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1.0 INTRODUCTION

This submittal introduces the Sierra® Slope Retention System to transportation agencies for review and approval as an alternative earth retention system. Provided herein is a discussion of the history, structural components, design methodologies, performance, experience, and case studies that document that this system meets all current standards for mechanically stabilized earth (MSE) systems. The Sierra System is the natural looking alternative to conventional or precast MSE retaining wall systems (Figure 1.1).

The Sierra Slope Retention System is a complete reinforced soil slope system specifically developed for public transportation applications. The system consists of proven Tensar® Geogrids for soil reinforcement, drainage composite for internal drainage; an Erosion Control System by Tensar Earth Technologies (TET) design based on local soil types, climate, vegetation and slope angle; and the expertise of TET for design and installation. Through a combination of technologies, the Sierra Slope Retention System provides reliable performance backed by years of research and experience on completed projects worldwide.

We request that the Sierra System be approved for use and included as an alternative MSE system for all grade separation requirements including retaining walls on future agency projects.

2.0 SIERRA SYSTEM

2.1 Background

The Sierra System was developed specifically to meet, or exceed, the high standards for MSE systems set by transportation agencies. The Sierra System is an MSE system that includes:

- Tensar Geogrid soil reinforcement
- Drainage Composite
- Erosion Control Systems
- Design and engineering
- On-site technical assistance
- Twenty years of technical expertise and construction experience to handle any site-specific detail, design question, or construction issue

Throughout this manual, we will use the familiar term *Mechanically Stabilized Earth* (MSE) to describe multiple layers of reinforcement inclusions that act as reinforcement within soil fill. FHWA NHI-00-043, 2001 describes the form of MSE that incorporates planar reinforcing elements in constructed earth-slope structures with free inclinations of less than 70°, as *Reinforced Soil Slopes* (RSS).

2.2 History

The Tensar Corporation introduced synthetic structural geogrids in North America and is the recognized leader in geogrid soil reinforcement technology. For over two decades, Tensar reinforced soil slopes have provided a natural and economical alternative to conventional MSE wall systems. The Tensar Corporation offers far more installations and experience than any other enterprise in the industry.

2.2.1 Tensar Structural Geogrids

Tensar Geogrids were developed in the late 1970s by Netlon Limited of Blackburn, England, specifically for permanent reinforcement of soil and aggregate materials. Principal applications are roadway subgrade improvement and base reinforcement, reinforced soil retaining walls, reinforced soil slopes, and embankments constructed over soft ground. The first installation of Tensar Geogrids in the United States was a Tensar reinforced soil slope in 1982 for the Texas State Department of Transportation. Since then, thousands of projects have been completed and are performing successfully. There have been no known failures of Tensar reinforced soil slopes due to failure of the product or technology since its development.

Tensar Geogrids have been manufactured in Morrow, Georgia since 1984.
2.2.2 Erosion Control Systems
The Tensar Corporation has been designing erosion control systems for reinforced slopes since the first installation in North America in 1982 for the Ministry of Transportation - Ontario, Canada. Effective vegetative erosion control systems combine engineered products as well as horticultural technologies. The experience of Tensar Earth Technologies in the design and construction of hundreds of Sierra Slopes, in a wide variety of climates using several types of vegetative systems, is unparalleled in the industry.

2.3 Material Components
Tensar Geogrids, drainage composites and erosion control systems combine to form a safe, reliable, and durable slope system that offers a very cost-effective alternative to retaining walls. Figure 2.1 illustrates a typical Sierra Slope.

Structural geogrids are manufactured through a series of precise steps. The result is a unique material with specific performance capabilities as a soil reinforcing element. Both the Tensar manufacturing process and the Tensar product are covered by U.S. patents.

A brief summary of the manufactured process has been presented by Wrigley:

“A simplified depiction of the manufacturing process is presented in Figure 2.2. Accurately controlled polymer (typically HDPE or PP) sheet is first punched with a precise pattern of holes. This punched sheet is then drawn in the machine, longitudinal direction under closely controlled conditions at a temperature below the melting point of the chosen polymer. This produces either a ‘uniaxial’ geogrid or feed stock for subsequent transverse drawing into a ‘biaxial’ geogrid. The form and performance of these patented products is controlled by the precision of the thickness and holes of the ‘punched’ sheet and the drawing conditions.

In the extruded sheet, the polymer is in the form of essentially randomly arranged small crystallites separated by thin amorphous zones. Most molecules are sufficiently long to pass through several crystallites thus linking them together with strong molecular chains (Wrigley^2). During drawing below melting temperature the crystallites and the molecular chains in the amorphous zones are aligned (oriented) in the direction of draw. The importance of this continuation of molecular orientation into the junction zones on load-bearing performance was recognized in the product patents.”

![Figure 2.1 — Typical Section, Sierra Slope Retention System](image-url)
The Tensar Corporation operates a comprehensive Quality Assurance (QA) program in its manufacturing plant. Quality Control (QC) is independently conducted by a separate department/laboratory.

2.3.2 Drainage Composite
Drainage composite consists of a geotextile bonded to both sides of an integrally formed polyethylene geonet structure with uniform channels, open area, and thickness to assure uniform flow throughout the structure.

2.3.3 Erosion Control System
The erosion control system is generally composed of a combination of long-term nondegradable Turf Reinforcement Mats (TRMs), structural geogrids, SierraScape™ facing elements, geotextile or other approved facing products. These materials can be used alone or in combination.

Tensar Earth Technologies offers two TRM products, TM3000 and TB1000. Each are typically specified for a particular project based on local soil types, climate, vegetation, slope angle, aesthetics, and maintenance considerations. For more information on either product, please see Tensar Earth Technologies’ TRM Brochure. You may order a copy by calling 800-TENSAR-1, e-mailing info@tensarcorp.com, or visiting www.tensarcorp.com.

The typical erosion control system will employ a biotechnical design using engineering technology and horticultural experience that relies on a combination of geosynthetic materials as well as vegetation to create a stable and aesthetic slope facing system. To address these issues and provide a design that will function well under local environmental conditions, Tensar has consulted with landscape architects experienced in providing local and regional designs for plant selection, landscape design, and erosion control solutions for the Sierra Slope Retention System. Sierra Slope erosion control systems typically will specify products from a list of pre-approved systems. Vegetation options to provide a complete and stable facing solution can be specified by the agency or by Tensar, but supply of the vegetation is by others.

2.4 System Supply
The Sierra Slope Retention System is a complete package system, including materials, engineering design and on-site technical assistance. All material components are proven, and are provided with quality assurance documentation.

2.5 System Approval
The recent growth of geosynthetic reinforcement types and suppliers of such geosynthetics requires consideration of different alternatives prior to preparation of contract documents so that contractors are given clear direction as to which systems are acceptable. The FHWA has outlined proposed guidelines for the review and approval of reinforced slope systems. The following sections are based on those recommendations.

A) A supplier or their representative requests in writing prior to bid to be placed on this list.

B) The Agency approves the system and the supplier based upon the following considerations:
   i) The geosynthetic reinforcement, drainage details, and erosion control system for the system be reviewed and approved for use as a complete system.
   ii) The supplier must have a large enough operation and necessary experience to supply and support the construction on a timely basis.
Because the proposed applications are for critical structures, past experience in construction must be documented. Suppliers shall provide certificate of insurance showing adequate professional engineers “Errors and Omissions” insurance.

To facilitate review by the Agency, the supplier must submit a package which satisfactorily addresses the following items:

A) System development and year it was commercialized
B) Organization structure of the supplier of the system including specific engineering and construction support personnel
C) Limitations and disadvantages of system
D) List of users including names, addresses, and telephone numbers
E) Erosion control details as a function of climactic, geographic, and slope steepness features
F) Sample material and construction control specifications - showing material type, quality, certifications, field testing, and placement procedures
G) A well documented field construction manual describing in detail, and with illustrations where necessary, the step by step construction sequence (copies of this manual should also be provided to the contractor and the project engineer at the beginning of the slope construction)
H) Typical unit costs, supported by data from actual projects
I) Detailed information on slope design and slope stability analysis techniques
J) Material acceptance and rejection criteria: as outlined in Appendix A of this document. Actual test data must be provided to substantiate adherence to the FHWA guidelines

3.0 SIERRA SLOPE DESIGN

3.1 Design Standards

Design requirements for MSE slope structures are set forth in FHWA NHI-00-043, “Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines.” Reference is made to applicable American Society for Testing of Materials (ASTM) test standards for the erosion control system, geogrid reinforcement, and drainage composite materials. Applicable Geosynthetic Research Institute (GRI) test standards and standards of practice are also referenced where ASTM standards do not yet exist.

3.2 Terminology

A mechanically stabilized earth (MSE) slope consists of six major components: 1) reinforced slope fill; 2) random backfill behind the reinforced zone; 3) foundation soil; 4) structural geogrid reinforcement; 5) internal drainage element; and 6) erosion control system (Figure 2.1).

3.3 Design Overview

The Sierra Slope Retention System is designed so that it is stable, both internally and externally. Internal stability requires that the reinforced soil structure is coherent and self-supporting under the action of its own weight and any externally applied forces. This is accomplished through stress transfer from the soil to the structural geogrid reinforcement by friction and passive resistance mobilized by interlock.

The self-supporting gravity mass is created by the structural geogrid reinforced soil. The erosion control system is used to prevent surface sloughing of the slope face, provide an aesthetic exterior finish and can also facilitate compaction of the reinforced slope fill.

The steps in the design of a Sierra Slope Retention System are:

- Qualifying geogrid design assumptions
- Defining soil, geometry, reinforcement, and loading parameters
- Determining slope stability calculations
- Qualifying assumptions for internal drainage, erosion control system, and landscape design
- Developing construction drawings & specifications
3.3.1 Design Assumptions
The design methods presented herein are directly applicable to each Sierra Slope meeting the following assumptions:

1. The soil parameters for the reinforced, retained, and foundation soils are defined. Reinforced fill may include all highway embankment construction fills and is not limited to select or granular backfill.

2. Design strength ($T_a$) of the geogrid reinforcement is approved by the agency prior to design based on FHWA Guidelines with consideration of installation damage, creep, chemical and biographical degradation, and joints.

3. Geogrid-soil interaction coefficients ($C_i$) for the structural geogrid are approved by the agency prior to design based on review of pullout tests using GRI:GG5 test methods conducted with representative soils or site specific testing.

4. Soil reinforcement is provided by horizontal layers of Tensar Geogrids as outlined on project specific design drawings.

5. Any loads anticipated above and behind the reinforced zone are accounted for in the design.

6. Positive drainage is provided to assure no hydrostatic forces develop in the reinforced zone.

7. If seismic forces are to be considered in this design, the appropriate gravitational force must be defined.

8. Slope angle, surficial stability and facing material/vegetation selection must be considered in the design of the erosion control system.

3.3.2 Total Stress vs. Effective Stress Parameters
An important element of slope stability analysis is soil shear strength. When choosing value(s) it may be necessary to consider both total and effective stresses. These analyses are relevant to short-term (or end-of-construction) stability and long-term stability, respectively. Prior to performing a design, available soil information from testing should be appropriately classified into one of these two categories.

In total, stress (undrained or short-term) analysis failure due to shear stresses and increased pore pressure during construction is assumed. This situation occurs in clays when pore water pressure induced by construction has not had time to dissipate. In this case, the shear strength of the soil is attributed only to cohesion (i.e. $\phi = 0$).

Effective stress (drained or long-term) analysis is used for most natural slopes and embankments. Pore pressures are assumed to be in equilibrium and are determined by the groundwater table or a known steady flow pattern. When using effective stress parameters, attention to the type of soil test and expected in-situ soil conditions are particularly important.

3.3.3 Geometry
For a typical slope, the slope height, $H$ (ft or m), slope angle $\beta$ (degrees), and uniform surcharge, $q$ (lb./ft$^2$ or kN/m$^2$), are illustrated in Figure 2.1. Complicated geometries such as broken back slopes, transition slopes or unusual foundation conditions can also be designed. The dimensions and slope angles for these geometries must be known. In addition, a value for minimum vertical spacing between geogrid layers, $s_{min}$ (ft or m), is required. As a construction expedient $s_{min}$ is usually set equal to the soil lift thickness to be used during construction.

3.3.4 Structural Geogrid Reinforcement Parameters
The Sierra Slope Retention System consists of Tensar Geogrids arranged in horizontal planes in the backfill to resist outward movement of the reinforced soil mass. Geogrids transfer stress to the soil through passive soil resistance on transverse members of the grid and friction between the soil and horizontal surfaces of the geogrid. Geogrid long-term design strength ($T_a$) is determined by long-term creep testing. Durability factors include site damage, chemical degradation, and biological degradation. The degradation caused by these factors may result in either a decrease in tensile strength of the geogrid or a decrease in tensile strength of the geogrid/soil interaction (coefficient of interaction, $C_i$). Values for $T_a$ and $C_i$ should be selected based on the geogrid and soil type used in the reinforced slope fill. The methods for quantifying these parameters are presented below with detailed discussion in Appendices A and B.
For Sierra and all other MSE slopes, the allowable geogrid design strength \( T_a \) is:

\[
T_a = \frac{T_{ULT}}{RF_{CR} \times RF_{ID} \times RF_D}
\]

- \( T_a \) = allowable geogrid tensile strength, for use in stability analyses
- \( T_{ULT} \) = ultimate geogrid tensile strength per ASTM D6637
- \( RF_{CR} \) = reduction factor for creep rupture and ratio of \( T_{ULT} \) to creep rupture strength (dimensionless)
- \( RF_{ID} \) = reduction factor for installation damage (dimensionless)
- \( RF_D \) = reduction factor for durability/aging (dimensionless)

### 3.3.5 Slope Stability

The techniques used for analysis of Tensar MSE slopes are an extension of routine slope stability procedures. An MSE slope, however, is more complex than an unreinforced slope and requires more steps in the analytic process. Permanent, critical, geogrid reinforced structures should be designed using comprehensive slope stability analysis. A structure may be considered permanent if its design life is greater than 5 years. A reinforcement application is considered critical if there is mobilized tension in the reinforcement for the life of the structure, if failure of the reinforcement results in failure of the structure, or if the consequences of failure include personal injury or significant property damage.

Failure modes of MSE slopes include:

i) **internal**, where the failure plane passes through the reinforcing elements

ii) **external**, where the failure surface passes behind and underneath the reinforced mass

iii) **compound**, where the failure surface passes behind and through the reinforced soil mass

A MSE slope may have several potential “critical” failure planes. Tensar Sierra Slope Retention System designs consider the number of reinforcement layers, design tensile force of each layer, anchorage requirements, and length of the reinforcing layers which affect the location of the critical failure plane. The critical failure surface will most likely not be the same as the unreinforced failure surface with the lowest factor of safety. Therefore, a computerized search of all potential failure surfaces within the “safe” unreinforced failure zone should be conducted. Additionally, safety factors may be plotted as contours of safety factors. The contours should be drawn on the field of failure circle centroids. This plotting assists in locating the various centroids of failure circles with low safety factors, and in locating all potential critical failure surfaces (Figure 3.1).

### 3.3.6 Analysis Methods

#### 3.3.6.1 Limit Equilibrium Methods

The object of slope stability analysis is to quantify the possibility of excessive deformation or collapse of the slope or embankment. The accurate prediction of deformation requires definition of many hard-to-evaluate parameters and use of complex analytical methods not available to most engineers. Thus, analysis using limit equilibrium to determine a factor of safety against collapse of the slope is most commonly used. It is assumed by requiring an adequate factor of safety through limit equilibrium methods that deformations of the slope will be limited to an acceptable level.
3.3.6.2 Simplified Bishop Method of Slices. The Bishop Method of Slices may be used to analyze the stability of slopes with varying soil properties, pore water pressure, and an irregular geometry. The failure surface is assumed circular and the soil mass is divided into vertical slices. The forces on each slice are evaluated using limit equilibrium methods (i.e. summing moments about the center of rotation of the failure plane).

The forces acting on each slice of a slope include the weight of the slice, W; normal and shear forces acting on the base of the slice, P and S; normal and shear forces acting on the vertical sides of the slice, E and T. (Figure 3.2) The vertical normal and shear forces are related to deformation and stress-strain characteristics of the soil which are not easily evaluated. To achieve a statically determinate system, the “simplified” method assumes side forces to be equal with coincidental lines of action. Thus, the forces cancel each other and are set equal to zero in calculations. The effect on the accuracy that this assumption has on the determination of the factor of safety of the slope is in the range of 1% to 10%.

![Figure 3.2 — Forces Acting on a Typical Slice](image)

3.3.7 Safety Factors
The factor of safety for slope stability should be adequate to address all uncertainties in the assumptions and design. Recommended minimum stability factor of safety is 1.3 against external, deep seated failures; compound failure surfaces; and internal failure, unless local codes require a higher value.

This safety factor is the minimum recommended for permanent structures. Higher factors are recommended in the absence of thorough geotechnical investigation and analysis.

Higher factors may also be desired in cases where slopes are supporting structures. Lower safety factors may be acceptable for temporary and/or noncritical structures.

3.3.8 Seismic Design
Under seismic loading, a reinforced soil slope is subjected to dynamic forces in addition to static forces. The allowable tensile stress of the geogrid reinforcement may be increased for short-term seismic loading conditions.

The recommended method of seismic analysis for earth slopes is pseudo-static analysis with a slope stability computer program. A horizontal pseudo-static force, which is some percentage of the slice weight, is applied to each slice in the analysis. A vertical force may also be simultaneously applied, if dictated by local codes or practice. Internal, external, and compound failure modes should be analyzed with an additional horizontal pseudostatic acceleration force included. The target safety factor is typically taken as greater than or equal to 1.1 for these potential failure modes.

The magnitude of the pseudo-static force coefficient will typically be dictated by local codes and practice. A detailed map seismic risk is presented in the AASHTO Bridge Manual (1991). Pseudo-static techniques may not be appropriate for areas subject to high seismic loadings or slopes adjacent to critical structures. Comprehensive dynamic analysis procedures should be utilized for these cases.

Use of pseudo-static dynamic earth pressures according to the Mononobe-Okabe procedure may be acceptable for slopes steeper than approximately seventy degrees (70°). This pseudo-static analysis was developed for retaining walls and assumes that the soil behind the wall behaves as a rigid body. The factor of safety against failure by outward sliding should be greater than or equal to 1.1. This wall analysis is also sensitive to the slope angle of the retained backfill, as discussed in Supplement A, Standard Specifications for Seismic Design of Highway Bridges, of the AASHTO Bridge manual (1991) and by Seed and Whitman.

Use of pseudo-static dynamic earth pressures according to the Mononobe-Okabe procedure may be acceptable for slopes steeper than approximately seventy degrees (70°). This pseudo-static analysis was developed for retaining walls and assumes that the soil behind the wall behaves as a rigid body. The factor of safety against failure by outward sliding should be greater than or equal to 1.1. This wall analysis is also sensitive to the slope angle of the retained backfill, as discussed in Supplement A, Standard Specifications for Seismic Design of Highway Bridges, of the AASHTO Bridge manual (1991) and by Seed and Whitman.
3.4 Soil-Reinforcement Interaction

Two types of soil-reinforcement interaction coefficients or interface shear strengths must be determined for design: pullout coefficient and direct shear coefficient. Pullout coefficient is used in stability analysis to compute mobilized tensile force at the front and tail of each reinforcement layer. The direct shear coefficient is used in checking factors of safety against outward sliding of the reinforced mass on top of any layer of reinforcement. A detailed discussion on the use of these coefficients is provided by the FHWA.

A test method standardizing laboratory pullout testing of geogrids (GRI:GG5) was published by the Geosynthetic Research Institute (GRI) in 1991. Determination of an interaction coefficient is defined as either short-term or long-term by this standard, and is dependent on the method of pullout force application. Short-term testing with controlled strain rate, controlled stress rate, or incremental stress methods of pullout force application provide short-term interaction coefficients. A constant stress (creep) method of pullout force application yields a long-term pullout coefficient. Typical design practice is to define an interaction coefficient with a controlled strain (deformation) method of testing, per the GRI test method, and apply the coefficient to long-term designs.

TET has performed long-term pullout tests of both singular and composite manufacture type of geogrids. The results of approximately 1,000-hour sustained load pullout tests were compared with a quick pullout test (strain rate of 1 mm/min) to determine an efficiency of the geogrid with respect to pullout. Efficiency was computed as the ratio of long-term coefficient of interaction to the short-term coefficient of interaction. Use of quick tests to define long-term pullout capacity for use in design is not recommended. This practice inherently assumes that an efficiency of 100% or greater exists between long-term and short-term pullout capacity.

However, the pullout test results presented by Collin and Berg demonstrate that it can not be assumed that the long-term pullout performance of geogrids can be determined through quick tests. Short-term coefficient of interaction $C_{is}$ may not be equal to the long-term coefficient of interaction $C_{is}$. This testing substantiates that “through-the-junction” creep testing outlined in GRI:GG3 is critical when determining the long-term coefficient of interaction through quick tests.

3.5 Internal Water Drainage

Uncontrolled subsurface water seepage can decrease stability of MSE slopes and could ultimately result in slope failure. Hydrostatic forces on the rear of the reinforced mass will decrease stability against sliding failure. Uncontrolled seepage into the reinforced mass will increase the weight of the reinforced mass and may decrease the shear strength of the soil, hence decrease stability. Seepage through the mass can reduce pullout capacity of the geogrid at the face and increase soil weight, creating erosion and sloughing problems. A detailed discussion of internal drainage is provided by the FHWA.

Drainage composites can be utilized in subsurface water drainage design for Sierra Slopes. The use of geocomposite drainage is briefly addressed in this document with specifications provided in Section 7.0. Drainage composites should be designed with consideration of:

i) peel strength of the geotextile from the geonet
ii) reduction of flow capacity due to intrusion of geotextile into the core
iii) inflow/outflow capacity
iv) filtration characteristics between the soil and geotextile

A measurement of peel strength of the geotextile from the geonet is an important consideration to insure that a shear failure does not occur from the load created by the backfill on the drainage composite. ASTM F904-84 test procedure Comparison of Bond Strength or Ply Adhesion of Similar Laminates made from Flexible Materials should be followed.
Intrusion of the geotextiles into the core and inflow/outflow capacity should be measured with a sustained transmissivity test. The ASTM D 4716 test procedure (1987), Constant Head Hydraulic Transmissivity of Geotextiles and Geotextile Related Products, should be followed. Load should be maintained for 50 hours or until equilibrium is reached, whichever is greater, at a pressure equal to or greater than the expected pressure for the specific application. Flow rate is measured at a standard gradient of 1.0. In addition, slope stability analysis should account for interface shear strength along a geocomposite drain. The geotextile that is laminated to the geonet should be designed to act as a filter to prevent the migration of soil. Guidelines for the filter design are provided in the FHWA Guidelines 4.

Special emphasis on the design and construction of subsurface drainage features is recommended for MSE slope structures. Drainage is critical for maintaining slope stability. Redundancy in the drainage system is also recommended.

3.6 Surface Drainage & Erosion Protection

Stability of a slope can be threatened by erosion due to surface water runoff. Erosion rills and gullies can lead to surface sloughing and possibly deep seated failures. Erosion control and revegetation measures must be an integral part of all reinforced slope system designs and specifications.

3.6.1 Surface Water Drainage

Surface water runoff should be collected above the reinforced slopes and channeled or piped below the base of the slope. Standard agency drainage details should be utilized. It is also important not to allow surface waters to infiltrate from the top of the slope into the reinforced slope fill. This water will tend to percolate out of the slope face potentially causing surficial slumps.

3.6.2 Surficial Stability

In-depth discussions of surficial slope failure mechanisms have been presented by Terzaghi and Peck (1967) 14, Campbell (1975) 15, and Theilen and Collin (1993) 16. These failures are usually initiated by water infiltrating the near surface soils. The source of this water may be rainfall, broken utilities, landscape watering, or failure to intercept upslope drainage. When infiltration exceeds the transmissivity of the soil, a perched water table with seepage parallel to the slope face can develop. Intermediate layers of secondary reinforcement are usually required at the face of reinforced slopes to control surficial slope failures. Design is dependent upon soil type, slope angle, slope height, and primary reinforcement spacing. The intermediate layers of reinforcement aid in achieving compaction at the face, thus increasing soil shear strength and resistance to erosion. These layers also act as reinforcement against shallow or sloughing types of slope failures. Intermediate reinforcement is typically placed on each or every other soil lift, except at lifts where primary structural reinforcement is placed. Intermediate reinforcement is also placed horizontally adjacent to primary reinforcement, and at the same elevation as the primary reinforcement, when primary reinforcement is placed less than 100% coverage in plan view. The intermediate reinforcement typically extends 3 to 6 feet into the fill from the face.

Slopes steeper than 1:1 typically require facing support during construction. TET’s SierraScape facing elements are typically used. SierraScape facing elements are mechanically connected to the geogrid reinforcement providing enhanced protection against surficial failure during and immediately following construction.

3.6.3 Landscape Design Considerations

Unlike conventional MSE wall systems, the Sierra Slope Retention System can be designed for a wide variety of visual impressions. Sierra Slopes can be faced with grass or wildflowers, revegetated to a natural state or landscaped as mulched ornamental bedding. Sierra Slopes can also be combined with traditional flat fill slopes to create contoured grades that are indistinguishable from adjacent natural slopes.

The various vegetation options available for the Sierra Slope Retention System place an emphasis on choosing the proper landscape design to fit the site constraints. A low maintenance grassed slope may work well on a seldom seen highway downslope, but may be a poor choice for a slope on a highly visible urban roadway interchange. A landscaped slope may be a better choice for the latter site.

Landscape design is usually provided by the agency. TET can provide local and regional expertise in landscape design, plant selection, and erosion control solutions for Sierra Slopes.
3.6.4 Erosion Control Systems

MSE slopes typically are vegetated during or immediately after construction to prevent or minimize erosion due to rainfall and runoff on the face. On sites where vegetation cannot grow (i.e., abutments under bridges, below water, desert, or arid regions) non-vegetated erosion control systems can be provided. Vegetation requirements will vary by geographic and climactic conditions and are therefore project specific. Steep grades can be difficult locations on which to establish and maintain vegetative cover. The steepness of the grade limits the amount of water absorbed by the soil before runoff occurs. Once vegetation is established on the face, it must be protected to ensure long-term survival.

Consequently, for grassed or wildflower faced slopes, a long-term nondegradable erosion control mat that is stabilized against ultra-violet light and is inert to naturally occurring soil-born chemicals and bacteria is required. The erosion control mat serves four functions:

A. Protects the bare soil face against erosion until vegetation is established
B. Reduces runoff velocity for increased water absorption by the soil thus promoting long-term survival of the vegetative cover
C. Reinforces the root system of the vegetative cover to create veneer reinforcement element for the sod
D. Protects seed and enhances seed germination and seedling establishment over the design life of the structure to ensure complete vegetation cover on the entire slope face.

Sierra Slopes usually employ low maintenance vegetation options but depending on the site and actual plant material selected, some maintenance of vegetation may be required.

3.6.5 Erosion Control System Selection

Selection of the appropriate vegetation and an erosion control system is a four-step process. These steps are:

A. Agency determines or designs desired slope angles based on site constraints, soil types, etc.
B. Agency and/or supplier reviews the surrounding site for existing vegetation, visibility factors, and horticultural growing conditions.

C. Agency chooses vegetation option based on considerations outlined above.
D. Agency specifies appropriate erosion control system as a pre-approved system.

The Sierra approach for erosion solutions uses several predetermined erosion control systems. This approach is preferable to a component or material approach, because it can address the multitude of factors that must be considered in designing erosion control and facing treatments and it simplifies the approval process for the Agency. The erosion control system approach addresses surficial bare soil erosion control, vegetation establishment, surficial stability, facing support during construction, and facing aesthetics.
4.0 SIERRA EXPERIENCE

Some of the completed Sierra Slope Retention System projects for government agencies are summarized below. Additional information, including contact people, on these projects is available upon request. An extensive completed project list for slopes used in property development is also available upon request.

ALABAMA
Project: County Rd 81
Location: Ft. Payne, Alabama
Owner: Dekalb County
Engineer: Ladd Environmental Consultants, Inc. and Gallet & Associates
Contractor: Jackson Paving
Constructed: Winter 1999
Max. Height: 63 ft.; 1:1 slope

ARIZONA
Project: Bush Highway
Location: Maricopa County, Arizona
Owner: Maricopa County, Arizona
Engineer: Maricopa County Highway Department
Contractor: McMurry Bros.
Constructed: Fall 1987
Max. Height: 70 ft.

Project: Carefree Highway
Location: Maricopa County, Arizona
Owner: Maricopa County, Arizona
Engineer: Tensar Earth Technologies, Inc.
Contractor: Ames Construction
Constructed: Spring 1993
Max. Height: 35 ft; 1:1 slope

ARKANSAS
Project: Cannon Creek, Highway 16
Owner: Arkansas State Highway and Transportation Department
Engineer: Raymond Technical
Contractor: Machen Construction
Constructed: Summer 1987
Max. Height: 75 ft.; 2:1 slope repair

Project: Fort Smith
Location: Fort Smith, Arkansas
Owner: City of Fort Smith
Engineer: Mickale, Wagoner & Coleman
Contractor: Forsgren Construction
Constructed: Summer 1996
Max. Height: 22 ft.

CALIFORNIA
Project: Highway 84
Location: LaHonda, California
Owner: Cal Trans
Engineer: Cal Trans District 4
Constructed: Fall 1986
Max. Height: 42 ft.; 1:1 slope

Project: Highway 9
Location: Felton, California
Owner: Cal Trans
Engineer: Cal Trans District 4
Contractor: Dan Caputo
Constructed: Summer 1992
Max. Height: 46 ft.; 0.5:1 slope

Project: Van Duzen-Peanut
Location: Northern California
Owner: USDA Forest Service
Engineer: FHWA; Central Division
Contractor: Stimpl-Wiehelhaus
Constructed: Fall 1988
Max. Height: 60 ft.; 1:1 slope

COLORADO
Project: I-270
Location: Denver, Colorado
Owner: Colorado DOT
Engineer: Colorado DOT
Contractor: Cat Construction
Constructed: Spring 1994
Max. Height: 14 ft.; 1.25:1 slope

FLORIDA
Project: State Road 70 Overpass
Location: Okeechobee, Florida
Owner: Florida DOT
Engineer: Professional Engineering Consultants
Contractor: Sheltra Construction Company
Constructed: Summer 1996
Max. Height: 28 ft.; 1:1 slope
Project: State Road Highway 60  
Location: Lake Wales, Florida  
Owner: Florida DOT  
Engineer: Jammal & Associates  
Contractor: Mid States Paving  
Constructed: Fall 1991  
Max. Height: 18 ft.; 1:1 slope

Project: I-75 Weight Station  
Location: Wildwood, Florida  
Owner: Florida DOT  
Engineer: Boyles Engineering  
Contractor: DAB Construction  
Constructed: Fall 1991  
Max. Height: 12 ft.; 1:1 slope

Project: Maitland Pedestrian Overpass  
Location: Maitland, Florida  
Owner: Florida DOT  
Engineer: Sverdup Corporation  
Contractor: Martin Paving Company, Inc.  
Constructed: Spring 1998  
Max. Height: 21 ft.; 1.2:1 slope

Project: State Route 15 Realignment  
Location: Debary, Florida  
Owner: Florida DOT  
Engineer: Greiner & Associates  
Contractor: DeWitt Excavating  
Constructed: Fall 1993  
Max. Height: 30 ft.; 1:1 slope

GEORGIA

Project: Airport Expansion  
Location: Atlanta, Georgia  
Owner: Atlanta Hartsfield Authority  
Engineer: Tensar Earth Technologies, Inc.  
Contractor: Gilbert & Southern  
Constructed: Fall 1992  
Max. Height: 40 ft.; 1:1 slope

Project: I-285  
Location: Atlanta, Georgia  
Owner: Georgia DOT  
Engineer: Georgia DOT  
Contractor: C.W. Matthews  
Constructed: Fall 1994  
Max. Height: 35 ft.; 1.25:1 slope

IDAHO

Project: Kootenai Cutoff  
Location: Sandpoint, Idaho  
Owner: Idaho DOT  
Engineer: Idaho DOT  
Contractor: DeAtley Company Inc.  
Constructed: Summer 1996  
Max. Height: 8 ft.

ILLINOIS

Project: Peck Road  
Location: Geneva, Illinois  
Owner: Kane County, IL  
Engineer: Terracon  
Contractor: Plote Construction  
Constructed: Spring 2000  
Max. Height: 20 to 25 ft.; 2:1 slope

LOUISIANA

Project: I-10  
Location: Baton Rouge, Louisiana  
Owner: Louisiana DOT  
Contractor: Angelo IAFRATI Construction  
Constructed: Fall 1997  
Max. Height: 19 ft.

KANSAS

Project: I-35 & Johnson Drive Exit  
Location: Olathe, Kansas  
Owner: Kansas DOT  
Engineer: Howard, Needles, Tammen & Bergendoff  
Contractor: Clarkson Construction Company  
Constructed: Summer 1988  
Max. Height: 15 ft.; 1:1 slope

Project: Route 150  
Location: Topeka, Kansas  
Owner: Missouri DOT  
Engineer: Tensar Earth Technologies, Inc.  
Contractor: Idecker, Inc.  
Constructed: Winter 1998  
Max. Height: 52 ft.; 1:2 slope

Project: I-135  
Location: Salina, Kansas  
Owner: Kansas DOT  
Engineer: Tensar Earth Technologies, Inc.  
Contractor: Clarkson Construction  
Constructed: Summer 1999  
Max. Height: 20 ft.; 2:1 slope
PROJECT: US 50
Location: Kinsley, Kansas
Owner: Kansas DOT
Engineer: Tensar Earth Technologies, Inc.
Contractor: APAC
Constructed: 2000
Max. Height: 25 ft.; 1:5-1 slope

PROJECT: Highway 156
Location: Ellsworth County, Kansas
Owner: Kansas DOT
Engineer: Tensar Earth Technologies, Inc.
Constructed: 2001
Max. Height: 9 ft.; 2:1 slope

KENTUCKY
Project: Cincinnati Airport
Location: Hebron, Kentucky
Owner: USPS
Engineer: QORE
Contractor: James H. Gray
Constructed: Winter 1999
Max. Height: 18 ft.

Project: U.S. Highway 23
Location: Prestonsburg, Kentucky
Owner: Kentucky DOT
Engineer: Bowser - Morner
Contractor: Bizzack Construction
constructed: Spring 1992
Max. Height: 30 ft.; 1:1 slope

MAINE
Project: Poland Springs
Location: Poland Springs, Maine
Owner: Perrier Group of America
Engineer: Pinkham & Greer and Tensar Earth Technologies, Inc.
Contractor: White Brothers, Inc.
Constructed: Summer 1996
Max. Height: 37 ft.; 1:1 slope

MARYLAND
Project: Route 410
Location: Prince George City, Maryland
Owner: Maryland DOT
Engineer: Tensar Earth Technologies, Inc.
Contractor: Driggs Corp.
Constructed: Summer 1989
Max. Height: 48 ft.; 1.5:1 slope

PROJECT: State Route 100
Location: Howard County
Owner: Maryland DOT
Engineer: KCI Technologies, Inc.
Contractor: Williams Construction
Constructed: Fall 1994
Max. Height: 50 ft; 1:1 slope

MASSACHUSETTS
Project: Pearl Street
Location: Braintree, Massachusetts
Owner: Mass Bay Transit Authority (MBTA)
Engineer: Tensar Earth Technologies, Inc.
Contractor: DeMatteo Construction
Constructed: Fall 1996
Max. Height: 25 ft.

MICHIGAN
Project: Highway M44
Location: Grand Rapids, Michigan
Owner: Michigan DOT
Engineer: Tensar Earth Technologies, Inc.
Contractor: K & R Contracting
Constructed: Summer 1991
Max. Height: 40 ft.; 1:2-1 slope

MINNESOTA
Project: Blake Road
Location: Edina, Minnesota
Owner: City of Edina
Engineer: STS Consultants
Contractor: C.S. McRossan
Constructed: Fall 1992
Max. Height: 10 ft.; 0.125:1 vegetated wall

Project: E-80 Cooper Train Loading
Location: Kellog, Minnesota
Owner: CPRR
Engineer: Tensar Earth Technologies, Inc. and CPRR
Contractor: Lunda Corporation
Constructed: Summer 1999
Max. Height: 22 ft.; 1:1 slope with temporary wall
MISSISSIPPI
Project: Maryland Hts. Subdivision
Location: Natchez, Mississippi
Owner: Natchez Housing Authority
Engineer: Jordan, Kaiser & Sessions
Contractor: Great River Stone
Constructed: Fall 1991
Max. Height: 45 ft. 1:1 slope

MISSOURI
Project: Elm Street Overpass
Location: St. Louis, Missouri
Owner: Missouri DOT
Engineer: Midwest Testing Engineer
Contractor: Fred Weber Contracting
Constructed: Fall 1992
Max. Height: 40 ft.; 50° Bridge Abutment

MONTANA
Project: Dickey Lake
Location: Lincoln Cty., Montana
Owner: Montana Highway Department
Engineer: Midwest Highway Department
Constructed: Summer 1990
Max. Height: 60 ft.; 1:1 slope

NEBRASKA
Project: Davis Creek Dam
Location: Ord, Nebraska
Owner: Bureau of Reclamation
Engineer: Bureau of Reclamation
Contractor: Gilbert Central Corporation
Constructed: Summer 1990
Max. Height: 29 ft., 1:1 slope

NEW HAMPSHIRE
Project: Route 3A
Location: Hooksett, New Hampshire
Owner: New Hampshire DOT
Engineer: Tensar Earth Technologies, Inc.
Contractor: R.S. Audley
Constructed: Fall 1990
Max. Height: 40 ft. 1.25:1 slope

NEW MEXICO
Project: US 64
Location: Dulce, New Mexico
Owner: New Mexico DOT
Engineer: Highway Department
Contractor: Weeminuche Construction Authority
Constructed: Winter 1999
Max. Height: 22 ft.

NEW YORK
Project: Ithaca County Courthouse
Location: Ithaca, New York
Owner: Ithaca County
Engineer: Empire Soils
Constructed: Summer 1992
Max. Height: 10 ft. Vegetated Wall

Project: Route 174
Location: Onondaga County, New York
Owner: New York DOT
Engineer: Tensar Earth Technologies, Inc.
Contractor: Sut-Kote Construction
Constructed: Summer 1994
Max. Height: 33 ft.; 1.25:1 slope

NORTH CAROLINA
Project: Bethlehem Road
Location: Rocky Mount, North Carolina
Owner: North Carolina DOT
Engineer: North Carolina DOT
Contractor: Barnhill Construction
Constructed: Spring 1991
Max. Height: 25 ft.; 1.1 slope

Project: Robbinsville Tellico Plains Road
Location: Robbinsville, North Carolina
Owner: FHWA
Engineer: FHWA
Contractor: Robbinsville Contracting
Constructed: Fall 1993
Max. Height: 40 ft.; 1.5:1 slope

Project: Route 74
Location: Graham City, North Carolina
Owner: North Carolina DOT
Engineer: North Carolina DOT
Contractor: Gilbert Southern
Constructed: Fall 1999
NORTH DAKOTA
Project: Teddy Roosevelt National Park, ND
Owner: National Park Service
Engineer: National Park Service
Constructed: Summer 1986
Max. Height: 20 ft.; 2:1 landslide repair

OHIO
Project: Ohio Turnpike
Location: Cleveland, Ohio
Owner: Ohio DOT
Constructed: Spring 2000
Max. Height: 60 ft.; 1:1 slope

PENNSYLVANIA
Project: Pennsylvania Turnpike
Location: Morgantown, Pennsylvania
Owner: Penn. Turnpike Authority
Engineer: GeoMechanics
Contractor: Stabler Construction
Constructed: Summer 1988
Max. Height: 35 ft.; 1:1 slope

SOUTH CAROLINA
Project: Highway 17
Location: North Charleston, South Carolina
Owner: South Carolina DOT
Engineer: F & ME
Contractor: Banks Construction
Constructed: Spring 1997
Max. Height: 20 ft.

Project: Route 5
Location: York County, South Carolina
Owner: South Carolina DOT
Engineer: Foundation and Material Engineers
Contractor: Jenkins Construction
Constructed: Fall 1990
Max. Height: 50 ft.; 2:1 landslide repair

TEXAS
Project: Combat Arms Training Facility
Location: Dyers AFB, Texas
Owner: Corps of Engineers
Engineer: Lockwood Greene
Constructed: Summer 1988
Max. Height: 24 ft.; 1:1 slope

Project: RM 2222
Location: Austin, Texas
Owner: Texas DOT
Engineer: Tensar Earth Technologies, Inc.
Contractor: Austin Filter Systems
Constructed: Spring 1990
Max. Height: 10 ft.; 1:1 Temporary Wall

VERMONT
Project: Gold Hill Road
Location: Montpelier, Vermont
Owner: City of Montpelier
Engineer: Pinkham Engineering Associates
Contractor: Morrill Construction
Constructed: Fall 1992
Max. Height: 75 ft.; 1:1 slope

Project: Route 30
Location: Townshed, Vermont
Owner: Vermont Agency of Transportation
Engineer: Vermont Agency of Transportation
Contractor: Miller Construction
Constructed: Summer 1991
Max. Height: 35 ft.; 1:1 slope

WASHINGTON
Project: 140th Avenue
Location: Kent, Washington
Owner: King County
Engineer: Hong West Associates and Parsons Brinckerhoff
Contractor: Scarsella Brothers
Constructed: Fall 1999
Max. Height: 96 ft.; 2:1 slope

Project: State Route 20
Location: Concrete, Washington
Owner: Washington DOT
Engineer: Washington DOT
Constructed: Summer 1991
Max. Height: 60 ft.; 1:1 slope

WEST VIRGINIA
Project: Buckhannon Airport
Location: Buckhannon, West Virginia
Owner: Upshur City Airport
Engineer: HC Mutting & Chapman Technical Group
Contractor: Kimberly Industries
Constructed: Winter 1996
Project: Highway 52  
Location: McDowell County, West Virginia  
Owner: West Virginia DOT  
Engineer: West Virginia DOT  
Contractor: Alan Stone  
Constructed: Summer 1984  
Max. Height: 35 ft.; 1.5:2 Landslide Repair

Project: Tri-State Airport  
Location: Kenova, West Virginia  
Owner: Tri-State Airport Authority  
Engineer: Delta Engineers  
Contractor: McCoy Construction  
Constructed: Winter 1996

ONTARIO

Project: Highway 410  
Location: Brampton, Ontario  
Owner: Ministry of Transportation  
Engineer: Ministry of Transportation  
Constructed: 1983  
Max. Height: 26 ft.; 1:1 slope

Project: Highway 407  
Owner: Ministry of Transportation  
Engineer: DS-Lea Associates, LTD  
Contractor: Graham Bros. Construction  
Constructed: Fall 1994  
Max. Height: 37 ft.; 1:1 slope
5.0 ADVANTAGES & DISADVANTAGES

5.1 Advantages

There are several advantages associated with the use of a Sierra Slope Retention System versus reinforced MSE walls or cast-in-place walls. Some of the safety, performance, construction, aesthetic, and cost advantages are listed as follows:

- The Sierra Slope Retention System provides an attractive, natural appearance, with the use of vegetation as a facing element versus concrete units used in MSE wall systems.
- Sierra Slopes can be built at varying grades so that the entire RSS structure blends into existing grades. Concrete MSE wall structures create monolithic structures which can clash with the natural landscape.
- The Sierra System is a synergistic system, with consistent engineering through design, material manufacture, and construction. Agencies can specify Sierra with confidence knowing that the components will create a successful RSS structure.
- The Sierra Slope Retention System offers a significant in-place cost savings (up to 50%) over MSE walls (see Figure 6.1).
- A fairly wide range of backfill soils (i.e. typical highway embankment fills) have been successfully used with the Sierra System. Suitable quality backfill material can frequently be found on or near the construction site and thus need not be imported, potentially resulting in significant cost savings.
- Tensar Geogrids are inert and non-conductive; therefore, they provide excellent resistance to degradation in highway environments, particularly in the presence of decier salts and stray current environments.
- The Sierra System allows an Agency roadway design group greater flexibility in balancing cut and filling quantities on a job site.
- The deformation response of a Tensar Geogrid reinforced soil mass and the absence of concrete units provide a Sierra Slope with the flexibility to absorb unexpected large lateral and vertical deformations. This flexibility also makes the system ideal for use on sites with poor foundations or seismic activity.
- The vegetated Sierra surface provides better sound attenuation than smooth concrete surfaces.
- Construction is accelerated by the lack of need for forms or temporary bracing systems.
- Backfill placement and compaction proceeds quickly since no concrete facing elements are required.
- Slope construction does not require specialized contractors, skilled labor, or specialized equipment.
- Tensar Geogrids, drainage composites, and TRMs are relatively light and easy to handle.
- Post-construction maintenance costs such as cleaning and graffiti removal are avoided.

5.2 Possible Disadvantages

There are relatively few disadvantages associated with the Sierra Slope Retention System. Possible disadvantages are listed below along with methods to mitigate these potential disadvantages.

- The Sierra System may be new to Agency construction inspectors. Therefore, a preconstruction meeting of TET engineers, agency engineers and inspectors may be required to review the proper construction techniques.
- The Sierra System may be new to a contractor. Therefore, site assistance, in addition to that routinely provided on projects, may be required to educate the labor force on the proper construction technique.
- The Sierra System offers the option of a vegetation facing system that may require plant selection and landscape design aspects which are unfamiliar to some engineers or agencies familiar with the MSE wall structures. TET has the necessary expertise to address these issues so that highway agencies can specify Sierra with confidence.
In summary, the Sierra Slope Retention System constructed in accordance with this design specification will provide low cost, reliable, safe, and durable structures. The advantages of this system far outweigh any potential disadvantages.

6.0 Typical Costs

Typically, the in-place cost of a Sierra Slope Retention System is quoted per unit area of vertical face projection (i.e., per sq ft). This pricing includes:

- Engineering and construction drawings
- All structural geogrid, drainage composite, and erosion control system materials
- Installation of structural geogrids, drainage composite, and erosion control system
- Placement and compaction of reinforced backfill soils
- Material and installation costs of vegetation

7.0 Specification for Mechanically Stabilized Earth Retention System

This section is written in CSI 3-part format and in CSI page format. Notes to the specifier, such as this, are indicated with a ## symbol and must be deleted from the final specification. It is assumed that the general conditions being used are AIA A201-87. Section numbers are from the 1995 edition of Master Format.

For the most recent version of this section, please visit our web site at www.tensarcorp.com.

7.1 General

7.1.1 Summary

Section includes furnishing and testing materials, and the design and construction of a Mechanically Stabilized Earth (MSE) slope retention system. Work consists of:

1. Furnishing structural geogrid reinforcement, drainage composite, and erosion control system as shown on the construction drawings.
2. Storing, cutting, and placing structural geogrid reinforcement, drainage composite, and erosion control system as specified herein and as shown on the construction drawings.
3. Furnishing sealed design calculations and construction drawings for MSE slope; providing supplier representatives for pre-construction meeting with the Contractor and Engineer.
4. Excavation, placement, and compaction of reinforced fill and backfill material as specified herein and as shown on the construction drawings.

## Edit list below to confirm project requirements. Verify section numbers and titles.

7.1.1.1 Related Sections

A. Section 2200 – Site Preparation
B. Section 02300 – Earthwork

7.1.1.2 Alternates

A. Geotextile materials will not be considered as an alternate to geogrid materials. Geotextile may be used to provide separation, filtration, or drainage; however, no structural contribution will be attributed to the geotextile.

B. Alternate geogrid materials shall not be used unless submitted to the Engineer and approved in writing by the Engineer at least 7 days prior to the bid letting. The Engineer shall have absolute authority to reject or accept alternate materials based on the
requirements of this Section and the Engineer’s judgment. Polyester geogrids, whether coated or uncoated, will not be approved for use in calcareous, alkaline, or highly acidic environments, including lime-treated or cement-treated soils, crushed lime rock, or soils potentially exposed to leachate from cement, lime, or de-icing salts. In no case shall polyester geogrids be used in soils with a pH > 9. In order to be considered, submittal packages for alternate geogrid materials must include:

1. A list of 10 comparable projects that are similar in terms of size and application, are located in the United States, and where the results of using the specific alternate geogrid material can be verified after a minimum of 3 years of service life.
2. A sample of alternate geogrid material and certified specification sheets.
3. Recommended installation instructions.
4. An explanation of engineering techniques used and sample design drawings and calculations prepared and sealed by a Professional Engineer licensed in the applicable state.
5. Additional information as required by the Engineer.

7.1.2 References

## DELETE REFERENCES NOT USED IN PART 7.2 OR PART 7.3.

A. American Society for Testing and Materials (ASTM)

<table>
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<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>D374-94</td>
<td>Test Methods for Thickness of Solid Electrical Insulation</td>
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<tr>
<td>D1388-96</td>
<td>Standard Test Method for Stiffness of Fabrics, Option A</td>
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<tr>
<td>D2455-96</td>
<td>Standard Test Method for Identification of Carboxylic Acids in Alkyd Resins</td>
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<td>D4595-94</td>
<td>Standard Test Method of Tensile Properties of Geotextiles by the Wide-Width Strip Method</td>
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<tr>
<td>D4355-92</td>
<td>Standard Test Method for Deterioration of Geotextiles from Exposure to Ultra-violet Light and Water (Xenon-Arc Type Apparatus)</td>
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<td>D4603-96</td>
<td>Test Method for Determining Inherent Viscosity of Poly(Ethylene Terephthalate) (PET) by Glass Capillary Viscometer</td>
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<td>D4716-95</td>
<td>Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products</td>
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<tr>
<td>D4759-92</td>
<td>Practice for Determining the Specification Conformance of Geosynthetics</td>
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<td>D5818-95</td>
<td>Practice for Obtaining Samples of Geosynthetics from a Test Section for Assessment of Installation Damage</td>
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<td>D 6637-01</td>
<td>Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Test Method</td>
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<tr>
<td>F904-91</td>
<td>Standard Test Method for Comparison of Bond Strength or Ply Adhesion of Similar Laminates Made from Flexible Materials</td>
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B. Geosynthetic Research Institute (GRI)

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<th>Description</th>
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<tr>
<td>GG2-87</td>
<td>Standard Test Method for Geogrid Junction Strength</td>
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<tr>
<td>GG4-91</td>
<td>Determination of the Long-Term Design Strength of Geogrids</td>
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<tr>
<td>GG5-91</td>
<td>Standard Test Method for “Geogrid Pullout”</td>
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<tr>
<td>GG7</td>
<td>Standard Test Method for Carboxyl End Group Content of Poly (Ethylene Terephthalate) (PET) Yarns</td>
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<td>GG8</td>
<td>Determination of the Number Average Molecular Weight of Poly(Ethylene Terephthalate) (PET) Yarns Based on a Relative Viscosity Value</td>
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C. U.S. Federal Highway Administration (U.S. FHWA)

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<tr>
<td>FHWA NHI-00-043</td>
<td>Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines (Demonstration Project 82)</td>
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<tr>
<td>FHWA NHI-00-044</td>
<td>Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes</td>
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D. U.S. Environmental Protection Agency (U.S. EPA)

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<td>EPA 9090</td>
<td>Compatibility Test for Wastes and Membrane Liners</td>
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</tbody>
</table>
E. U.S. Army Corps of Engineers (USACE)
Draft Specification for Grid Aperture Stability by In-Plane Rotation

7.1.3 Definitions

**Structural Geogrid** - A structural geogrid is formed by a regular network of integrally connected tensile elements with apertures of sufficient size to allow interlocking with surrounding soil, rock, or earth and function primarily as reinforcement.

7.1.4 Submittals

A. The Contractor shall submit 6 sets of detailed design calculations, construction drawings, and shop drawings for approval at least 30 days prior to the beginning of construction. The calculations and drawings shall be prepared and sealed by a Professional Engineer, licensed in the State. Upon approval, the Engineer will make available 2 sets of the drawings to the Contractor. The Contractor shall obtain the approved drawings prior to commencing construction.

B. Submit geogrid product samples approximately 4 in. x 7 in. or larger and consisting of at least 4 entire apertures.

C. Submit Manufacturer’s installation instructions and general recommendations.

7.1.5 Quality Assurance

A. Qualifications - The Engineer’s approval of the system and the supplier will be based upon the following considerations:
   1. The geogrid reinforcement has been reviewed and approved for use.
   2. The supplier has a large enough operation and the necessary experience to supply and support the construction on a timely basis.
   3. Past experience in the design and construction of at least 10 projects of a similar magnitude of the proposed system can be documented.

B. The design shall be signed by a registered Professional Engineer who shall demonstrate a minimum Errors and Omissions insurance coverage of $1,000,000 by furnishing the Engineer with a current certificate of insurance.

C. Pre-Construction Conference - Prior to the installation of the geogrid, the Contractor shall arrange a meeting at the site with the geogrid material supplier and, where applicable, the geogrid installer. The Owner and the Engineer shall be notified at least 3 days in advance of the time of the meeting. The representative of the geogrid supplier shall be available on an “as-needed” basis during construction.

7.1.6 Delivery, Storage & Handling

Storage and Protection

A. Prevent excessive mud, wet concrete, epoxy, or other deleterious materials from coming in contact with and affixing to the geogrid materials.

B. Store at temperatures above -20° F (-29° C).

C. Rolled materials may be laid flat or stood on end.

7.2 PRODUCTS

7.2.1 Manufacturers

A. Acceptable Suppliers - A supplier or their representative must request, in writing 60 days prior to the bid date, to be placed on the approved supplier list. An approved source is The Tensar Corporation, Morrow, GA or their designated representative.

B. Substitutions - See Section 01600 and sub-part 7.1.1.2 of this Section.

7.2.2 Materials

THE PLANS SHOULD INDICATE WHERE GEOGRID TYPE(S) IS/ARE TO BE USED.

7.2.2.1 Structural Geogrid

The required physical and mechanical properties of geogrid reinforcement shall be as shown on the plans or established in writing by the Engineer at least 30 days prior to the bid.
A. **Primary Geogrid** - The primary geogrid, identified as types P1, P2, P3, and P4 shall provide the following allowable tensile properties:

### LOAD CAPACITY

<table>
<thead>
<tr>
<th>Property</th>
<th>Method</th>
<th>Primary Reinforcement Types</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
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<tbody>
<tr>
<td>True Initial Modulus, lbs/ft</td>
<td>ASTM D6637*</td>
<td>P1</td>
<td>161,070</td>
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<td>Tensile Strength</td>
<td>ASTM D6637*</td>
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<td>@ 5% Strain, lbs/ft</td>
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<td>Long term (Tₐ), lbs/ft</td>
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<td>P4</td>
<td>65,110</td>
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</tbody>
</table>

**Where:**

1. **Tₐ** = \( \frac{T_{ULT}}{RFCR \times RFID \times RFD} \)

### INTEGRITY OF PRODUCT STRUCTURE

<table>
<thead>
<tr>
<th>Property</th>
<th>Method</th>
<th>Primary Reinforcement Types</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction Strength, lbs/ft</td>
<td>GRI-GG2-87 @ 10%/min.</td>
<td>P1</td>
<td>4,520</td>
<td>7,200</td>
<td>9,250</td>
<td>10,970</td>
</tr>
</tbody>
</table>

**Where:**

1. **Tₐ** is determined with this test conducted without artificially deforming test materials under load before measuring such resistance or employing an artificial secant or offset tangent basis of measurement so as to overstate tensile properties.

2. **RFCR** - The Reduction Factor for Creep is the ratio of **Tₐ** divided by the creep-limited strength determined in accordance with ASTM D5262-97. Long-term tensile-strain-time behavior of the reinforcement shall be determined from controlled laboratory testing conducted for a minimum duration of 10,000 hours. The requirement for the minimum creep test period may be waived for a new product if it can be demonstrated that is sufficiently similar to a proven 10,000 creep tested product of a similar nature. When these conditions are met, creep testing shall be conducted for at least 1,000 hours and the results compared to the similar product tested for 10,000 hours. The 1,000-hour creep curves must pattern very closely to the 1,000-hour porting of the similar product to demonstrate equivalency. Creep test data at a given temperature may be extrapolated over time by one order of magnitude. Accelerated testing is required to extrapolate 10,000-hour creep data to a 75-year design life. Procedures for test acceleration are discussed in GRI-GG4. Creep testing is required on representative samples of the finished product and not a single component of the geogrid (e.g., fiber and/or yarn). The ultimate strength used in this calculation shall be that of the roll used in the testing and not the MARV for the product. Creep rupture testing, that has been performed through the use of alternative techniques (e.g., stepped Isothermal Method), must be supported with creep data conducted for a minimum of 10,000 hours at 20°C.

In no event shall the minimum value of **Fₛₜᵣ** be less than:

- PVC-coated PET geogrid: 1.75
- Acrylic-coated PET geogrid: 1.75
- HDPE uniaxial geogrid: 2.15
- PP biaxial geogrid: 4.00

3. **RFₐ** - The Reduction Factor for Installation Damage is the ratio of the virgin reinforcement **Tₐ** divided by the **Tₐ** of a sample of the same material recovered from an installation damage test. Tests shall be conducted using the actual backfill from the project in accordance with GRI-GG4. However, in lieu of such testing, the Manufacturer may supply test results from other backfill soils if such soils can be shown to result in more severe construction damage than the proposed backfill. **Tₐ** shall be determined in accordance with ASTM D6637-01 and sample recovery shall be consistent with ASTM D5818-95.

4. **RFₐ** - Reduction Factor for Durability/Aging is the combined partial factor for potential chemical and biological degradation. **RFₐ** shall be determined from polymer specific (HDPE and PP as identified by their mechanical properties, and PET as identified by CEG number and number average molecular weight, Mn) durability testing covering the range of expected soil environments. Polyolefin geogrids can...
be used in a pH range from 2 to 12, and polyester geogrids can be used within a pH range of greater than 3 and less than 9.

The minimum Reduction Factor for Durability/Aging for HDPE and PP shall be 1.0. The minimum reduction factors for PET geosynthetics are as follows:

<table>
<thead>
<tr>
<th>Product</th>
<th>Reinforced &amp; Retained Fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester geogrids</td>
<td>3.0</td>
</tr>
<tr>
<td>Mn &lt; 20,000; CEG &lt; 50</td>
<td>2.0</td>
</tr>
<tr>
<td>Polyester geogrids</td>
<td>1.3</td>
</tr>
<tr>
<td>Mn &gt; 25,000; CEG &lt; 30</td>
<td></td>
</tr>
</tbody>
</table>

5. For soils of potential concern, as presented below (modified soils shall include lime stabilized soil, cement stabilized soil, or concrete), only polymers listed as “no effect” shall be used within or adjacent to (3 feet shortest measurable distance) these soil environments (Ref: Table 8, FHWA NHI-00-044).

6. $Ci$ - Soil Interaction Coefficient value shall be determined from long-term effective stress pullout tests per GRI-GG5, unless the junction creep testing of the geogrid is used to determine $T_a$. The $Ci$ value is determined as follows:

$$Ci = \frac{F}{2L\sigma_N\tan\phi}$$

Where:
- $F$ = Pullout force (lbs/ft), per GRI-GG5
- $L$ = Geogrid Embedment Length in Test (ft)
- $\sigma_N$ = Effective Normal Stress (psf)
- $\phi$ = Effective Soil Friction Angle, Degrees

B. Secondary Geogrid - The secondary geogrid, identified as Types S1 and S2, shall meet the following physical property requirements:

**LOAD CAPACITY**

<table>
<thead>
<tr>
<th>Property</th>
<th>Method</th>
<th>Secondary Reinforcement Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength*</td>
<td>ASTM D6637</td>
<td>S1: 90  S2: 1,340</td>
</tr>
<tr>
<td>@ 2% Strain, lbs/ft*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 5% Strain, lbs/ft*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**INTEGRITY OF PRODUCT STRUCTURE**

<table>
<thead>
<tr>
<th>Property</th>
<th>Method</th>
<th>Secondary Reinforcement Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction Efficiency, % of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>GRI-GG2-87 @ 10% / min</td>
<td>S1: 93  S2: 93</td>
</tr>
<tr>
<td>Flexural Stiffness* mg-cm</td>
<td>ASTM D1388, Option A</td>
<td>250,000  750,000</td>
</tr>
<tr>
<td>Aperture Stability**</td>
<td>Corps of Engineers</td>
<td>3.2  6.5</td>
</tr>
</tbody>
</table>

Unless noted otherwise, values shown are for the cross machine direction and represent minimum average roll values with the exception that Flexural Stiffness, which is determined in the machine direction and represents typical values. The tensile strength at 2 percent and 5 percent strain shall be determined with this test conducted without artificially deforming test materials under load before measuring such resistance or employing an artificial secant or offset tangent basis of measurement so as to overstate tensile properties.

* Bending resistance values determined in the machine direction using specimen dimensions of 864 millimeters in length by 1 aperture in width.

**Resistance to in-plane rotation movement measured by applying a 20 kg-cm moment to the central juncture of a 9-inch by 9-inch specimen restrained at its perimeter and measured in units of kg-cm/deg.

7.2.2.2 Geosynthetic Drainage Composite

A. The drainage composite shall consist of geotextile bonded to both sides of a polyethylene net structure. Drainage products manufactured with a cusped core shall not be acceptable.

B. The minimum allowable transmissivity as per ASTM D4716-95 shall be equal to or greater than 1.5 gal. per min. per ft. of width at a confining pressure of 10,000 lbs. per sq. ft. for a gradient of 1.0.

C. The minimum allowable peel strength of the geotextile from the geonet as per ASTM F904-91 shall be equal to or greater than 250 gm. per in. of width.

7.2.2.3 Erosion Control System

A. The erosion control system shall consist of a combination of long-term nondegradable TRM, geogrid, SierraScape facing element, and/or geotextile.

B. The erosion control system can vary based on soil types, slope angle, climate, and vegetation requirements. Supplier shall provide specific erosion control system design for approval by Agency on a job-by-job basis.
7.3 Execution

7.3.1 Examination
The Contractor shall check the geogrid upon delivery to verify that the proper material has been received. The geogrid shall be inspected by the Contractor to be free of flaws or damage occurring during manufacturing, shipping, or handling.

7.3.2 Preparation
The subgrade soil shall be prepared as indicated on the construction drawings or as directed by the Engineer. Foundation soil shall be excavated to the lines and grades as shown on the drawings or as directed by the Engineer. Overexcavated areas shall be filled with compacted backfill material.

7.3.3 Installation
A. Geogrid shall be laid at the proper elevation and orientation as shown on the construction drawings or as directed by the Engineer. Where percent coverage and truncation options are shown on the plans, alternate layers of primary UX Geogrid reinforcement shall be placed in a staggered pattern such that the layer above is placed with the center line of the geogrid in alignment with the centerline of the open space below. The maximum horizontal spacing between geogrids where percent coverage design alternates are employed shall be 4 to 6 inches. Correct orientation (roll direction) of the geogrid shall be verified by the Contractor. Geogrid may be temporarily secured in place with staples, pins, sand bags, or backfill as required by fill properties, fill placement procedures, or weather conditions, or as directed by the Engineer.

B. Geogrid soil reinforcement shall be connected/spliced when required to provide continuity of tensile resistance. Geogrids manufactured using polyolefins (e.g., HDPE and PP) shall be connected with a mechanical polymer bar. Geogrids manufactured of polyester shall be connected by sewing with Kevlar sewing thread perpendicular to the direction of loading at the ends of the materials.

C. Overlap connections may be used if the Contractor provides the Engineer independent test documentation which demonstrates that the load/deformation characteristics of the overlap of geogrid materials is equal to or exceeds those of the geogrid. The minimum overlap shall be 5 feet.

7.3.4 Fill Placement Over the Geogrid

## VERIFY SECTION NUMBERS AND TITLES

A. Backfill material shall be placed in lifts and compacted as directed under Section 02300. Backfill shall be placed, spread, and compacted in such a manner that minimizes the development of wrinkles in and/or movement of the geogrid.

B. Tracked construction equipment shall not be operated directly on the geogrid. A minimum fill thickness of 6 inches is required prior to operation of tracked vehicles over the geogrid. Turning of tracked vehicles should be kept to a minimum to prevent tracks from displacing the fill and damaging the geogrid. Rubber-tired equipment may pass at slow speeds (less than 10 mph) over extruded polyolefin geogrid reinforcement placed atop competent substrate. Sudden braking and sharp turning shall be avoided. Rubber-tired equipment shall not pass over polyester geogrid reinforcement. A minimum fill thickness of 6 inches is required prior to operation of rubber-tired equipment over polyester geogrid reinforcement.

7.3.5 Repair
A. Any geogrid damaged during installation shall be replaced by the Contractor at no additional cost to the Owner.

B. Coated geogrids shall not be used if the coating is torn, shedding, cracked, punctured, flawed or cut, unless a repair procedure is carried out as approved by the Engineer. The repair procedure shall include placing a suitable patch over the defective area or applying a coating solution identical to the original coating.

7.3.6 Protection
Follow the Manufacturer’s recommendations regarding protection from exposure to sunlight.
8.0 SIERRA INSTALLATION GUIDE

Step 1 – Site Excavation. The site should be properly excavated to the lines and grades as shown on the construction drawings or as directed by the Engineer. Excavation should include removal of soil to ensure firm foundation and benching the back cut into competent soils to improve stability.

Step 2 – Internal Drainage. Drainage composite shall be rolled out onto the benched back cut prior to installation of geogrid and fill placement. Roll drainage composite up the back cut until approximately 2/3 of the reinforced slope height is reached. Drainage composite is typically placed to achieve 30% coverage unless design considerations dictate otherwise. The drainage composite is normally terminated against a slotted drain pipe within geotextile wrapped gravel (See Figure 8.1).

Step 3 – Geogrid Lengths and Types. Two types of Tensar structural geogrids are used in Sierra Slopes: Uniaxial (UX) and Biaxial (BX). These terms refer to the number of directions in which a punched sheet of polymer has been drawn in the manufacturing process. Uniaxial has one direction of draw and biaxial has two. (Figure 8.2)

For construction using Tensar UX Geogrids, the longitudinal roll direction must be oriented perpendicular to the slope face. In construction using Tensar BX Geogrids, the transverse roll direction is typically oriented perpendicular to the slope face. A simple check of Tensar UX Geogrid orientation is to ensure that the longer of the two geogrid aperture axes is perpendicular to the slope face alignment.

Primary reinforcement lengths are typically longer than secondary reinforcement lengths and may vary with location and elevation. Generally, secondary reinforcement length is the same throughout the slope.

Simple procedures can minimize the potential installation of incorrect geogrid lengths. For construction expedience, the geogrid reinforcement is often cut to length in a staging area. These cut lengths are then stockpiled and marked or tagged to indicate their length.
A potential problem can arise on projects where two different geogrids are utilized. For instance, different grades of Tensar UX Geogrids may look very much alike. Confusion between different structural geogrids can be eliminated by proper separation during stockpiling, precutting, and tagging operations. The geogrids may also be color coded with spray paint.

**Step 4 – Geogrid Placement.** Geogrid layers should extend back from the slope face to the distance specified and placed at the elevations shown on the construction drawings. (Figure 8.3) Adjacent geogrid strips should be butted together side-by-side without overlap (Note: A small overlap may be specified for wrap-around construction of the slope face). Some designs may call for partial coverage requiring a space between geogrid strips. Soil is usually piled on the ends of the strips or use of “U” shaped ground anchors to avoid movement of the geogrids during fill placement.

Care must be taken to prevent slack from becoming trapped within the geogrid as fill is placed. Tracked construction equipment must not be operated directly upon the geogrid. Rubber-tired equipment may pass over the geogrid at slow speeds. Sudden braking and sharp turning that can displace geogrids from their intended positions should be avoided.

Overlapping geogrids on convex curves of slope alignments should be separated by at least three inches of compacted slope fill. Geogrids on concave curves may simply diverge from the slope face as shown in Figure 8.4.

**Step 5 – Common Fill and Topsoil Fill Placement.** Fill can be placed and spread directly upon the geogrids. Compact the soil to specifications using standard equipment and procedures (Figure 8.5 and 8.6). Lift thickness should be great enough to ensure that sheepsfoot will not come in direct contact with the geogrid.

Topsoil is typically placed up to a depth 1–2 feet back from the slope face during the fill placement process. This insures that an adequate layer of topsoil is in place to support vegetation and be reinforced by the geogrid reinforcement.
During construction, soil may cascade over the slope edge and begin to pile up on the slope face. This soil should be removed to insure a consistent grade is maintained. Failure to remove this soil will result in localized sliding of the slope face. Typically, the slope face will be overbuilt 2–4 feet to achieve adequate compaction. The slope face can be cut back to final grade by the use of a backhoe with a smooth bucket. Care should be taken to insure that grid layers are exposed at the face of the slope indicating that geogrid reinforcement extends completely to the slope face.

The final treatment of the slope face may require compaction to create a relatively smooth surface to ensure adequate performance of the erosion control system.

**Step 6 – Erosion Control System.** The erosion control system is often constructed at the completion of the slope after all other construction is completed. This method is usually limited to slopes that are 45° or flatter and do not require a wrap technique. Placement of a long-term non-degradable erosion blanket can be done quickly and easily with a minimum of hand labor. Beginning at the crest of the slope bury the transverse terminal end of the blanket to secure and prevent erosive water flow underneath (Figure 8.7). Unroll blanket from top of the slope face and secure with 8 in. - 12 in. “U” shape metal staples. Blanket should lay flat. DO NOT PULL BLANKET TAUT. Pulling taut may cause blanket to bridge depressions in the surface and allow erosion underneath. Refer to Manufacturer’s Installation Guidelines for specific details. Temporary erosion control measures during and shortly after construction must be taken to ensure proper establishment. Water must be prevented from overtopping the slope crest and forming erosion ruts in the face of the slope. Design considerations must be taken to pipe or channel water away to the toe of the slope.

**Wrapped Face System.** Slopes steeper than 45°, landscaped slopes, and rock faced slopes will typically require a wrapped face system. SierraScape facing elements should typically be used for this purpose. TET’s SierraScape System provides superior protection against surficial slope failure during and immediately following construction where vegetation is being established. In addition, SierraScape facing elements serve as forming devices to ensure a consistent slope angle and enhance compaction at the face. A typical wrapped-face system is shown in Figure 8.8. Other techniques using welded wire or boards may be used. Consult your manufacturer representative for details on these systems.
Step 7 - Vegetation Installation. The landscape design of a Sierra Slope will specify details on vegetation choices and installation. Common methods used for establishment of grass or wildflowers are to hydroseed, dry spread seed, or sod. Seed or sod is placed by these techniques on the prepared soil of the slope face and held in place by geogrids or long-term non-degradable erosion mattings. Landscaped or revegetated native slopes will typically require the use of containerized, balled and burlap, or bare root plantings. Planting holes are usually dug by hand using hand tools or hand-held mechanical augers. Care must be taken to ensure worker safety by the use of safety lines, ladders, and proper supervision.

9.0 MAINTENANCE & MOWING

Maintain slopes in accordance with owners specifications. Additional guidelines for mowing do’s and don’ts are as follows:

Mowing Operation Do’s

- Avoid mowing slopes steeper than 2.5:1 with a regular mower unit.
- Mow slopes steeper than 2.5:1 with side mounted mower on a boom if the tractor unit remains on flatter surfaces while mowing.
- Operate side-mounted or boom mower units on the uphill side of the tractor to limit the possibility of overturning the tractor.
- Replace broken or lost chain guards to deflect debris immediately. Using flail-type mowers reduces the amount of debris thrown.
- Cover all v-belts, drive chains, and power takeoff shafts.
- Raise mowers when crossing driveways or roadways.
- Shut off power before checking any mower unit. Block a mower before changing, sharpening, or replacing a blade. Any blade being re-installed should be checked for cracks or damage that will lead to failure.
- Using flashing signals and slow-moving-vehicle signs on all mower tractors.

- Use signs to warn traffic, such as “Mowing Ahead, Mowing Area, Road Work Ahead” or similar legends. Signs should not be more than one to two miles ahead of the mowing. Signs saying “Mowing Next ___ Miles” may be used in advance of the operation, but the distance limits should not be shorter than two miles nor longer than five miles.

Mowing Operation Don’ts

- Mow too often. This wastes money, exposes mowing crews to traffic hazards more than needed, and can damage the vegetation.
- Mow at the wrong time. Good timing reduces the frequency of mowing required by cutting the vegetation in the right stage of growth.
- Mow too short. Leaving the proper height helps maintain the stand of vegetation and keeps small litter objects hidden.
- Mow steep slopes if you don’t need to. Steep slope operations increase risk of mower accidents.
- Mow patterns inconsistently and mow a regular area incompletely. Drivers watch the pattern of a mowed area to help understand the safety of an area. Consistent mowing of similar areas helps drivers evaluate the safety of the roadway.
- Mow when wet. This is hard on equipment.
- Operate equipment carelessly and scar trees and shrubs. Mowing is tedious but care must be taken to avoid accidents and preserve valuable plantings.
APPENDIX A
REINFORCED FILL SOIL
PARAMETERS

A.1 Gradation, Plasticity Index, and
Chemical Composition

Gradation9: Recommended backfill requirements
for MSE slopes per FHWA4 are:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 inch</td>
<td>100-75</td>
</tr>
<tr>
<td>No. 4</td>
<td>100-20</td>
</tr>
<tr>
<td>No. 40</td>
<td>0-60</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-50</td>
</tr>
</tbody>
</table>

Definition of total and effective stress shear
strength properties become more important as
percent passing the No. 200 sieve increases.
Likewise, drainage and filtration design are
more critical.

Plasticity Index9. \( \text{PI} \leq 20 \) (AASHTO T-90) and a
magnesium sulfate soundness loss < 30% after 4
cycles is required.

Note that fill materials outside of these
gradation and plasticity index requirements
have been used successfully9,44. Performance
monitoring is recommended if fill soils fall
outside of the requirements listed above.

Chemical Composition. The chemical
composition of the fill and retained soils should be
assessed for affect on durability of reinforcement
(pH, chlorides, oxidation agents, etc.). Soils with
\( \text{pH} > 12 \) or with \( \text{pH} \leq 3 \) should not be used
in Sierra Slopes12. A pH range \( \geq 3 \) to \( \leq 9 \) is
recommended. Specific supporting data should
be required if \( \text{pH} > 9 \).

A.2 Soil Fill Design Properties

Shear Strength. Peak shear strength parameters
should be used in the analysis8. Effective stress
strength parameters \( (\phi', c') \) should be used for
granular soils with less than 15% passing the
No. 200 sieve. Parameters should be determined
using direct shear or consolidated-drained (CD)
triaxial tests.

For all other soils, peak effective stress and total
stress strength parameters should be determined.
These parameters should be used in the analysis
to check stability immediately after construction
and long-term. Use consolidated drained (CD)
direct shear tests (sheared slowly enough for
adequate sample drainage) or consolidated-
undrained (CU) triaxial tests with pore water
pressures measured for determination of total
stress parameters.

It is recommended that shear strength testing be
conducted. However, use of assumed shear values
based on agency guidelines and experience may
be acceptable for some projects. Verification of site
soil type(s) should be made after excavation is
made or borrow pit identified, as applicable.

Unit Weights. Dry unit weight for compaction
control, moist unit weight for analysis, and
saturated unit weight for analysis (where
applicable) should be determined for the fill soil.

A.3 Topsoil

Successful vegetation establishment and survival
is a key component in the long-term design of
an MSE slope. Consequently, based on local
conditions, placement of a topsoil may be
required. Topsoil qualities can vary widely but
typically a topsoil fill classified in the AASHTO
A-2-6 to A-2-7 ranges can be used. A minimum of
2% organic matter is also valuable to successfully
support plant life.
APPENDIX B
VEGETATION AND EROSION
CONTROL SYSTEM
SELECTION GUIDELINES

B.1 Vegetation Facing Selection

A key feature of the Sierra System is the flexibility it offers the designer to create an attractive and natural facing. Selection of the vegetation component is an integral part of the overall design of the erosion control system. Vegetation should be selected to blend with or accent existing site conditions. Slope angle should also be considered when the vegetation selection is made. There are four primary types of vegetation facings available. Table B.1 below describes these options and typical sites where they can be used.

B.2 Erosion Control System Selection

After the desired slope angle and vegetation selection are made an erosion control system can be designed. The typical erosion control system will employ a biotechnical design. Engineering design techniques and horticulture experience are used to combine geosynthetic materials and vegetation to create a stable slope facing system. These options can be divided into three groups based on slope angle. Table B.2 on the following page describes the most common erosion control products and vegetation options used on Sierra Slopes.

Table B.1
Recommended Maximum Slope Angle and Typical Sites
For Vegetation used on Sierra Slopes

<table>
<thead>
<tr>
<th>Type of Vegetative Facing</th>
<th>Slope Angle</th>
<th>Recommended Typical Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass or Crown Vetch</td>
<td>1/2:1 or flatter</td>
<td>- Downslope roadway embankment</td>
</tr>
<tr>
<td>Wildflower</td>
<td>1:1 or flatter</td>
<td>- Backside or low visibility side of development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Rural site</td>
</tr>
<tr>
<td>Landscaped Slope</td>
<td>1:1 or flatter</td>
<td>- Upslope roadway embankment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Native landscape setting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Suburban setting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Rural site</td>
</tr>
<tr>
<td>Native Planting</td>
<td>1:1 or flatter</td>
<td>- Urban or suburban road widening</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Property entrance or frontage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Homeowners slope</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Native rural landscape</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Wetlands site</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Arid mountain side</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Reforested area</td>
</tr>
</tbody>
</table>
## Table B.2
### Erosion Control System Selection Guidelines

<table>
<thead>
<tr>
<th>Slope Angles</th>
<th>Vegetation¹</th>
<th>Erosion Control System Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:5:1 Flatter</td>
<td>Grass, crown vetch or wildflower mix</td>
<td>Excelsior Blanket Straw Blanket Geosynthetic Erosion Blanket</td>
</tr>
<tr>
<td></td>
<td>Landscape slope planted shrubs in mulched bed</td>
<td>Geotextile wrapped face²</td>
</tr>
<tr>
<td></td>
<td>Native planting seeded native grasses, ground covers, and planted shrubs or trees</td>
<td>Excelsior Blanket Geosynthetic Erosion Blanket</td>
</tr>
<tr>
<td>1:1 - 1:5:1</td>
<td>Grass crown vetch or wildflower mix</td>
<td>Geosynthetic Erosion Blanket</td>
</tr>
<tr>
<td></td>
<td>Landscaped slope with planted shrubs in mulched bed</td>
<td>Geosynthetic wrapped face²</td>
</tr>
<tr>
<td></td>
<td>Native planting using seeded native grasses, ground covers, and planted shrubs or trees</td>
<td>Geosynthetic Erosion Blanket</td>
</tr>
<tr>
<td>1/2:1 – 1:1</td>
<td>Grass sod held by geogrid wrap</td>
<td>Tensar BX Geogrid wrapped face with wire forms</td>
</tr>
<tr>
<td></td>
<td>Grass and crown vetch seeded mix</td>
<td>Geotextile and geogrid wrapped face with wire forms</td>
</tr>
<tr>
<td></td>
<td>Grass seeded mix applied through erosion blanket</td>
<td>Geosynthetic Erosion Blanket and Tensar BX Geogrid wrap with wire forms</td>
</tr>
</tbody>
</table>

¹ General recommendations on vegetation options are outlined in Sierra Slope Facing Selection Manual.
² Use a professional grade landscape fabric or 6 oz. (min.) needle-punched nonwoven geotextile.
REFERENCES


