U.S. Guidelines for Reinforced Slopes in Transportation Applications

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ABSTRACT: Comprehensive guidelines for the design, specification and contracting of mechanically stabilized earth slopes on firm foundations were recently developed by the Geotextile Division of the Industrial Fabrics Association International (IFAI) in conjunction with the U.S. Department of Transportation, Federal Highway Administration (FHWA). The key features and elements of these guidelines, which represent the recommended practice in the United States, are summarized within. This paper is directed toward specifiers and designers of geosynthetic slopes, both for government and private projects.

1 INTRODUCTION

Geosynthetic mechanically stabilized earth (MSE) slopes are soil structures constructed at angle of repose greater than the soil's angle of friction. MSE slopes consist of the four primary components of soil, geosynthetic reinforcement, erosion protection, and drainage, as shown in Fig. 1. MSE slopes are an economical alternative to conventional highway construction of flattened slopes, select-fill embankments, or retaining walls.

An FHWA document on the design, specification, and contracting of geosynthetic MSE slopes on firm foundations (Berg, 1993) has recently been published to provide guidance to transportation agencies for utilization of reinforced slopes. These guidelines are available from the IFAI and the FHWA. The guidelines are based upon published FHWA guidelines and research reports. The guidelines address both a material specification approach and a system specification approach. Objectives of the guideline are to: i) obtain agency-wide uniformity; ii) establish standard procedures for review, specification, and acceptance of geosynthetics used in MSE slope construction and for MSE systems; iii) establish standard procedures for design, specification, and contracting of MSE slopes; and iv) to establish and delineate responsibilities for review, design, and construction control.

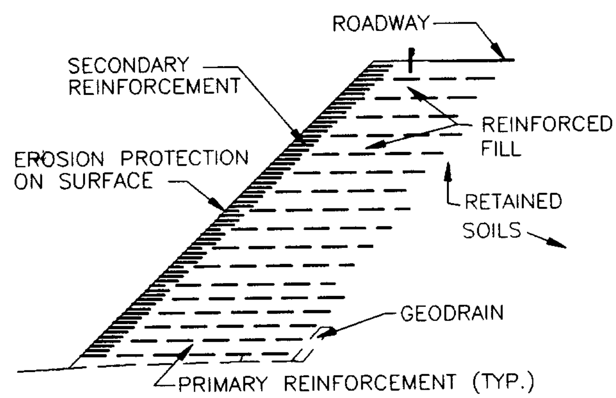

Fig. 1 Cross section of an MSE slope

2 MATERIAL EVALUATION GUIDANCE

2.1 Soil fill

Recommended fill gradation requirements for reinforced slopes are: 100-75% < 100 mm; 100-20% < 4.75 mm; 60-0% < 0.425 mm; and 50-0% < 0.075 mm. The maximum size should be limited to 20 mm unless tests are performed to evaluate geosynthetic strength reduction due to installation damage. It is also recommended that the fill plasticity index (PI) ≤ 20. Performance monitoring is recommended if fill soils fall outside of these requirements.

Chemical composition of the fill and retained soils should be assessed for their effect on durability of the reinforcement (pH, oxidation agents, etc.). Soils with pH ≥ 12 or with pH ≤ 3 should not be used in reinforced slopes (TF 27 Report, 1990). A pH range ≥ 3 to ≤ 9 is recommended. Specific supporting test data should be required if pH > 9.

2.2 Allowable long-term geosynthetic tensile strength

Allowable tensile strength (T_a) of the geosynthetic shall be determined using a partial factor of safety (FOS) approach. The allowable geosynthetic design strength, T_a, is:

$$T_a = \frac{T_{ult}}{FS_{CR} \times FS_{ID} \times FS_{CD} \times FS_{BD} \times FS_{JNT}}$$

where: T_a = allowable geosynthetic tensile strength (kN/m), for use in slope stability analyses; T_{ult} = ultimate geosynthetic tensile strength (kN/m); FS_{CR} = partial FOS of creep, ratio of T_{ult} to creep limiting strength (dimensionless); FS_{ID} = partial FOS for installation damage (dimensionless); FS_{CD} = partial FOS for chemical degradation (dimensionless); FS_{BD} = partial FOS for biological degradation, used in environments where biological degradation potential may exist (dimensionless); and FS_{JNT}= partial FOS for joints/seams (dimensionless).

Use of default partial FOS values is allowed for some parameters when actual test documentation is not available. Recommended default values are: 3.0 for installation damage; 5.0 for creep; 2.0 for chemical degradation; 1.3 for biological degradation; and 2.0 for joint/seam strength.

2.3 Soil-reinforcement interaction

Design of reinforced slopes requires an evaluation of the geosynthetic pullout performance. A normalized definition of pullout resistance is recommended as presented in FHWA Reinforced Soil Structures (Christopher et al., 1989). Pullout resistance can most accurately be obtained from pullout tests performed in the specific, or representative, project fill. Testing produces coefficients that may be classified as either short-term or long-term. Design of geosynthetic reinforced soil slopes for permanent applications require use of long-term interaction coefficients.

Direct shear coefficients are used in checking FOS against outward sliding of the entire reinforced mass. Soil-geosynthetic direct shear resistance should be determined with geosynthetic direct shear performance tests.

3 DESIGN GUIDANCE

3.1 Stability analysis

The techniques used for analysis of MSE slopes are extensions of routine slope stability procedures. An MSE slope, however, is more complex than an unreinforced slope and requires more steps in the analytical process. 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; and iii) compound, where the failure surface passes behind and through the reinforced soil mass. Chart-form solutions and computer programs are available for analysis of MSE slopes.

Permanent, critical reinforced structures should be designed using comprehensive slope stability analyses. Comprehensive slope stability analysis requires the use of a computer program. Several reinforced slope programs are commercially available, and one is currently being developed by the FHWA. Computer programs should directly incorporate tension of each reinforcement layer into the safety factor computations. Programs also should directly include anchorage, or pullout, length requirements in computation of mobilized reinforcement tension. The factor of safety for slope stability should be adequate to address all uncertainties in the assumptions and design.

The recommended method of seismic analysis for earth slopes is a pseudo-static analysis with a slope stability computer program. The magnitude of the pseudo-static force coefficient will typically be dictated by local codes and/or practice. A detailed map of seismic risk is presented in the AASTHO Bridge Manual (1991). However, 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.

3.2 Drainage

Surface water runoff should be collected above the reinforced slope and channeled or piped below the slope. Standard agency drainage details should be utilized.

Geosynthetic drainage composites can be utilized in subsurface drainage design. Drainage composites should be designed with consideration of: i) geotextile filtration/clogging; ii) long-term compressive strength of the polymer core; iii) reduction of flow capacity due to intrusion of geotextile into the core; and iv) long-term inflow/outflow capacity. Long-term compressive stress and eccentric loadings on the core of a geocomposite should be considered during design and selection. The following criteria are suggested for addressing core compression. The design pressure on a core should be limited to either the: i) maximum sustained pressure in a test of 10,000 hour minimum duration; or ii) crushing pressure, as defined with a quick loading test, divided by a factor of safety of 5. For cases where a crushing pressure cannot be defined, suitability should be based on required flow capacity.

Intrusion of the geotextiles into the core and long-term outflow capacity should be measured with a sustained transmissivity test. Load should be maintained for 300 hours or until equilibrium is reached, whichever is greater.

3.3 Erosion control

Reinforced slopes should be vegetated after construction to prevent or minimize erosion due to rainfall and runoff. Consequently a synthetic erosion control mat that is stabilized against ultra-violet light and is inert to naturally occurring soil-born chemicals and bacteria may be required. The erosion control mat serves three functions: 1) protects the bare soil face against erosion until vegetation is established, 2) reduces runoff velocity for increased water absorption by the soil thus promoting long-term survival of the vegetative cover, and 3) reinforces the root system of the vegetative cover.

A permanent mat may not be required in applications with flatter slopes ($< 1:1$), short slopes, and/or moderate runoff. A temporary (degradable) erosion blanket may be specified to protect the slope face and promote growth until vegetative cover is firmly established. Temporary erosion control material should not be used where the calculated flow-induced tractive shear stress on such slopes could exceed 96 N/m^2 (Chen and Cotton, 1987).

4 REVIEW AND APPROVAL PROCEDURES

Reinforced soil slopes may be contracted using two different approaches: i) in-house (agency) design with geosynthetic reinforcement, drainage details, erosion measures and construction execution specified; or ii) system or end-result approach using approved systems, with lines and grades noted on the drawings. Both approaches are acceptable if properly implemented. Each approach has advantages and disadvantages.

4.1 Initial approval of materials

Material approval is needed for both the in-house design approach and the end-result approach. Any proprietary material should undergo an agency review prior to inclusion as either an alternate offered during design or construction phase. The manufacturer/supplier must submit a package for review that satisfactorily addresses: a) geosynthetic material development; b) capability to supply material; c) polymer and additive composition of geosynthetic, including any coating materials; d) descriptions and photos of applications; e) limitations and disadvantages of the material; f) representative list of transportation users; g) sample long-term design strength and interaction values, and index property specifications; and h) typical unit costs. Furthermore, the submittal package should satisfactorily document, per these guidelines (Berg, 1993) the required laboratory tests for quantifying the partial FOS values used in computation of allowable design strength and the long-term soil-interaction values.

4.2 Initial system approval

A reinforced slope system from an approved supplier consists of: i) sealed design calculations and construction drawings; ii) geosynthetic reinforcement material; iii) erosion measures; iv) drainage details; and v) construction site assistance. Any system must undergo an agency approval prior to inclusion as either an alternative or experimental feature during design, or as a value engineering alternate offered during construction.

The supplier must submit a package for review that satisfactorily addresses: a) system development history; b) system supplier organization structure, specifically engineering and construction support personnel; c) limitations and disadvantages of system; d) list of users; e) erosion control details as a function of climatic, geographic, and slope steepness; f) sample material and construction control specifications - showing material type, quality control, certifications, field testing, acceptance and rejection criteria, and placement procedures; g) a field construction manual describing in detail, the step-by-step construction sequence; h) typical unit costs, supported by data from actual projects; and i) detailed information on slope design and slope stability analysis techniques.

5 CONTRACTING & SPECIFICATION GUIDANCE

Reinforced slopes may be designed in-house or may be designed by a geosynthetic reinforcement supplier based upon a performance specification. Geosynthetic reinforcement, erosion measures, and drainage details need to be specified when contracting an in-house design. Line and grade drawings, erosion control design and a specification for a system must be provided by the agency for the second option. Geosynthetic reinforcement, drainage composite, and erosion control materials must be reviewed in conformance with agency requirements and accepted, prior to their use in construction of reinforced slopes.

5.1 Material specification approach

Some agencies may elect in-house design. Then, a fully detailed set of reinforced slope plans and material specifications prepared by the agency will be contained in the bidding documents. Agencies may elect to design all structures in-house or may elect to only design the more typical and/or less critical structures.

Detailed construction plans, furnished by the agency in the bidding documents shall include all details, dimensions, quantities and cross sections necessary to construct the slope(s). The geotechnical report shall be made available for inspection by the bidders and suppliers. The fully detailed plans shall be prepared to agency standards and shall include: a) plan and elevation sheet; b) typical details of primary and secondary reinforcement, and material specification reference; c) surface water drainage details; d) facing details for erosion control, and material specification reference; e) temporary slope face support, if required; f) all details for slope construction around drainage facilities, overhead sign footings, and abutments; and g) geotechnical report and design computations.

5.2 System specification approach

An agency may use a conceptual plan approach. Then, detailed reinforced slope plans will not be contained in the bidding documents. The conceptual plan, furnished by the agency in the bidding documents will contain the geometric, geotechnical, and design project specific information. Bid documents should require that bidders indicate the slope system supplier they intend to use. Within thirty days of contract award and a minimum of sixty days prior to slope construction, the Contractor must submit a detailed design and shop drawings for approval.

The final design shall include detailed design computations and all details, dimensions, quantities and cross sections necessary to construct the slope(s). The detailed plans shall be prepared to agency standards and shall include: a) plan and elevation sheet; b) typical details of primary and secondary reinforcement; c) facing details for erosion control; d)temporary slope face support, if required; e) all details for construction of slope around drainage facilities, overhead sign footings, and abutments; f) detailed design computations; g) statement of design responsibility, in accordance with agency requirements; and h) the plans and design computations shall be prepared and sealed by a professional engineer, licensed in the State.

6 RECOMMENDATIONS

It is recommended that individual transportation agencies develop and document the following procedures for implementation of the proven technology of MSE slopes: (i) review and approval of soil reinforcing materials; (ii) review and approval of drainage composite materials; (iii) review and approval of erosion control materials; (v) in-house design of reinforced slopes; and (iv) review and approval of geosynthetic reinforced slope systems and system suppliers; (vi) contracting for outside design and supply of reinforced slope systems.

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