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MARYLAND STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

SOIL/AGGREGATE MIX FOR HIGHWAY SHOULDERS

BIOLOGICAL RESOURCES ENGINEERING DEPARTMENT

UNIVERSITY OF MARYLAND

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16. Abstract:

Results showed that geo-web design (Appendix III) will be the most desirable design regarding hydrologic performance and cost effectiveness. This design calls for, from top to bottom; 4-inch deep perforated geoweb with topsoil (hydrologic soil group A or B) infill, a thin layer of geotextile mat, 6 inches of 50/50 soil-gravel mixture, 6 inches of #57 stone, and a homogenous base of native soil beneath. The geotextile was included to prevent mixing of the soil layers. Tall fescue grass seed was sown and allowed to grow on both the experimental design and control sections of the model for several weeks, and was trimmed uniformly to 6 inches one time prior to testing. This design model was also tested with the grass mix (provided by Mr. Cober of SHA) and it performed as well as the fescue grass with respect to design parameters such as runoff and erosion reduction, surface vegetation cover and the stability. This study concluded that using geo-web and proper layers of soil material in designing road shoulders is a viable and cost effective method, but in-situ testing of these systems is recommended before its wider application by SHA. In addition, simple cost analysis indicated that geosynthetic reinforced shoulders may be cost effective if the value of water, aesthetics, and overall environmental health is considered. The cost to install systems incorporating geosynthetic material is projected to be between two and seven times that of the practices currently in use by SHA for stabilization of road shoulder backfill areas. However, with this proposed system the design life maintenance and environmental degradation costs are perceived to be minimal, unlike those of the existing practices in use by SHA.

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A Comparative Analysis of Geosynthetic Reinforced, Biologically Engineered Vegetation Road Shoulder Stabilization to Conventional Methodologies

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Comparative Analysis of Geosynthetic Reinforced, Biologically Engineered Vegetation Road Shoulder Stabilization to Conventional Methodologies

Executive Summary

In January 1999, representatives from the State Highway Administration (SHA) and the Biological Resources Engineering Department at the University of Maryland, College Park met to discuss design improvements to the existing road shoulder backfill areas. These backfill areas are directly beyond the limits of the primary road (asphalt road) and are designed to serve as safety pull-off zones, away from the mainstream of traffic, for highway maintenance and emergency/disabled vehicles. Following this meeting and some background study, University of Maryland submitted a proposal to SHA in November 2000. Proposal was accepted and dated to start from September 1, 2000.

The overall goal set forth in this proposal was to evaluate the effectiveness of the biologically engineered and geosynthetic reinforced road shoulder regarding its ability to reduce runoff and erosion, endure forces of up to 80 psi, and promote proper growth of vegetation. The project also decided to perform a preliminary cost analysis regarding the implementation of new design as compared with the existing design procedures.

To accomplish the project, four steps were taken as follows:

1) To perform a thorough literature synthesis on road shoulders, their design, using geosynthetic material, identification of the soil type to be used to fill in the webs, etc. This portion was conducted by a Master of Science graduate student (Appendix II),
2) To have a group of senior students to evaluate the new road shoulder design using geo-block as their capstone design project (Appendix III),
3) To have another group of senior students to evaluate the new design using geo-web as their capstone design project (Appendix IV),
4) With the help of a student to perform some preliminary cost analysis on the use of geosynthetics in road shoulders considering the environmental and water quality benefits of the new design.

Results showed that geo-web design (Appendix III) will be the most desirable design regarding hydrologic performance and cost effectiveness. This design calls for, from top to bottom; 4-inch deep perforated geoweb with topsoil (hydrologic soil group A or B) infill, a thin layer of geotextile mat, 6 inches of 50/50 soil-gravel mixture, 6 inches of #57 stone, and a homogenous base of native soil beneath. The geotextile was included to prevent mixing of the soil layers. Tall fescue grass seed was sown and allowed to grow on both the experimental design and control sections of the model for several weeks, and was trimmed uniformly to 6 inches one time prior to testing. This design model was also tested with the grass mix (provided by Mr. Cober of SHA) and it performed equal as well as the fescue grass with respect to design parameter such as runoff and erosion reduction, surface vegetation cover and the stability. This study concluded that using geo-web and proper layers of soil material in designing road shoulders is a viable and cost effective method, but in-situ testing of these systems is recommended before its wider application by SHA.

Following sections provide a brief report of the study with supplemental appendices outlining each individual effort put forth to accomplish the project.

Background

The need for safe, efficient, aesthetically pleasing, and environmentally sound transportation systems for motorists has led the State Highway Administration (SHA) to seek alternative methods for constructing road shoulder backfill areas that are able to withstand adequate loads while remaining aesthetically pleasing and environmentally sound. Current methodologies for road shoulder backfill areas in use by SHA are not capable of simultaneously providing both environmental and roadway operational benefits desired by regulatory and transportation agencies.

Current road shoulder treatments include the implementation of a range of soil-gravel mixtures, and in some cases, vegetative cover. The most common design methodologies involve variable width strips of gravel adjacent to the roadway, vegetative cover strips in pure topsoil, and mixtures of topsoil and gravel in approximately equal proportions. While these methods each meet some of the design parameters, none of them have been successful in providing stability, preventing runoff, and supporting vegetative groundcover to the extent required by the SHA.

To ameliorate these problems, Environmental Solutions Inc. proposed alternate methods of road shoulder stabilization that addresses the concerns of the SHA on a multi-tiered basis. Improvement of current designs is based on three primary goals; increasing infiltration, reducing soil loss through erosion, and encouraging uniform vegetative cover growth. The new design concepts incorporate geosynthetic materials, soil and gravel mixtures, and SHA sanctioned groundcover to increase the soil hydraulic conductivity, and therefore reduce the amount of runoff from the shoulder by improving infiltration.

This document includes the initial proposal (**Appendix I**) to investigate the efficacy of geosynthetics written by Dr. Adel Shirmohammadi in August of 2000, as well as a scholarly paper (**Appendix II**) prepared by master's student Andrew Schall, P.E. outlining design recommendations for the use of geosynthetics in road shoulder stabilization applications. Based on recommendations in Schall's paper and literature synthesis, two undergraduate research groups refined and tested the overall design. Each group refined the proposed design for a different geosynthetic material. The first group designed and tested a model with **geoblock material**, and the second group designed and tested a model with **geoweb material**. Both groups tested their designs against a control design of the gravel-topsoil mixture currently used by the SHA. The results and analysis of each of these tests are also included herein (**Appendices III and IV**).

Design Objectives

Both groups developed their proposed designs under similar design criteria. The designs aimed to support a static load of 80-psi without deformation, encourage uniform vegetative groundcover at greater than 90 %, and reduce runoff volume by 50% by increasing infiltration. The designs also strived to mitigate the deleterious effects of soil loss by erosion, and the safety hazards associated with inadequately stabilized shoulder slopes.

Geoblock Pilot Study

The first group proposed a layered soil composite media, incorporating geoblock material for stability and structural support in the road shoulder backfill area. The experimental geoblock design was tested against a control of the 50/50 gravel-topsoil mixture currently used by the SHA. A pilot scale model including experimental design and control sections was constructed with the appropriate layers of gravel, topsoil, and geoblock material. The control section consisted of a 5-inch layer of the 50/50 gravel-topsoil mixture on the surface, and a homogenous base of native soil beneath. The experimental design section consisted of the following profile layers, from top to bottom; 1 inch topsoil, 2 inches of geoblock material, 6 inches of 75/25 soil-gravel mixture, 6 inches of pure gravel, and a homogenous base of native soil beneath. Fescue sod was placed on the surface of both sections of the model; however, the grass was closely trimmed on the control side to simulate the poor stands of vegetative cover typically encountered with the 50/50 gravel-topsoil mixture.

Two methods of testing were used to evaluate the efficacy of the design in regard to meeting the above design criteria. The Instron compression test was used to determine the deformation of the soil composite under loading by packing cylindrical columns with the appropriate material profile as given above and exposing the column to a direct force. The testing indicated that the column reinforced with geoblock was as successful as the control in supporting the applied load. Erosion and infiltration testing was performed under a rainfall simulator to assess the ability of the design to mitigate runoff and erosion. The pilot scale model described above including the design and control sections was subjected to a 30-minute storm with an intensity of 11 inches per hour. Surface runoff and total suspended solids were then measured in order to evaluate the adequacy of the design specifications.

The relatively high intensity used in the erosion and runoff segments of the testing was large compared to most storms encountered in the state of Maryland. The original design objectives required the design to adequately withstand a 10-year, 30-minute storm (corresponding to an intensity of 4.6 inches/hour); however, due to preliminary data concerning the lack of spray uniformity for the rainfall simulator at low rainfall intensities, the higher intensity was used. The model was therefore tested under these conditions in order to minimize the error that may have been introduced in the testing due to limitations imposed by the rainfall simulator, such as dissimilar droplet size and low uniformity coefficient within the test area.

Geoweb Pilot Study

The second group proposed a design incorporating perforated geoweb material along with gravel and soil infill material. The experimental geoweb design was tested against a control of the 50/50 gravel-topsoil mixture currently used by the SHA. A pilot scale model including experimental design and control sections was constructed with the appropriate layers of gravel, topsoil, and geoweb material. The control section consisted of a 6-inch layer of the 50/50 gravel-topsoil mixture on the surface, and a homogenous base of native soil beneath. The experimental design section consisted of the following profile layers, from top to bottom; 4-inch deep perforated geoweb with topsoil infill, a thin layer of geotextile mat, 6 inches of 50/50 soil-gravel mixture, 6 inches of #57 stone, and a homogenous base of native soil beneath. The geotextile was included to prevent mixing of the soil layers. Tall fescue grass seed was sown and allowed to grow on both the experimental design and control sections of the model for several weeks, and was trimmed uniformly to 6 inches one time prior to testing.

To assess the ability of the design to meet the required specifications for runoff and erosion, the pilot scale model was tested under a rainfall simulator for the conditions of a 25 year, 30 minute storm (corresponding to an intensity of 5.29 inches per hour). Preliminary testing of the rainfall simulator found that a uniformity coefficient of 70% was achieved when the machine was run at this intensity; therefore, the use of a higher intensity was not necessary. Runoff was collected from both sections of the model, and the samples were analyzed for runoff volume and total suspended solids.

Load stabilization capacity was tested using an Instron Compaction machine to determine soil profile deformation with applied load for the control and experimental designs. Rectangular testing pans were packed with the appropriate material profile as given above, and the material was exposed to a direct force from the Instron machine while the deformation was measured. Data did not support the load stabilization goals by adequately supporting an 80-psi load compared to the control due to limitations in the size of the design pans; however, the manufacturer's specifications indicate that the geoweb material is suitable for such an application. In order to show the full load stabilization benefits of the geoweb, the design should be tested ***in situ*** so that a larger section of geoweb may be utilized.

Results

Table 1 provides a summary of the results from the geoblock and geoweb testing trials. Experimental data for each design is given with respect to its own control section, as described in the study descriptions above.

As the data in the above table indicate, both designs were very successful in reducing runoff and erosion significantly. Results show that using a geosynthetic road shoulder stabilizer such as geoweb with proper top soil and surface cover (vegetation) has an excellent potential for their building aesthetically pleasing and environmentally friendly road shoulders. Detailed results on runoff and sediment loss are presented in the Appendix III and Appendix IV for Geoblock Design and Geoweb Design, respectively.

Table 1. Summary of results obtained from two capstone design projects.

	Geoblock Design	Geoweb Design
Storm intensity (in/hr)	11	5.3
Direct surface runoff (DSR)	Reduced 42%	Reduced 83%
Sediment erosion (TSS)	Reduced 200%	Reduced 47%

Percent vegetative cover	100% cover	100% cover
Load stabilization	Successful	*

* Due to size limitations in the testing pans, this data is inconclusive; however, the manufacturer's specifications indicate that geoweb is able to adequately support an 80-psi load.

Cost Consideration

Literature review and analysis in Schall's report (Appendix II) provided some idea regarding the economics of using geo-synthetic road shoulders. Results of the analysis showed that the estimated cost to install geosynthetic systems is between $3 and $15 per square foot. This compares to a construction cost of approximately $2 per square foot of the current 50/50 gravel and topsoil SHA design. Even at the high end of this estimate range, this improved design could be of considerable value to highway design and maintenance because of the increased benefits it can provide through increased reinforcement and reduction of surface water volumes and velocities from pavement systems. Additionally, the system is designed to be self-sufficient once vegetative growth is established, requiring little maintenance as compared to the current design. Although maintenance cost data for the in-use systems is unknown, SHA speculates the costs to be in the vicinity of 20 percent of the installation cost, or $0.40 per square foot per year.

Other design life costs to the current SHA backfill area systems are those associated with degradation to the surrounding environment (water and land) as a result of accelerated erosion from these sites. Often these values are not considered in the design selection process because they are not reflected in discrete line items of transportation budgets. However, they do constitute a value to society and therefore should be considered in the overall cost evaluation.

In a report issued by Resources for the Future (1996), economic value of freshwater, based on geographic region, is estimated. In the New England region, water was priced at $4 per acre-foot. By extension, any degradation of these waters would constitute a reduction in overall value; hence the more degradation, the less valuable the water.

Loss in land (property) value due to erosion of topsoil from nearby areas would only increase this total ecological damage value. This devaluation cannot be seen as appreciably in terms of its direct cost, but rather in terms of its indirect costs associated with use limitation and loss of production to the land itself and reduced submerged aquatic vegetation (SAV) and dissolved oxygen levels to nearby watercourses, thus reducing the health of aquatic biology. When these factors are considered, it is expected that the increased cost of this improved system could pay for itself within five to ten years using the cost savings currently encumbered by annual maintenance and environmental degradation costs to shoulder backfill area stabilization methods in use by the SHA.

To demonstrate these savings, the cost for a geosynthetic system was evaluated for a hypothetical site. In the specific example used in this project, it was determined that for a road shoulder backfill area adjacent and up-stream of a one-mile long, twenty (20) foot wide stream flowing at an average annual depth of 2 feet, and assuming the environmental damage was found to be ten percent of the overall water value, or $0.40 per acre-foot, (of which only five (5) percent, or $0.02 per acre-foot,) could be linked to the accelerated runoff from the upstream pavement system, over the course of a year this would amount to over three (3) million dollars in damages to the water itself assuming a discharge rate of 4.8 acre-ft per second.

Loss in land (property) value due to erosion of topsoil from nearby areas would only increase this total ecological damage value. This devaluation cannot be seen as appreciably in terms of its direct cost, but rather in terms of its indirect costs associated with use limitation and loss of production to the land itself and reduced submerged aquatic vegetation (SAV) and dissolved oxygen levels to nearby watercourses. Finally, such environmental damages would affect the aquatic production in terms of fish and other biota.

Huntington and Ksaibati (2000) performed a study to evaluate the geogrid- reinforced granular base pavement, which was desired by the Wyoming Department of Transportation. Their objective was to determine if using reinforced-geogrid will help to decrease the need for thick granular sub-layer. Their study concluded that geogrid can be effectively used to decrease the thickness of the granular base. They also performed an economic analysis to find the breakeven haul distance for granular base considering the added cost due to geogrid. Table 2 shows the cost of the granular base, both with and without geogrid reinforcement, at various haul distance and geogrid costs. Haul costs are $0.099/Mg-km ($0.145/ton-mile). The granular base cost is $3.86/Mg ($3.5/ton). As in-situ granular base cost increase due to longer haul distances, geogrid reinforcement becomes more economically viable.

Table 2. Cost Comparison of Base Materials With and Without Geogrid[1].

	No Geogrid	Cost/km Geogrid at $1.75/m^2$	Geogrid at $2.50/m^2$	Geogrid at $3.75^a/m^2$
No Haul	$55,407	$59,344	$70,594	$82,249
5 km Haul	$62,539	$63,604	$74,854	$86,509
10 km Haul	$69,671	$67,863	$79,113	$90,768
20 km Haul	$83,934	$76,383	$87,633	$99,288
45.5 km Haul[b]	$120,369	$98,144	$109,394	$121,050
50 km Haul	$126,724	$101,940	$113,190	$124,846
100 km Haul	$198,040	$144,537	$155,787	$167,442
Break Even Haul Distance, km		7	26	47

a. Actual Cost b. Actual Haul Distance

[1] Huntington, G. and K. Ksaibati. 2000. Evaluation of reinforced granular base. Geotechnical Fabrics Report, 18, 1(Jan/Feb 2000): 22-26,28.

This simple, yet telling example shows in economic terms the benefits that this improved design may have to offer transportation professionals. From this coarse analysis, although there is a higher cost to installing this new design, it may prove to be a more cost-effective solution, paying for itself within five to ten years with the annual maintenance and environmental degradation cost savings presently spent on and applied to existing road shoulder backfill systems.

Conclusions

Results obtained in this study showed that geosynthetic reinforced, biologically engineered road shoulder stabilization has a significant advantage over the conventional methods used by SHA at the present time. Experiments conducted on design models showed that new design reduced both runoff and erosion significantly. In addition, simple cost analysis indicated that geosynthetic reinforced shoulders may be cost effective if the value of water, aesthetics, and overall environmental health is considered. The cost to install systems incorporating geosynthetic material is projected to be between two and seven times that of the practices currently in use by SHA for stabilization of road shoulder backfill areas. However, with this proposed system the design life maintenance and environmental degradation costs are perceived to be minimal, unlike those of the existing practices in use by SHA.

Further in-situ investigation into the design is recommended for a full-scale analysis of the benefits offered by the design. The preliminary data are very promising, and warrant a thorough set of in-situ and repetitive tests so that the strengths and weaknesses of the design may be identified and addressed. The final stage of testing would be accomplished upon implementation of the design into an actual road shoulder backfill area, in which natural ambient conditions like wind and heat could also impact the success of the design. This type of testing is necessary because the integrity of the geosynthetic material is largely dependent on its force-distributing area, which can be difficult to simulate in the laboratory.

Appendix I

Project Proposal

A Comparative Analysis of Geosynthetic Reinforced, Biologically Engineered Vegetation Road Shoulder Stabilization to Conventional Methodologies

Adel Shirmohammadi

August 1, 2000

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Abstract

This project will evaluate the effectiveness of earthen and asphalt road shoulder stabilization practices to that of the biologically engineered vegetation with geosynthetic reinforcement (biologically-engineered, reinforced stabilization) road shoulder stabilization technique. The goal of this proposal is to determine which methodology or methodologies is or are more suitable, from a construction, ecosystem sustainability and cost standpoint, for a given roadway shoulder function, useful life, and soil texture. Testing of the current road shoulder stabilization techniques will be done from reinforcement and drainage perspectives. Testing of the biologically engineered, reinforced stabilization will be done from reinforcement, drainage, and vegetative perspectives. A control test will also be completed on the biologically engineered stabilization without reinforcement. Complete project findings should be available within two years.

Justification

Roadways and their functionalities date back to the Roman Empire, almost 1800 years ago. They served as conduits for moving the military, but had little economic function in the lives of the common population. Changes in agricultural methods and later, industrial mechanization changed this situation. Today, roadways are essential elements of our existence. Our civilization relies on them to carry the population from one area to another and goods and services throughout the world. We depend on their integrity and have concentrated much of the research efforts on ways of maximizing their useful life and traffic volume. To this end, over the last twenty-five years the linear footage of roadways has almost doubled in the United States. Additionally, roadways have become wider and more rigid to meet our ever-increasing demands.

As a result, water flows from these roadways are more concentrated with relatively higher velocities. These impervious flow paths, carrying substantial volumes of runoff, can cause potential degradation to both the road surface and the surrounding environment if not properly addressed. The standard practice of roadway design addresses runoff to the limits of pavement and providing a suitable capacity outlet for discharge. The standard practice of roadway maintenance retains the functionality of the roadway for the volumes of expected traffic, which in some cases may not take into account either proper drainage paths or outlet structures. This is not to say that either of these approaches is wrong because the pressures on those in the highway design and maintenance fields are constant and gauged on minimizing closures, delays and detour routings. We simply need a more cost effective and environmentally sensitive way of dealing with the peripheral areas of our roadways.

As engineers, we must demand and become more holistic in our approach to roadway design and maintenance. As all engineering disciplines and their associated technologies change, we must remain committed to changing with them. By providing infiltratable, long-term stabilization to our road shoulders, we will inherently diminish some of the environmental burdens of nonpoint-source pollution to our surface water reservoirs. Additionally, it is hoped that it will also alleviate the need, or at a minimum, reduce the frequency of, on-going, repetitive maintenance issues associated with road shoulders, such as erosion (undercutting) and siltation.

All too often, negative environmental impacts are associated with roadway construction. By utilizing the biologically engineered, reinforced road shoulder methodology, the impact of the impervious roadway surface can be minimized. This will allow maximum opportunity for reducing runoff velocities and increasing infiltration from our road surfaces, thus decreasing accelerated erosion and inherently improving water quality and integrity of nearby rivers, creeks, and streams, not to mention the overall integrity of the road shoulders themselves.

The vast majority of the research conducted on road shoulders has been done with asphalt, soil (Portland) cement, and concrete. This innovative approach of using geosynthetics, which have been used in the roadway pavement area for a significant period of time, that enhance drainage and provide separation and reinforcement to subgrade as shown in Figure 1, in conjunction with biologically-engineered vegetation that have the durability to withstand road shoulder design loadings and can slow runoff velocities to non-erosive rates, is a combination that, if proven successful, will be of invaluable benefit to all those who work in the highway sector. No matter the outcome of this project, we will have advanced research in an area that has been minimally explored.

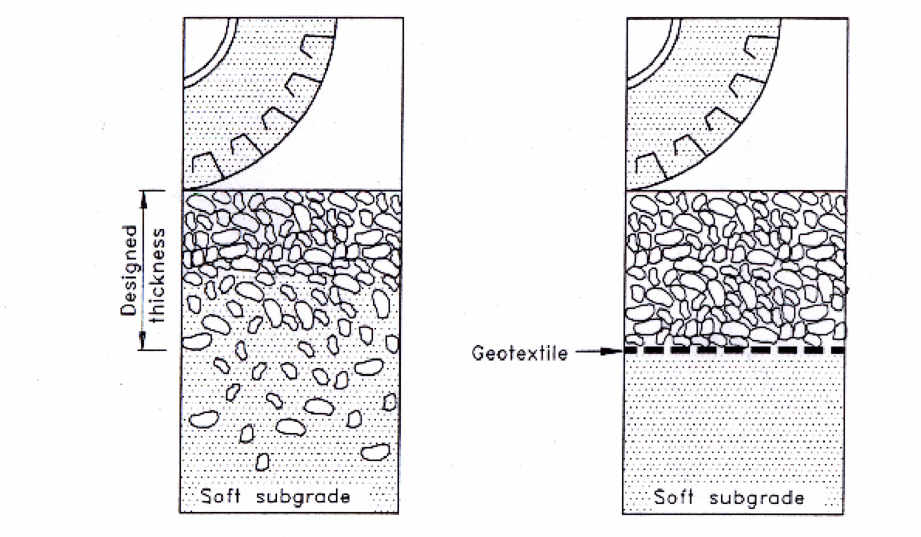

Figure 1. Concept of geotextile separation and reinforcement in roadways (Holtz et. al., 1997)

It is hoped that the results obtained in this study can be continued by analyzing the long-term runoff quality and effects of this project. Additionally, this study is meant to serve as a springboard for analyzing additional innovative approaches to road shoulder stabilization, ensuring its long-term economical and ecological sustainability.

Literature Review

Though a review of related engineering publications, research in the specific area of biologically engineered vegetation, geosynthetic reinforced road shoulders has not received much consideration. The vast majority of the research on road shoulders has focused on rigid pavements (asphalt, Portland cement, or concrete stabilization) or compacted earth. All information provided in publications that mention vegetative stabilization for shoulders indicated only that vegetative stabilization alone did not fare well during testing because it was unable to support required traffic loadings without significant deformation under high moisture conditions. Additionally, some publications talk in general to the fact that winter maintenance equipment and anti-skid materials would probably have a significant impact@ on its functionality. Figure 2 shows the benefits that geosynthetics can provide to soil subgrade.

Biologically engineered vegetation (trees, shrubs, and grasses) have been explored on steep slopes, abandoned mine lands, and other areas of land where establishment of traditional grasses has proved ineffective. In these instances, no required surcharge loadings (live or dead) had to be supported on these projects and overall goal of each was to establish the vegetation to minimize accelerated erosion.

In Maryland, the Federal Highway Administration (FHWA) has completed several studies on Portland cement stabilization of reinforced slopes, adjacent to and upslope of roadways. Again, no required surcharge loadings had to be supported with the overall goal being slope stabilization. The FHWA has also been involved with projects focused on geosynthetic reinforcement of roadways and road shoulders, using geogrids and geonets as reinforcement and drainage under impervious materials such as asphalt and concrete.

It would seem that research on geosythetics has focused on the reinforcement and drainage aspects of roadway projects and research on biologically engineered vegetation has focused on ecological projects in nature. On this basis, and noting the relative effectiveness of both in their specific areas according to published reports, the potential success of bringing these two concepts together in an innovative methodology cannot be ignored. The possible benefits to this technology can only be approximated, but the value to those involved in managing, designing, or maintaining roadways could be significant in the near term, with additional applications likely to follow with time and increased research attention given to the subject.

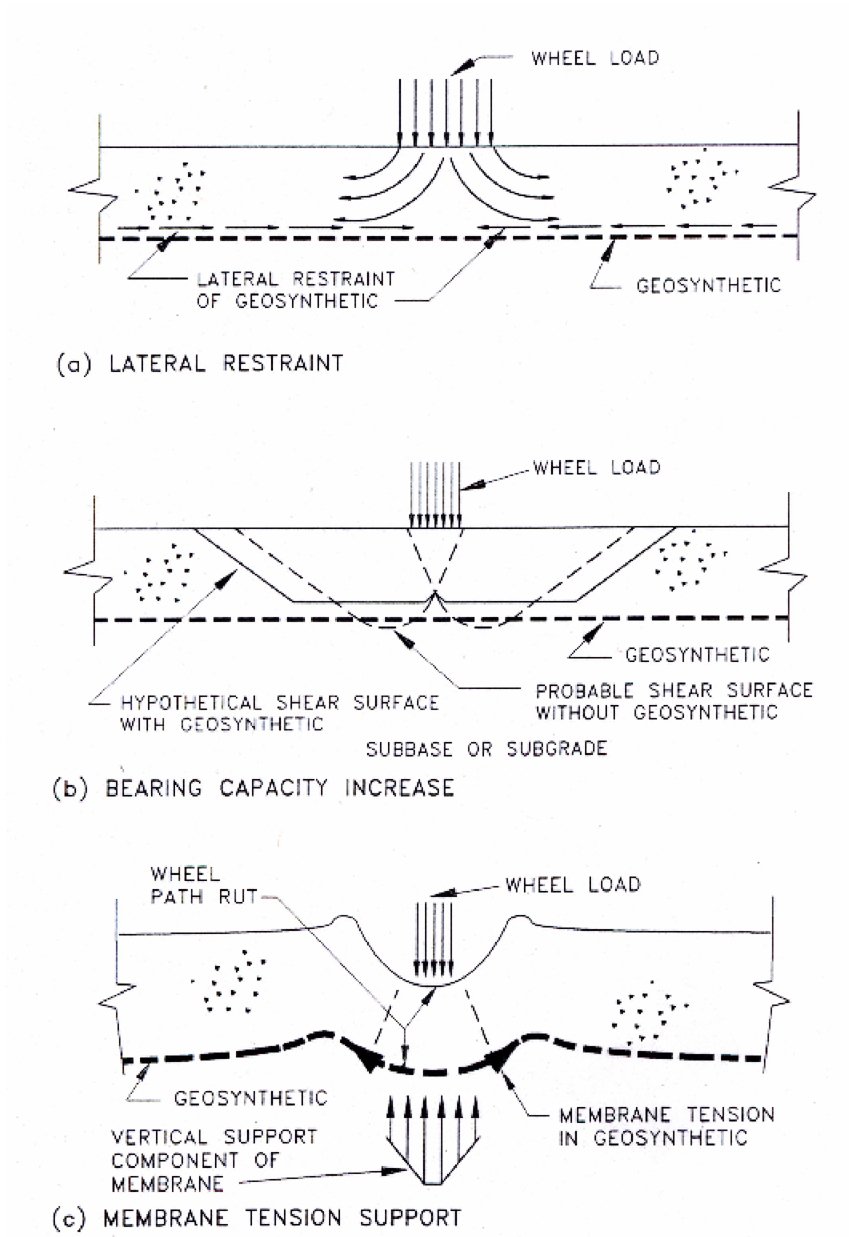

Figure 2. Possible reinforcement functions provided by geosynthetics in roadways: (a) lateral restraint, (b) bearing capacity increase and 8 membrane tension support (Holtz, et. al., 1997).

Objectives

1. To evaluate the effectiveness of compacted earth and asphalt road shoulder stabilization techniques from a reinforcement and drainage perspective.

2. To evaluate the effectiveness of biologically-engineered, geosynthetic reinforced and the non-reinforced road shoulder stabilization method from a reinforcement, drainage, and vegetative sustainability perspective.

3. To compare the constructability and cost-effectiveness of biologically-engineered vegetation, geosynthetic reinforced shoulder stabilization to current methodologies from reinforcement, drainage, and long term sustainability perspectives for different hydrologic soil groups.

Procedures

Before any evaluation can begin, the project parameter for road shoulder surcharge (live and dead) loadings should be provided. Given that information, the design criticality (survivability) for the site can be obtained. The survivability rating of either low, medium, or high is based on anticipated traffic loadings shown in Table 1. Should the shoulder surcharge loadings not be given, judgment will be used to set this control criterion to provide consistency throughout the project.

Table 1. Construction Survivability Ratings (Holtz, et al., 1997).

Site Soil CBR at Installation[1]	< 1		1 to 2		> 3	
Equipment Ground Contact Pressure (kPa)	> 350	< 350	> 350	< 350	> 550	< 550
Cover Thickness[2] (compacted, mm)						
100[3,4]	NR[6]	NR	H[6]	H	M[6]	M
150[5]	NR	NR	H	H	M	L[6]
300	NR	H	M	M	M	L
450	H	M	M	M	M	L

NOTES:

1. Assume saturated CBR unless construction scheduling can be controlled.
2. Maximum aggregate size not to exceed one-half the compacted cover thickness
3. For low-volume, unpaved roads (ADT < 200 vehicles).
4. The 100 mm minimum cover is limited to existing road bases and is not intended for use in new construction.
5. Maximum aggregate size ≤ 30 mm
6. NR = NOT RECOMMENDED; L = LOW; M = MODERATE; and H = HIGH

The effectiveness of current road shoulder stabilization methods shall be evaluated according to the appropriate subsections of Section 600 of the Maryland Department of Transportation, State Highway Administration=s Standard Specifications for Construction and Materials (1993) and through laboratory testing.

The effectiveness of the biologically-engineered, geosynthetic reinforced road shoulder stabilization methodology shall be assessed as follows:

Selection of several geosynthetics for evaluation based on FHWA criticality (survivability levels). Geosynthetic physical property requirements shall be:

Physical Property	Test Method
Grab Strength	ASTM D 4632
Puncture Resistance	ASTM D 4833
Tear Resistance	ASTM D 4533
Apparent Opening Size	ASTM D 4751
Permeability	ASTM D 4491
Ultraviolet Degradation	ASTM D 4355
Geotextile Acceptance	ASTM D 4759

The Minimum Average Roll Values (MARVs) for each geotextile evaluated shall meet or exceed the physical property values established by FHWA for the survivability level established for the project given in Table 2.

Drainage parameters will be developed based on soil type and roadway classification for design purposes. These values will later be measured when the geosynthetic and biologically-engineered grass materials are developed into their composite form. Both construction and vegetation selection will be evaluated in the laboratory at the University of Maryland.

After determining the most appropriate vegetation, the most suitable geotextile will be combined as a composite material in a trial bin and analyzed for reinforcement, drainage, and vegetation effect. Appropriate statistical methods and values will be used in the analysis.

Table 2. Geosynthetic Physical Property Requirements (Croney and Croney, 1991)

Survivability Level	Grab Strength[4] ASTM D 4632 (N)		Puncture Resistance[4] ASTM D 4833 (N)		Tear Strength[4] ASTM D 4533 (N)	
	< 50% Geotextile Elongation[2,3]	> 50% Geotextile Elongation[2,3]	< 50% Geotextile Elongation	> 50% Geotextile Elongation	< 50% Geotextile Elongation	> 50% Geotextile Elongation
High (Class 1)	1400	900	500	350	500	350
Moderate (Class 2)	1100	700	400	250	400	250
Low (Class 3)	800	500	300	180	300	180

Additional Requirements	Test Method
Apparent Opening Size 1. < 50% soil passing 0.075 mm sieve, AOS < 0.6 mm 2. > 50% soil passing 0.075 mm sieve, AOS < 0.3 mm	ASTM D 4751
Permeability k of the geotextile > k of the soil (permittivity x the nominal geotextile thickness)	ASTM D 4491
Ultraviolet Degradation At 500 hours of exposure, 50% strength retained	ASTM D 4355
Geotextile Acceptance	ASTM D 4759

NOTES:

1. For the index properties, the first value of each set is for geotextiles which fail at less than 50% elongation, while the second value is for geotextiles which fail at greater than 50% elongation. Elongation is determined by ASTM D 4632
2. Values shown are minimum roll average values. Strength values are in the weakest principal direction.
3. The values of the geotextile elongation do not relate to the allowable consolidation properties of the subgrade soil. These must be determined by a separate investigation.
4. AASHTO classification.

For reinforcement and drainage, the same testing as was done with the current methodologies will be used. For growth sustainability, the height of the grass will be measured regularly with samples evaluated for deformation, areas void of vegetation, and overall stand health. Once successful in the trials, this composite section should be implemented along a roadway section in a future project (Phase II) and be tested.

A synthesis analysis of the cost-effectiveness and cost-to-construct of the selected methodologies under the different soil types will follow. Relationships can be formulated from the soil type used with the composite material and correlated back to the soil types evaluated with the current methodologies. Both tangible and intangible benefits of the new design will be discussed.

Intended Project Results

Rigid paving road shoulder systems are susceptible to various types of distress that can pose hazard to the motoring public, including rutting and fatigue and thermal cracking. Upon completion of this project by the University of Maryland and acceptance of our findings by the Maryland Department of Transportation State Highway Administration (SHA), the end-product of the study, in addition to being effective from constructability, ecosystem sustainability, and cost perspectives is intended to be a safer-alternative to the current in-use paving systems, reducing injuries to motorists and damage to their vehicles and surrounding property.

As the developed system will be a composite material without bituminous or concrete additives, distress caused by fatigue and thermal cracking should be non-existent. Also, the reinforced composite member should perform as well or better than the current technologies in distress caused by rutting as described in previous sections of this proposal. The summation of these benefits should show the effectiveness of our product to an extent sufficient to justify replication of it by the SHA on other sites across the State of Maryland in future projects.

Special Funding/Equipment Needs

It is anticipated that the funding provided under the research grant will be sufficient to cover the cost of this project and that all specialty equipment needed to carry out the required analyses is currently available on the College Park campus. Therefore, no special equipment needs are required.

Budget

Category	**Amount**	
	1st year	2nd year
Salary		
PI -5% yearly	$4,350	$5,000
Graduate Assistant (GA)	$15,000	$15,000
Shop Work	$1000	$1000
(@ $45/hr.)	(20hrs)	
Fringe Benefits		
PI – Benefits (%)	$1436	$1650
GA - Insurance	$5,000	$6,000
Equipment		
Misc. Equipment	$4,000	$4,000
Supplies and Materials		
Misc. Supplies and Materials	$3,500	$4,000
Travel	$2,000	$2,000
Tot. Dir. Cost	$36,286	$38,6 50
Overhead (26%)	$9,434	$10,049
Total Cost	$45,720	$48,699

Total Project Cost (2 years) = $94,419

CALENDAR

Project Scope of Work	Dates
Analysis on Current Methodologies	September- December 2000
Laboratory Analysis on Biologically-Engineered Methods (1^{st}. test)	January - May 2001
Completion of a synthesis report on Biologically-Engineered Shoulders	June 2001 – Sept. 2001
Analysis and Write-up of Findings with 1^{st}. set of tests	October-Nov. 2001
Review of the previous findings and set up of 2^{nd}. Test system	Nov.-Jan. 2002
Lab. Analysis of new Bio-engineered Shoulders	February-May 2002
Analysis of the data and completion of the report	June-August 2002

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Croney, David and Paul Croney. 1991. The Design and Performance of Road Pavements, 2nd edition. McGraw-Hill Co., Inc., New York, New York.

Holtz, Robert D., Christopher, Barry R. and Ryan R. Berg. 1997. Geosynthetic Engineering. BiTech Publishers Ltd., Richmond, British Columbia, Canada.

Maryland Department of Transportation - State Highway Administration. October 1993. Standard Specifications for Construction and Materials.

Richardson, Gregory N. and David V. Brock. Field Evaluation of Geosynthetic Survivability. Geotextile Fabrics Report, September 1998, pp. 34-38.

<u>Possible Publication Titles/Journals</u>

1) Geosynthetic Engineering (Periodical). BiTech Publishers Ltd., Richmond, British Columbia, Canada.
2) Engineering News Record (Periodical). McGraw-Hill Co., Inc., New York, New York.

Appendix II

Andy Schall's (MS Student) Literature Synthesis Paper on the Project

(May 2001)

An Integrated Approach to the Design of Road Shoulder Backfill Areas

Master's Degree Non-Thesis Option
Biological Resources Engineering
May 2001

Prepared for: Biological Resources Engineering Department
University of Maryland – College Park

Submitted by: Andrew J. Schall, P.E.

Supported by: Dr. Adel Shirmohammadi, Ph.D., Biological Resources Engineering Department, Committee Chairman

Dr. Gary Felton, Ph.D., Biological Resources Engineering Department, Committee Member

Dr. Robert Kratochvil, Ph.D., Department of Natural Resources and Landscape Architecture, Committee Member

Table of Contents

Executive Summary

The intent of this paper is to provide a composite media for use on road shoulder peripherals that provides increased stability, attenuation of surface runoff and uniform vegetative cover compared to methods currently used by the Maryland State Highway Administration (SHA). Although this evaluation originated from a desire by SHA representatives to explore better techniques for the establishment of "green spaces" adjacent to pavement systems in Maryland, the information provided in this document can provide insight into design considerations that apply to all sites with varying application requirements.

Over the last twenty-five years, the linear footage of pavement systems in the United States has almost doubled (Rollings, 1996). Roadways have also become wider and more rigid to meet our ever-increasing traffic demands. As a result, water flows from these systems are more concentrated with relatively higher velocities. These impervious flow paths, carrying substantial volumes of runoff, have the potential to cause degradation of both the roadway surface and the surrounding environment if not properly addressed.

Since 1900, approximately 170 million tons (155 metric tons) of sediment have been deposited within Maryland's portion of the Chesapeake Bay watershed (U.S. Geological Survey, 1996). Although only a small percentage of this total may have come from runoff associated with pavement systems, a contribution of even one percent, on average of 17,000 tons per year, would be significant to adversely effect neighboring ecosystems.

Standard practices used in roadway design address runoff to the pavement limits and provide a suitable outlet for discharge. The function of roadway maintenance involves upkeep of the roadway functionality to support for the volume of expected traffic. In some cases, this may not take into account either proper drainage paths or suitable outlet structures. This is not to say that these approaches are to be condemned; pressures on those in the highway design and maintenance fields are constant and gauged on minimizing closures, delays and detour routings. We simply need more cost effective and environmentally sensitive ways of dealing with the peripheral areas of our roadways.

As engineers, we must become more holistic in our approach to roadway design and maintenance. As our disciplines and their associated technologies change, we must remain committed to changing with them. By providing infiltratable, long-term stabilization beyond the limits of these pavement systems, we will inherently diminish some of the environmental burdens of nonpoint-source pollution to our surface water reservoirs. Additionally, it is hoped that it will alleviate the need, or at a minimum, reduce the frequency of, on-going, repetitive maintenance issues, such as erosion (undercutting) and the resulting deposition (siltation).

Central to the improved design is the use of a four inch (4") deep geoweb (H – 10 AASHTO minimum rating), which will provide the stipulated 80 psi (minimum) reinforcement to the overall system. The geoweb infill material will be select topsoil – within hydraulic soil groups A or B – to promote the establishment of a sustainable biological system that supports uniform vegetative growth, increased infiltration of surface water runoff and reductions in overall runoff volume and velocity of flow.

Media used in the creation of the subsoil layers, whether existing or obtained from off-site are flexible, so long as they do not significantly increase or decrease the composite's overall hydraulic conductivity. In all applications, site specific adaptations of the model should also be evaluated. These include the use of a woven erosion control blanket, placed over the topsoil infill of the geoweb, to facilitate rapid and uniform vegetative growth and the incorporation of a non-woven geosynthetic, between the geoweb and the subsoil layers, to enhance in-plane drainage and to provide separation.

Additionally, the installation of a perforated pipe at the base of the composite and/or an edge drain at the downslope limit of the backfill area should be considered to promote water flow out of the system if surrounding soils prove limiting. Where concentrated flows are created, either through channelization or pipe flow conditions, requisite outlet protection should also be provided.

The cost to install this system is projected to be between two and seven times that of the practices currently in use by SHA for stabilization of road shoulder backfill areas. However, with this proposed system the design life maintenance and environmental degradation costs are perceived to be minimal, unlike those of the existing practices in use by SHA.

When these factors are considered, it is expected that the increased cost of this improved system could pay for itself within five to ten years using the cost savings currently encumbered by annual maintenance and environmental degradation costs to shoulder backfill area stabilization methods in use by the SHA. Follow-up laboratory and field testing of this model is recommended to prove its value and overall effectiveness under a variety of design constraints and applications.

Background

In January 1999, representatives from the University of Maryland at College Park, Biological Resources Engineering Department (UMCP–BRE) met with officials from the Maryland State Highway Administration (SHA) to discuss design improvements for road shoulder backfill areas. These backfill areas are directly beyond the limits of the primary road shoulder and are designed to serve as safety pull-off zones, away from the mainstream of traffic, for highway maintenance and emergency/disabled vehicles.

UMCP-BRE prepared a research proposal in August of 1999 to evaluate the effectiveness of current SHA road shoulder backfill stabilization methodologies as well as several other techniques that were to be designed using a combination engineered soil and geosynthetic material, to provide infiltration and reinforcement, respectively. Due to budget and manpower constraints, the full scope of this research proposal has not been executed.

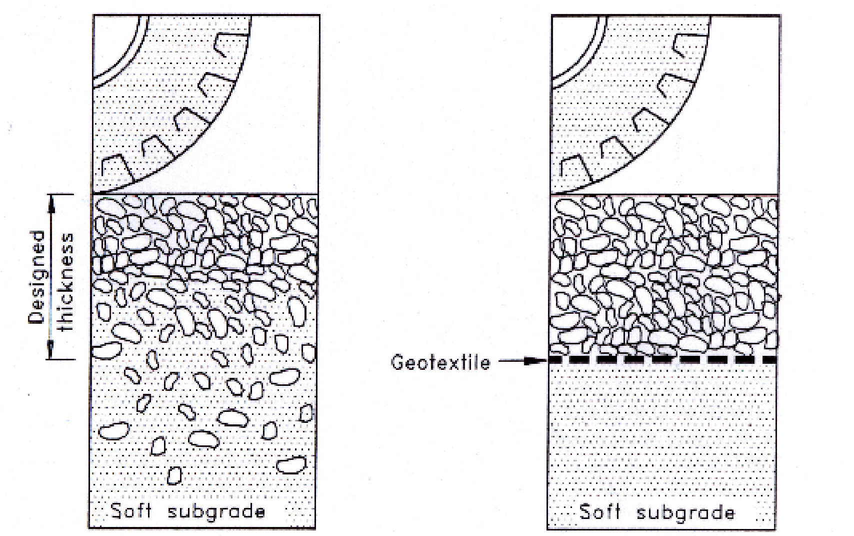
In August 2000, UMCP-BRE identified this research proposal as a foundation on which to base their Capstone course program for the Fall 2000 and Spring 2001 semesters – ENBE 485 and ENBE 486, respectively. With the time and workload demands of the students enrolled in these classes, the August 1999 proposal was refined and consolidated into the evaluation of one particular engineered soil and geosynthetic material combination for implementation at a specific SHA site. Their site is located in Howard County (Central Maryland) adjacent the Maryland Route 108 exit ramp to eastbound Maryland Route 100. A summary of this research project is to be released in May 2001.

Existing Design Methods

The standard design methodology for road shoulder backfill areas in use by SHA consists of a variable width edge strip of gravel adjacent the primary road shoulder, approximately six inches (6") in depth. Although this gravel layer does provide adequate reinforcement to support traffic requirements, the environmental consequences of high runoff volumes and velocities from the adjacent roadway and primary shoulder, collectively referred to as the pavement system, creates rills in the gravel, exposing the subsoil to accelerated erosion. As these results are contrary to SHA's mission of providing "highway systems . . . in an environmentally responsible manner," other options consistent with their mission statement are being sought.

One such alternative that SHA has considered is the use of a 100% topsoil mixture stabilized with a vegetative cover to attenuate the runoff volumes and velocities from the adjacent pavement systems. The major issue with this design has been the topsoil's inability to support traffic loads under conditions of moderate to high moisture.

To counter this weakness in soil structure, SHA instituted an alternative design consisting of a 50/50, aggregate gravel and topsoil, mixture. Its intent is to promote growth of vegetation and provide necessary reinforcement, but neither objective is being met. Grass growth has been inconsistent and uneven with an approximate average uniform vegetated cover documented at 15 percent (Photograph 1). Additionally, without separation between this mixture and the underlying subsoil layers, the gravel is allowed to migrate into the subsurface layers over time, pushing the subsoil to the surface where it is again susceptible to erosion (Figure 1).



Photograph 1. Shoulder backfill area shown with SHA's 50/50 aggregate and topsoil mixture.

Figure 1. Concept of geotextile separation and reinforcement applications
(Holtz et. al., 1997)

This lack of cover can be attributed to a number issues pertaining to the mixture and has little to do with site conditions themselves. Gravel, unlike soil, cannot retain nutrients and water that the vegetation needs to establish itself and grow. Gravel also has a higher permeability compared to soil. This allows surface water runoff to move through and out of the system before the soil can retain the water needed to adequately support vegetation.

Although it is thought that the percentage of grass cover could be increased to within acceptable limits (greater than 90% uniform cover), the continual application of water, fertilizer and seed required to do so is not economically feasible. Therefore, other design options that provide both the reinforcement (stability) and vegetative growth, with minimal maintenance, are being sought for these fringe areas.

Review of Subject Literature

Until recently, research in the specific area of road shoulder backfill stabilization with vegetated material had not received much consideration. With heightened public and regulatory concerns over stormwater management and the need to minimize impervious areas, the role of geosynthetics (geogrids, geowebs and some woven and non-woven geosynthetics) that provide reinforcement, the ability to establish vegetation and do not limit infiltration from surface runoff are receiving greater study (Rollings, 1996; Koerner, 1998).

From a strict reinforcement standpoint geowebs (Figure 2), a member of the family of products known as porous pavements, and geogrids (Figure 3) offer the highest levels of strength to a given application. What separates the two materials apart is the type of material they are able to reinforce. Because geowebs are three-dimensional cellular structures, their ability to provide reinforcement is achieved through infill confinement of both compacted (e.g. aggregate, subsoil) and non-compacted materials (e.g. topsoil placed to establish vegetation) over the limits of their depth (Amoco, 2000). When overtopped, they act like geogrids and only afford reinforcement to compactable materials (Holtz et. al., 1997). If non-compactable materials are used above their confinement depth, this unconfined layer would be subject to rutting (Koerner, 1998).

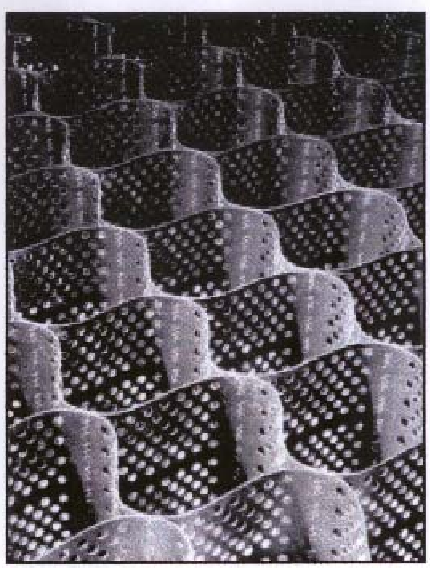
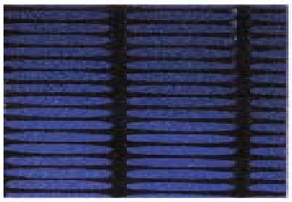
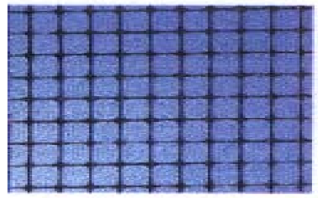


Figure 2. A perforated geoweb (Soil Stabilization Products Co., 2001).





(a) (b)

Figure 3. (a) A uniaxial geogrid and (b) a biaxial geogrid (Tensar Corporation, 2001).

As can be seen in Figures 2 and 3, both geowebs and geogrids have high percentages of open area, thus not limiting infiltration rates and media permeability. At steady-state conditions, their infiltration and permeability is governed by the amount of compaction (sealing) of the surface layer and the media layer with the lowest hydraulic conductivity within the composite system, respectively (Giroud, 1989). Due to the amount of open area that these synthetic materials provide, they are unable to contribute a separation function to a given application.

Woven and non-woven fabrics, like geogrids, cannot provide reinforcement to non-compactable media. When a high degree of reinforcement is not of concern for compactable media, woven and non-woven geotextiles can prove useful. Figure 4 shows the benefits that geosynthetics can provide to soil subgrades.

Non-woven geotextiles, because of their manufacturing process, can afford much higher permittivity and percent elongation values than that of woven fabrics. Both give comparable tensile, burst and shear stress values that are well suited to applications where a separation function (of media layers) is desired (Richardson and Wyant, 1987). In reinforcement situations where media drainage is critical, the use of non-woven materials are preferred over woven materials (Amoco, 2000).

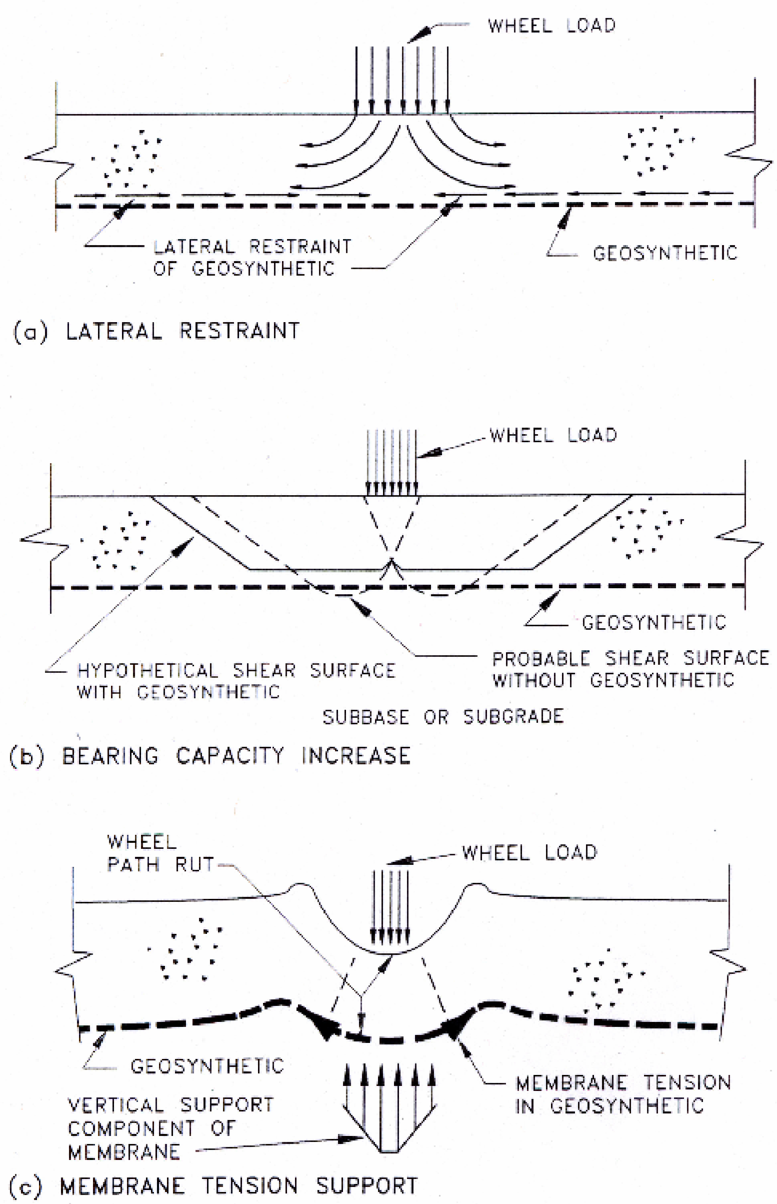


Figure 4. Possible reinforcement functions provided by geosynthetics: (a) lateral restraint, (b) bearing capacity increase and (c) membrane tension support (Holtz, et. al., 1997).

Koerner (1998) provides the following equations for calculating the normal stress induced on the subgrade soil media with and without geosynthetic reinforcement:

$$p_o = [P / \{(B + 2h_o * \tan \alpha_o)(L + 2 h_o * \tan \alpha_o)\}] + \gamma_o h_o \qquad \text{(Equation 1)}$$

and,

$$p = [P / \{(B + 2h * \tan \alpha_o)(L + 2 h * \tan \alpha)\}] + \gamma h \qquad \text{(Equation 2)}$$

where,

p_o = normal stress on the soil subgrade without reinforcement,
p = normal stress on the soil subgrade with reinforcement,
P = tire load (load supported by one tire in contact with the ground),
B = tire contact area base (width),
L = tire contact area length,
h_o = depth of material over subgrade without reinforcement,
h = depth of material over subgrade with reinforcement,
α_o = angle of load distribution without reinforcement,
α = angle of load distribution with reinforcement,
γ_o = unit weight of material over subgrade without reinforcement,
γ = unit weight of material over subgrade with reinforcement.

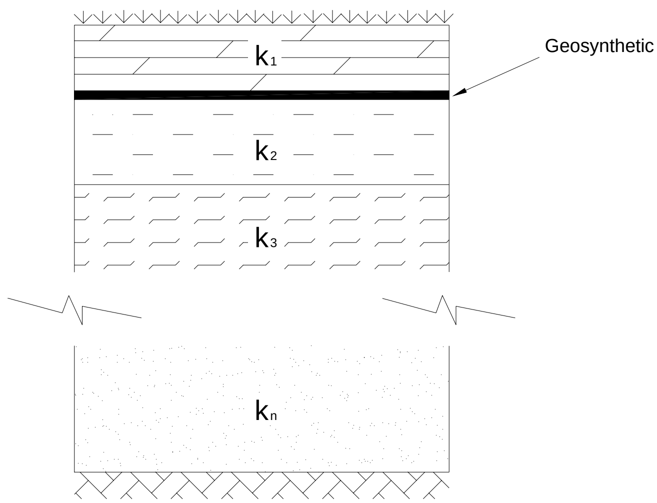
Like asphalt and concrete, soil is stronger in compression than in tension. One of the main advantages in using geosynthetics for soil reinforcement comes in their ability to increase tensile strength through the elongation of material fabric under applied loads. This effect increases the soil media bearing capacity from its elastic limit to its plastic limit (Koerner, 1991).

One of the main causes for geosynthetic failure in many applications occurs during the construction process (Holtz et. al., 1997). Heavy construction equipment (trucks, dozers, graders, etc.) allowed to operate directly on the geosynthetic while installing backfill material can cause premature geosynthetic elongation and deformation, thus compromising its overall effectiveness – similar to that of an inelastic rubber band or a spring that is unable to return to its original form. Most design manuals (Holtz et. al., 1997; Koerner, 1998) suggest using an installation damage safety factor between 1.1 and 2.5, depending on the type of application, slope and projected magnitude of damage or loss of life caused by system failure, in the design and selection of geosynthetics.

These design manuals also call for the placement of a fill layer over the geosynthetic during construction in areas were heavy traffic is anticipated to greatly reduce installation damage and preserve its functionality. Additionally, factors of safety for creep (sliding) and chemical and biological degradation should be considered when selecting a geosynthetic for reinforcement applications (Koerner, 1998). These added design buffers will aid in ensuring that the material selected for a particular application meets the intended project requirements (Meyer, 1998).

Failure of geosynthetics after installation most commonly occurs due to a build-up of hydrostatic (soil water) pressure through lack of adequate drainage (Holtz et. al., 1997). This is especially common in areas behind retaining walls and adjacent pavement systems such as road shoulders and shoulder backfill areas.

Rollings and Rollings (1996) suggest insistence on a geosynthetic having a higher hydraulic conductivity (k), expressed in units of length per time (e.g. inches/hour), than that of the surrounding media. If layers of different types of media are present, the geotextile should have a higher hydraulic conductivity than the layer directly above it and each of the subsequent, subsurface media layers should have a hydraulic conductivity equal to or greater to that of its overlying layer (Figure 5). This will afford proper drainage to the system and not compromise its design.



$$k_n \geq k_3 \geq k_2 \geq k_{geosynthetic} \geq k_1$$

Figure 5. Appropriate media hydraulic conductivity structure in a layered system with a geosynthetic.

For reinforcement applications, the ability of geosynthetics to provide resistance to induced normal (perpendicular) stresses is of utmost importance. Bonczkiewicz et. al. (1988) reports the testing of several different types of geosynthetics (woven geotextiles and geogrids) and their resistance to pull-out or sliding; the force necessary to pull a specimen out of a soil mass, under varying normal stresses (loads) and soil types. Their findings indicated that the pull-out resistance of the geosynthetics was not influenced by soil type and geogrids have a significantly higher resistance (approximately 350 pounds/inch) to pull-out than do woven and non-woven (needle punched) geotextiles (approximately 100 pounds/inch).

One noted caveat to this study – it was performed over a short duration with limited trials involving soil media with one specific moisture/density relationship. Follow-up testing is needed to confirm these conclusions over a longer time period with variations to the soils' moisture/density ratio.

Lentz and Pyatt (1988) reported pull-out resistance of geogrids in sands to be directly proportional to normal stress. Their laboratory testing indicated that for a given soil condition, the more rigid the geogrid, the longer the specimen must be to reach a constant pull-out stress. But in field application, with embedment lengths far in excess of those used in the laboratory, the material should often be of sufficient length for the pull-out stress to be insignificant part of the overall design. Caution should be taken however when using stiff geogrids on soils with steep slopes (greater than 30 percent) and those with high shrink-swell potentials (e.g. soft clays), as pull-out stresses may be in excess of those recommended for the geogrid.

The width of the geogrid also plays a role in relation to pull-out stress; passive resistance provided by the grid members perpendicular to the direction of pull-out and frictional resistance offered by members parallel to the direction of pull-out (Figure 6). The wider the specimen, the larger area over which the load was distributed, thus decreasing the magnitude of the pull-out stress (Rollings, 1996).

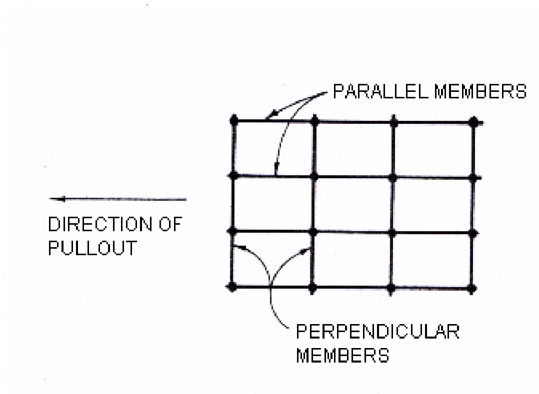


Figure 6. Geogrid sample configuration (Lentz and Pyatt, 1988).

The U.S. Army Corps. of Engineers, Waterways Experiment Station (1990) first developed geowebs for use in the stabilization of extreme slopes, but have also been proven successful in other applications such as reinforcing soils for pavement overlays, establishing stream and low water crossings and providing support for underground pipelines. They are unique because their strength by confinement is achieved through a series of three dimensional perforated or non-perforated cells which, when expanded into position, have the appearance of a large honeycomb – one of nature's most efficient structures.

These porous pavement systems are generally made from either the polymers polyethylene or polypropylene. The benefits gained in using geowebs with perforations, which connect each cell to adjacent cells, can be seen in increased root lock-up and in the transmission of water, nutrients and soil organisms between cells. This creates a healthier soil environment than systems without perforations (Presto Products Company, 1998).

Not all porous pavement systems are made from polymers, in fact the first porous pavement systems were made out of brick and concrete (Amoco, 1988). As with all geosynthetics, their physical properties can be quite different depending on the manufacturer and the material used in their construction. Therefore, they must be carefully selected based on the intended application and design constraints (Tensar Corporation, 2000).

Acceptance of these technologies for use as alternatives to impervious surfaces such as asphalt and concrete has proven difficult, as they have not been applied and studied in as much detail as rigid pavement systems (Carroll et. al., 1994). As research is advanced, greater acceptance and use of these technologies is anticipated.

A study performed by Presto Products Company (1998) involved the use of their geoweb product line, the GEOWEB Confinement System (each section of dimension 20 feet long by 8 feet wide by 4 inches deep), in establishing a grassed parking area where a paved parking lot had previously existed. Sand, compacted to 98% (modified proctor), was selected as the infill material and sod was established on the media surface. After three years of use, the parking lot has no visable signs of deformation (rutting) and vegetation has been maintained above 85 percent uniform cover.

Although the compaction efforts during construction likely had some effect on the overall infiltration and permeability of the system, the total surface runoff generated by the 2 year, 24 hour storm measured from the site was found to be approximately 30% less than the surface runoff volume generated on the impervious parking lot (Simmons et. al., 2000). This was most likely due to the coarse sand infill material that was used.

Similar studies by the TENSAR Corporation (2000) and North American Green (2001) on grassed parking areas showed reductions in 2 year, 24 hour surface water runoff volumes of approximately 50 and 60 percent, respectively for silt loam infill material that was hydrotamped (non-mechanical compaction; allowed to compact over several days via rainfall or manual application of water) and then overseeded with a native grass species mix. After three months of the initial seeding, vegetation had established at 80 percent (approx.) uniform cover.

In another engineering application, Hogan and Zeinert (1998) documented the geoweb's successful use in stabilization of a 130 foot high shale embankment on a 67 percent (1.5H:1V) slope. In this scenario, no surcharge loads were required to be supported, but due to the steepness of the slope, soil alone would have failed internally and slid, independent of vegetative growth. When options such as rip-rap reinforcement and the construction of a retaining wall were found to be in excess of budget constraints, the geoweb solution was identified as a viable option – one that would be within budget and provide for a natural look.

A non-woven geosynthetic was used to provide separation between the undisturbed soil and geoweb with sandy loam infill material. Hydrotamping was allowed to occur for several days until the design compaction was achieved, as any mechanical compaction would have hindered root growth and the overall development of vegetation. Hydroseeding with a native grass mix involving Bermuda grass, Weeping Love grass, Creeping Red Fescue and K-31 grasses was performed and covered with a woven erosion-control blanket to prevent washout. Photographs 2 and 3 show the construction and fully stabilized conditions of this project respectively.

Photograph 2. Infill is spread over the cellular-confinement system as installers rake the materials into the cells (Presto Products Co., 1998).

Photograph 3. The fully stabilized slope after construction (Presto Products Co., 1998).

When using a geoweb on steep slopes for reinforcement and/or erosion control, Wu and Austin (1994) document the critical need to evaluate the cellular confinement system for its resistance to sliding forces imposed by the infill soil and slope angle. The internal resisting forces should be between 1.3 and 2 times the internal sliding forces, depending on the consequences of failure (safety factor). If not, additional reinforcement should be provided.

Upon evaluation of the resisting forces to the sliding forces for the application documented by Hogan and Zeinert (1998), it was found that the safety factor against internal sliding was 0.67, less than half of the required safety factor of 1.3 for the given application. To increase the sliding resistance, the non-woven geotextile was anchored at the top of the slope to provide additional resistance to the soil surface. Additionally, tendons were installed that interconnected the individual geoweb sections, then reinforcement stakes (steel "j" hooks) were installed at a sufficient number of tendon locations and driven to a depth of 24 inches into undisturbed soil. These stakes served as restraint pins, transferring the loads on each tendon to the geoweb sections, increasing the requisite safety factor to within project requirements.

Objectives

The objective of this study is to develop a stable road shoulder backfill area design that meets the following criteria:

1) reinforcement to support a minimum uniform static load of 80 pounds per square inch (psi) without deformation,

2) surface runoff volume reduction of fifty percent (50%) for the 2 year, 24 hour storm over the current 50/50 aggregate and topsoil SHA design, and

3) uniform vegetative cover established at ninety percent (90%) minimum with an SHA approved grass species mix,

4) surface runoff velocities for the 2 year, 24 storm below those determined to be erosive for the SHA approved native grass species mix.

Improved Design Methods

Given the previous information presented as to the effectiveness of different geosynthetics in various engineering applications, the geoweb with perforations will be the central reinforcement member in all design scenarios presented. This is due to its reinforcement, through confinement, of topsoil media – a function in which no other geosynthetic has been proven successful. These systems are reported by their manufacturers to be approximately twice to three times as expensive to install than traditional geosynthetics, depending on the size of the job and its location. However, their ability to meet the design parameters make them viable, cost-effective solutions over the life of the system in terms of their low maintenance and long-term stability.

1. Reinforcement

The design reinforcement value of 80 psi was selected as it is the standard tire pressure for a dual axle wheel load on a one-layered system used by the U.S. Forestry Service (USFS) (Holtz et. al., 1997). USFS specifications, and not Department of Transportation (DOT) specifications, were used in establishing this value because many design manuals (Amoco, 2001; Holtz et. al., 1997; Koerner, 1998; Rollings, 1996) cite USFS reinforcement specifications, and not those from DOTs, in geosynthetic reinforcement applications.

To ensure the reinforcement criteria of 80 psi (minimum) is being met, the designer should verify the rated loading capacity of the geoweb. While Equation 1 holds valid for use by designers for non-reinforced subsoil, due to the specific nature and configuration of the geoweb, the use of Equation 2 will give incorrect normal stress results under the reinforced condition. This is because the topsoil that will be used as infill material to the geoweb will not be at a depth above the top of its cellular structure. If it were, this unconfined layer would be susceptible to rutting which could seriously compromise the design of the system. Instead, the following equation should be used:

$p = W_g / (n * B * L)$ (Equation 3)

where,

p = approximate normal stress on the soil subgrade with the geoweb reinforcement (psi),
W_g = gross weight, including cargo, of load (lbs.),
n = number of tires vehicle has in contact with the ground,
B = tire contact area base or width (in.),
L = tire contact area length (in.).

Manufacturers follow a universal load rating classification system developed by the American Association of State Highway Transportation Officials (AASHTO) for use in bridge design to specify the maximum reinforcement ability of their geowebs. This rating system involves the letter 'H', a dash, then a number; for example "H – 15." A geoweb with a rating of H – 15 means it has been proven to provide reinforcement to a standard four-wheel vehicle weighing 15 tons, including cargo, without any measured deformation. Similarly, a geoweb with rating H – 20 means it has been documented to support a standard four-wheel vehicle weighing 20 tons, including cargo, without deformation.

Using tire data obtained from the Goodyear® Tire Company (Goodyear, 2001), a 22.5" special service tire primarily for over the road use, but also moderate off-road service (G186), is maximally rated for 6,175 pounds per tire (gross) or 24,700 pounds (12.5 tons approx.), assuming a vehicle with four tires at 105 psi inflated pressure (normal stress). From this information, a geoweb with an H-15 rating would provide enough reinforcement to support this vehicle, but may be over-designed for our 80-psi design objective. On other sites where higher tire pressures and resulting reinforcement levels are mandated by DOT specifications, a road shoulder backfill system using a geoweb with this rating classification or that of the H – 20 should be considered.

For the 80-psi objective, the same 22.5" G186 Goodyear® tire can carry a load of 4990 pounds per tire (gross) or 19,960 pounds (10 tons approx.) assuming a four-wheel vehicle. In this instance, a geoweb with an H – 10 rating would meet the given reinforcement criterion. If the particular application would call for an additional factor of safety, generally taken to be 1.3, a geoweb with H –15 classification should be specified.

2. Surface Water Runoff Volume

For reduction in the overall surface water runoff volume generated by these areas by 50% over the existing SHA gravel and topsoil composite, the Natural Resources Conservation Service (NRCS) TR-55 technique, based on 24-hour duration precipitation events, can be used. Namely,

$Q = \{(I - 0.2 * S)^2 / (I + 0.8 * S)\}$ (Equation 4)

where,

Q = estimated direct surface runoff depth (in.),

I = design storm rainfall amount (in.),
S = maximum potential difference between rainfall and runoff, starting at the time rainfall begins (in.),

where,

$$S = (1000 / CN) - 10 \quad \text{(Equation 5)}$$

where,

CN = runoff curve number that can vary between 0 (pervious – no runoff) and 100 (impervious – complete runoff).

Depending on the importance of the installation, the runoff curve number, which is based upon land use and hydrologic soil group, can be modified from the typical Type II Antecedent Moisture Condition (AMC), which reflects average values, to that of the Type III AMC. This more stringent condition reflects heavy rainfall or light rainfall and low temperatures within five (5) days prior to the given storm event. As with any design, an attempt to meet the criteria under the worst case scenario should be attempted. The site evaluated by the UMCP-BRE Capstone Design students in Howard County, Maryland will be used to determine if a 50 percent reduction in surface water runoff volume can be achieved by using the geoweb composite.

From the TR-55 manual, the 2 year, 24 hour storm for this area is approximately 3.2 inches, which will be applied over a unit area. This 50/50 gravel and topsoil mix design was assumed to be classified within hydraulic soil group D – those soils with the highest runoff potentials – due to its lack of established vegetation and noted high amount of surface sealing. Its land use was taken to be “lawn in poor condition” (approx. 15 percent cover), which returned a curve number of 89 under Type II AMC conditions. When converted to the Type III AMC, the resulting curve number was found to be approximately 96.

Under the design incorporating the use of the geoweb, assume the topsoil used as infill would be classified within hydraulic soil group C – those soils with moderately high runoff potential – on the same site in Central Maryland, the resulting curve number for the land use of lawn in good condition (greater than 75% cover) for Type III conditions is 87. Using Equation 4, the estimated direct surface runoff from the SHA mix and the geoweb system was found to be 2.75 and 1.92 inches, respectively. This indicates an estimated reduction in surface runoff with the geoweb system of 30 percent which is significant, but not the 50% desired by the flow volume design objective.

If a soil with hydraulic soil group B – those with moderately low runoff potentials – is used as the infill material instead (Type III AMC CN = 79), the estimated direct surface runoff would be 1.33 inches, a reduction in runoff volume of approximately 52 percent over the existing design. Therefore, this criterion can be met by using topsoil classified within either hydraulic soil group B or A. Group A soils are those with the lowest runoff potentials and provide a runoff volume reduction of over 86 percent compared to that of the SHA mix.

3) Vegetative Cover

Where the supply of topsoil, free of debris, in either hydraulic soil group A or B is available on-site, it may be used to satisfy the third design objective – establishment of a uniform vegetative cover to at least ninety percent (90%) uniform cover with an SHA approved grass species mix. If project resources allow, it is good practice to field verify and test on-site topsoil reserves prior to the design of these road shoulder backfill systems to insure adequate topsoil infiltration and permeability properties. Where the use of nearby topsoil is not possible, costs associated with bringing in suitable topsoil from areas off-site should be expected.

The depth necessary to establish a good stand of vegetation with the design coverage density requirement varies based on such factors as soil type, pH and climate, which influence the amount of biological activity within the media. Several studies by the Pennsylvania Department of Environmental Protection (PADEP) (1996) suggest a topsoil layer not less than four inches (4") deep is required to provide adequate rooting depth and long-term vegetative survivability.

As the SHA currently promotes the use of a tall fescue grass mixture, this will be the selected mixture of choice. This is not to say that other grass mixtures are not supported by SHA, but rather this is their most preferred as the mix contains tall fescue and Kentucky bluegrass, which are cool season grasses that adapt easily to a given area. Since both of these grasses are less resistant to the environment when seeded by themselves, a mixture containing these and other, more hardy, grasses such as rye and wheat should be used to induce growth of the desired species.

4) Surface Water Runoff Velocity

Table 1 suggests maximum permissible (non-erosive) velocities for various grass mixtures when used in combination with a geoweb. The table does not discern allowable velocities for different types of grasses. This is mainly because of insufficient research on the use of cellular reinforcement systems with topsoil infill material to establish and sustain vegetative growth.

Table 1. Suggested Design Flow Values for Geoweb Infill Material (adapted from Wu and Austin, 1994).

Infill Material	Roughness Coefficient (n)	Maximum Permissible Velocity (ft/sec)
Bare topsoil	0.017	2.9
Vegetated topsoil	0.024	4.9
Coarse sand	0.020	5.9
Gravel	0.022	8.9
Concrete	0.013	15.1

Haan et. al. (1994) suggests between 3 and 5 fps for unreinforced grass mixtures, depending on slope and soil erodibility conditions. This value of 4.9 fps for vegetated topsoil appears reasonable in comparison to these values, given that the geoweb most likely allows for an increase in runoff velocity over the system. Therefore, this will be the established rate of maximum flow to remain below erosive conditions.

If steady-state flow conditions are assumed, the slope of the energy line is equal to the slope of the land surface flow path for sheet flow conditions or that of the channel bed for concentrated flow applications. Manning's equation is typically used to calculate a reliable estimate of the flow velocity conditions:

$$v = (1.49/n) * R_h^{0.67} * E^{0.5} \qquad \text{(Equation 6)}$$

where,

v = average velocity of surface runoff flow (ft/sec),
n = Manning's roughness coefficient,
R_h = hydraulic radius (ft),

where,

$$R_h = A / P \qquad \text{(Equation 7)}$$

where,

A = cross-sectional flow area (ft^2) and,
P = wetted perimeter (ft.)

For sheet flow conditions, where the flow depth is less than 10 times the flow width, the hydraulic radius can be approximated by the flow (runoff) depth (D), (ft.):

$$R_h \approx D \qquad \text{(Equation 8)}$$

E = energy or slope gradient (ft/ft).

The use of Equation 6 in conjunction with the continuity equation (Equation 9), will determine if the runoff velocity from the design storm are below the recommended limiting flow rates given in Table 1. If the calculated velocity is greater than the maximum non-erosive velocity listed, the design should be altered because the vegetated soil surface is considered unstable.

$$v = Q / A \qquad \text{(Equation 9)}$$

where,

v = average velocity of surface water flow (ft/sec),
Q = design volumetric flow rate (ft^3/sec) and,
A = cross-sectional flow area (ft^2).

The design rainfall event equating to the 2-year, 24-hour storm event for Central Maryland is approximately 3.2 inches (0.267 ft.). For the road shoulder backfill area design, assume the following: 1) sheet flow conditions prevail and, 2) all of the rainfall becomes runoff, which is close to reality on impervious surfaces such as rigid pavements ($n \approx 0.015$). To be more correct, we should use Equations 4 and 5 under Type III AMC to determine the total surface runoff volume, but this approximation builds in a factor of safety, albeit a small one, to the overall design.

In order to exceed the limiting velocity of 4.9 feet per second, the topography upon which a 30 square foot [30 foot wide (2–10 foot traffic lanes and a 10 foot shoulder) by unit length] pavement lies must be in excess of 35 percent, which greatly exceeds typical road slopes of between 2 and 5 percent. From this calculation, a reasonable conclusion can be inferred – for all sheet flow conditions involving the use an appropriately designed system, surface runoff velocities will be non-erosive. For those instances where the cellular confinement system must accept concentrated flows, this may not be the case and therefore these situations should be evaluated using Equations 6 through 9.

If it is found that design requires modification due to erodible runoff velocities with vegetated topsoil, the use of a coarser soil infill media, such as sand should be considered. The ability of this modified design to be used in these instances may come at a cost, however, in terms of the media's ability to retain essential water and nutrients during periods of dryness that may compromise the overall functionality of the system. It is therefore important to evaluate the use and effectiveness of this and other options in which a designer may feel appropriate for the specific project in which it is being applied.

The previous example underscores a common theme in stormwater management – low intensity, long duration storms are rarely cause for runoff and erosion concerns, but almost all stormwater and erosion control regulations are written to focus upon them. More critical are the high intensity, short duration events, such as the 2 year, 1 hour design storm of 1.6 inches for Central Maryland (Schwab et. al., 1993), that pose the biggest threat to environmental degradation, but receive little regulatory attention.

<u>Additional Design Considerations</u>

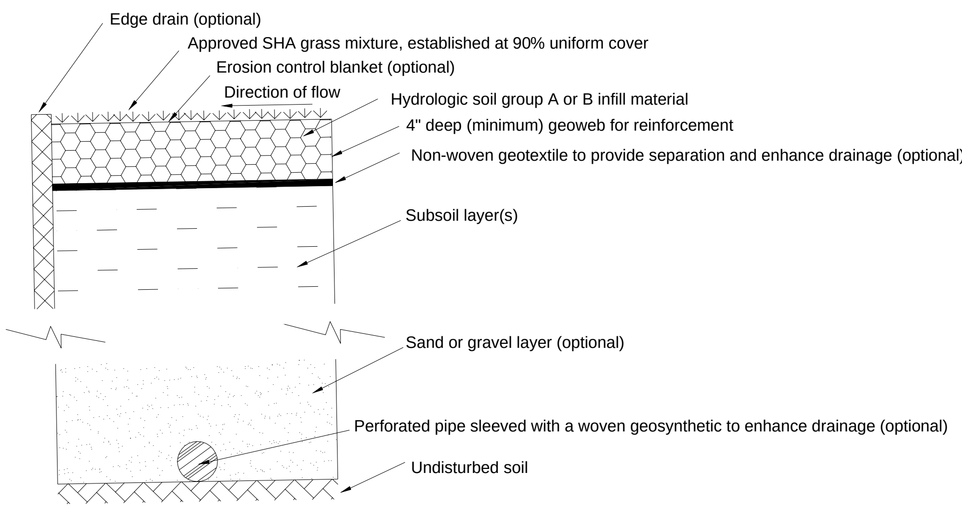
While these road shoulder backfill areas are constructed to provide adequate reinforcement and biological activity to sustain vegetation under design constraints, they should also provide for efficient transmission of excess water through the profile and out of the system. It is therefore important that media and geosynthetics used in subsurface layers of the composite should have the same or greater hydraulic conductivity as the topsoil layer. Caution should be taken in selecting an underlying composite layer with a hydraulic conductivity greater than one and one-half times that of the layer above it, as the integrity of the system can be compromised (Rollins and Rollins, 1996).

Should surrounding down gradient soils have poor permeability, an appropriately sized perforated pipe, placed sufficiently below the geoweb composite to maintain a viable environment for biological activity and growth of vegetation within the infill soil, should be considered (Wu and Austin, 1994). The drainage pipe should be outfitted with a porous geotextile sleeve and embedded in a layer of gravel to prevent clogging and preserve the profile's overall drainage characteristics.

In severe applications, consideration should also be given to the installation of an edge drain that would serve a dual role in collecting excess surface water runoff and any horizontal flow.

In all applications, the use of a non-woven geotextile should be considered between the undisturbed soil and geoweb system to provide separation and facilitate in-plane drainage of groundwater seepage from the underlain soil. For installation on slopes, a check of the safety factor against downslope internal sliding should be performed. If below the recommended value for the given application, appropriately designed anchorage and bracing that provide additional reinforcement should be included such as the stake, tendon and crest-anchor configuration depicted in Figures 7 and 8. To ensure stability induced by frost heave processes, the crest-anchor and reinforcement stakes must be installed below the frost line, which in Maryland varies from 18 inches (Eastern Shore) to 36 inches (Western Panhandle). As with any design, each application is different, therefore project specific modifications to this configuration may be required.

Finally, the use of an appropriate erosion control blanket can aid in preventing accelerated erosion and allow for the timely establishment of vegetation to provide a complete and sustainable system. Figure 7 illustrates the general concept design for backfill areas that meet the criteria established for this paper. It also shows the manner in which several of these optional considerations can be integrated into the composite system.



$k_{pipe} \geq k_{sand} \geq k_{subsoil\ layer(s)} \geq k_{non\text{-}woven} \geq k_{in\text{-}fill\ soil}$

Figure 7. Profile of a composite geoweb road shoulder backfill system, meeting the design criteria and shown with optional considerations.

Conclusions

The design discussed in this paper concludes that the geoweb composite system with appropriate safety factors is a viable and environmentally sound methodology for the stabilization of road shoulder backfill areas. The cost to install these systems is estimated at between $3 and $15 per square foot (R.S. Means, 1998; Tensar, 2001), depending on their composition, which is likely to vary by project and application. This compares to a construction cost of approximately $2 per square foot of the current 50/50 gravel and topsoil SHA design.

Even at the high end of this estimate range, this improved design could be of considerable value to highway design and maintenance because of the increased benefits it can provide through increased reinforcement and reduction of surface water volumes and velocities from pavement systems. Additionally, the system is designed to be self-sufficient once vegetative growth is established, requiring little maintenance as compared to the current design – a major issue for transportation departments such as the SHA. Although maintenance cost data for the in-use systems is unknown, SHA speculates the costs to be in the vicinity of 20 percent of the installation cost, or $0.40 per square foot per year.

Other design life costs to the current SHA backfill area systems are those associated with degradation to the surrounding environment (water and land) as a result of accelerated erosion from these sites. Often these values are not considered in the design selection process because they are not reflected in discrete line items of transportation budgets. However, they do constitute a value to society and therefore should be considered in the overall cost evaluation.

In a report issued by Resources for the Future (1996), economic value of freshwater, based on geographic region, can be estimated. In the New England region, water was priced at $4 per acre-foot. By extension, any degradation of these waters would constitute a reduction in overall value; hence the more degradation, the less valuable the water.

Assuming a road shoulder backfill area would be adjacent and up-stream of a one-mile long, twenty (20) foot wide stream flowing at an average annual depth of 2 feet, at any one time (on average) approximately 4.8 acre-feet of water would exist within this control volume. If the sum environmental damage was found to be ten percent of the overall water value, or $0.40 per acre-foot, of which only five (5) percent, or $0.02 per acre-foot, could be linked to the accelerated runoff from the upstream pavement system, over the course of a year this would amount to over three (3) million dollars in damages to the water itself.

Loss in land (property) value due to erosion of topsoil from nearby areas would only increase this total ecological damage value. This devaluation cannot be seen as appreciably in terms of its direct cost, but rather in terms of its indirect costs associated with use limitation and loss of production to the land itself and reduced subaquatic vegetation and dissolved oxygen levels to nearby watercourses.

This simple, yet telling example shows in economic terms the benefits that this improved design may have to offer transportation professionals. From this coarse analysis, although there is a higher cost to installing this new design, it may prove to be a more cost-effective solution, paying for itself within five to ten years with the annual maintenance and environmental degradation cost savings presently spent on and applied to existing road shoulder backfill systems.

It is hoped that the design options included in this study can be evaluated in road shoulder backfill areas under varying conditions and design constraints to gauge their effectiveness and functionality. Additionally, this paper is meant to serve as a framework for analyzing additional approaches to road shoulder backfill area stabilization, ensuring its long term economical and ecological sustainability. Regardless of the study outcome, research will be advanced in an area that has been minimally explored.

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Appendix III

First Capstone Design on the Project (GEO-Block) (Completed 2001)

TREGS BIOENGINEER FIRM
1598 Green Shoulder Road
College Park, MD 20742

May 16, 2001

Board of Directors
Dr. Wheaton
Biological Resources
University of Maryland
College Park, MD 20742

Dear Dr. Wheaton,

Enclosed is a design report detailing a road shoulder backfill area for use in the highway construction. This provides a stable, economical and environmentally sound road shoulder backfill alternative to current method of backfilling. The design also provides a more smooth transition between the highway and the surrounding environment. If you have any comments or questions regarding the contents of this design report, please do not hesitate to contact our team at 301-405-1194.

Sincerely,

Tony Chang

Gabriela Hernandez

Erin Hypes

Rachel Michaud

Enclosure

TREGS BIOENGINEERING FIRM

Green Shoulder: A Bioengineered Vegetative Road Shoulder Backfill

Tony Chang, Gabriela Hernandez,
Erin Hypes, and Rachel Michaud

Capstone (ENBE 486)
Dr. Shirmohammadi

16 May 2001

EXECUTIVE SUMMARY

Road shoulder backfill in the state of Maryland currently consists of either a row of gravel, or experimentally, a 50/50 mixture of gravel and topsoil. Both of these methods are unattractive. They also present an environmental threat, as the infiltration in these areas is low and coupled with the high-velocity runoff from the neighboring asphalt road. This presents a high danger of erosion. The high-energy runoff has the potential to create gullies in the road shoulder backfill area, concentrating the flow and further compacting the erosion problem. The State Highway Administration (SHA) is seeking a method to grow vegetation adjacent to the edge of the asphalt, in order to increase the infiltration rate and to reduce the amount of erosion on the side of the road.

TREGS Bioengineering Firm proposed a layered soil composite media, incorporating a geosynthetic material for stability of land and for structural support in the road shoulder backfill area. Two methods of testing will be used for the composite media. The Instron compression test was used to determine the deformation of the soil composite under a specific loading. A target load for the composite is 80 psi. Instron compression tested will include containing the proposed composite media and crushing it to the point of failure. The second type of testing was erosion and infiltration testing, completed in a rainfall simulator. A box mimicking the study area was subjected to a 30-minute storm with an intensity of 11 inches per hour. There was one experimental containment device containing two different configurations. The first model is the control. The other model is the experimental model, containing the new geocomposite. The infiltration and total suspended solids in the direct surface runoff were compared to analyze meeting the specifications.

TREGS Bioengineering Firm has developed a budget totaling about $2682.72 to complete this project. The actual cost of this project was $144 including overhead. This budget included the cost of the materials needed for testing, as well as machine shop labor.

The geocomposite material met all of the design specifications within reason. Infiltration was increased 42% and erosion was decreased by 200%. The geoblock used is rated at 420 psi, so bearing the load of 80 psi will not be a problem. Using the Instron machine, the 50/50 mixture and the geocomposite showed similar deformations of approximately ¼". Because the geogrid is expensive, it is recommended that the SHA only use the geogrid in areas where it is known that cars often drive onto the backfill area. In other areas, a woven turf support should be used to support vegetation and increase the stability of a region. While these areas will not be as strong as those containing the geoblock, it would be more economically feasible to implement.

Table of Contents

Project Justification

The mission statement for the State Highway Administration (SHA) reads as follows…

> "To provide mobility for our customers on a safe, well-maintained and attractive highway system that supports Maryland's economy in an environmentally responsible manner."

The current methods for stabilizing the road shoulder backfill areas in Maryland are impeding this mission. This proposal focuses on improving one particular study area, of interest to the Maryland State Highway Administration (SHA), located adjacent the Maryland Route 108 exit ramp to Eastbound Maryland Route 100. It is expected that the findings from this study area can be applied to other similar situations, both inside the state of Maryland and elsewhere.

SHA's evaluation of their current road shoulder backfill technologies has lead to a need for improvement of existing conditions. Along I-70 near Ellicott City, Photograph 1 in Appendix E illustrates gravel placed within the road shoulder backfill area, six weeks after roadway rehabilitation. This gravel was placed in order to stabilize the asphalt road shoulder after rehabilitation of the roadway. Photograph 2 in Appendix E illustrates the conditions of this area approximately one year later. Uneven grass growth through the gravel gave a patchy, unkempt look and contributed to increased erosion.

From an ecological standpoint, the gravel has other disadvantages. The runoff volume from the asphalt highway is high, as the infiltration into asphalt is practically zero. While gravel particles are large and generally require great amounts of energy to move, once they have spread, the earth beneath is susceptible to a more erosion from the roadway runoff. This eventually forms gullies in the surrounding environment. These gullies carry the runoff at high velocities, further compacting the erosion problem.

One alternative measure that SHA has considered in road shoulder stabilization is growing grass right to the edge of the road shoulder. The grass stabilizes the earth and helps to reduce erosion. Vegetated areas have higher infiltration rates than non-vegetated areas, reducing the overall runoff volume. The grass also acts as a resisting force for erosion, retarding the high velocity of the water running off from the asphalt roadway and decreasing the energy it carries.

Grass and earth alone, however, do not provide adequate support for traffic loads on the road shoulder backfill area. In order to create a more stable backfill that can support vegetation, SHA experimented with mixing aggregate with topsoil into a 50/50 mixture, as seen in Photograph 3 and Photograph 4 in Appendix E. This mixture provides a stabilization technique that works from a structural engineering standpoint, but was unable to support a uniform coverage of vegetation. Mr. Donald Cober, Environmental Analyst with SHA, affirmed that it was possible to grow grass at this site, but it would require large amounts of fertilizers and seeding. This solution is not viable economically, and presents a threat to the surrounding environment.

TREGS Bioengineering Firm proposes an alternative, utilizing a geosynthetic material for stability instead of aggregates and providing a porous environment. The geosynthetic material will be placed beneath a layer of topsoil. This will provide favorable drainage and stabilization properties for the soil to grow and maintain vegetation.

REVIEW OF LITERATURE/PATENTS

Geosynthetic materials include geotextiles, geogrids, geonets, geomembranes, geopipe, geocomposites (Koerner, 1998), and geocells (Theisen, 1992). Most geosynthetics are manufactured from polymers including polyester, polypropylene, polyethylene, polyamide, and polyvinylchloride (Netherlands Geotextile Organization, 1995). Geosynthetics are used in a wide variety of applications, including subsurface drainage systems (Holtz *et al.*, 1995), prefabricated highway edge drains, (Frobel, 1991; Goddard, 1991), erosion control, reinforcement of paved and unpaved roads, and embankment stabilization. These applications, among others, have catalyzed the growth of the geosynthetic materials industry, which has surpassed 1.6 billion dollars (Koerner, 1998).

Erosion control has come into focus since the 1970's as one of the most important conservation practices. In the 1970's, the annual soil lost was estimated to be over 900 million tons of soil in the United States (Schwab *et al*., 1993). The two primary forces driving erosion are wind and moving water, which displace the top layers of soil. (Weggel and Rustom, 1992). While these two forces are natural and have caused the geologic weathering that results in soil, their effects have been compacted and accelerated by human and animal use of the land. (Schwab *et al*., 1993).

Geotextiles, which are fabrics made from synthetic fibers (Koerner, 1998), were first introduced for erosion control in the 1960's. They are used beneath hard armor such as concrete or rip rap, as well as beneath vegetated surfaces to prevent erosion caused by groundwater seepage, rainfall, and surface runoff (Carroll *et al*., 1992). Other geosynthetic materials that are used in erosion control are erosion control meshes and erosion control blankets. These geonets are designed to protect the soil surface from erosion by either wind or water, during the development of vegetation (Theisen, 1992). One geonet used for these purposes is a tufted mat. Stephens and Frauenfelder Krock (1997) developed a method for making tufted mats from scrim. The tufting allows a large number of gaps which enhance the attachment of root systems, soil retention, and the control of flowing water. The success of geonets or blankets, however, varies depending on a variety of factors, as illustrated by Harris *et al*. (1992).

Harris *et al*. (1992) studied the case history of two different landfill sites where a multi-layered, polyethylene geonet was used to prevent erosion at the site. The first site, the Glenwillow Landfill in Northern Ohio, was an example of the successful implementation of this geonet. Two channels at this site were compared, one with the geosynthetic mat and the other without. After several months, there were large ruts in the unprotected channel, while the matted section showed only minor signs of erosion. The second site, however, did not perform as successfully as the first site.

The Redbird Landfill, located in Eastern Missouri, installed the same type of geonet as the Glenwillow Landfill. The mat was in place in October, but by the end of November, there were significant signs of erosion. The soil had begun to break up and the soil beneath the geosynthetic was eroding. The geosynthetic material shifted and gradually migrated down the channel slope. The rainfall event that triggered the major failure was estimated to be a 5 year, 1-h storm, with an intensity of 2.5 inches/hour. Upon analyzing the failure, the main causes were found to be the sudden rainfall event mentioned above, poor grass coverage due to the season of installation, and the large drainage area for an experimental setup. The manufacturer added that the geosynthetic needed to be applied further beyond the crest of the slope than was done in order to reduce slippage (Harris *et al.*, 1992).

Important physical properties to consider when choosing a geosynthetic material for erosion control include thickness, porosity, ground cover, stiffness, resiliency, tensile strength, elongation, UV stability and durability (Carroll *et al*., 1992). When geosynthetics are used in combination with vegetation, one important consideration is the flow resistance of the geosynthetic material, before, during, and after the establishment of vegetation. When designing a channel using a geosynthetic, two basic approaches can be used (Theisen, 1992). The first approach addresses the permissible velocity in the channel as the critical parameter. In order to calculate the mean velocity in a channel, Manning's equation is used. The formula is as follows (Schwab *et al*., 1993):

$$v = \frac{R^{2/3} s^{1/2}}{n}$$

where v = average velocity of flow in m/s,

n = Manning's roughness coefficient for the channel,

R = hydraulic radius of the channel (cross-sectional area/wetted perimeter),

s = hydraulic gradient (slope of the channel) in m/m.

The second approach emphasizes the tractive forces causing shear stresses to develop at the boundary between the flowing water and the channel. Tractive force can be calculated using the following equation (Theisen, 1992):

$$\tau = \gamma D s$$

where τ = tractive force

γ = unit weight of water

D = maximum depth of flow

s = average bed slope or energy slope

Theisen (1992) also provides duration of flow as a critical parameter, because as this duration increases, the channel's resistance to erosion decreases.

Another use of geosynthetic materials is prefabricated highway edge drains. These drains economically increase the life of the road (Steffes *et al*., 1991). In highway design and rehabilitation, drainage systems are a necessary consideration, because water can become trapped beneath the impervious asphalt surface and the base soil (Goddard, 1991). These types of drainage systems are comprised of a drainage core wrapped in a geotextile filter. When designing a prefabricated highway edge drain, the drainage core and geotextile filter must be considered separately. The stresses on the core, as well as the required flow rate, must be analyzed. The filter must also be able to pass a certain flow rate and sustain different stresses than the core. The filter has the additional task, however, of anchoring the soil adjacent to the drain system (Koerner and Hwu, 1991). The core needs to be tested in compression, not only with a normal force applied, however, but also with the force applied at various angles. Strength at different angles is important, because the edges of many roadways are sloped

(Frobel, 1991). Flow capacity of a geocomposite drain varies under different loading conditions. When the drain is in compression, the flow capacity can be reduced, due to compression or deformation of the core itself. When the geotextile elongates or creeps under various hydraulic gradients, the flow capacity of the drain is again reduced (Stuart *et al*., 1991). In one case study, a geocomposite drain system was found to be less efficient than the traditional pavement base drain. The geocomposite drain clogged easily and had a smaller flow capacity than the pavement base drain. The authors believe that the problem was rooted in the geotextile opening size compared to the percentage of fines in the soil and recommend that these parameters are studied further in the design of geocomposite drainage systems (Highlands *et al*., 1991).

Another aspect of roadway design where geosynthetic materials are found is soil reinforcement in both paved and unpaved roadways. In paved roadways, a geogrid can be integrated with the base course material beneath the pavement, to stabilize the subgrade material (Brandon, *et al*., 1996). Geosynthetics are useful in roadway reinforcement when soils are poor, when the soil subgrade has an undrained shear strength less than 90 kPa (13 psi), when there is a high water table at the site, and when the soil subgrade is highly sensitive to a variety of factors. Geotextiles have been used to separate the aggregate layer from the subgrade layer in these situations. This separation keeps the aggregate layer from mixing with the softer subgrade, and keeps the aggregate layer at its designed bulk density and thickness (Holtz *et al*., 1995).

Geogrids have also been placed within the pavement itself. The geogrids have been found to substantially decrease rutting of the road, and aid in the prevention of asphalt cracking. It is difficult, however, to install geogrids in pavement properly, and the hot asphalt affects the modulus of elasticity of the grid (Koerner, 1998). Holtz *et al*. (1995) warn that the stresses on a geosynthetic material used in a roadway are often much higher during construction than at any other time. When selecting a geosynthetic material, therefore, construction stresses must be taken under consideration.

Both geogrids and geotextiles have also been used in the construction of unpaved roads. Koerner (1998) describes the pressure distribution through unpaved roadways with and without geosynthetic reinforcement in the equations below.

$$p_0 = \frac{P}{(B + 2h_0 \tan\alpha_0)(L + 2h_0 \tan\alpha_0)} + \gamma_0 h_0$$

$$p = \frac{P}{(B + 2h \tan\alpha)(L + 2h \tan\alpha)} + \gamma h$$

Where

p_0	= stress on the soil subgrade without geogrid reinforcement
p	= stress on the soil subgrade with geogrid reinforcement
P	= tire load
B	= Tire contact area base
L	= Tire contact area length
h_0	= Height of material on top of subgrade without reinforcement
h	= Height of material on top of subgrade with reinforcement
α_0	= Angle of load distribution without reinforcement
α	= Angle of load distribution with reinforcement

γ_0 = Unit weight of material on top of subgrade without reinforcement

γ = Unit weight of material on top of subgrade with reinforcement

One of the main advantages of geosynthetic reinforcement is the decrease in amount of aggregate material needed to support the same load. (Koerner, 1998). Another advantage of soil reinforcement in this manner is an increase in tensile strength. Soil is strong in compression, but has almost no tensile strength. Geosynthetic materials are strong in tension, so combining the soil with the geosynthetic increases the strength of the entire composite in multiple loading situations (Bonaparte *et al*., 1987). Problems with using geogrids and geotextiles in soil reinforcement that must be accounted for in a factor of safety flaws in installation of the geogrid, *in situ* creep factors, and chemical and biological degradation of the geogrid (Koerner, 1998). Meyer and Mattel (1998) have developed one method for implementing a geogrid for subgrade stabilization and base course reinforcement.

DESCRIPTION OF PROJECT

Objectives

TREGS Bioengineering Firm designed the road shoulder backfill area with the primary focus of improving the composite media within the study area and its associated hydrological properties. The objectives of this project are as follows:

1. Design prototypes to improve the road shoulder backfill area within the Maryland Piedmont region and other similar hydrologic areas.

2. Assemble prototypes for testing using scaled models of the study area.

3. Test prototypes for hydrological and strength properties.

4. Evaluate test results against established target design parameters.

Target Design Parameters

1. Load: 80 psi.
2. Vegetation: 90% uniform coverage.
3. Infiltration: 50% increase over existing infiltration rate.
4. Erosion: 50% decrease over existing erosion rate.

Design Concept

In designing for the road shoulder backfill area, the parameters above were determined in order to meet the objectives stated in the previous section. These parameters were used to evaluate the final prototypes to determine if the objectives of the project were met.

In order to meet the specification, the design composite should efficiently support a pressure of 80 psi. This is the design standard tire pressure for a dual wheel load on a one-layered system, used by the United States Forestry Service (Holtz 1997).

The road shoulder backfill area needed to be able to support vegetation with a 90% uniform coverage. The current combination of 50% clayey topsoil and 50% coarse gravel is not supporting the grass, but rather unwanted weeds or empty space, as seen in Photograph 5 in Appendix E. The bare ground contributes to additional runoff and erosion that would normally be reduced if vegetation were present.

SHA is currently using a tall fescue grass for shoulder backfill vegetation. The model used for the rainfall simulation contained tall fescue sod. Tall fescue is a cool seasoned grass that adapts easily to its seeded area and is used on recreational areas and roadside in Mid-Atlantic regions. Adaptation is important when planting along highway and heavy traffic areas because a proper growing environment is necessary.

The current composite media reduced the amount of water infiltrating into the water table because it reduced the amount of micro-pores. Using TR-55, the weighted curve number for the study area was calculated for both the current composite media and the designed composite media. Hydrologic soil group C was assumed for this calculation. TR-55 used the following equation to determine the weighted curve number for an area.

$$C_w = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i}$$

Where

C_w = weighted curve number

C_i = curve number for the i^{th} area

A_i = i^{th} area

The current composite media curve number was 89 and the designed composite media curve number was 88. When comparing the curve numbers, the difference was one. However, it indicated a favorable change in the infiltration rate. The TR-55 program may not have been accurate because it is designed to calculate curve numbers for sites larger that one-acre. The study area is less that one acre creating estimated calculation.

In addition, the current composite media provides more loose particles, such as small gravel and topsoil to be eroded from the surface. When these particles are removed, the bare ground is more likely to be subjected to rilling and deterioration. Also, this erosion causes turbidity in local waterways. The road shoulder backfill area should increase the infiltration rate by 50% and was measured in comparison to the control prototype.

Test Models

In order to test the target design parameters and complete the four objectives, a total of two prototype models for the rainfall simulation were assembled and tested for accuracy. The first prototype model was designated the control, which represented the current conditions of the road shoulder backfill. The second prototype had a composition that mimics the soil profile of an asphalted road, but will include a proposed composite media and a geosynthetic material. The designed composite media has a sub-aggregate base of 75% topsoil and 25% coarse gravel in the soil profile. The geosynthetic material will be placed on top of the proposed composite media, which was covered with a layer of United States Department of Agriculture grade topsoil.

A geosynthetic material has several advantages. One advantage of using the geosynthetic material in the soil composite was that it increased the strength of the soil subgrade from its elastic limit to its plastic limit. This can be seen in the following two equations from Koerner (1997).

$$p_e = \pi c_{uN} + \gamma h_0$$

$$p_{\lim} = (\pi + 1) c_{uN} + \gamma h$$

Where

p_e	= bearing capacity pressure based on the elastic limit (non-reinforced case)
p_{lim}	= bearing capacity pressure based on the plastic limit (reinforced case)
c_{uN}	= undrained soil strength at the Nth vehicle passage

Another advantage to the geosynthetic material is its improved load distribution to the soil subgrade, as shown in Equations 2 and 3 in Appendix B. A third advantage of the geosynthetic material is its ability to hold the soil in place and keep the composite media from eroding.

Procedures and Methods

Material List

- 4 1-ft of PVC pipe, diameter 7”
- Base soil, currently used by the SHA
- Soil subgrade, currently used by the SHA
- Aggregate made of gravel
- 75:25 mixture of USDA grade top soil and gravel (soil:gravel)
- 4 blocks of Presto GeoBlock Porous Pavement System
- 15 bags of USDA graded top soil
- 1 4’ x 4’ piece of ½”plywood
- 5 2’ x 4’ pieces of ½” plywood
- 3 2”x4”x4’ wood
- 1 5-lb box of 6-penny common galvanized nails
- 6 tubes of Liquid Nails Heavy Duty Construction
- 2 tubes of silicon sealant

- 4 aluminum cooking pans
- 2 rolls of tall fescue sod
- 1 roll of door screening

Equipment List

- Instron machine
- Circular saw
- Drill and various size bits
- Hammer
- Screwdriver
- Paintbrushes
- Rainfall simulator

Procedure

1. Set up the Instron compression machine for the compression of 80 psi.
2. Fill the PVC pipe section with the layered composite material in the following order, assuming that the 12 inches of sub grade soil is incompressible (Figure C1, Appendix C):
    a. 3 inches of aggregate.
    b. 6 inches of a 75:25 soil:gravel mixture.
    c. Presto GeoBlock
    d. 1 inch of topsoil.
3. Use the Instron compression machine to compress the sample 80 lb/min and record the deformation of the composite sample.
4. Repeat the compression three more times to provide sufficient data collection.
5. Determine the average deformation per the loading of the composite material and compare the two composites.
6. Construct two containment devices for rainfall simulation testing using the following procedure for each. The engineering drawings for the device can be seen in Figure C3, Appendix C.
    a. Cut 1 inch off of one 2'x4'.
    b. Cut ½ inch each off two of 2'x4' plywood.
    c. Using Liquid Nails and common nails, glue and nail two pieces of plywood from step b to each side of the plywood in step a to make a plywood frame.
    d. Cut ½ inch off of two 2"x4"x4' pieces of wood and cut 5" off the last piece of 2'x4"x4' piece of wood.
    e. Do the same for the 2"x4"x4' pieces of wood as for the plywood in step c to make a 2"x4" frame.
    f. Place the 2"x4" frame inside the plywood frame and nail together.
    g. Place the nailed 2"x4" and plywood frames onto the 4'x4' piece of ½ " plywood and nail together.
    h. Cut 5" off a piece of 2"x4"x4' plywood.
    i. Liquid Nail's the cut piece of plywood in step h in the middle of the two pieces of plywood in step b.

j. Cut 1’½” off the last piece of 2’ x 4’ plywood.
k. Liquid Nail’s the plywood from step j in front of the plywood glued in step I and towards the open end of the box.
l. Drill ½” holes every 3”, in the bottom piece of plywood.

7. To the open end of the box, Liquid Nail’s the screening across the entire opening.
8. Fill one side of the box in the front with the screen with the current composite materials.
9. Fill the other side in the front with the screen with the designed composite materials.
10. Place the rolls of sod on both the current and designed composites at a 30° angle, with the respected vegetation covering percentages.
11. Lay a piece of wood covered with plastic over the non-filled portion of the box (i.e. the back), and angle it to a 3% grade.
12. Subject each box to the equivalent of a 10-year storm for the College Park area with duration of 30 minutes. The intensity of such a storm is 11.0 inches/hr.
13. Analyze the direct surface runoff, the total suspended solids in the runoff, and the infiltration volume for each sample. Repeat the testing for each box at four times.
14. Compare the two sides to determine which method has the highest infiltration rate, the lowest direct surface runoff, and the least amount of total suspended solids in the runoff.
15. Fill 8

RESULTS

The results of the direct surface runoff measurements are summarized in Table 1. The results are illustrated in Figure 1.

Table 1: Direct Surface Runoff Measurements

Run	Control (mL)	Experimental (mL)
1	895	316
2	1030	730
3	1022	986
4	892	671
Average	**960**	**676**

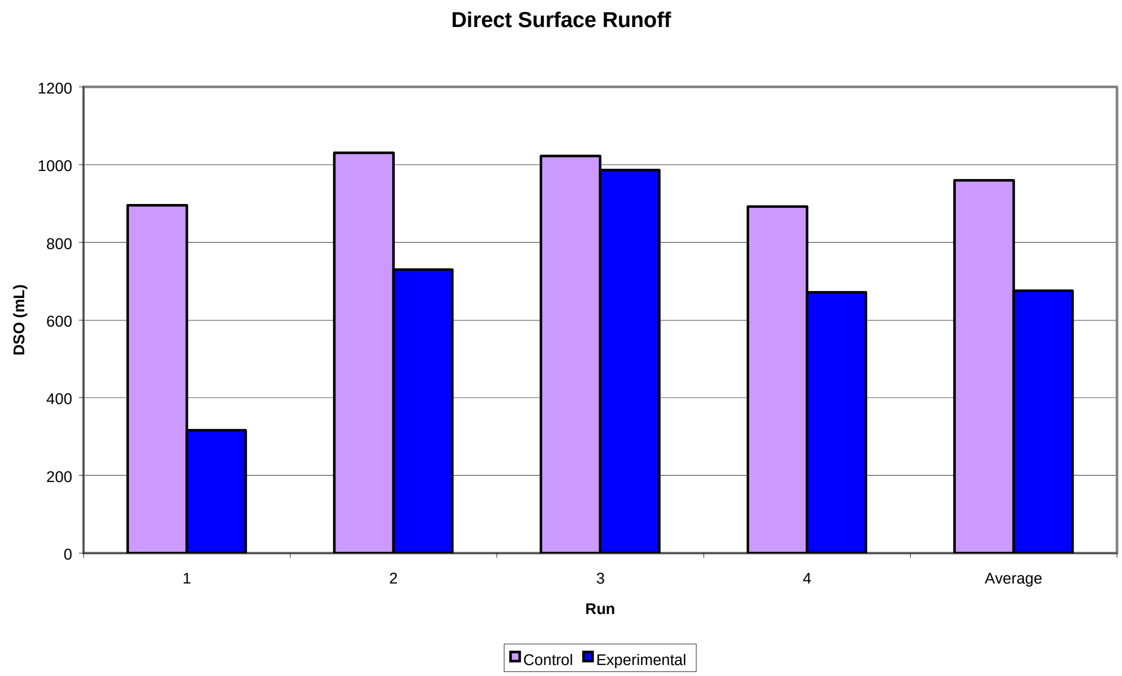


Figure 1: Direct Surface Runoff

In each experiment, the direct surface runoff was greater on the control side of the box than the experimental side. The average experimental runoff was 42% less than the average control surface runoff.

The results of the total suspended solids (TSS) measurements are summarized in Table 2 and illustrated in Figure 2.

Table 2. Total Suspended solids (TSS) in runoff discharge from both control and the geodesign.

Run	Control (g)	Experimental (g)
1	0.0937	0.0863
2	0.0265	0.0305
3	0.1005	0.0288
4	0.2450	0.0090
Average	**0.1164**	**0.0387**

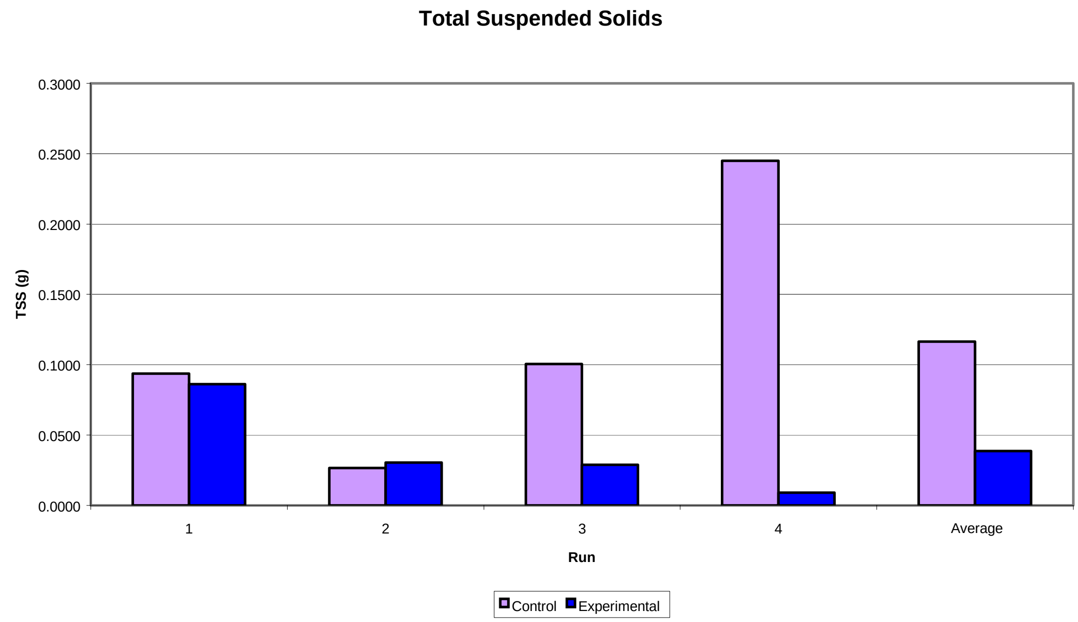


Figure 2: Total Suspended Solids

As can be seen from this figure, the total suspended solids and hence the amount of erosion was greater on the control side of the box than on the experimental side for three out of the four runs. The average erosion on the control side, however, was three times greater than that of the experimental side.

Three composites were subjected to 240-pound loads during the deformation testing. The 50/50 composite deformed by 3/8”, while each of the experimental composites deformed by ¼” after being subjected to the load three times, for three minutes each time.

DISCUSSION

When analyzing the direct surface runoff data, it is important to consider the conditions under which each simulation was run. The first simulation was run when the composite material was completely unsaturated, giving results similar to those that would be found during summer months when the water table is low. The runoff was approximately three times lower on the experimental side than on the control side, because the infiltration rate was much higher on the experimental side. When the soil is dry, the infiltration rate will be maximum for each composite. During subsequent runs, saturation conditions varied based upon the time between runs and the conditions in the storage room, which affected the drying rate of the composites.

Comparing the performance of the experimental side versus the control side, it is seen that overall, there was a 42% decrease in surface runoff, indicating a 42% increase in infiltration. Before beginning the project, the target increase in infiltration was 50%. Given that in varying saturation conditions, the increase averaged 42%, the specification was met to the satisfaction of the engineers. When the 50% goal was set, it was meant for a 10-year storm. Because changing the flow rate in the rainfall simulator decreases the uniformity of spray, the simulator was set at its maximum flow rate, which gives a storm with intensity of 11 inches per hour, instead of 4 inches per hour, the 10-year storm.

In analyzing the total suspended solids, it was noted that after the first run, when the grass and soil were new to rainfall testing, the erosion on the experimental side was at its greatest. After this time, it continued to decrease until it was a minimal 0.009 g for 2 ft^2 area. The control side did not show the same pattern, however. The erosion on the control side varied with each run. This variation is probably due to rill formation on the control side of the box. At the outset of this project, a target reduction of 50% in erosion was the goal. This specification was more than met, with a 200% decrease in the amount of erosion on the experimental side. Even if the last data point on the control side is faulty, as it seems extreme, new calculations show that the experimental side still had a 100% reduction in erosion when compared with the experimental side.

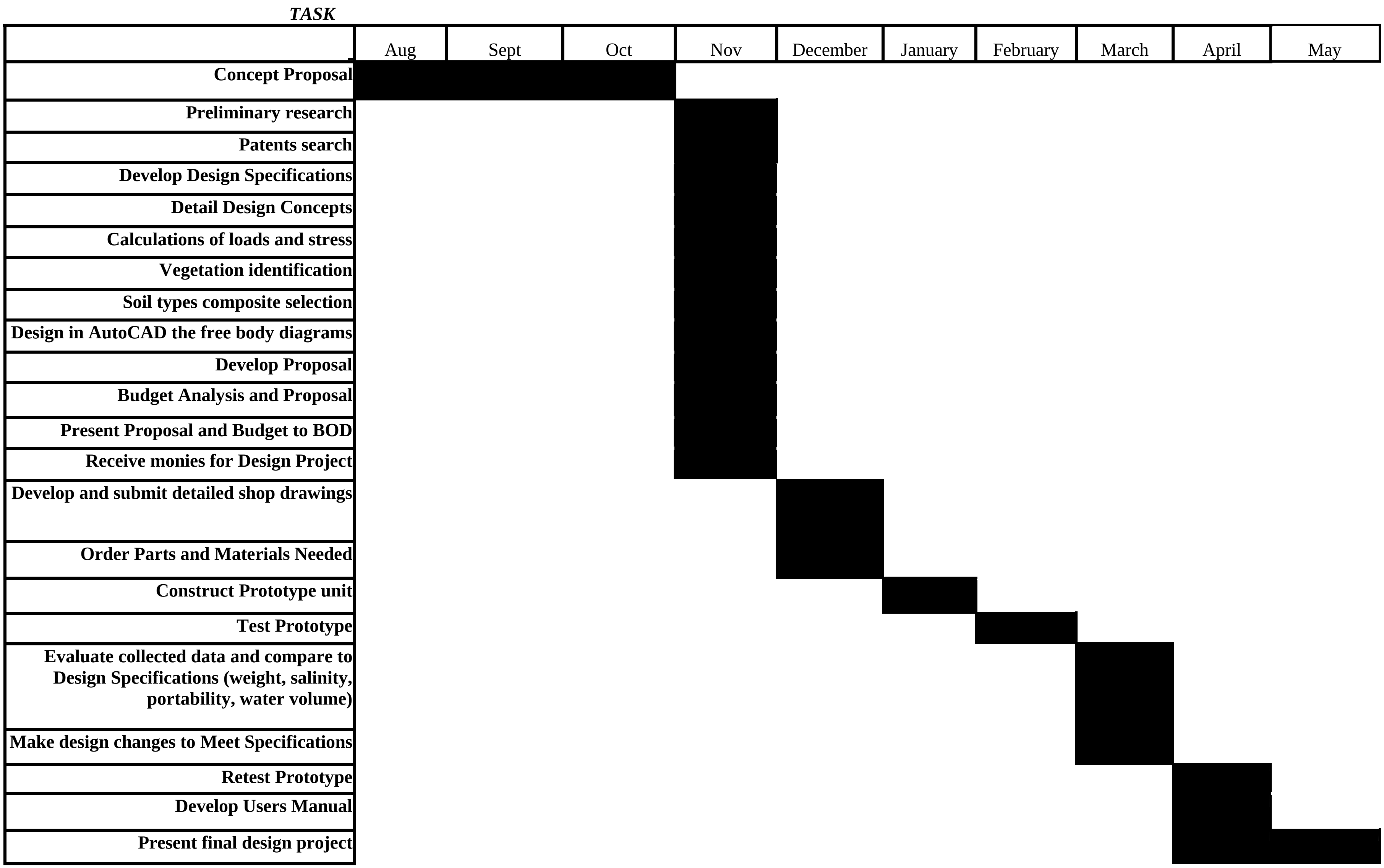
The specification regarding vegetation cover was not measured during this project. Because the top layer of the composite material was topsoil, which is a well-established material in the growth of turf, it was assumed that the topsoil used would support a full turf. With the approval of the advisor, sod was used to simplify the experiment. At his suggestion, the control side was modified to resemble pictures taken of the present situation on Maryland Route 29.

Because the geogrid is rated by the American Society for Testing and Materials to withstand pressures up to 420 psi, the 80 psi loading specification was met. In order to determine if the deformation was similar to that of the current solution, the Instron machine was used. The composite materials were loaded according to advice from the laboratory operators and graduate students in the civil engineering department. Both the experimental and control composites deformed by approximately the same amount. Because the State Highway Administration feels that the control solution is safe, the deformation in the experimental composite is acceptable.

CONCLUSION

While the gecomposite designed met the required specifications, there was one factor not taken into consideration: the cost to the State Highway Administration. The geogrid tested in the geocomposite designed costs approximately $10 per square foot. It is recommended, then, that this geogrid only be used in areas along the highway where it is known that cars often drive onto the road shoulder backfill area, such as the ramp areas. In other areas of the highway, the strength of the road shoulder backfill is not as critical. In these areas, a woven turf support or geotextile should be used to maintain the turf cover and give the area extra stability. While these areas probably will not be as strong as areas using the geogrid, they will have significantly less erosion and runoff than the current solution.

MILESTONE CHART



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APPENDIX A: ENGINEERING CALCULATIONS AND EQUATIONS

Intensity Calculations

$$I = 0.0256(C - A)x + 0.000256[(D - C) - (B - A)]xy + 0.01(B - A)y + A \qquad (1)$$

Where

I	= rainfall amount in inches
x	= return period variate
y	= duration variate
A	**= 2-year, 1-h rainfall in inches**
B	= 2-year, 24-h rainfall in inches
C	=100-year, 1-h rainfall in inches
D	=100-year, 24-h rainfall in inches

This equation and the values used are taken from Schwab *et al*., 1993, and are for a 10-year storm of duration 30 minutes in the College Park area.

Table B2: Values for Equation 1

Variable	*Value*	*Location in Schwab et al., 1993*
x	16.1	Table 2.1
y	-15.6	Table 2.2
A	1.8 inches	Figure 2.6a
B	3.5 inches	Figure 2.6b
C	4 inches	Figure 2.6c
D	8 inches	Figure 2.6d

Using these values, the rainfall in this storm will be 2.3 inches, resulting in an intensity of 4.6 inches/hr.

Load Distribution Equations

$$p_0 = \frac{P}{(B + 2h_0 \tan\alpha_0)(L + 2h_0 \tan\alpha_0)} + \gamma_0 h_0$$

$$p = \frac{P}{(B + 2h \tan\alpha)(L + 2h \tan\alpha)} + \gamma h$$

Where,

p_0	= stress on the soil subgrade without geosynthetic material reinforcement
p	= stress on the soil subgrade with geosynthetic material reinforcement

P	= tire load
B	= Tire contact area base
L	= Tire contact area length
h_0	= Height of material on top of subgrade without reinforcement
h	= Height of material on top of subgrade with reinforcement
α_0	= Angle of load distribution without reinforcement
α	= Angle of load distribution with reinforcement
γ_0	= Unit weight of material on top of subgrade without reinforcement
γ	= Unit weight of material on top of subgrade with reinforcement

Known parameters:

P	= 3042 lbs
B	= 9.7 inches
L	= 7.1 inches
h_0	= 3 inches
h	= 1 inch
α_0	$\cong 26°$
α	$\cong 35°$

$\therefore\ p_0 = 24 \text{ psi} + 3\gamma_0$

$p = 32 \text{ psi} + \gamma$

Factor of Safety

$$FS = \frac{T_{allowable}}{T_{req}}$$

Where

$T_{allowable}$	= tensile strength of geosynthetic material from laboratory testing
$T_{required}$	= required tensile strength as obtained from design for the particular field situation

$$T_{allowable} = T_{ult}\left(\frac{1}{RF_{ID} * RF_{CR} * RF_{CD} * RF_{BD}}\right)$$

Where

T_{ult}	= ultimate tensile strength from a standard in-isolation wide-width tensile test
RF_{ID}	= reduction factor for installation damage
RF_{CR}	= reduction factor for avoiding creep over the duration of the structure's lifetime
RF_{CD}	= reduction factor against chemical degradation

RF_{BD} = reduction factor against biological degradation

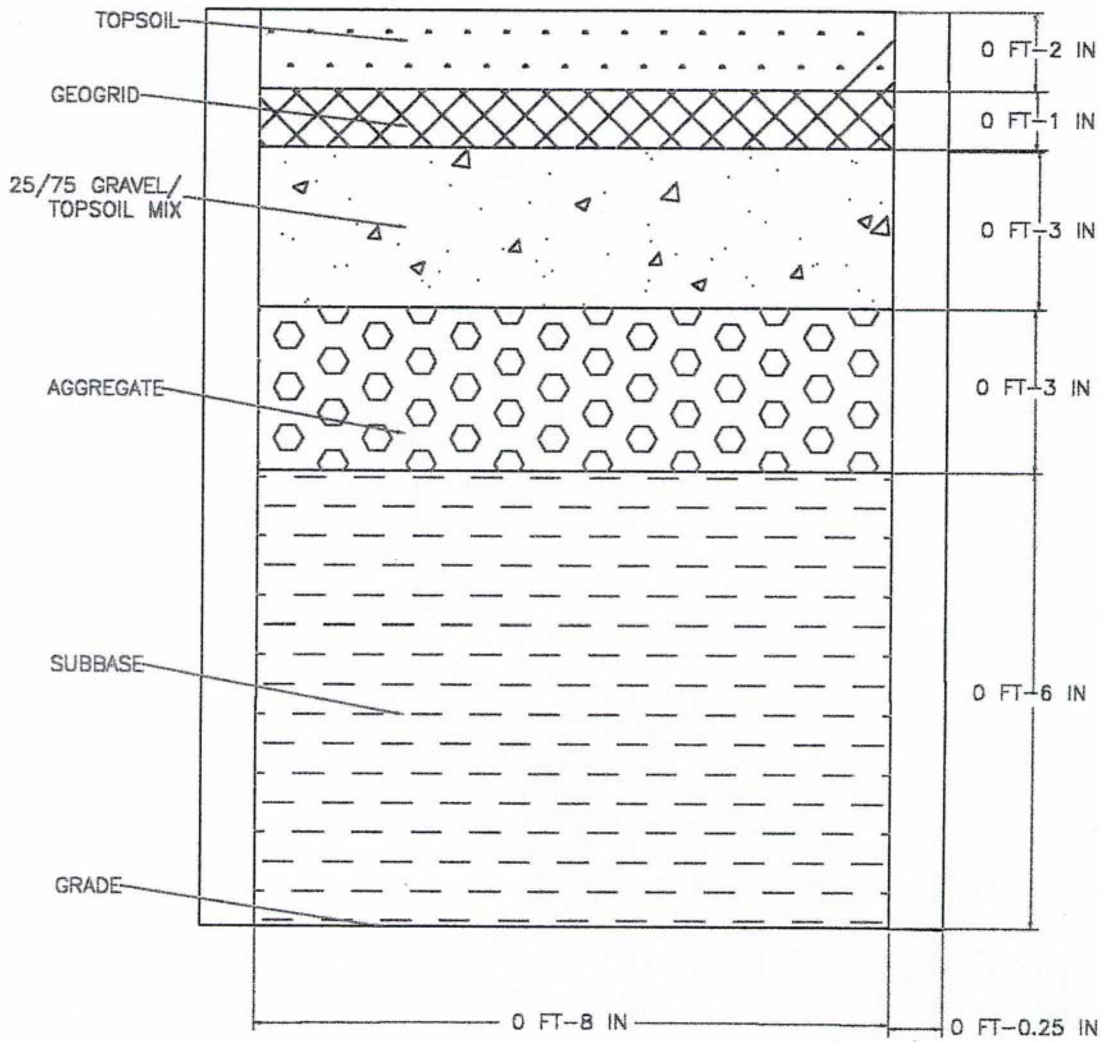
From Table 3.3 of Koerner (1997)

RF_{ID} = 1.3
RF_{CR} = 2.0
RF_{CD} = 1.3
RF_{BD} = 1.1

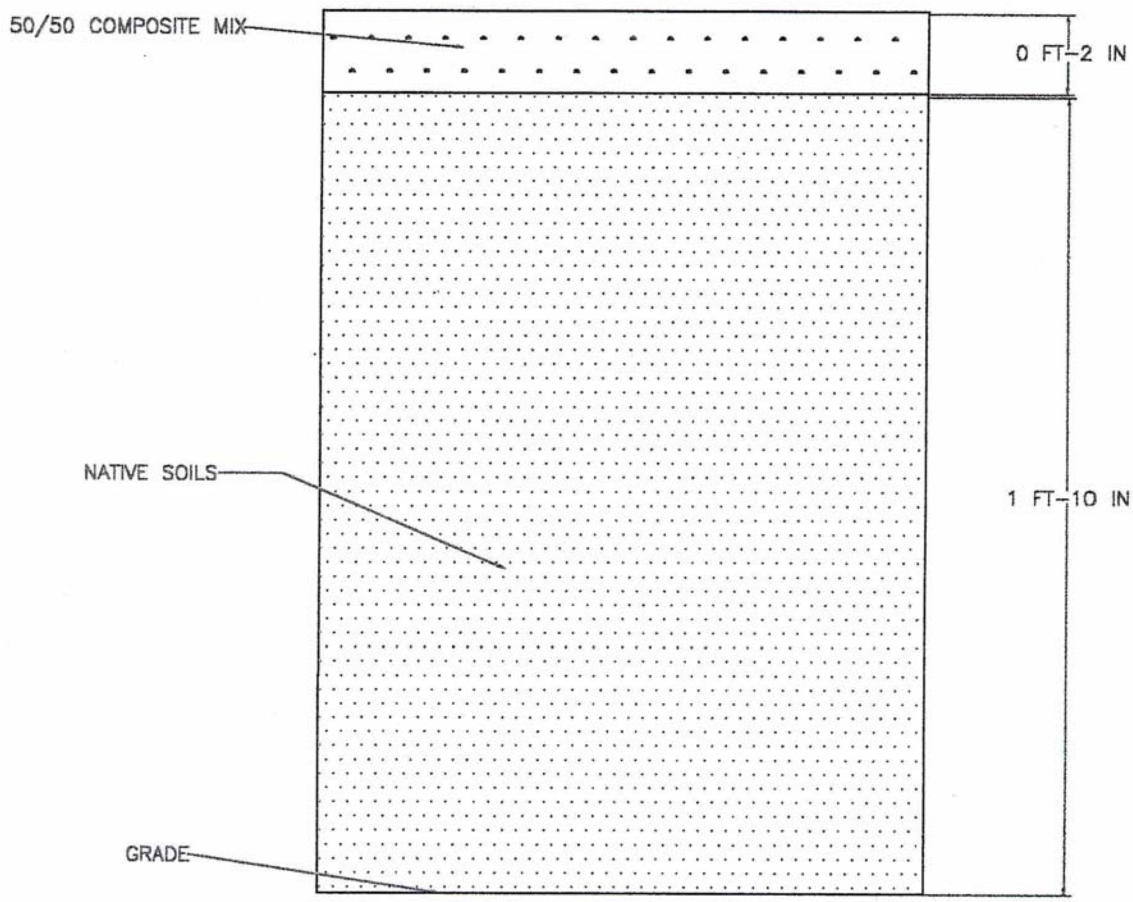
$$T_{allowable} = 0.27 T_{ult}$$

$$\therefore FS = \frac{0.27 T_{ult}}{T_{required}}$$

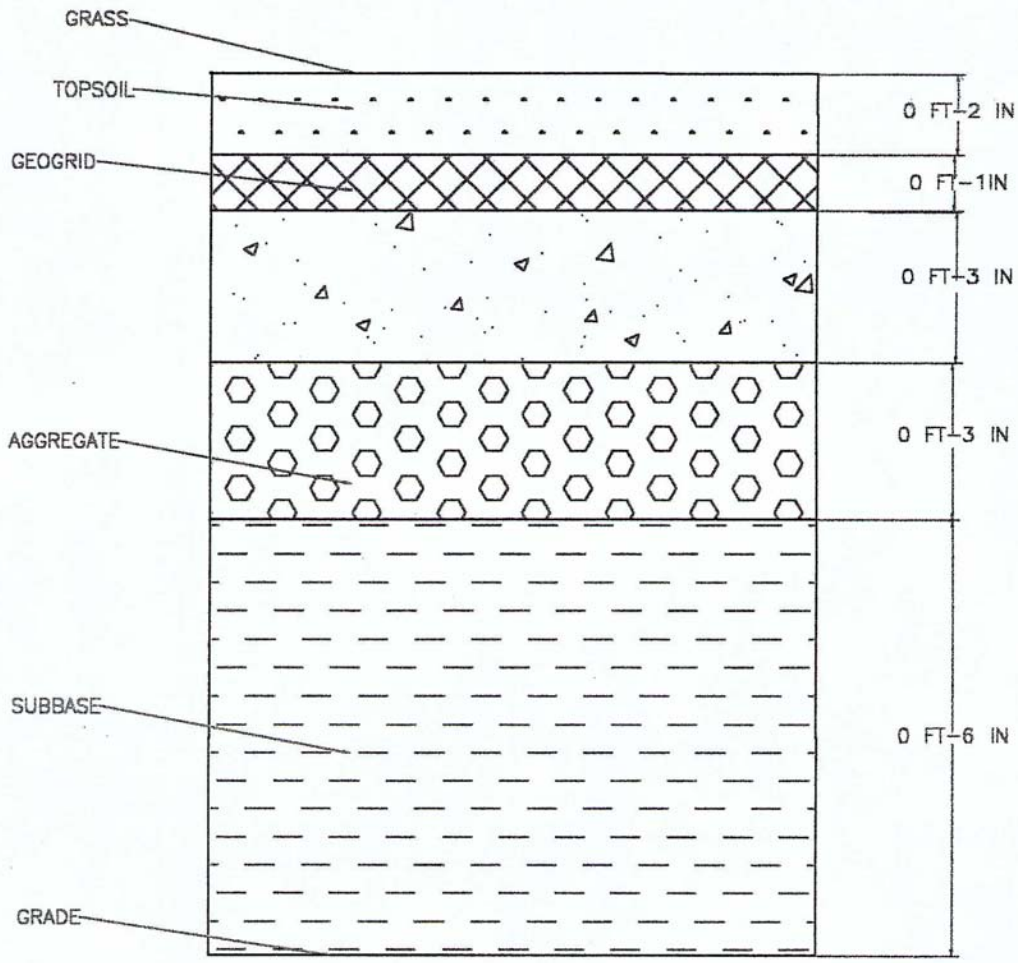
APPENDIX B: DETAILED ENGINEERING DRAWINGS



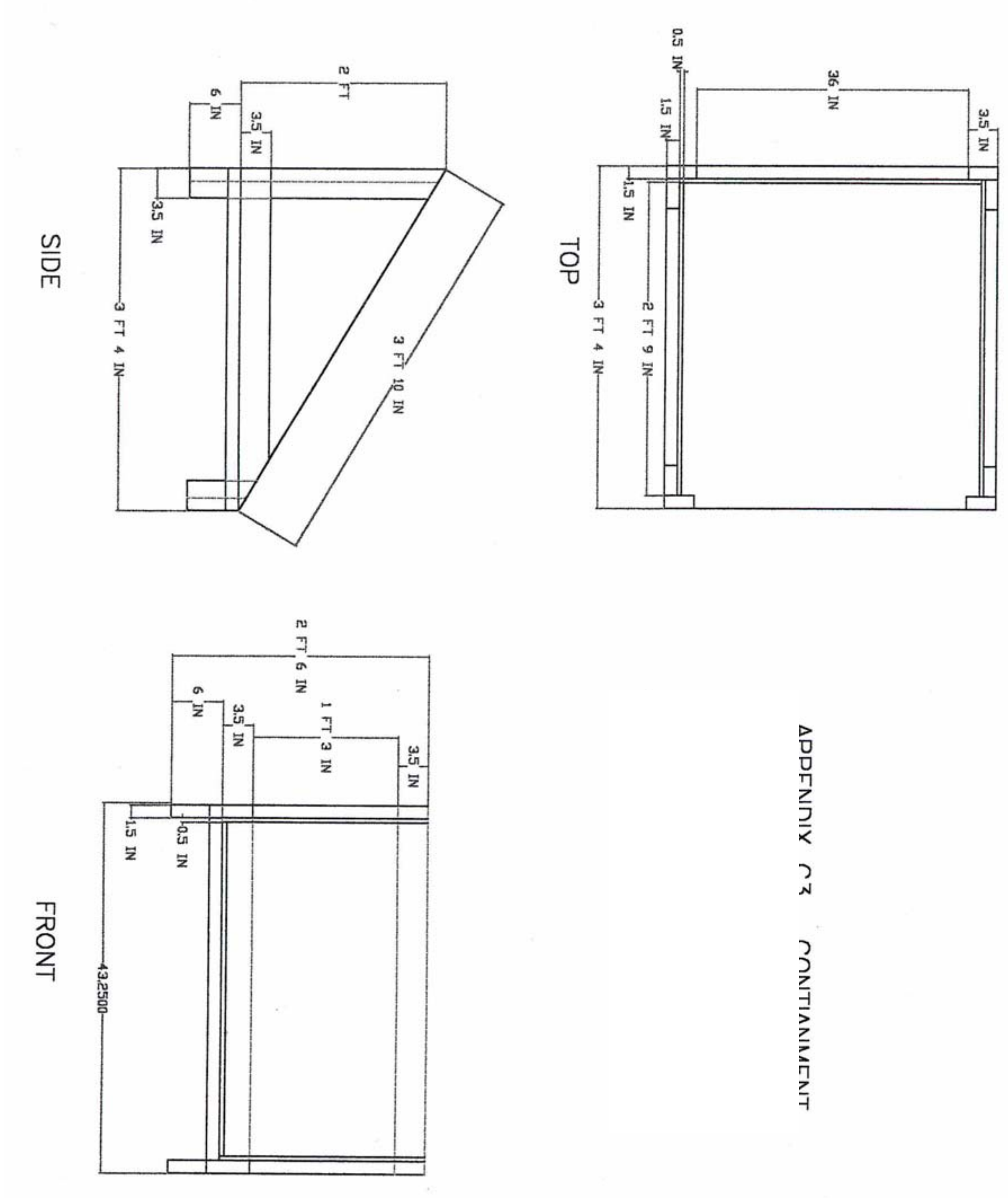
APPEB X C1. A COMPRESSION TEST WILL BE PERFORMED ON THE SOIL PROFILE OF THE ROAD SHOULDER BACKFILL AREA. THIS PROFILE IS FOR PROTOTYPES 2 AND 4. PROTOTYPES 1 AND 3 WILL CONSIST OF THE SOIL BACKFILL USED CURRENTLY BY SHA.



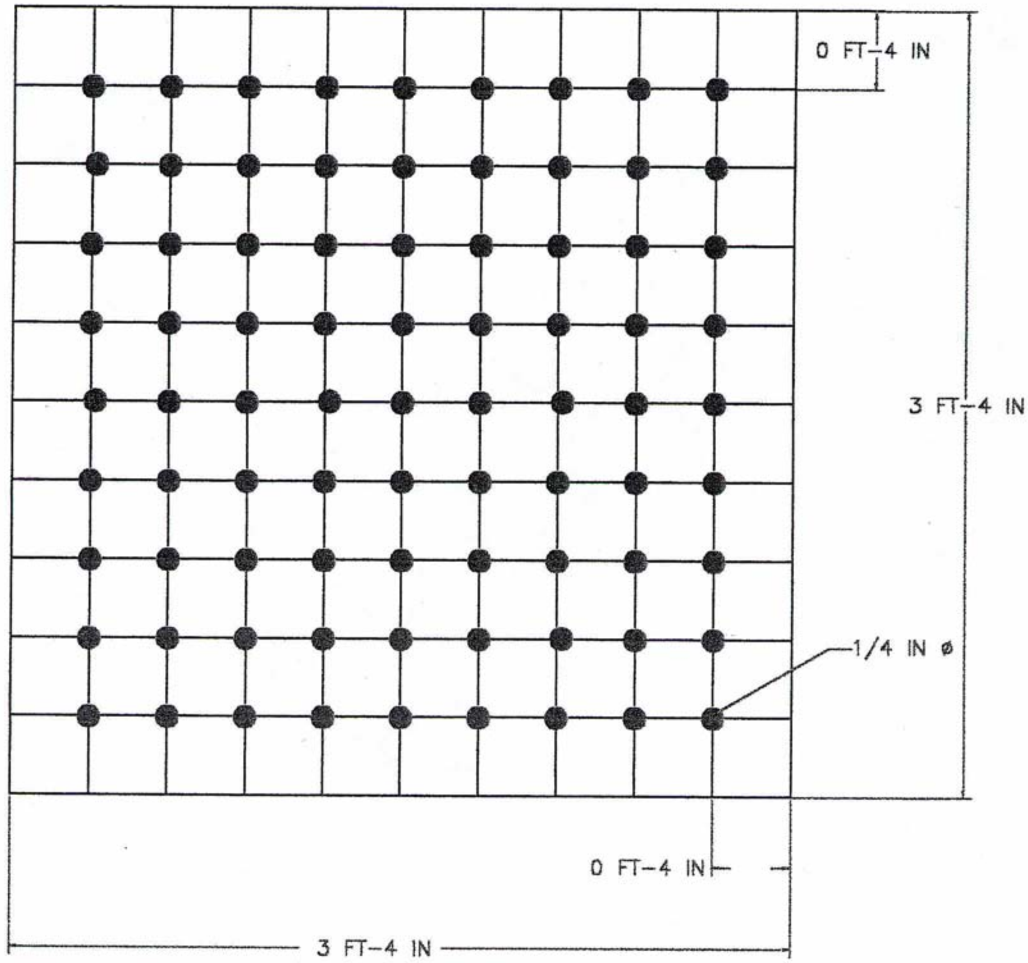
APPEB2 C2A. THE ROAD SHOULDER BACKFILL AREA WILL BE COMPARED TO THE CONTROL. THE CONTROL CONSISTS OF THE BACKFILL THAT IS CURRENTLY BEING USED AFTER INSTALLATION OFA ROADWAY. THE BACKFILL USED IS A 50/50 GRAVEL/TOPSOIL MIX ON TOP OF NATIVE SOILS.



APPI B2b. C2B. THE ROAD SHOULDER BACKFILL AREA CONSISTS OF A SOIL PROFILE, WHICH MIMICS THE STRUCTURE OF AN ASPHALT ROAD, BUT REPLACES THE TOP LAYERS WITH A 25/75 GRAVEL/TOPSOIL MIXTURE AND A GEOGRID. THE GEOGRID IS THEN COVERED WITH 2 INCHES OF TOPSOIL FOR ULTIMATE GROWTH OF TALL FESCUE MIX GRASS.



Appendix B3. Containment Device for Infiltration, Runoff, and Erosion Testing With Rainfall Simulator.



APPE B4.(C4. IN ORDER TO ALLOW DRAINAGE DURING THE RAINFALL SIMULATOR, HOLES OF 1/4 INCHES IN DIAMETER WILL BE DRILLED INTO THE BOTTOM PEICE OF PLYWOOD. EACH HOLE WILL BE PLACED 4 INCHES APART, CREATING A 9X9 GRID OF HOLES.

Appendix C: Photographs

Photograph 1: Patches of grass visible in 6-week old gravel backfill on I-70

Photograph 2: Patchy grass growing in the median strip on I-70 after approximately one year.

Photograph 3: The SHA's attempt at vegetating the shoulder backfill using a 50/50 soil/gravel mixture

Photograph 4. A view of the road shoulder designed by SHA 50/50 soil/gravel mixture

Photograph 5. This is a picture taken from I-70, near Columbia, Maryland; this shows the current problem with shoulder backfill unkempt look.

Photograph 6. This is a picture taken from I-70, near Columbia, Maryland; this shows the interface between the road shoulder and the vegetated median in the middle.

Appendix IV

Second Capstone Design on the Project (GEO-Block) (Completed 2002)

Environmental Solutions, Inc.

Design of a Road Shoulder Backfill Stabilization Plan Using Geosynthetic Material:

Pilot-Scale Testing and Analysis

Kate Mackey
Rick Davis
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(B.S. CANDIDATES, MAY 23, 2002)

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Signed and Submitted: 17 May 2002

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EXECUTIVE SUMMARY

The need for safe, efficient, aesthetically pleasing, and environmentally sound transportation systems for motorists has led the State Highway Administration (SHA) to seek alternative methods for constructing road shoulder backfill areas that are able to withstand adequate loads while remaining aesthetically pleasing and environmentally sound. Current road shoulder treatments meet some of the design parameters, but none have been successful in providing stability, preventing runoff, and supporting vegetative groundcover to the extent required by the SHA.

To ameliorate these problems, Environmental Solutions, Inc. proposed an alternate method of road shoulder stabilization that addresses the concerns of the SHA on a multi-tiered basis. Improvement of current designs was based on three primary goals; increasing infiltration, reducing soil loss through erosion, and encouraging uniform vegetative cover growth. The design incorporated geosynthetic materials, soil and gravel mixtures, and SHA sanctioned groundcover to increase the soil hydraulic conductivity, and therefore reduce the amount of runoff from the shoulder by improving infiltration.

The proposed road shoulder design was developed in detail in the "Proposal for a Road Shoulder Backfill Stabilization Design Using Geosynthetic Material" (Davis, Kibec, and Mackey, 2001). The design aims to support a static load of 80-psi without deformation, encourage uniform vegetative groundcover at greater than 90 %, and reduce runoff volume by 50% by increasing infiltration. The design mitigates the deleterious effects of soil loss by erosion, and the safety hazards associated with inadequately stabilized shoulder slopes.

To assess the ability of the design to meet the required specifications, a pilot scale model was constructed and tested in a rainfall simulator. Load stabilization was tested using an Instron Compaction machine to determine soil profile deformation with applied load for the control and experimental designs. Based on the pilot-scale modeling of the system, the behavior of the full-scale system for various conditions was predicted. Experimental data suggest that the experimental design is able to reduce direct surface runoff by 83%, reduce sediment erosion by 47%, and support a full stand of vegetative cover. We conclude that our design will enhance infiltration, reduce runoff and erosion, and support the requisite load if tested *in situ*.

ACKNOWLEDGMENTS

We would like to thank our advisor, Dr. Adel Shirmohammadi, for his suggestions and leadership throughout the course of this project, and for providing suggestions during the design proposal and testing phases of the project. We would also like to thank the members of the Biological Resources Engineering faculty and graduate students who assisted us during our model testing. We would like to thank Mr. Don Cober of the State Highway Administration for providing us with a site tour of Maryland highway project sites and the SHA for their funding. We would further like to thank Dr. Debra Goodings and her staff for their help in developing the soil compaction-testing portion of the project.

Design Project Selection

This project was selected and developed in response to interest from the SHA to develop and test an innovative design that is biologically and technically feasible. The ultimate goal was to design a system that will provide aesthetic value while reducing runoff and erosion, and while providing adequate load stabilization.

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PROJECT JUSTIFICATION

In response to the growing needs of travelers and motorists, national public road mileage has increased 1.3 percent since 1985, and highway travel has increased nearly 37 percent. This substantial increase in the amount of impermeable surfaces has resulted in greater runoff velocities and concentrated flow volumes in highly urbanized areas. These flow patterns accelerate deterioration of the roadway, and may impose serious environmental impacts.

The need for safe, efficient, aesthetically pleasing, and environmentally sound transportation systems for motorists has led the State Highway Administration (SHA) to seek alternative methods for constructing road shoulders that are able to withstand adequate loads while remaining aesthetically pleasing and environmentally sound. Current methodology for road shoulder backfill areas in use by SHA are not capable of simultaneously providing both environmental and roadway operational benefits desired by regulatory and transportation agencies.

Current road shoulder treatments include the implementation of a range of soil-gravel mixtures, and in some cases, vegetative cover. The most common design methodology involves a variable width strip of 6-inch gravel adjacent to the roadway; however, this technique may lead to elevated runoff volumes and velocities, which tend to exacerbate erosion. Vegetative cover strips consisting of pure topsoil have also been applied to road shoulder designs, but these fail to support the requisite load under conditions of moderate moisture. Mixtures of topsoil and gravel in approximately equal proportions are commonly employed to promote vegetative growth and shoulder stabilization; however, the results of these efforts have been largely unsuccessful due to the high runoff potential of gravel.

Environmental Solutions, Inc. proposes an alternate method of road shoulder stabilization that addresses the concerns of the SHA on a multi-tiered basis. Improvement of current designs is based on three primary goals; increasing infiltration, reducing soil loss through erosion, and encouraging uniform vegetative cover growth. The design incorporates geosynthetic materials, soil and gravel mixtures, and SHA sanctioned groundcover to increase the soil hydraulic conductivity, and therefore reduce the amount of runoff from the shoulder by improving infiltration.

This proposal discusses the general requirements for a road shoulder stabilization system that is applicable for most conventional road shoulder morphologies. The proposed road shoulder design is a general version from which a pilot-scale model may be built and tested. Based on the pilot-scale modeling of the system, the behavior of the full-scale system for various conditions may be predicted. The system may then be adapted to specific sites along highways based on individual site characteristics and specific design criteria. Due to the diverse characteristics of road shoulders, various design options are included in the proposal.

The proposed road shoulder design aims to support the static load required by the SHA without deformation, encourage uniform vegetative groundcover, and reduce runoff volume by increasing infiltration. The design will mitigate the deleterious effects of soil loss by erosion, and the safety hazards associated with inadequately stabilized shoulder slopes.

Literature Review

Background

In January 1999, members of the Maryland State Highway Administration (SHA), along with representatives from the University of Maryland, College Park, Biological Resources Engineering (BRE) Department began working to develop improvements for road shoulder backfill areas. Backfill areas are located adjacent to the road shoulder, functioning as extensions of the shoulder for disabled and emergency vehicles.

Beginning in August 2000, a senior undergraduate group in the BRE department researched and wrote a proposal for the implementation of a road shoulder stabilization design that would incorporate geosynthetic material for a specific site in Howard County, Maryland. The group built and tested a pilot-scale model, and wrote a final summary of their findings that was completed in May 2001.

In May 2001, a graduate student in the BRE department explored an alternate design approach involving geoweb systems specifically. Recommendations on geoweb implementation and general road shoulder stabilization design techniques were included in the report (Schall, 2001).

Environmental Solutions, Inc. further researched and wrote a proposal for the implementation of geoweb material in a road shoulder stabilization design. The proposal outlined the recommendations and design specifications for the new design, and included the methodology for testing it. The specifications for a pilot-scale model were also developed. The procedures, testing, and data discussed in this report were the culmination of the proposed design, and were used to evaluate the strengths and weaknesses of the design.

Geosynthetics

Present day increases in impervious roadway surfaces have intensified the need to predict, assess, and prevent the potential deleterious environmental and human safety impacts stemming from increased runoff. Resultantly, research on road shoulder stabilization techniques involving geosynthetic materials capable of providing reinforcement, supporting vegetative material, and increasing infiltration has ensued.

Koerner (1994) describes geosynthetics as planar products manufactured from polymeric material that are used along with rock, soil, and other geological materials as an integral part of a synthetic structure or system. Geosynthetics encompass many different sub areas, including geowebs, geogrids, and woven and non-woven fabrics, all of which are used in standard construction techniques. Geosynthetics are capable of providing soil reinforcement (Koerner, 1994), increased soil drainability (Berkhout et al, 1994), and increased ability of soil to establish quality vegetation (Gray et al, 1996).

GEOWEB

Soil confinement systems based on cellular geotextiles, (fabric-like geosynthetics), were first developed and evaluated by the Laboratoire Regional des Ponts et Chaussees in France during the mid 1970s (Raymond et al, 1993). Investigations by the U.S. Army corps of Engineers and Presto Products Company during the late 1970s and early 1980s modified the concept of cellular confinement systems to develop a new geosynthetic material, called Geoweb, capable of stabilizing extreme slopes (Gray et al, 1996). Further research and development has lead to the refinement of the geoweb material specifications, and has resulted in applications to many soil stabilization

Figure 1: Perforated geoweb. The perforated geoweb structure supports non-compacted soil, encouraging the growth of vegetative cover (Presto Products Company, 2001).

problems worldwide including ground stabilization, channel protection, earth retention, and stream crossing (Martin et al, 1998).

The geoweb material is a polymeric compound consisting of either polyethylene or polypropylene. The strength of geoweb material is achieved through its three-dimensional, expandable structure (see figure 1). Geowebs are composed of repeating, perforated or non-perforated cellular units in a honeycomb arrangement that are designed to retain soil and prevent erosion. Geowebs provide several advantages over other geosynthetics in that they have the greatest available open area for increasing infiltration, while delivering the highest level of reinforcement in a variety of different applications. Notably, most geosynthetics like geogrids and woven and non-woven fabrics are ideally suited to provide reinforcement to compacted soils. The geoweb design may be implemented with non-compacted soils, such as topsoil, which makes possible the growth of groundcover (Rollings et al, 1996).

Perforated geowebs offer the additional benefit of connecting adjacent cells, allowing greater root dispersion and plant anchorage. The perforations also facilitate the lateral flow of water and nutrients between cells, preventing anoxic and nutrient-poor conditions in the root zones of the plants. Additionally, the perforations permit soil invertebrates to travel freely from cell to cell, improving soil quality and aeration.

Figure 2 demonstrates that geowebs are capable of providing reinforcement through three possible mechanisms. Lateral restraint prevents the applied load from displacing the soil sideways, while bearing capacity increase distributes shear away from the point of application.

Membrane tension support provides upward vertical reinforcement of the soil. (Holtz et al., 1997).

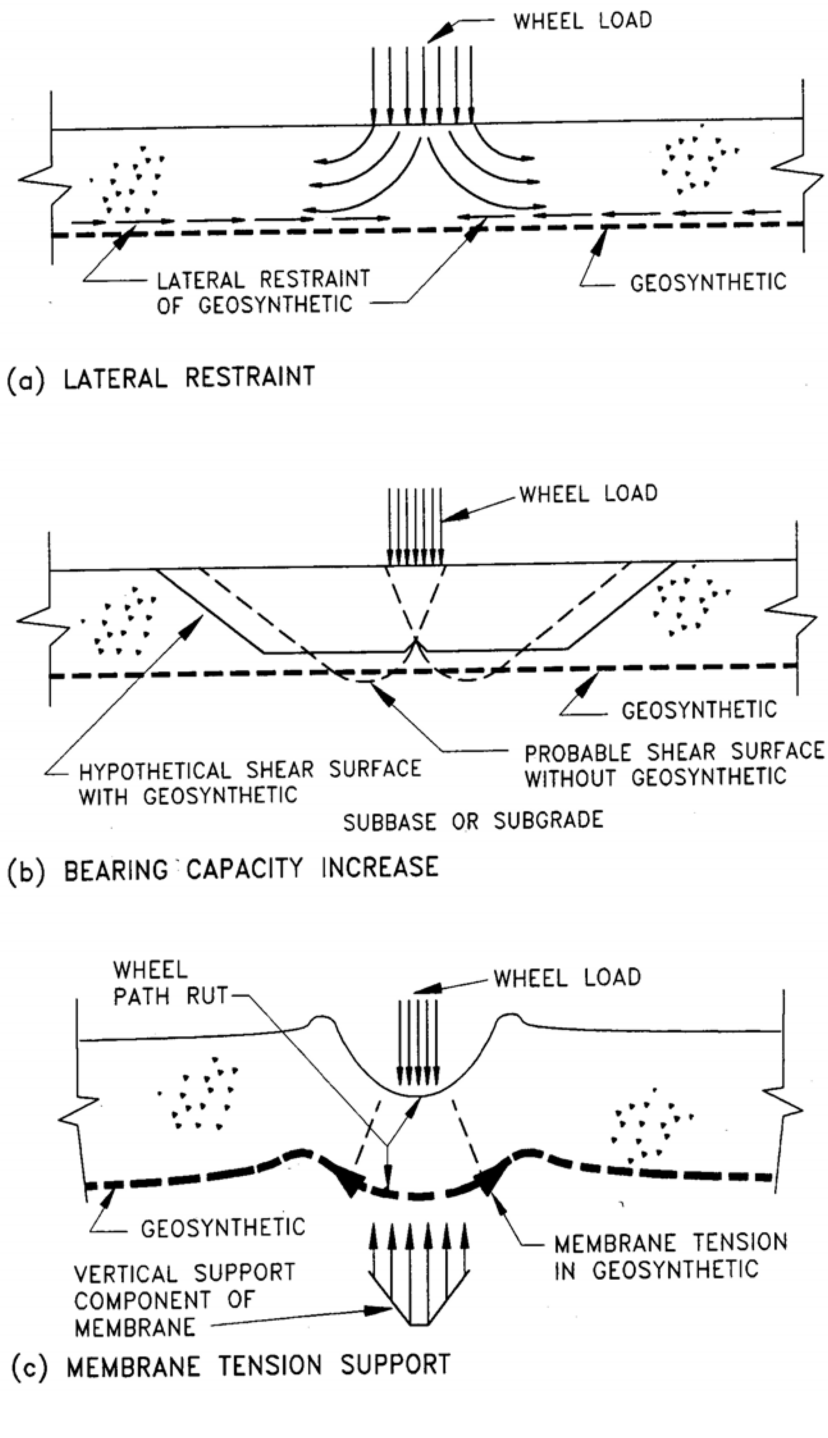

Figure 2: Three possible reinforcement mechanisms of geowebs. (a) Lateral restraint; (b) Bearing capacity increase; (c) Membrane tension support.

GEOTEXTILES

Woven and non-woven fabrics are geotextiles used primarily to increase soil stability and improve performance of weak subgrade soils primarily by separating the upper aggregate soil layer from the subgrade soil layer. Woven fabrics have a higher degree of strength due to the orientation of the fiber (Jewel, 1996). Woven and non-woven fabrics alike are used where high levels of reinforcement are not required, although these fabrics do allow slow infiltration (see figure 3).

Geowebs and non-woven geotextiles both offer distinct advantages over non-geosynthetic building techniques because they provide stability and erosion control without sacrificing aesthetic appeal. Non-woven geotextiles reinforce compacted material only, and are therefore not ideal when topsoil loss is a concern. Conversely, geowebs offer reinforcement to both compacted and non-compacted substrates, although sealing of the subsoil beneath the geoweb may occur. Sealing results from settling of particles at the topsoil-subsoil interface, and impedes infiltration. Use of both geoweb and non-woven geotextile layers may offer the broad reinforcement ability of the geoweb, while providing prevention from sealing offered by non-woven geotextiles. Inclusion of a non-woven geotextile layer also prevents the subsoil layer from mixing with the topsoil contained in the geoweb.

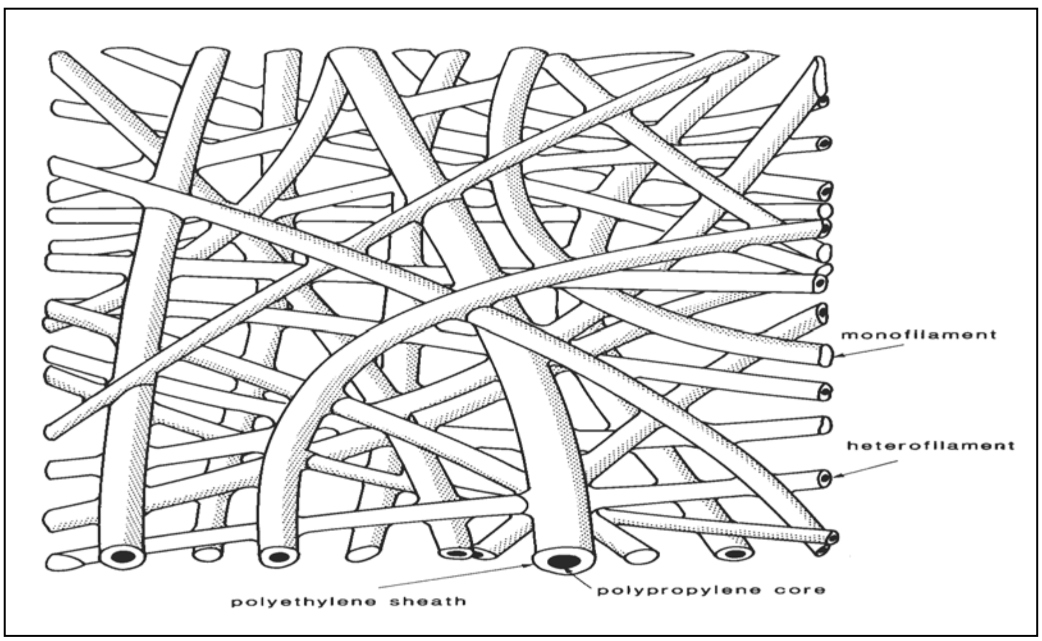

Figure 3: Schematic of non-woven geotextile. ***Non-woven geotextile prevents mixing of the topsoil and substrata levels.***

CASE STUDIES

The Virginia Department of Transportation (VDOT) used an application of Geoweb in Virginia for the re-stabilization of a sandy clay slope along Rout 220 near Collinsville, VA. In this case the steep slope was heavily eroded and the vegetative cover was stressed due to heavy rains. The VDOT tried numerous attempts to stabilize the soil but failed. In April of 1988, the VDOT installed the geoweb cellular confinement system over the heavily eroded area, which had slopes as great as 1:1. For this application, the VDOT utilized 8ft x 20ft x 4 in geoweb cellular sections that were installed according to the manufacture's specifications (Presto, 2001). The fill material used in the geoweb cells was composed of sandy clay topsoil that was graded and seeded with tall fescue grass, and then mulched. With the geoweb installed, the once heavily eroded slope now supports a thick cover of grass that has with stood years of exposure.

In February 1995, engineers from Presto Products were faced with the task of economically and efficiently constructing a 300 m^2 access roadway and parking area for 61 cars over an environmentally sensitive wetland without disturbing the natural subgrade materials. The successful design consisted of using 6 in deep perforated geoweb sections with # 57 stone infill to support the vehicle loads and function as a storm water retention system. Before application of the geoweb, a geotextile was placed above the muck soil to provide further stabilization. Due to the 40% void spaces from the stone, the system was capable of storing 2.8 in of water. The permeability of the underlying soil, 3 in/hr, allows the system to drain within 2.3 hours following a storm. To ensure maximum retention and drainage, an additional 2 in of stone was placed on top of the geoweb system.

The U.S Army Corps of Engineers (1999) designed and constructed a channel protection system of a brook located in New Jersey. Repetitive flooding with high stream velocities, as a result of inadequate channel capacity, had caused significant erosion of the banks. The geoweb cellular confinement system was chosen over conventional solutions such as riprap, which consists of placing large rocks in the water and up the slope of the eroding shoreline. Riprap is commonly used to control erosion along stream banks and lakeshores where vegetation is not sufficient to prevent erosion caused by high water or wave action; however, it is comparatively expensive to install and is often installed incorrectly. A 54 in thick riprap section would have been needed for velocities approaching 20 ft/s along the 300 ft sharp bend in the channel; however, using 4 in perforated geoweb filled with low-slump concrete achieved the same results at an estimated savings of 25%.

In addition to the channel protection systems used in the brook, several earth retention systems were built using geoweb gravity walls to increase the structural integrity of the embankments. With a maximum height of 14 ft, the geoweb wall was composed of 8 in deep layers of geoweb containing native silty sand and gravel, except for the outer 5 layers, which were filled with ¾ in stone to prevent loss of material from the wall. Each layer of the geoweb was extended 3ft-7.5ft from the face into the bank, and was set back 2 in from the face of the underlying layer to allow vegetation to grow in the exposed front cells.

In two similar cases, Presto's geoweb was used to establish grassed parking areas were conventional methods of pavement were once used. In the first case, four inch deep geoweb had been filled with 98% compacted sand, and covered with sod. Total surface runoff generated by a 2 year, 24 hour storm had been found to be approximately 30% less than the volume generated from previously impervious parking areas (Simmons et. al., 2000). Three years later, the parking area has maintained approximately 85% uniform cover without any visible signs of deformation or rutting.

In the second study of grassed parking areas, performed by the Tensar Corporation (2000) and North American Green (2001), silt loam that was hydrotamped, (non-mechanical compaction allowing soil to compact for several days by application of water), was chosen as the infill material. A native grass species mix was then seeded on the geoweb surface. Total surface runoff generated for 2 year, 24 hour storms had shown significant reductions of runoff volumes on the order of 50 to 60 percent. Vegetation had also been established at 80% uniform cover after the initial three months of seeding.

Alternative Methods

The mission of the SHA is to provide safe, efficient, aesthetically pleasing, and environmentally sound transportation systems for the motorist. Current methodology for road shoulder backfill areas in use by SHA are not capable of simultaneously providing both environmental and roadway operational benefits desired by regulatory and transportation agencies. Further, the significant increase in road construction has increased roadway and environmental impacts associated with high runoff volumes.

The most common design methodology used in road shoulder stabilization involves a variable width strip of 6-inch gravel adjacent to the roadway. Although gravel is capable of supplying adequate structural reinforcement to support the static loads imposed by stopped vehicles, environmental concerns regarding high runoff volumes and velocities are not met. As runoff from the asphalt highway displaces particles of gravel, creation of rills results in the gravel, exposing the subsoil to accelerated erosion. The runoff effects are exacerbated by the lack of vegetative cover in these areas, as groundcover does not thrive in gravel substrate.

In an attempt to control the runoff volumes and velocities from the impervious pavement, SHA has considered the use of 100% topsoil mixture to support a uniform vegetative grass cover adjacent to the roadway. From an environmental standpoint, vegetated areas have the ability of increasing infiltration rates, reducing runoff volume, and reducing erosion compared to non-vegetated areas (Schwab et al, 1995). Although this design is appealing in its ability to accommodate environmental and aesthetic issues, it is not capable of providing adequate reinforcement to support the SHA minimum static load requirement. Under conditions of moderate to high moisture content, the soil deforms easily under an applied load. Deformation and subsequent plant disturbance requires time and money to repair, and it is therefore desirable to avoid these complications by ensuring adequate shoulder stability prior to planting.

In another attempt to meet both roadway safety and environmental requirements, SHA has experimented with mixing aggregate with topsoil in a 50/50 mixture. The intent if the design is to counter weaknesses in the soil structure introduced in the pure topsoil design, while providing the uniform vegetation growth lacking in the pure gravel design. Results indicate that while the mixture supports traffic loads, it has been unable to provide vegetation growth greater than approximately 15 percent. Another drawback of the design includes mixing of the aggregate/topsoil mixture with the underlying subsoil layer. The result is migration of gravel into subsoil layers over time, which forces the subsoil to the soil surface where erosion occurs.

PROJECT DESIGN

OBJECTIVES

The need for safe, efficient, aesthetically pleasing, and environmentally sound transportation systems for motorists has led the State Highway Administration (SHA) to seek alternative methods for constructing road shoulders that are able to withstand adequate loads while remaining aesthetically pleasing and environmentally sound. Concurrently, the objectives of the study proposed by Environmental Solutions, Inc. are to develop a road shoulder backfill area design that meets the following criteria:

1. Reinforcement of the area to support a minimum uniform static load of 80 pounds per square inch (psi) without deformation.
2. Establishment of a uniform vegetative cover at a minimum of 90 percent with an SHA approved grass.
3. Reduction of surface runoff volume by 50 percent over the current 50/50 aggregate and topsoil mix for a 2 year, 24 hour storm.

Design Concepts

In order to provide reinforcement to topsoil through confinement such that vegetative cover may become established, the perforated geoweb material was selected as the key component of the road shoulder backfill area stabilization design. The proposed design recommendations were outlined in the design proposal phase of this project, and are summarized below. The design involved the use of vegetative groundcover grown within a geoweb layer to stabilize topsoil and prevent soil loss through erosion. Implementation of a non-woven geotextile directly beneath the geoweb layer was included to mitigate the sealing effects and subsequent obstruction of infiltration created by the subsoil. The non-woven geotextile also prevented potential mixing of the topsoil and subsoil layers. A gravel layer beneath the non-woven geotextile was suggested to increase the hydraulic conductivity of the soil system, and to ensure that adequate infiltration occurs at greater soil depths such that stagnation of water beneath the soil surface would not occur.

The proposed design was used to design a pilot-scale model of a road and backfill area. The model contained all of the recommended system components, and was used to assess the ability of the proposed arrangement to meet the design requirements stated in this report. The pilot-scale model also included a control modeled after the SHA 50/50 soil-gravel mixture backfill design. The model was tested in a rainfall simulator in order to assess the affects of the geoweb design on controlling runoff and erosion.

The design was also tested for load stabilization using a compaction test that compared the SHA 50/50 soil-gravel mixture backfill (control) design to the proposed geoweb (experimental) design. Two boxes were constructed to simulate the control and experimental designs. Deformation of the soil profile upon application of a force was measured for various forces, and the values were used to assess the ability of the geoweb design to adequately support the requisite 80-psi load.

Design Specifications

The proposed design for a road shoulder backfill stabilization system is based on the objectives of supporting the required load, reducing surface runoff, and establishing vegetative groundcover. The design incorporates geosynthetic materials, various soil and gravel substrates, and SHA approved groundcover to meet these goals.

The proposed design involves a layered approach in which each successive layer increases in hydraulic conductivity. The substrata must have greater hydraulic conductivities than the topsoil layer in order to ensure proper drainage and to prevent stagnation of water beneath the topsoil. The design therefore incorporates aggregate and soil mixtures in the subsoil layers, and also includes a non-woven geotextile layer between the geoweb and subsoil to prevent sealing effects.

The detailed design schematics in Appendix A demonstrate the proposed substrate layers of the design. From the lowest layer up, the sections are arranged as follows: The base of the design is the native soil of the site. A six-inch gravel layer is placed above the native soil, and a six-inch soil-aggregate mixture is layered on top of the gravel. (In typical road shoulder construction practice, aggregate-soil mixtures are taken from nearby construction sites to reduce cost.) A non-woven geotextile layer is installed above the aggregate-soil mixture, and the geoweb is placed above the non-woven geotextile. High-grade, screened topsoil in hydrologic soil group A or B is used as the fill material for the geoweb cells. The topsoil is then given a seed layer to promote the growth of fescue grass. A biodegradable erosion control blanket is placed over the seeded layer to protect the seeds and topsoil from washing away prior to germination of the seeds. Together, these strata create mutually reinforcing layers that make the system optimal for sites where the native soil is impermeable, and when sealing at the topsoil-subsoil interface is anticipated. The design may be modified based on specific site characteristics. For example, in sites with naturally permeable soils that are not prone to sealing, the non-woven geotextile layer may not be essential. However, inclusion of the geoweb layer is recommended for all designs because of its essential role in the stabilization of topsoil and vegetation.

The pilot-scale model included all of the design components, except for the erosion control blanket, and simulated a sloped site. Because the fescue was seeded and grown on the model in controlled greenhouse conditions, seed and soil loss were not a concern for the model, and therefore did not necessitate the use of an erosion control blanket. The model included a control section that simulated a backfill area with a 50/50 soil-gravel mixture on the same degree slope as the test model. The test model had the same layers as described above, including the non-woven geotextile, geoweb, and the appropriate gravel and soil substrates.

PROCEDURES AND METHODS

PRELIMINARY SETUP

Preliminary assessment tests of the rainfall simulator were conducted in order to determine the uniformity coefficient for the rainfall area, and to calibrate the rainfall simulator pump. The simulator consists of a metal frame approximately 15 feet tall, with an oscillating water nozzle attached to the top beam. An electric, battery-powered pump that maintains water pressure at user-specified values pumps water from a large holding tank through a flexible tube up to the nozzle.

The water pressure is directly related to rainfall intensity, although the pressure-intensity relationship is not perfectly proportional. Therefore, the simulator was run for brief, 10-minute intervals at varying pressures, and samples were collected during the run to assess intensity for each pressure value. Further, the uniformity coefficient for each run was calculated in order to ensure that the distribution of rainfall over the test area was consistent. Based on the data, an operating pressure of .30 bar, corresponding to a rainfall intensity of 5.29 in/hr was selected. At .30 bar, the uniformity coefficient for the simulator was 70%. This intensity represents a 25-year, 30-minute storm. This return period and duration are appropriate for the testing of the model because the geoweb product should be able to withstand more severe storms than other designs. Therefore, whereas other designs may seek to withstand only 10-year storms or less, the geoweb should be expected to withstand larger storms. This consideration is important because of the comparative expense of purchasing geoweb over using the traditional gravel-topsoil mixture. The greater resiliency of the design in more severe storms should therefore offset the economic cost of the geoweb product. The detailed calculations for the uniformity coefficient and for various storm intensities is provided in Appendix C.

Construction and Testing of the Pilot-Scale Model

The pilot scale model was constructed according to the methods outlined in the design proposal document. Walnut Hill Woodworks, a fabrication shop, constructed the frame of the model, which required a time of manufacturing of 10 hours.

The soil layers for the control and experimental sections of the model were added in the specified order, and were compacted to 98% using a hand-tamping technique. Fescue grass seed was sown on the surface of the model, and was grown to maturity in a greenhouse prior to testing the model. The model was watered every morning, such that each side of the model received the same amount of water. When the grass reached a height greater than one foot, it was trimmed by hand to approximately 5 inches in height.

The model was then relocated to the testing area with the rainfall simulator. As some settling of the soil occurred during transport, a portion of the Plexiglas on the front panel of the model was shaved down so that runoff from the simulation would not be impeded.

The model was tested by placing the model in the rainfall simulator and exposing the model to the conditions of a 25-year, 30-minute rain event. Runoff was collected from the control and test sections of the model separately, and was analyzed for runoff volume and total suspended solids. The test for total suspended solids was an indicator of the amount of sediment lost by the system to erosion. Three test replications were completed, and sufficient time was allowed between runs for the model to expel water from the previous test and establish the appropriate antecedent conditions before running the next test. For this reason, the tests were run at least 7 days apart. After the third simulation, an additional test run was completed the next day in order to assess the effects of back-to-back storms on the proposed design. This additional test provided information about how the design would function under wet antecedent conditions, as the soil profile was only given 24 hours to drain.

The test results were analyzed using Microsoft Excel software to determine the success of the design conditions based on the stated experimental objective of lowering runoff by 50%. The data averages for the control and test conditions were compared in order to ensure that the proposed design was able to decrease runoff and erosion by a sufficient amount.

CONSTRUCTION AND TESTING OF THE COMPACTION TEST

Assessment of the ability of the proposed design to support a static load up to 80-psi was accomplished using Instron compression machines. Based on the recommendations of the Soil Mechanics Laboratory at the University of Maryland under the direction of Dr. Debra Goodings, two stainless steel boxes measuring 16 ¼ " x 15 ¼ " x 12" were filled with material in the same proportions as the rainfall simulation model, except that no fescue grass was included.

Because the integrity of the geoweb depends almost entirely on the distribution of the load throughout large areas of geoweb material, edge effects in the test boxes could potentially lead to erroneous data if they were not accounted for. For this reason, the geoweb was secured to the sides of the box with clamps such that it would not fold inward during the compaction test.

Each box was then tested using the Instron compaction machine. A metal plate area of a standard 22-inGoodyear truck tire (156 in^2) was placed on the center of the soil surface, and the machine delivered its compacting load onto the plate. The plate was constructed of a one-inch thick metal alloy slab (12"x13"), with a cylindrical projection on one face. Another plate was attached to the other end of the cylinder, providing a stable, uniform surface to which the Instron machine delivered the load. Because the model was designed at actual scale, the forces delivered normal to the soil surface was exactly the amount required to simulate an 80-psi pressure. Therefore, an applied force of 12,480 pounds was applied to the test boxes.

The control box was tested first, followed by the experimental box. Baseline measurements were taken at several points along the soil surface to ascertain the initial depth of the soil surface prior to testing. These measurements were then averaged. The Instron machine delivered steadily increasing force to the test boxes at a rate of 300-pounds per minute. When the required 12,480-pound load was reached, the machine was stopped and the amount of compaction of the soil was recorded in the same way that the baseline measurements were taken.

Because the SHA accepts the 50/50 soil-gravel mixture as a suitable design, the proposed design needed to resist deformation at least as well as the control in order to meet the stated design objectives. Therefore, a simple comparison of the two deformation values was used to assess the ability of the design to support the required load.

ASSESSMENT OF GROUNDCOVER

Percent groundcover was to be assessed using a quadrat method in which the percentage of exposed earth was estimated. However, the fescue grass grown on the model reached a percent cover of nearly 100% for both the control and experimental designs.

Results and Discussion

RUNOFF AND EROSION FROM THE PILOT-SCALE MODEL

Three experimental replicate trials were performed for the rainfall simulation testing of the pilot scale model. In each of the three trials, direct surface runoff (DSR) was greater from the control than the experimental design. The results for the three trials, which are shown in figure 4, were averaged and the standard deviation was calculated. Figure 5 shows the average direct surface runoff volumes for the control and experimental designs. The average runoff volume for the experimental design was approximately 1.2 gallons, while the average runoff volume for the control was approximately 7.2 gallons. The data therefore suggest that direct surface runoff was reduced by 83% in the experimental design compared to the control.

The experimental results for total suspended solids (TSS), which was used to assess the amount of sediment displaced during the rain event, are summarized in figure 6. The results for the three trials were averaged, and standard deviations were calculated for the data (see figure 7). The average TSS for the experimental design was 17 mg/l, while the average TSS for the control was 32 mg/l. The data therefore show a 47% reduction in sediment lost to erosion in the experimental design over the control. The standard deviation for the trials, as shown by the error bars in figure 7, suggest that the values obtained from the trials were not as valid as those obtained from the DSR measurements. The standard deviation for the control, for example, was approximately 15.6mg/l, which is large compared to the average TSS value of 36 mg/l. Further, the trials produced considerable fluctuations in TSS, as the values first decreased and then increased again.

Figure 8 shows the runoff volumes obtained from the fourth trials that were conducted under wet antecedent conditions, and figure 9 shows the TSS measurements obtained from that run. Because only one replicate was obtained for this type of trial, no statistical analysis may be completed for this data. However, the data offer useful preliminary values that suggest the experimental design is able to mitigate direct surface runoff and sediment erosion even under wet antecedent conditions. The DSR data shown in figure 9 is particularly promising, in that the experimental design was able to produce a nearly 5-fold decrease in runoff volume over the control. The TSS for the experimental design was 39% less than the control, indicating that the experimental design may retain more sediment than the control, even during consecutive storms. Further investigation into the behavior of the design under wet conditions would need to be conducted in order to determine the reproducibility of these results.

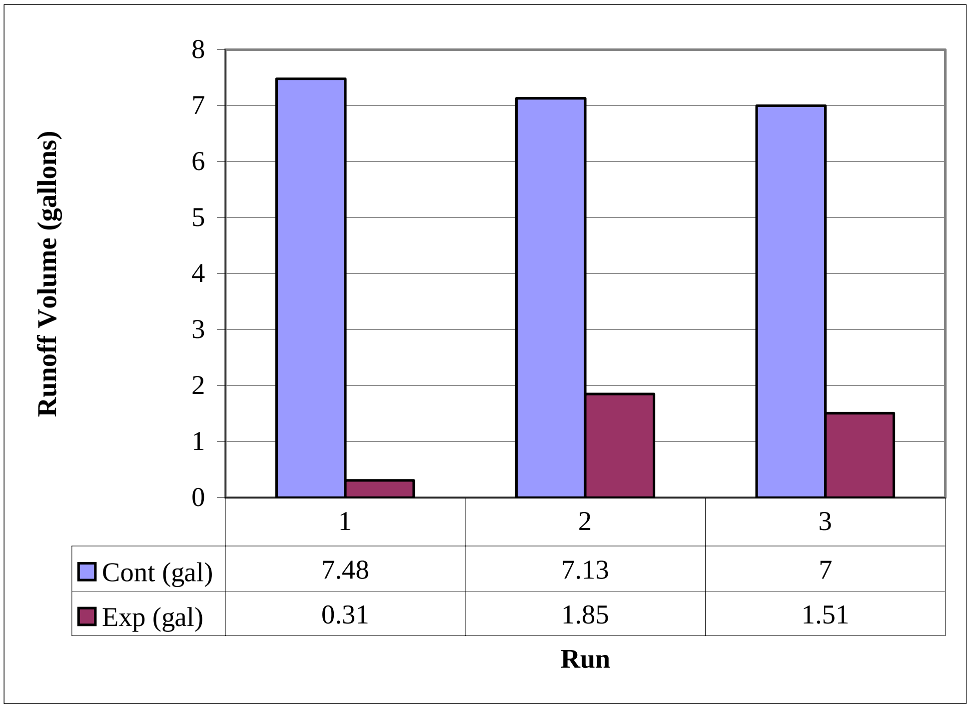

Figure 4: DSR data from the three test trials in the rainfall simulator.

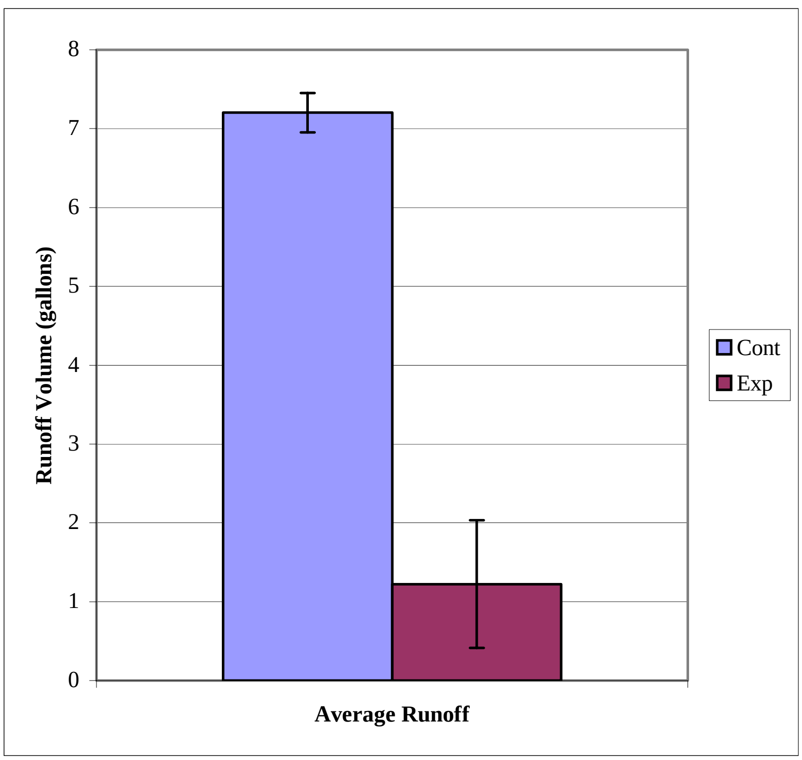

Figure 5: Average DRS values for the experimental and control sections of the model.

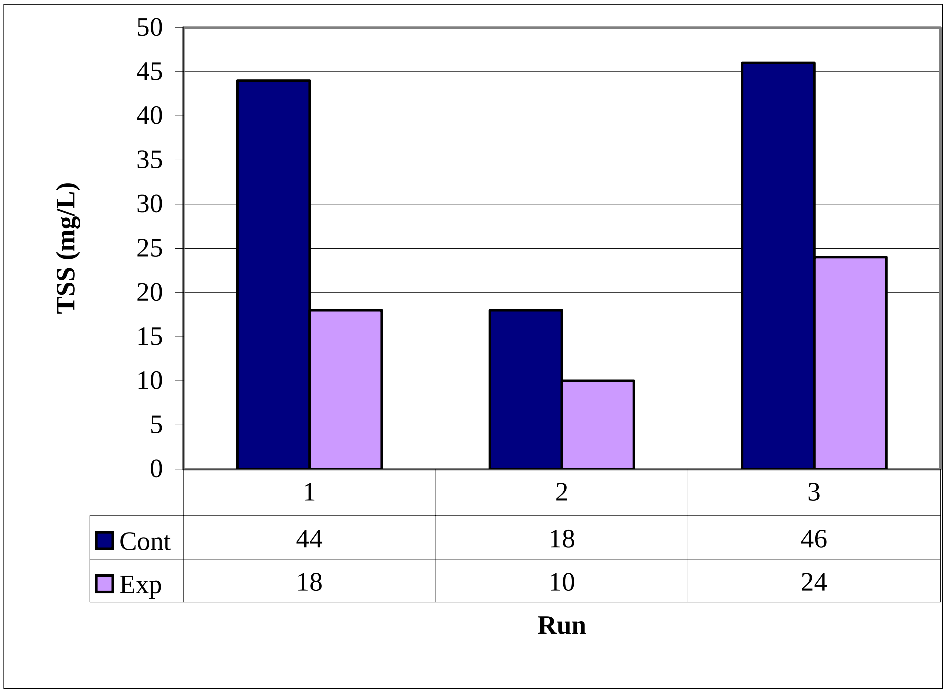

Figure 6: TSS data from the three test trials in the rainfall simulator.

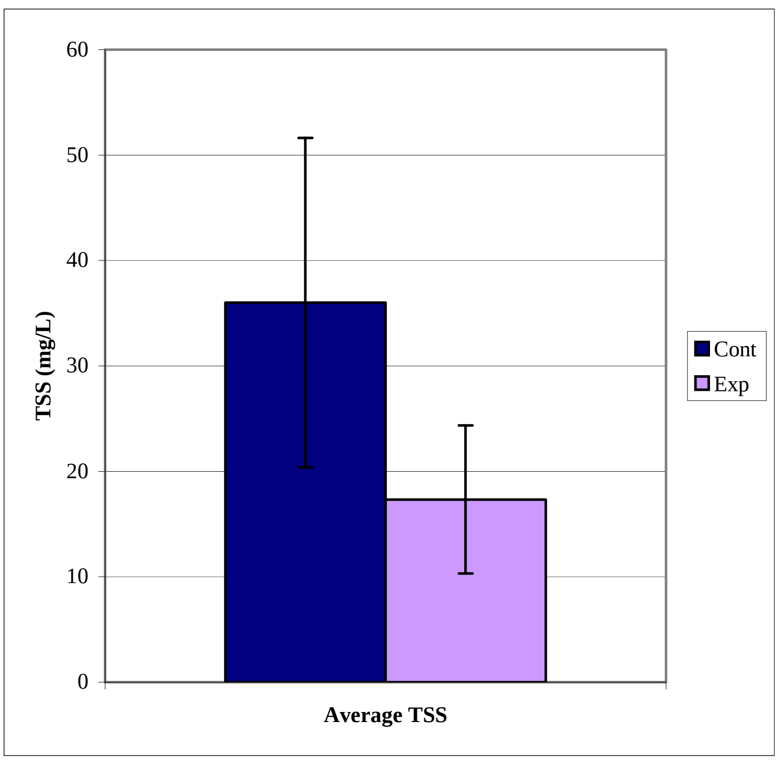

Figure 7: Average TSS values for the experimental and control sections of the model.

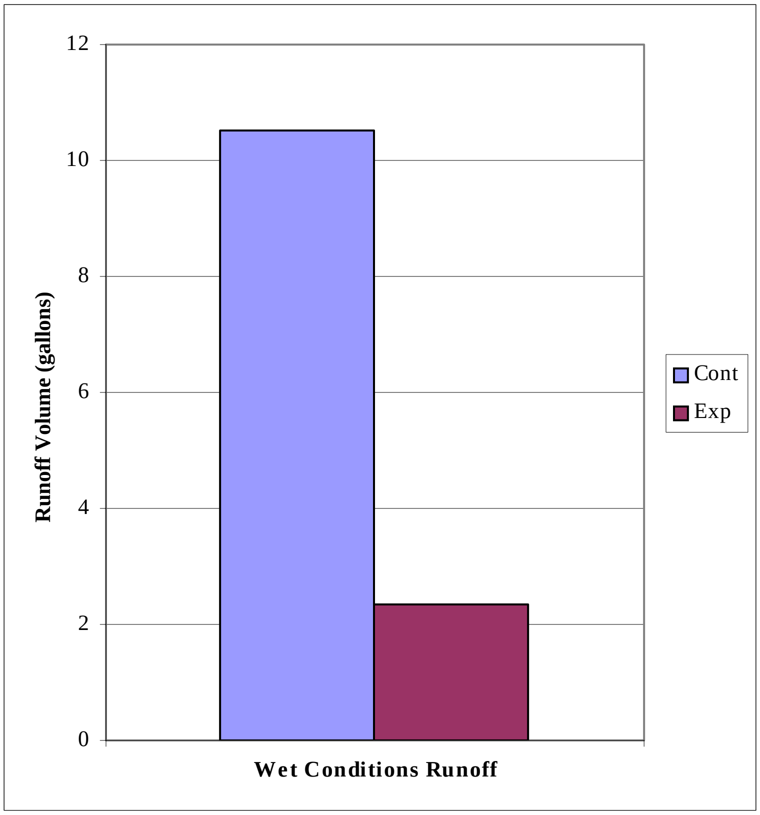

Figure 8: DSR value for wet antecedent conditions from the fourth run.

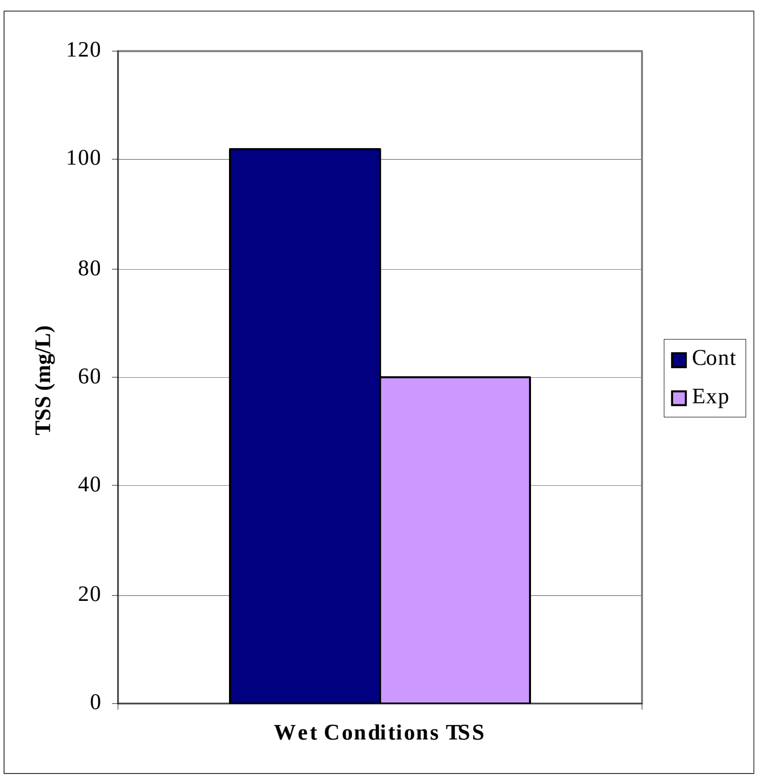

Figure 9: TSS value for wet antecedent conditions from the fourth run.

Soil Compaction

The compaction test was completed according the procedures described above; however, the outcome of the test on the experimental box was unanticipated. As discussed, the structural integrity of the geoweb and its ability to laterally distribute loads throughout its neighboring cells are what allow it to stabilize large forces, such as the weight of a car. The box design that was tested in the compaction test did not allow for this load distribution, and the soil profile of the experimental box collapsed upon application of approximately 1,000 pounds by the test machine. As the geoweb began to deform under the applied load, the clamps that secured it to the walls of the box could not prevent it from sinking inward under the plate. The geoweb material was pushed down through the soil profile, which contained soft topsoil, and the soil was forced upward, out from under the plate. The deformation of the test box due to the collapse of the geoweb nullified the measurements for that portion of the experiment.

The control box performed exceptionally well under the test conditions, deforming less than ½ -in under the 80-psi pressure. Further, none of the surrounding soil in the box was disturbed, and none of the soil was displaced toward the sides of the box, as in the experimental box.

The load stabilization ability of the geoweb material is dependent upon the ability of the material to distribute forces throughout its web-like structure. In that way, each geoweb cell is anchored and supported by the surrounding cells, particularly those that are not directly adjacent to it. As a force is applied over two or three of the cells, cells several feet away that are full of soil and anchored to the earth prevent the geoweb from sinking downward at the point of application of the force. In other words, the material must be held relatively taut in order to distribute its load. In the compaction test, the boxes were not large enough to accommodate multiple cells, so the load could not be distributed. In the experimental box, only three entire cells were able to fit without bending, a number too small to have the desired stabilizing effects.

In order to show the full load stabilization benefits of the geoweb, the design should be tested *in situ* so that a larger section of geoweb may be utilized. The manufacturer’s specifications indicate that the geoweb is able to withstand the 80-psi load. Further testing supports the manufacturer’s claims, as discussed in the case studies section of this report.

Conclusion

The data obtained from the DSR and TSS analyses indicate that the experimental design was effective in mitigating runoff and sediment erosion. The pilot scale model also suggests that the geoweb design is able to support a full stand of vegetative ground cover. However, it is necessary to consider the time constraints that were present during the testing phase of the design development. Reproducibility and smaller statistical error were both sacrificed to some degree by the limited number of test runs that could be performed. Additional error may have been introduced by the first run, in which higher sediment erosion values would be expected.

The model was effective in meeting two of the three design specifications outright. The specification of reduction of surface runoff volume by 50 percent over the current 50/50 aggregate and topsoil mix for a 2-year, 24-hour storm was successfully met with the design. The actual test was performed for a 30-minute, 25-year storm, which provides an intensity of 5.29 in/hour, which is significantly greater than for a 2-year, 24-hour storm, which has an intensity of 0.15 in/hr (calculations based on storms in the Washington, DC area).

The rainfall simulation was performed at this high intensity for two reasons. The first concern involves the economic considerations of utilizing geoweb material in a design. Because the economic investment is higher with the proposed design than in the control design, it is desirable that it should withstand more severe storms without failure. The second concern involved the uniformity coefficient of the rainfall simulator at varying pump pressures. Preliminary testing revealed that the rainfall simulator produced uniform precipitation at higher intensity values. Because of these two considerations, rainfall intensities for various storms were calculated, and the 30-minute, 25-year storm was selected for testing. Success of the model at the higher intensity demonstrated a significant runoff reduction (83% compared to control), indicating that the DSR design specification was adequately accomplished.

The soil compaction test did not provide reliable data on the ability of the geoweb design to stabilize the 80-psi load required by the SHA. In order to obtain more meaningful and satisfactory measurements, the design would need to be tested *in situ*, such that a large area of geoweb is available to laterally distribute the applied load. However, the manufacturers specifications indicate that the geoweb is able to support the required 80-psi load, and the case studies reviewed in this analysis indicated that geoweb has been used successfully in such a capacity in previous projects. It is therefore expected that the same success would be enjoyed by the proposed road shoulder design, and that further testing with a larger surface area would validate these claims. However, compaction testing during this analysis failed to support the design specification requiring the design to support a static load of 80-psi.

The fescue grass grown on the model reached a percent cover of nearly 100% for both the control and experimental designs. The design specification goal of establishing greater than 90 % vegetative groundcover was therefore met successfully by this project and design. It is further anticipated that the ability of the design to maintain this amount of groundcover would persist over conventional methods, as less sediment would be lost through erosion, and more nutrient-rich topsoil would be made available to the fescue grass.

Further investigation into the design is recommended for a full-scale analysis of the benefits offered by the design. The preliminary data are very promising, and warrant a thorough set of repetitive tests so that the strengths and weaknesses of the design may be identified and addressed. The final stage of testing would be accomplished upon implementation of the design into an actual road shoulder backfill area, in which natural ambient conditions like wind and heat could also impact the success of design. This type of testing is necessary because the integrity of the geoweb is largely dependent on its force-distributing area, which can be difficult to simulate in the laboratory.

A final consideration of the utilization of geoweb in a road shoulder stabilization design is the cost compared to the traditional 50/50 gravel-topsoil mixture. The traditional design is very inexpensive because the SHA uses aggregate and soils from surrounding, close-by construction sites. The fill material is therefore free and easy to procure because it does not have to be ordered, and occurs naturally. The geoweb material varies in cost depending on the size and type of material that is selected. Presto Products offers a price quote for its products that is available directly from the company; however, they do not offer an exact price per square foot. The cost depends on the area of geoweb required, and the number and types of anchors that must be included.

List of External Resources

- Construction of the pilot-scale model was completed at the Walnut Hill Woodworks fabrication shop.

- The sample section of Geoweb material was provided courtesy of Mr. Charles Porter of AFC Environmental.

- The rainfall simulation tests were performed in the Soil and Water Engineering Laboratory of the Biological Resources Engineering Department at the University of Maryland, College Park.

- The compaction test was performed in the Soil Mechanics Laboratory of the Civil Engineering Department at the University of Maryland, College Park.

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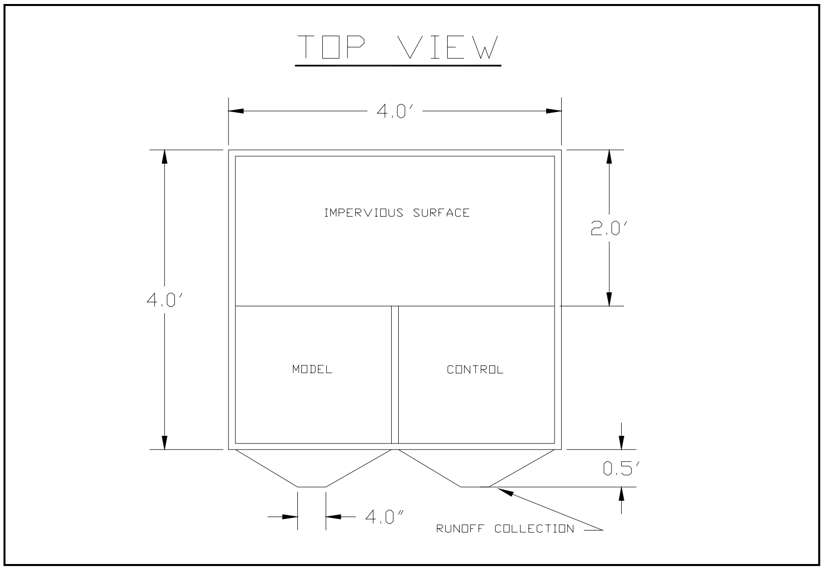
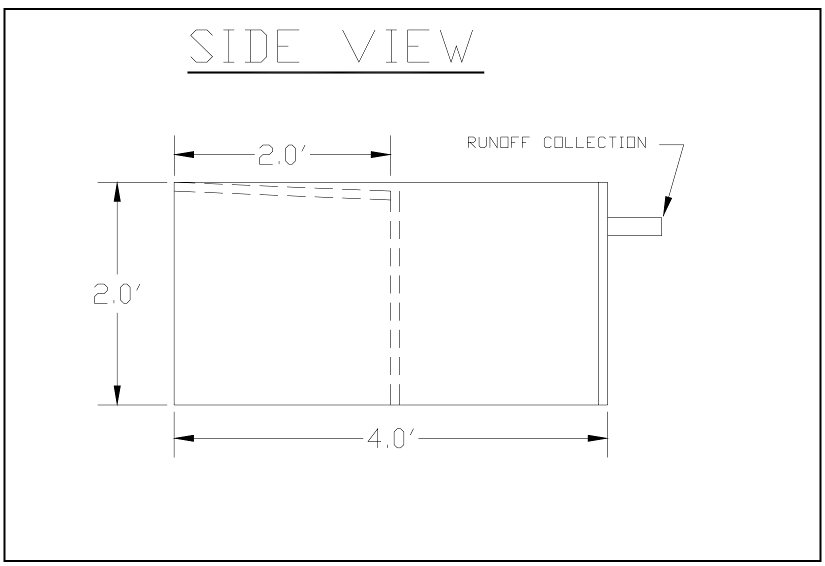
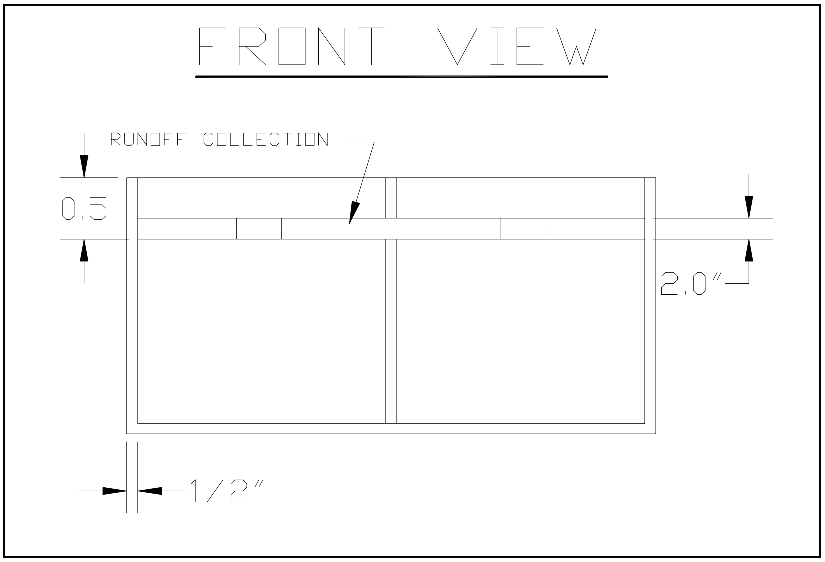
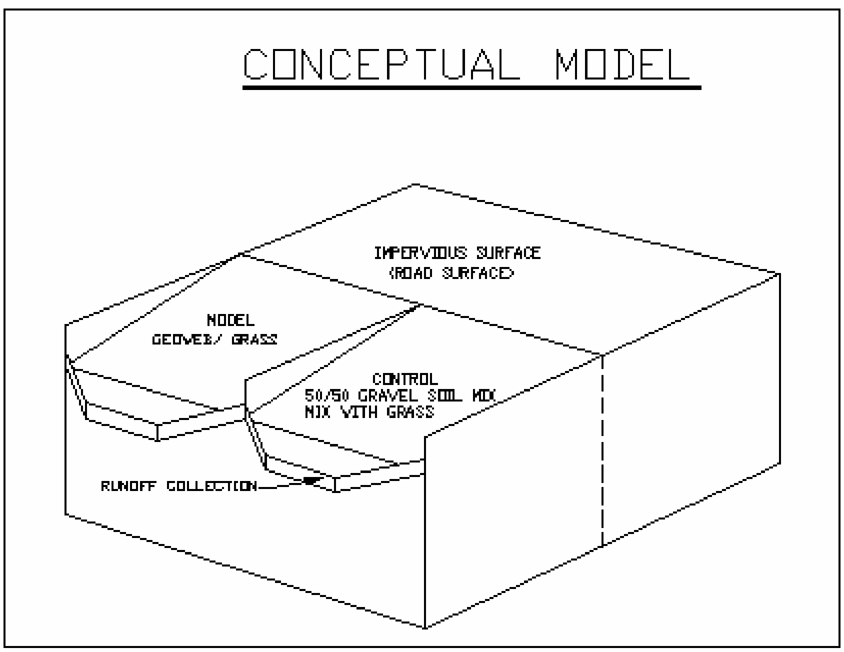
Appendix A

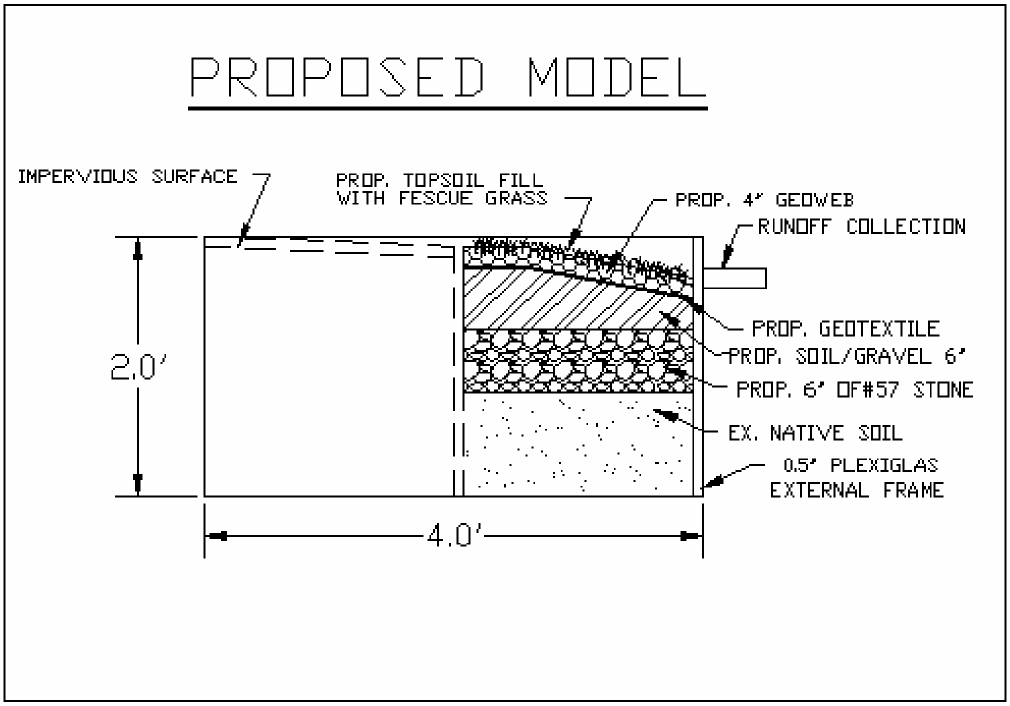
Engineering drawings of the pilot-scale model.

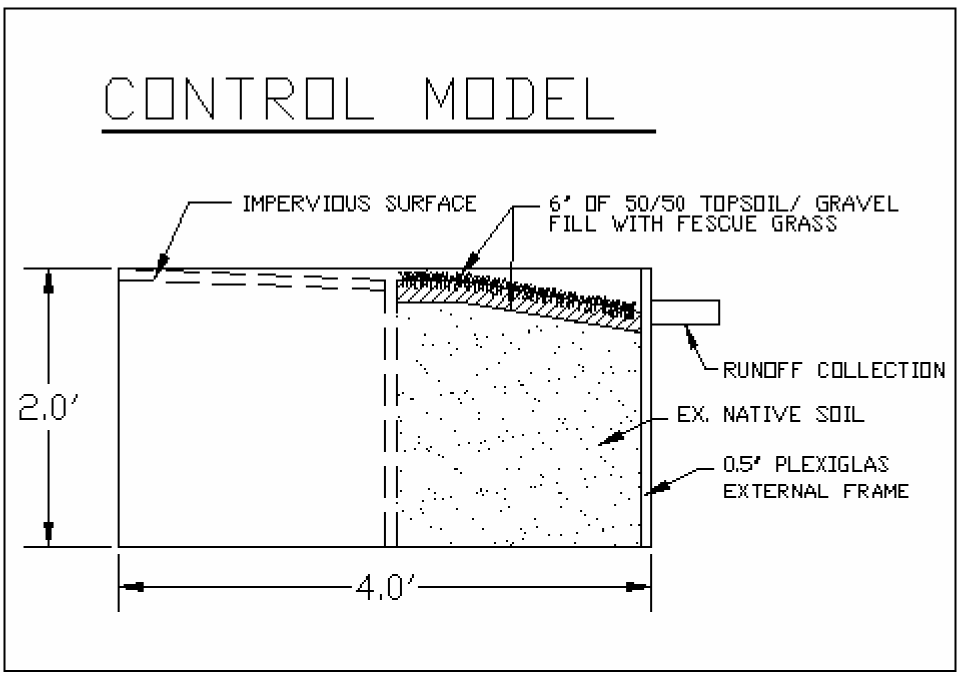

TOP VIEW
4.0′
IMPERVIOUS SURFACE
2.0′
4.0′
MODEL
CONTROL
0.5′
4.0″
RUNOFF COLLECTION


SIDE VIEW
2.0′
RUNOFF COLLECTION
2.0′
4.0′


FRONT VIEW
RUNOFF COLLECTION
0.5
2.0"
1/2"


CONCEPTUAL MODEL
IMPERVIOUS SURFACE
(ROAD SURFACE)
MODEL
GEOWEB/ GRASS
CONTROL
50/50 GRAVEL SOIL MIX
MIX WITH GRASS
RUNOFF COLLECTION

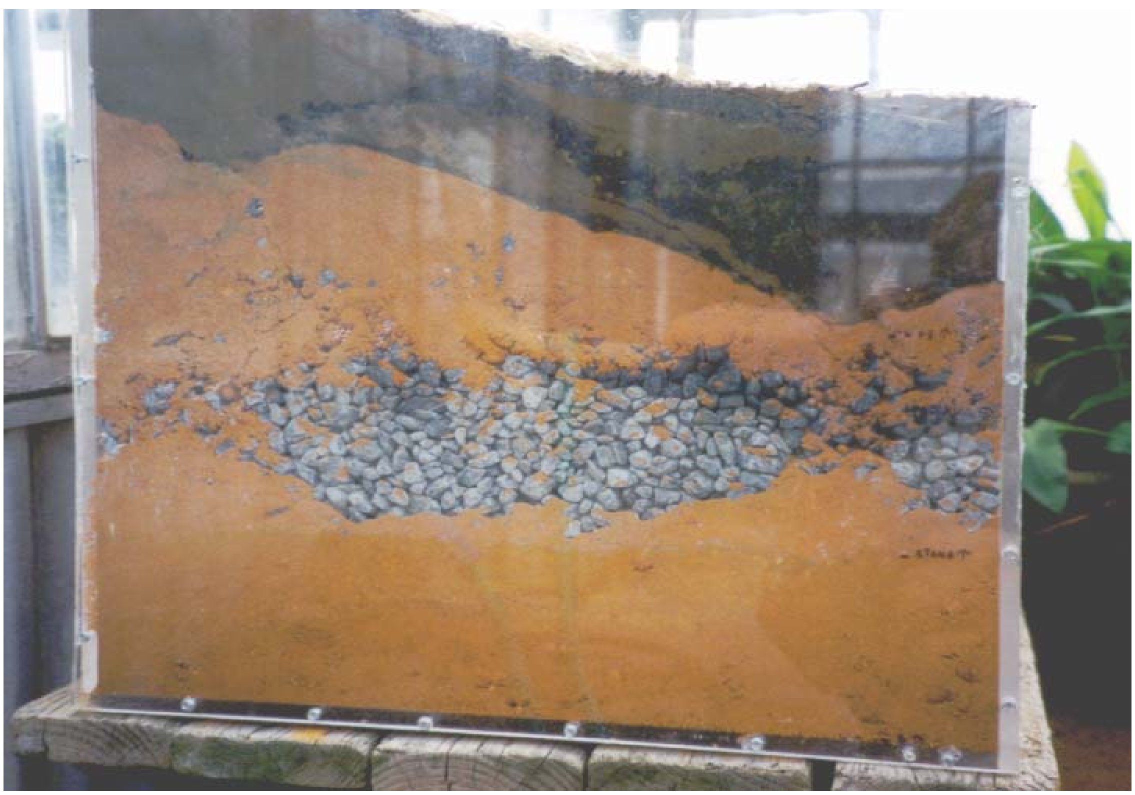

PROPOSED MODEL
IMPERVIOUS SURFACE
PROP. TOPSOIL FILL
WITH FESCUE GRASS
PROP. 4" GEOWEB
RUNOFF COLLECTION
PROP. GEOTEXTILE
PROP. SOIL/GRAVEL 6"
PROP. 6" OF#57 STONE
EX. NATIVE SOIL
0.5" PLEXIGLAS
EXTERNAL FRAME
2.0'
4.0'


CONTROL MODEL
IMPERVIOUS SURFACE
6" OF 50/50 TOPSOIL/ GRAVEL
FILL WITH FESCUE GRASS
RUNOFF COLLECTION
EX. NATIVE SOIL
0.5" PLEXIGLAS
EXTERNAL FRAME
2.0'
4.0'

Appendix B

Photographs of the pilot-scale model prior to and during the establishment of vegetative groundcover.

Front profile of the model on the day of seeding.



Side profile of the experimental side.

Appendix C

Detailed calculations for the rainfall simulator uniformity coefficients and rainfall intensities for various storms.

Calculations for Uniformity Coefficient

Pump pressure	.45 barr		.3 barr		.2 barr	
	x	xi-xave	x	xi-xave	x	xi-xave
	200	120.83	300	29.17	200	41.67
	400	79.17	275	4.17	250	8.33
	350	29.17	275	4.17	200	41.67
	350	29.17	250	20.83	200	41.67
	375	54.17	275	4.17	200	41.67
	250	70.83	250	20.83	400	158.33
ave	320.8333		270.8333		241.6667	
UC	-0.194805		0.692308		-0.37931	

UC = 1-y/d = 1-(sum(xi-xave)/d)

I = 0.0256 (C - A)x + 0.000256 [(D - C)- (B-A)]xy + 0.01 (B - A)y + A

A	1.6
B	3.5
C	4
D	8

x = 10ln(T/2)
y = 143.2 (D^1/6 -1)

Calculations of Rainfall Intensity for Various Storms

period (y)	duration(h)	x	y	I (inches)	i (in/hr)
10	0.5	16.1	-15.6	2.16	4.32
10	1	16.1	0.0	2.59	2.59
15	0.5	20.1	-15.6	2.37	4.74
15	1	20.1	0.0	2.83	2.83
20	0.5	23.0	-15.6	2.52	5.05
20	1	23.0	0.0	3.01	3.01
25	0.5	25.3	-15.6	2.65	5.29
25	1	25.3	0.0	3.15	3.15
2	24	0	100.0	3.50	0.15

All equations and coefficient values were obtained from Schwab, et al, 1993.
Values were assumed for the Washington, DC area.