FACING OPTIONS FOR REINFORCED STEEPED SLOPES

Prepared by:

TenCate™ Geosynthetics North America
365 South Holland Drive
Pendergrass, GA 30567
Tel 706 693 2226
Fax 706 693 4400
www.tencate.com

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Introduction

Reinforced steepened slopes, also termed Mechanically Stabilized Earth (MSE) slopes, are defined as structures with face inclinations of less than 70° (Berg, 1993). A critical aspect of the design of reinforced slopes is the facing system. The facing system includes the surface erosion protection and the secondary reinforcement. The erosion protection facilitates the establishment of vegetation and/or provides structural support for the forming of "over-steepened" slopes. The secondary reinforcement facilitates compaction and helps prevent surficial sloughing at the slope face. Figure 1 shows a general cross-section and the various components of a reinforced slope system.

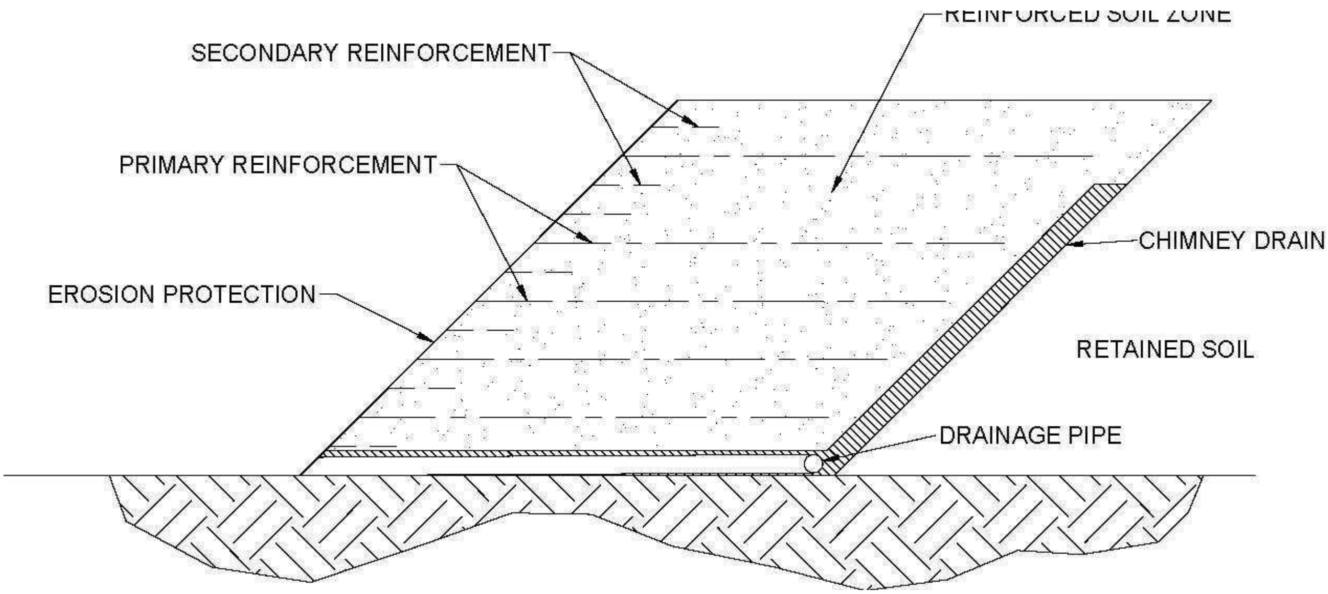
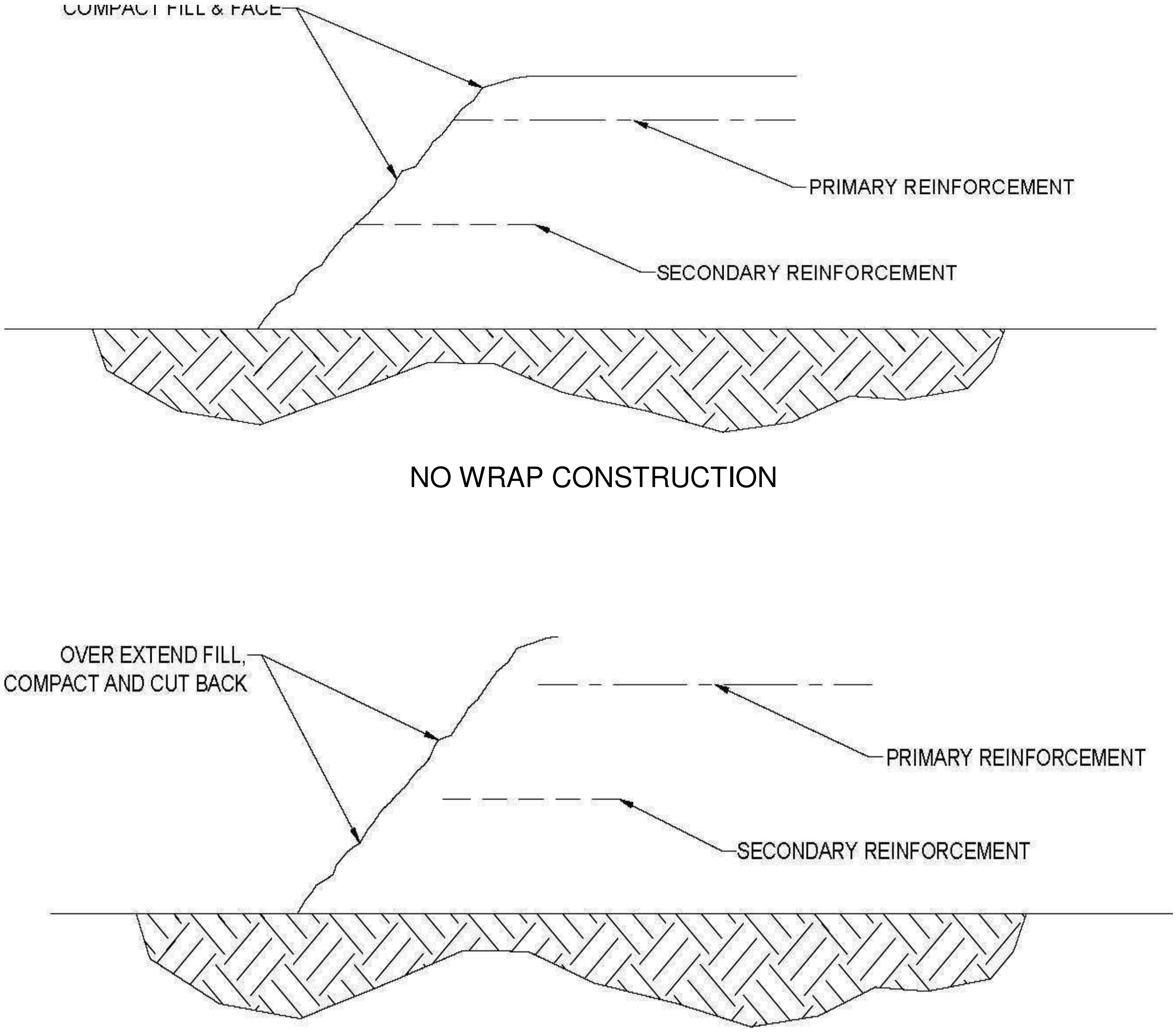


Figure 1. General Cross-Section of a Reinforced Slope System

The stability of a slope can be threatened by erosion due to surface water runoff, or more severe erosive forces associated with water currents and wave attack. Slope face erosion may create rills and gullies, and result in surface sloughing and possibly deep-seated failure surfaces (Berg, 1993). Erosion control and re-vegetation measures must, therefore, be an integral part of all reinforced slope system designs and specifications. General facing systems include 'soft' or vegetated, and 'hard' or armored systems, which may or may not include a geosynthetic face wrap. The purpose of this Technical Note is to provide guidance on the selection of geosynthetic reinforced slope facia systems.

Reinforced Slopes Without a Geosynthetic Wrap Face

A face wrap is generally not required for 1(H): 1(V) slopes or flatter, if the reinforcement (secondary and/or primary) is maintained at a close vertical spacing (Elias et al., 1997). In this case, the reinforcement can be simply extended to the face with subsequent placement of the surficial erosion protection. Alternatively, the slope face may be over-built and subsequently cut back to the desired slope grade. However, care must be taken to prevent damaging the reinforcements at the slope face. Figure 2 illustrates the two typical methods of forming the face of a reinforced slope without a face wrap.



NO WRAP CONSTRUCTION

Figure 2. Face Forming Techniques for Reinforced Slopes Constructed Without a Face Wrap

Reinforced 1(H): 1(V) slopes constructed with most soil types and not subjected to severe erosive forces should be vegetated after construction to prevent or minimize erosion due to rainfall and runoff on the face. A synthetic erosion control mat may be used as a permanent facing, but must be stabilized against ultra-violet light (Elias, 1997). The erosion control mat serves to: 1) protect the bare soil face against erosion until vegetation is established, 2) reduce runoff velocity for increased water absorption by the soil, thus promoting long-term survival of the vegetative cover, and 3) reinforce the root system of the vegetative cover (Berg, 1993).

For reinforced slopes subjected to severe erosive forces associated with water currents and wave attack, the erosion protection system must be specifically designed to resist these forces. Typically, these severe cases will require a 'hard' armor erosion protection system such as riprap, gabions, articulating concrete blocks, or fabric-formed concrete. A geosynthetic face wrap is not generally incorporated, however, a geotextile filter should be placed along the slope face, underneath the erosion protection system. Figure 3 shows general cross-sections of reinforced slopes without a geosynthetic wrap.

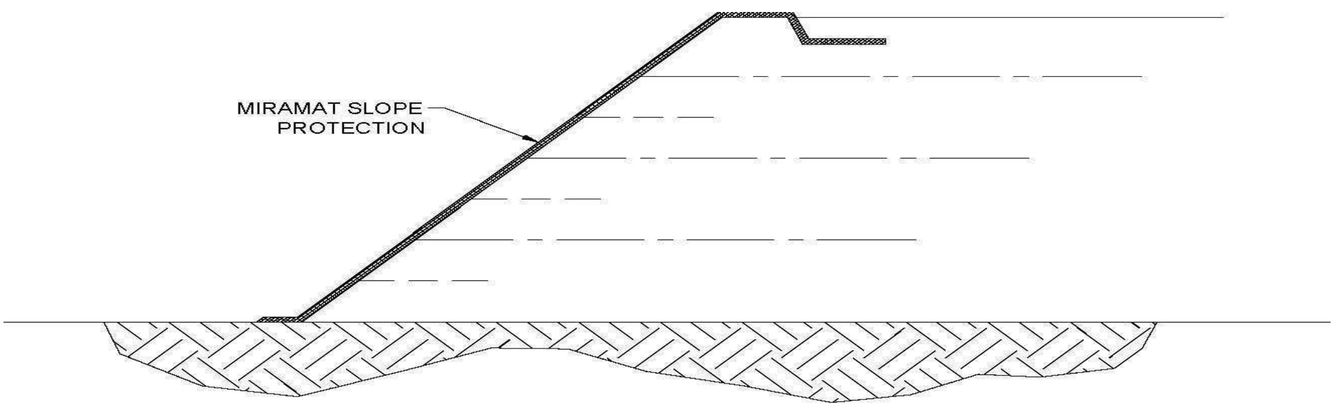


FIGURE 3(a) Miramat TM8 Slope Protection

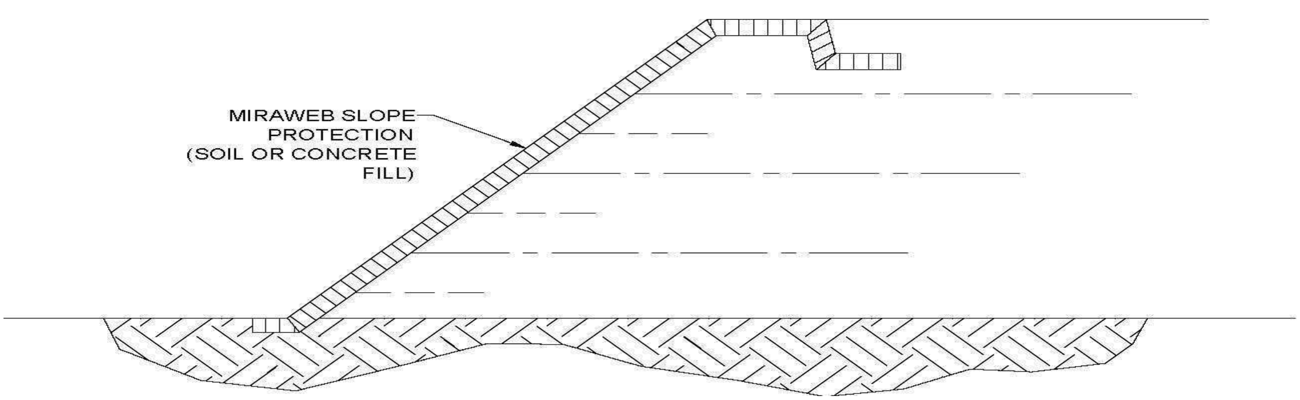


FIGURE 3(b) Miraweb Slope Protection

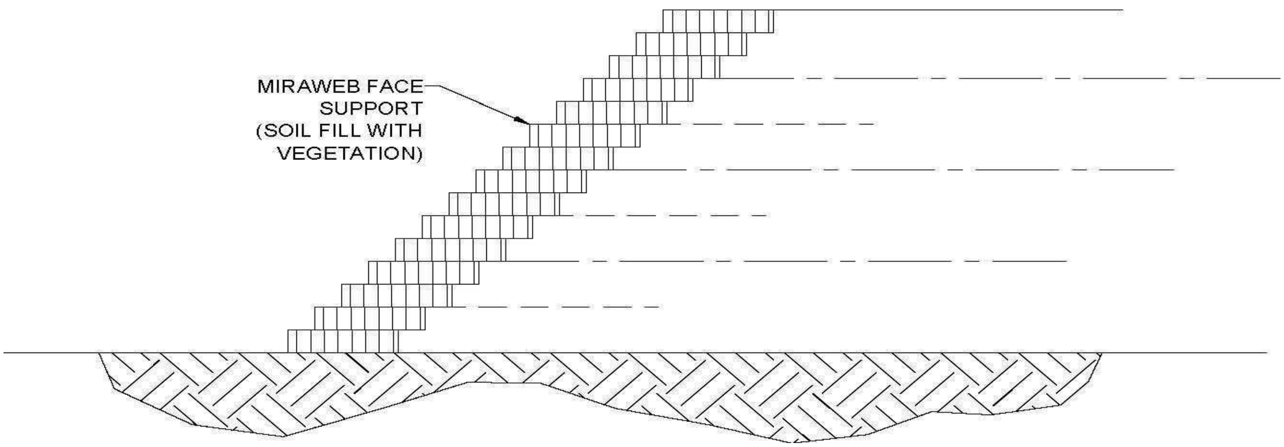


FIGURE 3(c) Miraweb Face Support

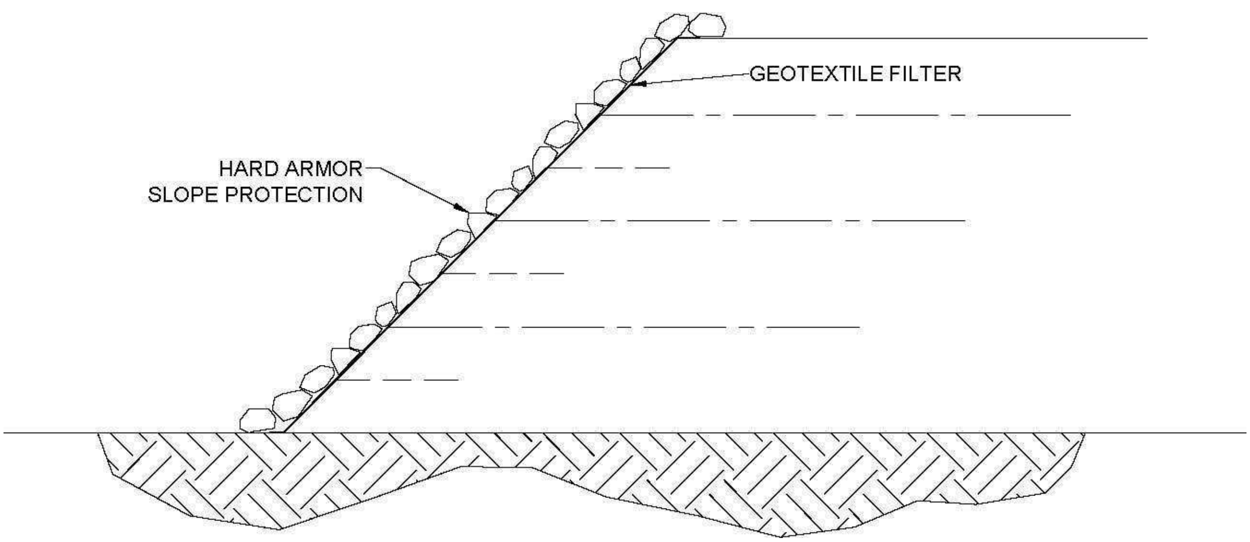
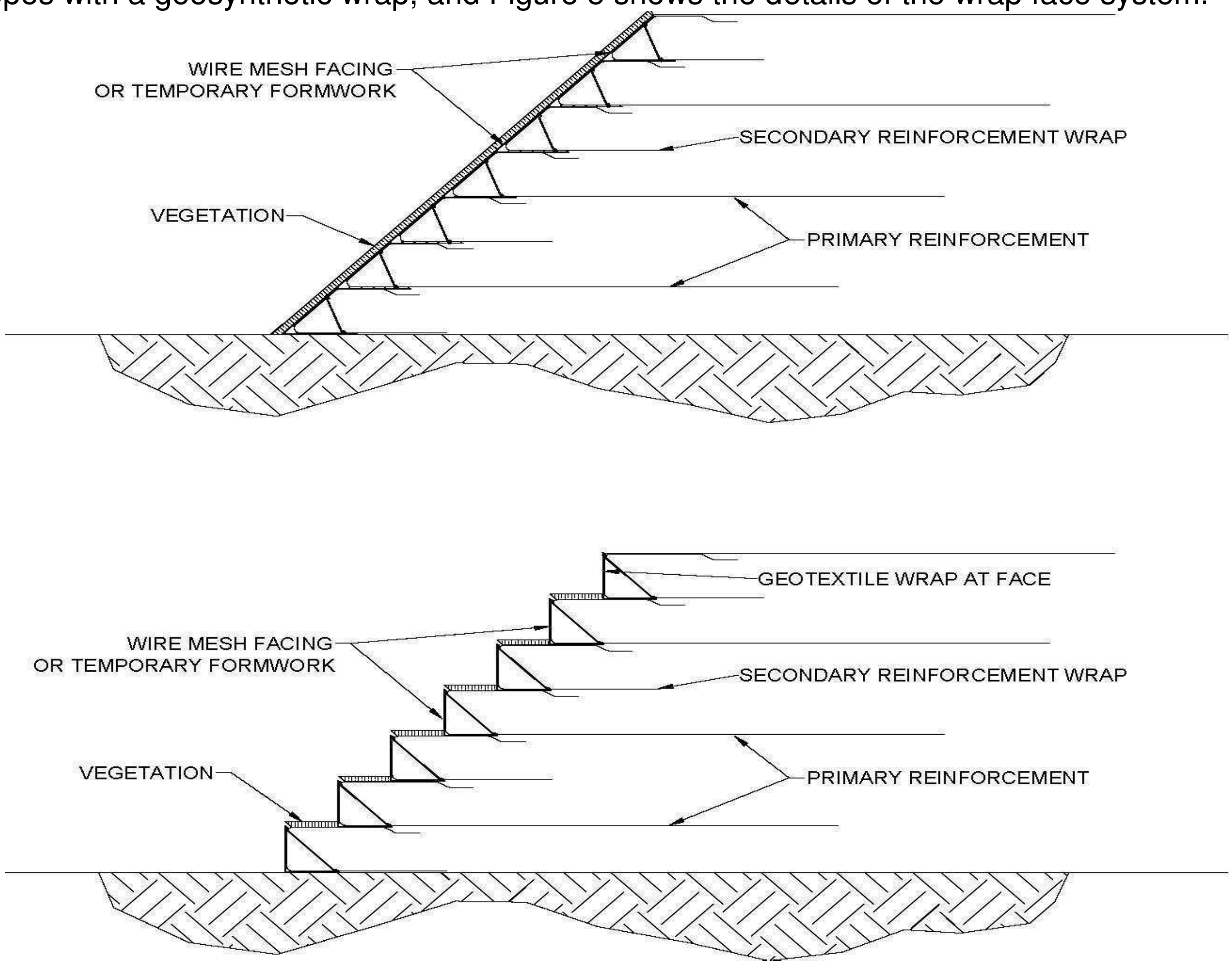


FIGURE 3(d) Hard Armor Slope Protection

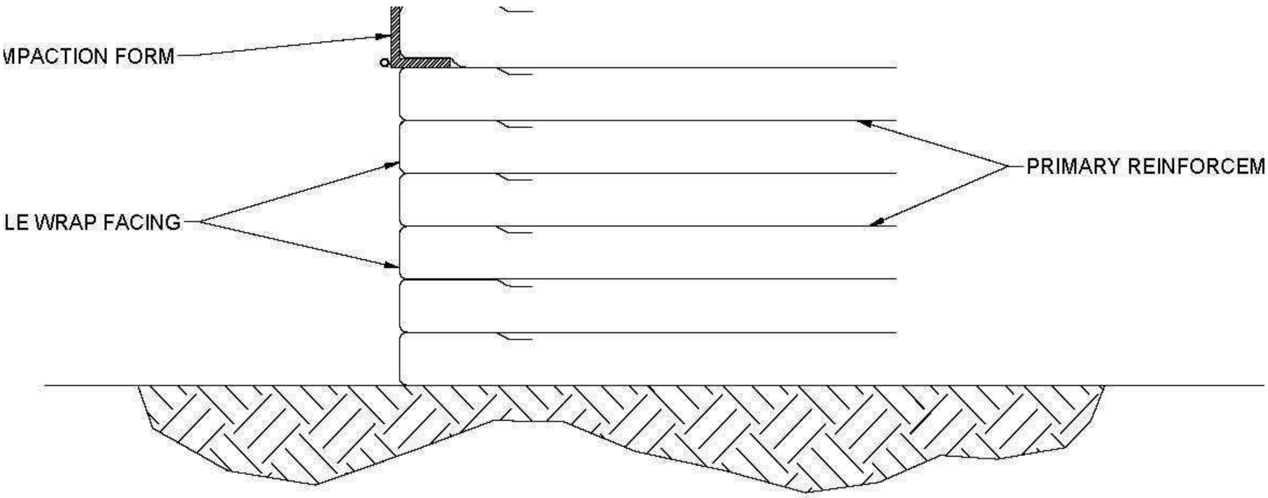
Reinforced Slopes With a Geosynthetic Wrap Face

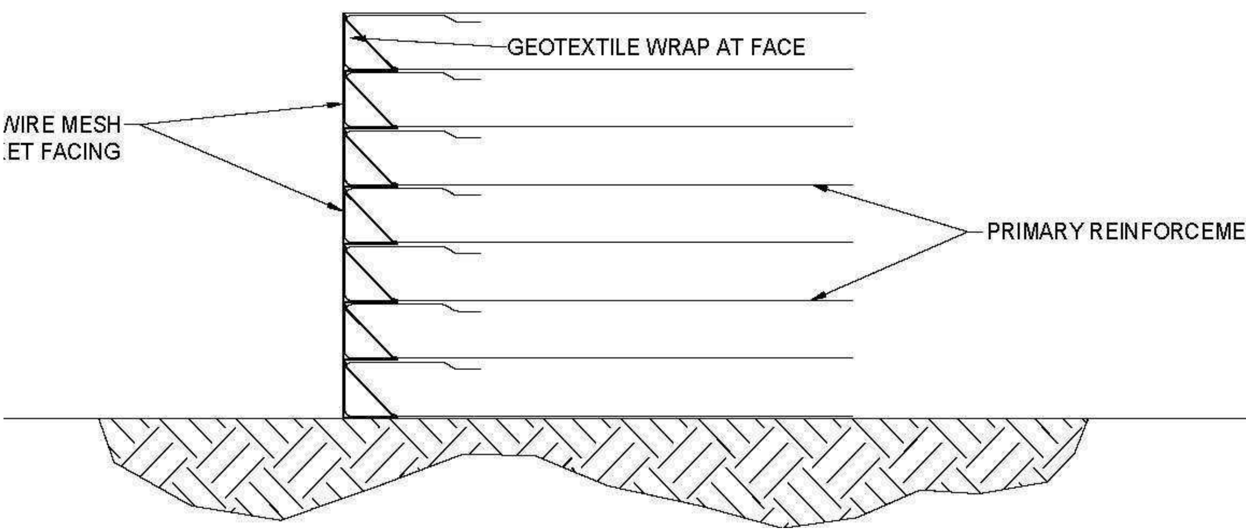
Reinforced slopes steeper than approximately 1(H): 1(V) typically require facing support during construction (Berg, 1993). A geosynthetic face wrap and/or a hard armor facing support system is often used in this application. However, a face wrap and/or a hard armor facing system may be required when constructing a 1(H): 1(V) slope with silts and poorly graded sands and gravels, or if the slope face is subjected to external erosive forces associated with mild water currents and/or wave attack. When wrapping the slope face, a permanent facing such as gunite or emulsified asphalt may be applied or vegetation developed to provide long-term ultra-violet light protection.

In wrapping the face of a slope, removable facing supports (e.g. wooden forms) or left-in-place welded wire mesh forms are typically used, especially if the lift thickness is 18 inches (450 mm) to 24 inches (600 mm) or greater (Elias et al., 1997). The recommended maximum lift thickness depends on the angle of reinforced lift. For instance, vertical lift construction of a 'stepped' slope face should require a maximum lift thickness of 18 inches (450 mm). Whereas, a maximum lift thickness of 24 inches (600 mm) is recommended for 0.5(H): 1(V) slopes, or flatter, with face support. In wrapping the slope face, the reinforcement is turned up at the face and returned a minimum of 3 feet (1 meter) into the embankment below the next reinforcement layer (Elias et al., 1997). Further, when wrapping a slope face with a geogrid, a geotextile filter may be required at the face to retain backfill soils, particularly for slope lifts steeper than 1(H): 1(V). Figure 4 shows general cross-sections of slopes with a geosynthetic wrap, and Figure 5 shows the details of the wrap face system.



(4a) Sloping Face with Wire Mesh





(4b) Vertical Lifts with Wire Mesh or Wooden Formwork

Figure 4. General Cross-Sections of Reinforced Slopes With a Geosynthetic Wrap

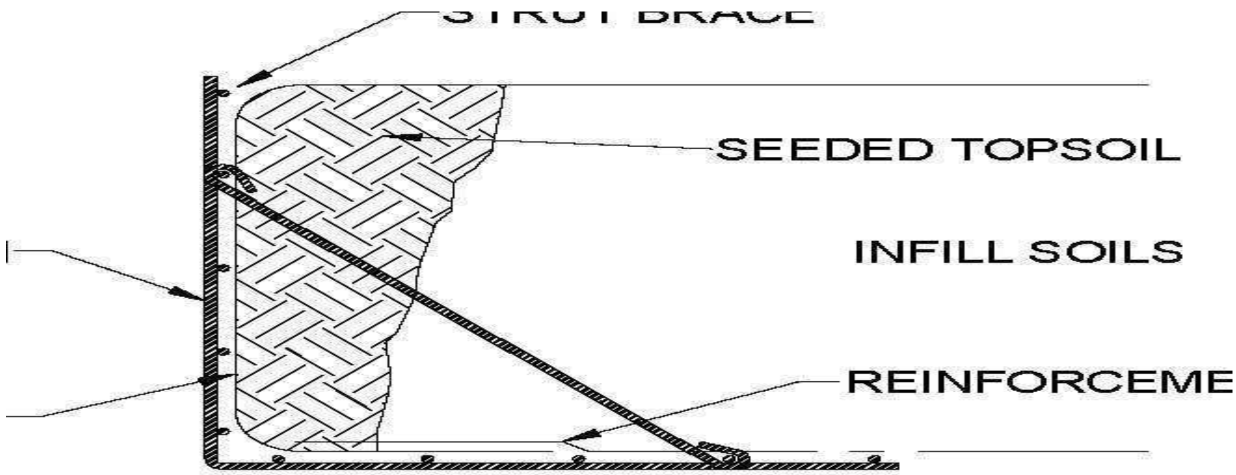


FIGURE 5(a)

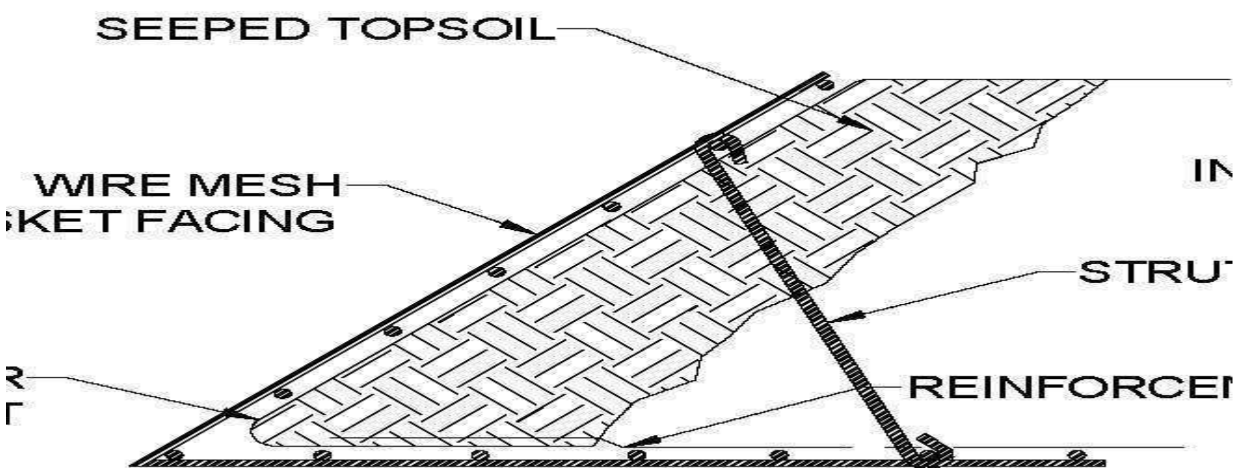


Figure 5. Facing Details for Wrapped-Face Construction

In assessing these various slope face options, there are several considerations. For instance, using a wire mesh face support will typically result in higher material costs, yet lower labor costs than using temporary wooden formwork. However, the wire mesh may provide additional long-term face protection from ultraviolet light degradation and potential vandalism. Further, the use of temporary wooden formwork will require access from the exterior of the slope face in order to insert and remove forms. Finally, compaction difficulties near the slope face may arise when constructing a sloping wrap-faced system, particularly for slopes flatter than 0.5(H): 1.0(V).

Facing System Recommendations
As discussed herein, slope facing system requirements depend on soil type, slope angle, and reinforcement spacing. Table 1 has been modified from its original version to incorporate TC Mirafi products.

Table 1. Reinforced Slope Facing Options (from Elias et al, 1997)

Soil Face Angle and Soil Type	Vegetated Face w/out Geosyn. Wrap	Hard Facing w/out Geosyn. Wrap	Vegetated Face with Geosyn. Wrap	Hard Facing with Geosyn. Wrap
> 1(H): 1(V) All Soil Types	Not Recommended	Miraweb	Miramesh GR w/seed or sod	Wire Baskets Stone Shotcrete
1 - 1.5(H): 1(V) Poorly Graded Sands and Gravels (SP, GP)	Not Recommended	Miraweb	Miramesh GR w/seed or sod	Wire Baskets Stone Shotcrete
1 - 1.5(H): 1(V) Silts (ML) Sandy Silts (ML)	Miramat TM8 w/ seed or sod	Miraweb	Miramesh GR w/seed or sod	Wire Baskets Stone Shotcrete
1 - 1.5(H): 1(V) Silty Sands (SM) Clayey Sands (SC) Well Graded Sands and Gravels (SW, GW)	Miramat TM8 w/seed or sod	Hard Facing Not Needed	Geosynthetic Wrap Not Needed	Geosynthetic Wrap Not Needed
1.5 - 2.0(H): 1.0(V) All Soil Types	Miramat TM8 w/seed or sod	Hard Facing Not Needed	Geosynthetic Wrap Not Needed	Geosynthetic Wrap Not Needed

Secondary Reinforcement

Secondary reinforcement may be required at the face of reinforced slopes. Need is dependent upon soil type, slope angle, slope height, and primary reinforcement spacing. Secondary reinforcement should be placed in continuous layers and does not need to be as strong as the primary reinforcement, but it must be strong enough to survive construction and provide localized tensile reinforcement to the surficial soils (Elias et al. 1997). These intermediate, or secondary, layers of reinforcement aid in achieving compaction at the face, thus increasing soil shear strength and resistance to erosion (Berg 1993). These layers also act as reinforcement against shallow or sloughing types of slope failures. Secondary reinforcement is typically placed on each or every other soil lift, except at lifts where the primary reinforcement is placed. Secondary reinforcement is also placed at the same elevation as the primary reinforcement, when primary reinforcement is placed at less that 100% coverage in plan view. Typically, secondary reinforcement extends 3 to 5 feet back in the fill, from the face. However, longer lengths may be required if large seepage forces at the face are likely to develop. Table 2 provides typical vertical spacing and embedment lengths for secondary reinforcement. A detailed analysis may be performed using the method described by Thielen and Collin (1993) for critical applications or where large seepage forces may develop.

Table 2. Typical Secondary Reinforcement Design References

Soil Face Angle and Soil Type	Embedment Length ft (m)	Vertical Spacing ft (m)
Vertical	3.0 (1.0) *wrap-back length	1.5 (0.45) *w/face support
0.5(H): 1.0(V) All Soil Types	4.0 (1.2) *wrap-back length	2.0 (0.6) *w/face support
1.0(H): 1.0(V) All Soil Types	4.0 (1.2)	1.0 (0.3) *w/no face support
1.5(H): 1.0(V) Silts (ML) Poorly graded sands and gravels (SP, GP)	4.0 (1.2)	1.0 (0.3)
	5.0 (1.5)	1.5 (0.45)
1.5(H): 1.0(V) Silty Sands (SM) Clayey Sands (SC) Well graded sands and gravels (SW, GW)	5.0 (1.5)	1.5 (0.45)
	6.0 (1.8)	2.0 (0.6)
2.0(H): 1.0(V) All Soil Types	6.0 (1.8)	2.0 (0.6)

References:

Berg, Ryan R. (1993), Guidelines for Design, Specification, and Contracting of Geosynthetic Mechanically Stabilized Earth Slopes on Firm Foundations, Federal Highway Administration, Publication No. FHWA-SA-93-025.

Elias, V., and Christopher, B.R., (1997), Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Design and Construction Guidelines, Federal Highway Administration, Demonstration Project 82, Publication No. FHWA-SA-96-071, Washington, D.C., August.

Thielen, D.L., and Collin, J.G. (1993) "Geogrid Reinforcement for Surficial Stability of Slopes", Geosynthetics '93 Conference Proceedings, pp. 229-241, Vancouver, Canada.

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