Stabilizing Embankments Using Geosynthetic Reinforcement

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Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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Research Report
KTC-25-16

Stabilizing Embankments Using Geosynthetic Reinforcement

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16. Abstract

Reinforced soil slopes (RSSs) can be a feasible solution for embankments where there exist right of way restrictions, environmental issues, rolling or mountainous topography, unfavorable geology, and other limiting factors. They can be an alternative to retaining walls or importing select fills to construct steeper, stable embankment slopes where flatter embankment slopes may result in unwanted impacts, costs, and maintenance issues. This report discusses the advantages and limitations of using geosynthetic reinforcement to construct RSSs. Researchers investigated current design, specification, and construction practices to determine which practices can be adopted by the Kentucky Transportation Cabinet (KYTC). Specifications were developed for using locally available soil materials to construct RSSs where select granular fill is not readily available or cost prohibitive. A standard RSS design was developed that reduces design and review time, supports a more equitable bid environment for contractors, and encourages further use of the technology. Researchers also updated KYTC's Special Note for Reinforced Soil Slopes and prepared guidance on using RSSs. It expands on information in the Cabinet's *Geotechnical Guidance Manual* and includes information on design requirements, selection of an appropriate earth retention system, design methodologies, material selection, and plan development. The results of the study can help KYTC expand use of RSSs as well as the use of locally available soils for constructing RSSs, when appropriate.

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Executive Summary

Reinforced soil slopes (RSSs) can be a feasible solution for embankments where there exist right of way restrictions, environmental issues, rolling or mountainous topography, unfavorable geology, and other limiting factors preventing the use of flattened embankment slopes. They can be an alternative to retaining walls or importing select fills to construct steeper, stable embankment slopes when flatter embankment slopes result in unwanted impacts, costs, and maintenance issues.

Reinforced fills are typically constructed with granular materials with less than 50 percent of the material passing the No. 200 sieve so they are free-draining. Locally available soil materials (e.g., some silts and clays) can be used to construct reinforced fills if the soil parameters are well known, appropriate construction procedures are followed, and drainage features are included to prevent saturation of reinforced fill. Using locally available soil as reinforced fill can be a viable alternative to importing select fills, particularly if sources of select fill are not near the construction site.

This report outlines requirements for reinforced fill consisting of locally available soil that are inclusive of common soil types found throughout Kentucky. Because Standard RSS designs can provide an economical solution for smaller projects, researchers developed a standard design that can be used by the Kentucky Transportation Cabinet (KYTC). The design includes reinforcement details and construction requirements. It was established with minimum variation across possible designs to simplify construction, reduce the risk of construction errors, and encourage the use of the standard. Standard RSS designs are limited to certain embankment heights, groundwater conditions, loading conditions, soil types, and foundation conditions. Advantages of the standard designs are they require less personnel time for design, establish a more equitable bid environment for contractors, and provide KYTC more opportunities to utilize the technology.

Researchers evaluated current design, specification, and construction practices to identify practices that may be adopted by KYTC. The Cabinet's Special Note for Reinforced Soil Slopes was updated and a guidance document for the use of RSSs prepared. This guidance expands on the information in KYTC's *Geotechnical Guidance Manual* and includes information on design requirements, selection of an appropriate earth retention system, design methodologies, material selection, and plan development.

Materials generated as part of this study can help KYTC grow its use of RSSs and the use of locally available soils for construction of reinforced fills as appropriate. Recommended steps for implementing study results include developing approved lists of geogrid materials, developing prequalification for manufacturers and/or suppliers of RSS systems, piloting the standard RSS design, identifying locations where RSSs are viable alternatives to retaining walls, evaluating previously constructed RSSs, and revising special notes and guidance as needed.

Chapter 1 Introduction

1.1 Background and Problem Statement

Kentucky highway construction projects frequently involve moving earth materials to create cuts and embankments to achieve target alignments and grades. Excavated materials from cuts are typically used to construct embankments, and the characteristics of these materials directly influence embankment slope stability. Materials such as limestone, sandstone, and durable shales have higher strengths and allow embankments to be constructed with steeper slopes. Materials such as clays, silts, and non-durable shales have lower strengths and require flatter slopes to provide adequate stability.

In areas with right-of-way restrictions, environmental issues, rolling or mountainous topography, unfavorable geology, and other limiting factors, flatter embankment slopes may result in unwanted impacts, costs, and maintenance issues. Common approaches in these instances are to construct retaining walls or import select fill materials (e.g., crushed stone) to construct steeper, stable embankment slopes. Another option entails using geosynthetics to provide soil reinforcement. Soil reinforcement allows for stable embankments to be built at typical slope angles, particularly when using locally available soil which could require flatter slopes when unreinforced. It can also enable construction of over-steepened slopes when typical embankment slope angles are not feasible or desirable. If sufficient right of way is available to construct typical or over-steepened slopes with reinforcement, this option is often less expensive than constructing a retaining wall or importing select fill.

The use of geosynthetic reinforcement for construction of mechanically stabilized earth (MSE) walls and reinforced soil slopes (RSSs) in the United States began in the 1970s and has grown since then. Design and construction guidelines for MSE walls and RSSs are well-documented, however, KYTC has utilized RSSs sparingly. Current KYTC specifications for RSSs are performance-based and require the use of a granular, free-draining material as the reinforced fill. Fill material is usually crushed stone with a specific gradation, and the use of soil and rock materials from roadway excavation are often excluded.

1.2 Objectives

This study highlights the advantages and limitations of using geosynthetic reinforcement to construct RSSs. We investigated current design, specification, and construction practices to determine which practices can be adopted by KYTC. Our team also evaluated the use of locally available soil materials for constructing RSSs where select granular fill is not available or cost prohibitive. A standard RSS design was developed that reduces design and review time, supports a more equitable bid environment for contractors, and encourages further use of the technology. The study can help KYTC expand use of RSSs as well as the use of locally available soils for constructing RSSs, when appropriate.

Chapter 2 Literature Review

2.1 Reinforced Soil Slopes

RSSs consist of horizontal, or nearly horizontal, planar reinforcing elements placed within a soil mass to resist outward movement of reinforced fill (Berg et al., 2009). Figure 2.1 shows an example of a RSS. Reinforcements are typically geosynthetics — geotextiles, geogrids, or a combination of both — although metallic strips and grids can be used. RSSs can have slopes up to 70°. Slopes greater than 70° are considered walls and should be designed accordingly.

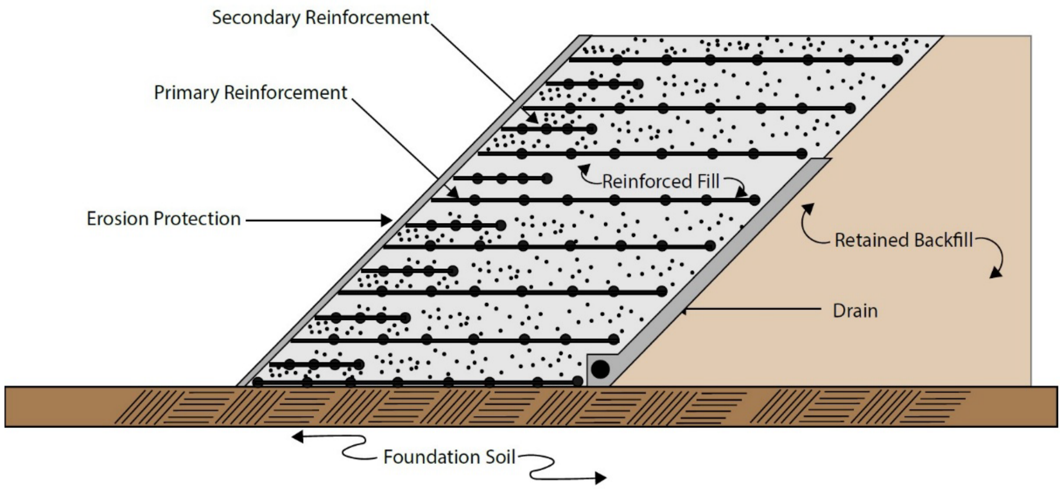

Figure 2.1 Generic cross section of a reinforced soil slope structure

RSSs can be cost-effective where the cost of fill, right of way, and other considerations make steeper embankment slopes the preferred option (Berg et al., 2009). Where sufficient right of way is available to construct a steeper slope, RSSs can be an alternative to a retaining wall. Reinforced fills may consist of typical embankment materials, as opposed to importing select fills, if properly designed. However, higher-quality fill materials (e.g., free-draining granular fills) introduce fewer concerns related to durability, placement, and compaction. RSSs can be less expensive than retaining walls, importing select fill, or obtaining additional right of way for unreinforced, stable embankment slopes. RSSs do require large spaces to cut and install reinforcement, and shared design responsibility for RSSs between owners and material suppliers can lead to conflicts if specifications are unclear.

Factors that influence the selection of MSE walls or RSS types include geology, topography, environmental conditions, right of way availability, size of structure, aesthetics, durability, performance criteria, material availability, experience, and cost (Berg et al., 2009). Tanyu et al. (2008) proposed a systematic process for wall system evaluation and selection to help organizations determine the most cost-effective, practical, stable, aesthetic, and environmentally compatible wall type for a specific site. This evaluation system can easily be adapted to include RSSs as an option. Using a selection matrix, 11 selection factors are weighted based on their relevance and importance to the project and site requirements. Multiple earth retention systems, including RSSs and unreinforced slopes, are then assigned a suitability rating for each selection factor. A score for each selection factor is obtained by multiplying the weight by the rating and summing the values for each factor. The highest-scoring earth retaining system can be further developed, or other high scoring systems can be presented as acceptable alternatives. An example of a selection matrix is presented in Table 2.1.

Table 2.1 Earth Retention System Selection Matrix

ERS Selection Matrix

Project Name: Example Matrix

Importance Selection Factor (ISF)		**Ground Type**	**Groundwater**	**Construction Considerations**	**Speed of Construction**	**ROW**	**Aesthetics**	**Environmental Concerns**	**Durability and Maintenance**	**Tradition**	**Contraction Practices**	**Cost**	**Displacement**	**Total Weighted Rating (WR_T)**
ERS Type	**IR**	3	2	2	3	1	1	2	2	3	1	3	3	
MSE Wall – Precast Facing	**SF**	4	1	3	3	1	4	4	3	4	2	3	2	
	WR	**12**	**2**	**6**	**9**	**1**	**4**	**8**	**6**	**12**	**2**	**9**	**6**	**77**
Gabion Wall	**SF**	3	1	3	1	4	1	4	4	1	3	1	4	
	WR	**9**	**2**	**6**	**3**	**4**	**1**	**8**	**8**	**3**	**3**	**3**	**12**	**62**
Cast-In-Place Concrete Gravity Wall	**SF**	4	1	1	1	1	4	2	4	3	4	1	2	
	WR	**12**	**2**	**2**	**3**	**1**	**4**	**4**	**8**	**9**	**4**	**3**	**6**	**58**
Reinforced Soil Slope	**SF**	4	1	1	4	4	3	1	4	2	2	4	1	
	WR	**12**	**2**	**2**	**12**	**4**	**3**	**2**	**8**	**6**	**2**	**12**	**3**	**68**
Unreinforced Embankment	**SF**	3	1	2	4	1	3	1	3	4	4	2	1	
	WR	**9**	**2**	**4**	**12**	**1**	**3**	**2**	**6**	**12**	**4**	**6**	**3**	**64**

Each SF should be rated between 1 (least suitable) and 4 (most suitable).

Modified from Tanyu et al. (2008)

RSS design is similar to the design of unreinforced soil slopes and is based on classical limit equilibrium methods modified to account for reinforcements (Berg et al., 2009). Factors of safety must be adequate for both short- and long-term conditions for all failure modes, including:

- Internal — Failure surfaces pass through reinforcing elements.
- External — Failure surfaces pass behind and underneath the reinforced zone.
- Compound — Failure surfaces pass behind and through the reinforced zone.

Figure 2.2 illustrates RSS failure modes. Wedge- or block-type failure surfaces both beyond and through the reinforced zone, deep-seated instability, and local bearing capacity failure (lateral squeeze) also require evaluation. RSSs tolerate settlement well, but excessive settlement effects must be considered if adjacent structures are supported by a RSS. The impacts of seismic activity should also be evaluated when appropriate. When external stability is not sufficient, RSSs can be combined with other foundation improvement options such as excavation and replacement, shear keys, staged construction, and ground improvement methods.

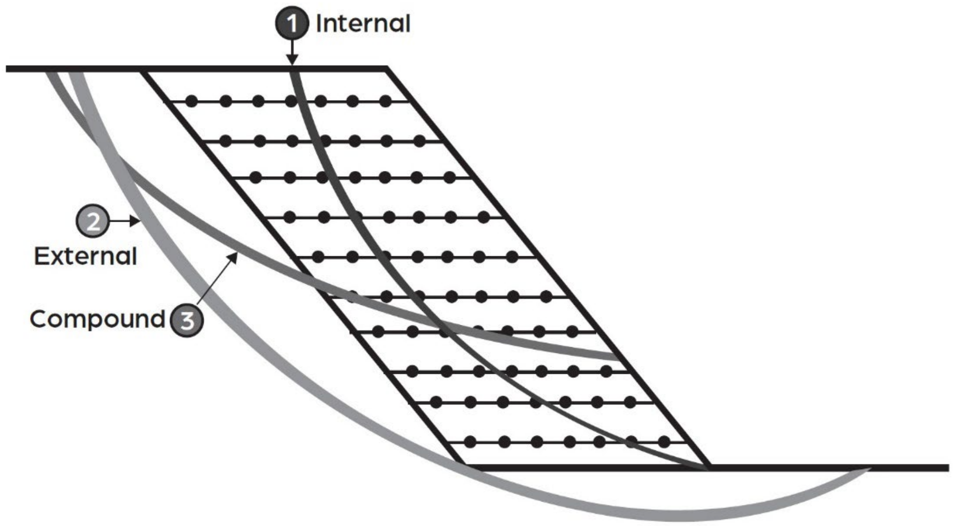

Figure 2.2 Failure Modes for Reinforced Soil Slopes

Multiple design methods have been proposed to evaluate the effects of reinforcement on soils. Kim et al. (2016) surveyed transportation agencies, educational institutions, consultants, and other personnel with experience designing or constructing RSSs about recommended design procedures. 84% of respondents recommended using the FHWA method (Berg et al., 2009) for designing RSSs. Other design methods for RSSs include but are not limited to Jewell (1991), Leshchinsky and Boedeker (1989), EBGEO (Germany), and Eurocode.

The FHWA method uses a limit equilibrium, allowable stress approach to address both short- and long-term conditions for all failure modes (Berg et al., 2009). Charts are available to help designers develop preliminary reinforcement designs which can be further refined using conventional slope stability software programs. Charts help designers determine the number of layers, length, design strength, and vertical spacing of reinforcement. They are based on limiting assumptions such as competent foundations, no seismic forces, surcharge limits, cohesionless soils, and no pore pressures within the slope. When site conditions differ from the limiting assumptions, further analysis and verification of reinforcement designs by conventional slope stability methods should be performed. Conventional slope stability software programs that account for the stabilizing effects of reinforcement are ideal for reinforced slope design, but the user must understand how the programs incorporate reinforcement into the analysis as it can impact the computed factor of safety (Berg et al., 2009).

Several authors discuss design methods and construction details for RSSs. Berg et al. (2009) provides detail on the design and construction of reinforced soil slopes in *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volumes 1 & 2*. Holtz et al. (2008) presents similar information for RSSs using geosynthetic reinforcement in *Geosynthetic Design and Construction Guidelines*. Readers should consult these documents for more information on the mechanics of soil reinforcement using geosynthetics as well as RSS design methods.

Subsurface investigations are needed to assess RSS performance (Berg et al, 2009; Samtani and Nowatzki, 2021; Kim et al., 2016; Keller, 1995; Kim et al., 2019). Properties of reinforced fill, retained backfill, and foundation soils are important factors in RSS design. Properties of particular importance include soil strength, grain size, plasticity, compaction behavior, pH, electrical resistivity, and salt content. Testing of fill material is particularly important when fine-grained or poorly draining materials are used (Keller, 1995; Samtani and Nowatzki, 2021).

Since RSSs typically involve slope faces that are steeper than normal, it is necessary to check for slope sloughing and determine if facing is needed (Berg et al., 2009). Vegetation, armoring, geosynthetic wrap, woven wire mesh (WWM), gabions, rip rap, stone veneer, modular block units, fabric-formed concrete, and structural-facing units may be used to stabilize slope faces and prevent erosion. For areas with aesthetic concerns, slope faces can be designed to blend in with the environment. RSS designs must also consider details such as guardrail, traffic barriers, drainage considerations, and obstructions that penetrate or pass through reinforced fill.

RSSs are generally constructed using continuous geosynthetic sheets (Berg et al., 2009), but geosynthetic strips, metallic strips, and welded wire mesh can be used as reinforcement. Geosynthetics may be more suitable than steel strips or grids when not using select fills because of the larger contact area and their corrosion resistance (Samtani and Nowatzki, 2021). Establishing the long-term allowable tensile strength of geosynthetic reinforcement is an essential part of RSS design. Ultimate strength of geosynthetics is reduced for long-term use due to construction damage, creep under load, and durability. Geosynthetic durability is impacted by physicochemical activity like hydrolysis, oxidation, and environmental stress, and depends on polymers used, additives, and product geometry. Some geosynthetic products, through the American Association of State Highway and Transportation Officials (AASHTO) Product Evaluation and Audit Solutions (formerly NTPEP – National Transportation Product Evaluation Program), have undergone testing to assess their strength as well as construction damage, creep, and durability reduction factors. Manufacturers of geosynthetics generally perform testing to determine these values. If using manufacturer data, it is important to ensure tests utilized the same standards and completeness as third-party testing. It is also important to verify testing is representative of the actual materials utilized onsite.

2.2 Reinforced Fill Requirements

Fill materials used in the reinforced zone are an important factor in RSS design and performance. FHWA recommends low-plasticity granular, free-draining fill material for the reinforced zone (Berg et al., 2009). Since RSSs typically have flexible facings and can tolerate some distortion, fill requirements for RSSs are usually less stringent than for MSE walls. Table 2.2 shows recommended FHWA specifications for RSS granular reinforced fill. These requirements have been selected to facilitate compaction of fill, prevent development of water pressures within fill material, and provide sufficient strength to minimize reinforcement requirements. When project-specific testing is not feasible and construction control may be in question, many agencies adopt conservative requirements for reinforced fill. However, reasonable construction control and inspection should still be performed (Berg et al., 2009; Samtani and Nowatzki, 2021).

Reinforced fill that do not comply with these requirements have been used both with and without success for both RSSs and MSE Walls (Berg et al., 2009; Samtani and Nowatzki, 2021; Marr and Stulgis, 2013; Lawson, 2005; Mitchell and Zornberg, 1995; Christopher et al., 1998; Dobie, 2011; Keller, 1995; Koerner and Koerner, 2012). Select granular fill is used to minimize deformations, minimize issues attributable to poor drainage, provide adequate shear strength, minimize excess pore pressures, and reduce difficulty in compaction; however, the use of select granular fill is not always practical if the materials are not locally available (Samtani and Nowatzke, 2021). The benefits of using locally available materials instead of select granular fill for RSS construction include reduced cost (compared to construction using expensive select fill), improved performance of compacted clay structures that would otherwise be constructed without reinforcement, and use of materials that may otherwise require disposal (Christopher et al., 1998).

Table 2.2 RSS Granular Reinforced Fill Requirements

Gradation: (AASHTO T-27)	U.S. Sieve Size	Percent Passing
	4 in. (102 mm)[a,b] ¾-inch (20 mm)[a]	100
	No. 4 (4.76 mm)	100-20
	No. 40 (0.425 mm)	0-60
	No. 200 (0.075 mm)	0-50
Plasticity Index, PI: (AASHTO T-90)	$PI \leq 20$	
Soundness: (AASHTO T-104)	Magnesium sulfate soundness loss less than 30% after 4 cycles, based on AASHTO T-104 or equivalent sodium sulfate soundness of less than 15% after 5 cycles	

Note:
(a) To apply default F* values, C_u should be greater than or equal to 4
(b) As a result of recent research on construction survivability of geosynthetics and epoxy coated reinforcements, it is recommend that the maximum particle size for these materials be reduced to ¾-in. (19 mm) for geosynthetics, and epoxy and PVC coated steel reinforcements unless construction damage assessment tests are or have been performed on the reinforcement combination with the specific or similarly graded large size granular fill. Prequalification tests on reinforcements using standard agency fill materials should be considered.

Source: Berg et al. (2009)

Using materials other than select granular fill presents challenges to the design, construction, and maintenance of mechanically stabilized structures. Koerner and Koerner (2012) evaluated failed geosynthetic reinforced MSE walls and noted the following issues that contributed to failures:

- 62% used silt or clay backfill materials in the reinforced zone.
- 75% had poor to moderate compaction.
- 90% were caused by improper design or construction.
- 58% resulted from internal or external water, while the remaining 42% were caused by soil-related issues.

Similar reasons for RSS failure have been noted by others (Berg et al., 2009; Lawson, 2005; Mitchell and Zornberg, 1995; Christopher et al., 1998; Dobie, 2011; Keller, 1995). However, the use of soil-like fill materials with a high proportion of fines can be successful if the following items are considered during the selection, design, and construction of a structure:

- The structure is specifically designed for the strength properties of fill material used.
- Drainage is provided to mitigate the generation of pore pressures in reinforced fill from seepage or infiltration. Surface drainage should be controlled to prevent infiltration into fill.
- Fill is placed properly, including control of lift heights, compaction effort, moisture content, and density.
- Soil materials with high plasticity or volume change potential are avoided.
- Durability and corrosion of reinforcements are evaluated with regard to the fill used.
- Tests are performed on the fill material for both design and verification purposes, including classification, strength, permeability, electrochemical, pH, moisture-density, and field density.
- Construction quality control/quality assurance (QC/QA) of the RSS is carefully monitored.

Marr and Stulgis (2013) developed guidelines and specifications to allow finer-grained materials within the reinforced zone of MSE walls. Full-scale test walls were constructed as part of the study. They found MSE wall backfill with up to 25% fines can perform adequately, but drainage provisions to prevent development of pore pressures within the reinforced fill were needed. They recommended placing a geomembrane atop the reinforced fill zone to limit surface infiltration. They emphasized the importance of testing material high in fines, including classification, strength, electrochemical, pH, moisture density, and field density.

Samtani and Nowatzki (2021) evaluated the use of soil materials other than select fill for MSE walls. They noted the use of terms such as "marginal" has a negative connation when used to describe fills as they suggest these materials are inferior. They recommended using the term Locally Available Sustainable Resources (LASR) to describe these fill materials and noted they can meet required performance criteria if appropriate design, testing, and analysis is performed. They indicated the following considerations are important when using LASR materials in MSE walls:

- Knowledge of the fill material properties is important in the selection and use of LASR materials.
- Each MSE-LASR system must be treated on a project- and site-specific basis with attention to appropriate laboratory testing and construction control.
- A project-specific risk assessment document should be developed to acknowledge potential risks associated with the use of a MSE-LASR system.
- Significantly more testing and evaluation is required with deployment of a MSE-LASR system.
- Geosynthetics may be more suitable than steel strips or grids for reinforcement of LASR applications because of the larger contact area and resistance to corrosion from salts.
- Their recommended limiting criteria for MSE-LASR wall fills closely mirrors recommended reinforced fill criteria for RSSs listed in Table 2.2.

Table 2.3 Reinforced Soil Slope Specifications Reviewed

State	Allows Soil-Like, Poorly Draining Materials as Reinforced Fill
Florida	No
Georgia	No
Kentucky	No
Minnesota	No
New York	No
North Carolina	Yes
Ohio	Yes
Pennsylvania	Yes
South Carolina	No
Tennessee	Requirements listed in plans

We reviewed RSS specifications from nine state departments of transportation (DOTs) plus KYTC. Table 2.3 lists these states and indicates whether their specifications allow the use of soil-like, poorly draining materials with a high percentage of fines as reinforced fill. Material gradations and classifications allowed as reinforced fill vary by state. States that prohibit the use of poorly draining material as reinforced fill generally follow FHWA-recommended material specifications (see Table 2.2) but adjust gradation to meet locally available select fill requirements (i.e., they comply with standard fine or coarse aggregate sizes or gradations). Often these specifications further restrict the amount of material passing No. 200 sieve to a percentage less than the FHWA-recommended value (< 50%) to help ensure material drains freely.

Other states list several types of suitable materials for reinforced fill that may include natural or processed clays, silts, sands, gravels, and aggregates. Each of these materials may have specific gradation and plasticity requirements.

States that allow poorly drained materials appear to do so to allow the use of locally available materials (e.g., use of local embankment materials or reuse of soils in landslide repairs) as opposed to importing select granular material. Soil property requirements for locally available materials in these states are generally broad; compared to the requirements for select fill, few details are provided. Where states offer details, soil property requirements limit allowable materials to low-plasticity silts and clays that have little potential for volume change. Some specifications require submitting verification tests and material samples to ensure reinforced fill material meets strength, gradation, moisture/density, and pH requirements as required by the RSS design.

2.3 Reinforced Soil Slope Contracting Approaches

RSSs are customarily designed on a project- or site-specific basis with vendors providing detailed designs after contract bid and award (Berg et al., 2009; Holtz et al., 2008). With this performance-based approach, the agency provides geometric requirements and material specifications. RSS systems and materials commonly come from a list pre-approved by a DOT, and the agency must review and approve the technology. The disadvantages of this approach are that many details are not addressed until after contract award, and the agency may not have sufficient in-house expertise to understand some technologies.

Another approach is to have the bid package contain a complete design from the agency or supplier (Berg et al., 2009). In this method the design can be developed and reviewed over a longer time. The agency is more responsible for RSS design details and integration of the RSS design with other components. Materials and material combinations are evaluated pre-bid. With this method the agency makes design decisions instead of vendors, and it requires that engineering staff be trained and experienced in RSS design and construction. Alternative designs, if allowed, must be provided and reviewed. One drawback of this method is that newer systems and components may not receive consideration.

Standard RSS designs are one option and have some advantages over a site-specific design approach (Berg et al., 2009), including:

- The agency assumes greater responsibility for design details and integrating slope design with other components.
- Materials and material combinations are evaluated and pre-approved as opposed to evaluating contractor submittals post-bid.
- Standard agency designs may be more economical versus vendors designing and stamping of each small, reinforced slope.
- The agency makes design decisions instead of vendors or contractors.
- The bid environment is more equitable as the agency is responsible for design details and vendors do not make varying, potentially incommensurable assumptions.
- Approved product lists help filter out substandard materials, systems, and designs.

Standard RSS designs are limited by geometric and subsurface conditions as well as financial constraints (Berg et al., 2009). Generic designs and materials are required for standard RSS designs, and this typically includes the development of approved product lists for soil reinforcements and face erosion materials. Standard RSS designs also use generic material properties such as shear strength and unit weight for reinforced fill, retained backfill, and foundation soils as applicable to the agency’s specifications and regional geology. Projects that do not meet these constraints should have project-specific designs.

Berg (2000) developed standard MSE wall and RSS designs for the Minnesota DOT following FHWA guidelines. He noted that standard designs were economical for small- to moderate-sized projects. RSS designs were based on limiting factors such as slope height, slope angle, surcharge, groundwater depth, soil properties, and reinforcement strengths. Project-specific designs were recommended for larger projects or where the site conditions differ from the limiting factors. Using standard RSS designs carries several benefits:

- Less personnel time is needed for design, material evaluation, construction inspection, and contract administration.
- Standard designs are more conservative than typical project-specific designs.
- Manufacturers/suppliers do not have to invest in the predesign of structures, possibly resulting in lower bid prices.

Berg et al. (2009) advocated establishing a formal policy for MSE and RSS systems. Formal policies accomplish the following:

- Ensure agencywide uniformity.
- Establish standard policies and procedures for design, technical review, and acceptance of systems and/or components.
- Establish a policy for review/acceptance of new systems and components.
- Delineate responsibility for plans prepared by consultants and material suppliers.
- Develop design and performance criteria to be used on all projects.
- Develop and update material and construction specifications to be used on all projects including:
    - Pre-approval of systems and products.
    - Review and approval of system components.
    - Review and approval of geosynthetics for establishment of a long-term allowable tensile strength.
- Establish contracting procedures by weighing the advantages/disadvantages of prescriptive or end-result– (i.e., performance) based methods and specifications.

Chapter 3 Survey on Geosynthetic Reinforced Embankments

We conducted an online survey to gain insight from practitioners about their use of geosynthetic reinforced embankments and identify organizations with existing guidelines and specifications for constructing RSSs. Appendix A includes a summary of responses and a copy of the original survey. Invitations to complete the surveys were sent to the following groups:

- Transportation Research Board Standing Committee on Transportation Earthworks, AKG50
- Transportation Research Board Standing Committee on Geosynthetics, AKG80
- International Geosynthetic Society Technical Committee on Soil Reinforcement
- International Geosynthetic Society — North America

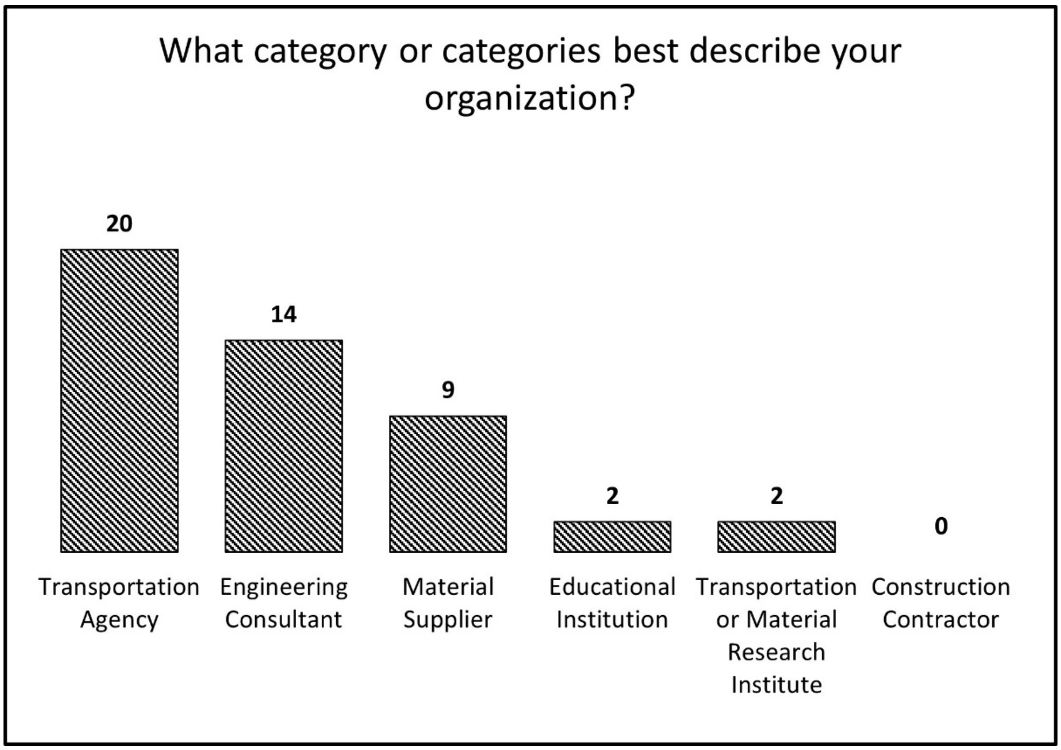

Figure 3.1 Organization Category of Responders to Survey

Forty-seven (47) respondents completed the survey. Figure 3.1 shows the categories that best describe the organizations of participants. Twenty respondents worked for transportation agencies. Along with summarizing all survey results, to understand concerns specific to DOTs we broke out the answers submitted by agency personnel. We distributed a summary of responses to those who indicated wanted a copy. A follow-up request to provide copies of RSS specifications was made to state DOTs that indicated the availability of such specifications. A summary of the survey responses is provided below, and readers are encouraged to review detailed survey information in Appendix A.

The most common ground improvement/reinforcement method used to ensure global stability of potentially unstable embankments is geosynthetic reinforcement. Piled foundations, including rigid inclusions, were another option used for embankment stabilization. Some respondents commented that selecting a method for stabilizing embankments hinges on many factors, including the nature of the instability, site constraints, type of solution, time, cost, and risk. Most respondents viewed geosynthetic reinforcement as the most cost-effective stabilization method. Comments on this question also reflected that a method's cost-effectiveness depends on the project need, size, location, site conditions, and other factors, and that several methods may meet the schedule, cost, and performance requirements.

Responses to the question about the most concerning disadvantage of using geosynthetic reinforced embankments were wide-ranging. Damage to the geosynthetic during construction garnered the most responses, followed closely by *others*, use of native soils versus granular materials, settlement, reliable geosynthetic design parameters, and installation QC/QA. Among respondents based at DOTs, the most concerning issues were installation QC/QA followed and damage to the geosynthetic during construction. This appears to reflect concerns by DOTs about having the ability to adequately monitor installation and construction. Respondents noted in their comments that their concerns could be addressed with appropriate design, specifications, and construction QC.

The FHWA method for designing geosynthetic reinforced embankments was the most recommended procedure for designing RSSs. Respondents could select more than one method for this question, resulting in 60 responses. Other design methods mentioned in the comments were EBGEO (Germany), BS (British Standards), and block sliding. Respondents noted that each method has merits and drawbacks, and that what method is used can depend on the specific situation. The Bishop and Janbu methods were used for non-rigorous computer-aided stability analyses, and Morgenstern-Price or Spencer methods were used when more rigorous stability analyses were required.

The most recommended geosynthetic materials for embankment reinforcement were geotextiles and geogrids with uniaxial geogrids garnering the most responses. Comments indicated that both geogrids and geotextiles are suitable for RSSs, but that they should not be combined due to strain incompatibility.

Responses to four yes/no questions are summarized below:

- Has your organization designed or constructed geosynthetic reinforced embankments?
  - 41 of 47 respondents (18 out of 20 DOT staffers) answered yes.
- Does your organization have a specification for geosynthetic reinforced embankments?
  - 23 of 47 respondents (14 out of 20 DOT staffers) answered yes.
- Does your organization have guidelines for geosynthetic reinforced embankment installation?
  - 27 of 47 respondents (16 out of 20 DOT staffers) answered yes.
- Is your organization currently monitoring geosynthetic reinforced embankment for long-term performance?
  - 11 of 47 respondents (3 out of 20 DOT staffers) answered yes.

The survey included a final section that let respondents provide additional comments. Several common threads ran through the responses:

- Geosynthetic reinforced embankments should be an option for stabilizing embankments; their appropriateness depends on conditions at individual sites.
- Construction QC/QA, including ensuring that materials meet specifications, is important to the successful completion and performance of RSSs.
- Both geogrid and geotextiles can be used as reinforcement successfully.
- Monitoring of completed RSSs has typically been done by visual inspection.

Chapter 4 Reinforced Backfill Materials

4.1 KYTC Granular Reinforced Fill Materials

KYTC's current specification for constructing reinforced fill for RSSs requires use of granular material. Table 4.1 shows reinforced fill specifications from FHWA and several state DOTs, including the Cabinet. DOT specifications generally follow FHWA recommendations, with some minor adjustments, although most states further limit the percentage of fill passing the No. 200 sieve to maintain free-draining fill.

Table 4.1 Granular Reinforced Soil Slope Fill Requirements

Sieve Size	Percentage Passing Given Sieve Size						
	FHWA (2009)	MoDOT	SCDOT	FDOT	PennDOT	NYDOT	KYTC
4”	100(1)			100 (3.5”)		100 (6”)	
2”					100		
1”							100
3/4”	100	75-100	100	70-100			80-100
3/8”							20-80
No. 4	20-100	20-100	20-100	30-100	50-100		0-30
No. 8							0-10
No. 10							
No. 40	0-60	0-60	0-60	15-100	15-55	0-60	
No. 100			0-30	5-65			
No. 200	0-50	0-50	0-15	0-15	0-35	0-40	
	PI<=20	PI<=20	PI<=5, LL<=30	PI<=6, LL<=15			
	Cu>=4		4<=Cu<=20		(2)	(3)	(4)

(1) Can allow up to 4” top size with construction damage assessment, else limit size to < 3/4”
(2) Gradation Ratio of % Passing No. 200/% Passing No. 40 <= 70%
(3) Also allows coarse aggregate meeting requirements of AASHTO No. 8, No. 57, No. 67, and PennDOT No. 2A
(4) KYTC Sizes No. 67, 68, 710, and 78 fall within the limits. Sizes No. 57 and No. 610 may fall within the limits depending on specific gradation used.

KYTC's specification for granular reinforced fill calls for a coarser aggregate mixture than FHWA and other state DOTs use. A coarser mixture has advantages in terms of strength, compaction, and ability to support free drainage. Using this gradation has several drawbacks, such as the higher likelihood of construction installation damage to geosynthetics from the coarse mixture as well as haul distances required to bring material to a site.

KYTC's specification allows for reinforced fill material to consist of either processed limestone or sandstone from a Cabinet-approved quarry or durable limestone or sandstone sourced from roadway excavation. Durable limestone and sandstone from roadway excavation typically require onsite processing (e.g., crushers and sieving equipment) to ensure material meets specifications. While onsite processing can provide suitable reinforced fill materials, it can be more difficult to meet specifications as opposed to more controlled processing environment found at quarries.

Figure 4.1 depicts reinforced fill gradation curves for KYTC's specification, FHWA, and AASHTO Product Evaluation and Audit Solutions (formerly NTPEP). The AASHTO gradations are used to evaluate geosynthetic reduction factors for construction damage. AASHTO testing can benefit DOTs by providing an independent evaluation of products as well as establishing geosynthetic property values that may be used to develop RSS designs. In particular, construction damage testing may be used to determine construction damage reduction factors by comparing the D_{50} value of the specified reinforced fill to values obtained from the three AASHTO gradations.

KYTC's granular reinforced fill has a gradation that lies near or above the coarser limits of FHWA-recommended values. But its gradation falls within those used by AASHTO for construction damage testing. This indicates geosynthetic product testing performed by the AASHTO Product Evaluation and Audit Solutions can likely be applied to KYTC projects, and that testing can be used to both approve and evaluate products for use on Cabinet projects. In particular, AASHTO's construction damage assessment may be used to evaluate construction damage reduction factors for geosynthetics.

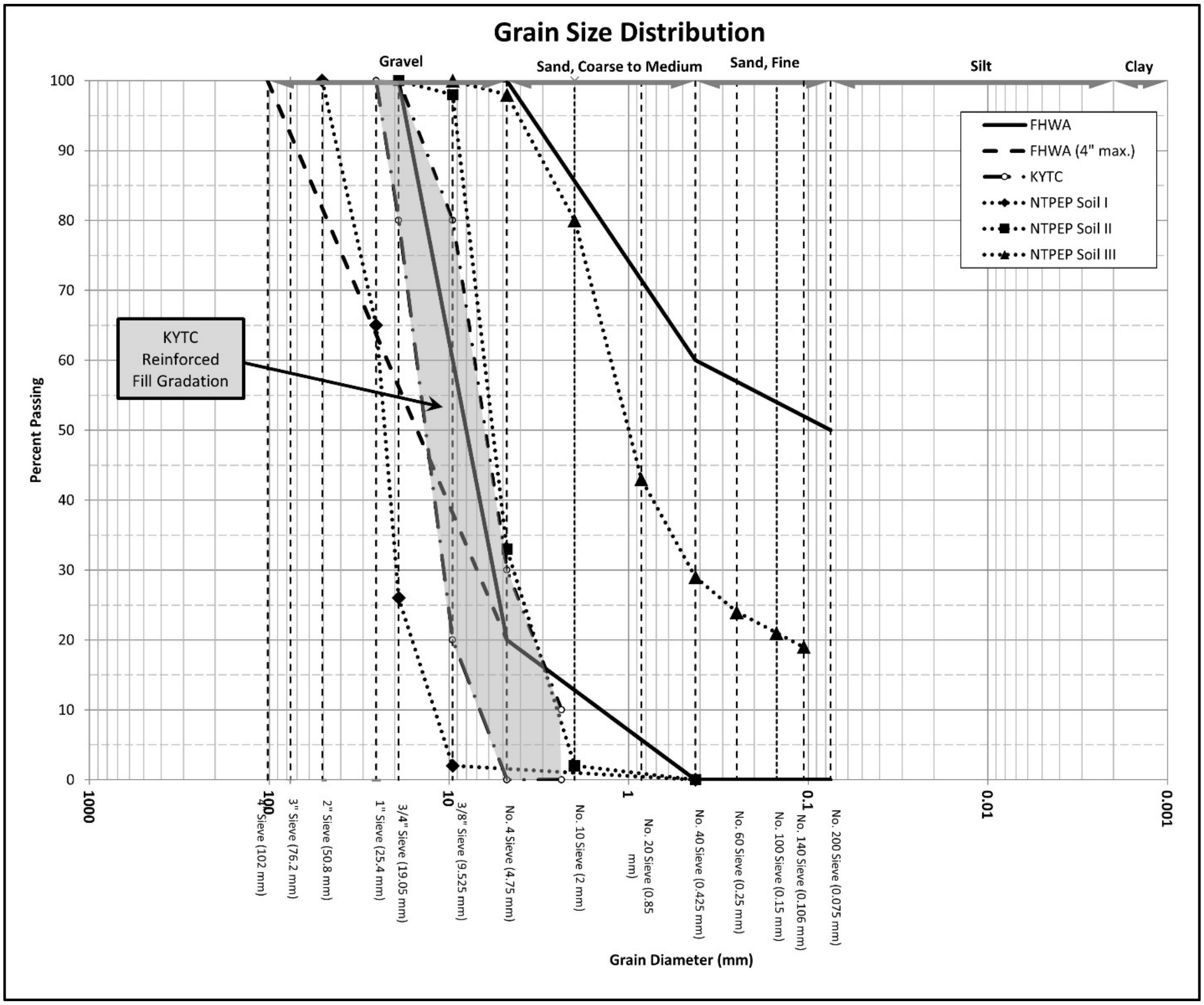

Figure 4.1 Gradation Curves for KYTC, FHWA, and AASHTO Reinforced Fill Materials

KYTC's coarser reinforced fill gradation will likely lead to larger construction damage reduction than a gradation that is more well-graded and has a higher percentage of finer material (i.e., D_{50} for the gradation is smaller). As the Cabinet gains more experience with RSSs, the agency may wish to consider revising granular reinforced fill gradations to allow a more well-graded mixture with higher sand fraction percentages.

KYTC specifications stipulate that the gradation of granular reinforced fill may be adjusted if project-specific construction damage and shear strength testing is performed. However, granular material must meet the following requirements:

- Internal friction angle $\geq 34^\circ$
- 100% passing the 4" sieve
- $\leq$ 5% passing the No. 200 sieve
- Uniform fine sands or gap graded materials are not permitted

Since KYTC's granular reinforced fill gradation is considered free-draining, saturation of granular fill is unlikely if the following design features are included:

- The foundation beneath the reinforced fill is graded appropriately, allowing granular reinforced fill to drain under gravity. Foundation grading that produces a bathtub effect where water stands in the reinforced fill should be avoided.
- A fabric-wrapped perforated pipe is placed within reinforced fill near the bottom and backslope with the retained fill. This pipe should be installed at an appropriate grade to enable drainage. It should include a headwall and have outlets at a location that drains away from the reinforced slope as well as at a location where outflow will not erode the steepened slope.
- Fabric – Geotextile Class 2 (Separator) that encapsulates the granular reinforced fill to separate it from retained backfill as well as from pavement subgrade layers. This separator prevents migration of fines from the retained backfill or pavement subgrade into the reinforced fill. Fines can clog reinforced fill and prevent it from draining freely.
- A wrapped face or facing units is provided, when necessary, to prevent erosion of the steepened slope.

4.2 Locally Available Soil Materials

We evaluated the use of locally available soil materials for RSS construction where select granular fill may not be available or are cost prohibitive. In Kentucky, most locally available soils are clays, silts, and silt-clay mixtures with typical soil classifications of CL, CH, ML-CL, and ML. AASHTO classifications for typical Kentucky soils include A-4, A-6, and A-7-6. Many soils in Kentucky are residual and result from the weathering of sedimentary bedrock. Aeolian deposits of silt (e.g., loess) occur, particularly in the far western portion of the state; these thin gradually moving eastward. Alluvial (moving water), lacustrine (lake bottoms), glacial, and colluvium (gravity or landslide) deposits also are present.

KYTC has used a standard gravity wall design for many years, with the most recent update to the design occurring in February 2020. The design, which is detailed in Standard Drawings BGX-023 and BGX-024, has wall dimensions for six wall cases covering multiple backfill slopes, backfill soil requirements, foundation-bearing surfaces, and surcharge loadings. Few failures of standard gravity walls have been noted by the Cabinet. Where standard gravity walls performed poorly, the performance typically could be attributed to poor drainage, saturation of the wall backfill, or a failure to comply with usage restrictions for the standard design (e.g., wall heights too tall, backfill slopes too steep, surcharge loads exceeding allowable). The 2020 update to the standard gravity wall design charts define the soil parameters used to develop the design (Table 4.2).

Table 4.2 KYTC Standard Gravity Wall Soil Design Parameters

Material	Cohesion	Friction Angle	Moist Unit Weight
Soil Backfill	c' = 0 psf	Ø' = 28°	γ = 120 pcf
Foundation Soils (Total Stress)	c = 1200 psf	Ø = 0°	γ = 120 pcf
Granular backfill or foundation replace-ment (if used)	c' = 0 psf	Ø' = 38°	γ = 115 pcf

Values in Table 4.2 for soil backfill and foundation soils are within the typical range of compacted soil properties for low-plasticity clays, silts, and silt-clay mixtures (e.g., CL, ML, ML-CL soils). They are also considered by KYTC to conservatively represent, based on experience with laboratory tests for actual KYTC projects, low-plasticity clays and silts typically found in Kentucky.

As noted in Table 2.3, three state DOTs allow the use of silty or clayey soil materials as reinforced fill for RSSs. Table 4.3 summarizes soil materials requirements for each state. In general, these requirements seek to allow the use of clays and silts found within project limits while restricting soil plasticity to reduce their sensitivity to moisture and volumetric changes.

Table 4.3 DOT Reinforced Fill Specifications for Soil-like Fill

State DOT	Soil Parameter Requirements
North Carolina	• Silty or clayey soils classified as A-4 using AASHTO M 145 • A-5, A-6, and A-7 soils are acceptable if LL ≤ 50, 7 ≤ PI ≤ 20
Pennsylvania	• % passing No. 200 sieve ≥ 20% • Dry Density ≥ 95 pcf • LL ≤ 65, PI ≥ LL – 30 for soils with 41 ≤ LL ≤ 65 • Specify min. Ø consistent with excavated materials to construct reinforced slope, soils readily available on site, or soils available from local borrow sites • Submit sample for verification testing
Ohio	• Natural soils classified as A-4-a, A-4-b, A-6-a, A-6-b, or A-7-6 • A-5 and A-7-5 soils are not allowed • Dry Density ≥ 90 pcf • LL ≤ 65

4.3 Proposed Requirements for Reinforced Fill Consisting of Locally Available Soils

Table 4.4 lists proposed requirements when using locally available soil as RSS reinforced fill. These requirements do not apply to reinforced fill for MSE walls as current KYTC specification do not allow locally available soil nor geosynthetic reinforcement to be used. The requirements for RSS reinforced fill consisting of locally available soil were selected to:

- Limit permissible soils to low-plasticity silts and clays (e.g., CL, ML, and ML-CL for Unified Soil Classification or A-4 and A-6 using AASHTO classifications). Other materials may be allowed with KYTC approval.
- Be inclusive of soil types commonly found throughout Kentucky.
- Be consistent with soil types and parameters used for development KYTC's Standard Gravity Wall.

Verification testing is particularly important when using locally available soils. Strength testing confirms material used as reinforced fill meets design requirements. Since the characteristics of onsite soils can vary considerably over small areas, confirming that soils meet design requirements during construction reduces the risk of poor RSS performance.

Table 4.4 Proposed Requirements for RSS Reinforced Fill Consisting of Locally Available Soils

Soil Property	Value
% Passing 4-inch Sieve	100
Liquid Limit (LL)	≤ 40
Plasticity Index (PI)	≤ 20
Organic Content	≤ 2%
pH	3 < pH < 9 (5 < pH < 8 if geogrids contain polyester)
Internal Angle of Friction, Ø'	≥ 28° (Maximum of 32° allowed for design)
• Material must be free of coal, shale, friable sandstones, or other deleterious materials • Bank gravels, creek gravels, and sands may be used subject to Department review and approval • Other materials may be used subject to Department review and approval • Cohesion of reinforced fill material shall be ignored for the design of primary reinforcement and slope stability of the RSS. Cohesion of reinforced fill material may be considered when evaluating facing stability, sloughing, and secondary reinforcement requirements. • Representative samples of material and a Certificate of Analysis containing the results of required verification tests must be provided by the Contractor.	

4.4 Subsurface Drainage Requirement When Using Reinforced Fill Consisting of Locally Available Soils

Soils meeting requirements listed in Table 4.4 are typically less permeable than materials that follow KYTC's granular reinforced fill gradation curve and thus are not considered free-draining. As such, it is more likely that reinforced fill consisting of locally available soils will become saturated from groundwater movement and precipitation infiltration. Subsurface drainage should be provided behind and underneath reinforced fill consisting of locally available soils to prevent saturation of reinforced fill and accompanying loss of soil strength. Surface drainage should also be addressed to prevent pavement runoff and precipitation from entering reinforced fill and eroding steepened slopes. Recommended design features to prevent saturation of reinforced fills consisting of locally available soils include:

- Extending a rock drainage blanket (1' minimum thickness) wrapped in Fabric – Geotextile Class 2 (Subsurface Drainage) under the full width of the reinforced fill zone and to approximately 2/3 of the fill height up the backslope between the reinforced and retained fills. Construct a rock toe berm at the drainage blanket outlet to maintain free drainage of the blanket. An alternative to a rock drainage blanket is an appropriately sized geocomposite drain. Maintain separation between the rock drainage blanket or geocomposite drain and the pavement subgrade layers.
- Grading of the foundation beneath reinforced fill should allow the drainage blanket (or geocomposite drain) to drain under gravity.
- Maintaining separation between reinforced fill and pavement layers. Pavement layers may become saturated and facilitate water infiltration into reinforced fill. Pavement edge drains or daylighting pavement layers can help prevent water infiltration into reinforced fill. If necessary, a geomembrane can be placed between pavement layers and the reinforced fill to stop water infiltration into reinforced fill.

- Control pavement runoff to prevent saturation of reinforced fill and erosion of the steepened slope. When possible, use wedge curbs and flumes to prevent sheet flow of pavement runoff over the steepened slope. Erosion control mats with appropriate vegetation or facings must be established on the steepened slope to prevent its erosion and raveling.

Chapter 5 Standard Reinforced Soil Slope Design

5.1 Reinforced Soil Slope Standard Design Requirements

The purpose of this study was to develop a standard design for RSSs for the Cabinet. A standard design would benefit KYTC by:

- Providing an economical design for small- to moderate-sized projects.
- Requiring less personnel time for design, evaluation, and construction inspection.
- Providing a more equitable bid environment for material suppliers and vendors.
- Providing KYTC with more opportunities to utilize and gain experience with RSS technology.

The Study Advisory Committee discussed concerns and provided directions for developing the RSS standard design. These items included:

- A design like the KYTC standard for gravity walls that, with certain limitations, can conservatively be used across Kentucky.
- Limits on where and when the standard design is applicable.
- Design charts that clearly outline requirements for reinforcement strength, length, and spacing.
- Construction details that are relatively consistent with minimum variation across different designs to simplify construction, reduce the risk of construction errors, and encourage use of the standard.

We reviewed standard RSS designs from the Minnesota and North Carolina DOTs to evaluate design criteria that could be used to develop a Cabinet standard. Variables featured in the designs include slope height, slope angle, reinforced fill properties, backfill properties, foundation soil properties, groundwater levels, reinforcement long-term strength, reinforcement length, and reinforcement spacing. Accordingly, the Study Advisory Committee recommended the following design requirements and restrictions for KYTC's standard RSS design:

- Foundation and backfill soil parameters consistent with those used for KYTC's standard gravity walls.
- Reinforced fill soils include both granular and locally available soils.
- Slope heights (H) $\leq$ 30 feet.
- Design slope angle cases of (a) up to 45° (1H:1V) for both granular and locally available soil reinforced fill; and (b) up to 70° (1H:2.75V) for granular reinforced fill only.
- Depth to groundwater (d_w) cases of 0' (ground surface) and one-half slope height (H/2) below base of the reinforced fill.
- Traffic surcharge of 250 psf.
- Target factors of safety (FS) consistent with KYTC's *Geotechnical Guidance Manual*.
  - Long-term (effective stress) conditions, FS $\geq$ 1.5.
  - Short-term (total stress) conditions, FS $\geq$ 1.3
  - Lateral squeeze, FS $\geq$ 2.0 (FS $\geq$ 1.3 allowable with rigorous stability analyses).
  - Stability analyses consider internal, compound, global, block sliding, and sliding along geosynthetic interface conditions.
- Drainage provided to prevent reinforced fill saturation.
- Geogrids are used for reinforcement.
- Slope is vegetated, has geosynthetic-wrapped face, or has facing units to prevent erosion and sloughing.
- Subsurface investigations are required to verify field conditions comply with standard design limits.

5.1.1 Standard RSS Design Cases

We analyzed three combinations of reinforced fill types and slope angles. Table 5.1 lists the stability analyses that were completed. Analysis of each case was conducted at the maximum slope angle for that case. Slope heights were evaluated at 5’ increments. Groundwater depths were evaluated at 0’ and for H/2 for each case and slope height.

Table 5.1 Design Case Geometry for Stability Analyses

	Case	Reinforced Soil Fill	Slope Angle, β
Design Cases	1	Locally Available Soil	≤ 45° (evaluated at 45°)
	2	Granular	≤ 45° (evaluated at 45°)
	3	Granular	45° < β ≤ 70° (evaluated at 70°)
Slope Height, H	10’ ≤ H ≤ 30’ (evaluated in 5’ increments)		
Groundwater Depth, d_w	0’ ≤ d_w < H/2 (evaluated at 0’)		
	H/2 ≤ d_w (evaluated at H/2)		

5.1.2 Standard RSS Soil Strength Parameters

Table 5.2 lists soil strength parameters used in stability analyses. Reinforced fill consists of either locally available soil (Table 4.4) or of KYTC’s specification for granular fill (Table 4.1). Retained backfill and foundation soil parameters were chosen to closely match those used for KYTC’s standard gravity wall designs. Reinforced fill materials would be either granular and free draining or have drainage provisions to prevent saturation. Foundation soils were evaluated for both total and effective stress conditions.

Table 5.2 Standard RSS Design Soil Strength Properties

Soil Type	Strength Parameters
Locally Available Soils	γ_{tot}=120 pcf, c'=0 psf, Ø'=28°
Granular Fill	γ_{tot}=115 pcf, c'=0 psf, Ø'=34°
Retained Backfill	γ_{tot}=120 pcf, c'=0 psf, Ø'=28°
Foundation (total stress)	γ_{tot}=120 pcf, c=1200 psf, Ø=0°
Foundation (effective stress)	γ_{tot}=120 pcf, c'=200 psf, Ø'=26°

5.1.3 Standard RSS Geogrid Reinforcement

Table 5.3 lists long-term available strengths (T_{avail}) assumed when analyzing both primary and secondary geogrid reinforcement. Minimum primary and secondary reinforcement lengths considered in analyses were 8’ and 6’, respectively. Geogrid coverage was assumed to be 100% for both primary and secondary reinforcement. The coefficient of interaction for the geogrid was set at 0.67 as per FHWA recommendations when the actual reinforcement type is unknown; however, the coefficient of interaction for geogrids is typically near 0.8.

Table 5.3 Geogrid Reinforcement Long-Term Available Strength

Reinforcement Type	Long-Term Available Strengths, T_{avail} (lb/ft)
Primary	700, 1000, 1300, 2000
Secondary	700 min.

5.2 Standard RSS Design Development

We developed preliminary reinforcement layouts and strengths using the method in Berg et al. (2009). Primary reinforcement lengths were assumed to be the same throughout each case evaluated. Vertical spacing of primary reinforcement was assumed to be 2' regardless of the case. Assumptions for lengths and vertical spacing of primary reinforcements were established to simplify RSS design and construction details. Long-term available strengths for preliminary primary reinforcement were rounded up to the next highest value listed in Table 5.3.

Checks for potential lateral squeeze concerns were performed for multiple depths of foundation soils. These checks indicated either that the FS against lateral squeeze exceeded 2.0 or that deep-seated stability would control. Thus, lateral squeeze was not of concern for the foundation conditions and slope configurations evaluated.

Once preliminary reinforcement layouts and strengths were established, we performed slope stability analyses via Spencer's method using Rocscience's SLIDE2 software. Figure 5.1 illustrates a typical stability analysis. Three failure mechanisms were analyzed for each case:

- Circular failure surfaces which allowed for the simultaneous evaluation of internal, compound, and global stability.
- Block failure surfaces along the foundation/base of the reinforced fill.
- Block sliding along the geogrid interfaces.

If the FSs were less than the target values given in Section 5.1, primary reinforcement lengths and/or strengths were adjusted. This process continued until adequate FSs were achieved for all three failure mechanisms for a given reinforcement length/strength combination. Analyses confirmed it is possible to maintain a vertical spacing of the primary reinforcement at 24" (2') for all slope configurations analyzed.

Checks were then performed for three additional cases representing slope angles that are somewhat less than the maximum slope angles presented in Table 5.1:

- Case 1, 1.5H:1V (33.7°) slope, H=30', d_w=0'
- Case 2, 1.5H:1V (33.7°) slope, H=30', d_w=0'
- Case 3, 1H:1.5V (57.5°) slope, H=30', d_w=0'

In each of the additional cases the FS met targets given in Section 5.1.

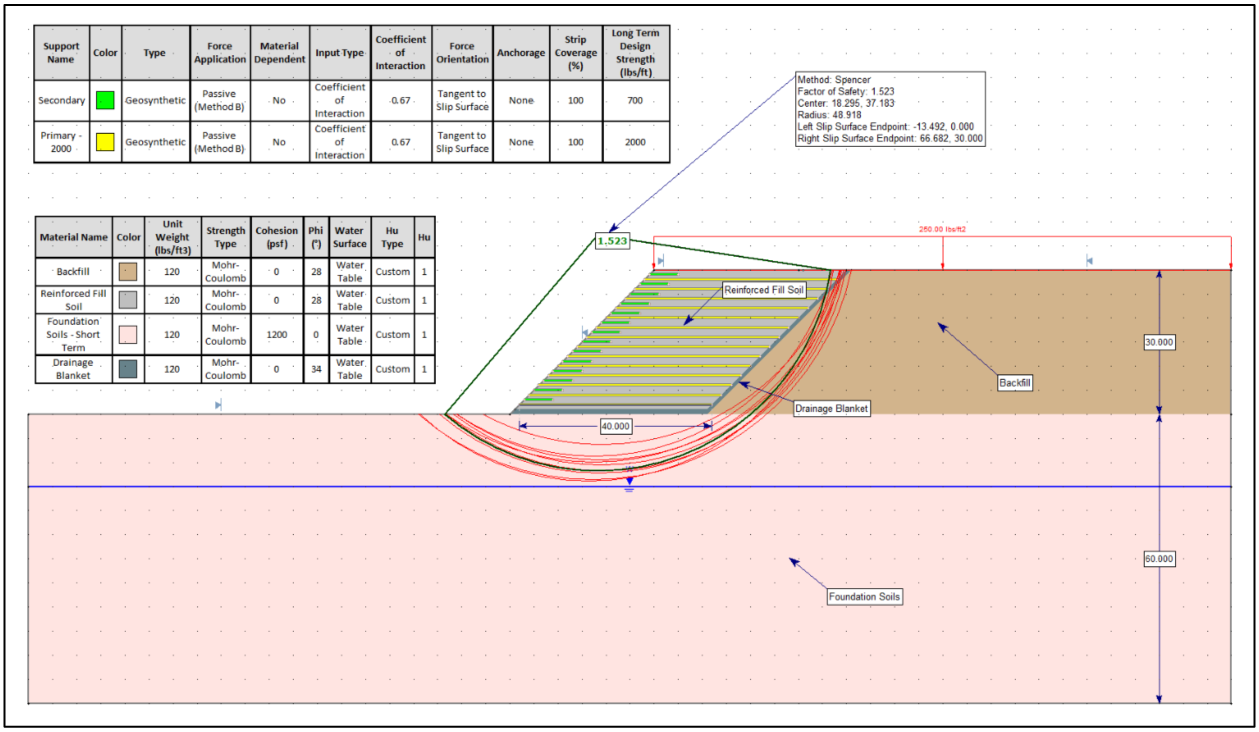

Figure 5.1 Typical Slope Stability Analysis

5.3 Secondary Reinforcement for Face Stability

We evaluated the need for secondary reinforcement for slope-face stability of Cases 1 and 2 using methods presented in Berg et al. (2009). Case 3 (granular reinforced fill with slopes greater than 45°) has either wrapped faces or facing units to help maintain face stability. For Case 1 with locally available soils, slope face stability was evaluated assuming the face was saturated and that the material had minimal cohesion (c' = 20 psf). Case 2 with granular fill assumed no saturation and Ø' = 34°, although the KYTC specification for this material would likely result in a strength greater than Ø' = 38°. A minimum secondary reinforcement length of 6' and long-term available strength of 700 lb/ft were assumed.

Analyses indicated that secondary reinforcement spacing of 12" (1') and 8" (0.67') were needed for Cases 1 and 2, respectively, to provide adequate FSs for face stability. To provide simplicity and consistency for construction across cases, as well as considering lift heights and compaction requirements, the Study Advisory Committee recommended using a secondary reinforcement spacing of 8" for all cases.

5.4 Standard RSS Design Table

Based on the results of analyses, we propose the following design table for KYTC's Standard Reinforced Soil Slopes:

Table 5.4 Standard Reinforced Soil Slope Design Table

Case	Maximum Slope Height, H (ft)	Minimum Primary Reinforcement Long-Term Strength, T_{avail} (lb/ft)	Minimum Primary Reinforcement Length, L (ft)	
			$d_w \geq H/2$	$0 \leq d_w < H/2$
Case 1, Locally Available Soils, Maximum 45° Slope	H ≤ 10'	1000	1.33 H	1.33 H
	10' < H ≤ 20'	1300		
	20' < H ≤ 30'	2000		
Case 2, Granular Fill, Maximum 45° Slope	H ≤ 20'	700	1.2 H	1.2 H
	20' < H ≤ 25'	1000		
	25' < H ≤ 30'	1000		1.3 H
Case 3, Granular Fill, Maximum 70° Slope	H ≤ 20'	1300	1.0 H	1.2 H
	20' < H ≤ 30'	2000		

Notes:

- $T_{avail} = T_{ult} / (RF_{id} * RF_d * RF_c)$
- d_w = Depth to Groundwater below RSS
- Minimum Foundation Soil Strength: c = 1200 psf, c' = 200 psf, Ø' = 26°, γ_{tot} = 120 pcf
- Minimum Backfill Soil Strength: c' = 0 psf, Ø' = 28°, γ_{tot} = 120 pcf (cohesion ignored for design of primary reinforcement)
- Case 1, Locally Available Soils Minimum Reinforced Soil Strength: c' = 0 psf, Ø' = 28°, γ_{tot} = 120 pcf (cohesion ignored for design of primary reinforcement)
- Case 2 and 3 Minimum Reinforced Soil Strength: c' = 0 psf, Ø' = 34°, γ_{tot} = 115 pcf
- Traffic Surcharge = 250 psf
- Minimum Primary Reinforcement Length = 8 ft
- Maximum Primary Reinforcement Vertical Spacing, S_1 = 24 in
- Required Secondary Reinforcement Long-Term Strength = 700 lb/ft
- Required Secondary Reinforcement Length = 6 ft
- Maximum Secondary Reinforcement Vertical Spacing, S_2 = 8 in
- 100% Coverage for Primary and Secondary Reinforcement
- Reinforced Fill Limits shall extend a minimum of 1 ft beyond the end of Primary Reinforcement

5.5 Drainage Requirements

Proposed requirements for locally available soil (see Section 4.3) allow materials that may not be free draining. As a result, providing drainage within and behind reinforced fills consisting of locally available soils is necessary to prevent saturation and the resultant loss of shear strength within the reinforced zone. After consulting with the Study Advisory Committee, we recommended that a 1'–thick rock drainage blanket meeting the requirements of Section 805.09 of the Standard Specifications (Coarse Aggregate for Rock Drainage Blanket) extend underneath and behind the reinforced fill zone for Standard RSS designs using Case 1. This drainage blanket should be wrapped in a separator geotextile fabric to prevent clogging with fines from the backfill and foundation soils. A rock toe berm should be installed at the toe of the fill to provide a free draining outlet for the drainage blanket.

For standard RSS designs using Cases 2 or 3, granular reinforced fill material is considered free draining. A separator fabric should be placed between the reinforced fill and backfill soils to prevent migration of fines into the reinforced zone as well as between reinforced fill and overlying subgrade layers. We also recommend placing a fabric-wrapped perforated pipe at the bottom and back of the reinforced zone to provide additional drainage capacity in case water becomes trapped within the reinforced zone. Perforated pipe should be graded to drain and outlet at an appropriate location with a headwall.

For all standard RSS cases, foundation soils should be graded from back to toe of the slope to facilitate drainage of the drainage blanket or reinforced fill.

5.6 Slope Facing Requirements

According to the Special Note for Reinforced Soil Slopes, a contractor is responsible for providing slope-facing and/or permanent vegetation to stabilize and prevent erosion of the slope face. The RSS designer must provide calculations and justification for the selected slope face treatment for KYTC review and approval. Representative material samples and certifications that materials meet requirements of the RSS design must be provided to KYTC and include but are not limited to geosynthetic face wraps, turf reinforcement mats, temporary erosion blankets, wire mesh forms, gabion units, fertile soil, soil supplements, mulch, seed mixtures, sod, and drainage components. Where possible, materials on KYTC's List of Approved Materials should be used for the slope facing.

5.7 Standard RSS Designs

We developed typical cross sections for the three standard RSS design cases to visualize slope design and construction details. Figures 5.2 – 5.4 show typical cross sections for these three cases.

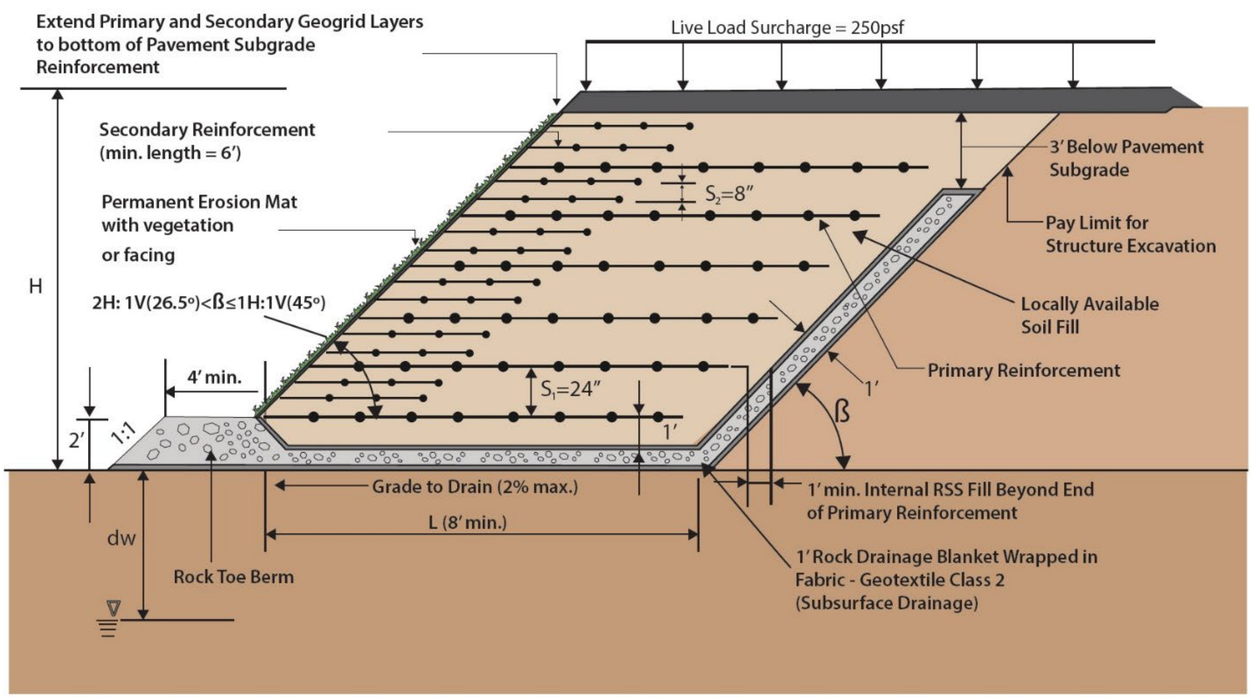

Figure 5.2 Case 1 Standard RSS Design, Locally Available Soil Reinforced Fill, Maximum 45 Degree Slope

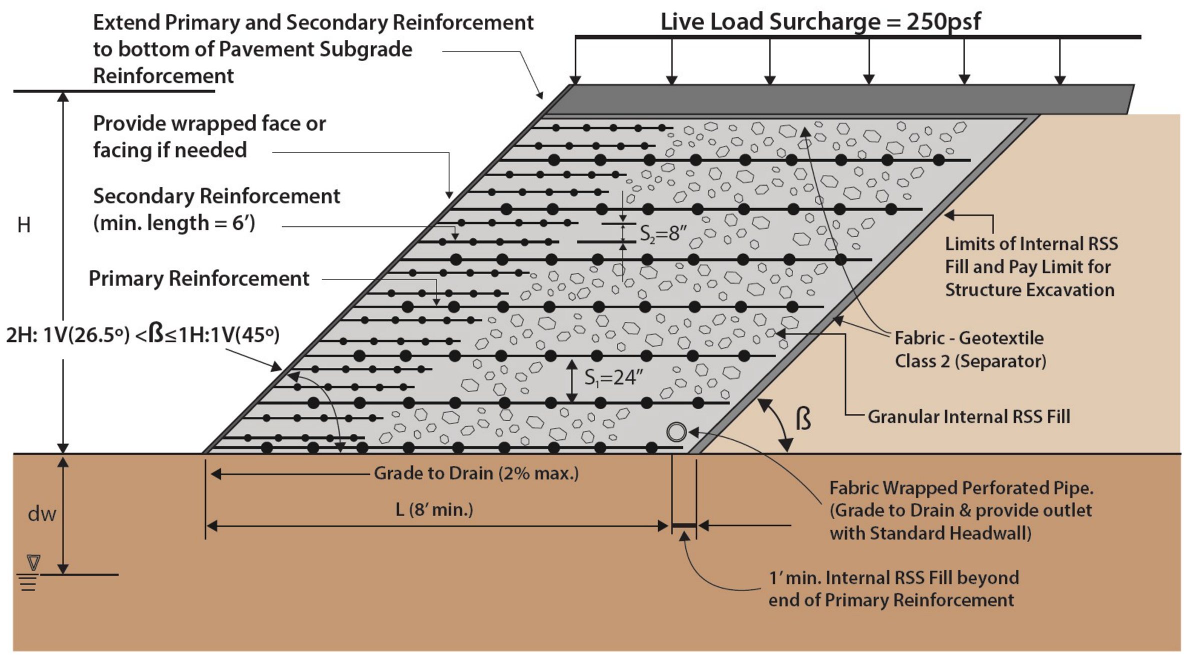

Figure 5.3 Case 2 Standard RSS Design, Granular Reinforced Fill, Maximum 45 Degree Slope

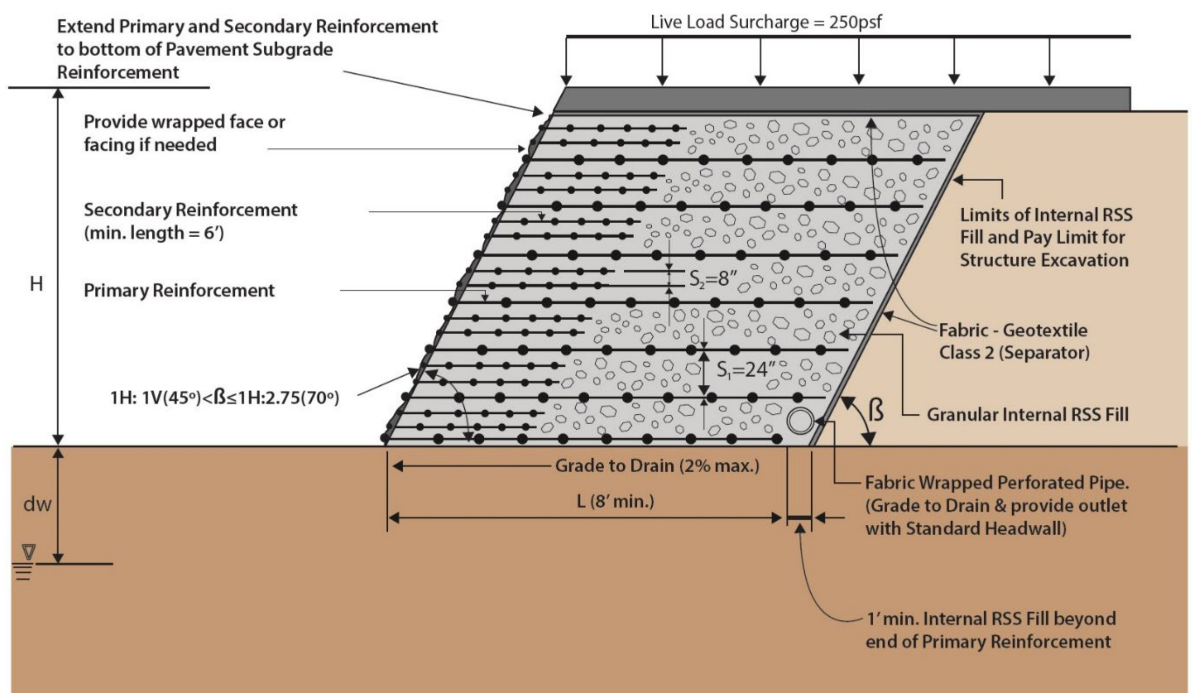

Figure 5.4 Case 3 Standard RSS Design, Granular Reinforced Fill, Maximum 70 Degree Slope

5.8 Use of Standard RSS Design

KYTC developed drawings based on the recommendations in this Chapter. The drawings are shown in Appendix B. These drawings can be included in project plans where Standard RSS slopes are proposed. The drawings include general notes, RSS design criteria, definition of terms, typical cross sections of each case, RSS design table, and other construction details.

While the standard RSS design can be used in multiple situations, there are limitations on its use:

- While the standard RSS design can be used for nearly any square footage of slope face, it is best suited for small- to moderate-sized installations (≤ 5000 sq ft slope face). Larger installations may benefit from a more site-specific, efficient, and cost-effective design.
- Geotechnical investigations and laboratory testing are required to verify soil parameters and groundwater depths used in design.
- Standard RSS designs are not suitable for locations with traffic surcharges exceeding 250 psf, sites with slopes above and below the RSS, sites with permanent structures, locations with seismic considerations, and other permanent loading situations. Designs for these sites require special consideration.
- Water levels above the RSS base (standing water or high-water situations) require special consideration.

When site conditions do not meet the Standard RSS Design criteria, then the standard cannot be used and:

- Special design for current site conditions must be performed in accordance with the Special Note for Reinforced Soil Slopes, or
- Analysis must be provided in accordance with the Special Note for Reinforced Soil Slopes indicating that the standard design tables provide adequate factors of safety for the current site conditions.

Chapter 6 Revisions to Special Note for Reinforced Soil Slopes

As part of this study, we reviewed and updated KYTC's current Special Note for Reinforced Soil Slopes. The note was compared to specifications from other states (Table 2.3) to identify potential improvements or additions. Based on our analysis, we made the following revisions:

- Formatted the document to be more consistent with other KYTC special notes.
- Updated how reference materials are identified.
- Updated requirements and terminology.
- Identified and reduced conflicting or unclear requirements.
- Modified design requirements to be more consistent with the slope stability guidelines in KYTC's *Geotechnical Guidance Manual*.
- Added requirements for Locally Available Soils when used as reinforced fill.
- Updated material testing requirements and allowable test methods.

Most updates were related to the addition of locally available soils as this required modifying the note's Materials, Sampling and Testing, Geotechnical Design Parameters, and Compaction sections.

The Study Advisory Committee was included in the identification, review, and approval of potential changes to the special note. See Appendix C for the special note.

Chapter 7 Guidance Document Development

KYTC's *Geotechnical Guidance Manual* provides limited information on the use, design, and construction of RSSs. To fill this knowledge gap, we developed guidance on the design and construction of reinforced embankments and soil slopes. The guidance includes:

- Design considerations and requirements
- Methodology for selecting an appropriate earth retention system (e.g., retaining wall(s), reinforced slope, or unreinforced slope)
- Design methodologies
- Material selection and approval
- Plan development and requirements

The Study Advisory Committee reviewed the proposed guidance and provided feedback. KYTC can provide this guidance to contractors, consultants, and designers as it elaborates on guidance in the *Geotechnical Guidance Manual*. This document may be incorporated into future *Geotechnical Guidance Manual* updates. Appendix D includes a copy of the proposed guidance.

Chapter 8 Conclusion

RSSs can be a feasible solution for stabilizing embankments where there exist right of way restrictions, environmental issues, rolling or mountainous topography, unfavorable geology, and other limiting factors. They can be an alternative to retaining walls or importing select fills to construct steeper, stable embankment slopes in circumstances where flatter embankment slopes may result in unwanted impacts, costs, and maintenance issues.

We evaluated the use of locally available soil materials for construction of RSSs as an alternative to importing select granular material for construction of reinforced fill. Requirements for reinforced fill consisting of locally available soil were developed that are inclusive of soil types commonly found throughout Kentucky and are consistent with soil types used for development of KYTC's standard gravity wall standard drawing. Since soil properties exhibit considerable spatial variation across even small areas, verification testing is required to confirm locally available soil meets design requirements to reduce the risk the RSS will not perform adequately.

Our team developed a standard RSS design that is economical enough to be used on smaller projects. A standard RSS design requires less personnel time for RSS design, fosters a more equitable bid environment, and gives KYTC more opportunities to use and gain experience with RSSs. The standard design is limited to certain embankment heights, groundwater depths, loading conditions, soil types, and foundation conditions. We prepared design tables and notes for construction drawings that outline information on reinforcement strength, length, and spacing requirements. Construction details such as reinforcement length and spacing were established with minimum variation across designs to simplify construction, reduce the risk of construction errors, and encourage use of the standard.

We investigated current design, specification, and construction practices to identify practices that may be adopted by the Cabinet. KYTC's Special Note for Reinforced Soil Slopes was reviewed and revised. In addition, a guidance document on the use of RSSs was developed to expand on information in KYTC's *Geotechnical Guidance Manual*. The guidance includes information on design requirements, selecting an appropriate earth retention system, design methodologies, material selection, and plan development.

To implement the results of this study, we recommend that KYTC:

- Develop a list of approved geogrid materials for use in RSSs to aid design processes and reduce review time for construction submittals.
- Develop prequalification for manufacturers and/or suppliers of RSS systems that addresses reinforcement, facing, drainage, and construction components. This will aid design processes and reduce construction submittal review times.
- Pilot use of the standard RSS design. Develop contract documents, contract projects, and evaluate construction against the Special Note for Reinforced Soil Slopes and the standard RSS design requirements.
- Identify locations where RSSs are viable alternatives to building a retaining wall, using flatter embankment slopes, or using select granular fill materials for embankment construction.
- Identify and monitor locations where RSSs have been constructed. Installations where locally available soils are used should be noted and their performance evaluated.
- Revise the special note, guidance document, and standard RSS design as needed.

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Appendix A Survey on Geosynthetic Reinforced Embankments

Survey on Geosynthetic Reinforced Embankments

The University of Kentucky Transportation Center thanks you for responding to our survey regarding the use of geosynthetic materials for stabilizing embankments. The survey was conducted for a State Planning and Research (SPR) project for the Kentucky Transportation Cabinet (KYTC). Findings of this survey will be used to determine the feasibility of constructing geosynthetic reinforced embankments on KYTC projects.

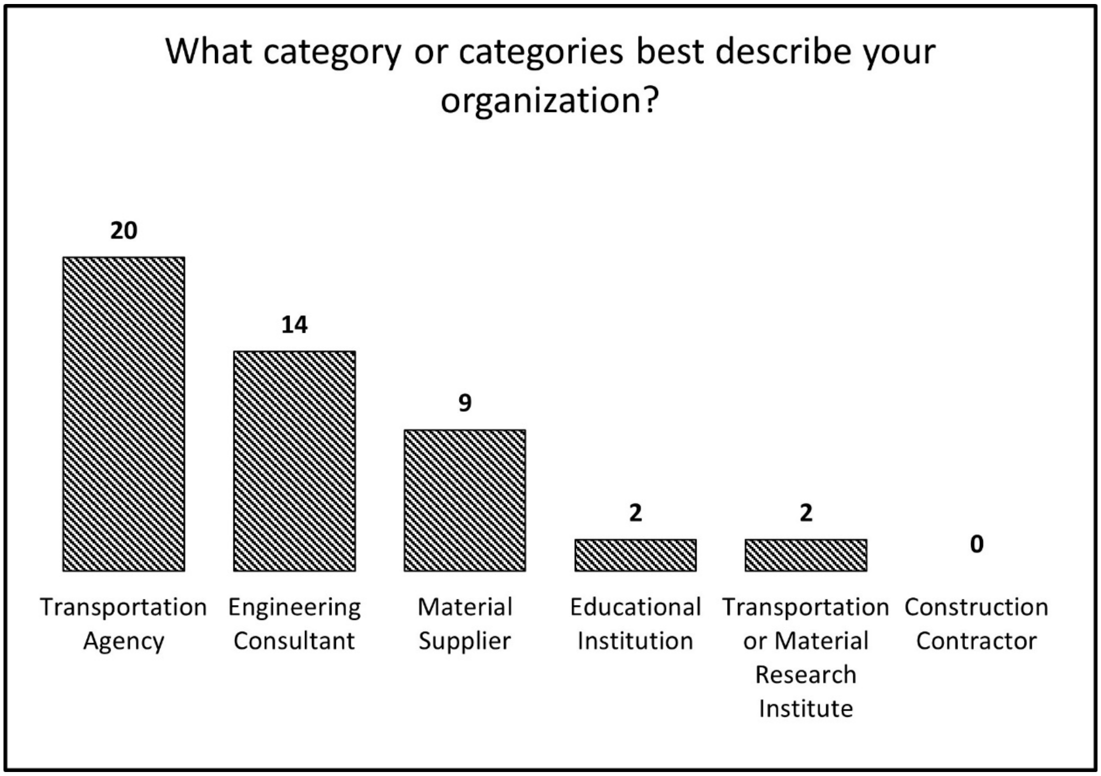
The results of the survey are summarized below. A total of forty-seven (47) individual responses were submitted. Where possible the results were summarized using all responses as well as using only those coming from DOT responders. This was done to highlight any differences in responses by DOTs as opposed to all participants in the survey. In some instance the responses to "Other" comments were edited for clarity or to provide a more generic response to a specific manufacturer/product mentioned.

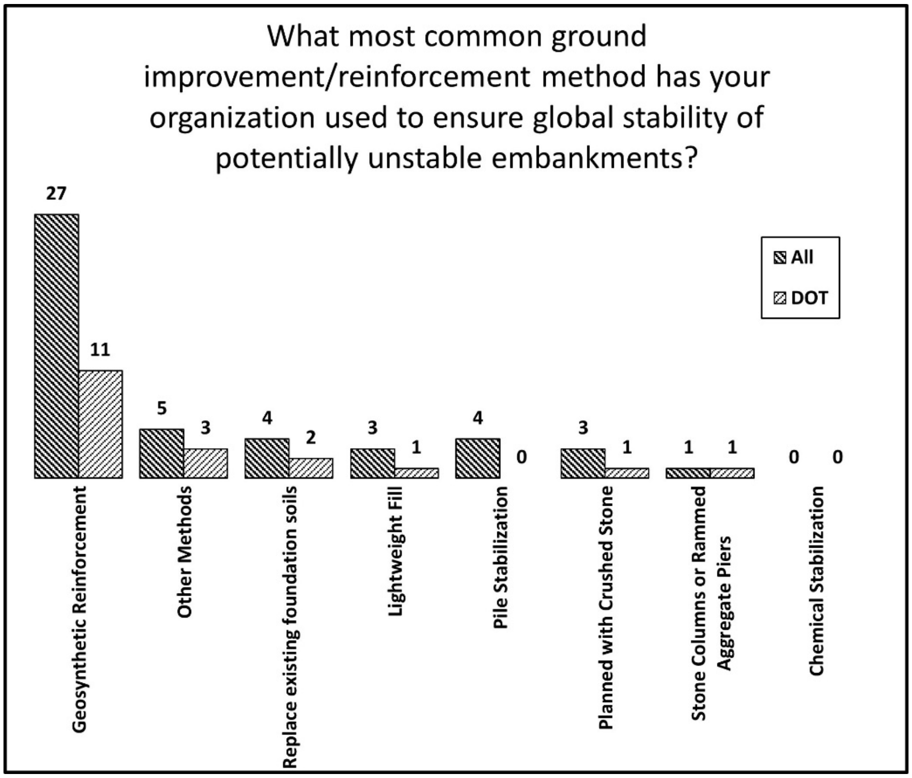
A copy of the original survey form is attached at the end of the document for reference.

Please feel free to contact us if you have any questions concerning this survey or any additional information you are willing to share that may assist us with this project.

Daryl J. Greer, PE
Research Engineer
daryl.greer@uky.edu

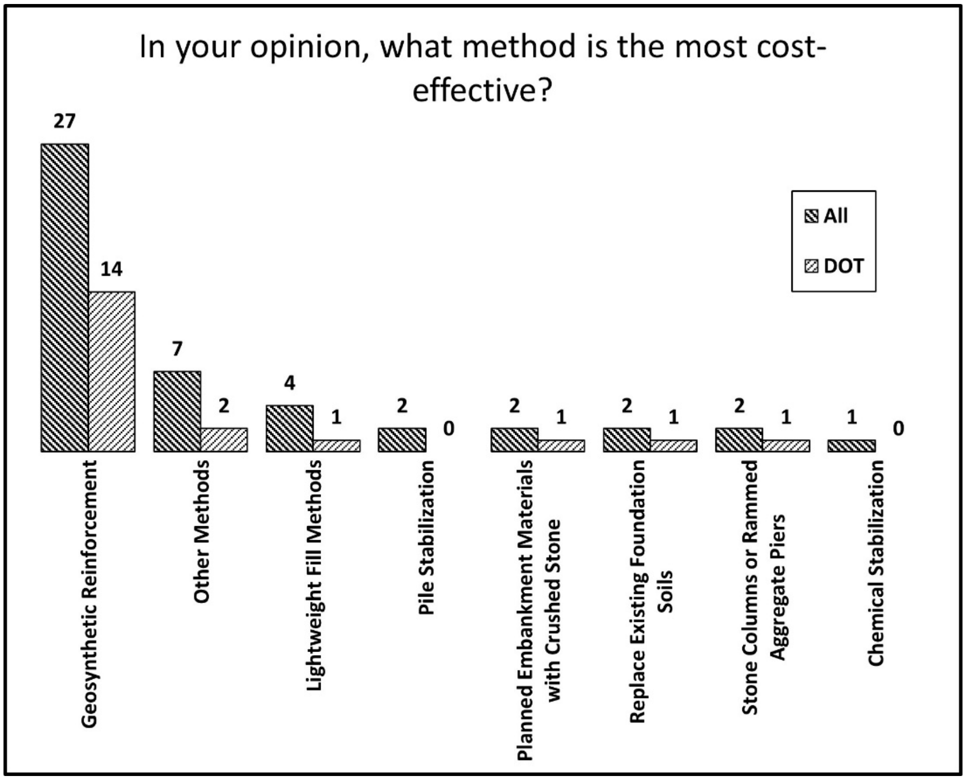
Charlie Sun, PE, PhD
Principal Investigator
charlie.sun@uky.edu


What category or categories best describe your organization?
20
14
9
2
2
0
Transportation Agency
Engineering Consultant
Material Supplier
Educational Institution
Transportation or Material Research Institute
Construction Contractor



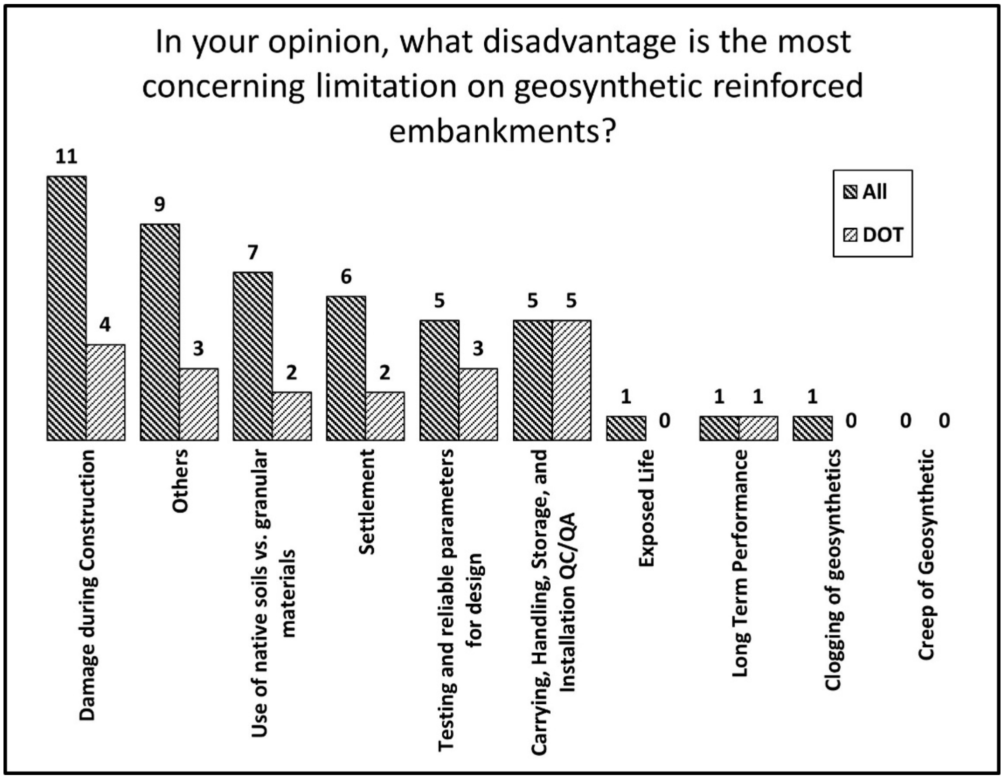
Responses to Other Methods

- Piles
- Piled foundations - including rigid inclusions
- It really depends on the nature of the instability and many other factors. Geosynthetics are extremely effective for mitigation of shallow embankment instability.
- The ground improvement methods are generally selected based on the site constraints. We have used most of the above-stated methods on our projects.
- All these ground improvement methods and others can and have been used. The selection of which to use is site specific based on available time, cost, and risk. Selection is also based on the type of solutions that will work better under the given condition.
- All



Responses to Other Methods

- This question is too broad. Cost effectiveness depends on the project needs, size, and location.
- Low-Density Cellular Concrete
- Geosynthetics are typically the most cost effective and generally have less environmental impacts in shallow instability applications.
- Varies. Depends on source of instability, space to work with, desire of performance, etc.
- Site specific.
- It depends.
- The question of how cost effective it is depends on the specific site conditions and project criteria. If time is not an issue, then the methods that have some excavation and replacement or stabilize the foundation soils will be less expensive. If time is more important than $$$ then your options are going to be some type of rigid inclusion with a load transfer platform and column supported embankment. There are many combinations in between as well that may address the schedule and performance requirements.



Responses to Others

- Each of the above concerns can be addressed with good design, specifications, and quality control during construction.

- IMO, the limitation is a lack of knowledge in the engineering community of RSS and GRS principles. Everything on this list can be accounted for in the design and specifications.

- Space in which to work.

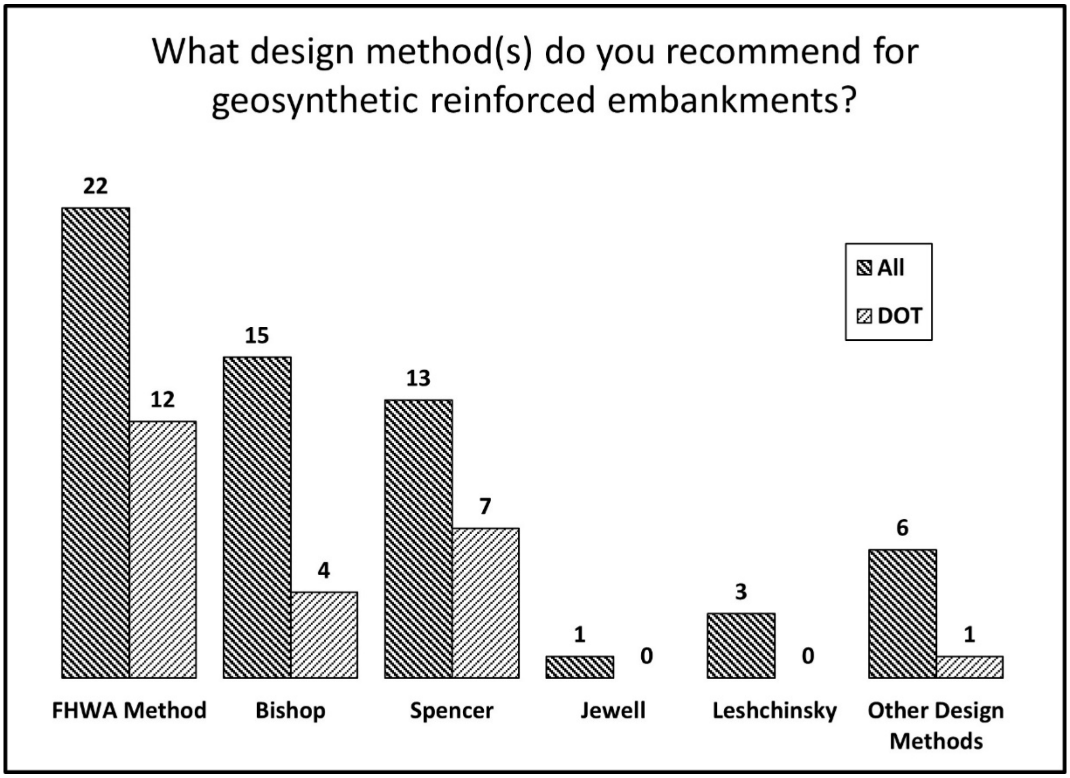
- Each project is different with regard to access, failure mode, etc.

- Cannot be used for stabilizing existing embankments.

- If designed and handled properly there is no real concern. Many successfully carried out projects proof this.

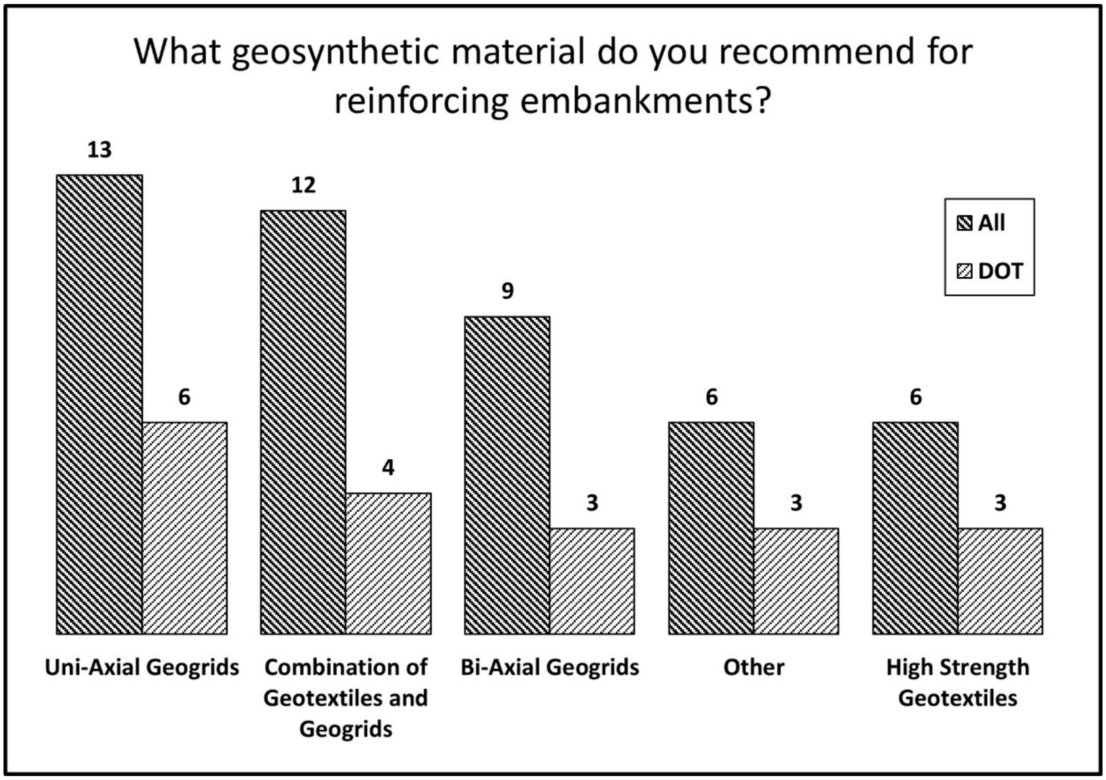
- Technical knowledge and standard gap

- All these are really design considerations that are addressed for the specific site conditions and the desired performance. Non are concerning only that they need to be considered. Now with the NTPEP program you can get the geosynthetic parameters as the QC/QA verification of the reduction factors that address these items.



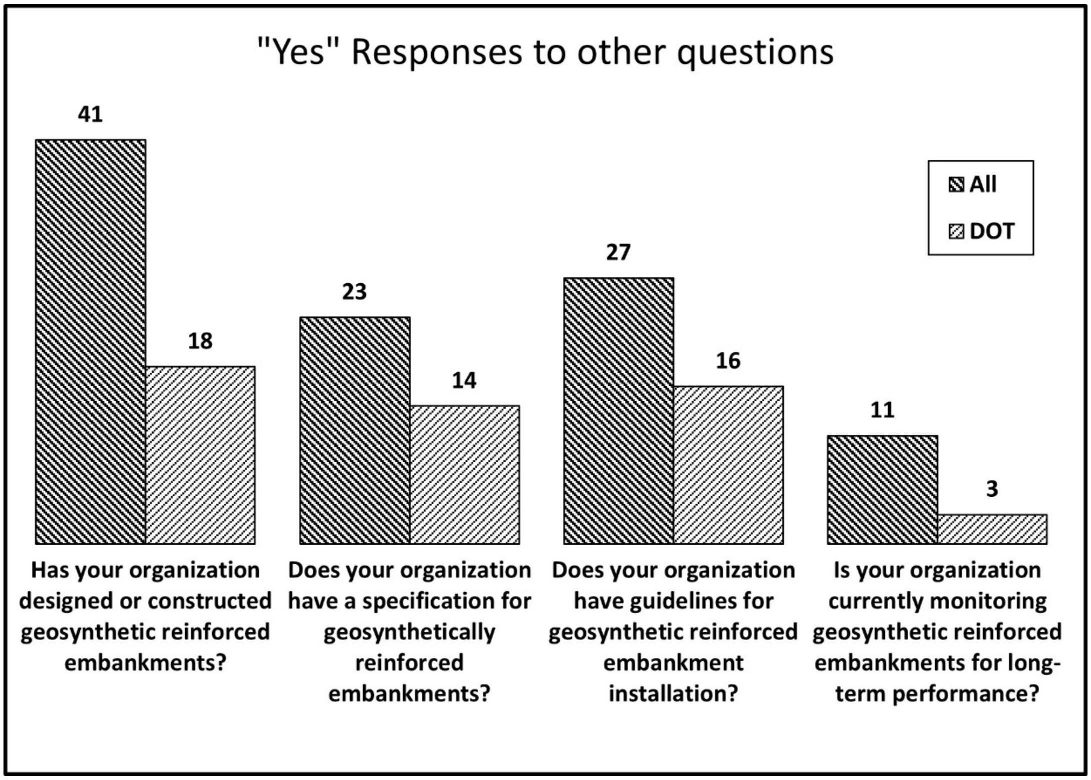
Responses to Other Design Methods

- Each of the above methods has merits and drawbacks.
- We use the Bishop or Janbu Method for non-rigorous stability analysis and Spencer or Morgenstern-Price Method for rigorous stability analysis.
- It really depends on the specific situation. Deep patch design methods are applicable in some situations (especially low volume roads with shallow instabilities).
- Block sliding method
- Both Bishop and Polygonal Block Sliding or Janbu, internal, compound, ev. external
- EBGEO or BS



<u>Responses to Other</u>

- Low-Density Cellular Concrete
- I have designed embankment repairs with all of these but would not combine geotextiles and geogrids without due consideration of strain incompatibility.
- GRS - closer spaced reinforcement allows for use of mid strength to lower strength geotextiles
- For embankments on soft soil use uni-axial geotextiles (required strength results from the design). For piled embankments use uni-axial geogrids, which are placed crosswise to each other (strength from design).
- All of the above should be considered for all applications.


"Yes" Responses to other questions
All
DOT
41
18
23
14
27
16
11
3
Has your organization designed or constructed geosynthetic reinforced embankments?
Does your organization have a specification for geosynthetically reinforced embankments?
Does your organization have guidelines for geosynthetic reinforced embankment installation?
Is your organization currently monitoring geosynthetic reinforced embankments for long-term performance?

Additional Comments

- In 2017 we did some work for FHWA related to their experience around the country with Geosynthetic Reinforced Soil Abutments and Integrated Bridge Systems (GRS-IBS). We prepared several case histories, typical notes and details in Autocad and Microstation, and a Synthesis Report.

- The Georgia Department of Transportation has been using geosynthetic reinforced slopes and embankments for some time. We have a dedicated Geogrid Material Standard Specification, a dedicated Special Provision for high strength grids and fabrics, a dedicated Geogrid Reinforced Slope and Embankment Construction Special Provision, and details for construction plans. We've also begun using the geosynthetic reinforced walls (GRS) which we have a special provision for based on the FHWA recommendations. We don't have many of the GRS walls yet.

  We've performed them both in mountainous terrain and coastal regions for new embankments, as well as when benching into existing embankments/slopes around the state. We've also used them in conjunction with other methods like lightweight fill/geofoam/ground improvements/etc. when settlement was a concern.

  We use both geotextiles and geogrids for construction. We've had really good success with our construction specifications and performance so far. I will say from construction experience- biaxial geogrid is more forgiving from a construction standpoint when it comes to geogrids. We have used uniaxial geogrid, but the QA/QC has to be more stringent to ensure proper placement in the field. Also, for issues we've had with geogrid- most common issues come from mishandling the geogrids/textiles or materials not meeting the specifications such as not meeting ultimate tensile strengths.

  We do perform some internal design work for geogrid reinforced slopes/embankments using SLIDE to ensure global stability has been met. The vast majority of our designs are consultant/contractor designs.

- We use geosynthetics frequently for a multitude of applications, including reinforced embankments (both the foundation area and for reinforced slopes). Specifying, testing and acceptance (especially if proprietary products become involved) has been difficult in the past. We have been using more and more high strength geotextiles vs. geogrids because of the proprietary nature that often occurs with grids.

- Geosynthetic reinforced embankments should definitely be in everyone's playbook as a solution to stabilizing embankments. As with any engineering design, the successful implementation will depend on the specific subsurface conditions, design criteria, and site constraints. I've successfully implemented deep patch on hundreds of sites - these were mostly low volume roads in mountainous terrain with shallow embankment instabilities.

- Access the SCDOT Geotechnical Design website for local geotechnical design practices. https://www.scdot.org/business/geotech.aspx

- Why are you only asking for the disadvantage of geosynthetics? Shouldn't there be also the question about their advantages then?

- Geocells can be very effective for base stabilization and for supporting embankments constructed on soft clays. Prefabricated vertical drains installed through geocells make this solution more effective.

- If settlement and/or construction time are not critical, the classic basal reinforced embankments (usually in combination with vertical strip drains) are a good solution. If construction time and/or settlements are critical, one should go for what I call "supported embankments": piles, columns, geotextile encased columns with horizontal geosynthetic reinforcement on top of them. Based on my experience I should recommend the German

Code EBGEO: design procedures and recommendations can be found there for all the options mentioned above.

- Regarding long term monitoring, we visually inspected most of our RSS sites a few years back and generated a white paper of our findings. Generally speaking, erosion of a slope steeper than 2:1 is the biggest issue.

- Geosynthetic reinforcement is usually the easiest and most cost-effective solution for the construction of embankments on soft soils. The geosynthetic properties can be easily controlled during production and inspected when received in the job site. Design methods are available and very well known, and there is a large quantity of successful case histories.

  There is no standard solution to be specified, since the short- and long-term mechanical requirements for the geosynthetic may vary a lot depending on the soft soil properties and the embankment geometry.

  Combined solutions of geosynthetic reinforced embankments with wick drains or (encased) granular columns might be applicable in situations of embankments on very soft soils.

- We designed embankment over soft soils and voids (shafts) using high strength geosynthetics (ei > 300 kN). Check this article from GE Magazine UK (November 2022). https://www.geplus.co.uk/tag/tailor-engineering/

- Both biaxial geogrid and geotextiles have been used in embankment reinforcement, but uniaxial geogrids have been most often used.

  They have been used in both landslide repairs and in "Deep Patch" road shoulder reinforcement.

- There are many applications for the use of geosynthetics in reinforced embankments as well as many types of geosynthetics that can address the many different functions needed when designing and constructing a soil embankment. Geosynthetics are generally cost efficient and have been used widely to stabilize slopes, improve site conditions when constructed over soft soils, improve drainage, and provide for erosion control.

- I have been designing reinforced embankments for over 40 years, I have used all types of reinforcement. In terms of foundation treatment, I choose the most appropriate solution for the site conditions. I have used different design methods, mainly Bishop, for overall stability but sometimes use Spencer's method.

- We have used rammed aggregate piers in the past, but generally our foundation soils are not so weak as to require this commonly. Geosynthetics are our main mitigation method in embankments (soil nails or rock buttresses in cut slopes). Not all reinforcement requires high-strength geotextile/geogrid - in lower-strength cases, we use uni-axial geotextiles. We currently have specifications for lower-strength and high-strength geotextiles, including approved lists. We have constructed one demonstration project using Geosynthetic-Reinforced Soil - Integrated Bridge Structure.

- We only have a handful of these installed, but we do have a specification and seem to be installing them more frequently in the past few years. We monitor them, but visual only - not a bad idea to use lidar and change mapping, maybe something we would consider.

- In many cases, the construction of the reinforced embankments is not done correctly. This results in excessive deformations at the face making the finished face not looking reasonable.

Survey on Geosynthetic Reinforced Embankments

University of Kentucky Transportation Center (UKTC) respectfully requests your participation in a short survey regarding the use of geosynthetic materials for stabilizing embankments. The survey is being conducted for a Kentucky State Planning and Research (SPR) project. Findings of the present study will be used to determine the feasibility of constructing Geosynthetic Reinforced Embankments in Kentucky.

The survey will only take a few minutes to complete. You can submit your survey with full answers or partial answers. We would greatly appreciate your participation. As a "Thank you" for your participation, all participants who submit the survey with their email addresses will receive a final report of this survey.

Thank you in advance for your participation.

1. Which category or categories best describe your organization?

- ☐ Transportation Agency
- ☐ Educational Institution
- ☐ Engineering Consultant
- ☐ Construction Contractor
- ☐ Material Supplier
- ☐ Transportation or Material Research Institute
- ☐ Other Category (Please Specify)

2. What most common ground improvement/reinforcement method has your organization used to ensure global stability of potentially unstable embankments?

- ○ Chemical stabilization (e.g., lime stabilization, lime/cement columns)
- ○ Geosynthetic reinforcement
- ○ Lightweight fill methods (e.g., geofoam applications, shredded tires)
- ○ Pile stabilization (i.e., spaced drilled piers or micropiles)
- ○ Planned embankment materials with crushed stone
- ○ Replace existing foundation soils
- ○ Stone columns or Geopier rammed aggregate piers
- ○ Other Methods (Please Specify)

3. In your opinion, what method is most cost-effective?

- ○ Chemical stabilization (e.g., lime stabilization, lime/cement columns)
- ○ Geosynthetic reinforcement
- ○ Lightweight fill methods (e.g., geofoam applications, shredded tires)
- ○ Pile stabilization (i.e., spaced drilled piers or micropiles)
- ○ Planned embankment materials with crushed stone
- ○ Replace existing foundation soils
- ○ Stone columns or Geopier rammed aggregate piers
- ○ Other Methods (Please Specify)

4. In your opinion, what disadvantage is the most concerning limitation on geosynthetic reinforced embankments?

- ○ Creep of the geosynthetic
- ○ Testing and reliable parameters for design
- ○ The exposed life of geosynthetics, being polymeric, is less than unexposed as when soil is backfilled
- ○ The geosynthetic reinforcement cannot reduce pore water pressure during fill placement and, thus, settlement is still a big issue
- ○ For long term performance of geosynthetics, they are chemically ultraviolet stabilized, which is harmful
- ○ Use of native soils vs. crushed stone or granular materials
- ○ Clogging of geosynthetics is challenging for specific soil types or unusual situations. For example, loose soils, fine cohesionless silts soil are troublesome
- ○ Carrying, Handling, Storage, and Installation must be assured by careful quality control and quality assurance
- ○ Damage of the geosynthetic during actual construction of the embankment
- ○ Others (Please Specify)

5. Has your organization designed or constructed geosynthetic reinforced embankments?

- ○ Yes
- ○ No

6. What design method(s) do you recommend for geosynthetic reinforced embankments?

☐ United States Federal Highway Administration Method
☐ Bishop Method
☐ Spencer Method
☐ Jewell Method
☐ Leshchinsky Method
☐ Other Methods (Please Specify)

7. What geosynthetic material do you recommend for reinforcing embankments?

○ High Strength Geotextiles
○ Uni-Axial Geogrid
○ Bi-Axial Geogrid
○ Combination of High Strength Geotextiles and Geogrids
○ Others (Please Specify)

8. Does your organization have a specification for geosynthetic reinforced embankments?

○ Yes
○ No

9. Does your organization have guidelines for geosynthetic reinforced embankments installation?

○ Yes
○ No

10. Is your organization currently monitoring geosynthetic reinforced embankments for long-term performance?

○ Yes
○ No

11. Please provide any additional comments in the space provided below.

12. Please provide your name and email address if you would like to receive the survey summary report.

Name:
Organization:
Email Address:

13. May we contact you to further discuss your answers and experience with geosynthetic reinforced embankments? If so, please include your contact details below.

Name:
Organization:
Email Address:

Appendix B Standard Reinforced Soil Slope Drawings

STANDARD REINFORCED SOIL SLOPE

STANDARD RSS GENERAL NOTES

Provide detailed shop drawings for construction in accordance with Section 5 of the Special Note for Reinforced Soil Slopes. Design calculations for reinforcement strength, length, and spacing are not required for submittals that meet the requirements of the Standard RSS Design Criteria and Design Tables. The RSS Designer shall certify the design meets the requirements of the plans, specifications, Special Note for Reinforced Soil Slopes, and the Standard RSS Design Criteria and Design Tables.

Deviations from the design tables by value engineering is only allowed on slopes over 5000 square feet and slopes which do not meet the requirements of the basis of the Standard RSS design.

All roadway and drainage excavation shall conform to Section 204 of the Standard Specifications.

Pay limits of excavation, if required, for reinforced fill shall equal angle of slope face and as is shown in the standard drawings. Actual excavation slope shall be determined by OSHA regulations and in-situ soil conditions. Excavation beyond pay limits is at Contractor's expense.

Provide Internal RSS Fill and Geogrid in accordance with the requirements of the Special Note for Reinforced Soil Slopes.

Provide facing and/or vegetation for the RSS in accordance with Section 7.3 of the Special Note for Reinforced Soil Slopes.

Compact reinforced fill in accordance with Section 206 of the Standard Specifications and the requirements of the Special Note for Reinforced Soil Slopes unless otherwise specified by the project designer and accepted by the Engineer.

Refer to the Special Note for Reinforced Soil Slopes, the Geotechnical Notes Sheets, and Geotechnical Drawings for other requirements concerning Reinforced Soil Slopes.

DEFINITION OF TERMS

Term	Description
RSS	Reinforced Soil Slope
H	Slope Height
β	Slope Angle (in degrees or H:V) not to exceed 70° (1H:2.75V)
L	Length of Primary Reinforcement (8' minimum)
Primary Reinforcement	Reinforcement used across width of reinforced fill
Secondary Reinforcement	Reinforcement placed at face between primary layers (minimum 6' length)
S_1	Vertical Primary Reinforcement Spacing (24" maximum)
S_2	Vertical Secondary Reinforcement Spacing (8" maximum)
T_{ult}	Reinforcement Ultimate Strength
T_{avail}	Reinforcement Long Term Strength, $= T_{ult} / (RF_{id} * RF_d * RF_c)$
RF_{id}, RF_d, RF_c	Reinforcement Reduction Factors for installation damage, durability, and creep
Reinforcement Coverage Ratio	Width of soil reinforcements to horizontal spacing (100% coverage ratio required for both primary and secondary reinforcement)
d_w	Depth to groundwater level below base of RSS

RSS DESIGN CRITERIA

Designs are based upon FHWA-NHI-10-024 and FHWA-NHI-10-025, "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Volumes I and II." Designs are based on Allowable Stress Design (ASD) with the following Factors of Safety:

- Min. FS for Global, Compound, Internal, and Sliding under Effective Stress (Long Term) Conditions = 1.5
- Min. FS for Global, Compound, and Sliding under Total Stress (Short Term) Conditions = 1.3
- Min. FS for Sliding along Geosynthetic = 1.5
- Min. FS for Lateral Squeeze = 2 (1.3 allowed with rigorous stability analysis to check for squeezing and stability issues)

A geotechnical investigation and laboratory testing of materials is required to verify the design soil parameters and groundwater depths in accordance with the Special Note for Reinforced Soil Slopes.

The standard designs are based on a level top of slope, level bottom of slope, and a surcharge at the top of slope. Slopes above or below the RSS, other than those needed for surface drainage (maximum 2% slope), are not suitable for application of the standard designs and require special consideration by the RSS Designer and the Engineer. Traffic surcharges exceeding 250 psf, permanent structures, seismic loads, or other permanent loading situations at the top of slope are not suitable for application of the standard designs and require special consideration by the RSS Designer and the Engineer.

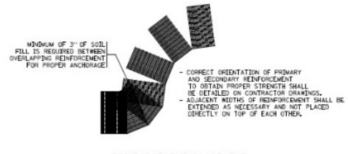
The standard designs are based on the depth to groundwater (d_w) below the RSS either greater than one-half the slope height (d_w >= H/2) or between one-half the slope height and the base of the RSS (0 <= d_w < H/2). The standard designs are not suitable for application if water levels are above the base of the RSS (standing water or high-water scenarios) and require special consideration by the RSS Designer and the Engineer.

Use Case 1 for slopes between 2H:1V (26.5°) and 1H:1V (45°) maximum with the Internal RSS Fill constructed of Locally Available Soil meeting the requirements of Section 7.1.2 of the Special Note for Reinforced Soil Slopes. Install a rock drainage blanket in accordance with the typical drawing for Case 1. Erosion control measures including facing units, wrapped faces, or erosion control mats with vegetation are required for stabilization of the slope faces of Case 1 RSSs.

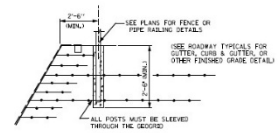
Use Case 2 for slopes between 2H:1V (26.5°) and 1H:1V (45°) maximum with the Internal RSS Fill constructed of Granular Materials meeting the requirements of Section 7.1.1 of the Special Note for Reinforced Soil Slopes. Facing units or wrapped faces may be used for Case 2 RSSs if needed to stabilize the slope face.

Use Case 3 for slopes between 1H:1V (45°) and 1H:2.75V (70°) maximum with the Internal RSS Fill constructed of Granular Material meeting the requirements of Section 7.1.1 of the Special Note for Reinforced Soil Slopes. Facing units or wrapped faces are required for Case 3 RSSs.

REINFORCED SOIL SLOPE DETAILS



REINFORCEMENT PLACEMENT AROUND CURVES AND CORNERS



POST DETAIL
TYPICAL HANDRAIL, FENCE POST, SIGN POST, OR OTHER VERTICAL OBSTRUCTION

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COMMONWEALTH OF KENTUCKY DEPARTMENT OF HIGHWAYS | REVISION | DATE | PREPARED BY: Division of Structural Design Geotechnical Branch | DATE: 05-JUNE-2025 | DESIGNED BY: KTC | DETAILED BY: E. BAILEY | CHECKED BY: T. SHEFFIELD, E. SCOTT | CROSSING: Standard Reinforced Soil Slope | ROUTE: KY 0000 | ITEM NO. 0-0000 | SHEET NO. | COUNTY OF: COUNTY | DRAWING NUMBER: S-000-2024

OpenRoads Designer v23,00,01,11 USER: $$$$USER$$$$ DATE PLOTTED: $$$$DATE$$$$ FILE NAME: $$$$design$file$specification$$$$

STANDARD REINFORCED SOIL SLOPE

RSS FILL CHARACTERISTICS

A. Internal RSS Fill:
 a. Locally Available Soil (Case 1)
  i. Use native or borrow soil material meeting requirements of Section 7.1.2 of the Special Note for Reinforced Soil Slopes:
  ii. Internal Angle of Friction, ϕ'_r = 28° Minimum
  iii. Cohesion, c'_r = 0 psf (Value to be used for design calculations. Material may exhibit a small amount of cohesion. Cohesion can be considered when evaluating stability of the slope face.)
  iv. Moist Unit Weight, γ_r = 120 pcf Maximum
 b. Granular Materials (Cases 2 and 3)
  i. Use Granular Materials in accordance with Section 7.1.1 of the Special Note for Reinforced Soil Slopes:
  ii. Internal Angle of Friction, ϕ'_r = 34° Minimum
  iii. Cohesion, c'_r = 0 psf
  iv. Moist Unit Weight, γ_r = 115 pcf Maximum

B. Retained Backfill
 a. Internal Angle of Friction, ϕ'_b = 28° Minimum
 b. Cohesion, c'_b = 0 psf (Value to be used for design calculations. Material may exhibit a small amount of cohesion.)
 c. Moist Unit Weight, γ_b = 120 pcf Maximum

C. Foundation Soil
 a. Effective Stress Internal Angle of Friction, ϕ'_f = 26° Minimum
 b. Effective Stress Cohesion, c'_f = 200 psf Minimum
 c. Total Stress Internal Angle of Friction, ϕ_f = 0°
 d. Total Stress Cohesion, c_f = 1200 psf Minimum
 e. Moist Unit Weight, γ_f = 120 pcf Maximum

TRAFFIC SURCHARGE

A 250 psf traffic surcharge is applied over the entire top of the slope (i.e., the surcharge begins at the slope break). Note: This surcharge requirement exceeds what is required in AASHTO LRFD Bridge Design Specifications, Section 3.

RSS GEOGRID REINFORCEMENT CHARACTERISTICS

A. Primary Reinforcement Length and Strength shall conform to the minimums in design tables for applicable reinforced soil fill type, maximum slope angle, and maximum slope height.
B. Reinforcement coverage for both primary and secondary reinforcement shall be 100%.
C. Minimum Primary Reinforcement Length (L) shall be 8'.
D. Maximum Primary Reinforcement Spacing (S_1) shall be 24'.
E. Minimum Secondary Reinforcement Long-Term Strength (T_{avail}) shall be 700 lb/ft (roll direction perpendicular to slope).
F. Minimum Secondary Reinforcement Length shall be 6'.
G. Maximum Secondary Reinforcement spacing (S_2) shall be 8'.
H. Internal RSS Fill limits shall extend a minimum of 1' beyond the end of the primary reinforcement.

If site conditions do not meet the above criteria, RSS Standard Design tables cannot be used and:

A special design for current site characteristics must be developed in accordance with the Special Note for Reinforced Soil Slopes, or

Analysis must be provided in accordance with the Special Note for Reinforced Soil Slopes indicating that the standard design tables provide adequate FSs for the current site characteristics.

Rock Drainage Blanket Requirements

When required, place a 1' thick rock drainage blanket underneath and extending up the back slope of reinforced fill as shown in the typical drawing for Case 1. The rock drainage blanket shall meet the following requirements:

- Coarse aggregate for the rock drainage blanket shall meet the requirements of Section 805.09 of the Standard Specifications.
- The rock toe drain shall consist of Channel Lining, Class II, meeting the requirements of Section 805.13.04 of the Standard Specifications.
- The drainage blanket shall be wrapped in Fabric-Geotextile Class 2 (Subsurface Drainage) meeting the requirements of Section 843 of the Standard Specifications and placed in accordance with Section 214 of the Standard Specifications.
- The rock drainage blanket shall tie into the rock toe drain. Extend the bottom layer of the geotextile fabric under the entire width of the rock toe drain. The top layer of the geotextile fabric shall extend up the slope of the rock toe drain and shall be tucked into the rock toe drain in such a manner that it will not be exposed to weather and sunlight. Internal RSS Fill material shall then be placed directly on the fabric; it shall not be in contact with the toe drain.
- Payment for the rock drainage blanket, rock toe drain, and geotextile fabric is incidental to the unit price bid for Reinforced Soil Slope.

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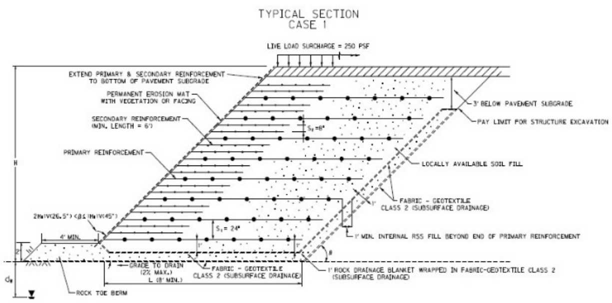
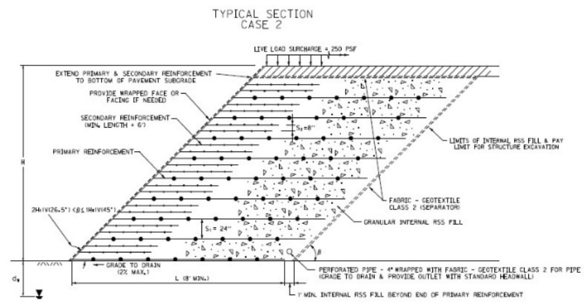
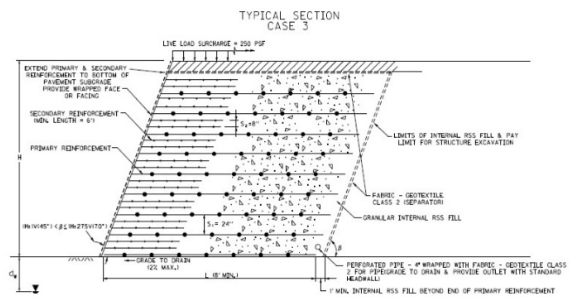
STANDARD REINFORCED SOIL SLOPE





MINIMUM PRIMARY REINFORCEMENT REQUIREMENTS

Case	Maximum Slope Height, H (ft)	Minimum Primary Reinforcement Long-Term Strength, T_{avail} (lb/ft)	Minimum Primary Reinforcement Length, L (ft)	
			$d_w \geq H/2$	$0 \leq d_w < H/2$
Case 1, Locally Available Soils, Maximum 45° Slope	H ≤ 10'	1000	1.33 H	1.33 H
	10' < H ≤ 20'	1300		
	20' < H ≤ 30'	2000		
Case 2, Granular Fill, Maximum 45° Slope	H ≤ 20'	700	1.2 H	1.2 H
	20' < H ≤ 25'	1000		
	25' < H ≤ 30'	1000		1.3 H
Case 3, Granular Fill, Maximum 70° Slope	H ≤ 20'	1300	1.0 H	1.2 H
	20' < H ≤ 30'	2000		



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COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

Division of Structural Design
Geotechnical Branch

DATE: 05-JUNE-2025
DESIGNED BY: KTC
DETAILED BY: E. BAILEY
CHECKED BY: T. SHEFFIELD, S. SCOTT

Standard Reinforced Soil Slope

ROUTE KY 0000 | ITEM NO. 0-0000 | COUNTY OF COUNTY | DRAWING NUMBER S-000-2024

Appendix C Special Note for Reinforced Soil Slopes

SPECIAL NOTE FOR REINFORCED SOIL SLOPES

1) REFERENCES

All references to the Standard Specifications are to the Kentucky Department of Highways Standard Specifications for Road and Bridge Construction, Current Edition, with all Supplemental Specifications.

All references to AASHTO are to the AASHTO LRFD Bridge Design Specifications, Current Edition, with applicable Interim Revisions. All references for FHWA-NHI-10-024 and FHWA-NHI-10-025 are to the Federal Highway Administration's "Design & Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Volumes I and II."

The requirements in the Standard Specifications or AASHTO shall be used for information not provided. Where there are conflicts between the Standard Specifications and AASHTO, the Standard Specifications shall govern.

The Contractor shall provide the Reinforced Soil Slope (RSS) Designer with a complete set of project plans and specifications and shall ensure that the RSS design is compatible with all other project features that can impact the design and construction of the slope. Various terms of interest for this special note are defined below.

2) 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 functions primarily as reinforcement.
Department/Engineer - Refers to the Kentucky Transportation Cabinet representative and/or a designated consultant acting on behalf of KYTC.
Supplier - The entity contractually retained by the Contractor to provide approved Structural Geogrid.
Designer – The entity that provides specific design of an accepted RSS system as described in the special note. The "Supplier" and "Designer" may be the same entity or separate entities retained by the Contractor.
Manufacturer – The entity that oversees and facilitates production of the geogrid from its component materials.
Working Drawings – A detailed plan set for the RSS, providing all information required to complete RSS construction.

3) SCOPE OF WORK:

Furnishing and testing materials, and the design and construction of a Reinforced Soil Slope retention system. Work consists of:

1. Furnishing structural geogrid reinforcement, drainage composite, and erosion control vegetative facing system (or other facing alternate) 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 the RSS.
4. Providing Supplier and Designer representatives for on-site pre-construction meetings with Contractor and Engineer and as needed during construction. The Representatives shall be onsite for a minimum of the first five (5) days of RSS construction.
5. Excavation, placement, and compaction of reinforced fill and backfill material as specified herein and as shown on the construction drawings.

Acceptance of the Contractor's design calculations and construction plans does not constitute endorsement or approval of the work submitted. The acceptance is an acknowledgment of the work performed and authorization for the Contractor to proceed with the project.

4) DESIGNER QUALIFICATIONS:

The RSS Designer will need to meet the following minimum qualifications:

1. The selected geogrid reinforcement has been previously reviewed and approved for use by the Department District Materials personnel, Division of Materials, and Division of Structural Design, Geotechnical Services Branch.
2. The Designer has the operational capacity and necessary experience to provide expert support to the Contractor on a timely basis.
3. At least 3 years of experience in the design of Reinforced Soil Slopes.
4. Past documented experience in the design of at least three (3) projects of a similar magnitude to the proposed RSS that have been constructed successfully.
5. All calculations and RSS construction plans shall be dated, sealed, and signed by a registered Professional Engineer licensed to practice in Kentucky.

5) CALCULATIONS AND PLANS:

A materials list, draft working drawings, and design calculations clearly showing conformance with the Standard Specifications, AASHTO, this Special Note, and contract plans shall be submitted for review. The format for the construction plans shall be in accordance with the Division of Structural Design's Guidance Manual. The first sheet shall be a title sheet.

All review submittals shall be submitted electronically in .PDF format through the Contractor to the Engineer. Half-sized prints are preferred. The Engineer may request full size (22″ X 36″) PDF sheets if necessary. The Engineer shall forward the submissions to the Geotechnical Branch.

The Contractor shall allow 30 calendar days for the Department to review each submission. While this process does not require submission of paper copies, the Department reserves the right to require such copies on a case-by-case basis. The thirty-day period begins when submissions are received in the Geotechnical Services Branch. Revisions may be required by the Department. The revised package shall be resubmitted to the Engineer for review. The Engineer shall have 15 calendar days to complete review of the revised package. This review process shall be repeated until the entire submittal is accepted by the Engineer. Additional time required by the Department to review resubmissions shall not be cause for increasing the number of contract working days. The additional work required by the Contractor to provide resubmissions shall be at no cost to the Department and with no extension of contract time. The Working Drawings shall include the following items:

A. Plan view showing the RSS disturbed limits.
B. Elevation view showing reinforcement placement requirements, soil slope layout, and geometric information.
C. Cross-sections showing RSS extents, slope face angle, reinforcement strengths, reinforcement vertical spacings, reinforcement lengths, subsurface drainage, surface drainage, slope facing, and slope face erosion protection including details for transitions between slope angles.
D. All design parameters and assumptions, including design life.
E. Clear and detailed descriptions of selected geosynthetic reduction factors for design, including test results that verify the chosen reduction factors. This also includes backfill properties, where applicable.
F. Accommodations for roadway drainage systems, subgrades, etc.
G. Show existing and proposed utilities impacted by slope.
H. Primary and secondary reinforcement lengths and spacing.
I. Selected facing system and justification, with specific construction methods, including information on facing, erosion protection products, and permanent vegetation establishment.
J. Overlap/seam requirements; include detailed overlap requirements for horizontal curves.
K. Special design considerations, if applicable, including but not limited to guardrail/sign post installation, reinforcement placement around deep foundations or other obstructions, drainage systems, foundation modifications, scour protection, etc.

Final working drawings shall not be produced until after the Department has approved all submittals. Final design calculations and construction plans shall be dated, sealed, and signed by a registered Professional Engineer licensed to practice in Kentucky. The Designer shall submit reviewed and approved shop drawings. The Designer shall provide the Department with a statement of assurance that the Working Drawings are accurate and satisfy project requirements. Each sheet of the drawings shall be dated, sealed, and signed by the RSS design engineer providing the design.

A Certificate of Analysis for the Internal RSS Fill Material (See Sections 7.1 and 7.4.1 herein) is required prior to final acceptance of the RSS design.

The Department assumes no responsibility for errors or omissions in the working drawings. Acceptance of the final working drawings submitted by the Contractor shall not relieve the Contractor of any responsibility under the contract for the successful completion of the work. Construction of the RSS shall not commence until the Contractor receives a written Notification to Begin RSS Construction from the Engineer, which will be issued once the complete package (drawings, calculations, construction procedures, Certificate of Analysis, etc.) is accepted. Fabrication of any RSS components before the written Notification to Begin RSS Construction shall be at the sole risk of the Contractor.

6) DESIGN:

The RSS design shall be in general accordance with FHWA-NHI-010-024, FHWA-NHI-010-025, and AASHTO. Exceptions to these requirements are listed in this note or shown elsewhere in the contract documents.

- Earth reinforcement elements in Reinforced Slope Systems shall be designed to have a corrosion resistance/durability to ensure a minimum design life of 100 years. Requirements may vary on a project-specific basis, and if so will be provided in the geotechnical notes.
- The length of primary reinforcement shall be the same throughout the RSS Structure. The minimum primary reinforcement length shall be no less than 8 feet.
- Construction and Traffic live load surcharge shall be as specified in the AASHTO LRFD Bridge Design Specifications, Section 3, except that no less than an additional two feet of earth surcharge shall be applied.
- The internal RSS fill material shall extend 1 foot, minimum, beyond the ends of the reinforcement.
- Granular Internal RSS fill, when used, should be separated from the non-reinforced embankment (where present) with Geotextile Fabric meeting requirements of current Standard Specifications Section 843 for Fabric-Geotextile Class 2 (Separation). Fabric placement shall be in accordance with current Standard Specifications Section 214.
- Locally Available Soil Internal RSS fill, when used, shall include drainage measures to prevent saturation and promote drainage of the Internal RSS fill. Measures to prevent surface water infiltration and groundwater migration into the Internal RSS fill shall be included in the design. These measures may include but are not limited to rock drainage blankets, perforated pipes, geomembranes, geosynthetic drainage composites, and surface drainage control systems.
- The target factors of safety for internal, compound, and global slope stability for RSS design shall be as specified in the current KYTC Geotechnical Guidance Manual. The RSS design shall consider effective (long-term) stress, total (short-term) stress, rapid drawdown, and seismic conditions as appropriate. In addition, the following minimum factors of safety will be used for RSS slope design.
  - Grid Pullout – 2.0
  - Sliding along Geosynthetic – 1.5
  - Block or wedge sliding below and behind reinforced zone – 1.4 minimum
  - Lateral Squeeze – 2 (1.3 allowed with rigorous stability analysis to check for squeezing and stability issues)
- Minimum geogrid anchorage length = 3 ft.

7) <u>MATERIALS:</u>

7.1 Internal RSS Volume:

7.1.1 Granular

Provide internally reinforced fill material consisting of either A) Quarry-processed limestone or sandstone from a Department-approved quarry or B) Durable Limestone/Sandstone from Roadway Excavation meeting all applicable general requirements of Section 805 of the Standard Specifications, current edition, and requirements herein. Approval of the material source by the Department is required prior to beginning RSS construction. The required gradation of internal RSS fill is shown in Table 1. S hear strength testing is not required if a design friction angle of 34 degrees is used (See Section 8).

Table 1: Gradation of Internal RSS Fill	
Sieve Size	**Percent Passing**
1"	100
3/4 "	80-100
3/8 "	20-80
No. 4	0-30
No. 8	0-10
Sizes No. 67, 68, 710, and 78 in the Department's Standard Specifications fall within these gradation limits. Sizes No. 57 and 610 may fall with these limits, depending on the specific gradation used.	

If optional product-specific construction damage testing is successfully performed, the gradation of the Granular Internal RSS fill may be adjusted to that used for the testing (See Section 7.2.2). Material not meeting the requirements of Table 1 shall meet the following requirements:

- Internal friction angle greater than or equal to 34 degrees
- 100% passing the 4" sieve
- $\leq$ 5% passing the No. 200 sieve
- Uniform fine sands or gap graded materials are not permitted

Project-specific shear strength testing meeting the requirements of Section 8 is required for materials not meeting the gradation in Table 1. The Designer is responsible for establishing and maintaining a quality control program to ensure compliance with this section.

Gradations for granular materials used in the RSS volume should be attained and verified per the requirements of Section 7.4.1 of this Special Note.

7.1.2 Locally Available Soil

Provide internally reinforced fill material consisting of locally available soils from roadway excavation or borrow excavation. Approval of the material source by the Department is required prior to beginning RSS construction. Locally available soil used as reinforced fill shall meet the following requirements:

- Material must be free of coal, shale, friable sandstones, or other deleterious materials.
- Liquid Limit (LL) ≤ 40, Plasticity Index (PI) ≤ 20.
- 100% passing the 4" sieve.
- Organic content ≤ 2%.
- 3 < pH < 9 (5 < pH < 8 if geogrids contain polyester).
- Internal Angle of Friction, $\varnothing'_r = 28°$ minimum (design $\varnothing'_r$ shall not exceed 32°)
- Cohesion of the reinforced fill material shall be ignored for the design of primary reinforcement and slope stability of the RSS. Cohesion of the reinforced fill material may be considered when evaluating facing stability, sloughing, and secondary reinforcement requirements.

Bank gravels, creek gravels, and sands may be used subject to Department review and approval. Other materials may be used subject to Department review and approval.

The contractor shall provide a representative sample of the material and a Certificate of Analysis containing the results of the required verification tests in accordance with Section 7.4.2 of this Special Note. The verification tests must confirm the design parameters used for the RSS design. If verification tests do not confirm the soil design parameters used for the RSS design, the Contractor must provide a revised RSS design using the verified soil parameters or change the material source to one that provides the required soil parameters from the original RSS design. Borrow excavation, if used for the RSS reinforced volume, shall comply with Section 205 of the Standard Specifications except that measurement for payment is included in the unit bid price for Reinforced Soil Slope.

7.2 Geogrid:

Use only geogrid products placed in Phase 9 of the Department's Kentucky Product Evaluation List (KYPEL) and accepted for use on a project basis. Geogrid Manufacturers are required to participate in the AASHTO Product Evaluation and Audit Solutions for Geosynthetic Reinforcement Products, and the product must have current test data posted in the program's DataMine. For products that do not have complete product test information in DataMine (i.e., construction damage testing, durability testing, creep testing, etc., have not been performed by AASHTO Product Evaluation and Audit Solutions), third-party test documentation complying with the requirements of AASHTO Product Evaluation and Audit Solutions and AASHTO Test Method R69 must be submitted for review and acceptance prior to the use of the product. Third-party laboratories shall be accredited by the Geosynthetic Accreditation Institute-Laboratory Accreditation Program (GAI-LAP).

Use a polymer geogrid consisting of High-Density Polyethylene (HDPE) or high tenacity Polyester (PET) formed into a uniform regular network of integrally connected elements with apertures greater than one-fourth (1/4) inch (6.35 mm) to allow interlocking with surrounding soil, rock, earth, or other specified materials to function primarily as reinforcement. Use a geogrid that is generally inert to biological degradation and commonly encountered chemicals and is free of defects or flaws that significantly affect its physical properties.

Ensure the geogrid has a minimum width of four (4) feet (1.22 meter) and that each roll is labeled with the manufacturers' name, product type, lot number, roll number, manufactured date, and roll dimension.

7.2.1 Packaging:

Protect the reinforcement from direct sunlight, ultraviolet rays, temperatures greater than 48°C (118°F), mud, dirt, dust, and debris during all periods of shipment and storage. Keep geogrids dry until installation, and do not store directly on the ground.

7.2.2 Physical Requirements:

Furnish geogrids meeting the requirements of the final design. The minimum weight shall be 8 oz/yd^2 to minimize construction damage.

Determine Long Term Design Tensile Strength based on the following:

$$T_{avail} = T_{ult} \div RF$$

Where:

T_{avail} = Long Term Design Strength

T_{ult} = Ultimate Tensile Strength determined in primary strength direction in accordance with ASTM D 6637 conducted at a strain rate of 10 % per minute. Tensile strength shall be reported without artificially deforming, manipulating, or massaging the test specimen under load before measuring such resistance or employing an artificial secant or offset tangent.

RF = Total Reduction Factor = RF_{id} x RF_d x RF_c

- Minimum RF with product specific testing: 3.15 for HDPE and 2.0 for PET (Minimum RF shall be the greater of the values listed above or the values obtained from product specific testing.)
- Minimum RF without test data: 10

RF_{id} = Reduction Factor for Installation Damage calculated in accordance with ASTM D 5818.

- Minimum RF_{id} with product-specific testing with appropriate backfill: 1.2 for HDPE and 1.1 for PET
- Minimum RF_{id} without test data: 2.0 for HDPE and 1.7 for PET
    - Note 1: Product-specific testing may allow adjustment of the gradation in Table 1, to that used in the construction damage testing, provided all other internal fill requirements are met.

- Note 2: When product-specific testing is conducted, if $RF_{id} > 1.7$, the particular combination of geogrid, internal RSS fill, gradation, and placement method shall not be used.

RF_d = Reduction Factor for Durability based on index properties in Table 2.

- If index properties are satisfied and $RF_{id} \leq 1.7$, $RF_d = 1.3$ (Default)
- Minimum RF_d with product specific durability testing: 1.10
- Minimum RF_d without durability or index test data: 2.0

RF_c = Reduction Factor for Creep Deformation for 100-year Design Life calculated in accordance with *GRI-GG4 using ASTM D 5262 for Long Term Strength.

- Minimum RF_c with product specific testing: 2.60 for HDPE and 1.60 for PET
- Minimum RF_c without test data: 5.0 for HDPE and 3.0 for PET
- *Either GRI-GG4 (a) or GRI-GG4 (b), depending on Flexural Rigidity value from ASTM D 1388.

Table 2: Required Values for Use of Default Durability Reduction Factor

Type	Index Test	Method	Value
HDPE	UV	ASTM D 4355	Min. 70% strength after 500 hours
PET	UV	ASTM D 4355	Min. 50% strength after 500 hours*
HDPE	Thermo-oxidation Resistance	ENV ISO 13438:1999, Method B	Min 50% strength after 56 days
PET	Hydrolysis Resistance	Inherent Viscosity Method (ASTM D 4603, GRI-GG8)	Min. Number (Mn) Molecular Weight of 25,000
PET	Hydrolysis Resistance	GRI GG7	Max. Carboxyl End Group Number of 30
HDPE & PET	Survivability	Weight per Unit Area (ASTM D 5261)	Min. 8 oz/yd^2
HDPE & PET	% Post-Consumer Recycled Material (by weight)	Certification	Max. 0%

* If buried in one week. If not, must meet minimum 70% strength after 500 hours.

7.3 Facing and Permanent Vegetation

Provide slope facing and/or permanent vegetation in accordance with Sections 7.4.3 and 9.2 of this Special Note. The RSS Designer shall provide calculations and justification for the selected facing treatment (See Section 5). Use products on the Department's List of Approved Materials when possible. Facing materials not on the List of Approved Materials shall be submitted to the Engineer for review and acceptance in accordance with the requirements of Section 7.4.3 of this Special Note. The selected facing components shall have corrosion resistance/durability to ensure a minimum design life of 100 years.

7.4 Sampling & Testing:

7.4.1 Internal RSS Fill:

To obtain source approval, the Contractor shall furnish the Engineer with an 80-pound representative sample of the Internal RSS fill material and a Certificate of Analysis containing results of all tests referenced in Table 3.1 or Table 3.2 at least four weeks prior to beginning construction of the Reinforced Soil Slope.

Table 3.1: Sampling Frequency for Granular Internal RSS Fill

Function	Tests[1]	Frequency
Source Approval: (Testing by Contractor and/or its Consultant)	Soundness (AASHTO T 104) Gradation (AASHTO T 27) Strength (AASHTO T236 or ASTM D4767) if required[2]	At least four (4) weeks prior to beginning RSS construction and once per material change and/or change in source. One set of tests is valid for up to 10,000 ft^2 of RSS area if there is no material change or change in source.[3]
Acceptance and Quality Control (Testing by Department)	Gradation (AASHTO T 27)	One per 2,000 cubic yards at job site. (A change of more than +/- 5.0 percent passing any sieve size may require additional Gradation testing by the Contractor.)
	Any other applicable requirements of Section 805 of the current Standard Specifications	As required by the current Materials Field Sampling and Testing Manual, Standard Specifications, and/or other Department policy.

[1] The laboratory performing these tests must be accredited by the AASHTO re:source for the tests they perform. The Contractor may consult the Geotechnical Services Branch to ensure that a lab is accredited or certified.
[2] Strength tests are required if the Internal RSS Fill material does not meet the requirements of Table 1 or if a design friction angle of greater than 34 degrees is used.
[3] e.g. 1 to 10,000 ft^2 of RSS requires 1 set of tests, 10,001 to 20,000 ft^2 requires 2 sets of tests, etc.

Table 3.2: Sampling Frequency for Locally Available Soils Internal RSS Fill		
Function	**Tests[(1)]**	**Frequency**
Source Approval: (Testing by Contractor and/or its Consultant)	Classification of Soils: AASHTO R58, T88 (KM-64-519), T89, T90, T99 (KM 54-511), T100, T265, T267, T289, and M145; ASTM D2487 Strength: ASTM D4767 (KM 64-502) or AASHTO T 236 as appropriate [(2)]	At least four (4) weeks prior to beginning RSS construction and once per material change and/or change in source. One set of tests is valid for up to 10,000 ft^2 of RSS area if there is no material change or change in source.[(3)]
Acceptance and Quality Control (Testing by Department)	Gradation (AASHTO T 27)	One per 2,000 cubic yards at job site. (A change in soil classification and/or gradation <u>may</u> require additional classification and strength testing by the Contractor.)
	Any other applicable requirements of Section 805 of the current Standard Specifications	As required by the current Materials Field Sampling and Testing Manual, Standard Specifications, and/or other Department policy.
[(1)] The laboratory performing these tests must be accredited by the AASHTO re:source for the tests they perform. The Contractor may consult the Geotechnical Services Branch to ensure that a lab is accredited or certified. [(2)] Strength tests are required. [(3)] e.g. 1 to 10,000 ft^2 of RSS requires 1 set of tests, 10,001 to 20,000 ft^2 requires 2 sets of tests, etc. Changes in material classification and/or gradation may require the contractor to perform additional classification and strength testing to verify the Locally Available Soil Internal RSS Fill complies with the design parameters.		

During construction, the Internal RSS fill material shall be sampled by the Engineer for acceptance and quality control testing, performed by the Department and/or an independent approved, third-party laboratory. A new sample and Certificate of Analysis shall be provided by the Contractor any time the material and/or source changes.

The RSS Designer will review all fill material tests and certify compliance with the design parameters. The RSS Designer shall evaluate any failed material placed in the RSS and will provide a signed, stamped recommendation for modification and/or repair of the RSS system to adjust for the failed material. The Contractor is responsible for any modification and/or repair of the RSS system due to the Internal RSS Fill not being in compliance with the design parameters.

Modification and/or repair of the RSS system due to the Internal RSS Fill not being in compliance with the design parameters is done at no additional cost to the Department.

7.4.2 Geogrid:

No project-specific geogrid testing will be required during construction; however, the Department reserves the right to require such testing of geogrid at any time. The Contractor shall provide representative samples of geogrids utilized to the Engineer and certification that these materials meet the requirements of the RSS design and this Special Note.

7.4.3 Slope Facing:

No project-specific testing of slope facing materials will be required during construction; however, the Department reserves the right to require such testing of slope facing materials at any time. Use products on the Department's List of Approved Materials when possible. The Contractor shall provide representative samples of slope facing materials to be utilized and certification that these materials meet the requirements of the RSS design and this Special Note to the Engineer for review and acceptance. Representative samples to be provided include, but are not limited to, geosynthetic face wraps, turf reinforcement mats, temporary erosion blankets, wire mesh forms, gabion units, fertile soil, soil supplements, mulch, seed mixtures, sod, and drainage composites.

8) GEOTECHNICAL DESIGN PARAMETERS:

Geotechnical Design Parameters are listed in Table 4.1 and Table 4.2.

Table 4.1. Granular Internal RSS Fill Geotechnical Design Parameters

	Granular Internal RSS Fill [(1)]	In-Situ Foundation and Retained Backfill Soil	Granular Embankment (if required) [(2)]
Unit Weight, γ (pcf)	120	See Geotechnical Notes & Drawings	115
Friction Angle, Ø (deg)	34 [(3)]		38
Cohesion, c (psf)	0		0

Notes:
[(1)] Design parameters for Granular Internal RSS Fill not meeting the requirements of Table 1 of Section 7.1.1 of this Special Note shall be as indicated in the design calculations and as verified by the requirements of Section 7.4.1 of this Special Note.
[(2)] See Subsection 805 of the Standard Specifications.
[(3)] If a design friction angle of greater than 34 degrees is used, the value must be substantiated by Direct Shear Test (AASHTO T236) or CU Triaxial Test (ASTM D4767) on project specific material in accordance with Section 7.4.1, Table 3.1, of this Special Note. The design friction angle may be increased up to a maximum of 40 degrees based on laboratory testing.

Table 4.2. Locally Available Soil Internal RSS Fill Geotechnical Design Parameters			
	Locally Available Soil Internal RSS Fill (1)	**In-Situ Foundation and Retained Backfill Soil**	**Granular Embankment (if required)** (2)
Unit Weight, γ (pcf), Minimum	120 Min.	See Geotechnical Notes & Drawings	115
Friction Angle, Ø (deg)	≥28 (3)(4)		38
Cohesion, c (psf)	0 (5)		0

Notes:

(1) Design parameters for Locally Available Soil Internal RSS Fill shall be as indicated in the design calculations and as verified by the requirements of Section 7.4.1, Table 3.2, of this Special Note.

(2) See Subsection 805 of the Standard Specifications.

(3) The design friction angle value must be substantiated by Direct Shear Test (AASHTO T236) or CU Triaxial Test (ASTM D4767) on project specific material in accordance with Section 7.4.1 of this Special Note.

(4) The friction angle used for design shall not be greater than 32 degrees regardless of the results of the strength tests performed.

(5) Cohesion of the reinforced fill material shall be ignored for the design of primary reinforcement and slope stability of the RSS. Cohesion of the reinforced fill material may be considered when evaluating facing stability, sloughing, and secondary reinforcement requirements.

The coefficient of friction for sliding resistance for cohesionless soils shall be no greater than tangent phi (tan Ø) of the weaker material. The coefficient of friction for sliding resistance for cohesive soils shall be no greater than the adhesion value for the in-situ soil.

In no case shall the geotechnical strength parameters used for design exceed the values allowed by the AASHTO Specifications.

9) <u>GENERAL</u>:

9.1 General requirements:

Comply with all dimensions shown on the contract plans and accommodate all other project features as shown on the contract plans and approved Working Drawings.

Section 107 of the current specifications shall apply to the use of patented devices, materials, slope systems, and processes.

Geogrid shall be installed at the proper elevation and orientation as shown on the construction drawings or as directed by the Engineer. Correct orientation (roll direction) of the geogrid shall be verified by the Contractor. Geogrid may be temporarily secured in place with staples, pins, sandbags, or backfill as required by fill properties, fill placement procedures, or weather conditions, or as directed by the Engineer. All connections shall be in accordance with the Designer's recommendations and drawings.

When wrapped-face slopes are required (see below), a minimum overlap of 6 inches is recommended along edges perpendicular to slope. Alternatively, the edges of the grid may be clipped or tied together. When wrapped-face slopes are not necessary, no overlap is required, and edges may be butted.

The non-reinforced embankment material (where present) shall be built concurrently with the Reinforced Soil Slope. The core cannot be constructed prior to the RSS.

Tracked construction equipment shall not be operated directly on the geogrid. A minimum fill thickness of 6 inches is required prior to operation of rubber-tired and 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.

Any geogrid damaged during installation shall be replaced by the Contractor at no additional cost.

9.2 Slope Facing Requirements:

Treatment of slope faces shall be in accordance with Section 8.4, Section 8.5, and Table 8-1 of FHWA-NHI-010-025, based on project specific conditions. Slope facing materials shall be in accordance with Section 7.3 of this Special Note. Construction of the facing shall be in accordance with the accepted Final Working Drawings.

9.3 Compaction Requirements:

Backfill material shall be placed in lifts and compacted according to Section 206 of the current Specifications, unless thinner lift thicknesses are required by the Designer. Sheepsfoot and grid type rollers are not permitted because of possible damage to the geogrid reinforcement. Backfill shall be placed, spread, and compacted in such a manner that minimizes the development of wrinkles in and/or movement of the geogrid. If Granular Internal RSS Fill is used, the Department shall monitor density with Plate Compaction Testing in accordance with the procedure outlined below in Section 9.4.

9.4 Plate Compaction Test Procedure:

Trial fill sections shall be constructed with Department personnel present to determine appropriate criteria to achieve adequate compaction. Trial fill sections may be included as part of the RSS construction if approved by the Engineer. The trial fill sections shall be performed as follows:

- One trial fill section is valid for up to 10,000 ft^2 of RSS area (e.g. 1 to 10,000 ft^2 requires 1 trial fill section, 10,001 to 20,000 ft^2 requires 2, etc.) and for no more than one individual RSS.
- The minimum dimensions of the test pad shall be 15 ft. wide by 50 ft. long.
- The lift thickness shall not exceed one (1) foot.
- Compaction shall be determined by using a level to measure the settlement of the trial section at a number of locations after each pass (e.g., a minimum of 5 locations measured at the center of a 1 ft. square metal plate or other methods approved by the Engineer).
- After constructing a total thickness of approximately 3 feet, the third lift shall be used to determine the appropriate number of passes for production, which will maximize compaction without excessively crushing the rock at the surface.
- The number of passes to achieve at least 80 percent of the maximum settlement will be required for production work.
- Only those methods and equipment used to establish compaction compliance in the trial fill section shall be used for production work.
- A material change, change in source, a difference of more than +/- 5.0 percent passing any sieve size, and/or change in the approved equipment shall require the Contractor to conduct a new trial fill section and obtain re-approval by the Engineer of the minimum number of passes and rolling pattern.
- The Department reserves the right to use other test methods to evaluate the adequacy of the compaction criteria.
- The trial fill sections are incidental to the bid price for Reinforced Soil Slope.

Within three (3) feet of the slope face, compaction criteria shall be determined using test pad sections with Department personnel present to determine appropriate criteria to achieve adequate compaction. The test pad sections shall be performed as follows:

- The minimum dimensions of the test pad shall be 5 ft. wide by 15 ft. long.
- The lift thickness shall not exceed one (1) foot.
- Compaction shall be determined by using a level to measure the settlement of the test pad section at a number of locations after each pass (e.g., a minimum of 3 locations measured at the center of 1-foot square plates or other methods approved by the Engineer).
- After constructing a total thickness of approximately 3 feet, the third lift shall be used to determine the appropriate number of passes for production, which will maximize compaction without excessively crushing the rock at the surface.
- The number of passes to achieve at least 80 percent of the maximum settlement will be required for production work.
- Only those methods and equipment used to establish compaction compliance in the trial fill section shall be used for production work.
- A material change, change in source, a difference of more than +/- 5.0 percent passing any sieve size, and/or change in the approved equipment shall require the Contractor to conduct a new test pad section.
- The test pad sections are incidental to the bid price for Reinforced Soil Slope.

9.5 Project Plans Changes:

Design data is based on subsurface conditions and original project parameters. If project plans are changed subsequently by the Department, an additional subsurface investigation may be needed to verify the design parameters of the in-situ soils and embankment materials. The Engineer should notify the Division of Structural Design, Geotechnical Services Branch, of any plan changes as soon as possible. It is estimated that it will take approximately three (3) months for the Geotechnical Services Branch to complete its investigation and make any necessary geotechnical recommendations that may affect design prior to any construction. The Contractor will be responsible for providing access for drilling equipment to this area.

In the event the Contractor or their subcontracted Designer requires additional geotechnical investigation for refinement of their final design drawings or for reasons other than plan changes by the Department, those costs are incidental to the RSS bid item and no additional time will be allowed.

10) METHOD OF MEASUREMENT AND BASIS OF PAYMENT:

RSS quantities are calculated and paid from vertical projection of reinforced slope (toe to crest). No field measurement will be made. The final quantity will be the contract plan quantity increased or decreased by authorized changes. Internal RSS fill material will not be included in the calculation of Embankment-in-Place.

If required by geotechnical note, any Roadway Excavation beneath the reinforced zone shall be measured and paid according to Section 204 of the Standard Specifications. When required by geotechnical note, the quantity of Granular Embankment or quarried stone for foundation replacement or rock embankment shall be measured and paid according to Section 206 of the Standard Specifications. The final quantities for these items will be the design plan quantity increased or decreased by authorized changes only. See Geotechnical Notes for the possible need for other bid items for RSS construction, including but not limited to Granular Embankment, Roadway Excavation, and Geotextile Fabric.

Additional quantities of reinforcement, RSS Volume, and labor necessary to satisfy the design shall be incidental to the unit price bid for the Reinforced Soil Slope.

The Internal RSS Fill material within the RSS volume, including the area that extends 1 foot minimum beyond the ends of the reinforced volume, shall be included in the unit price bid for Reinforced Soil Slope.

Surface and groundwater control measures such as rock drainage blankets, drainage geocomposites, perforated and non-perforated pipes, geomembranes, geotextiles, pavement wedge curbs and flumes, or other products or methods to prevent infiltration into and saturation of the Internal RSS Fill shall be included in the unit price bid for Reinforced Soil Slope.

The reinforcement shall be included in the unit price bid for Reinforced Soil Slope.

All work associated with providing the design, details, materials and construction for the facing shall be incidental to the unit price bid for Reinforced Soil Slope.

PAY ITEM	**UNIT**	**CODE**
Reinforced Soil Slope	Square Foot	21587EN

Appendix D Guidance for Use of Reinforced Embankments and Reinforced Soil Slopes

KENTUCKY TRANSPORTATION CABINET
DIVISION OF STRUCTURAL DESIGN
DRAFT GUIDANCE FOR USE OF REINFORCED EMBANKMENTS AND REINFORCED SOIL SLOPES

1. **DESCRIPTION.** Construction of roadways and bridges involves the movement of earth materials and construction of embankments and cut slopes. Often constraints and performance criteria impact how embankment or cut slopes are designed and constructed. Embankments can be constructed out of native materials sourced from roadway excavation, but sometimes native materials may be of poor quality, resulting in potentially unstable slopes or the need for additional right of way to construct flatter slopes. Poor quality foundation soils may be unable to support placement of an embankment.

   Unstable slopes can result in unplanned roadway maintenance and/or the inability keep a roadway open to traffic. Flatter slopes needing additional right of way impact adjacent resources, streams, environmental hazards, historical properties, businesses, and homes. Impacting these features can be costly to mitigate, and in some cases can prevent a project from being implemented. Thus, minimizing a roadway's footprint may be essential to controlling project costs and schedules.

   Solutions for unstable embankments often include use of select fill materials, improvement of foundation soils, drainage improvements, retaining walls, reinforced embankments, and reinforced soil slopes (RSSs).

   Reinforced embankments are often used where the quality of embankment material is suitable to provide stable slopes but foundation soils cannot support the embankment's weight (Figure 1). Reinforcement within the base of a new embankment is thus required to stabilize the embankment. Slopes for a reinforced embankment range from 2H:1V up to 1H:1V. Failure modes for reinforced embankments include bearing, rotational, and sliding. With reinforced embankments, end-of-construction conditions are typically the most critical concern for their stability, but long-term stability and settlement can also be a consideration.

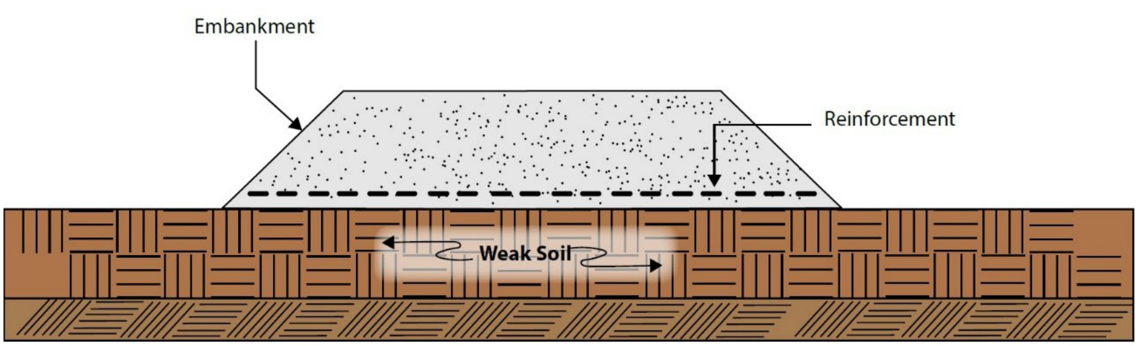

Figure 1. Typical Reinforced Embankment

RSSs differ from reinforced embankments or mechanically stabilized walls (MSEs) in that subgrade soils are anticipated to provide a stable foundation. Reinforcement enables the use of steeper slopes (up to 70°). RSSs with slopes steeper than 70° should be analyzed as MSE walls. RSSs typically require a facing treatment (e.g., facing elements, wrapped faces, special vegetation treatments) to prevent erosion, raveling, and surficial failures of the slope. They may require select backfill materials for construction of the reinforced fill portion of the embankment. Figure 2 shows a typical reinforced soil slope.

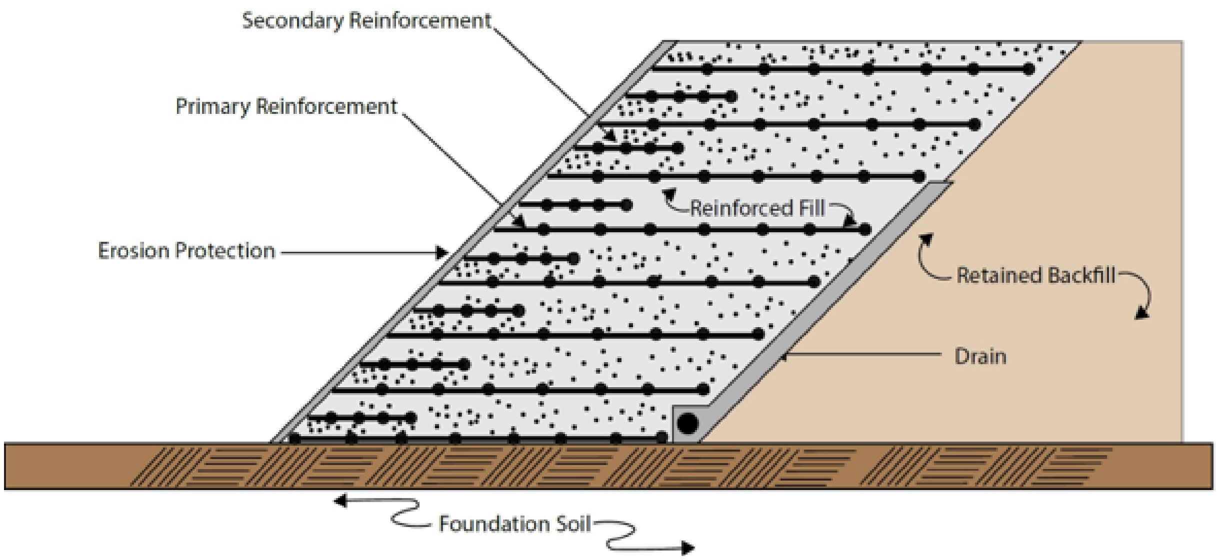

Figure 2. Typical Reinforced Soil Slope

This document provides administrative guidance and specifications the Kentucky Transportation Cabinet (KYTC) can use to design and construct reinforced embankments and RSSs. It covers:

- Design considerations and requirements
- Methodology for selecting an appropriate improvement type
- Design methodologies
- Material selection and approval
- Plan development
- Construction specifications

2. DESIGN CONSIDERATIONS.

2.1. Project Requirements. Identify geometry, external loads, performance criteria, and construction constraints, including:

- Line, grade, and anticipated slopes
- External loads generated by traffic, permanent features, and seismic forces
- Nearby or adjacent structures (e.g., bridges, walls, culverts, pipes, buildings)

- Anticipated hydrologic conditions (e.g., normal pool, high water elevations, scour)
- Target and required factors of safety
- Allowable limits of deformation and settlement
- Site accessibility and space restrictions
    - Limited right of way
    - Limited headroom
    - Onsite material storage areas
    - Access for construction equipment
    - Traffic disruption restrictions
- Utility locations, both above and belowground
- Environmental concerns
- Aesthetic requirements for vegetation or facings

2.2. Subsurface Conditions. A site's in-situ soil and rock parameters shall be identified using typical subsurface investigation techniques. Sufficient information shall be obtained to identify variation in soil and rock conditions across the anticipated length of affected embankment. Groundwater elevations shall be obtained. Subsurface investigations shall follow the procedure undertaken for embankments as outlined in Section GT-402-4 of KYTC's *Geotechnical Guidance Manual* and Transmittal Memoranda (Scope of Subsurface and Field Investigations: Embankments). Since RSSs are like retaining walls and retaining walls are a possible alternative, embankment borings shall be supplemented with additional borings as needed to comply with Section GT-403-4 of the *Geotechnical Guidance Manual* (Scope of Subsurface & Field Investigations: Retaining Walls). Often the need for a RSS or retaining wall is not known during the initial subsurface investigation, and it may be necessary to remobilize to obtain the needed subsurface information.

Laboratory testing of retrieved samples in accordance with Section 500 of the *Geotechnical Guidance Manual* shall be conducted to provide the required soil strength parameters. Consolidation testing of foundation soils should be conducted if settlement is expected to be a concern.

2.3. Material Availability. Sources of reinforced fill materials to construct the RSS shall be identified. These may be native materials from borrow pits, materials obtained from roadway excavation, or processed fine or coarse aggregates from pre-approved sources. When needed, laboratory testing shall be conducted to determine gradation, classification, moisture-density, and strength parameters. Depending on reinforcement types anticipated, reinforced fill soil should be tested for the potential for corrosion, chemical, and biological degradation. Costs and haul distances shall be considered when selecting reinforced fill materials.

Potential types of geosynthetic reinforcement compatible with reinforced fill materials shall be identified. Some geosynthetics may be less compatible with available fill materials and anticipated construction methods than others. Potential damage to geosynthetics from placement of proposed fill materials shall be considered when selecting possible geosynthetics.

Facing options shall be identified based on the slope angle, reinforced fill materials, and aesthetic requirements. Steeper slopes are less likely to support vegetation and may require reinforced fill materials that are unlikely to support vegetation. Slopes steeper than 1H:1V may require wrapped faces or facing elements (e.g., welded wire forms, blocks, geocells) to protect against raveling and shallow slope failures.

Where possible, items from the Division of Materials List of Approved Materials shall be utilized for geosynthetics and facing materials. The Department of Highways (referred to as *the Department* after this point) should develop pre-approved lists of geosynthetic reinforcement and RSS systems. Having pre-approved reinforcement and facing systems can substantially reduce time and effort for reviewing contract submittals. It also provides for up-front knowledge of potential materials that will be used on the project, which will aid in the refinement of reinforcement design. The Appendix provides information on the evaluation and approval of geogrid reinforcement.

2.4. Contracting Method. Reinforced embankments and RSSs can be designed and detailed by the Department, or they can be designed, detailed, and constructed by the Contractor. The method chosen impacts how much preliminary design is performed, the level of detail provided in the plans, and the level detail provided in the specifications. Department-designed slopes and embankments must have detailed plans and material specifications, and the contractor shall submit information indicating how materials they supply comply with those specifications. For contractor-designed slopes and embankments, the Department provides performance-related specifications and plans. The contractor then provides detailed plans and material submittals showing how performance specifications were met. Section 7 (Plan Development and Requirements) provides additional information about contract documents required for letting.

3. **SELECTION METHODOLOGY.** Selection of an appropriate alternative for a given site depends on many factors. Multiple alternatives often are technically feasible, so a process is needed to evaluate and rate alternatives to find the most appropriate alternative. Tanyu, et al. (2008) presented a method for evaluating earth retaining systems (ERSs). It involves 12 Importance Selection Factors (ISF) that are then assigned an Importance Rating (IR) based on the relevance and importance of the ISF to the site. IRs range from 1 (least important) to 3 (most important). Table 1 lists the 12 ISFs and briefly describes each.

ERSs compatible with site constraints and project requirements are then identified. An unreinforced embankment alternative should be included if it is compatible with site constraints and project requirements. Costs should not be included at this point as a justification to eliminate an ERS type.

Each ERS is evaluated against the ISFs and IRs and assigned a suitability factor (SF) based on how suitable a particular ERS is compared to the ISFs. The determination of SFs is subjective. SFs range from 4 (most suitable) to 1 (least suitable). If a site has soft foundation soils and large settlements are expected, a RSS may be assigned a SF of 4 for the Displacement Selection Factor since RSSs are better suited at handling settlement. A rigid cast-in-place retaining wall may be assigned a SF of 1 for the same Selection Factor since they are less adept at handling large displacements. If aesthetics are of concern, a MSE wall with attractive precast panels may be assigned a SF of 4 in that category as opposed to a gabion basket wall with exposed aggregate and wire cages being assigned a SF of 1.

Table 1. Importance Selection Factors (modified from Tanyu, et al. (2008))

Importance Selection Factor (ISF)	**Description**
Ground Type	Impacts of retained and foundation soils on ERS performance
Groundwater	Influence of groundwater on the ERS and the ability to lower groundwater behind the ERS
Construction Considerations	Availability of construction materials, equipment, site access, and labor to fabricate the ERS
Speed of Construction	Speed at which the ERS can be constructed and its impact on project completion
Right of Way (ROW)	Need for ROW for ERS and whether the ERS is required to support a transportation facility or adjacent owner
Aesthetics	Need for blending the ERS into the surrounding environment
Environmental Concerns	Impact of ERS on environmental concerns such as contaminated soil, noise, vibration, and sensitive areas.
Durability and Maintenance	Impact of environmental conditions on ERS durability and maintenance requirements for its anticipated life
Tradition	Familiarity of contractors and DOT with the ERS (i.e., commonly used system, or is it new or rarely used?)
Contracting Practices	Contracting methods (agency or contractor designed) and patent/sole source concerns
Cost	Total cost of the ERS including materials, ROW, environmental impacts, and construction delays.
Displacements	Ability of the ERS to handle anticipated settlements and deflections without excessive repair or maintenance

Next, a weighted rating (WR) for is derived for each ISF by multiplying the IR by the SF. A total weighted rating is then calculated by summing the WRs for all ISFs. The ERS with the highest rating should be selected. If scoring indicates several ERSs have similar WRs, then contract documents can specify several alternatives. Figure 3 provides a sample ERS Selection Matrix.

ERS Selection Matrix														
Project Name:		Example Matrix												
ERS Type / **ISF**		**Ground Type**	**Groundwater**	**Construction Considerations**	**Speed of Construction**	**ROW**	**Aesthetics**	**Environmental Concerns**	**Durability and Maintenance**	**Tradition**	**Contracting Practice**	**Cost**	**Displacement**	**Total Weighted Rating (WR_T)**
	IR	3	2	2	3	1	1	2	2	3	1	3	3	
MSE Wall - Precast Facing	**SF**	4	1	3	3	1	4	4	3	4	2	3	2	
	WR	**12**	**2**	**6**	**9**	**1**	**4**	**8**	**6**	**12**	**2**	**9**	**6**	**77**
Gabion Wall	**SF**	3	1	3	1	4	1	4	4	1	3	1	4	
	WR	**9**	**2**	**6**	**3**	**4**	**1**	**8**	**8**	**3**	**3**	**3**	**12**	**62**
Cast-in-place Concrete Gravity Wall	**SF**	4	1	1	1	1	4	2	4	3	4	1	2	
	WR	**12**	**2**	**2**	**3**	**1**	**4**	**4**	**8**	**9**	**4**	**3**	**6**	**58**
RSS	**SF**	4	1	1	4	4	3	1	4	2	2	4	1	
	WR	**12**	**2**	**2**	**12**	**4**	**3**	**2**	**8**	**6**	**2**	**12**	**3**	**68**
Unreinforced Embankment	**SF**	3	1	2	4	1	3	1	3	4	4	2	1	
	WR	**9**	**2**	**4**	**12**	**1**	**3**	**2**	**6**	**12**	**4**	**6**	**3**	**64**

Figure 3. ERS Selection Matrix (modified from Tanyu, et al. (2008))

4. DESIGN METHODOLOGY.

For design of reinforced embankments, see FHWA NHI-97-092, *Geosynthetic Design and Construction Guidelines* (Holtz, et al. (2008)).

For design of RSSs, see FHWA NHI-10-024 and FHWA NHI-10-025, *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, Volumes I & II* (Berg, et al. (2009)).

Target factors of safety for slope stability identified in KYTC's *Geotechnical Guidance Manual* (Section GT-601-3) shall be utilized for both external, deep-seated failure surfaces as well as compound failure surfaces. Target factors of safety are given as a range (e.g., 1.2 – 1.4) for different slope types and analysis conditions. Since RSSs are typically used in situations where site conditions prevent the use of normal slope angles and/or require steeper slopes, there is some additional risk or concern if a failure occurs. Therefore, when using RSSs it may be more appropriate to require factors of safety on the higher end of the ranges to mitigate some failure risk. Of particular concern are RSSs located at bridges, culverts, or other structures where failure may impact structure performance.

Where soft soil is located under embankments, checks for bearing capacity and lateral squeeze shall be performed. Minimum factors of safety for potential failure mechanisms are specified below.

- 1.5 against horizontal sliding along the base of the reinforced mass
- 1.5 against internal failure (within the reinforced mass)

- 1.3 against lateral squeeze if a weak layer exists beneath the embankment to a limited depth (depth of weak soil is less than width of embankment slope). If the factor of safety is less than 2, rigorous stability modeling and analysis shall be performed.
- 1.1 for seismic loading for the above failure modes.

Computer-assisted design can be used in lieu of or in conjunction with the noted references. Methods presented in the references can be used to develop preliminary reinforcement layouts that can be further refined using software. The use of computer-assisted design is particularly important for instances where site conditions do not match assumptions in the design references (e.g., external loading, groundwater, complex geometry, difficult foundation conditions).

While some software uses design methods from the references noted above, other software may use different methods and assumptions. If software assumes that reinforcement provides a negative driving force as opposed to resisting moment, adjustments need to be made to the long-term design tensile strength to account for the required factor of safety (Berg, et al. (2009)). Users should be aware those methods and assumptions impact stability analysis and reinforcement design. Furthermore, some software may be proprietary to specific reinforcement manufacturers, facing systems, or reinforcement types. Calculations and computer-generated output should be provided that clearly show design procedures, inputs, and assumptions.

Geosynthetic reinforcement elements shall be designed to have corrosion resistance/durability for a minimum design life of 100 years unless otherwise noted in the plans. Construction and traffic live load surcharge shall be as specified in the *AASHTO LRFD Bridge Design Specifications* (Section 3), except that no less than an additional two feet of earth surcharge shall be used. Additional design requirements can be found in the Special Note for Reinforced Soil Slopes.

5. **DRAINAGE SYSTEMS.** Controlling surface and subsurface water is necessary to ensure reinforced embankments and RSSs perform as intended. For reinforced embankments and slopes over soft, compressible, and wet soils, a drainage blanket may be the first layer of embankment fill to allow for dissipation of pore water pressure from foundation soil consolidation.

   For RSSs, saturated reinforced fill material can affect reinforcement performance and thus embankment stability. Drainage blankets, perforated pipes, trench drains, and geocomposite drains may be used below and behind reinforced fill material to control groundwater and reduce the potential for saturation of fill material. Reinforced fill and/or retained fill may need to be constructed out of free-draining granular materials to prevent saturation. Surface water shall be directed away from the slopes to prevent infiltration and saturation of the fill material, erosion of the slopes, and potential shallow sloughing of the RSS's outer slopes. Separate reinforced fill material from the pavement subgrade to prevent water that enters the pavement system from infiltrating and saturating reinforced fill.

   Granular internal RSS fill, when used, shall be separated from a non-reinforced embankment (where present) and from overlying subgrade layers with a separator fabric. If the granular internal RSS fill and non-reinforced embankment are of the same material, consideration may be given to omitting the separator fabric depending on site-specific conditions. The

Department also recommends placing a fabric-wrapped perforated pipe at the bottom and back of the reinforced zone to provide additional drainage capacity should water become trapped within the reinforced zone. Perforated pipe should be graded to drain and outlet at an appropriate location with a headwall.

Locally available soil internal RSS fill, when used, shall include drainage measures to prevent saturation and promote drainage of internal RSS fill. Measures to prevent surface water infiltration and groundwater migration into internal RSS fill shall be included in the design. These measures include but are not limited to rock drainage blankets, perforated pipes, geomembranes, geosynthetic drainage composites, and surface drainage control systems. Drainage blankets shall include a rock toe drain wrapped in a separator fabric to prevent fines from clogging the drainage blanket.

6. MATERIAL DETAILS.

6.1. Backfill Requirements.

Requirements for reinforced fill materials are provided in the Special Note for Reinforced Soil Slopes. Reinforced fill may consist of granular materials that are quarry processed or durable limestone or sandstone from roadway excavation. Reinforced fill may also consist of locally available soil from roadway excavation or borrow. Plan notes may be incorporated to restrict use of reinforced fill materials. The Special Note also includes requirements for submittals, testing, and construction control.

6.2. Geogrid Requirements.

Geogrid requirements are included in the Special Note for Reinforced Soil Slopes and in the plans. Geogrid long-term design strength shall meet the requirements in the plans for a 100-year design life unless otherwise noted.

6.3. Geotextile Requirements.

Geotextile fabric used to separate granular reinforced fill from retained fill shall meet requirements for Fabric-Geotextile Class 2 (Separation) as outlined in Section 843 of the Standard Specifications unless otherwise noted in the plans. Geotextile fabric used to wrap drainage blankets shall meet requirements for Fabric-Geotextile Class 2 (Subsurface Drainage) unless otherwise noted in the plans. Fabric placement shall be in accordance with Section 214 of the Standard Specifications.

6.4. Facing Requirements

Evaluate the slope face to determine which treatment is most appropriate. This may include facing units, wrapped faces, shotcrete, soil/cement, permanent vegetation, or combinations thereof. Treatment of the slope face shall be in accordance with the requirements of the Special Note for Reinforced Soil Slopes. Calculations and justification for the selected facing treatment shall be provided as noted in the Special Note for Reinforced Soil Slopes. Facing components shall have corrosion resistance/durability to ensure a minimum design life of 100 years.

7. PLAN DEVELOPMENT AND REQUIREMENTS

The level of detail provided in plans depends on whether plans are prepared by the Department or Contractor. Accordingly, the amount of detail and requirements in the Special Notes and Specifications for RSSs or reinforced embankments also depend on the contracting method. Contract plans and documents should include the following:

- Cross sections showing critical failure planes for internal, compound, and global failure modes.
- Reinforcement design requirements (e.g., design methods, minimum factors of safety, surcharge loads, seismic loads).
- Allowable reinforced fill, geosynthetic reinforcement types, geosynthetic reinforcement strengths, and facing/vegetation types.
- Other construction limitations such as right of way restrictions, environmental issues, disturbed limits, protected areas, etc.
- Required erosion control measures.
- Accommodations for roadway drainage including culverts, pipe, pavement edge drains, subsurface drainage, ditches, flumes, and headwalls.
- Bid and material quantities as appropriate.
- Construction sequences, procedures, observation, and testing requirements, including construction damage tests for the geosynthetic if required.
- Submittal requirements (e.g., material certification, material tests, construction details for specific reinforcement/facing system, design calculations, and computer outputs for contractor design).
- Elevation (profile) view showing top and toe of slope, beginning and end stations, final ground lines, slope angles, drain pipe outlets, facing penetrations, reinforcement placement details, and transitions between differing reinforcement layouts.
- Cross sections detailing slope angle, primary reinforcement types, secondary reinforcement, reinforcement lengths, reinforcement vertical spacing, extents of reinforced fill volume, subsurface drainage details, surface drainage details, excavation limits, fill requirements, and slope-face erosion details.
- Facing construction details including welded wire fabric (WWF) forms, wrap-around facing, erosion mats, vegetation, and facing penetration details (e.g., culverts or pipes), including material and fabrication requirements.
- General and plan notes.
- Special notes and provisions for reinforced embankment or RSS construction.

When the Department provides a RSS design, much of the plan detail noted above shall be included in the plans. The Department may require the contractor/RSS designer to provide details on facing systems, erosion protection, geogrid properties, fill properties, reinforcement layout, or other items. If the Department does not provide the RSS design, sufficient preliminary design and development must be performed to determine if and which ERSs are viable options. Section 5 of the Special Note for Reinforced Soil Slopes provides additional detail on required calculations and plan details.

The Standard RSS Design table, if used, is intended to be applied to small- to moderate-sized RSSs (typically ≤ 5000 sq ft of face). RSS faces exceeding 5000 sq ft may benefit from site-specific designs that are more efficient and cost-effective. When the Standard RSS Design table is used, design calculations for reinforcement strength, length, and spacing are not required for submittals if site characteristics meet the limiting criteria for using the table. While design calculations are not required, the RSS Designer shall still certify the design meets the requirements of the plans, specifications, Special Note, design criteria, and design tables. The RSS Designer may also need to provide calculations and justification for the selected RSS face treatment.

Appendix

Draft KYTC Guidelines for Geogrid Reinforcement Evaluation

A.1 Introduction

Geogrids used to reinforce soil or aggregate for soil slopes and embankments shall be evaluated prior to use. Products shall be submitted to KYTC's Kentucky Product Evaluation List (KYPEL) for evaluation. The Division of Materials Structural Materials Branch and the Division of Structural Design Geotechnical Services Branch shall review geogrids submitted for approval. Approved products will be placed in Phase 9 of KYPEL (i.e., specifications exist for the product; however, there is no List of Approved Materials for this type of product at this time). After a geosynthetic is approved for Phase 9, renewal is (a) required every 5 years, (b) when the geosynthetic or manufacturing process changes, or (c) when a new AASHTO Product Evaluation and Audit Solutions (formerly NTPEP) Qualification Evaluation is available. Failure to submit a renewal as required will result in removal of the geogrid reinforcement from KYPEL and from use on KYTC projects.

A.2 Definitions

Terms and abbreviations are defined below followed by the source of the definition, if applicable:

- Cross-Machine Direction — The direction in the plane of the geogrid perpendicular to the direction of manufacture. (*Standard Terminology for Geosynthetics*, ASTM D4439)
- Geogrid — A geosynthetic formed by a regular network of integrally connected elements with apertures greater than ¼" to allow for interlocking with surrounding soil, rock, earth, and other surrounding materials to function primarily as a reinforcement.
- High Density Polyethylene (HDPE) or Polypropylene (PP) Geogrid — Geogrid manufactured by extruding and orienting sheets of polyolefins. (*Geosynthetic Design and Construction Guidelines*, FHWA-NHI-07-092)
- Long-Term Design Strength (LTDS) — Nominal long-term reinforcement tensile strength in accordance with 11.10.6.4.3b of the *AASHTO LRFD Bridge Design Specifications*.
- Machine Direction (MD) — The direction in the plane of the geogrid parallel to the direction of manufacture. (*Standard Terminology for Geosynthetics*, ASTM D4439)
- Polyester Type (PET) Geogrid — Geogrid manufactured from multifilament polyester yarns, joined at the crossover points by a knitting or weaving process and encased with a polymer-based, plasticized coating. (*Geosynthetic Design and Construction Guidelines*, FHWA-NHI-07-092)
- Reduction Factors — Strength reduction factors that account for potential long-term degradation due to installation damage, creep, and chemical and biological degradation in accordance with 11.10.6.4.3b of the *AASHTO LRFD Bridge Design Specifications.*
- Soil Type I — Material that meets the requirements of AASHTO Product Evaluation and Audit Solutions REGEO-19-01 (Section 11.3) and classified as sand in accordance with ASTM D2487 with a d_{50} size within the range of 0.2 to 2.0 mm. ASTM D5818 recommends silty sand (SM) with a $d_{50} > 0.4$ mm.

- Soil Type II — Material that meets the requirements of AASHTO Product Evaluation and Audit Solutions REGEO-19-01 (Section 11.3) with a gradation that falls between Soil Types I & III. ASTM D5818 recommends concrete sand (SW) with a $d_{50} > 1.0$ mm.
- Soil Type III — Material that meets the requirements of AASHTO Product Evaluation and Audit Solutions REGEO-19-01 (Section 11.3) classified as an angular to subangular gravel in accordance with ASTM D2488 with a d_{50} size ≥10 mm. ASTM D5818 recommends coarse gravel (GP) with a $d_{50} > 20$ mm.

A.3 Submittals

Submit the properties listed below for each geogrid seeking approval. Sources for the properties shall be from AASHTO Product Evaluation and Audit Solutions or from qualified testing laboratories. Testing laboratories other than AASHTO Product Evaluation and Audit Solutions shall submit information verifying their qualification to perform the specified tests.

Table A.3.1 Geosynthetic Property Test Methods

Geosynthetic Property	Test Method
Tensile Strength at Ultimate	ASTM D6637 per AASHTO R 69
Reduction Factors for Installation Damage, Durability, and Creep	AASHTO R 69
Pullout Resistance[1]	ASTM D6706
Direct Shear[1]	ASTM D5321
[1] If the manufacturer does not have test data for pullout resistance and direct shear, they may indicate the use of minimum values from *AASHTO LRFD Bridge Design Specifications*. This value may be no greater than 0.67; however, the Department reserves the right to require the use of a lesser value when approving a geogrid.	

After receiving a complete submittal, and provided no additional information is required during the review, the geogrid will be approved or rejected within 30 days. Test data should not be more than 9 years old, but older data may be accepted by the Department depending on the data quality and provided the geosynthetic has not changed since tested.

Do not include AASHTO Product Evaluation and Audit Solutions reports in submittals. For approvals, submit the following for each geosynthetic:

- Any laboratory testing data separate from AASHTO Product Evaluation and Audit Solutions reports, including gradation and angle of internal friction (Ø) of materials used to determine reduction factors, coefficient of interaction, pullout resistance, and direct shear.
- Qualifications for third-party testing laboratories (i.e., laboratories other than AASHTO Product Evaluation and Audit Solutions) including AASHTO re:source for soil testing and Geosynthetic Accreditation Institute-Laboratory Accreditation Program (GAI-LAP) for geosynthetic testing.
- Required information as shown in the following table (add rows to table for each geogrid seeking approval.

Table A.3.2 Geogrid Property Submittal Table

Geogrid and Direction (MD, CD)	Polymer (PET, HDPE, PP)	Geogrid Aperture Size (in)	Tult[A], lb/ft	RF_{cr}			
				3-yr	75-yr	100-yr	RF_d

Geogrid and Direction (MD, CD)	Soil Type I										
	RF_{id}	RF			T_{al}, lb/ft			C_i	F*	C_{ds}	ρ (deg)
		3-yr	75-yr	100-yr	3-yr	75-yr	100-yr				

Geogrid and Direction (MD, CD)	Soil Type II										
	RF_{id}	RF			T_{al}, lb/ft			C_i	F*	C_{ds}	ρ (deg)
		3-yr	75-yr	100-yr	3-yr	75-yr	100-yr				

Geogrid and Direction (MD, CD)	Soil Type III										
	RF_{id}	RF			T_{al}, lb/ft			C_i	F*	C_{ds}	ρ (deg)
		3-yr	75-yr	100-yr	3-yr	75-yr	100-yr				

[A]"Minimum Average Roll Values" (MARV) in accordance with ASTM D4439

Where,

T_{ult} = Ultimate Tensile Strength, lb/ft
RF_{cr} = Creep Reduction Factor for 3, 75, and 100-year design life
RF_d = Durability (degradation) Reduction Factor
RF_{id} = Installation Damage Reduction Factor
RF = (RF_{cr} x RF_{id}) for 3-yr design life or (RF_{cf} x RF_d x RF_{id}) for 75 and 100-year design life
T_{al} = Short-Term Design Strength for 3-yr design life or Long-Term Design Strength (LTDS) for 75 and 100-yr design life, lb/ft = T_{ult}/RF
C_i = Coefficient of Interaction
F* = Pullout Resistance Factor = C_i x tan Ø
C_{ds} = Coefficient of Direct Sliding
tan ρ = Soil-Geogrid Friction Angle (deg) = C_{ds} x tan Ø