CORPS OF ENGINEERS CRITERIA FOR MSE WALLS AND REINFORCED SOIL SLOPES

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ABSTRACT

The US Army Corps of Engineers (USACE) is typically cautious of accepting new technologies for use on USACE projects. A long project design life and applications that often involve special considerations, such as waterfront usage and potential for loss of life, combine to create a desire to design using methods that are time proven. USACE is recognizing that the continuing use of mechanically stabilized earth (MSE) wall and reinforced soil slope (RSS) structures is providing a history of performance that demonstrates these structures can achieve a long, safe design life. Design guidance and guide specifications for MSE and RSS structures have been prepared by USACE in response to the expanding library of performance data, the potential for significant retaining wall cost savings, and the potential use of steeper slopes to reduce real estate costs. The design guidance summarizes the design procedures and criteria for different applications and modes of failure; the guide specifications provide guidance for use by designers and specification engineers during the development of plans and specifications for USACE projects. Industry experience was used in the development of this guidance through the use of two peer reviewers funded by the Geosynthetic Materials Association (GMA) and the National Concrete Masonry Association (NCMA). This paper discusses the USACE design guidance and the special considerations that need to be addressed when using MSE walls and RSS structures on USACE projects. This paper is directed towards both government and private designers and specifiers of materials and methods for these structures.

INTRODUCTION

Mechanically stabilized earth (MSE) walls and reinforced soil slope (RSS) structures have readily become accepted construction for use on private and many public funded projects. The use of these structures on publicly funded projects appears to vary between agencies. The Federal Highway Administration (FHWA) and many State Departments of Transportation (DOTs) have widely used MSE structures on a variety of projects. The use of MSE structures by the US Army Corps of Engineers (USACE) to date has been minimal, but appears to be increasing with an expanding experience base. The continuing use of these structures is providing a history of performance, helping to assure the designers that these structures can achieve a long design life.

The use of segmental retaining wall (SRW) systems has proven to be very cost effective when compared to traditional cast-in-place gravity walls or cantilever or anchored sheetpile structures (Koerner (1999)). It is this economical aspect that has led to the rapidly expanding use of these wall systems. The combined efforts of private industry and the transportation departments of federal and state governments has resulted in sufficient past and ongoing research and testing such that these walls can be designed and constructed with confidence. The FHWA has a significant amount of experience in MSE wall construction and has completed much research in support of these walls on federally funded projects. Much of this experience has led to the use of MSE walls in nearly every type of application where conventional earth retaining structures have been used in the past. Experience in waterfront projects will continue to expand the potential use of these walls to many USACE civil works projects.

USACE Missions/Projects

USACE supports a number of different missions for the military and for civil works. USACE is the executive agent for contract and construction management of Army and Air Force facilities and infrastructure construction throughout the world. Traditional USACE projects for civil works applications include navigation, flood control, water supply and emergency response for disaster declarations. These missions often involve construction associated with: locks and dams; dredging of harbors and channels; dams (earth, rockfill, concrete); levees; floodwalls; channels; etc.

Retaining structures are required for a number of differing applications. Besides retaining earthen materials for grade separation, structures often retain floodwaters caused by rain, snowmelt or wind generated waves. In a channel environment, retaining walls may be exposed to turbulent as well as non-turbulent flow conditions. These flows can carry various types of debris or ice. Approach walls on hydraulic structures "train" inflow so that passage of water will be as efficient and economical as possible. Guidewalls on lock facilities aid in aligning incoming or outgoing navigation vessels. These few examples of different applications for walls used on USACE projects identify the varying uses that are typical of USACE projects, but atypical of most other public agencies.

Design Issues

The differing functions of USACE project walls, as noted above, often require designing for a number of different load and impact conditions. Since many walls are used in wet environments, differing water conditions require designs that accommodate flow into or out of the bank. Walls may be exposed to normal, or usual, water levels, but must also be designed for unusual load conditions that may be applied by very high or very low water levels. Recognizing that some load conditions are rare, USACE criteria is set accordingly by accepting more risk for those design cases through the use of lower minimum acceptable factors of safety.

In addition to different load cases and water-related concerns, USACE projects are typically designed for a long project life. A 100-year design life is often sought for flood control projects and a 50-year life can be expected for many navigation structures. MSE structures, used for these applications would also be expected to perform for those lengths of time. If walls have to be replaced prior to reaching the project design life, replacement costs need to be considered in the economic analyses. This could affect the decision as to the type of wall used.

Another consideration for use of MSE structures on USACE projects is the risk associated with failure of a critical project component. Failure of an approach wall on a navigation structure could close a river to traffic, resulting in significant economic loss. Failure of a floodwall could induce significant flood damages with the potential for loss of life. Failure of a wall used for an embankment dam raise could result in overtopping, and potential dam break, putting many lives at risk.

The number of design issues that must be considered for USACE projects has likely contributed to a slower acceptance of MSE applications than has been experienced by other public agencies. The need to address these design issues led to the development of USACE Engineering Circular (EC) EC 1110-2-311, *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes* (USACE, 2000). USACE (2000) is a design guidance document addressing MSE walls (specifically for SRW facing units and geosynthetic soil reinforcement) and geosynthetic reinforced soil slopes for USACE applications. Design considerations for MSE structures have been combined with USACE design criteria. In addition to the design document, guide specifications have been prepared for construction of segmental retaining walls and reinforced steepened slopes.

DESIGN CRITERIA FOR MSE WALLS

Design Methods

The current state-of-the-practice for designing MSE SRWs for private industry applications is presented in NCMA (1997), and for transportation structures in FHWA (1997) and AASHTO (1996). These design procedures may be performed using the NCMA's SRWall software (Earth Improvement Technologies and Bathurst (1997 and 2000)) and the FHWA's MSEWall design software (ADAMA, 1998), respectively. Koerner and Soong (1999) have compared FHWA and NCMA design methods, concluding that: the FHWA approach is the more conservative of the two procedures; both design procedures are considered adequate for current MSE SRW projects; and the selection of which method to use is site-specific or owner/specifier specific. Either method is considered acceptable for use on USACE projects. The limitations of the NCMA and FHWA design procedures, with respect to USACE projects, include: the documents do not address the varying load cases, including water effects, that are typical of USACE projects; and, slope stability requirements vary depending on the design conditions required to be analyzed. Most standard USACE design requirements are applicable to the design of SRWs. The USACE EC 1110-2-311 (USACE, 2000) design guidance is intended to supplement NCMA (1997) and FHWA (1997) for use on USACE applications.

Internal and Local Stability of SRW Units

NCMA (1997) identifies internal stability analyses as that necessary to *"... examine the effectiveness of the geosynthetic reinforcement in holding the reinforced soil mass together so the geosynthetic layers and soil function as a monolithic block."* The internal analyses address: tensile overstress in the geosynthetic reinforcement; pullout of the reinforcement through the reinforced soil mass; and internal sliding along reinforcement layers.

Local stability evaluates the column of SRW units. These analyses consider: facing connection between the SRW units and the reinforcement; bulging of the SRW units between reinforcement layers; and the maximum unreinforced height of the SRW units at the top of the wall. The procedures for these analyses are discussed in detail in NCMA (1997). These analyses are based on conditions that do not involve partial submergence or forces due to seepage. An assumption that is often made during design of SRWs that are fully or partially inundated is that the most critical load condition for these analyses will occur after the submerged period when moist soil unit weights may be higher than normal and are not offset by uplift conditions. In waterfront applications, care should be taken to assure drainage aspects have been fully addressed and that assumed pore water pressures reflect the field conditions to be encountered.

External Stability

External stability evaluates the minimum length of geosynthetic reinforcement necessary to satisfy base sliding, overturning and bearing capacity factors of safety. The SRW units and the reinforced soil zone are treated as a rigid body and are analyzed following the same procedures as for rigid gravity walls except for the bearing capacity analyses. FHWA (1997) states *"Due to the flexibility and satisfactory field performance of MSE walls, the adopted values for the factors of safety for external failure are in some cases lower than those used for reinforced concrete cantilever or gravity walls. For example, the factor of safety for overall bearing capacity is 2.5 rather than a higher value, which is used for more rigid structures. Likewise, the flexibility of MSE walls should make the potential for overturning failure highly unlikely. However, overturning criteria (maximum permissible eccentricity) aid in controlling lateral deformation by limiting tilting and, as such, should always be satisfied."* This empirical evaluation appears appropriate for USACE applications.

The external stability analyses utilize active lateral earth loads on the driving side. Passive resistance is neglected in the NCMA and FHWA procedures due to the potential for removal of these soils resulting from erosion or unforeseen excavation. Due to the relatively shallow depth of embedment used for many MSE walls, the passive resistance is generally small and neglecting this resistance is not overly-conservative. The selection of using the Coulomb earth pressure theory for determining the lateral earth pressure is partially consistent with the USACE approach for evaluating the sliding stability of concrete structures. USACE procedures utilize the Coulomb earth pressure theory and the General Wedge method to estimate the at-rest earth pressures, used for design of cast-in-place structures, by applying a strength mobilization factor to the shear strength of the backfill soil. These loads are then applied to the retaining wall, generally neglecting wall friction. The Coulomb earth pressure theory, as applied in NCMA (1997), is considered acceptable by USACE for the design of both reinforced and unreinforced SRWs.

Sliding, overturning and bearing capacity of retaining structures is discussed in USACE (1989). This manual provides detailed guidance for designing concrete gravity and T-type cantilever reinforced concrete retaining walls subject to hydraulic loading. The factors of safety recommended in USACE (1989) expand beyond those recommended in NCMA (1997) or FHWA (1997) to account for differing loading and foundation conditions. The stability criteria for sliding, overturning, and bearing capacity analyses for MSE wall design utilizing SRWs, as recommended in USACE EC 1110-2-311(2000) are summarized in Table 1. Values for the usual load condition are described in USACE (1989) as "*The backfill is in place to the final elevation; surcharge loading, if present, is applied (stability should be checked with and without the surcharge); the backfill is dry, moist, or partially saturated as the case may be; any existing lateral and uplift pressures due to water are applied. This case also includes the usual loads possible during construction which are not considered short-duration loads.*" Unusual loading is considered to be the same as the usual "*except the water table level in the backfill rises, for a short duration, or another type of loading of short duration is applied; e.g., high wind loads, equipment surcharges during construction, etc.* Earthquake loading is also the same as the usual load condition "*with the addition of earthquake-induced lateral and vertical loads, if applicable; the uplift is the same as for (the usual load case).*" Use of these values for flexible SRW structures have not been fully researched, but appear reasonable until further investigations or field experience is available.

Due to the flexible nature of MSE walls, computations for bearing capacity differ from those recommended for rigid structures. Instrumented MSE walls indicate that the stress distribution along the base of the walls can be reasonably modeled using a Meyerhof-type stress distribution. A Meyerhof-type stress distribution assumes that loading is applied uniformly over the effective base width. Bearing capacity factors for embedment and ground slope are applied to the general bearing capacity equation, but factors for base tilt (MSE walls are generally constructed with no base tilt) and load inclination are not included. Lack of inclusion of the load inclination factor provides a reasonable basis for USACE adopting the FHWA (1997) bearing capacity design factor of safety of 2.5, for the usual loading condition, rather than the bearing capacity factor of safety of 2.0 recommended for MSE structures in USACE (1989).

Table 1. Sliding, Overturning and Bearing Capacity Stability Criteria (USACE, 2000).

Loading Condition	Sliding Factor of Safety	Overturning Criteria Minimum Base Area in Compression		Minimum Bearing Capacity Safety Factor
		Soil Foundation	Rock Foundation	
Usual	1.5	100%; $e \leq B/6$	75%; $e \leq B/4$	2.5
Unusual	1.33	75%; $e \leq B/4$	50%; $e \leq B/3$	2.0
Earthquake	1.1	Resultant within base	Resultant within base	≥ 1.0

Global and Compound Stability

Global stability refers to the overall slope stability analysis involving the wall or wall system. Compound stability is a slope stability analysis where the failure surface passes through both the reinforced and unreinforced fill (Berg et al. 1989). The extensible nature of the reinforcement and the integral manner in which it is placed in the backfill creates a reinforced soil mass that can sustain minor deformations. A practice that has been used in the past to model the reinforced soils, for the purposes of analyzing slope stability, and perhaps may be used [incorrectly] by some designers today, was to assign an artificially high shear strength to the entire reinforced soil mass. The philosophy behind this methodology was that search routines used in locating the critical failure surface would not find critical surfaces that may have passed through or within what was perhaps perceived as a zone of high shear strength soil due to the inclusion of the reinforcement. This procedure, however, does not evaluate those potential failure surfaces passing between or through the reinforcement layers, which may have lower factors of safety against slope stability failure. Instead, both global and compound slope stability should be modeled using slope stability software that has the capability to include reinforcement in the model as discrete reinforcing elements.

The wall designer needs to understand the characteristics of the slope stability software and how it computes the factor of safety. Some slope stability programs compute the factor of safety by applying the resisting forces from the reinforcement as a resisting moment; other programs will treat the resisting force as a reduction to the driving moment. If the program does not apply the iterated factor of safety to the reinforcement strength, the allowable tensile strength (i.e., long-term strength reduced by a factor of safety) of the reinforcement should be used in the model. If the program does apply the computed factor of safety to the reinforcement, the long-term strength may be used.

The influence of water on global and compound stability can be significant and must be considered to the same extent that is routinely given to USACE projects (USACE, 1970; USACE, 1978). Table 2 presents and summarizes the minimum required factors of safety, as presented in EC 1110-2-311 (USACE, 2000), for various design conditions. These factors of safety are considered applicable for walls designed in conjunction with embankment dams or along rivers or streams. Walls designed in conjunction with other uses (i.e. grade control structures; wingwalls; landscaping applications; etc.) should also follow this criteria. Levee stability criteria would govern for most design projects and dam stability criteria should be followed for walls that may be considered critical. Such projects would include instances where failure would involve loss of life or significant economic loss. Discussions on appropriate shear strength parameters to use for the differing design conditions are discussed in USACE (1970 and 1978).

Table 2. Slope Stability Minimum Factors of Safety (USACE, 2000).

Design Condition	Dam Stability Factor of Safety (min)	Levee Stability Factor of Safety (min)
End of Construction (EOC)	1.3	1.3
Sudden drawdown from max. pool for dams or from significant saturation elevation on levees	1.0	1.0
Sudden drawdown from spillway crest or top of gates	1.2	N/A
Intermediate river stage	N/A	1.4
Steady seepage (SS) with max. storage pool	1.5	N/A
Steady seepage with surcharge pool for dams or from full flood stage for levees	1.4	1.4
Earthquake (EOC; SS)	1.0	1.0

The NCMA and FHWA design procedures both include a seismic coefficient method for a pseudo static analysis. NCMA (1998) provides a detailed discussion of the revised equations in the design procedure. Both design procedures base the seismic coefficient on an "A value", which is the pseudo acceleration with a 10% probability of exceedance in 50 years. The NCMA manual stipulates that the seismic coefficient method is only applicable for a value of A less than or equal to 0.4. If the A value is beyond this stated limit, a response spectrum (dynamic) analysis is recommended. With the FHWA procedure, it is recommended that if the seismic coefficient is 0.29, a seismic design specialist should review the stability and potential deformation for the structure. If the structure could cause hazardous conditions related to loss of human life, appreciable property damage, disruption of lifeline services, or unacceptable environmental consequences, then the design requirements in USACE (1995), which includes more stringent requirements for response spectrum or time-history analyses, should be followed.

Drainage

Surface water and pore water pressures can be detrimental to the internal stability when destabilizing seepage forces are present. The current design procedures for SRWs assume completely drained conditions; this assumption affects all modes of failure. Seepage forces, in the case of a sloping phreatic surface, will increase the lateral loading on the blocks, while at the same time reducing the pullout resistance of the geosynthetic reinforcement. The resulting seepage conditions will have an effect on the wall stability, thereby illustrating that drainage of the reinforced backfill is very important to properly constructed SRWs. All walls should include a minimum 12 inches of gravel drainage aggregate behind the facing elements.

For typical applications in upland areas, the drainage requirements are easily met. Open graded gravel is often placed for drainage in all soil types without consideration for filter criteria. Without any significant flow across the soil/drain interface, there is no mechanism for deterioration of the structure.

For waterfront applications, there is commonly a strong gradient near the water body. Along rivers and reservoirs, the case of rapid drawdown imposes the most critical loading for drains. For waterfront applications, design considerations for drainage and filters become much more important than for typical commercial applications.

Redundancy in drainage is necessary for critical applications. A perforated pipe at the toe of the wall (interface between retained backfill and reinforced backfill) may be used to reduce water levels in the infill soil. Additionally, the reinforced fill should not create resistance to drainage of the retained fill; therefore, it is recommended that the reinforced fill have a higher permeability than the retained fill. Another design consideration is the permeability of the geosynthetic reinforcement when used in projects that may be adversely impacted by infiltration and groundwater seepage. Geotextiles, if used for reinforcement, should be designed with a permeability greater than that of the reinforced soil so water flow within the reinforced fill is not impeded.

Saturation levels in the reinforced fill for external, global, and compound stability analyses should be determined following the procedures for dams (USACE, 1986) and levees (USACE, 1978). The derivation of the equations for internal stability tacitly assumes that a phreatic surface does not exist within the reinforced fill. It is recommended that drainage be designed to minimize horizontal seepage forces within the reinforced fill and facing materials.

To avoid loss of backfill through the blocks, the backfill material immediately behind the blocks usually consists of clean gravel. The gravel is predominantly in the ½ to ¾ inch size range to provide satisfactory retention when considering movement through block gaps that may form from settlement or from poor construction practice. The gravel, however, does not retain most soils and requires a filter at the interface between the drainage and reinforced fills. Due to the difficulty in maintaining a uniform thickness of near vertical layers of filters, geotextile filters become an attractive option for SRWs.

Walls constructed in areas where drains will frequently be active should be designed with consideration of clogging potential of geotextile filters. The appropriate geotextile should be used for the project soil conditions; the apparent opening size and percent open area should be important design considerations (Holtz, et al. 1997).

Ice and Impact Conditions

Ice expansion on lakes has been reported to move blocks laterally by impinging on the wall face. Ice loads can be estimated in accordance with USACE (1999). In addition to expansion, ice may adhere to the blocks and pull them out of alignment with changing reservoir levels. The following should be considered: water/ice levels near the top of the wall (little confining stress on the blocks) and reservoirs that are regulated in the winter so that water levels fluctuate when the ice sheet is bonded. Also, ice sheets driven by wind effects might impact walls causing movement of blocks.

Little information is available regarding the effects of impact loads on the face of SRWs. It can be envisioned that blocks can be displaced or broken by impacts from vehicles, ice or debris and that solid blocks would be more resistant to damage from impacts than hollow blocks. The wall designer should consider the potential for impact damage when specifying SRW units.

Cold Regions

Walls designed for use in cold regions need to address block durability and foundation treatment in frost zones. Freeze-thaw damage is being studied by the Minnesota DOT, FHWA and NCMA. Freeze-thaw damage in concrete is aggravated by saline water, such as in coastal applications or due to road deicing chemicals. Wall designers should consult FHWA/AASHTO or NCMA criteria for the most recent required material specifications for blocks. The current block durability requirements in American Society for Testing and Materials (ASTM) Designation C 1372 are default for warm weather climates; some state DOTs may have standard specifications for block durability requirements that are more appropriate to their climate. In the absence of specific information, Table 3 provides criteria for inclusion in project specifications. The above studies have determined that increasing the concrete compressive strength of the blocks, decreasing the allowable absorption of the block materials, and spraying the surface of the blocks with a sealer to reduce absorption, may reduce the rate of degradation.

DESIGN CRITERIA FOR REINFORCED SOIL SLOPES

Incorporating reinforcement in a soil slope is not a new procedure and has been used on many projects applying current design methods (Holtz, et al. 1997). Use of reinforcement can greatly

Table 3. Suggested SRW Unit Material Requirements for Cold Climates (USACE, 2000).

Testing Procedure	No Freezing	Freezing – No Deicing Salts	Freezing – Use of Deicing Salts
Minimum 28-day Compressive Strength (ASTM C 140)	28 MPa (4000psi)	28Mpa (4000 psi)	40 Mpa (5800 psi)
Maximum Moisture Absorption Rate (ASTM C 140)	7%	5%	5%
Freeze-Thaw Durability (ASTM C 1262)	None	Less than 1% weight loss after 150 cycles for 5 of 5 specimens OR less than 1.5% weight loss after 200 cycles for 4 of 5 specimens (tested in water)	Less than 1% weight loss after 40 cycles for 5 of 5 specimens OR less than 1.5% weight loss after 50 cycles for 4 of 5 specimens (tested in 3% saline)

increase a slope angle resulting in cost savings associated with increased land utilization, reduced fill quantities or eliminating the need for a more costly retaining wall. Schedule benefits may also be realized from decreased construction time by allowing "less desirable onsite material" to be used within the reinforced zone than would typically be allowed with other retaining structures. As in SRWs, geogrids and geotextiles have both been used successfully in RSS construction.

Reinforced Soil

FHWA (1997) states, "*Because a flexible facing (e.g. wrapped facing) is normally used, minor distortion at the face that may occur due to backfill settlement, freezing and thawing, or wetting and drying can be tolerated. Thus, lower quality backfill than recommended for MSE walls can be used. The recommended backfill is limited to low-plasticity, granular material [i.e., a plasticity index (PI) less than or equal to 20 and less than or equal to 50 percent of the infill soil should be finer than a particle diameter of 0.075 mm]. However, with good drainage, careful evaluation of soil and soil-reinforcement interaction characteristics, field construction control, and performance monitoring ... most indigenous soil can be considered.*" These recommended backfill requirements should be followed for USACE projects.

Internal Stability

The recommended method for determining the amount of primary reinforcement required for the RSS is a trial and error method incorporating reinforcement directly into a slope stability program (e.g., UTEXAS) capable of handling individual reinforcement layers. Reinforcement lengths, strengths and locations can be changed in the computer model until stability requirements are met. Anchorage lengths must be determined and incorporated in the model.

Since some slope stability codes can readily apply internal reinforcement, it is relatively easy to design the internal reinforcement in the following manner. This is a simplified description and the designer is referred to the FHWA (1997) or to Holtz et al. (1997) for further clarification and details.

a. Assume a primary reinforcement layout (layers spaced not greater than 24 inches vertically if intermediate reinforcement is not proposed).

b. Set the reinforcement lengths longer than is necessary in order for program search routines to locate the critical failure surface within the reinforced soil.

c. Vary the reinforcement spacing and strength for an optimal design. The reader is referred to FHWA (1997) for design suggestions.

Global/Compound Stability

These stability concerns are discussed in detail in the design for MSE walls and are applicable to RSS structures. Once the internal stability has been designed following the above procedure, the reinforcement lengths can be shortened until the sliding and global and compound stability requirements are just met. Minimum factors of safety for varying design conditions are presented in Table 2.

Sliding Stability

Sliding along reinforcement layers is checked using a wedge failure surface. Multiplying by the coefficient of direct sliding reduces the infill shear strength to model the interface conditions. Stability results are found by fixing the failure surface along the reinforcement location and then increasing the reinforcement lengths if required.

Seismic Conditions

Seismic conditions can be modeled following current USACE procedures.

Drainage

Since many USACE civil works projects are water related, it is reasonable to assume that most applicable RSS structures need to address seepage and drainage aspects. Less restrictive requirements on infill soil translates into use of lower permeability materials and an increased concern for raising the phreatic surface within the RSS mass. The steep slope face will inherently be unstable when subjected to emerging seepage. Drains should typically be installed on projects with seepage concerns, but also on many projects without visible seepage problems. The cost of installing a drain can be a relatively inexpensive component in the RSS system.

Facing

Slope face treatment may consist of vegetation (sod; seed) or hard facing (gabions; shotcrete; stone). The face may be wrapped with reinforcement or left unwrapped. Temporary or permanent erosion control mats (ECM) may be incorporated. Whatever method is used, some type of slope face treatment is required to inhibit erosion. Table 4 provides recommendations for facing treatments for differing project conditions (Collin, 1996 and FHWA, 1997).

SUMMARY

Engineering design criteria has been established for MSE wall and RSS structures used on USACE projects. This criteria and discussion of design procedures and recommendations is included in an Engineer Circular, EC 1110-2-311, Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes (publication pending). This criteria is an extension of, and builds upon, existing FHWA and industry guidelines. In addition to the design guidance document, two guide specifications have been prepared for the construction of segmental concrete block faced, geosynthetic reinforced MSE retaining walls (USACE, 1999a) and geosynthetic reinforced soil slopes (USACE, 1999b). These documents are currently available on the USACE TechInfo website: www.hnd.usace.army.mil/techinfo/cegs/cegstoc.htm.

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Table 4. RSS Slope Facing Options and Guidelines for Selection (modified from Collin, 1996).

Slope Face *Angle and soil type*	**Type of Facing**			
	When geosynthetic is not wrapped at face		When geosynthetic is wrapped at face	
	Vegetated Face	*Hard Facing*	*Vegetated Face*	*Hard Facing*
> 50° All soil types	Not recommended	Gabions	Sod; Permanent erosion blanket w/ Seed	Wire baskets Stone; Shotcrete
35° to 50° Clean sands; Rounded gravel	Not recommended	Gabions; Soil-Cement	Sod; Permanent erosion blanket w/ seed	Wire baskets; Stone; Shotcrete
35° to 50° Silts; Sandy silts	Bioreinforcement; Drainage Composites[1]	Gabions; Soil-Cement; Stone Veneer	Sod; Permanent erosion blanket w/ seed	Wire baskets; Stone; Shotcrete
35° to 50° Silty sands; Clayey sands; Well graded sands and gravels	Temporary Erosion blanket W/ seed or sod; Permanent erosion mat w/ seed or sod	Hard facing not needed	Geosynthetic wrap not needed	Geosynthetic wrap not needed
25° to 35° All soil types	Temporary Erosion blanket W/ seed or sod; Permanent erosion mat w/ seed or sod	Hard facing not needed	Geosynthetic wrap not needed	Geosynthetic wrap not needed

Notes: [1]Geosynthetic or natural horizontal drainage layers to intercept and drain the saturated soil at the face of the slope

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