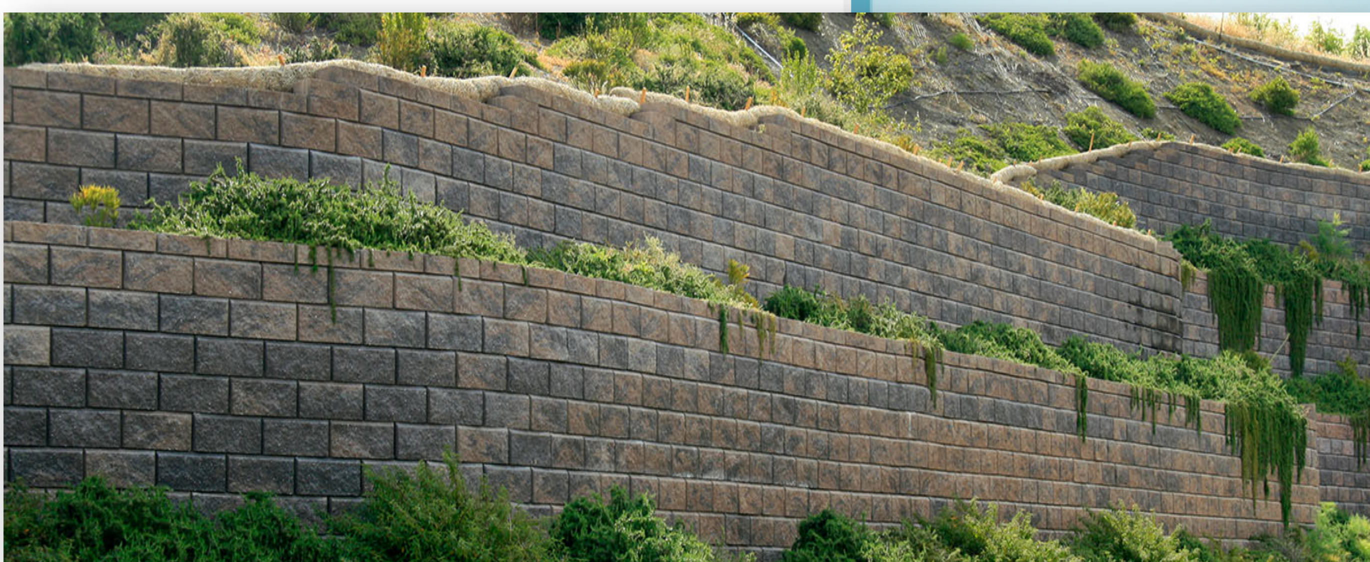
STABILIZED EARTH STRUCTURES MECHANICALLY



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CONTENTS

I. INDUSTRY DESIGN METHODS AND PROGRAMS

The two most popular design methodologies for MSE walls in USA are the National Concrete Masonry Association (NCMA) and FHWA (Federal Highway Administration) methods. Reference to the design manuals are noted below:

- AASHTO - American Association of State Highway and Transportation Officials uses FHWA Publication No. "NHI-00-043, Mechanically Stabilized Earth Walls and Reinforced Soil Slopes - Design and Construction Guidelines", March 2001.
- NCMA - National Concrete Masonry Association uses the "NCMA Design Manual for Segmental Retaining Walls", (First Edition 1993, Second Edition 1997 and Third Edition 2009)

Basic Difference between NCMA and AASHTO

NCMA	**AASHTO**
L/H ratio ≥ 60 % of wall height.	L/H ratio ≥ 70 % of wall height.
Uses Coulomb Earth pressure.	Uses Rankine Earth pressure.
Variable reinforcement lengths.	Uniform reinforcement lengths.
Re-use of on-site soils (if possible).	Select fill in the reinforced zone.
Uniform Loads – Limited Design.	Uniform & Strip Loads - Full Design
Reduced block embedment depths.	Minimum embedment of 2-feet.
Commercial & Private projects only.	Public & Private projects.
Simple Structures & Geometry.	Complex Structures & Geometry.
Uniform Surcharge Loading.	Uniform Surcharge, Strip & Footing Loads.
Minimum design life of 75-years	Minimum design life of 75-years.

The NCMA method will work but is somewhat limited as it does not properly address complex structures. Failure rate of MSE walls is estimated to be 4.6%, which is unacceptable for an engineered system. Failure of MSE walls investigated by the author *with respect to design issues* show that all used the NCMA method with fine grained soil quality, shorter reinforcement length, either no global stability or global stability not properly performed and active earth pressure coefficients (K_a) less than the geotechnical engineers' recommendation.

II. PRODUCTS AND SOIL TESTING

COMPONENTS OF MSE WALLS

- Geosynthetic Reinforcement
    - There are several brands of soil reinforcement products available for constructing MSE walls and slopes.
    - Geotextiles and geogrids commonly used in MSE walls are man-made products comprised of High Tenacity Polyester or High-Density Polyethylene HDPE.
- Masonry Block Facing Units
    - Blocks can be classified as having friction or mechanical connection capacity.
- Soil
    - Soil accounts for approximately 98% of the volume of MSE walls.
    - Soil is inexpensive and abundant construction material. The quality of the soil used in MSE system is critical.
    - The MSE wall engineer is responsible for providing soil specifications addressing soils for the structure that include the reinforced, retained and foundation zones.
        - The specification with respect to MSE wall soils must address required strength, unit weight, bearing capacity (foundation soil), classification, gradation and plasticity.
- Leveling Pad
- Drainage System

EXAMPLE OF GEOSYNTHETIC REINFORCEMENT "GEOTEXTILES"

EXAMPLE OF GEOSYNTHETIC REINFORCEMENT "GEOGRID"

GEOSYNTHETIC REINFORCEMENT DATA

In order to determine the geosynthetic-reinforcement allowable design strength the MSE wall engineer must….

- Begin with the ultimate tensile strength of the reinforcement (T_{ult}), which is the minimum average roll value (MARV) ultimate tensile strength per ASTM D4595)
  - this value is adjusted by the Creep Reduction Factor, RF_{cr} (a minimum of one 10,000- hour creep tension test per ASTM D5262 is required to determine RF_{cr})
  - along with the Durability Reduction Factor, RF_d (combined partial factor for potential chemical and biological degradation, default RF_d=2.0 should be used if durability testing has not been conducted)

- and Installation Damage Reduction Factor, RF_{id} (determined from construction damage tests for each reinforcement product based on ASTM D5818. Default RF_{id}=3.0 shall be used if such testing has not been conducted with a minimum RF_{id}=1.10)
- finally, apply a load

reduction factor of FS_{UNC} = 1.5 The end result is defined by the

$$LTDS = \frac{T_{Ultimate}}{RF_{CR} \times RF_{ID} \times RF_{D}} \qquad T_{Allowable} = \frac{LTDS}{FS_{UNC}}$$

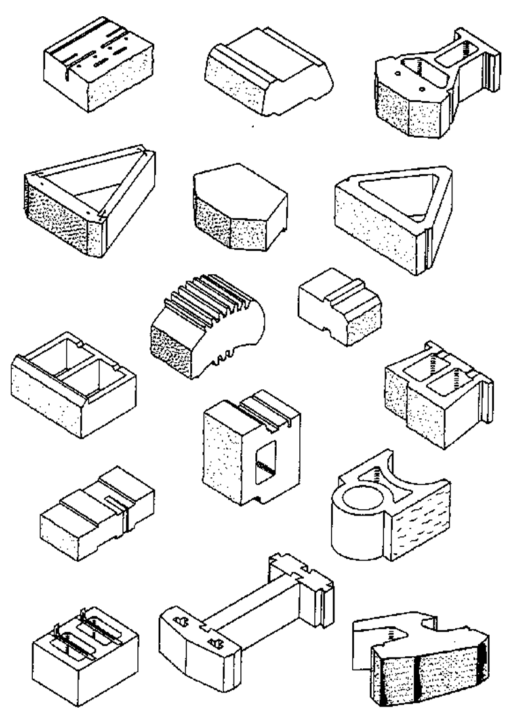
equations….

Geosynthetic - reinforcement ultimate strength along with reduction factors are available through reinforcement suppliers.

COMPONENTS OF MSE WALLS - "MASONRY BLOCK UNITS"

- Masonry block facing units.
- Block units are categorized as having a mechanical or frictional connection.

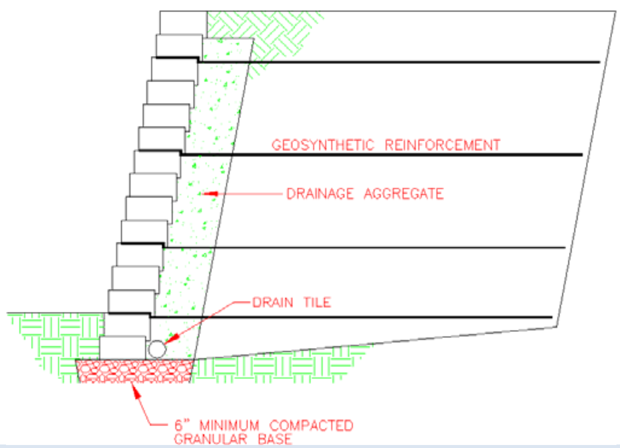
EXAMPLES OF COMMERCIALLY AVAILABLE SEGMENTAL UNITS (NCMA, 1997)



In design it does not matter whether the segmental block is mechanical or frictional, however the MSE wall design engineer must use correct connection capacity and block shear data for the specific segmental block and reinforcement combination in order to meet all factors of safety regarding facing stability, i.e. pullout or failure and serviceability per NCMA.

COMPONENTS OF MSE WALLS

- Drainage system - drainage systems must be constructed to contain and/or control surface and subsurface water.
- Blanket drains are required when ground-water is close to the MSE wall foundation.
- Blanket and chimney drains are required when ground-water rises above the MSE wall foundation.



DRAINAGE AGGREGATE, SOILS, AND GRAVEL LEVELING PAD

The geotechnical soil investigation should provide information with respect to the location of the high groundwater table at the proposed MSE wall location to the MSE wall design engineer. If geotechnical data is not provided MSE wall engineers will typically assume:

(1) that the groundwater table elevation is deep enough such that seepage into the reinforced and retained backfill is minimal and foundation stability is not affected; and
(2) the groundwater table is well below the leveling pad elevation, at a depth greater than or equal to 0.66H, so as to not affect internal, external or global stability.

If water is found to be present in the vicinity of the wall during excavation or construction, a proper functioning drainage system must be installed and sufficient drainage be provided such that hydrostatic loading (pore pressure) will not develop in the wall's reinforced zone. In the event of geotechnical consultant determines during construction or by additional subsurface testing at the wall location prior to construction that the groundwater table is at a depth less than 0.66H, then a blanket drain should be constructed at the base of the MSE wall as noted in the NCMA design manual (1997).

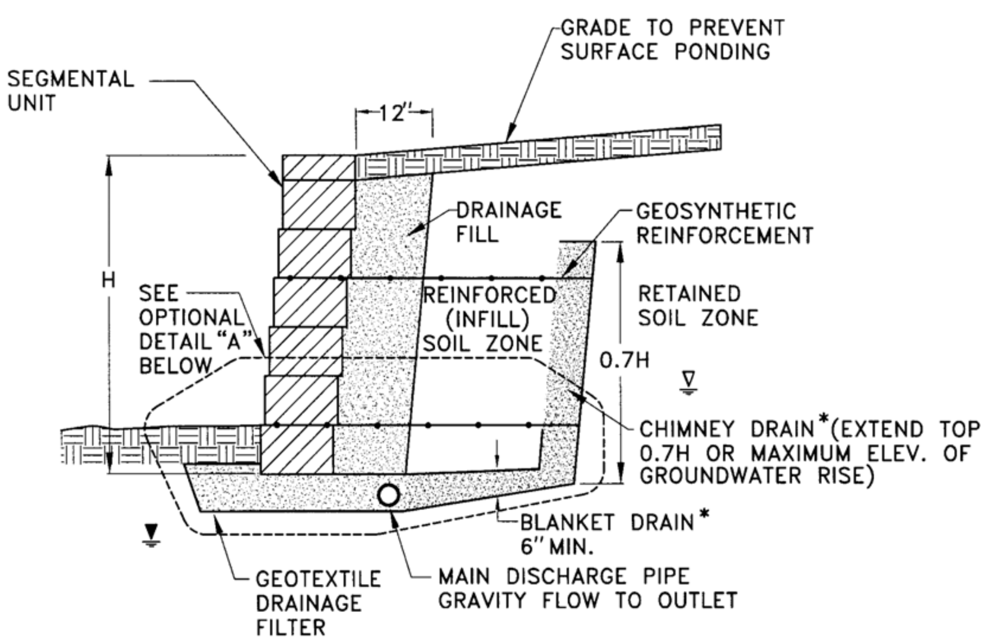
If geotechnical report determines that the groundwater table is present within the retained soil zone, then a blanket drain should be constructed at the base and backside of the geosynthetic-reinforced zone of the MSE wall as noted in the NCMA design manual (1997). The drainage aggregate should be encapsulated within a geotextile filter fabric to minimize the migration of finer soil particles into the drainage gravel.

In the event surface or subsurface water diversion or drainage system details are required to prevent the infiltration of surface water into the MSE wall's reinforced fill zone.

DRAINAGE AGGREGATE, SOILS, CHIMNEY DRAIN AND BLANKET DRAIN (NCMA, 1997)

GROUNDWATER CONDITIONS FOR CASE 3

1. GROUNDWATER TABLE NEAR BOTTOM OF WALL (▼) OR POSSIBLE LATERAL (HORIZONTAL) FLOW INTO REINFORCED (INFILL) SOIL AND RETAINED SOIL ON A SEASONAL BASIS (∇).
2. LATERAL (HORIZONTAL) GROUNDWATER FLOW INTO REINFORCED SOIL WILL OCCUR.
3. THIS COMPLETE DRAINAGE SYSTEM PROVIDES MAXIMUM PROTECTION FOR SRWs AND SHOULD BE UTILIZED WHEN THERE IS UNCERTAINTY AS TO THE ACTUAL SITE GROUNDWATER CONDITIONS.



III. DESIGN INFORMATION

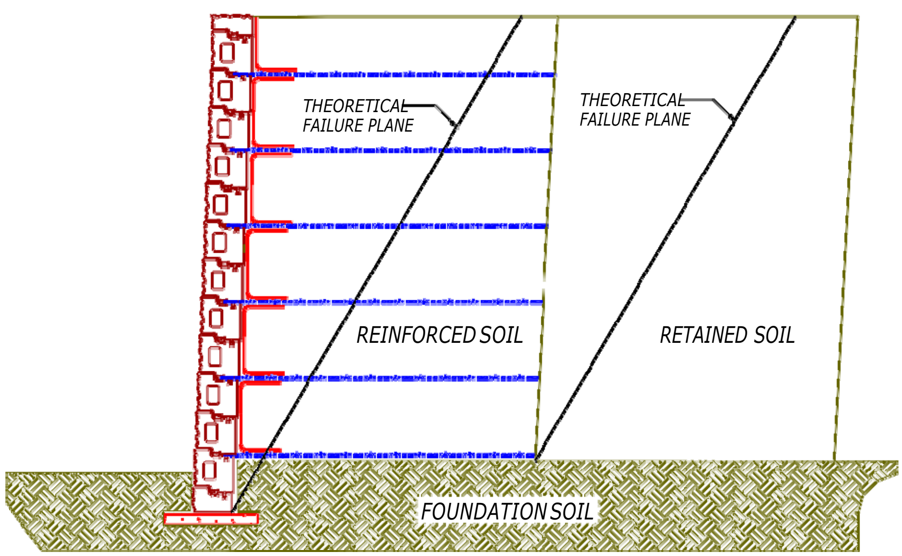
Information Needed for an MSE Wall Design

- Soil Data Information
- Civil Drawings - Site Specific Information
- Geosynthetic Reinforcement Data
- Block Information
- Connection Strength Testing
- Unit to Unit Shear Testing

THE ROLE OF SOILS

- The 98% of a segmental retaining wall system consists of soil.
- Therefore, accurate soil parameters specific to the construction site are *essential* to an accurate design.

SOIL ZONES



THIS INFORMATION IS NEEDED FOR ALL SOIL ZONES:

- Friction Angle (ϕ) - Triaxial or Direct Shear Test

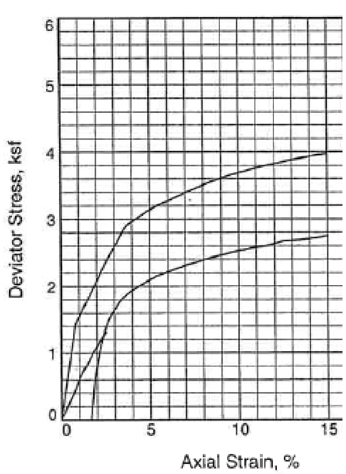
- Cohesion (c) - Triaxial or Direct Shear Test (ignored in reinforced and retained soil)
- Unit Weight (γ) - Proctor Test or Density Test

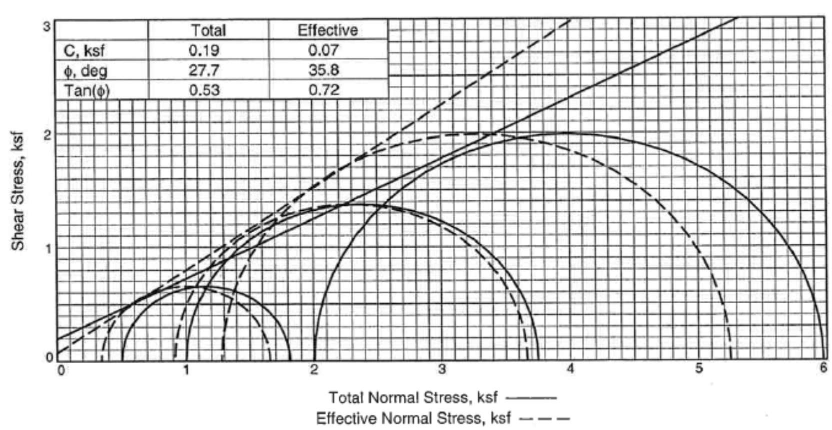
THIS SOIL INFORMATION IS IMPORTANT BECAUSE:

- In order to successfully design a segmental retaining wall, the MSE wall engineer needs to know or must be able to define the soils Effective Internal Friction Angle (ϕ'). This is a property of the soil type and defines the soil in terms of shear strength. The higher the angle, the “stronger” the soil in terms of resistance to sustained loads.
- Moist unit weight of the soil, known as gamma (γ). This affects the driving and resisting forces.
- Cohesion (c’). This should also be determined. However, cohesion is ignored for the reinforced and retained soil zones, and is only used in the foundation soil zone.
- Geotechnical engineers describe soil shear strength using Mohr-Coulomb failure criteria.

Mohr Diagrams are plotted by the geotechnical engineer that depict the soil shear parameters "c’" and "ϕ’". Also plotted are the stress-strain curves for each specimen as well as the effective and total stress paths (p-q diagrams).

“STRESS VS. STRAIN” AND MOHR DIAGRAM FROM CU TRIAXIAL TEST





DISCUSSION ON ALLOWABLE SOIL BACKFILL

The success or failure of an MSE wall or slope is greatly dependent upon the soil used to construct the geosynthetic-reinforced zone and, to a lesser extent, the retained zone (soils located behind the reinforced zone). The selection of soil backfill with respect to the reinforced zone is extremely critical since about 98 percent of the structure is soil. Fine-grained soils such as SC, ML, CL, MH and CH can have a negative effect on the behavior of a wall or slope and therefore should not be used with any of the Mechanically Stabilized Earth (MSE) walls.

Fine-grained soils have a much greater potential for time-dependent movement (creep deformation) of the MSE wall system, leaving MSE walls and slopes more susceptible to failure if backfilled with fine-grained soils. The use of backfill with a large amount of fines is also a problem with all types of retaining walls. The lack of drainage, which may evolve over time, can eventually cause failure of any wall unless the wall is designed to retain water.

The NCMA method does allow for some fine-grained soil types within the reinforced zone and there are MSE wall design engineers who will design with such soils. If a designer specifies the reinforced zone soils to classify as silt or clay a geotechnical engineer must be involved in the design to make sure the soil does not exhibit creep behavior.

The liquid limit, LL, and Plasticity Index, PI, can have a significant effect on the performance of an MSE wall. Soils used to construct the geosynthetic-reinforced zone must have a LL<35 and PI<10. This is to assure that time dependent deformation will not be excessive and that backfill drainage will not be minimized.

Non-creeping soil types must be used for construction. Creep of MSE walls depends largely on the creep characteristics of the geosynthetic-reinforced soil. Field performance data have indicated that creep deformation of MSE walls is minimized when "well compacted granular fill" is used.

The creep rate of geosynthetics and soil are different. Where “non-creeping” soil is used (*e.g.,* granular with less than 35% passing the #200 sieve), the reinforcement will creep faster than the soil and thus the soil will serve to restrain creep of the reinforcement, causing it to relax (reducing the load in the reinforcement by increasing the load transfer into the soil along its common interfaces with the reinforcement).

By contrast, clayey backfill enhances creep of geosynthetics by creeping itself more than the geosynthetics. If a fine-grained silty or clayey soil (*e.g.*, more than 50% passing the #200 sieve) were to be used to construct the reinforced zone, it may creep faster than the reinforcement and transfer load to the geosynthetic, resulting in increased load and rate of creep in the geosynthetic, leading to possible failure. Fine-grained silty or clayey soil, including SC, ML, CL, MH and CH, should therefore not be used for construction of the MSE wall or slopes.

Ideal soil for the reinforced zone (and retained zone if fill) of an MSE wall:

SAND "or" CLAY

Reinforced zone soil that classify as coarse grained (sand and gravel) is recommended because:

- They are easier to place and compact.
- Have higher permeability which assists drainage.
- Have greater friction angle which reduces stresses.
- Are generally less susceptible to creep.
- While not recommended, but if silt or clay are used the designer must:
    - Make absolutely sure that proper drainage is installed.
    - Be sure that the soil has a low to moderate frost heave potential.
    - The internal cohesive shear strength parameter "c" is ignored.
    - Pay special attention to the creep potential.
    - Plasticity Index (PI) should never be greater than 20.

SEGMENTAL RETAINING WALL BLOCK INFORMATION NEEDED FOR DESIGN

- Block Dimensions
    - Typical dimensions of segmental retaining wall block used in MSE wall construction are 8" height, 18" width and 12" depth.
- Block Setback
    - Most segment block systems have a built-in face batter between near vertical and 10-degrees.
- Weight of the Individual Blocks

    - This can range from 30 Kg to 55 Kg depending on the block shape and volume of the core.
    - Infilled weight of the blocks that includes #57-stone with in the block core and between adjacent units typically measures to be about 1950 kg/m3.
    - Segmental block units should have a minimum 28-day compressive strength of 21 Mpa on the net area and have a maximum absorption rate of 8.0 percent.
- Block/Grid Connection Strength
    - Determination of Connection Strength between Geosynthetics and Segmental Concrete Units
- Unit to Unit Shear
    - Determination of Shear Strength between Segmental Concrete Units

Each unit has unique unit-to-unit shear-strength properties as well as unique connection properties with each individual reinforcement type. Therefore, the designer must choose a specific segmental block facing unit and reinforcement combination. And he/she needs to know the specific block and grid combination.

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.

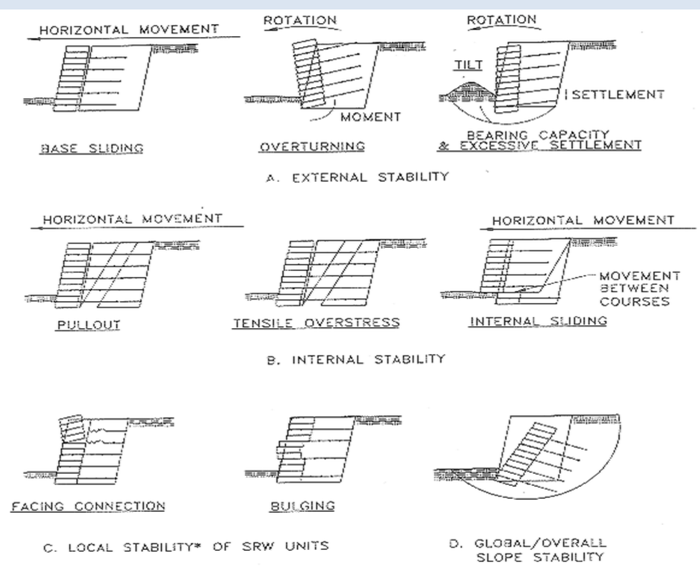
A grading and drainage plan must be designed by a qualified civil engineering consultant clearly showing the MSE wall location with respect to line and grade.

WALL DESIGN ANALYSIS

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

- External Stability
- Internal Stability
- Facing Connection
- Seismic Analysis
- Global Stability
    - 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 (FSSL) - 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.

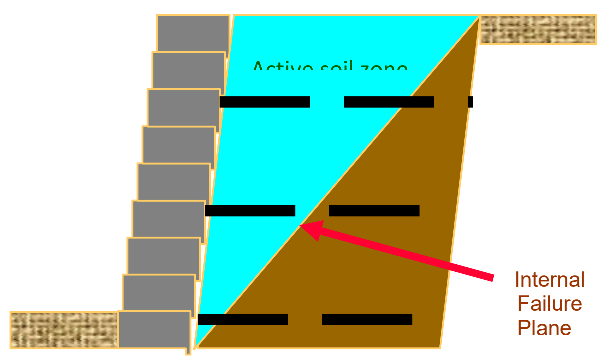
OVERTURNING (FSOT) - Theoretically if the bottom reinforcement is not long enough an overturning failure could occur, however failure due to overturning is likely to not occur as moments within a reinforced soil mass cannot be developed. The main purpose of calculating stability due to overturning is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

BEARING CAPACITY (FSBC) - 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 (FSPO) - 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 (FSOS) - 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 (FSSL) – 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.

THE MSE WALL DESIGN AND SPECIFICATIONS MUST ADDRESS:

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

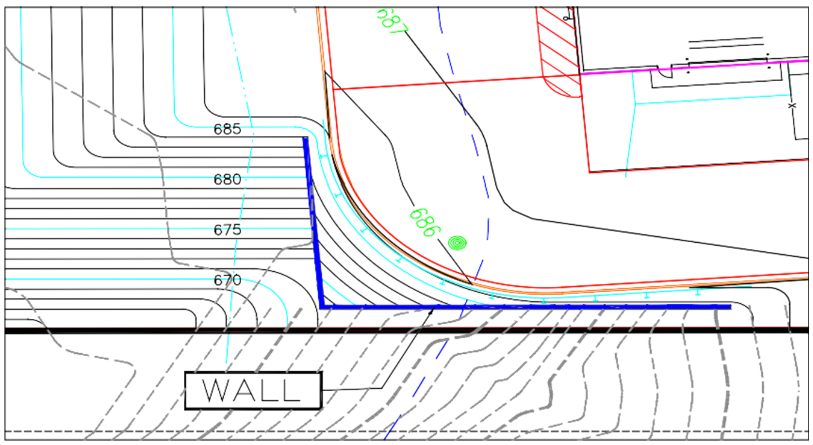
Run Consolidated-Undrained Triaxial Shear Tests and report the stress strain test results as well as present the Mohr-Coulomb failure diagram for peak and residual stress levels, as required by ASTM. The geotechnical consultant will provide a recommended effective internal friction angle based on their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

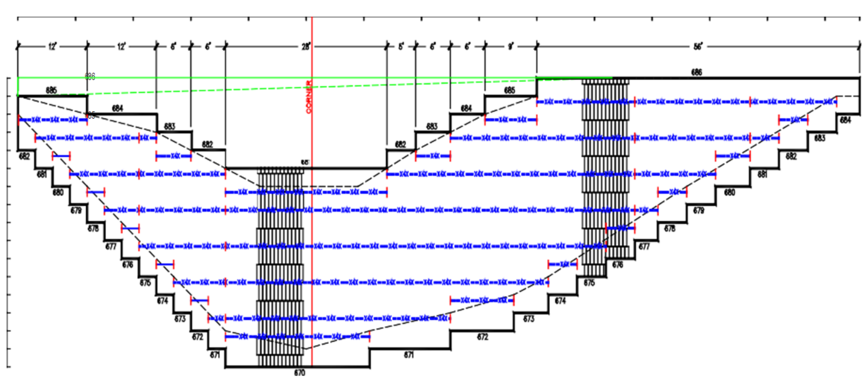
V. DESIGN CONSIDERATIONS FOR MECHANICALLY STABILIZED EARTH WALLS

- 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

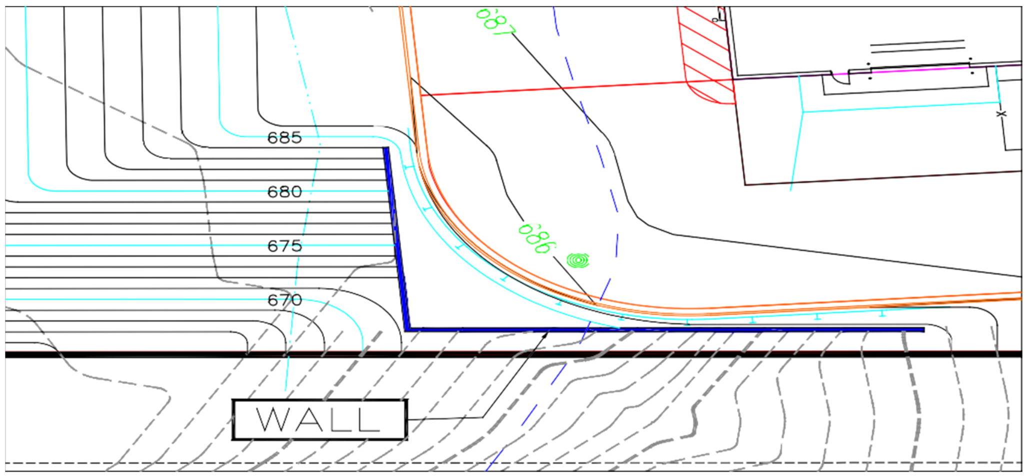


AVOID CREATING LOW SPOT BEHIND WALL - ORIGINAL PROFILE

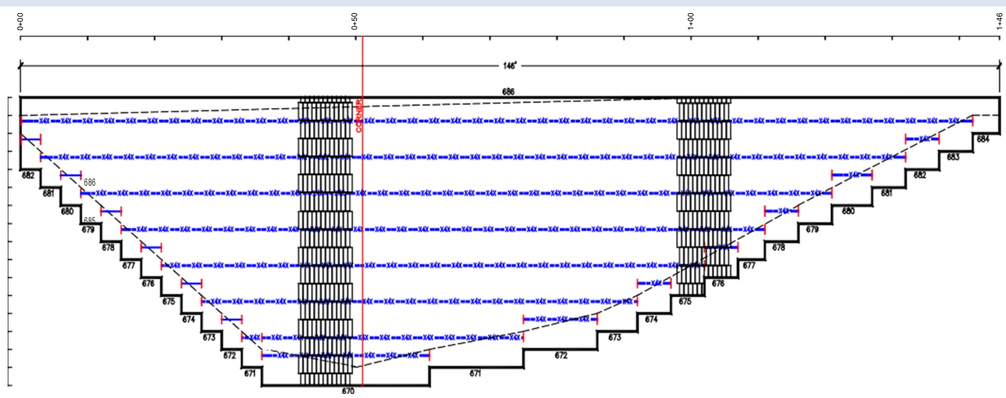


Top of wall grades must be set to allow for positive surface water flow across the top of wall and to exit at one or both ends of the wall. Low spot elevations graded in the middle of the wall, as noted in the example profile, serves as a concentrated point to collect water and creates a situation in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

REMOVAL OF LOW SPOT BEHIND WALL - PREFERRED GRADING PLAN

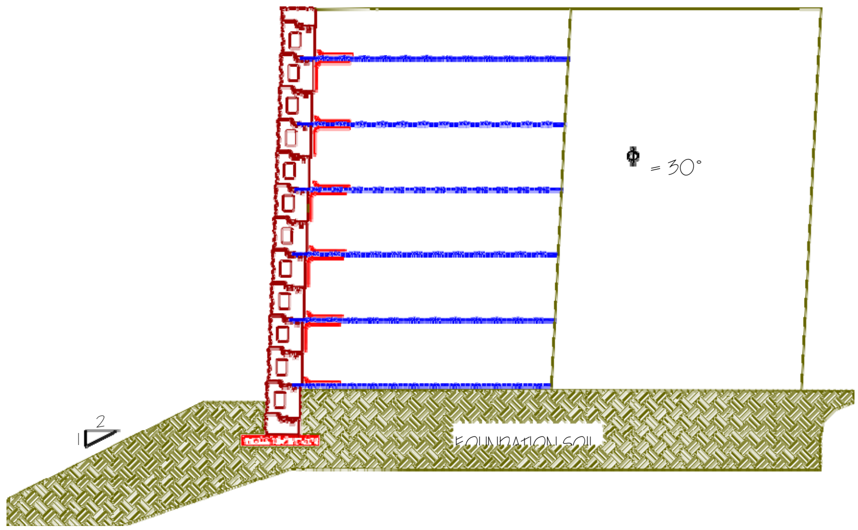


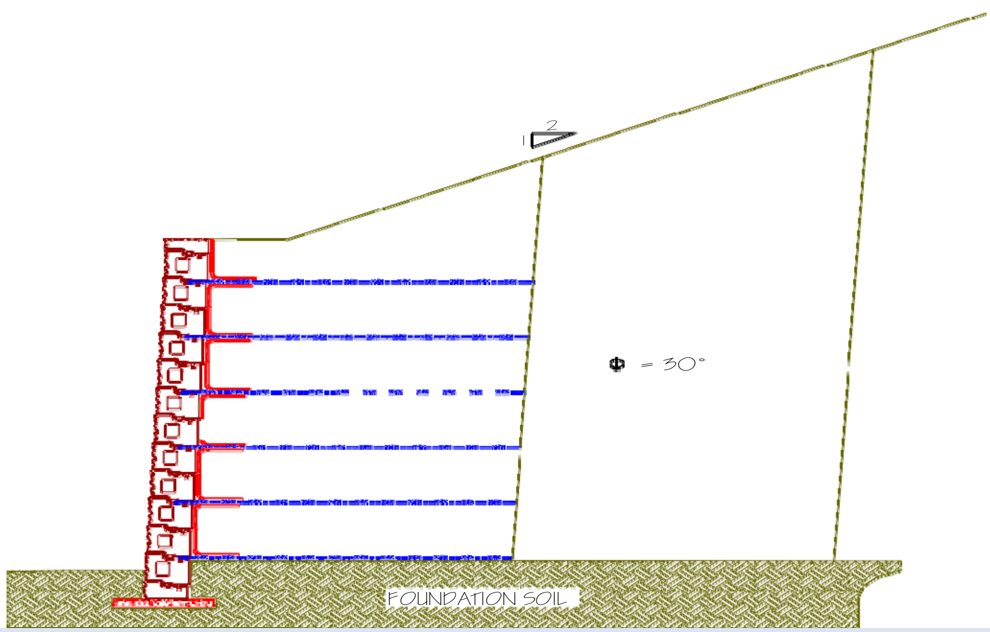
REMOVAL OF LOW SPOT BEHIND WALL - PREFERRED WALL PROFILE



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.

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

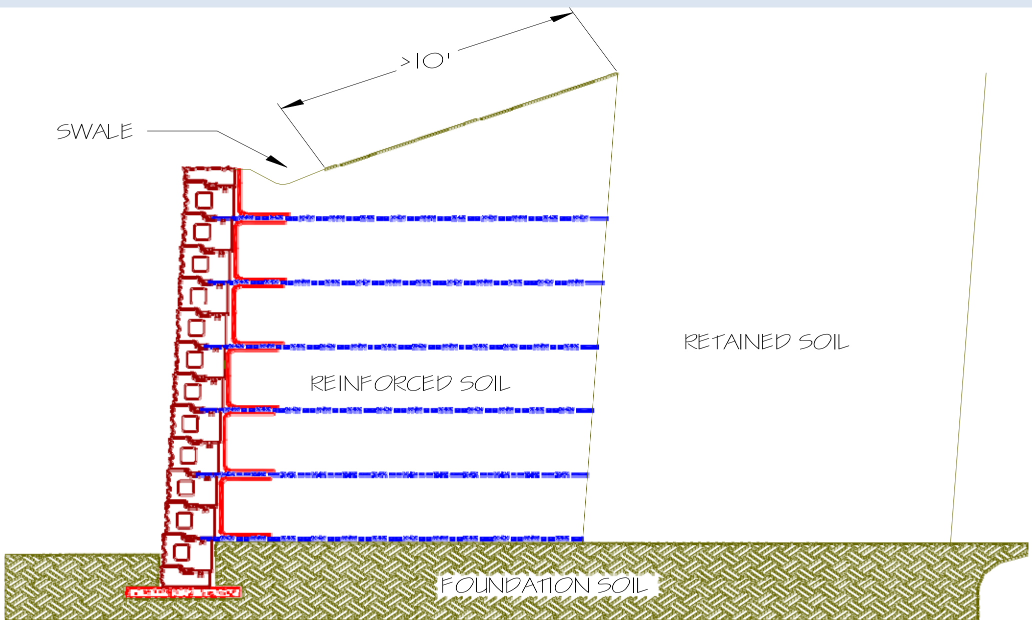
Should any repairs to the wall or slope be required post construction during the design life, they can be made much more easily without the slope on top of the wall.

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

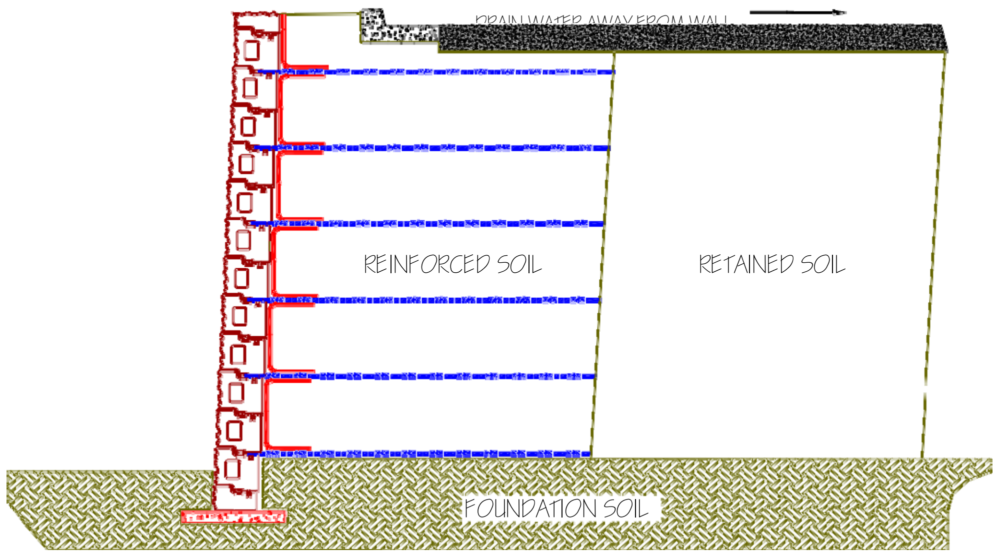
- Add swales to walls with crest slopes greater than 5-feet in height.
- Remove low spots from walls.
- Provide scour protection.

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



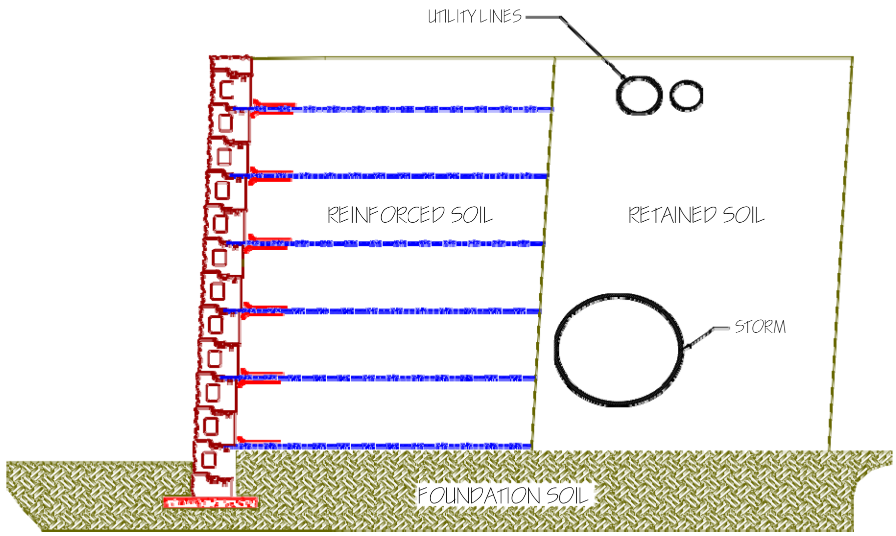
Where parking lots or roadways are constructed behind the crest of a MSE wall or slope, it is important to make sure surface water or sheet flow is directed away from the wall and collected in drop inlets located outside of the geosynthetic-reinforcement zone.

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.

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