding (FS_{SL}) – Internal sliding is a failure mode in which a failure plane develops along or between reinforcement layers and is driven by the external soils and slopes. Most often this occurs when the reinforcement spacing is large and/or the reinforcement lengths are too short. Key point here is, do not mess with reinforcement lengths.......several years ago an automobile commercial stated that "*wider is better*" when referring to the wheel base and how the car performed. The same holds true for reinforcement lengths in that "*wider is better*".

Direct Sliding Coefficient, C_{ds} value is determined from pullout tests per GRI:GS-6. The maximum pullout force used to determine C_{ds} shall be limited to the lesser the allowable reinforcement strength (T_a) or force that yields 1.5 inches displacement. The minimum C_{ds} value shall never be greater than 1.0 where the C_{ds} value is determined follows:

$$C_{ds} = \frac{F}{L\,\sigma_N \tan\phi}$$ Where

F	=	Maximum shear resistance from direct shear test (lb/ft), per GRI:GS-6
L	=	Geosynthetic Embedment Length in Test (ft)
σ_N	=	Effective Normal Stress (psf) at range from 500 to 1000 psf
ϕ	=	Effective Soil Friction Angle, Degrees

Manufacturers will typically provide pullout tests and C_{ds} values for design. Direct sliding based on NCMA criteria uses the value of C_{ds} directly. Direct sliding design based on FHWA criteria uses the friction angle along reinforcement-soil interface $\rho = \tan^{-1}(C_{ds} * \tan\phi)$.

Connection - Calculated reinforcement loads must not exceed the load determined by connection strength testing for a specific combination of segmental block and reinforcement used, i.e. the MSE wall designer must have the connection test data!

Bulging can be a symptom of several failure modes or a sign of poor compaction, installation or product. Actual bulging or shear failure occurs when the shear along one or more planes exceeds the available shear resistance determined by the unit to unit shear test performed for the specific block unit used in the design. It may also occur if reinforcement spacing is too great. It is always better to use more layers of a weaker reinforcement than a few layers of very strong reinforcement. The designer limit reinforcement spacing to no more than 2 times the depth of the facing unit but should never exceed a vertical spacing of S_v=24 inches.

General Overview of Global Stability

Global stability is essentially a limit equilibrium assessment of a MSE wall's ability to globally withstand external and internal loading conditions. A global stability analysis must be performed for all MSE walls and is performed using a special computer program, which looks at circular or non-circular slip surfaces that pass behind, below or through the MSE wall system. Global stability takes into consideration the following measures:

1. The geometry of a cross-section of the MSE wall and toe/crest slopes (if any).
2. External loading conditions such as those from traffic and buildings.
3. Soil parameters including shear strength (ϕ' and c') and unit weight (γ) should be determined by the project geotechnical engineer based on a site-specific laboratory testing program. If site-specific shear strength and unit weight data are not available, the MSE wall design engineer may make conservative estimates for the global stability analysis. A qualified geotechnical engineer should confirm soil parameter estimates prior to construction.
4. Groundwater can have a negative effect on the stability of the MSE wall system and if present must be included in the global stability analysis. This is typically represented in slope stability programs by a phreatic line depicting the groundwater elevation.
5. If the wall is in a geologic region that has seismicity the effects of seismic loading must also be considered.

When does Global Stability Control?

- Steep slopes above and/or below the wall
- Poor foundation soils
- Heavy surcharges with a toe slope, and...

… terraced walls!

Global Stability *<u>HAS</u>* to be checked by *<u>SOMEBODY</u>*! Who is responsible for the different global stability failure modes?

Global stability can be broken down into three general analyses that address internal (slip surfaces that are contained within the reinforced zone), compound internal (slip surfaces passing through the reinforced zone and retained zone) and deep seated (slip surfaces that pass behind and below the reinforced zone). Global stability with respect to……

- Internal must be performed by MSE wall engineer
- Compound internal must be performed by MSE wall engineer

- Deep seated can be performed by MSE wall engineer, geotechnical or civil engineer.
  - The geotechnical engineer is the most qualified consultant to address deep seated global stability given their in-depth knowledge of subsurface conditions; however they rarely want to accept responsibility for this analysis. Typically the MSE wall engineer or geotechnical engineer will address deep seated stability.

How global stability analysis can help improve a MSE wall's design

Results of a global stability analysis are a limit equilibrium calculation of the MSE wall/slope factor of safety, Fs. A minimum factor of safety of 1.3 is required by NCMA (National Concrete Masonry Association) and FHWA (Federal Highway Administration). However for critical structures such as bridge abutments, the factor of safety may be 1.5. The MSE wall design engineer should also check with local jurisdiction requirements regarding global stability as some jurisdictions may require a minimum factor of safety of 1.5.

Results of a global stability analysis may show reinforcement lengths as determined through wall design calculations (using a design program such as MSEW) are not long enough to meet the required factor of safety for global stability. In order to increase the factor of safety and satisfy deep seated global stability requirements, reinforcement lengths may need to be lengthened.

Internal and compound internal stability is another important assessment

In addition to overall global stability, which is a measure of slip surfaces, passing behind the reinforced mass, the MSE wall engineer must perform an internal and compound internal stability analysis. This analysis looks at slip surfaces passing *through* the reinforced mass. For example, if low strength reinforcement and/or large vertical spacing greater than 24-inch is determined to be acceptable say from a NCMA analysis the potential for low factors of safety regarding internal and compound internal failures increases. In order to satisfy internal and compound internal factors of safety the reinforcement strength may need to be increased, reinforcement lengths may need to be lengthened, vertical spacing between reinforcement may be reduced or some combination of the fore mentioned.

Why global stability is a worthwhile measure every time

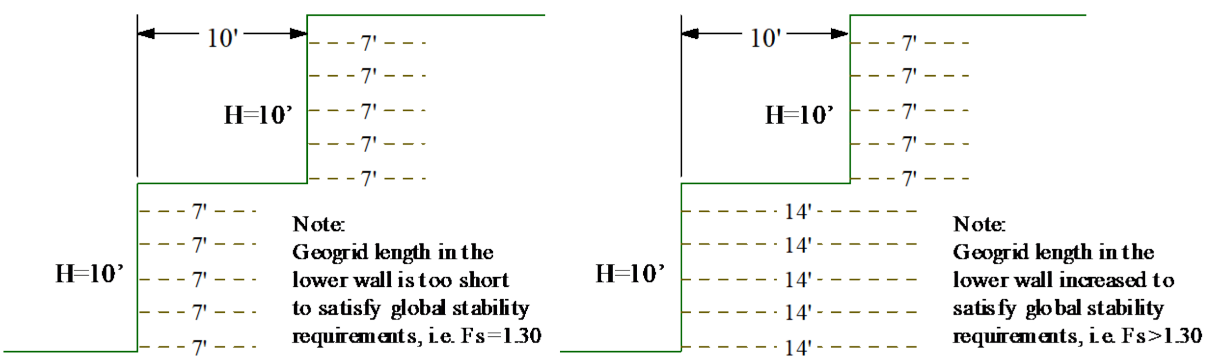
There is no question about the value of global stability analyses in retaining wall design. When there are slopes above/below a MSE wall or if a tiered wall system is present, global stability analyses are an absolute requirement, and must be conducted.

Tiered walls must be checked

Most wall designers realize the benefit of global stability analysis when a wall involves a crest slope (slope above the wall) or toe slope (slope below the wall) or a weak foundation. On the other hand, tiered walls are frequently overlooked when it comes to applying global stability analysis, to the detriment of the final product.

The condition that is the likely source of some global wall failures is tiered walls. To properly design these walls, a global stability analysis must be performed. To reduce the risk of a global failure when dealing with tiered walls, they should be spaced far enough apart such that they act independently. This distance is typically equal to or greater than twice the height of the lowest wall and the lowest wall the tallest. This is a general rule and there are exceptions, i.e. poor soils and steep slopes.

In tiered wall systems, a common mistake made by inexperienced engineers is to design each tier as a separate wall, rather than considering the influence of upper tier(s) on the lower tier(s). As a general example, consider a 10-foot high lower wall and level backfill, a second 10-foot high upper wall located 10-feet behind the lower wall (see cross section below). Assuming no slopes are present (a level surface above, between and below the walls), a properly reinforced lower wall could require a reinforcement length of L=14-feet or more (as opposed to 7 feet of geogrid for each individual tier). Increased reinforcement length is needed to compensate for the load from the upper wall. A global stability analysis provides this type of essential information for the proper construction of tiered weight-bearing walls.



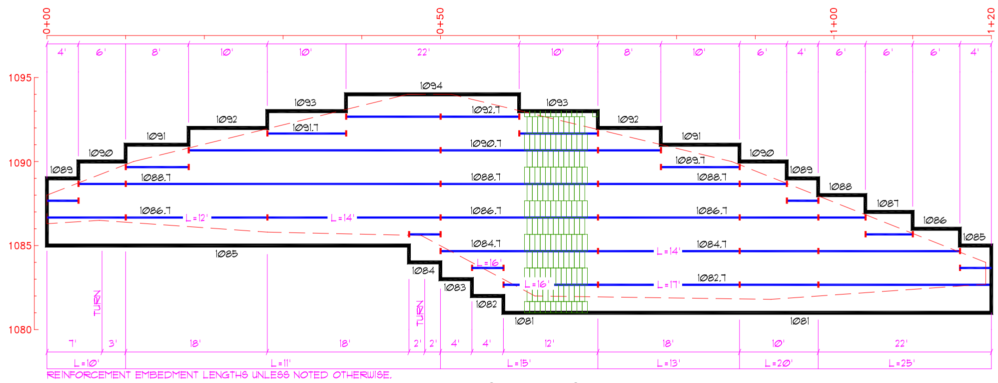
An easy way to build safer walls

MSE walls constructed without the benefit of a global stability analysis are on shaky ground, the results can be catastrophic and very costly. The good news is that global stability analyses are quite easy to perform. An engineer with a competent understanding of MSE wall design, geotechnical engineering and slope stability modeling techniques should be able analyze any given design wall/slope section in a reasonable amount of time. The following global stability programs are commercially available and offer information to ensure a complete wall design: ReSSA (3.0), ReSlope (4.0), PCSTABL6, G-SLOPE, SLIDE and others.

The author has used a number of slope stability programs over the past 20-years and has found the ReSSA program, which is integrated with the MSEW program to be the most efficient analytical tool for the design of MSE walls and slopes.

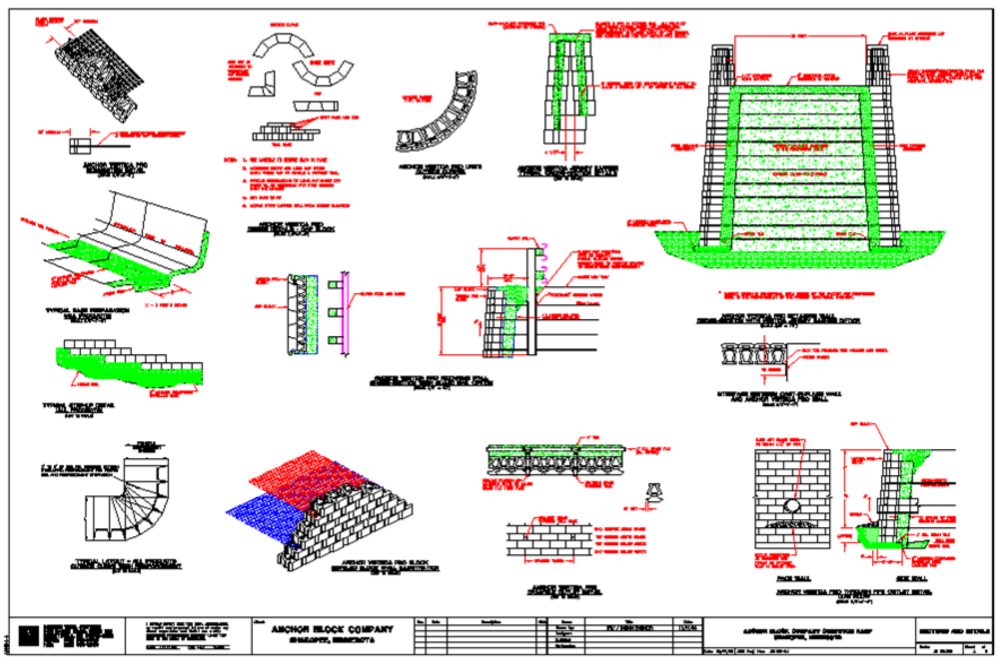
MSE Wall Plans and Specifications Must Include

- Wall elevation view that shows the wall outline and reinforcement with respect to type, length and vertical spacing.



WALL 4 FRONT ELEVATION
HORZ. SCALE: 1IN=10FT VERT. SCALE: 1IN = 5FT

Typical Sections and Details



The MSE Wall Design and Specifications Must Address:

- Reinforced Soil – An example testing requirement for the reinforced soil could be stated as follows:
  - o Every new soil type and/or every 2,000-cy run pH, Atterberg Limits, Sieve Analysis, Proctor new soil type per geotechnical field personnel.
  - o Triaxial Test on every appreciable different soil type based on index testing.

  - Run Consolidated-Undrained Triaxial Shear Tests and report the stress strain test results as well as present the Mohr-Coulomb failure diagram for peak and residual stress levels, as required by ASTM. The geotechnical consultant will provide a recommended effective internal friction angle based on their results.

- Soil Compaction - for example compaction testing could be performed as follows:
  - Every two-foot change in height and interval of 100-feet of wall length.
  - Run 4 compaction tests one within 4-feet of face, and three others randomly throughout the reinforced soil zone
- External & Internal Drainage Provisions
  - External drainage related to surface water design and control must be addressed by the project civil engineer. Internal drainage can be assessed between the MSE wall and geotechnical engineer based on subsurface water conditions.
- Adjacent Utilities
  - The presence of utilizes must be addressed in the design. Coordination of utilities in the vicinity of the wall must be done between the MSE wall and civil engineer.
- Surcharge Loads
  - External loading from traffic (live loads) and loading from building (dead loads) are critical in determining the reinforcement design.
- Crest & Toe Slopes
  - If slopes are present in the vicinity of the MSE wall they must be taken into account in the wall design and global stability analyses.
- Vertical & Horizontal Penetrations
  - These can include fence posts, guard rails, utilities and storm pipes.

Who Should Design SRW's?

- Recommended minimum qualifications of the MSE design engineer:
  - Strong background in geotechnical/geosynthetic engineering (Masters or PhD). A
  - 5-years design experience in mechanically stabilized earth design and analysis.

Who Should Construct SRW's?

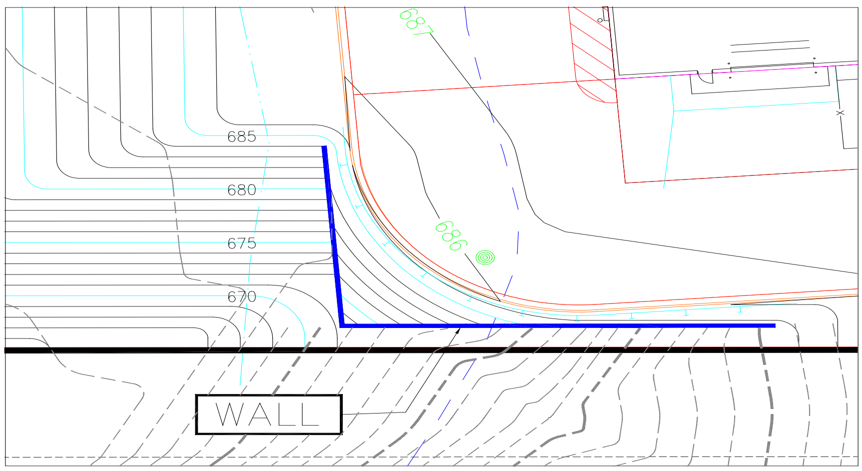
- Recommended minimum qualifications of the MSE wall contractor:
  - 5-years minimum construction experience.
  - Constructed at least 500,000-ft^2 of mechanically stabilized earth walls.

VI. Civil Design Considerations for Mechanically Stabilized Earth Walls

Civil Design Considerations for Mechanically Stabilized Earth Walls

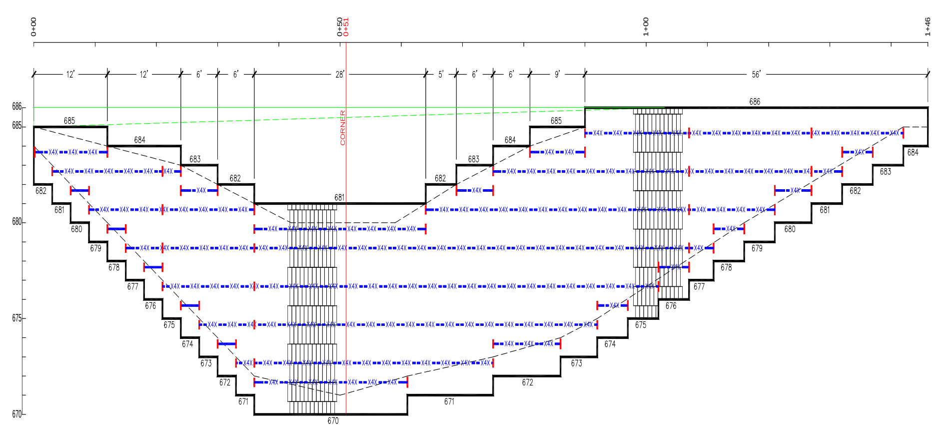
- Some Practical Do's & Don'ts
    - When at all possible…….get everything but soil and geosynthetic-reinforcement out of the reinforced zone!

Avoid Creating Low Spots behind Wall - Original Grading Plan



ORIGINAL DESIGN

Avoid Creating Low Spot behind Wall - Original Profile

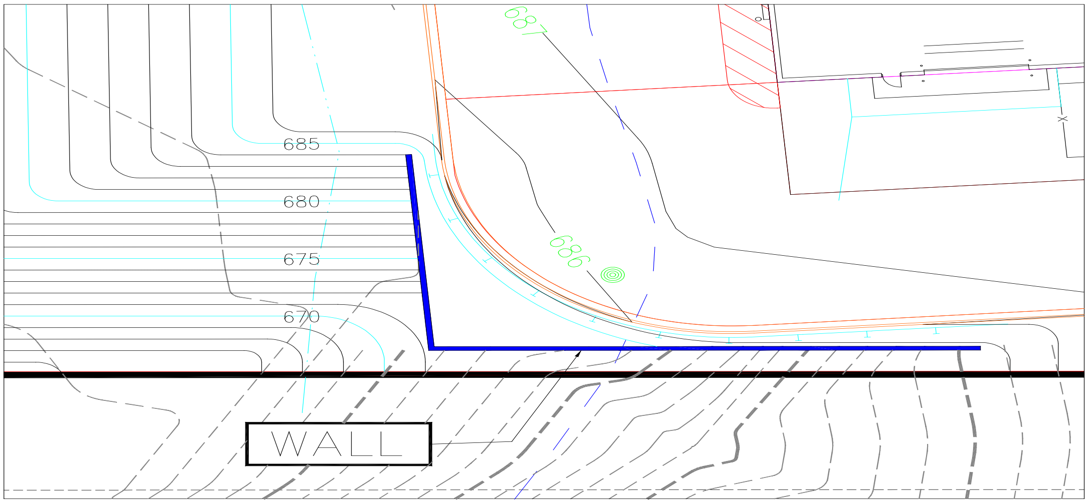


FRONT ELEVATION - RETAINING WALL - STA 0+00 to 1+46
HORZ. SCALE: 1IN=10FT VERT. SCALE: 1IN=5FT
ORIGINAL DESIGN

Top of wall grades must be set to allow for positive surface water flow across the top of wall and to exit at one or both ends of the wall. Low spot elevations graded in the middle of the wall, as noted in the example profile, serves as a concentrated point to collect water and creates a situation in which washout or wall failure can occur.

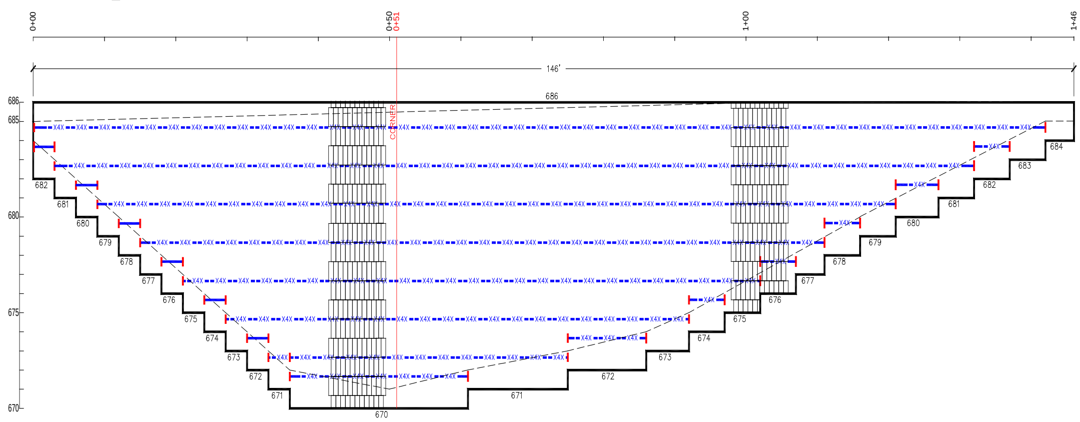
Civil Design Considerations

Removal of Low Spot behind Wall - Preferred Grading Plan



PREFERRED DESIGN

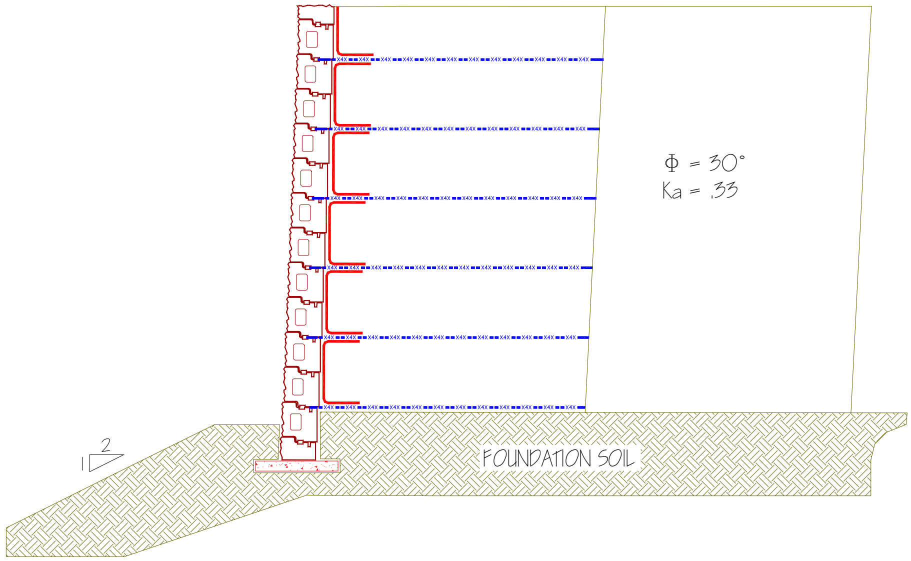
Removal of Low Spot behind Wall - Preferred Wall Profile



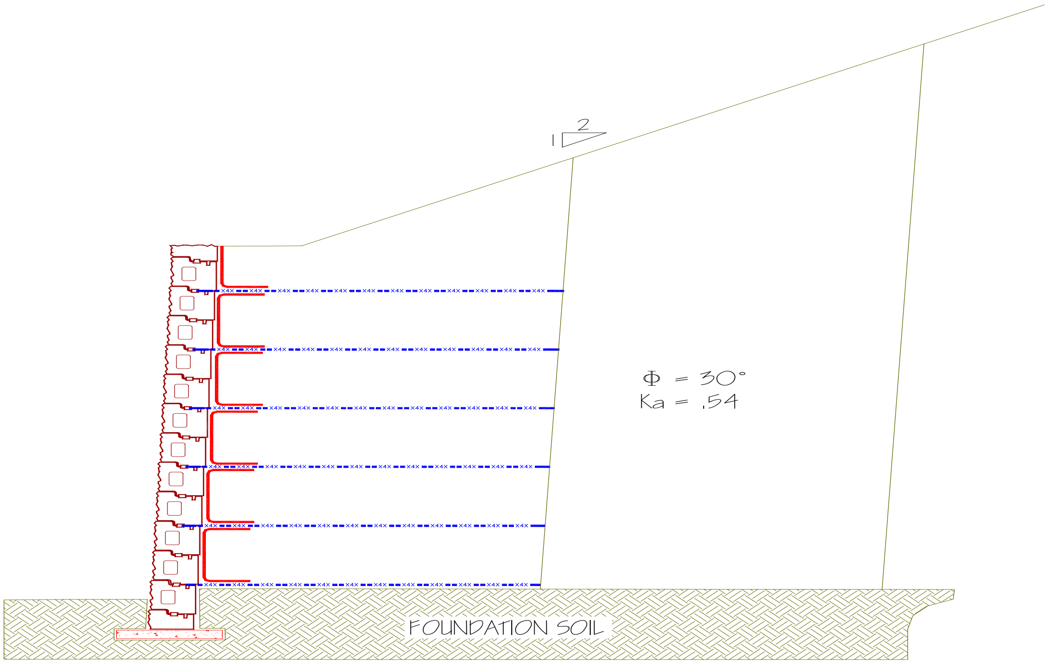
FRONT ELEVATION - RETAINING WALL - STA 0+00 to 1+46
HORZ. SCALE: 1IN=10FT VERT. SCALE: 1IN=5FT
PREFERRED DESIGN

Removing the low spot in the above example keeps surface water from collecting and flowing over the wall at the 90-degree outside corner. Standing water collected near an outside corner could cause a failure.

Walls Go On Top Of Slopes



Slopes on Top of Wall is Not Preferred



If a mechanically stabilized earth (MSE) wall or slope is to be constructed, it is preferred to locate the wall or slope on top of the toe slope. This type of geometry results in significantly less stress, both internally and externally, on the geosynthetic-reinforcement and the MSE facing system. As shown in the example above assuming a friction angle of 30-degrees.

- o A level backfill produces an earth pressure coefficient of K_a=0.33
- o A 2H:1V backfill produces an earth pressure coefficient of K_a=0.54

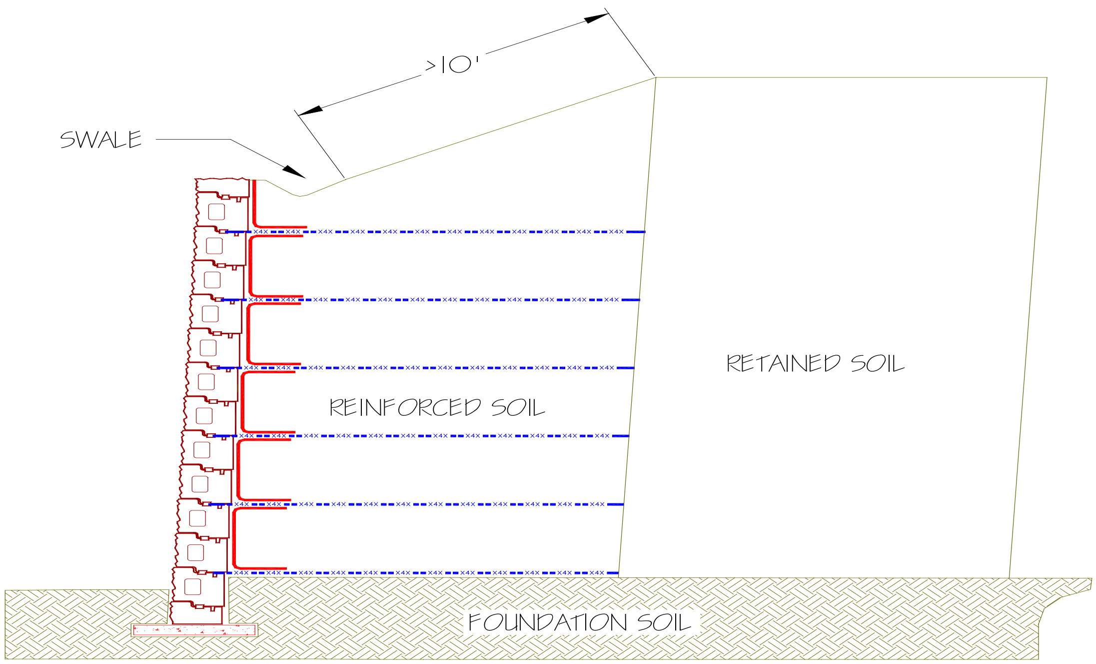
Should any repairs to the wall or slope be required post construction during the design life, they can be made much more easily without the slope on top of the wall.

If a 2H:1V, 2.5H:1V or 3H:1V toe slope is to be constructed or exists, a minimum "5-foot wide level bench" should be graded immediately in front of the MSE wall or slope. The 5-foot wide level bench provides a working platform for the contractor to begin the wall construction.

Civil Design Considerations

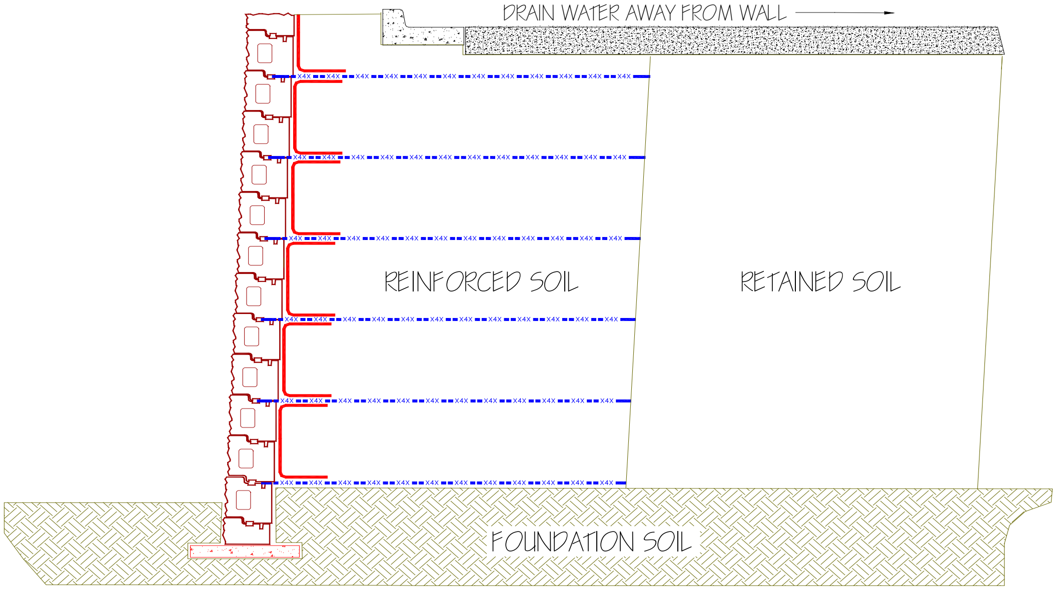
- Add swales to walls with crest slopes greater than 5-feet in height.
- Remove low spots from walls.
- Provide scour protection.

For Crest Slopes Longer Than 10ft – Swale



If a backfill or crest slope is to be graded at the top of a MSE wall or slope and the backfill or crest slope length exceeds 10-feet, then a drainage swale must be constructed behind the wall crest. To provide room for the swale, the wall height must be increased accordingly based on the swale width and depth as determined by the civil engineers hydraulic study. The grading and drainage plan must also reflect the presence of a swale.

At Parking Lots - Drain Water Away From Wall



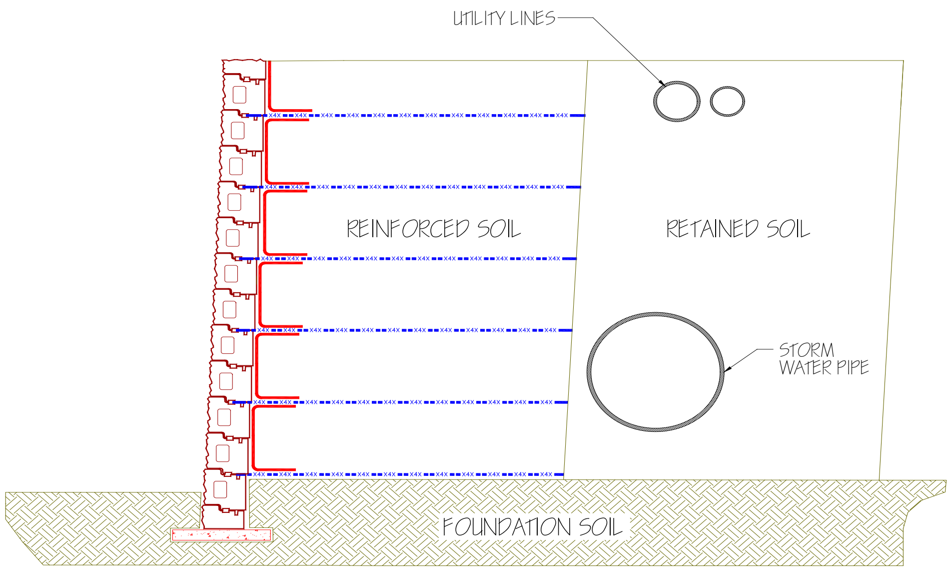
Where parking lots or roadways are constructed behind the crest of a MSE wall or slope, it is important to make sure surface water or sheet flow is directed away from the wall and collected in drop inlets located outside of the geosynthetic-reinforcement zone.

Many times the grading plan allows for surface water to sheet flow towards the wall and be collected in curb inlets located within the reinforced zone. If cracks develop in the pavement structure the water could flow through the cracks and seep into the reinforced zone. Water pressure could then cause the wall to deform or fail.

Locate The Following Structures Outside Of The Reinforced Zone

- Underground utilities
  - Storm pipes (use neoprene “0”-ring gaskets, minimize joints).
  - Electric, cable, etc. (wall contractor can install conduits).
  - Strom Water and Sewer lines.

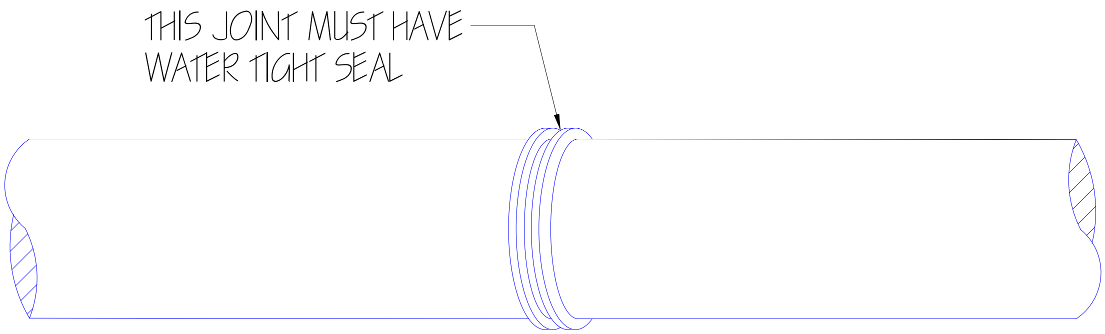
Locate Utilities Outside of Reinforced Zone.



If possible, all utilities must be located outside of the geosynthetic-reinforced zone. If a pipe must be located within the geosynthetic zone of "any MSE wall or slope" and the pipe has to be serviced or repaired after the structure is built, then to service the pipe layers of geosynthetic-reinforcement will have to be cut and the wall be dismantled to the elevation of the pipe. Also, it makes construction of the wall and pipe more difficult when two separate contractors (pipe and wall contractor) are working in the same area trying to coordinate the pipe elevation within the layers of geosynthetic-reinforcement.

If liquid bearing utilities are located within the geosynthetic-reinforced zone, the following must be considered. Storm water pipes are subject to separation at joints. If this occurs, water will seep into the adjacent soil and soil can migrate into the pipe. If the pipe is located within or next to the reinforced zone of a MSE wall or slope, it can cause excessive hydrostatic loads or result in settlement at the ground surface. Storm water pipes located inside or within 10-feet of the geosynthetic-reinforced zone should consist of either continuous pipe sections, or neoprene o-rings should be properly installed at the pipe joints. A double lined pipe system or a leak management system could also be implemented into the storm water design. Design and detail of all pipe systems is the responsibility of the project civil engineer.

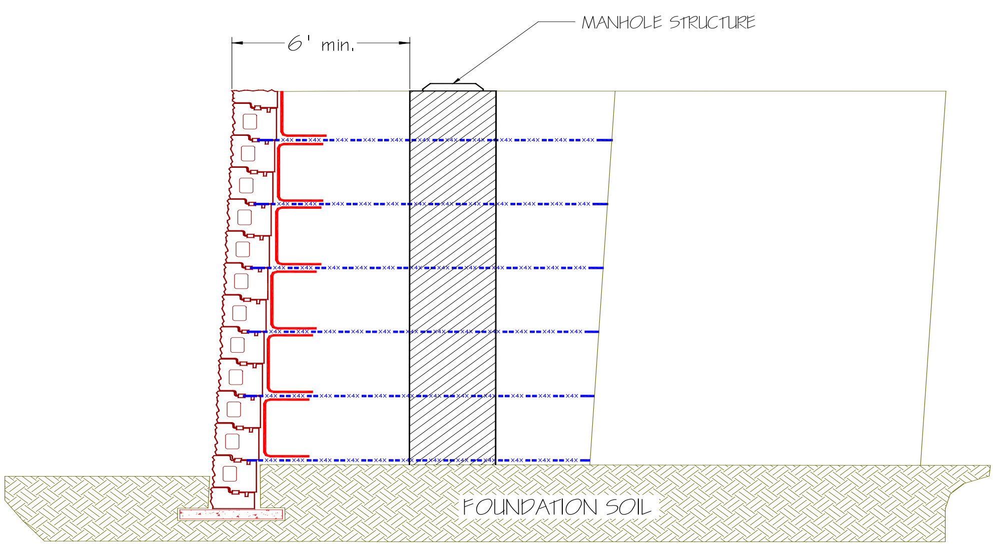
Storm Water Pipes Need Water Tight Joints



Try to get the following structures out of the reinforced zone:

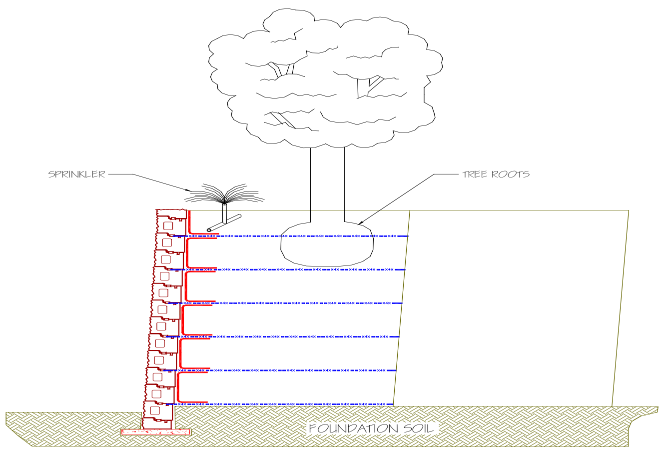
- Drainage structures/stand-pipe man holes
- Convert curb inlets to drop inlets

Manhole Structures No Closer Than 6-ft To Wall



If a vertical storm water riser is placed within the geosynthetic-reinforced zone, it should be located such that there remain at least 6.0-feet between the edge of the riser and the back of the MSE facing system. This amount of space allows for proper compaction of soil. However, it is strongly recommended that all utilities, i.e., storm pipes, electrical, gas, catch basins, drop inlets, etcetera be located outside the geosynthetic-reinforced zone.

Landscaping - Control Excavation & Irrigation



Landscaping above the geosynthetic-reinforced zone should be controlled. The wall designer should be consulted before excavating through layers of reinforcement for the planting of trees and shrubs. As a minimum, small shrubs should be located 5-feet from the MSE facing system and tress located 10-feet from the MSE facing system.

Subsurface irrigation systems are prone to leaking and saturating adjacent soil. If this occurs behind a MSE wall, the increase in horizontal pressure due to hydrostatic loading may induce wall failure. Therefore, subsurface irrigation systems should not be installed in slopes above or below the reinforced zone or within 20-feet behind the reinforced zone of the MSE wall.

Where parking lots or driveways are to be constructed behind a wall crest, the civil engineer must provide for adequate space behind the crest to account for wall better, fence posts and guard rails. Generally, if guardrails are located no closer than 3.0-feet behind the segmental blocks, and or fence post no closer than 2.0-ft, a structural engineer must design and detail these features. To calculate the batter of a MSE wall the following equation can be used:

- $x = H \tan(\Psi)$ where,
    - o x is the horizontal wall batter as measured from the toe to the crest front wall face.
    - o H is the total wall height (feet)
    - o Ψ is the angle of the batter.

Example: If the maximum wall height is 30-feet and the segmental retaining wall block has a 3-degree batter, the maximum batter is:

- x=30-feet [tan (3-degrees)] = 1.57-feet "or" 18.87-inch

Most civil plans use a wall line thickness at 1-ft. The depth of the block is 1-ft so the total batter from the bottom of the wall at the face to the top of wall at the backside of the block is 2.57-ft. A wall line thickness of 3-ft based on the tallest wall section should be used to determine the wall line thickness.

VII. Why Do MSE Walls Fail

The two main reasons walls fail is due to drainage issues and poor compaction.

Results of Poor Compaction

Poor compaction in the reinforced soil zone leads to settlement of the backfill zone causing cracks to develop in the pavement structure. If not fixed surface water enters the crack and has the potential to cause failure.

In the photograph to the left too much fill is placed at one time (over 3 feet, too much for the small walk behind compactor). The compacted lift thickness should be limited to 8-inch and monitored by the project geotechnical consultant as would be noted in the MSE wall specifications.

Internal settlement within the geosynthetic-reinforced zone may occur if improper soils, such as organic material or fine-grained soils with more than 50% passing the #200 sieve along with high liquid and plastic limits, are used to construct the MSE wall. Internal settlement can also occur if the reinforced soils are not compacted in strict accordance with the MSE wall Construction Specifications. The contractor must compact the reinforced soils in strict conformance with the compaction requirements outlined in project construction specification. The on-site geotechnical engineer must closely monitor contractor's fill operation to ensure that the maximum compacted fill lift thickness does not exceed 8-inches.

Not backfilling each course, contaminating drainage aggregate with fine grained soil. Also too many blocks stacked without core filling.

While some engineers may want to blame poor wall performance and failures on substandard construction there can also be problems related to design. Most projects are designed through suppliers or contractors with very few designed directly for the owner were communication between the owners' civil engineer and geotechnical engineer can be realized.

Vendor and design/build firms tend to reduce the amount of reinforcement in a MSE wall so they can "get the project". This liberal approach to design has substantially contributed to failures and has the potential to make others wary of using MSE technology. In reviewing MSE wall designs produced through vendors and design/build firms, the author opines that these entities understand the design process for proper MSE design however they minimize the design to their favor by ignoring aspects of design that should be accounted. This is usually accomplished by using a liberal design approach and ignoring or incorrectly addressing global stability.

In some failures global stability analysis was not have been or was inadequately performed as a part of the original MSE wall design. The term "design" pertains to a solved puzzle and not to some elements within the puzzle that perhaps are correctly solved or assumed. To perform a complete design, a qualified MSE engineer must address internal, external, facing and global stability (internal and compound internal) and meet minimum Fs values per the state-of-practice.

Engineers today are fortunate to have very sophisticated design programs, such as program MSEW 3.0 that assist engineers in performing MSE designs when the programs are properly used. Some MSE engineers who use commercially available or free vendor software may not understand the input or output and probably could not justify the design by a hand calculation to support the analysis output. A well-known professor of geotechnical engineering, Dr. William Kovacs, P.E., of the University of Rhode Island, made a statement regarding geotechnical software today saying: "*garbage in = gospel out*." This statement has great relevance in that the author's experience in reviewing designs has witnessed incorrectly entered input data that was not checked for accuracy.

Slope stability programs such are much better suited for analyzing global stability of MSE wall systems; simply, the search mechanism determining a minimum factor of safety is better suited than in wall design programs. MSE engineers must realize they need to conduct a minimization process to calculate the minimum Fs for a given cross section in regards to global stability.

A literature search with respect to geosynthetic design and failure was performed. The following excerpts have been taken from a paper written by J.P. Giroud, PhD, and entitled "*Lessons Learned from Failures Associated with Geosynthetics*", Geosynthetics '99 - Boston, Massachusetts. Dr. Giroud is the Chairman Emeritus of GeoSyntec Consultants and a Past President of the International Geosynthetics Society.

The paper lists "Two Lessons for Design Engineers".

1. If a design engineer predicts a failure using a rational method, the failure is likely to occur and, therefore, the design engineer should believe the prediction.
2. A design engineer should never take a risk such that, if a failure occurs, it can be explained by an expert using rational methods.

Dr. Giroud found the two principles listed above are useful in helping design engineers resist pressures from over-demanding clients or from over-zealous project managers, two situations that may lead some engineers to make mistakes that could lead to failure for which they would be held liable. Giroud (1999) addressed the question of how failures, involving the use of geosynthetics, can be prevented. The main lessons regarding the prevention of failures were summarized as follows:

- Geosynthetics should not be expected to make miracles in spite of claims by overzealous salespersons. Geosynthetics must be treated like other construction materials, and it must be recognized that, in some cases, geosynthetics may have a detrimental effect.
- At the design stage, design engineers must consider **all** potential mechanisms of geosynthetic failure. To that end, they must keep themselves abreast of observations made by others on the performance of structures incorporating geosynthetics, and they must learn about new design methods. It should be noted that the presence of geosynthetics makes possible some new mechanisms of failure, without eliminating most of the traditional mechanisms of failure.
- Design engineers must write specifications that are complete and precise and that address problems that might occur during construction.
- It is necessary to educate designers and contractors on the potentials and limitations of geosynthetics. Regarding designers, this means that, among other things, they should learn from polymer specialists, learn from failures, learn regarding installation constraints for geosynthetics, and educate contractors.

A high percentage of walls that fail are provided through vendors, design/build and contractor controlled design. The estimated 4.6% failure rate is unacceptable in engineering practice and the engineering community should control the wall design process where direct lines of communication can be realized among the civil engineer, geotechnical engineer, and MSE wall engineer.

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