SIERRASCAPE® SYSTEM DESIGN GUIDE

“Facing Stability Considerations”
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EXECUTIVE SUMMARY

Tensar Earth Technologies, Inc. (TET) pioneered the use of geosynthetic-reinforced slopes and flexible wire-faced walls. Since their introduction, these structures have demonstrated exemplary performance. This success has lead to a constant increase in acceptance and the widespread use of “soft” mechanically stabilized earth (MSE) structures. Moreover, the trend among owners and their engineers is toward requiring contractor or supplier design based on loose performance specifications. This trend, while cost effective and efficient in the bidding and construction phase, encourages use of the “low-cost” supplier. In general, these “low-cost” suppliers are able to provide materials that produce a globally stable MSE structure over the design life.

However, most performance-based specifications do not force suppliers to consider surficial stability in their designs. Hence, more and more of these “low-cost” MSE slopes and walls are experiencing surficial failures. Although surficial failures do not generally threaten the overall structural integrity of the system, they are costly to repair, aesthetically unappealing, and reduce general public confidence in MSE systems.

The primary purpose of this technical note is to provide owners and their engineer’s guidance to ensure proper consideration of surficial stability in specifications involving “soft” MSE systems (slopes and flexible faced walls).
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1.0 INTRODUCTION

1.1 Problem Statement

Flexible-faced mechanically stabilized earth (MSE) wall and slope structures are widely used due to their economy, appearance and tolerance of settlement. Materials used as facing range from stone filled gabion baskets to geotextile wrapped soil to simple vegetation (on relatively flat slopes). Steel welded wire mesh is widely used. The facing wire mesh can be an extension of the soil reinforcement, an L-shaped section where the horizontal leg extends a short distance into the reinforced soil mass, a gabion basket, or a planer face anchored to the reinforced soil mass. These types of MSE structures are generally designed using conventional wall and/or slope design methods to determine the soil reinforcement requirements. These accepted design methods do not address the structural requirements for the facing and for the connection of the facing to the soil reinforcement. As a result, facing materials and configuration, as well as facing connections to soil reinforcement, have been developed largely by trial and error.

1.2 Purpose

The purpose of this Tensar® Technical Note is to provide an understanding of surficial/facing stability of MSE slope and wall structures and to present methods for analysis and design of the connection between soil reinforcement and flexible facing.

1.3 Content

This technical note provides guidance for proper evaluation and design of flexible faced MSE systems. This guidance is written to allow the user to leverage the unique benefits of TET’s SierraScape Wire-Formed Retaining Wall System (namely the positive, mechanical connection). However, the concepts and methodology presented are applicable to all flexible-faced MSE structures.

The SierraScape System is described in Section 2. The surficial stability of reinforced soil slope (RSS) structures is addressed in Section 3. The facial stability of MSE wall (MSEW) structures is covered in Section 4.
2.0 SIERRASCAPE SYSTEM

2.1 General Description

The SierraScape System is a cost-effective alternative to traditional concrete walls for steep grade-separation projects. The system also provides lower maintenance alternatives to generic reinforced slope technologies. This unique, flexible MSE system is the best solution for a range of applications in terms of appearance, performance, and value.

In contrast to the stark appearance of most concrete walls, the SierraScape System’s wire-formed facing can be vegetated to blend naturally with the surrounding environment, or filled with stone to create a lower cost, armored facing. The SierraScape facing units may be erected to form a stair-stepped or a smooth face.

2.2 Range of Face Angles

The SierraScape System may be constructed at face angles up to 90° to fit project conditions. Traditionally, the design of MSE structures is performed following either retaining wall or reinforced slope analysis and design techniques. Per Federal Highway Administration (FHWA), MSE structures with a slope angle greater than or equal to 70° are designed as retaining walls, and structures at an angle of less than 70° are designed as reinforced soil slopes. This distinction is followed within this technical note.

2.3 Components of a SierraScape Structure

A SierraScape MSE structure consists of the following components, as illustrated in Figure 1: (a) primary reinforcement, (b) secondary reinforcement, (c) reinforced soil fill, and (d) SierraScape welded wire mesh facing units (e) with support struts. A (f) subsurface drain may be located behind and/or under the reinforced mass.

The primary reinforcement is connected to the facing units with a positive, mechanical connection, as illustrated in Figure 2. This connection ensures facing stability, better resists differential settlement, and offers exceptional performance in areas where soil saturation, seismic activity, and/or heavy external loads are a concern. This connection also provides a visual construction quality control check and better facing alignment control during construction.

Galvanized facing units are typically used in stone-filled facing applications. The welded-wire facing is sized to retain 2- to 4-inch stone as illustrated in Figure 2 (A). Alternately, a layer of (g) Tensar BX1120 Geogrid may be used at the face to retain smaller stone sizes as shown in Figure 2(B). A (h) geotextile filter is required between the stone and finer grained reinforced soil fill. For vegetated face applications the wire facing units provide surficial support during construction and until the root mass is well developed. Galvanized or non-galvanized wire facing units may be used. Where vegetation is anticipated to be well established within 1 to 2 years, a turf reinforcement mat, (TRM), such as TB1000 is used to retain the topsoil and promote vegetation establishment, as illustrated in Figure 3(C). If well-established vegetation is not anticipated within 2 years, a (g) BX1120 Geogrid face wrap is recommended for permanent support of the TRM.
Figure 1. SierraScape MSE Structure
Figure 2. SierraScape Welded-Wire Facing Unit Fill Details
2.4 Facing to Geogrid Connection Strength

Lateral loads on the SierraScape facing units are applied by the weight of the reinforced fill, compaction induced stress, surcharges on the MSE structure, seismic acceleration and, for slopes with vegetated soil fill, possibly hydrostatic pressure. These loads are transferred from the horizontal wires of the facing unit to the geogrid reinforcement through the mechanical connection. The connection loops at the end of each 0.192 inch diameter horizontal wire of the facing unit engage the cross bar of the geogrid through alternate apertures. Theoretically, these lateral loads on the facing could cause tensile failures of the wire in front of the connection, of the geogrid behind the connection, or of the wire or geogrid at the connection. These potential failure planes are illustrated in Figure 3 as planes A-A, B-B and C-C respectively.

![Figure 3. Theoretical Failure Planes for a Welded-Wire Facing Unit](image)

The following analyses of these potential failure planes have been conducted for the SierraScape System:

- For failure planes in front of the connection, the force resisting the lateral load on the facing is equal to lesser of the long-term (considering corrosion) tensile strength of the horizontal steel wires of the facing unit, or the pullout resistance of the horizontal wires plus the rupture strength of the facing unit-geogrid connection.

- For failure planes behind the connection, the resisting force is equal to the lesser of the long term tensile strength of the geogrid soil reinforcement, or the combined strength of the connection and the pullout resistance of the geogrid transverse bars; whichever is lowest.

- The resisting force at the connection is equal to the long-term rupture strength of the connection determined by laboratory testing.

These analyses show that for the SierraScape system, the connection strength is critical. Therefore, the facing stability analyses methods set forth in the following sections are focused on the strength and loads at the connection. For other systems, the three-part analysis outlined above should be conducted.
3.0 SLOPE STRUCTURES, SLOPE FACE ANGLE < 70°

3.1 MSE Mass Stability

The techniques used for analysis of Tensar MSE slopes, (also known as Reinforced Soil Slopes, RSS) are extensions of routine slope stability procedures developed for unreinforced slopes. In general, the analyses consist of defining a potential failure surface within the slope, calculating the driving forces due to gravity, seismic, surcharge loads and hydrostatic pressures that tend to cause shear failure along the surface, and calculating the resisting forces available from the soil shear strength and the strength of any reinforcement. The factor of safety is defined as the ratio between resisting and driving forces and/or moments. The process is repeated for other potential failure surfaces. The surface with the lowest factor of safety is termed the “critical” failure surface. The surfaces analyzed may pass through the reinforced soils as well as unreinforced soil behind or under a reinforced zone. Circular failure circles are most commonly assumed for slopes and embankments. Other surfaces may be applicable for special situations, for instance where there are thin deposits of relatively weak soil a planar failure surface is appropriate.

An MSE slope design involves the determination of the number of reinforcement layers, the required tensile strength of each layer and the lengths of each layer that are required to develop a required minimum factor of safety against a shear failure along all potential failure surfaces. Slope stability computer programs are used to perform the complex computations for the hundreds to thousands of potential failure surfaces that must be analyzed. There are several commercial programs available that can analyze geogrid reinforced slopes. TET routinely uses the “GSLOPE” program. GSLOPE uses the Simplified Bishop Method of Slices to analyze circular failure surfaces. The Bishop Method analyzes slopes consisting of different soil types, irregular geometries, complex ground water and pore water pressure conditions, seismic accelerations and, of course, geogrid reinforcement.

The FHWA recommends the use of Simplified Bishop Method of Slices stability for analysis and design of RSS. Thus, for SierraScape structures with a face slope angle of less than 70° the external stability factor of safety computations for compound and global failure modes and the internal stability factor of safety computations for soil reinforcement strength and vertical spacing are designed per FHWA RSS design methodology.
3.2 Surficial/Facial Stability

The computer programs used for overall slope stability design are not well suited for the analysis of the effect of the facing-to-reinforcement connection strength on stability of the slope face. Surficial stability can, however, be easily analyzed using “infinite slope” theory as is recommended by FHWA.

The infinite slope method considers the stability of a thin block, or wedge, of soil near the slope face that could slide along a failure plain oriented parallel to the slope face. For a SierraScape slope using a stepped-face configuration, the potential failure plane through the connections is parallel to the effective slope face angle as illustrated in Figure 4. The gravity and seismic forces that would cause the soil wedge to slide are resisted by the shear strength of the soil and the tensile strength of the reinforcement that connects the wedge to the soil mass behind the potential failure plane. The factor of safety for surficial stability at the SierraScape connection is the ratio of the resisting forces to the driving forces. Forces and geometry are shown in Figure 5. For saturated slopes, the hydrostatic pressures increase the driving forces and decrease the resisting forces.

![Figure 4](image-url)

**Figure 4. Effective Slope Angle of a Stepped-Face Structure.**

Application of the unreinforced infinite slope stability equation to RSS is documented in the following sections. Equations are presented for calculating loads and factors of safety at the SierraScape connection for static, seismic, dry and saturated conditions. Example design calculations for combinations of these conditions are available as separate publications, (see www.tensarcorp.com).

As noted above, the FHWA recommends the use of infinite slope stability analysis of the outer face of RSSs. **Thus, for SierraScape structures with a face slope angle of less than 70°, the surficial/facial stability factor of safety computations follow FHWA RSS design guidelines.**
Where:

- $h$ = vertical height of failure wedge
- $c'$ = effective soil cohesion
- $w$ = perpendicular width of failure wedge
- $f'$ = effective soil friction angle
- $l$ = length of failure plane
- $T_g$ = tensile reinforcement force
- $z$ = vertical depth to failure plane
- $W$ = total weight of failure wedge
- $x$ = horizontal distance to failure plane
- $N'$ = resultant effective normal force
- $N$ = total normal force
- $\beta$ = slope angle, from horizontal

Figure 5. Surficial Slope Stability Analysis Dimensions and Forces.

### 3.2.1 Computation of Facing Forces

The driving force, $F_d$, is the component of the “total” weight of the wedge that acts in a downward direction, parallel to the failure plane and slope face. The “total” weight is equal to the volume of the wedge times the saturated or moist unit weight. $F_d$ is calculated for a unit width of slope and is equal to:

$$ F_d = \{s \cdot hx\} \sin \theta \quad \text{or} \quad F_d = \{m \cdot hx\} \sin \theta $$  \hspace{1cm} (1)

Where

- $\theta = \text{saturated unit weight}$
- $\theta_m = \text{moist unit weight}$
The force resisting sliding of the wedge, \( F_{rs} \), that is contributed by the shear strength of the soil has a frictional component and possibly a cohesive component. The frictional component is a function of the “effective” normal pressure on the potential failure plane. For saturated soil at and above the failure plane, the effective pressure is calculated using the effective, or buoyant, unit weight of the saturated soil. For unsaturated conditions, effective unit weight is equal to total unit weight. \( F_{rs} \) acts in an upward direction, parallel to the potential failure plane and slope face, and is equal to:

\[
F_{rs} = c'l + \{ (\bar{g}_s \bar{g}_w) \times h \} \cos \theta \tan \phi \text{ or } c'l + \{ m \times h \} \cos \theta \tan \phi
\]

(2)

Two forces resisting sliding are developed by the tensile force the geogrid reinforcement, \( F_{rg} \). One force is the component of the tensile load parallel to the failure plane. The other is added frictional strength in the soil that is mobilized due the normal component of the tensile load in the geogrid. Both forces act in an upward direction, parallel to the potential failure plane and slope face. The combined reinforcement load is equal to:

\[
F_{rs} = F_{rg} (\cos \theta + \sin \theta \tan \phi)
\]

(3)

Where

\( F_{rg} = \) reinforcement force, equal to the long-term connection strength for the SierraScape system.

In general cases where a mechanical connection is not involved, \( F_{rg} \) is the lesser of reinforcement long term design strength or the pullout capacities available in the passive and active zones.

3.2.2 Facing Stability Factors of Safety for SierraScape Slopes

3.2.2.1 Static Conditions

The facing stability factor of safety, F.S., is the ratio of the sum of the resisting forces \( F_{rs} + F_{rg} \), to the driving force, \( F_d \), and is equal to:

\[
F.S. = \frac{c'l + \{ (\bar{g}_s \bar{g}_w) \times h \} \cos \theta \tan \phi + F_{rg} (\cos \theta + \sin \theta \tan \phi)}{\{ \bar{g}_s \times h \} \sin \phi}
\]

(4)

The friction angle, \( \phi' \), is for the soil or gravel that the potential failure plane passes through. If the plane is at an interface between two types of materials, use the lower friction angle. If the plane passes through both the reinforced and the facing unit fill in a consistent way due to a specified shape of the facing fill prism, a weighted average strength could be used, however, it may be prudent to design with the lesser of the two shear strengths. The same approaches are applicable to the cohesive component of shear strength, \( c' \). It is, however, common design practice to conservatively ignore cohesive strength, if there is any, in areas near the slope face.

Equation 4 is applicable to a slope where the soil is saturated from the slope surface to a depth below the potential failure plan. For unsaturated conditions, the moist unit weight, \( \bar{g}_m \), is used in lieu of the effective unit weight, \( \bar{g}_e \), and the total unit weight, \( \bar{g}_t \), of saturated soil. For conditions where surficial soils are saturated only to depths above the failure plane, a weighted average of the saturated and moist unit weights should be used in both the numerator and denominator. Where the potential failure plane passes through reinforced and facing unit fill, a weighted average unit weight could be used, but, as suggested above for average shear strength, a design should consider the possibility that more or less facing fill could be used in the slope.
For SierraScape, Equation 4 is used to analyze only the plane at the connection. Therefore the reinforcement tensile force, \( F_{rg} \), is equal to the long term connection strength of the particular geogrid being used and the distance between the face and the connection, \( x \), is equal to approximately 1.5 feet plus half of the setback of the facing units. It should be noted that the form of Equation 4 is slightly different from the equations derived in Reference 5 and included in FHWA Guidelines, Reference 1. The differences are due to the use of width of the failure wedge and length of the failure plane herein versus the use of depth of the failure plain and height of the failure wedge in the references. Factors of safety calculated by the respective equations are the same.

3.2.2.2 Seismic Conditions

For pseudostatic seismic analyses of slopes, it may be assumed that the full horizontal earthquake load component is critical and, therefore, the vertical component of seismic load can be conservatively ignored. The weight of the soil or rock mass within the facing unit in front of the connection plane and in the tributary area above and below the reinforcement is multiplied by the horizontal pseudostatic acceleration coefficient, \( k_h \). With this assumption, the horizontal seismic load is included in both the numerator of the stability equation, where it decreases the normal load, thus decreasing the frictional resistance to sliding, and in the denominator where it increases driving forces. A lower safety factor of 75% of static, or F.S. = 1.10, is normally used for design.

The surficial stability factor of safety for seismic conditions is equal to:

\[
F.S. = \frac{c'l + \{(l) \times xh \} \cos \theta \tan \theta \{kh\} k_h \sin \theta \tan \theta + F_g \left( \cos \theta + \sin \theta \tan \theta \right)}{\{kh\} (\sin \theta + k_h \cos \theta)}
\]  

(5)

Where
\[
k_h = \frac{a_h}{g} = \text{seismic coefficient}
\]
\[
a_h = \text{horizontal pseudostatic acceleration}
\]
\[
g = \text{gravitational acceleration}
\]

3.3 RSS Design Steps

The following steps are used to design reinforced slopes. (Note: A design worksheet listing these steps and a SierraScape Surficial Slope Stability Analysis spreadsheet are available at www.tensarcorp.com.)

1. Define soil zones and properties
2. Define geometry
3. Define long-term connection strengths
4. Determine depth of trial failure plane(s)
5. Define analysis cases
6. Compute factors of safety
STEP 1. DEFINE SOIL ZONES AND PROPERTIES
   1.a  Reinforced Soil Fill – $\phi$, $c'$, $\phi_b$, and $\phi_s$
   1.b  SierraScape Wire-Faced Fill – $\phi$, $c'$, $\phi_b$, and $\phi_s$

STEP 2. DEFINE GEOMETRY
   2.a  Slope angle, from horizontal – $\beta$
   2.b  Vertical analysis height, $h$. This may be an even reinforcement and face unit increment of the total slope height, or may be equal to the total slope height.
   2.c  SierraScape face unit geometry –
       Vertical Height = 1.5 feet
       Length of Horizontal Leg = 1.5 feet
   2.d  Vertical spacing of geogrid soil reinforcement, by grade and zone of slope.
       Complete the following table (see www.tensarcorp.com for values):

<table>
<thead>
<tr>
<th>Primary Geogrid Grade (Type)</th>
<th>Vertical Spacing</th>
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STEP 3. DEFINE LONG-TERM CONNECTION STRENGTHS
   Define long-term creep rupture connection strengths of the geogrid to wire-faced unit connections, by geogrid grade. Complete the following table (see www.tensarcorp.com):

<table>
<thead>
<tr>
<th>Geogrid Grade (Type)</th>
<th>Long-Term Connection Strength</th>
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STEP 4. DETERMINE DEPTH OF TRIAL FAILURE PLANE
   Compute the depth, $z$, of the failure plane through the connection below the effective slope face. (Note: The SierraScape surficial slope stability spreadsheet calculates the distance from the effective slope face to the connection plane, $x$, and multiplies it by analysis height, $h$, to calculate the weight of the surficial slice)
STEP 5. DEFINE ANALYSIS CASES
Determine which of the following are applicable:
5.a Saturation conditions
  5.a.1 Unsaturated conditions. Yes No
  5.a.2 Depth of saturation defined, in reference to depth Yes No
      of failure plane.
  5.a.3 Assess factor of safety with variable assumed Yes No
      saturation depths.
5.b Soil Cohesion (Note that soil cohesion is usually assumed Yes No
      equal to zero.)
5.c Seismic Loading Yes No

STEP 6. COMPUTE FACTORS OF SAFETY
Calculate long-term stability factors of safety for potential failure of the wire and geogrid connection.
6.a.1 Unsaturated conditions.
6.a.2 Depth of saturation, defined as above, at or under the connection.
6.a.3 Variable saturation depths, failure plane at saturation depth.

If values of safety factors are too low; adjust
reinforcement layout (Step 2.d) and repeat Step 6.
4.0 WALL STRUCTURES, WALL FACE ANGLE $\geq 70^\circ$

4.1 MSE Mass Stability

The techniques used for design of Tensar MSE walls are extensions of routine MSE retaining wall design procedures. TET recommends the use of elements of the National Concrete Masonry Association, (NCMA), methodology for the design of the geosynthetic reinforcement in SierraScape MSE structures having a face slope angle $\geq 70$ degrees. The NCMA methodology, based on limit equilibrium, addresses the internal and external potential modes of failure. The design for internal stability determines the strength, spacing, and minimum length of the geosynthetic reinforcement layers required to support the self-weight and seismic loads of the reinforced mass and surcharge loads applied to it. The internal stability design considers the long-term tensile strength of the geosynthetic and its resistance to sliding over and pulling out from the soil. It assures that the reinforced mass will act as a monolithic block that has a suitable factor of safety against internal shear failures. The design for external stability examines the stability of the monolithic block under the gravity, seismic and surcharge loads applied to it as well as the bearing capacity available from the foundation soil. The external design assures that the reinforcement layers are sufficiently long to prevent sliding or overturning of the MSE structure or a bearing capacity failure in its foundation. Compound or global failure modes are generally addressed using slope stability methodology. The potential problems of settlement of an MSE structure due to compression of its foundation or hydrostatic and seepage pressures due to saturation of the soil should also be considered by designers. Such problems are outside the scope of NCMA methodology.

Thus, for SierraScape structures having a slope angle equal or greater than 70 degrees, NCMA methodology is used to determine the soil reinforcement strength, length and vertical spacing required to provide adequate internal and external factors of safety.

4.2 Surficial/Facial Stability

The techniques used for analysis of the outer face of SierraScape Walls are based upon stiffness methods, which consider stiffness of the reinforced soil mass and stiffness of the facing elements. These methods are most appropriate for flexible facing systems such as SierraScape. TET recommends using the Washington State Department of Transportation’s (WSDOT) $K_o$-Stiffness Method to determine the loads in the geogrid reinforcement near the face, in the wire of the facing unit, and in the connection between these elements. It is felt that this method, which is based upon empirical data, provides a better estimate of reinforcement loads near the face of an MSEW.

Thus, for SierraScape wall structures having a slope angle equal or greater than 70 degrees, WSDOT $K_o$-Stiffness methodology is used to evaluate surficial facing stability.
4.2.1 Computation of Facing Forces

The $K_o$-Stiffness method for calculating loads in the facing components is performed per WSDOT $K_o$-Stiffness design methodology\(^3\).

The load in each layer of reinforcement near the wall face is calculated with the following formula:

$$T_{\text{max}} = 0.5 S_v K_o (H + S) D_{\text{t max}} S_{\text{local}} f_{\text{fb}} f_{\text{fs}} 0.25 \frac{S_{\text{global}}}{p_a}$$

(6)

Where

- $S_v$ = tributary area
- $K_o$ = at-rest lateral earth pressure = $1 - \sin \theta'$, ($\theta'$ = the peak friction angle of backfill)
- $H$ = vertical wall height
- $S$ = surcharge in terms of equivalent soil height
- $D_{\text{t max}}$ = distribution factor, function of depth from top of wall
- $S_{\text{local}}$ = local stiffness factor
- $f_{\text{fb}}$ = facing batter factor
- $f_{\text{fs}}$ = facing stiffness factor
- $S_{\text{global}}$ = global reinforcement stiffness
- $p_a$ = atmospheric pressure (constant = 101 kPa = 2117 psf)

The global stiffness, $S_{\text{global}}$, considers the stiffness of the reinforcement in the entire wall section, and it is calculated as follows:

$$S_{\text{global}} = \left(\frac{J_{\text{ave}}}{H/n}\right) = \sum_{i=1}^{n} \frac{J_i}{H}$$

(7)

Where

- $J_{\text{ave}}$ = average tensile modulus of all the reinforcement layers within the entire wall section
- $J_i$ = tensile modulus of an individual reinforcement layer
- $H$ = total wall height
- $n$ = number of reinforcement layers within the entire wall section.

The local stiffness considers the stiffness and reinforcement density at a given layer and is calculated as follows:

$$S_{\text{local}} = \frac{J}{S_v}$$

(8)

Where

- $J$ = tensile modulus of an individual reinforcement layer
- $S_v$ = vertical spacing of the reinforcement layers near a specific layer
The local stiffness factor, $f_{\text{local}}$, is then defined as follows:

$$f_{\text{local}} = \frac{S_{\text{local}}}{S_{\text{global}}}$$

(9)

Where $a$ = a coefficient that is also a function of stiffness. Observations from the available data suggest that setting $a = 1.0$ for geosynthetic walls is sufficiently accurate.

The wall face batter factor, $f_{\text{fb}}$, which accounts for the influence of the reduced soil weight on reinforcement loads, is determined as follows:

$$f_{\text{fb}} = \frac{K_{\text{abh}}}{K_{\text{avh}}}$$

(10)

Where

- $K_{\text{abh}}$ = horizontal component of Coulomb active earth pressure coefficient considering wall face batter
- $K_{\text{avh}}$ = horizontal component of the active earth pressure coefficient for a vertical wall. This assumes that the wall is vertical and $d$ equals a constant coefficient (recommended to be 0.5 based on empirical data).

The facing stiffness factor, $f_{\text{fs}}$, was empirically derived to account for the significantly reduced reinforcement stresses observed for geosynthetic walls with segmental concrete block and propped panel wall facings. On the basis of data available(3) it is recommended that this value be set equal to 0.5 for segmental concrete block and propped panel faced walls; 1.0 for all other types of wall facings (e.g., wrapped face, welded wire or gabion faced, and incremental precast concrete facings).

The soil reinforcement load distribution factor, $D_{\text{max}}$, was determined empirically from all of the available field wall case histories. This factor is shown in Figure 6 for geosynthetic-reinforced walls. Here $D_{\text{max}}$ is the ratio of $T_{\text{max}}$ in a reinforcement layer to the maximum reinforcement load in the wall, $T_{\text{mxmax}}$. The empirical distributions provided in Figure 6 apply to walls constructed on a firm foundation.

![Figure 6. Distribution of $T_{\text{max}}$ with Normalized Depth Below Top of Wall](image)

Figure 6. Distribution of $T_{\text{max}}$ with Normalized Depth Below Top of Wall(3).
It is recommended that a facing stiffness factor, $F_{fs}$, equal to 0.5 be used for SierraScape walls with stone facing basket fill. Furthermore, a facing stiffness factor, $F_{fs}$, equal to 1.0 is recommended for vegetated, SierraScape walls that have soil fill in the welded-wire facing units. This recommendation is based on actual field instrumentation of a SierraScape structure.

### 4.2.2 Facing Stability Factors of Safety for SierraScape Walls

#### 4.2.2.1 Static Conditions

After wall design using elements of NCMA methodology, compute the maximum reinforcement connection load at each layer of reinforcement with the following equation:

$$T_{max} = 0.5 S, K_o \Delta (H + S) D_{local} f_b f_s 0.25 \frac{S_{global}}{P_a}$$  \hspace{1cm} (11)

Where

- $\Delta = 0.5$ to be used for SierraScape walls with stone facing element fill
- $\Delta = 1.0$ for soil facing element fill

Calculate a factored maximum reinforcement load, at each layer, with the following equation:

$$T_{max f} = (T_{max}) \Box_{EH}$$  \hspace{1cm} (12)

Where

- $\Box_{EH}$ = “load factor” (partial “factor of safety” for the reinforcement load used in the LRFD methodology as recommended by WSDOT)

A $\Box_{EH}$ value equal to 1.65 for geosynthetic reinforcements is recommended in the WSDOT report.

The factored strength in the welded-wire faced components must exceed the factored design load, per WSDOT (Reference 3). For SierraScape, the long term connection strength controls, therefore:

$$T_{max f} \Box_{cr} T_{ac}$$  \hspace{1cm} (13)

Where

- $\Box_{cr}$ = resistance factor (LFRD partial factor of safety for long-term connection strength)
- $T_{ac}$ = long-term connection strength

A $\Box_{cr}$ value equal to 1.65 for geosynthetic reinforced MSEWs is recommended in the WSDOT report. If $T_{max f}$ does not meet this design requirement, the secondary and/or primary reinforcement must be modified.
4.2.2.2. Seismic Conditions

For pseudostatic seismic analyses of MSEW, the tensile loads in the reinforcements and connections are increased (from static loads) by the addition of the earthquake load. It is assumed that the full horizontal earthquake load component is critical and, therefore, the vertical component of seismic load can be conservatively ignored. A lower safety factor of 75% of static, or 1.10, is normally used for design.

The seismic load at the connection for SierraScape MSE walls is estimated in the same way as it is for slopes with facing angles less than 70 degrees. The weight of the soil or rock mass within the facing unit in front of the connection and in the tributary area above and below the reinforcement is multiplied by the horizontal pseudostatic acceleration coefficient.

4.3 MSEW Design Steps

The following steps are used to design MSEW structures (i.e. $\beta \geq 70^\circ$):

1. Define soil zones and properties
2. Define geometry
3. Define long-term connection strengths
4. Define analysis cases
5. Compute connection loads
6. Compute Factors of Safety

STEP 1. DEFINE SOIL ZONES AND PROPERTIES

1.a Reinforced Soil Fill -- $\mathcal{F}$, $c'$, $\mathcal{k}$
1.b SierraScape Facing Unit Fill

STEP 2. DEFINE GEOMETRY

2.a Slope angle, off of horizontal, $\beta$
2.b Vertical wall height, $H$, is the analysis height. Each layer of reinforcement must be analyzed.
2.c SierraScape face unit geometry –
   Vertical Height = 1.5 feet
   Length of Horizontal Leg = 1.5 feet
2.d Vertical spacing of geogrid soil reinforcement, by grade and height of wall. Trial reinforcement layout is based upon NCMA design methodology for internal (without connection check) and external stability. Tabulate layer number and reinforcement grade by distance down from top of wall. Complete the following table (see www.tensarcorp.com for values):
STEP 3. DEFINE LONG-TERM CONNECTION STRENGTHS
    Define long-term creep rupture connection strengths of the geogrid to welded-wire face unit connections, by geogrid grade. Complete the following table (see www.tensarcorp.com):

<table>
<thead>
<tr>
<th>Geogrid Grade (Type)</th>
<th>Long-Term Connection Strength</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

STEP 4. DEFINE ANALYSIS CASES
    For SierraScape walls, the required connection design load is not affected by the shear strength of the face fill as it is considered to be for surficial slope stability design. Therefore, saturation of face fill is not considered in wall design.

    Determine whether seismic loading is applicable.

STEP 5. COMPUTE CONNECTION LOADS
    Use $K_o$-Stiffness Method to compute connection load at each reinforcement layer either manually or with design spreadsheet.

STEP 6. COMPUTE FACTORS OF SAFETY
    Calculate long-term stability factors of safety for potential failure of the wire and geogrid connection for the given reinforcement layout.

<table>
<thead>
<tr>
<th>Layer #</th>
<th>Geogrid Grade (Type)</th>
<th>Distance Below Top of Wall</th>
<th>Connection Load</th>
<th>Connection Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

*If values of safety factors are too low; modify reinforcement layout (Step 2.d) and repeat Step 6.*
5.0 REFERENCES


