USE OF A SMALL-SCALE EROSION CONTROL MODEL

IN THE DESIGN OF SILT FENCE TIEBACKS

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USE OF A SMALL-SCALE EROSION CONTROL MODEL IN THE DESIGN OF SILT FENCE TIEBACKS

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VITA

Jarid Lane Halverson, son of Darnell R. Halverson and Mary M. Halverson, was born on January 11, 1975, in Le Sueur, Minnesota. He graduated from Sibley East Senior High School in Arlington, Minnesota in 1993. After graduating, he accepted an appointment to the United States Military Academy in West Point, New York and graduated in 1997 as a distinguished cadet with a Bachelor of Science degree in Civil Engineering. He was married to Jaime J. McCallister on October 23, 1999 and has two daughters, Kylie M. Halverson and Lauren E. Halverson. In August 2004, he entered the Graduate School at Auburn University to pursue a Master of Science degree in Civil Engineering.

THESIS ABSTRACT

USE OF A SMALL-SCALE EROSION CONTROL MODEL

IN THE DESIGN OF SILT FENCE TIEBACKS

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For most storm events, accelerated erosion caused by storm water runoff from construction sites can be mitigated through vigilant management efforts. The control measures that are designed to provide a practical field solution to pollution problems from all sources and sectors are known as best management practices. The primary goal of this research was to construct a small-scale erosion control model, in a laboratory environment, that models typical highway construction sites, accommodates the simulation of varying rainfall intensities, and ultimately allows for the extensive testing of various erosion control best management practices. The secondary goal of this effort involved developing a silt fence tieback design guide to assist designers and inspectors in the proper placement of silt fence tiebacks along highway construction projects. Finally, the last goal focuses upon testing the tieback design guidelines on the small-scale erosion

control model and quantifying the reductions in the total amount of sediment leaving highway construction sites and the overall improvements in the storm water quality.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The current rate of urbanization occurring within the United States has major, future environmental repercussions. As naturally vegetated areas are transformed into high density urban areas, the impervious areas from road networks, parking lots, driveways, rooftops, and sidewalks not only increases the total storm water runoff, but also reduces the time it takes for the runoff to reach the waterways. In addition, the higher concentrations of people within these urban areas are also responsible for introducing higher quantities of pollutants such as pesticides, fertilizers, oil, salt, litter, and sediment (U.S. EPA, 2000a). After a storm event, the excess storm water flushes these pollutants into the storm water drainage system that transports the pollutants directly to our waterways. The impacts of water pollution from urban runoff are tremendous and include fish kills, the destruction of aquatic habitats, the degradation of drinking water, and numerous health concerns for humans and animals (U.S. EPA, 2004b).

In an effort to address these issues, the United States Environmental Protection Agency (EPA) implemented a storm water program in 1990. Phase I of the program incorporated the National Pollutant Discharge Elimination System (NPDES) permit program requiring coverage for medium and large municipal separate storm sewer systems (MS4s) serving populations of 100,000 or greater, for construction activity with 5 acres or more of disturbed area, and for ten industrial activities (U.S. EPA, 2000a). Phase II of the program extends permit coverage of the NPDES storm water program to certain small MS4s, requiring the development of programs comprised of six elements that are expected to result in significant reductions of pollutants being discharged into waterways (U.S. EPA, 2000c). The six MS4 program elements are commonly referred to as minimum control measures and consist of the following: i.) public education and outreach, ii.) public participation, iii.) illicit discharge detection and elimination, iv.) **construction site runoff control**, v.) post construction runoff control, and vi.) pollution prevention/good housekeeping. In addition, Phase II requires operators of small construction activities that disturb one to five acres of land to apply for a NPDES permit and to implement storm water discharge management controls known as best management practices (BMPs).

1.2 PHYSICAL PROCESSES

In order to develop a clear understanding of the erosion process, a basic knowledge of the physical processes responsible for the detachment, transport, and deposition of sediment caused by construction activities is critical. Erosion is the process by which the earth’s land surface is worn away by the action of water, wind, ice, or gravity and is influenced by the climate, topography, soils, and vegetative cover. Natural erosion is responsible for shaping the earth as it exists today and continues at a relatively slow and uniform rate (Georgia Soil and Water Conservation Commission, 2000). However, the land disturbances caused by human development over the past 100-150 years have caused several inches of erosion to occur in a short period of time in comparison to the natural slower rate of erosion.

Of all the erosion processes, water generated erosion is the most damaging. The powerful erosive action of water is derived from both the energy imparted from the rain as it falls to the earth as well as the energy obtained from the water's movement across land. The force of falling rain is primarily applied in a vertical direction and is responsible for detaching soil particles from exposed soils. As the rainfall accumulates, the water begins to flow over the particles in a horizontal direction. The overland sheet flow of water is the major contributing factor in suspending and transporting the detached soil particles. As the velocities of the water increase, additional soil particles are detached and transported. As the overland flows begin to concentrate, small rills or channels begin to form followed by the creation of larger gullies or channels. Consequently, if construction activities on a newly disturbed site increase both the volume and the velocity of storm water runoff, the erosion process is accelerated at a rate greater than that of the natural geological erosion rate (Alabama Soil and Water Conservation Committee, 2003a).

Sedimentation is a process where the soil particles suspended in the moving water eventually are carried into downstream waterways where they are later deposited. Deposition occurs when the soil particles begin to settle out of suspension as the water velocity decreases. Of the major pollutants commonly discharged from construction sites, including sanitary waste, fertilizers, pesticides, construction chemicals, and oil and grease, sediment is usually the main pollutant of concern (U.S. EPA, 2000b). Sediment concentrations from construction sites range from 10 to 20 times greater than that of agricultural land and 1,000 to 2,000 times greater than naturally forested land. In fact, in just a short time period, discharges from construction sites can contribute more sediment to streams and rivers than can be deposited naturally during several decades (U.S. EPA 833/F-00/008, 2000b). According to Jerald S. Fifield, this accelerated erosion results in the following adverse impacts to the environment: i.) it causes reservoirs and harbors to clog with silt, ii.) it causes the loss of recreational areas and wildlife habitat, and iii.) it reduces the beneficial uses of water for humans and can harms plants, animals, and fish that live in water (Fifield, 2004). As a result, it is imperative that construction projects incorporate the necessary temporary control measures required to contain sediment on the construction site.

1.3 BEST MANAGEMENT PRACTICES (BMPS)

For most storm events, accelerated erosion caused by storm water runoff from construction sites can be mitigated through vigilant management efforts. The control measures that are designed to provide a practical field solution to pollution problems from all sources and sectors are known as best management practices (BMPs) (U.S. EPA, 2004b). BMPs consist of either a device, practice, or method used to remove, reduce, retard, or prevent storm water pollutants from reaching waterbodies and refers to both structural and nonstructural practices that have a direct impact on the release, transport, or discharge of pollutants (U.S. EPA, 2004b). Additionally, a construction best management practices plan (CBMPP) is the practical tool that incorporates all of the practices and temporary control measures necessary to reduce or prevent erosion on construction sites and minimize the impacts of sediment and hydrologic changes off-site (Alabama Soil and Water Conservation Committee, 2003a).

According to the EPA, there is a general lack of effective and economical technologies for sediment control. This proves to be a major problem for construction operations in residential, commercial, and industrial development; highway and other infrastructure construction; and other activities where heavy earth moving operations are required (U.S. EPA, 2004b). Currently, the Alabama Soil and Water Conservation recommends the installation of the following temporary BMPs for sediment control: i.) block and gravel inlet protection, ii.) brush/fabric dam, iii.) excavated drop inlet protection, iv.) fabric drop inlet protection, v.) filter strip, vi.) floating turbidity barrier, vii.) rock filter dam, viii.) sediment barrier/silt fence, ix.) sediment basin, x.) straw bale sediment trap, and xi.) temporary sediment trap (Alabama Soil and Water Conservation Committee, 2003a). The Alabama Department of Transportation (ALDOT) has adopted the following BMPs, in order of dependence, for sediment control during construction operations: i.) temporary seed and mulch, ii.) temporary mulch only, iii.) solid sod, iv.) vegetated buffer, v.) silt fence, vi.) hay bales, vii.) wattles, viii.) drainage sumps, ix.) sand bags, x.) Silt Saver™, xi.) rip rap ditch check, xii.) ALDOT No. 1 aggregate, xiii.) floating basin boom, xiv.) flocculents, and xv.) brush barrier (ALDOT, 2002). These BMPs can be utilized for soil stabilization, inlet protection, sediment barriers, or ditch checks. A photograph and physical description of each of these temporary BMPs is included in Appendix A.

1.4 RESEARCH OBJECTIVES

The primary goal of this research was to construct a small-scale erosion control model that models typical highway construction sites, accommodates the simulation of varying rainfall intensities, and ultimately allows for the extensive testing of various erosion control BMPs. The secondary goal of this effort involved developing a silt fence tieback design guide to assist designers and inspectors in the proper placement of silt fence tiebacks along highway construction projects. Silt fence tiebacks, commonly referred to as J-hooks, are created by turning the down-slope end of linear silt fence installations back into the fill slope at predetermined intervals. The installation of silt fence tiebacks along highway construction fill slopes creates small detention basins that allow solids to settle out of suspension and thereby reduce the total amount of sediment leaving highway construction sites. The final goal focuses upon testing the tieback design guidelines on the small-scale erosion control model and quantifying the reductions in the total amount of sediment leaving highway construction sites and the overall improvements in the storm water quality. The specific goals of the research are as follows:

1.) Obtain a comprehensive understanding of the erosion process to include the physical processes governing the detachment, transport, and deposition of sediment on highway construction projects.

2.) Conduct a field investigation to identify the specific needs for improving BMPs on highway construction projects.

3.) Design a small-scale erosion control model to test the effectiveness of BMPs in reducing the total suspended solid concentrations leaving highway construction sites.

4.) Develop silt fence tieback guidelines using an Excel™ spreadsheet program that models the storage capacity versus the length of silt fence prior to the installation of a tieback at various toe of slope grades.

5.) Conduct testing on the small-scale erosion control model to determine the effectiveness of using the silt fence tieback guidelines in reducing the total suspended solid (TSS) concentrations leaving highway construction sites.

6.) Provide recommendations for future erosion control testing conducted on either the small-scale erosion control model or on a field-scale erosion control testing facility.

1.5 ORGANIZATION OF THESIS

This thesis is divided into seven chapters that clearly organize, illustrate, and describe the steps taken to meet the defined research objectives throughout the duration of this project. Immediately following this chapter, Chapter 2: Literature Review, summarizes the body of knowledge pertaining to this study and synthesizes previous research efforts. The focus of the literature review centered upon the environmental regulations governing erosion control, the current BMPs used on construction sites in Alabama, the development of small-scale erosion control models, and evaluations of silt fence performance. Chapter 3: Site Investigations, highlights the results of a basic site investigation conducted on a typical highway construction project. The information gathered from the investigation essentially illustrates the necessity for both the development of a small-scale erosion control model for testing the effectiveness of silt fence tiebacks in reducing the TSS leaving construction sites and additional silt fence design guidelines. Chapter 4: Small-Scale Erosion Control Model Design Procedure, outlines the framework for the development of the small-scale erosion control model to include the rationale behind the typical cross section modeled, the storm event and rainfall simulator design, and the soil type chosen for the study. Chapter 5: Silt Fence Tieback Design Development and Guidelines, includes the development of a spreadsheet used to create standard silt fence tieback design charts for various typical road cross sections encountered in highway construction projects. Using the small-scale erosion control model in conjunction with the tieback design charts, the effectiveness of tiebacks in reducing the total sediment transport and TSS concentrations leaving highway construction sites was tested. The results of these tests are summarized in Chapter 6: Small-Scale Erosion Control Model Testing and Results. Finally, Chapter 7: Conclusions and Recommendations, provides input regarding future testing that can be conducted using the small-scale erosion control model as well as ideas for the development of a field-scale erosion control testing facility. Additionally, this chapter also identifies the potential for further research that can be conducted to improve upon this research effort.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The development of land from its natural state to urban landscapes results in a dramatic change in the hydrology of the area. The construction of buildings, roadways, parking lots, and sidewalks over native prairies or woodlands reduces the amount of water that infiltrates back into the soil and increases the surface runoff. The introduction of the impervious surfaces results in increased total runoff volumes, increased peak volumes, greater runoff velocities, and a reduction in the time of concentration. In addition, the reduction of the infiltration into the soil reduces the amount of water recharging back into the groundwater supply. When the increased runoff volumes traverse over areas disturbed during the construction process, with higher velocities, there exists a large potential for increased erosion. Erosion from construction sites and other disturbed areas contribute large amounts of sediment to the stream network and degrade the overall water quality (Atlanta Regional Commission, 2001). This excessive sedimentation is detrimental to the stream network as it: i.) deteriorates the aquatic habitat, ii.) results in rapid loss of storage capacity of reservoirs, iii.) transports nutrients that stimulate algal growth, iv.) carries organics, metals, and other toxins, v.) erodes streambanks, and vi.) increases the turbidity of the stream resulting in a reduction in photosynthesis (Novotny, 2003). The undesirable impacts of the storm water runoff can be controlled through the use of BMPs. These BMPs consist of either a device, practice, or method used to remove, reduce, retard, or prevent storm water pollutants from reaching waterbodies.

The primary goal of this research project was to construct a small-scale erosion control model that models typical highway construction sites, accommodates the simulation of varying rainfall intensities, and ultimately allows for the extensive testing of various temporary erosion control BMPs. The secondary goal of this effort involved developing silt fence tieback design guidelines to assist designers and inspectors in the proper placement of silt fence tiebacks along highway construction projects. The final goal focuses upon testing the tieback design guidelines on the small-scale erosion control model and quantifying the reductions in the total amount of sediment leaving highway construction sites and the overall improvements in the storm water quality.

In order to satisfy the research objectives identified in Section 1.4, the first critical step involved conducting a thorough literature review of several pertinent subjects. The literature review focused on identifying: i.) the federal, state, and local environmental regulations governing land disturbance activities, ii.) the state-of-the practice regarding the BMPs used on highway construction projects in the States of Alabama and Georgia, iii.) and the existing body of knowledge in regards to small-scale erosion control models, silt fence testing methods, and overall silt fence trapping efficiencies. Each of these individual topics will be covered in greater depth in the subsequent sections.

2.2 ENVIRONMENTAL REGULATIONS

In January 2000, the United States Environmental Protection Agency (EPA) issued a Storm Water Phase II Final Rule Fact Sheet Series broken down into four main components consisting of an overview, small MS4 programs, minimum control measures, and permitting. The distinct components cover the history of the storm water regulations, the need for the implementation of the guidelines, key parties required to comply with the regulations, the minimum steps needed for compliance, and the permitting process and reporting requirements.

Fact Sheet 1.0 is an overview that provides a general synopsis of the series of fact sheets. It states that although the quality of the nation's waters has improved dramatically, there are still a number of degraded waterbodies. In 1996, the National Water Quality Inventory surveyed the nation's waterbodies and found 40% are still impaired and do not meet water quality standards. One of the largest sources of impairment is polluted runoff from urban storm water systems and construction sites. The United States EPA instituted Phase I of the storm water program under the Clean Water Act in 1990. The first phase of the program created the National Pollutant Discharge Elimination System (NPDES) permit to restrict point discharges into the nation's waterways. The Phase I permits applied to medium and large municipal separate storm sewer systems (MS4s), construction activity disturbing five acres of land or greater, and ten additional categories of industrial activity. In 1999, The Storm Water Phase II Final Rule was implemented covering two additional groups of dischargers: operators of small MS4s and operators of small construction activities that disturb one to five acres of land (U.S. EPA, 2000a).

In regards to the first group of dischargers or MS4s, Fact Sheet 2.0 – ‘Small MS4 Storm Water Program Overview’, Fact Sheet 2.1 – ‘Who’s Covered? Designation and Waivers of Regulated Small MS4s’, and Fact Sheet 2.2 – ‘Urbanized Areas: Definition and Description’ go into great detail defining a small MS4, explaining the Phase II small MS4 program requirements, determining what information is required on a NPDES permit, how to implement the plan, and how to evaluate or assess the program. Ultimately, the Phase II Final Rule requires small MS4s to: i.) develop, implement, and regulate a storm water management program to reduce pollutant discharges to the maximum extent practicable, ii.) to implement six minimum control measures including public education, public participation, illicit discharge detection, construction site runoff control, post-construction runoff control, and pollution prevention, and iii.) to identify which BMPs will be used and the goals for each in the permit application. Each of the individual six minimum control measures are further defined in Fact Sheet 2.3 – ‘Public Education and Outreach’, Fact Sheet 2.4 – ‘Public Participation/ Involvement’, Fact Sheet 2.5 – ‘Illicit Discharge Detection and Elimination’, Fact Sheet 2.6 – ‘Construction Site Runoff Control’, Fact Sheet 2.7 – ‘Post-Construction Runoff Control’, and Fact Sheet 2.8 – ‘Pollution Prevention/Good Housekeeping’. Finally, Fact Sheet 2.9 – ‘Permitting and Reporting: The Process and Requirements’ discusses how to apply for a NPDES permit, how the conditions of the permit must be satisfied, and the required periodic reports on the status and effectiveness of the program.

The second group of dischargers, operators of small construction activities that disturb from one to five acres of land, are addressed in Fact Sheet 3.0 – ‘Small Construction Program Overview’. This fact sheet clearly identifies who is covered under

Phase II construction rules and what the Phase II construction program requires to ensure compliance. The requirements for Phase II are similar to the three general requirements in Phase I in that: i.) a notice of intent must be submitted, ii.) a storm water pollution prevention plan must be developed and implemented to reduce pollutant discharges, and iii.) a notice of termination must be completed when final stabilization of the site is achieved.

2.3 BEST MANAGEMENT PRACTICES (BMPS)

BMPs are operational activities, structural and non-structural controls, and maintenance procedures used to reduce the discharge of pollutants and minimize the impact on the receiving waters (U.S. EPA, 2004b). During the initial development phase of this research effort, it was necessary to gain a thorough knowledge of the various BMPs implemented on construction sites. This included developing an understanding of the varying applications for each BMP, their overall effectiveness in these uses, and the proper installation techniques and maintenance procedures. The *Alabama Handbook for Erosion Control* and the *Manual for Erosion and Sediment Control in Georgia* both provide extensive background information on these subjects and are quite similar in content. Both handbooks contains detailed descriptions of numerous temporary BMPs used for site preparation, surface stabilization, runoff conveyance, sediment control, storm water management, and stream protection.

While conducting the initial site investigation, the *Alabama Handbook for Erosion Control* was used as the benchmark in determining whether the BMPs located on the highway construction site were properly designed, correctly installed, and properly maintained. The site visits revealed that highway construction projects implement a multitude of temporary erosion control measures. However, the use of silt fence as a sediment barrier at the base of fill slopes appears to be the most widely used BMP and also the most ineffective due to improper design, installation, and maintenance. As a result, this research effort focuses on evaluating the overall effectiveness of silt fence tieback installations in reducing sediment transport off highway construction sites.

2.4 SILT FENCES

Silt fences are small temporary structures typically constructed of geotextile filter fabric supported by steel or wood posts. Silt fences are installed to prevent sediment carried by sheet flow from construction sites from entering the natural or storm drainage system. In order to be successful, the silt fence must be installed in a manner creating a containment system that allows suspended particles to be deposited. As a result, proper installation and rigorous maintenance are essential (Fifield, 2004).

Alabama is unique in that it specifically tailors its erosion control resources to two specific groups: i.) planners and designers and ii.) developers, contractors, and inspectors. In fact, the State has divided the previous handbook into two volumes catering to the specific needs of the above mentioned groups. The *Alabama Handbook for Erosion Control: Volume 1* contains information essential for planners and designers in developing sound engineering plans and designs. The *Alabama Handbook for Erosion Control: Volume 2* provides information for developers, contractors, and inspectors in regard to proper installation methods and maintenance procedures.

In regards to design considerations, the first volume identifies recommended usages of silt fences, drainage basin and slope limitations, and the geotextile fabric specifications. The recommended application of a silt fence in the handbook emphasizes using silt fence in areas where only sheet flow is expected and not concentrated flow. The drainage basin limitations are ¼ acre per 100 ft. for non-reinforced silt fence and ½ acre per 100 ft. for wire reinforced silt fence. The maximum slope length above the fence ranges from 100 ft. on slopes less than 2%, to 15 ft. on slopes greater than 20% (Alabama Soil and Water Conservation Committee, 2003a). Finally, the silt fence used on projects in the State of Alabama must meet the following material specifications:

Table 2.1 Geotextile Fabric Specifications

Specification	ASTM	Type A	Type B	Type C
Tensile Strength (lbs)	ASTM D-4632	Warp – 260 Fill – 100	Warp – 120 Fill – 100	Warp – 120 Fill – 100
Elongation (% max)	ASTM D-4632	40	40	40
Apparent Opening Size (AOS) (max sieve size)	ASTM D-4751	No. 30	No. 30	No. 30
Flow Rate (gal/min/sq. ft.)	GDT-87	70	25	25
Bursting Strength (psi)	ASTM D-3786	175	175	175
Minimum Fabric Width (in.)		36	36	22

Source: *Alabama Handbook for Erosion Control: Volume 1*

The Alabama *Handbook for Erosion Control: Volume 2* provides information for developers, contractors, and inspectors in regard to proper installation methods and maintenance procedures. The following recommendations are given for maximizing the effectiveness of silt fence on construction sites:

1.) Install silt fence on the contour in order to intercept runoff as sheet flow and to flare the ends uphill to provide temporary storage of water.

2.) Place silt fence in locations where runoff generated from disturbed areas must pass through the silt fence.

3.) Avoid the placement of silt fence across concentrated flow areas such as channels, ditches, or waterways.

4.) Locate silt fence far enough away from the toe of slope as to provide a long flat area for storage capacity of sediment.

Finally, the *Alabama Handbook for Erosion Control: Volume 2* recommends implementing the following maintenance procedures on construction sites in order to improve silt fence effectiveness:

1.) Inspect silt fences weekly and after each significant rain event.

2.) Promptly replace collapsed silt fences and torn or decomposed fabric.

3.) Remove sediment deposits when they reach a depth of 15 in. or approximately half the height of the silt fence.

A photograph and description of a properly installed and maintained silt fence is included in Appendix A.

2.5 SILT FENCE TESTING MODELS, METHODS, AND TRAPPING EFFICIENCIES

The U.S. EPA (1993) released quantitative trapping efficiencies for numerous sediment control practices including silt fence. Based on data from three research studies (Munson, 1991; Fisher et al., 1984; and Minnesota Pollution Control Agency; 1989), the

EPA determined the average percent removal for TSS for silt fence installations to be 70%. From the abovementioned research studies, the EPA observed silt fence trapping efficiencies ranging from 0 to 100%, with an 80 to 99% for sands, 50 to 80% for silt loam, and 0 to 20% for silt clay loam. The trapping efficiencies cited had two design constraints: i.) that the maximum drainage area be limited to half an acre per 100 ft. of silt fence, and ii.) that the silt fence is not installed in areas where concentrated flow exists (U.S. EPA, 1993).

Robichaud et al. (2001) conducted a field study of an agricultural hillslope erosion plot at the Agricultural Research Service Palouse Conservation Field Station in Washington. In the first year, the runoff and sediment data with a silt fence installed on an uncultivated agricultural plot (11 m in length and 1.8 m wide) was collected after each runoff event. For this test, the overall trap efficiency, as measured on an individual storm basis, was 93%. During the second year, the runoff and sediment data with the silt fence installation on the same plot (22 m in length by 3.6 m wide) was collected only at the end of the season. The seasonal trapping efficiency obtained in this test was 92%.

Robichaud and Brown (2002) developed easy to install, low cost techniques for testing and measuring hillslope erosion using silt fence and tipping rain gauges. The methods developed are useful in comparing the erosion rates of various silvicultural treatments, farming practices, grazing systems, road or trail erosion, wildfires, and natural rates of erosion. In their research, four typical test plot layouts were designed that illustrated the contributing areas, silt fence configurations, and methods to define upper boundaries. Using these layouts as a design basis, a series of tables were compiled that calculated the storage volume behind the silt fence for various slopes (5 to 70%), silt fence heights (0 to 2.5 ft.), and silt fence width combinations (10 to 50 ft.). The design assumes that the silt fence installations along the contour will be installed so that the ends of the trough gently curving back up the slope to prevent runoff from bypassing around the silt fence. In the end, the researchers developed future testing suggestions for determining the erosion amounts within a timber sales unit, the erosion rates for two seeding mixes after a wildfire, and the erosion amounts from a prescribed wildfire and a control, or no fire. However, the research effort does not validate any of the storage volume capacities calculated in the design tables with any field testing data.

Barrett et al. (1995) conducted testing on silt fence removal efficiencies in laboratory flume studies. The laboratory testing apparatus consisted of an elevated water supply tank, a mixing tank, and a steel flume. In this research, four types of silt fences were installed into a 61 m. long flume that is 0.76 m. wide and 0.6 m. deep with a 0.33% slope. The silt fences were installed approximately 7.6 m. from the mixing tank which allowed for a large ponded area to build behind the control section. This installation created temporary storage that resulted in large detention times and the ability for small fines to settle out of solution. A limitation of the study is the inability for the model to account for water losses due to infiltration. Using the steel flume as a barrier does not allow water to infiltrate and therefore increases the amount of flow occurring through the silt fence in the flume. The mean removal efficiencies of the testing in the flume ranged from 68% to 90%. A strong correlation was observed between the detention time of the runoff, and the total removal efficiency of the silt fence. As a result, recommendations were made to locate and install silt fences on construction sites in areas that maximize the potential for ponding to occur behind the silt fence. In conclusion, the authors state that a properly installed and maintained silt fence can reasonably attain a removal of 85%.

In addition, Barrett et al. (1995) evaluated the performance of silt fence in removing TSS and turbidity reductions during storm events on highway construction projects. A highway construction project was selected and six silt fence installations with easy availability, proper installation configuration, and with moderate flows or retention volumes were identified for evaluation. To establish the efficiency of the geotextile silt fence, the researchers compared the particle loading of the upstream pond and effluent downstream of the silt fence. The median removal efficiency was 0% with a standard deviation of ±26%. The results showed individual sampling efficiencies ranging from -61% to 54% with the negative value indicating an increase in TSS. In regards to turbidity reduction percentages, the testing revealed a 2% median removal with a standard deviation of ±10%. The turbidity removals ranged between -32% and 49%. The negative values calculated for both removal efficiency and turbidity removal limit the effectiveness of the study. The negative values were attributed to in-situ sampling error, disturbance of sediment during collection, and commingling of filtered and unfiltered flows on the down slope side of the silt fence.

Barrett et al. (1995) summarized the results obtained in the laboratory flume studies and field testing and offered the following conclusions. It is apparent that there is a huge discrepancy between results obtained in small-scale testing and actual field conditions. Part of the disparity is attributed to a difference in particle size distribution in the slurry mixtures tested on the flume in comparison with the particle size distribution on the construction sites. In addition, the researchers cite that the removal efficiencies are primarily dependent on detention time and that there were numerous installation and maintenance deficiencies observed during the field testing. Holes in the geotextile fabric and undercutting of the silt fence greatly reduce the detention time of the storm water runoff, thereby reducing the removal of suspended solids. In addition, these deficiencies allow the runoff to become concentrated, resulting in higher velocities and greater erosion. This study underscores the inherent complexity and multitude of factors that affect field data, making it difficult to model erosion accurately.

Wyant (1981) developed tests used for the formulation of specifications for purchasing filter fabrics to be used in silt fence applications. In total, seven tests were conducted on fifteen fabrics to evaluate their overall performance. Filtering efficiency was one of the tests and was determined by conducting laboratory testing in a flume with an 8% slope and a sediment laden mixture of 3000 ppm. The study does not go into detail as to the flume setup configuration and fails to mention if infiltration was accounted for in the laboratory apparatus. From the simulations, Wyant concluded: i.) with sandy soil the filter efficiencies of the various materials ranged from 92 to 99% with an average of 97%, ii.) with a silty soil the filter efficiencies ranged from 49 to 100% with an average of 92%, iii.) with a clayey soil the filter efficiencies ranged from 85 to 99% with an average of 95%.

Jiang et al. (1997) developed an equation representing the relationship between water discharge through the filter fabric and the hydraulic head upstream of the silt fence using various fabric parameters. The flow rate through the openings is the same at a given elevation, but different through openings at different elevations. The higher the hydraulic head, the higher the resulting flow rate. Applying Bernoulli's equation, a formula between head and discharge for filter fabric fence was developed. The equation is useful in either estimating the amount of flow that can be handled by the fabric before overtopping occurs or in calculating how high the silt fence should be in order to hold a given discharge.

In research conducted for the U.S. EPA, a Silt Fence Testing Site was constructed at the USDA-ARS Water Conservation Structures Laboratory in Stillwater, Oklahoma (U.S. EPA, 2004a). The test facility involved the construction of a 20 ft. wide by 40 ft. long fill area, referred to as the source area in the document, and a rainfall simulator. The source area was constructed at a constant 5% slope. The area between the end of the source area and the silt fence was approximately 20 ft. long at a 3:1 slope. This allowed the researchers to vary the slope of silt fence installed in this area from 0 to 14%. The rainfall simulator used four rows with seven nozzles per row for rainfall coverage and was built on a 5% slope, 10 ft. above the source area. The simulator was designed to deliver between 1 and 3 in./hr. of rainfall. Finally, the upslope and down-slope discharges were collected at the end of the silt fence into two sheet metal troughs. The flows were collected in a sump using buckets from which test sampling was conducted. A series of 18 tests were conducted under controlled test conditions, with simulated rainfall, and using commonly used silt fence materials to simulate conditions typically found on construction sites. From the testing, the researchers found that there is a strong natural randomness to the processes that control sediment detachment and transport. The rates of sediment production varied despite the fact that the slope and source area remained constant between tests with only minor fluctuations in the rainfall rates between tests. Despite this finding, there were a few trends observed during the testing to include:

i.) the concentration of sediment in the toe of the trench increased as slope increased, ii.) failure along the toe occurred as expected for the various soil types, and iii.) the looser the geotextile weave the higher the concentration passing through the fence.

2.6 SUMMARY

In order to minimize the impact of storm water runoff from highway construction projects, it is possible to implement both erosion control and sediment control measures. The scope of this research effort focuses on improving sediment control along highway construction projects using properly designed, correctly installed, and rigorously maintained silt fence installations. While conducting the literature review, it was found that Barrett et al. (1995), Robichaud (2001), and U.S. EPA (2004a) discuss the importance of tying silt fence installations back into the contour essentially creating small sediment basins to trap sediment, allowing it to settle out of suspension. However, it appears that there is a gap in the body of knowledge as to the proper placement of silt fence tiebacks along highway construction projects. Additionally, the literature review revealed a lack of erosion control research in which a small-scale erosion control model was used to attain mass balance and account for flow along the toe of silt fence, flow through the silt fence, infiltration, and the rainfall that falls off of the model. As a result, the primary and secondary research goals for this project were developed.

CHAPTER THREE

SITE INVESTIGATIONS

3.1 INTRODUCTION

In order to obtain a better understanding of the erosion process, to identify commonly utilized BMPs, and to evaluate the overall effectiveness of the various BMPs, the first stage of the research focused upon conducting a field investigation of highway construction sites. Although highway construction projects employ a multitude of erosion control measures, the use of silt fence as a sediment barrier at the base of fill slopes along the right-of-way (R.O.W.) boundary appeared to be the most utilized BMP on highway construction projects. In addition to being the most widely used BMP, silt fence installations were observed to be the most ineffective. In most cases, this erosion control boundary is usually the last erosion control measure installed preventing the sediment generated on a construction site from entering the surrounding stream network. The primary functional responsibility of silt fence installations is to reduce the impact of sediment pollution on the environment, wildlife species, and adjacent property owners. The field observations and data collected from these construction sites was incorporated into the preliminary planning of our small-scale erosion control model.

3.2 SITE INVESTIGATIONS

While conducting the site investigations and an internet query, it quickly became apparent that silt fences typically fail in one of five different modes. The first failure mode occurs when the watershed area above the silt fence generates more storm water runoff than the available storage volume located directly behind the silt fence. In this case, the storm water runoff overtops the silt fence as depicted in Figure 3.1.

Figure 3.1 Failure Mode: Watershed Too Large.
(Photo Courtesy of: Tommy, 2005)

A second failure mode occurs when silt fence is installed in long, linear runs and the storm water runoff accumulates at the toe of the silt fence resulting in concentrated flow, higher velocities, and increased erosive abilities. The increase in water velocity can cause the toe to be undercut, allowing sediment to pass under the silt fence as illustrated in Figure 3.2.

Figure 3.2 Failure Mode: Undercutting of the Toe.
(Photo Courtesy of: Tommy, 2005)

Another common failure mode occurs when the silt fence is not tied into the contour properly. In Figure 3.3, there was an effort to tie the silt fence back; however, the tieback was not installed to an elevation equal to the top of the silt fence at the toe of slope. As a result, the sediment accumulated until it reached an elevation at which point it bypassed the silt fence onto the adjacent property owner's land.

Figure 3.3 Failure Mode: Tie to the Contour.

The fourth failure mode frequently occurs over a period a time when multiple storm events cause a large amount of sediment to accumulate at the face of the silt fence as illustrated in Figure 3.4. This deficiency is easily corrected through the implementation of a rigorous maintenance program in which the sediment is removed after it reaches one-third to one-half the height of the silt fence (U.S. EPA, 2005).

Figure 3.4 Failure Mode: Improper Maintenance.

The final failure mode occurs primarily when installers do not follow the silt fence installation guidelines provided by various local or state agencies. In Figure 3.5, it is clear that the sediment barrier has not been installed correctly. In fact, it looks as if little to no effort was exerted in this installation rendering the silt fence completely ineffective.

Figure 3.5 Failure Mode: Improper Installation.

3.3 CONCLUSION

Of the five major failure modes, the last two are dependent upon the vigilance of the owner, contractor, engineer, and inspector of the construction project. However, the first three failure modes primarily occur because of improperly designed silt fence installations. The incorporation of silt fence tiebacks, essentially turning the silt fence back upslope at predetermined intervals along fill slopes, can address all three of these failure modes on typical highway construction projects. In practice, there is a definite need for the development of silt fence tieback design guidelines that can be used by designers and inspectors to assist in the proper placement and installation of silt fence tiebacks along highway construction projects.

In order for the design guides to be effective, they need to directly address the three failure modes identified in the site investigation. An effective silt fence tieback design must: i.) properly size the upslope watershed, ii.) attain a balance between the storm water runoff volume and the computed storage capacity of the silt fence per unit length of silt fence installation, and iii.) demonstrate how to properly anchor the silt fence tieback into an elevation equal to the top of the fence at the toe. If implemented correctly, the silt fence tiebacks will essentially act as a small sediment basin for retaining storm water runoff and allowing sediment to settle out of suspension thereby reducing the sediment leaving highway construction projects and entering the natural waterways.

CHAPTER FOUR

SMALL-SCALE EROSION CONTROL MODEL DESIGN PROCEDURE

4.1 INTRODUCTION

The primary objective of this research effort was to construct a small-scale erosion control model that models typical highway construction sites, accommodates the simulation of varying rainfall intensities, and ultimately allows for the extensive testing of various temporary erosion control BMPs utilized on highway construction sites. While developing the conceptual plans for the small-scale erosion control model, there were a multitude of factors that were considered. The major factors considered in the preliminary, conceptual stages of the design process included: i.) replicating as closely as possible a typical cross section of a roadway construction project, ii.) creating a very diversified model that allowed for the testing of multiple temporary erosion control BMPs, iii.) developing a rainfall simulator with the capacity to test various rainfall intensities and storm events, iv.) allowing for the testing of any type of base soil material, v.) incorporating the ability to test varying vertical road profiles and ditch slopes, and vi.) factoring in the ease of overall construction, available space requirements, and approximate development costs. As in most designs, some of the factors conflict with each other forcing the design team to weigh the competing interests. Multiple designs were considered during the iterative design process that resulted in the development of a well designed, multi-functional, and cost efficient erosion control model.

4.2 SMALL-SCALE EROSION CONTROL MODEL

The final design of the small-scale erosion control model included four distinct components: i.) the typical roadway cross section, ii.) the rainfall simulator, iii.) the base soil materials, and iv.) the temporary erosion control BMPs.

4.2.1 Typical Roadway Cross Section Development Process

The development of the model's typical roadway cross section involved the selection of a realistic roadway cross section, the development of an adequate scale and model dimensions, the drafting of design drawings, and the final construction of the model.

4.2.1.1 Typical Cross Section Selection Criteria

The first consideration in the design of the small-scale erosion control model focused upon selecting a rural, two lane, typical roadway cross section readily found on a highway construction project in the State of Alabama. To get a representative sample of the typical cross sections used within the State, standard details used by the Alabama Department of Transportation (ALDOT), the Lee County Highway Department, and the City of Auburn were reviewed for typical rural, two lane roadway cross sections. Figures 4.1, 4.2, and 4.3 represent the typical cross sections used at all three levels respectively.

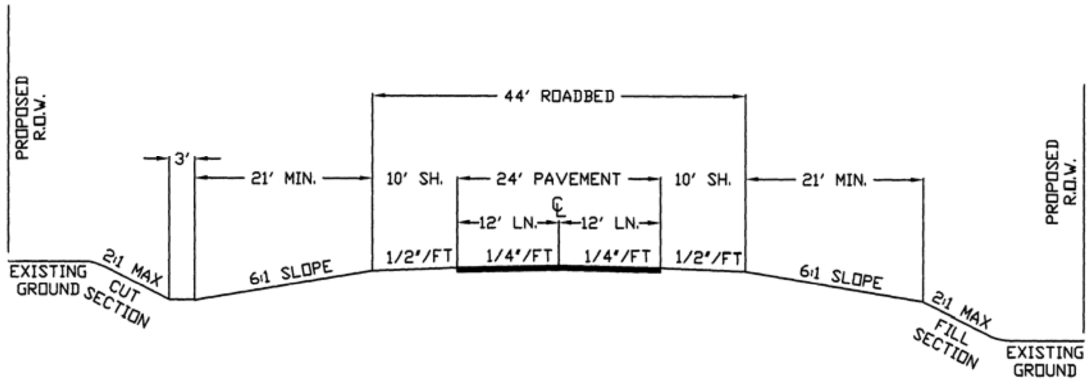


Figure 4.1 ALDOT: Rural, Two-Lane, Typical Cross Section.
(Source: ALDOT)
Not to Scale

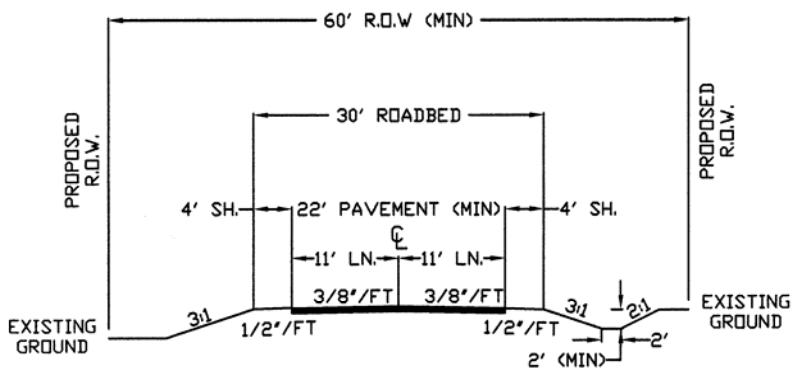


Figure 4.2 Lee County: Rural, Two-Lane, Typical Cross Section.
(Source: Lee County Subdivision Regulations)
Not to Scale

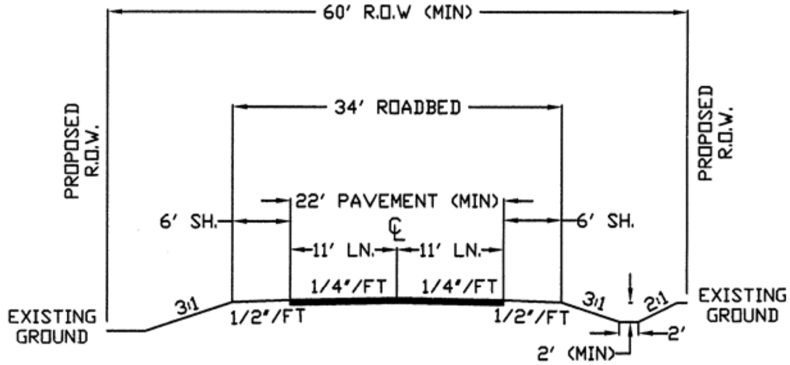


Figure 4.3 City of Auburn: Rural, Two-Lane, Typical Cross Section.
(Source: Auburn Subdivision Regulations)
Not to Scale

The design for the final test model was finalized using these three typical cross sections as a guide. The physical boundaries of the test model are represented by an upper boundary depicted by the centerline of the roadway and a lower boundary depicted by the R.O.W. The first consideration involved choosing a width and slope to model the roadway. After analyzing the three typical sections, an 11 ft. travel lane at a 2% cross slope was chosen to model the asphalt road surface. This is a standard width and slope used by ALDOT and the City of Auburn. The next consideration involved selecting a width and slope for the shoulder. A final width of 4 ft. with a 2% cross slope was selected to depict the gravel shoulder. Despite ALDOT's recommended use of a 10 ft. shoulder, the 4 ft. shoulder was selected because it is more representative of the majority of rural roads in the road network. Additionally, the cross slope was modified from the recommended 4% to 2% in order to ease the construction of the test model. Using a 2% slope, only one deck was required for the construction of the road and shoulder surface.

To model the fill slope, a compromise between the ALDOT 6:1 fill slope that extends for 21 ft. followed by a 2:1 fill slope to existing ground was selected. The research team chose to use a uniform 3:1 fill slope from the edge of the shoulder to natural grade. This is representative of the standard specified in the Lee County and City of Auburn typical section and will also make the construction of the test model easier as only one deck will need to be constructed for the fill slope. Additionally, the research team selected an existing ground slope of 2% from the toe of the fill slope to the R.O.W limit. Finally, the R.O.W. width was set at 100 ft. A schematic of the final typical section selected for the construction of the small-scale erosion control model is shown in Figure 4.4.

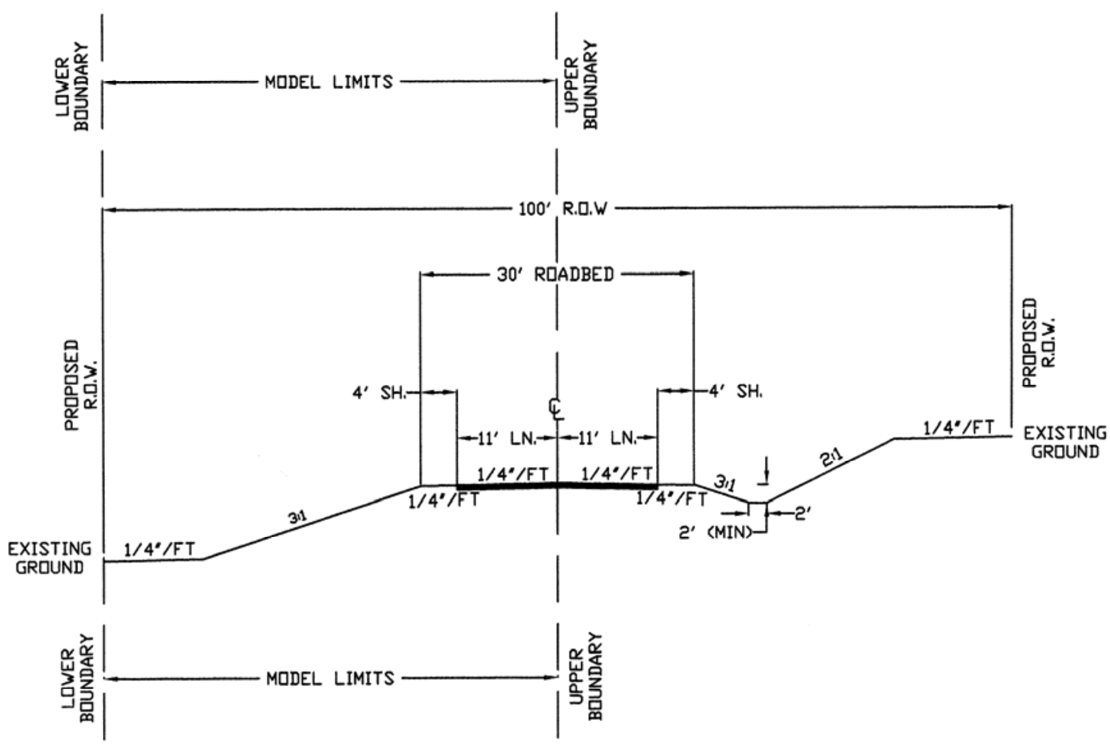


Figure 4.4 Small-Scale Erosion Control Model Typical Cross Section. (Not to Scale)

4.2.1.2 Model Scale and Dimensions

The next step in the development of the small-scale erosion control model focused on determining an adequate scale and final model dimensions. To take advantage of standard construction material lengths (8 ft. lengths), a scale of 1:6 was chosen to construct the small-scale erosion control model. The model's overall dimensions are 8 ft. by 8 ft. and represent a full-scale size of 48 ft. wide by 48 ft. long. The model will be constructed with the assumption that the upper boundary starts at the centerline of the road and extends to 2 ft. short of the R.O.W. This discrepancy is relatively insignificant due to the fact that silt fence is typically installed with a 2 to 5 ft. offset from the R.O.W. boundary on construction projects. Therefore, the last 5 ft. of the typical section do not necessarily need to be modeled on the small-scale erosion control model.

4.2.1.3 Model Components

The main structural components of the small-scale erosion control model consist of the roadway deck, the fill slope deck, the natural grade deck, the splash guard and rainfall overflow collection system, the infiltration collection system, the toe of slope collection system, and the down-slope (through fence) collection system. A set of detailed construction drawings, a bill of materials, and a cost estimate were drafted, revised, and finalized prior to beginning the construction phase. Figure 4.5 and Figure 4.6 contain the elevation and plan views of the construction drawings for the small-scale erosion control model.

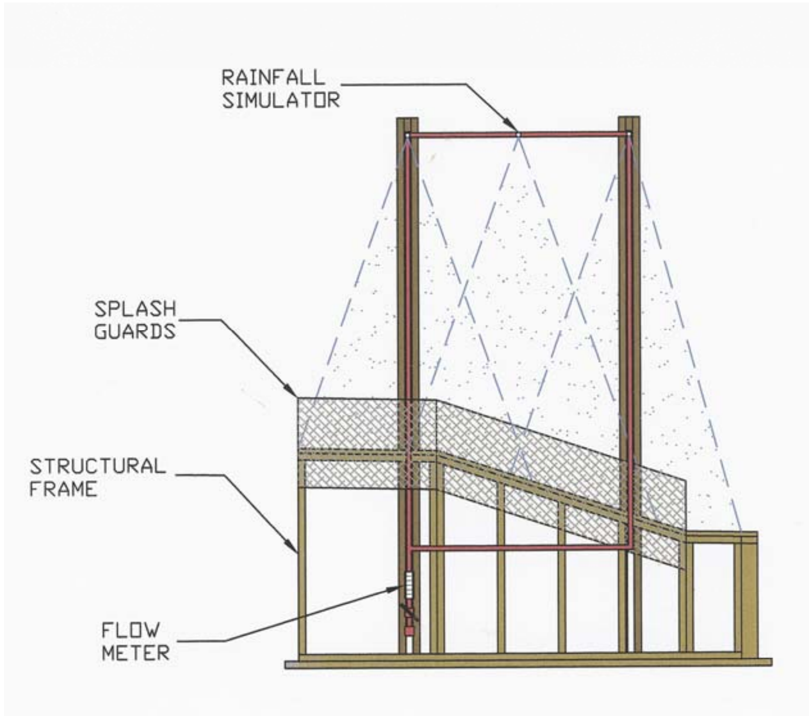


Figure 4.5 Small-Scale Erosion Control Model Elevation View.

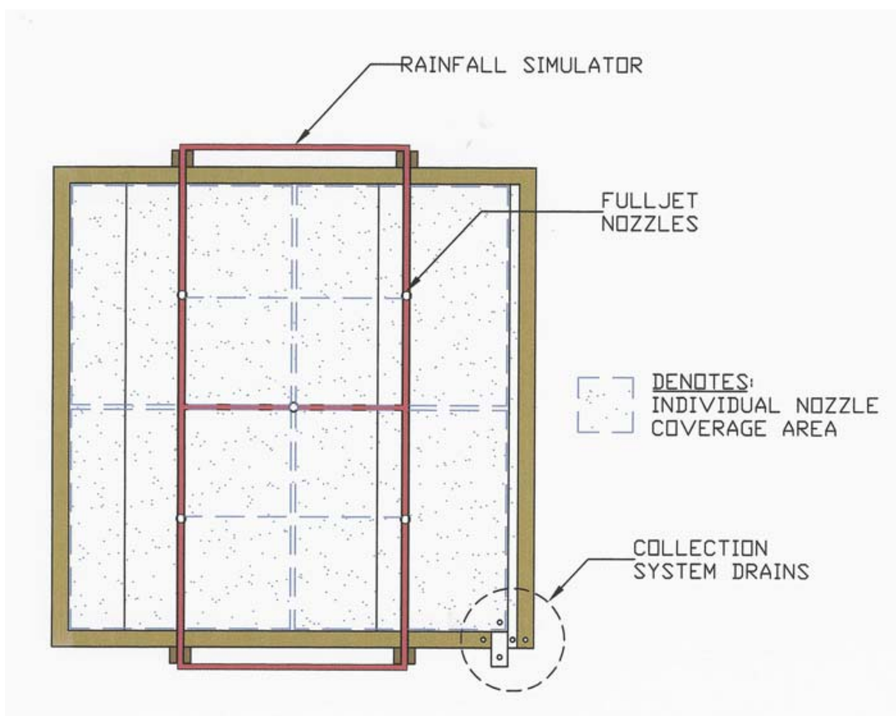


Figure 4.6 Small-Scale Erosion Control Model Plan View.

The bill of materials and cost estimate for the construction of this project is shown in Figure 4.7.

MATERIAL BILL OF MATERIALS & COST ESTIMATE FOR 8' x 8' SMALL-SCALE EROSION CONTROL TEST FACILITY:

Cross Section Material	Quantity	Units	Cost/Unit	Total
4' x 8' x 5/8" Plywood	4	SHEET	$16.95	$67.80
2" x 4" x 8'	50	EA	$2.83	$141.50
2" x 4" x 10'	12	EA	$3.67	$44.04
2" x 8" x 10'	2	EA	$7.95	$15.90
1" x 2" x 8'	1	EA	$1.09	$1.09
1" x 3" x 8'	2	EA	$1.35	$2.70
2" x 4" x 10' C-Channel	6	EA	$3.29	$19.74
1" x 2" x 10' C-Channel	1	EA	$0.00	$0.00
Pond Liner (8' x 12')	1	EA	$70.16	$70.16
Asphaltic Roll	1	EA	$15.59	$15.59

Rainfall Simulator Material	Quantity	Units	Cost/Unit	Total
3/4" x 10' PVC Pipe	6	EA	$1.69	$10.14
1/4" Square Fulljet Sprinkler Heads	4	EA	$0.00	$0.00
3/4" Threaded PVC Tee	4	EA	$0.44	$1.76
3/4" to 1/4" Brass Adapter	4	EA	$2.07	$8.28
3/4" 90º PVC Elbow	10	EA	$1.50	$15.00
3/4" PVC Tee	10	EA	$1.90	$19.00
3/4" PVC Coupling	10	EA	$1.10	$11.00
3/4" Gate Valve	1	EA	$2.94	$2.94
3/4" Female Adapter	1	EA	$1.74	$1.74
1" x 10' PVC Pipe	2	EA	$1.34	$2.68
1" 90º PVC Elbow	9	EA	$0.39	$3.51
1" PVC Tee	1	EA	$0.31	$0.31
Zip Ties	1	EA	$8.72	$8.72
PVC Primer	1	EA	$6.60	$6.60
PVC Cement	1	EA	$7.27	$7.27
Plumber's Tape	1	EA	$1.00	$1.00
0-5 GPM Flow Meter	1	EA	$75.00	$75.00
50' Hose	1	EA	$17.97	$17.97

Soil Material	Quantity	Units	Cost/Unit	Total
Porous Media - EZ Flow	1	CY	$0.00	$0.00
Clay	1	CY	$12.00	$12.00
Sand	4	CY	$22.00	$88.00

Erosion Control Material	Quantity	Units	Cost/Unit	Total
Filter Fabric (8' x 8')	1	EA	$0.00	$0.00
Silt Fence Fabric	24	LF	$0.00	$0.00
Silt Fence Stakes	3	EA	$1.78	$5.34
Silt Fence Wire Mesh	1	EA	$31.38	$31.38

Miscellaneous Material	Quantity	Units	Cost/Unit	Total
3" Wood Screws (5lb)	1	EA	$19.22	$19.22
2" Wood Screws (1lb)	1	EA	$4.11	$4.11
1 5/8" Wood Screws (1lb)	1	EA	$4.11	$4.11
Liquid Nails	9	EA	$1.97	$17.73
Silicon	2	EA	$3.47	$6.94
3 Gallon Bucket	30	EA	$0.97	$29.10
5 Gallon Bucket	6	EA	$4.00	$24.00
10' x 12' Tarp	1	EA	$10.97	$10.97
1/4" Wire Mesh	1	EA	$6.98	$6.98

Total Cost	$831.32
(+/- 10%)	$83.13
Budgeted Cost	$914.45

Note:
Donated Items (shaded)

Figure 4.7 Bill of Materials and Cost Estimate.

4.2.1.4 Model Construction

The construction of the small-scale erosion control model began with the creation of five modular wood frames. These five frames formed the structural framework for the entire project and will bear the entire loading due to the self weight of the model, the weight of the subbase material, and any applied live loads. Each frame consisted of three distinctively different sections (the roadway section, the fill section, and the existing grade section). The outer two structural frames were built to match the final surface elevations of the model. The inner three structural frames required more detailed attention in order to ensure each of the three sections accounted for the various depths of the decking above it and the depths of all material placed above.

After the completion of the structural frames, work began on the creation of the decking system. The roadway deck was the first deck constructed. Using an 11 ft. roadway with a 4 ft. shoulder as illustrated in the typical road cross section and the 6:1 scale, the small-scale measurements of the roadway deck are 30 in. × 96 in. The roadway was installed onto the structural frames at the 2% cross slope and the entire deck was covered with an impervious rolled asphalt roofing material which mimics an impervious asphaltic surface.

The fill slope deck was fabricated next at a small-scale of 57 in. × 96 in. This represents a 9 ft. full-scale fill condition. This deck was installed on the 3:1 fill slope illustrated in the typical road cross section. Additionally, this deck was installed 6 in. lower than the roadway deck to allow for the later installation of 3 in. of porous media and 3 in. of subbase soil material.

Finally, the existing grade deck was constructed at a small-scale of 12 in. × 96 in. This deck simulates tying the fill slope back into the existing grade on the highway construction project approximately 6 ft. prior to the R.O.W. Similar to the fill slope deck, the existing grade deck was installed 6 in. lower than the final grade to allow for the later installation of 3 in. of porous media and 3 in. of subbase soil material. Figure 4.8 contains a photograph of the isometric view of the model during the first stage of construction with the structural frames and decks complete.

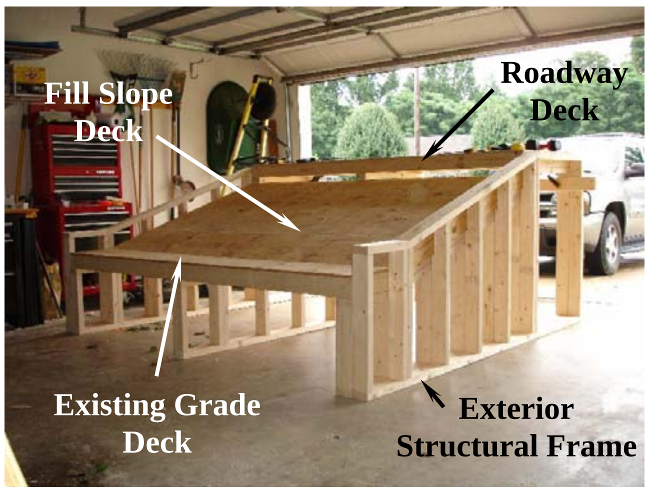


Figure 4.8 Structural Frames and Decking.

The next phase of the construction process involved the creation of a front structural wood frame, weather proofing the subbase area of the test model with plywood, and installing the splash guard and collection system. The function of the front structural wood frame is two-fold acting both as a barrier enclosing the front of the subbase soil area and as a frame to support the front portion of the rainfall overflow collection system. The subbase area of the test model consists of the area where the soil for this model will be located. Due to the fact that the structural frames do not provide containment, plywood was used to weather proof the subbase soil area. Finally, the model was designed with 12 in. tall splash guards to capture all moisture from the rainfall simulator that does not fall directly onto the test bed. Water droplets falling off of the model will hit the splash guards and be directed to a rainfall overflow collection system. This rainfall will be collected and accounted for in the final mass balance. Figure 4.9 depicts another isometric view of the model in the second phase of construction. Figure 4.9 shows the front structural frame complete, the back splash guard installed, and the rainfall overflow collection system in place.

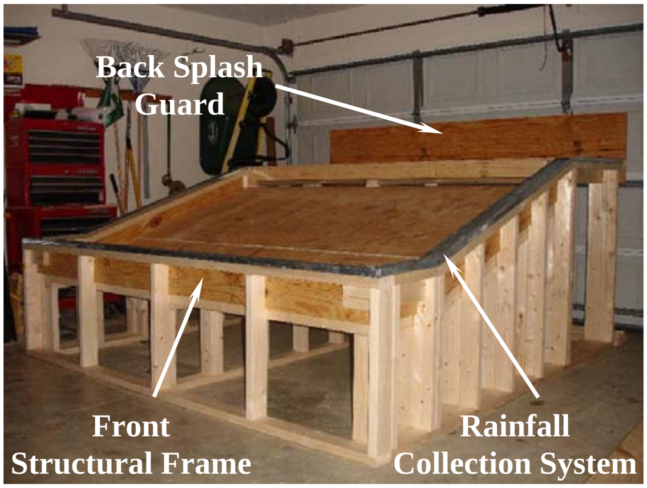


Figure 4.9 Front Frame, Splash Guard, and Rainfall Overflow Collection System.

The final phase of the cross section construction consists of installing the roadway surface material, waterproofing the subbase area, and sealing the splash guards and rainfall overflow collection system. First, an impervious asphalt roll of roofing material was selected and installed to simulate an asphaltic roadway surface. Next, the inside of the model bed area and the face of the splash guards were lined with a 12 mil plastic pond liner. Finally, all seams within the model bed area and the rainfall overflow collection system were sealed with caulking to ensure that the entire model was watertight. Figure 4.10 shows a portion of the model with the final installed roadway surface, the model bed area and splash guards lined with 12 mil plastic, and the applied caulking.

Figure 4.10 Roadway Surface, Waterproofing, and Sealing.

In order to ensure mass balance in the model, the research team designed and incorporated a rainfall overflow collection system, an infiltration collection system, a toe of fence collection system, and a down-slope (through fence) collection system. The infiltration collection system was included to monitor the infiltration rates of the subbase soil material. Within the model, the rainfall that infiltrates the soil material will be collected in a drain installed in the lowest corner of the model. Additionally, the model will collect runoff flowing along the toe of the fence. Finally, a collection trough for the runoff that permeates through the silt fence and off the R.O.W. was installed at the end of the existing grade. Figure 4.11 and Figure 4.12 illustrate a plan and elevation view of the collection points for all four collection systems (rainfall, infiltration, toe of fence, and through fence).

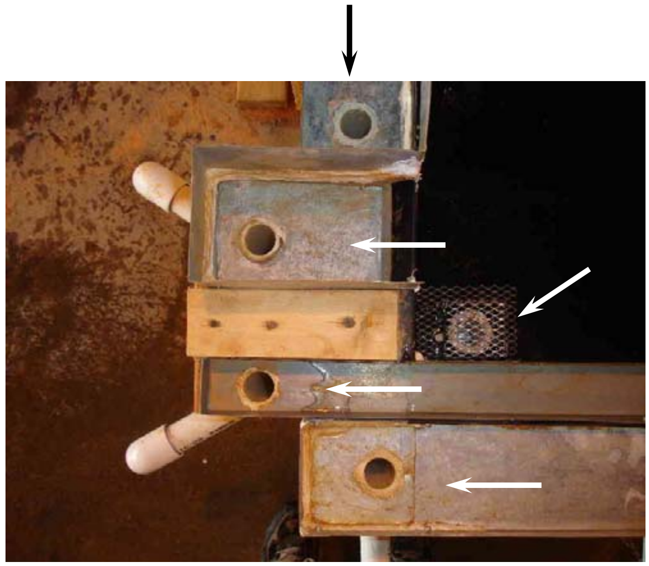


Figure 4.11 Rainfall Infiltration, Toe of Fence, Through Fence Collections Systems (Plan View).

Figure 4.12 Rainfall, Infiltration, Toe of Fence, Through Fence Collection Systems (Elevation View).

4.2.2 Rainfall Simulator

The primary objective of a man-made rainfall simulator is to accurately simulate naturally observed rainfall events. To meet this goal, the following criteria must be met: i.) create a drop size distribution representative of natural rainfall, ii.) obtain a drop impact velocity near that of natural rainfall terminal velocity, iii.) attain uniform rainfall intensity and random drop size distribution, iv.) apply uniform rainfall over the entire test area, v.) achieve vertical angle of impact, and vi.) simulate reproducible storm patterns of significant duration and intensity (Blanquies, 2003). Most research projects use the Norton Ladder Type Rainfall Simulator as the standard for research involving rainfall simulation (Blanquies, 2003). The Norton Ladder Type Rainfall Simulators were developed at the United States Department of Agriculture (USDA) Erosion Research Center at Purdue University. The simulator consists of a sweeping boom that oscillates by way of a cam. The intensity of the rainfall is computed based on the number of times the pressurized spray nozzles sweep past box openings which are configured to regulate spray pattern (Hallock, 2003). Although it is the industry standard, purchasing a Norton Ladder Type Rainfall Simulator is quite expensive. A rainfall simulator design created by another research team based on the Norton Ladder Type Rainfall Simulator cost approximately $7,000 (Blanquies, 2003). An alternative rainfall simulator utilizing high-pressured jet nozzles was constructed for erosion research conducted for the U.S. EPA at the USDA-ARS Water Conservation Structures Laboratory in Stillwater, Oklahoma (U.S. EPA, 2004a). The rainfall simulator used four rows with seven nozzles per row for rainfall coverage. The simulator was designed to deliver between 1 and 3 in./hr. of rainfall. Using the high pressured nozzle rainfall simulator developed at the USDA-ARS

Water Conservation Structures Laboratory as a guide, the design team designed a rainfall simulator with the capability of meeting the final three of the six main criteria listed above.

4.2.2.1 Rainfall Simulator Intensity

When designing the rainfall simulator storm intensity, the research team focused on modeling the effects of the first flush on construction projects. The first flush is defined as the washing action that storm water has on accumulated pollutants in the watershed. As the land surfaces, especially impervious surfaces, are flushed clean by the storm water there is a shock loading of pollutants (Alabama Soil and Water Conservation Committee, 2003a). Studies in Florida determined that the first flush equates to the first 1 in. of runoff which carries 90% of the pollution load in a storm (Alabama Soil and Water Conservation Committee, 2003a). The Georgia Stormwater Management Manual developed engineering criteria with the goal of treating 85% of the storms that occur in an average year. This level of treatment equates to providing water quality treatment for the runoff resulting from a rainfall depth of 1.2 in (Atlanta Regional Commission, 2001). Using the rainfall depth from the State of Georgia as a guideline, a two-year, 30 minute design storm was selected for the small-scale erosion control model. The rainfall depth resulting from this storm event is approximately 1.5 in. for the Auburn, Alabama area (U.S. Department of Commerce, 1963). Therefore, the rainfall intensity selected for the small-scale erosion control model is 3.0 in./hr. Although the design storm selected produces slightly more rainfall depth, this storm event will provide a fairly accurate representation of the typical storm intensity and duration that is targeted to improve water quality on construction projects. The selection of a 2-year, 30 minute design storm enabled the researchers to reproduce storm events satisfying the sixth criterion listed above for using a rainfall simulator to simulate natural rainfall events.

4.2.2.2 Rainfall Simulator Configuration

The next step in the design of the rainfall simulator included the selection of rainfall nozzles and the development of a rainfall apparatus configuration. This process was initiated with the intent of meeting three of the criteria listed above for using a rainfall simulator to simulate a natural rainfall event. The criteria include the ability of the rainfall simulator to apply uniform rainfall over the entire test area, achieve a vertical angle of impact, and simulate reproducible storm patterns of significant duration and intensity.

The construction of the rainfall simulator incorporated both the building of a rainfall simulator structure and a rainfall delivery system. The rainfall simulator structure is composed of four 10 ft. stands connected with support beams. This structure serves as the structural framework for the rainfall delivery system consisting of a female connection, a gate valve, a flow meter, water supply lines, five 1/8HH-3.6 SQ Fulljet nozzles, and various polyvinyl chloride (PVC) connections. Figure 4.13 shows a depiction of the rainfall simulator.

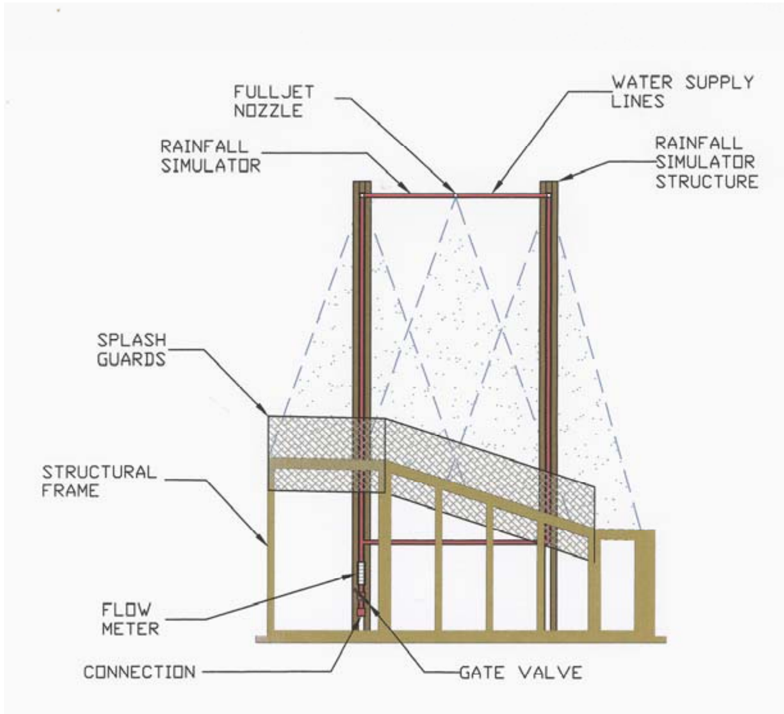


Figure 4.13 Rainfall Simulator Elevation View.

To identify the components of the rainfall delivery system, the description will begin at the point of flow origination and end at the nozzle discharge. The source of water for the rainfall simulator originates from a hose bib with a five gallon per minute (GPM) flow capacity and a 40 psi. operating pressure. A garden hose is used to connect the female threaded connection on the rainfall simulator to the hose bib. The flow entering the rainfall simulator can be controlled by a ¾ in. gate valve and measured using a flow meter. The hose, female connection, gate valve, and flow meter configuration is illustrated in Figure 4.14.

Figure 4.14 Rainfall Simulator Connection, Gate Valve, and Flowmeter.

For this project, a F-405 Series In-Line Flowmeter was purchased from Blue-White Industries, Ltd. The F-405 has a 0 to 5 GPM liquid flow rate with an accuracy of +/- 5%. A close up of the F-405 Series In-Line Flowmeter is provided in Figure 4.15 and the specifications for the F-405 Series In-Line Flowmeter are included in Appendix B.

Figure 4.15 F-405 Series In-Line Flowmeter.

The flow then enters the water supply lines consisting of ¾ in. PVC pipe and is discharged at the five 1/8HH-3.6 SQ Fulljet nozzles. The pipe network is looped to provide uniform flow within the system. Figure 4.16 provides an elevation view of the completed water supply system.

Figure 4.16 Water Supply System.

4.2.2.3 Nozzle Selection

Taking into consideration the final small-scale erosion control model's dimensions (8 ft. × 8 ft.), it was critical to find spraying nozzles that provided adequate coverage while providing the desired rainfall intensity. Several commercial nozzles were considered and the final nozzle selected for use in the model was a 1/8HH-3.6 SQ Fulljet nozzle. These nozzles are manufactured by Spraying Systems Co. and feature a solid cone-shaped spray pattern with a square impact area. The nozzles produce a uniform spray of medium to large drops across the entire spray area. The uniform spray distribution is attained through a unique vane design with large flow passages and superior spray control characteristics. A close up of the 1/8HH-3.6 SQ Fulljet nozzle is provided in Figure 4.17 and the specifications for the 1/8HH-3.6 SQ Fulljet nozzles are included in Appendix C.

Figure 4.17 1/8 HH-3.6 SQ Fulljet Nozzle.

For the rainfall simulator to adequately cover the entire test area, five nozzles were incorporated in three rows with a staggered offset design. The final nozzle configuration is shown in Figure 4.18 which depicts a plan view of the system.

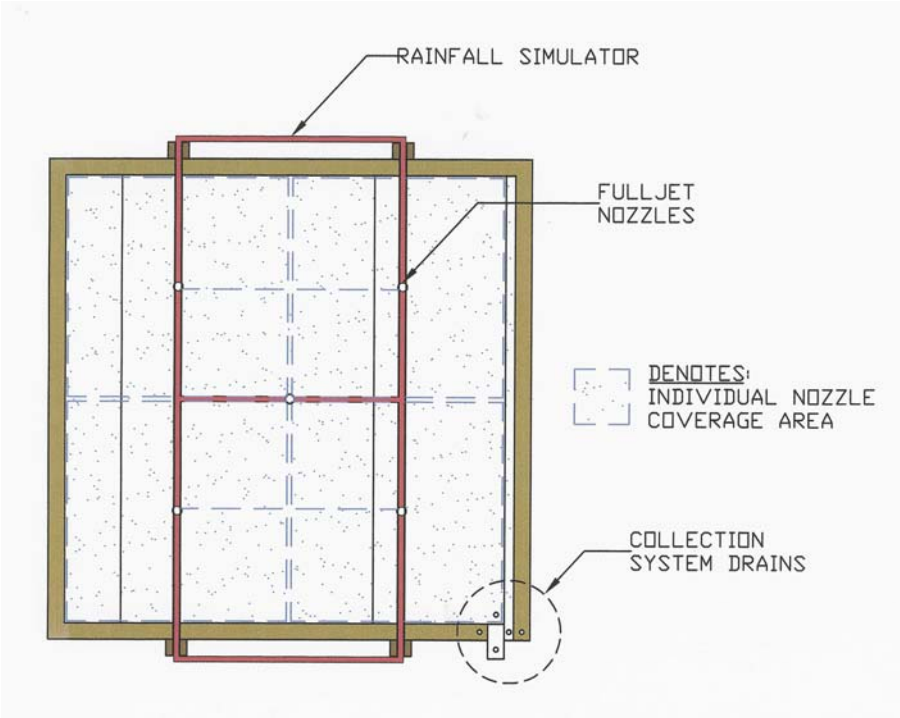


Figure 4.18 Nozzle Configuration (Plan View).

The initial design aimed at achieving a 4 ft. × 4 ft. square coverage area with each nozzle. To attain this coverage area, the nozzles were installed 60 in. above the roadway surface. However, the effects of gravity on the nozzle rainfall application reduced the coverage primarily in the corners of the square coverage areas. In addition to the lack of coverage on the outer corners of the model, the area in the center of the model where the four nozzles overlapped exhibited a lack of uniform rainfall coverage. As a result, it was necessary to incorporate a fifth nozzle in the center of the simulator to improve the coverage in the center of the model. This additional nozzle drastically improved the rainfall coverage and uniformity for the model. From visual inspection, approximately 80% of the model received uniform rainfall with only the outer perimeter and corners lacking complete coverage. This completed the construction of the rainfall simulator for the small-scale erosion control model. Figure 4.19 represents the small-scale erosion control model upon completion of the rainfall simulator.

Figure 4.19 Model With Rainfall Simulator.

4.2.3 Subbase Material

The next phase of the construction process centered upon the development of a typical soil strata to model the soil material used for the fill slope on a typical highway construction project. The final subbase strata consists of a 3 in. layer of gravel material, a woven geotextile filter fabric, a 1 in. layer of clay soil, and a 2 in. layer of silty sand soil and is shown in Figure 4.20.

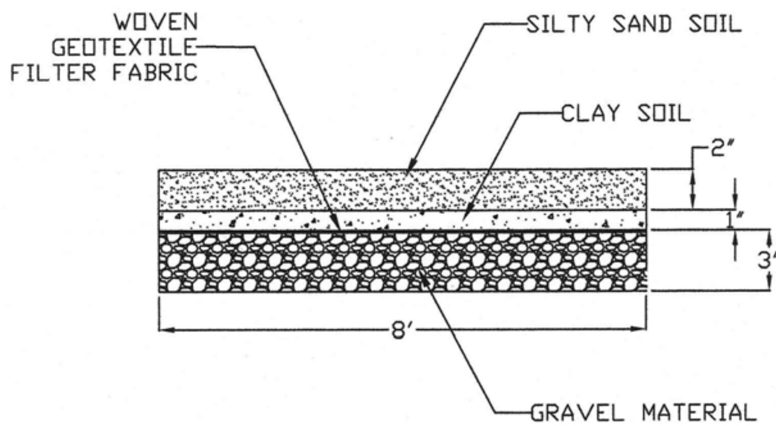


Figure 4.20 Subbase Strata.
(Not to Scale)

4.2.3.1 Subbase Cross Section Components

To simulate a typical soil subbase, the design team selected a 3 in. layer of gravel material. The intent of this layer is simply to allow for the collection and transport of all infiltration from the surface soil layers during the design storm's duration. To reduce the dead load from the gravel material, the design team used Expanded Polystyrene (EPS) aggregate made by Ring Industrial Group for the interceptor layer. In addition to being a lightweight and durable material, the EPS aggregate has a very high hydraulic conductivity. This layer allows the research team to collect and measure the infiltration rate on the model and obtain an approximate estimate of the percentage of rainfall that recharges back into groundwater. Figure 4.21 illustrates the small-scale erosion control model with the EPS aggregate layer installed.

Figure 4.21 Model With EPS Aggregate.

In the installation guidelines, Ring Industrial Group recommends the installation of a barrier to keep fine soil particles from entering the EPS aggregate. For this application, a woven filter fabric was chosen to separate the soil layers from the porous material layer. For the model, an 8 ft. by 8 ft. section of SKAPS W200 Woven Geotexile Fabric was selected as the barrier. Figure 4.22 depicts the woven geotextile fabric installed over the 3 in. EPS aggregate layer. In addition, the specifications for SKAPS W200 Woven Geotexile Fabric are included in Appendix D.

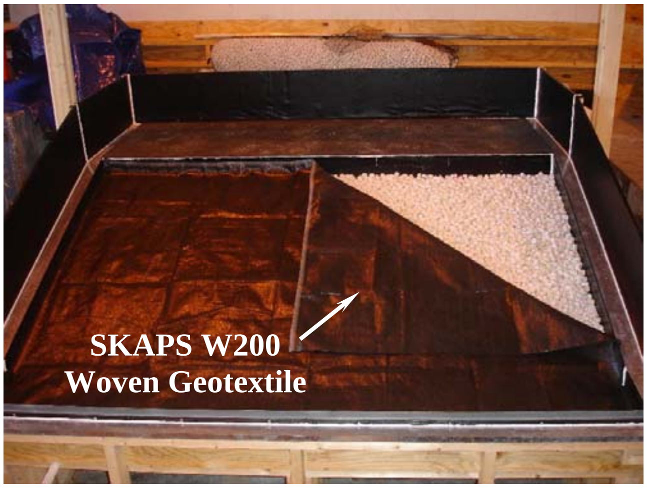


Figure 4.22 Model With SKAPS W200 Woven Geotextile Fabric.

The final components of the subbase strata consisted of the addition of a 1 in. lift of clay soil and a 2 in. lift of silty sand soil. The clay soil in the lower lift is a representative sample of the typical soil materials encountered in the Auburn, Alabama area. However, after conducting the soil classification (see section 4.2.3.2), it was determined that this clay soil is only moderately erodible (Fifield, 2004). Consequently, the research team decided to use a highly erosive silty sand in the upper lift for the testing of the small-scale erosion control model. The soils classification, soils characteristics, and the procedures used to compact the soil material are covered in the following sections.

4.2.3.2 USCS Soils Classification

To determine the soil characteristics of both the clay soil and silty sand soil, a Unified Soils Classification System (USCS) classification was conducted. After conducting the required testing, the clay material classified as an elastic silt, MH. The silty sand classified as a poorly graded sand, SP.

4.2.3.3 Moisture Contents and Model Compaction Standard

One of the variables identified as being critical for reproducing erosion rates in multiple test trials hinged upon the replication of the initial conditions of the soil in the small-scale erosion control model. The goals of the research team were to maintain a consistent grain size distribution, moisture content, and compaction density between each test trial. Preliminary test trials conducted on the model indicated that the majority of the erosion occurred in the top silty sand layer. As a result, the research team concluded that it was necessary to develop two different standard procedures for each of the soil layers.

Due to the fact that the bottom clay layer remained intact during the testing, it was only installed once at the beginning of the testing phase. A standard proctor test was conducted on the material and it was determined that the optimum moisture content was 22.5% which corresponds to a maximum compacted dry unit weight of 103.7 lb/ft.^{3}. The moisture content of the material stored in the stockpile was within $\pm$ 2% of optimum at 22.0%. To aid in compaction, an aluminum weighted roller was fabricated. After conducting several compaction tests with increasing amounts of energy or roller passes, it was determined that 20 passes over a 1 in. clay lift with the aluminum roller resulted in approximately 90% compaction or a compacted dry unit weight of 93.3 lb/ft.^{3}. This compaction was deemed adequate for the testing as it nearly approaches the 95% compaction requirements used on ALDOT highway projects.

The standard procedure followed for compacting the sandy silt material is different due to the concern that the re-use of material from one test trial to another results in both a change in the grain size distribution of the material as well as varying compaction due to changes in initial moisture contents. As a result, the research team decided to replace the top silty sand layer for each individual test trial. This ensures that for each test trial: i.) the grain size distribution remains approximately constant, ii.) the initial moisture content is approximately the same as it is stored in large stockpiles, and iii.) the compacted dry unit weight of the material will be nearly the same. A standard proctor test was conducted on the material and it was determined that the optimum moisture content was 13.0% which corresponds to a maximum compacted dry unit weight of 117.2 lb/ft.^{3}. The moisture content of the material stored in the stockpile was 7.0%. After conducting several compaction tests with increasing amounts of energy or roller passes, it was determined that even though the moisture content was less than optimum, 20 passes over a 1 in. silty sand lift with the aluminum roller resulted in approximately 90% compaction or a compacted dry unit weight of 106.8 lb/ft.^{3}. If the moisture content was within $\pm$ 2% of the optimum moisture content, less energy would have been required to reach 90% compaction. However, the labor incurred due to the additional rolling was far less than that anticipated from adding additional water, thoroughly mixing, and conducting additional soil testing. Figure 4.23 illustrates the small-scale erosion control model with the compacted soil subbase.

Figure 4.23 Model With Subbase.

4.2.4 Erosion Control Material

The final step in the small-scale erosion control model included the determination of which temporary BMPs to model. Based site investigation data, the research team determined that the primary effort should focus on silt fence applications. As a result, it was necessary to develop properly scaled silt fencing for installation at the base of the fill slope.

4.2.4.1 Silt Fence Types

The *Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas: Volume 1*, recommends the use of three types of silt fence: Type A, Type B, and Type C silt fence. Type A silt fence is 36 in. wide with wire reinforcement and is used where runoff flows or velocities are high or where slopes exceed a vertical height of 10 ft. Type B silt fence is also 36 in. wide, but only allows 1/3 of the flow rate vis-à-vis the Type A silt fence. It is used on projects with durations of six months or longer. Finally, Type C silt fence allows for the same flow rate as Type B silt fence, but is only 22 in. wide and should only be used on minor projects with durations of less than six months (Alabama Soil and Water Conservation Committee, 2003a).

ALDOT specifies the use of only Type A or Type B silt fence on highway construction projects. The ALDOT standard specification for silt fence types and components is included in Appendix E. The distinction as to appropriate uses for each silt fence type is addressed in the general notes on the standard detail. ALDOT uses Type A silt fence in areas of concentrated flow, while using Type B silt fence in areas with flow that is less severe or as directed by the engineer. Our field investigations indicated that the majority of silt fence installed on highway construction projects is Type A silt fence. Therefore, Type A silt fence, as specified by the ALDOT standard detail, was selected for the initial testing of the small-scale erosion control model.

4.2.4.2 Silt Fence Components

Type A silt fence consists of three major components: woven wire reinforcement, geotextile fabric, and wood posts. In addition, Type A silt fence has two minor components: ring fasteners and staples. The research team scaled the silt fence to a 6:1 scale to match the scale of the small-scale erosion control model. Figure 4.24 illustrates the major silt fence components at the reduced scale size.

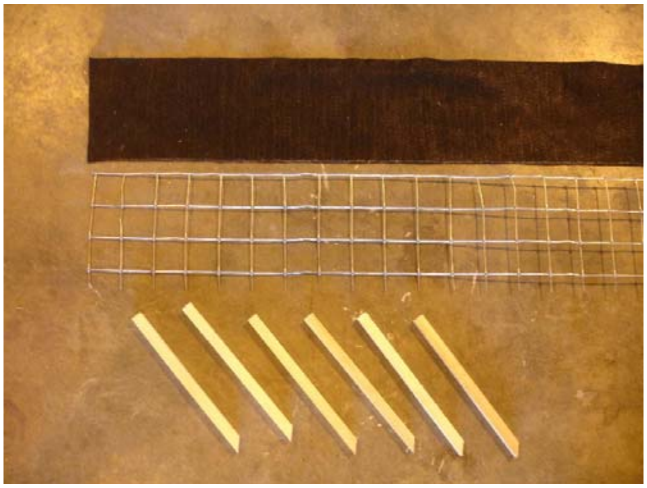


Figure 4.24 Major Silt Fence Components.

The scaled woven wire is 6 ½ in. wide, with a 2 in. × 2 in. grid, and is fabricated with 16 gauge wire. The geotextile fabric is 8 in. wide and is SKAPS GT 135 silt fence. The specifications for SKAPS GT 135 silt fence and a letter from ALDOT adding this material to List II-3, in the ALDOT Materials, Sources, and Devices with their Special Acceptance Requirements Manual approving it for use as a silt fence material is included in Appendix F. Finally, the wooden posts are 10 in. long and approximately ¾ in. × ¾ in. Standard 3/8 in. staples were used to attach the geotextile fabric to the wood posts and standard staples were used secure the top of the geotextile fabric to the woven wire mesh. Figure 4.25 depicts the Type A silt fence fully constructed and ready for installation in the small-scale erosion control model.

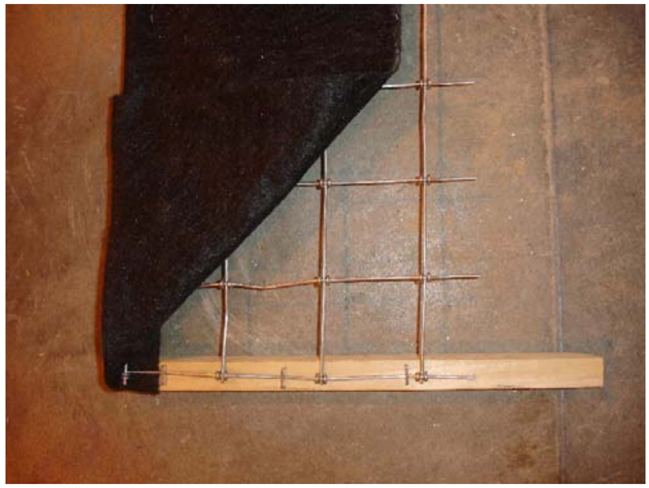


Figure 4.25 Small-Scale Type A Silt Fence.

4.2.4.3   Silt Fence Installation Procedure

The *Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas: Volume 2*, specifies the silt fence installation techniques for each type of silt fence in the State of Alabama. For Type A silt fence, the first step is the digging of 6 in. × 6 in. trench along the fence alignment. Next, the posts are to be driven at least 18 in. into the ground on the down-slope side of the trench at a spacing of 10 ft. or less. The woven wire is then fastened to the upslope side of the posts and extended 6 in. into the trench. At this point, the geotextile fabric is attached to the upslope side of the woven wire and posts. Finally, the bottom 8 in. of the fabric is placed in the 6 in. deep trench and backfilled with compacted earth (Alabama Soil and Water Conservation Committee, 2003b). A detail of this installation procedure for Type A silt fence is included in Appendix G.

The installation methods specified on ALDOT's standard silt fence detail are similar to the Alabama Handbook, with a few minor variations. Appendix E contains the

ALDOT standard detail for silt fence. To begin, a 6 in. × 6 in. trench is dug along the fence alignment. Next, the posts are to be driven at least 24 in. into the ground on the down-slope side of the trench at a spacing of 10 ft. or less. The woven wire is then fastened to the upslope side of the posts and extended 3 in. into the trench. At this point, the geotextile fabric is attached to the upslope side of the woven wire and posts. Finally, the bottom 12 in. of the fabric is placed in the 6 in. deep trench and backfilled with compacted earth. For the small-scale erosion control model, the ALDOT installation methods will be used as it is the most representative of the installation methods being utilized on highway construction projects in the State of Alabama. The size of the 6 in. × 6 in. trench will be reduced to 1 in. × 1 in. to maintain proper scaling. Figure 4.26 shows the trench after being excavated and awaiting the installation of the silt fence.

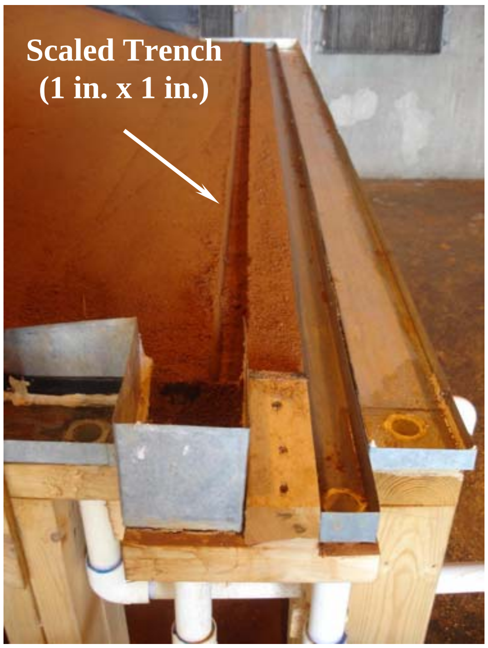


Figure 4.26 Small-Scale Silt Fence Trench.

Figure 4.27 shows the small-scale erosion control model with the silt fence installed.

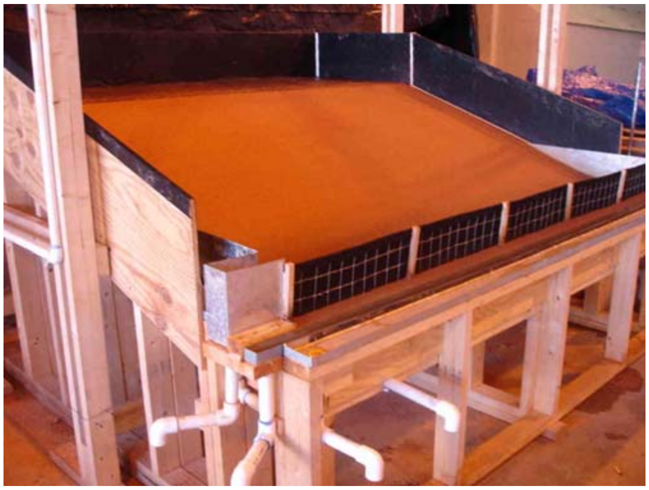


Figure 4.27 Silt Fence Installation.

Figure 4.28 depicts the final small-scale erosion control model upon completion of the construction phase and prior to the testing phase of the project.

Figure 4.28 Finalized Small-Scale Erosion Control Model.

With the construction of the small-scale erosion control model complete, it is now possible to test the effectiveness of various BMPs in reducing the total suspended solid concentrations leaving highway construction sites. As discussed previously, this research is specifically focused on determining the effectiveness of silt fence tiebacks in reducing total suspended solids leaving highway construction projects. The next step in the research process involves the development of silt fence tieback guidelines for use on typical highway construction projects.

CHAPTER FIVE

SILT FENCE TIEBACK DESIGN AND GUIDELINES

5.1 INTRODUCTION

The site investigation data indicated that there is a tremendous amount of sediment that is being detached and transported from highway construction sites and being deposited in nearby waterways. In many cases, the installation of silt fence along the construction R.O.W. serves as the final barrier keeping sediment from leaving highway construction sites. An extensive literature review revealed that there are general design guides available for addressing the recommended maximum size of the drainage area above silt fence as well as maximum slope lengths above the silt fence on specific slope conditions. Additionally, these sources discuss the importance of tying silt fence installations back into the contour essentially creating small sediment basins to trap sediment, allowing it to settle out of suspension (Barrett et al. 1995; Robichaud, 2001; and U.S. EPA 2004a). However, it appears that there is a gap in the body of knowledge as to the proper placement and frequency of silt fence tiebacks along highway construction projects. The goal of this chapter is to develop general design guidelines for designers and inspectors to assist in determining the proper placement and frequency of silt fence tiebacks along highway construction projects.

5.2 SILT FENCE TIEBACK GUIDELINE DEVELOPMENT

The design approach used in developing the silt fence tieback guidelines focused on using a hydrological model, Soil Conservation Service – Curve Number method (SCS - Curve Number method), to estimate the amount of storm water runoff from a watershed or construction site during a specified storm event per unit length of roadway. The goal is to achieve a balance with the computed storage capacity of the silt fence per unit length of silt fence. The overall intent is to provide design guidelines that are flexible enough to be adapted to individual construction projects on a case by case basis.

5.2.1 Predicted Storm Water Runoff: SCS - Curve Number

In order to determine the storm water runoff volume, the SCS – Curve Number method will be used to compute the excess rainfall from a storm. According to the Soil Conservation Service, the relationship between excess rainfall, P_e, and total rainfall, P, on a 24-hour basis is computed by:

$$P_e = \frac{(P - I_a)^2}{(P - I_a + S)} \tag{5.1}$$

where:

P_e = excess rainfall (in.)
P = total rainfall in 24-hour period (in.)
I_a = initial abstraction (in.)
S = maximum potential retention (in.)

From the results of studies on many small watersheds, an empirical relation was developed for the initial abstraction before ponding, I_a:

$$I_a = 0.2S \tag{5.2}$$

As a result:

$$P_e = \frac{(P - I_a)^2}{(P + 0.8S)} \tag{5.3}$$

The maximum potential retention is related to the curve number (CN) by the following relationship:

$$S = \frac{1000}{CN} - 10 \tag{5.4}$$

A table of runoff curve numbers for selected agricultural, suburban, and urban land uses is included in Appendix H.

After computing the maximum potential retention, *S*, and the initial abstraction, I_a, the excess rainfall, P_e, from a storm event can be calculated. The total volume of storm water runoff is obtained by multiplying the excess rainfall by the watershed area.

$$V_{total} = P_e * 3630 * A_{watershed} \tag{5.5}$$

where: V_{total} = total volume of storm water runoff (ft.^{3})
P_e = excess rainfall (in.)
$A_{watershed}$ = area of watershed (acre)

5.2.1.1 Storm Water Runoff Volume Spreadsheet

To simplify the computation of the storm water runoff from a highway construction site, an Excel™ spreadsheet was developed. The Excel™ spreadsheet is shown in Figure 5.1 with the input required from the designer or inspector depicted by white cells and the spreadsheet output depicted by gray shaded cells.

ROADWAY GEOMETRY:

ROADWAY WIDTH	W1 =		FT
SHOULDER WIDTH	W2 =		FT
FILL SLOPE WIDTH (WIDTH FROM SHOULDER TO R.O.W)	W3 =		FT
LENGTH OF FILL SECTION	L1 =		FT

DESIGN STORM PRECIPITATION:

PRECIPITATION	P =		IN

CURVE NUMBER:

ROADWAY CURVE NUMBER (CN)	CN1 =	
SHOULDER CURVE NUMBER (CN)	CN2 =	
FILL SLOPE CURVE NUMBER (CN)	CN3 =	
	CN (WEIGHTED) =	

COMPUTED VALUES:

S (MAX POTENTIAL RETENTION)	S =		IN
I_a (INITIAL ABSTRACTION)	I_a =		IN
P_e (EXCESS PRECIPITATION)	P_e =		IN
V (TOTAL RUN-OFF VOLUME)	V =		FT^3
	V =		GAL

Figure 5.1 Excel™ Spreadsheet: Total Storm Water Runoff Volume.

An example problem illustrating the functionality of the spreadsheet is described in the following section.

5.2.1.2 Storm Water Runoff Volume: Example Problem

The U.S. EPA states that silt fence should be designed to withstand the runoff from a 2-year, 24-hour storm event (U.S. EPA, 1998). Using this design guidance in conjunction with Technical Paper 40, the precipitation for a 2-year, 24-hour storm event is approximately 4.25 in. for Auburn, Alabama (U.S. Department of Commerce, 1963).

With this information, the Excel™ spreadsheet, and the problem information from Figures 5.2 and 5.3 below, the total volume of storm water runoff for this highway construction project can be computed.

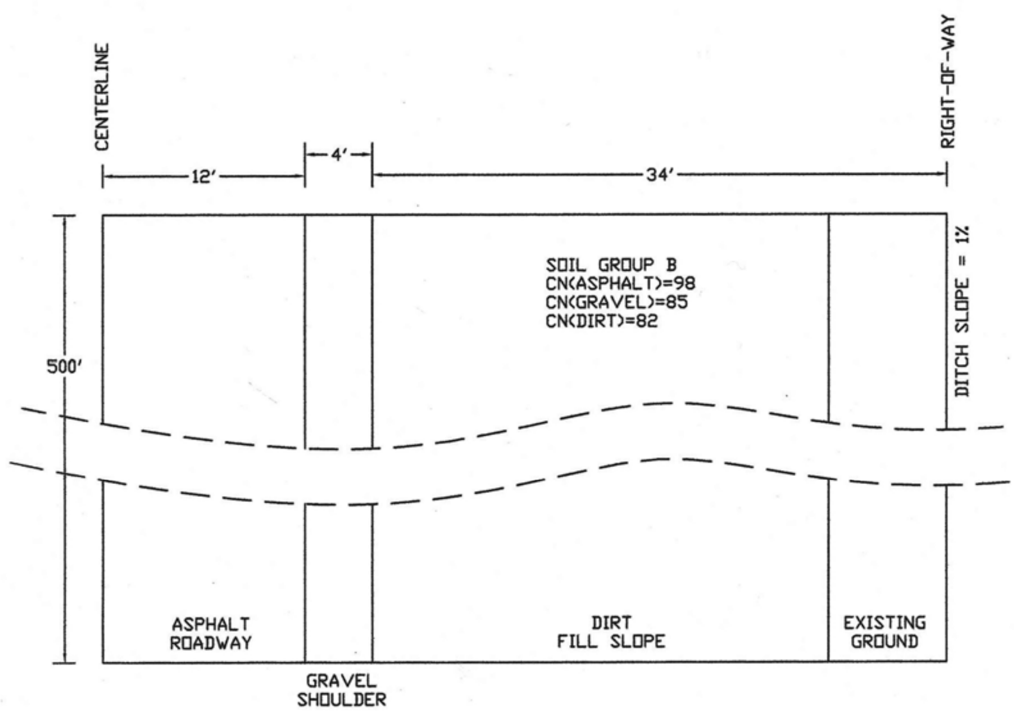


Figure 5.2 Example Problem: Plan View.

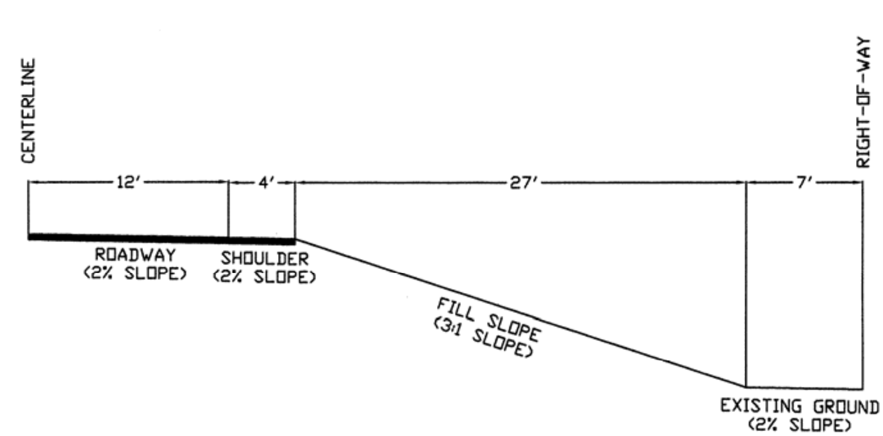


Figure 5.3 Example Problem: Cross Section View.

After entering the data into the Excel™ spreadsheet, the total runoff volume for the 2-year, 24-hour design storm is 5,794 ft.^{3} or 43,340 gallons. Figure 5.4 shows the data input and supporting Excel™ spreadsheet calculations.

ROADWAY GEOMETRY:			
ROADWAY WIDTH	W1 =	12	FT
SHOULDER WIDTH	W2 =	4	FT
FILL SLOPE WIDTH (WIDTH FROM SHOULDER TO R.O.W)	W3 =	34	FT
LENGTH OF FILL SECTION	L1 =	500	FT

DESIGN STORM PRECIPITATION:			
PRECIPITATION	P =	4.25	IN

CURVE NUMBER:			
ROADWAY CURVE NUMBER (CN)	CN1 =	98	
SHOULDER CURVE NUMBER (CN)	CN2 =	85	
FILL SLOPE CURVE NUMBER (CN)	CN3 =	82	
	CN (WEIGHTED) =	86	

COMPUTED VALUES:			
S (MAX POTENTIAL RETENTION)	S =	1.62	IN
I_a (INITIAL ABSTRACTION)	I_a =	0.32	IN
P_e (EXCESS PRECIPITATION)	P_e =	2.78	IN
V (TOTAL RUN-OFF VOLUME)	V =	5794	FT^3
	V =	43340	GAL

Figure 5.4 Example Problem: Excel™ Calculations.

5.2.2 Silt Fence Storage Volume

The second component of the general design guidelines for determining the proper placement of silt fence tiebacks along highway construction projects is the computation of the storage volume behind the silt fence per linear foot of silt fence installed along the

R.O.W. The storage volume calculations developed assume that the silt fence tieback will be anchored into an elevation equal to or greater than the top height of the silt fence at the toe of slope as shown in Figure 5.5.

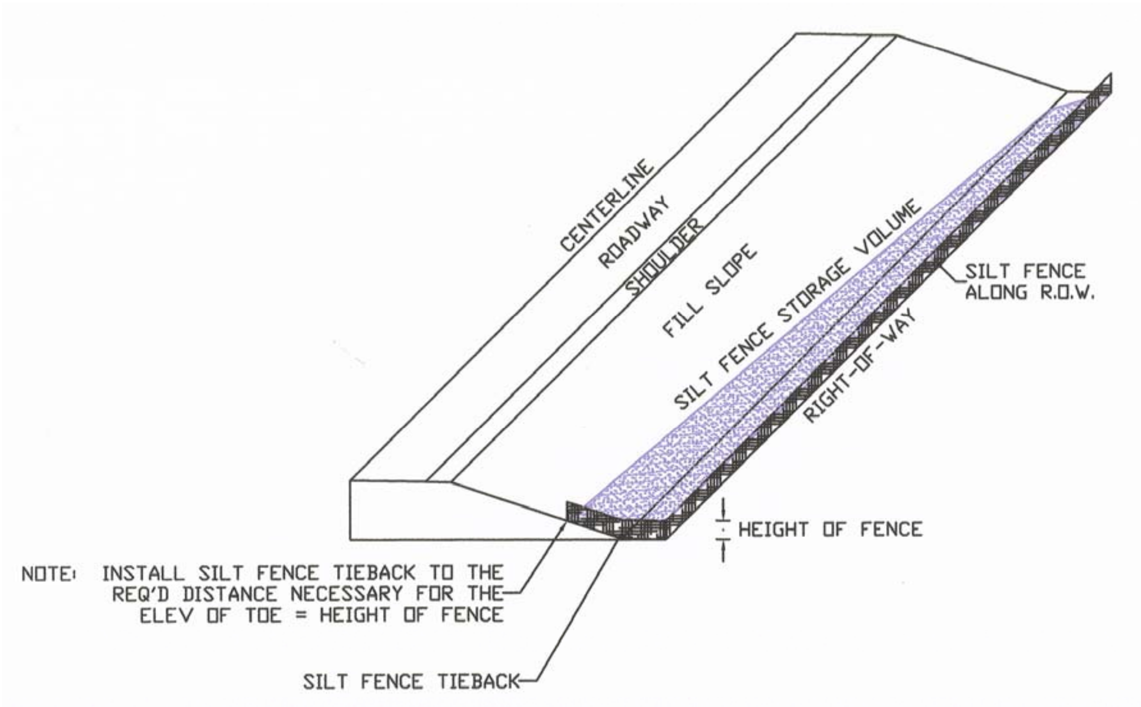


Figure 5.5 Silt Fence Tieback Configuration.

This tieback configuration ensures: i.) that storm water runoff will accumulate behind the tieback, ii.) that the storm water runoff will not be able to bypass around the toe of the silt fence tieback, and iii.) that simultaneous failure will occur over the top of the silt fence along the R.O.W. and around the toe of the tieback. Finally, this installation technique guarantees the maximum amount of storage volume along the length of the silt fence, therefore increasing the silt fence installation length prior to requiring a tieback along the R.O.W.

5.2.2.1 Silt Fence Storage Volume Spreadsheet

To calculate the total storage volume of silt fence along the R.O.W., another Excel™ spreadsheet was designed that computes the average storage volume per linear foot along the silt fence. After adding the incremental storage volumes, the spreadsheet will provide both, calculations and a tieback design chart for the cumulative storage volume per foot of installed silt fence. In order to make the spreadsheet user friendly, the user was allowed to input site specific data for each construction project. The required typical roadway cross section data for the spreadsheet is shown in Figure 5.6.

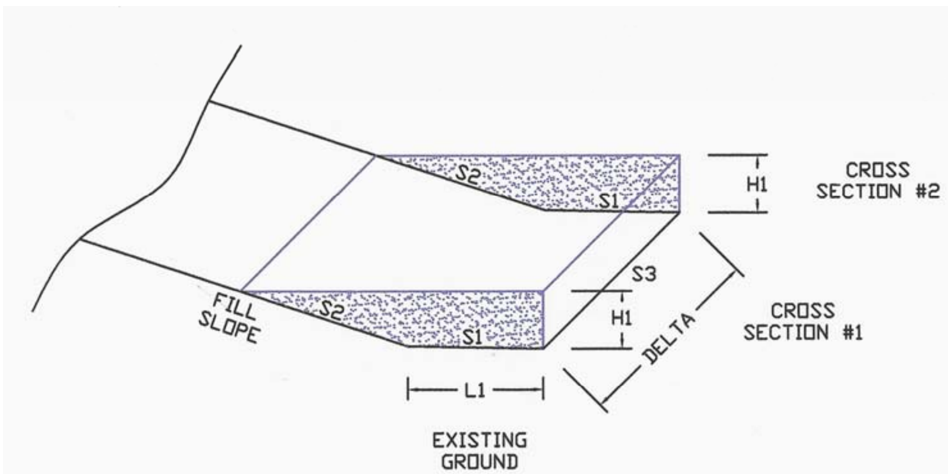


Figure 5.6 Required Typical Section Data.

The white cells depicted in Figure 5.7 represent all the user inputs required by the Excel™ spreadsheet to be entered in order to calculate the cumulative total storage volume per linear foot along the silt fence.

TIEBACK DESIGN INPUT:			
EXISTING GROUND SLOPE	S1 =		FT/FT
LENGTH OF EXISTING GROUND	L1 =		FT
FILL SLOPE	S2 =		FT/FT
DITCH (TOE) SLOPE	S3 =		FT/FT
DITCH STEP INTERVAL	DELTA =		FT
SILT FENCE HEIGHT	H1 =		FT

Figure 5.7 Excel™ Spreadsheet: Total Storage Volume.

5.2.2.2 Silt Fence Storage Volume: Example Problem

Given the information from the example problem provided in Figures 5.2 and 5.3, the user inputs entered into the Excel™ spreadsheet are shown in Figure 5.8

TIEBACK DESIGN INPUT:			
EXISTING GROUND SLOPE	S1 =	0.02	FT/FT
LENGTH OF EXISTING GROUND	L1 =	6	FT
FILL SLOPE	S2 =	0.33	FT/FT
DITCH (TOE) SLOPE	S3 =	0.01	FT/FT
DITCH STEP INTERVAL	DELTA =	0.50	FT
SILT FENCE HEIGHT	H1 =	3	FT

Figure 5.8 Example Problem: Excel™ Data Inputs.

The Excel™ spreadsheet calculates the total silt fence storage volume for various project conditions. The output of silt fence length versus total storage volume for various slopes using the example typical cross section data is illustrated in Figure 5.9.

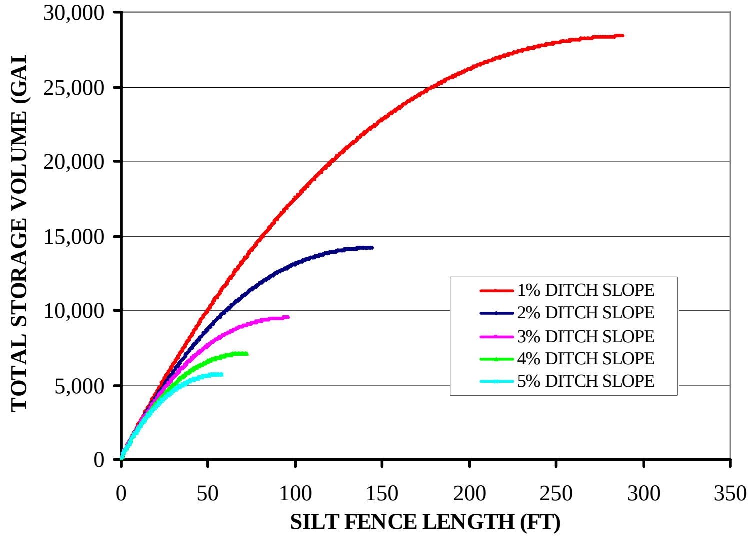


Figure 5.9 Example Problem: Total Storage Volume vs. Silt Fence Length.

From this chart, it is apparent that the longest length of silt fence that can be installed before failure with a 1% ditch slope is 300 ft. Additionally, the maximum storage volume that 300 ft. of silt fence can hold is approximately 28,500 gallons. From the SCS (Curve Number) method, the total runoff volume for the 2-year, 24-hour design storm is 43,340 gallons. In the problem definition, the watershed length was 500 ft. From the Figure 5.9 above, there are a number of alternative configurations that can be selected to effectively contain the storm water runoff on the construction site. However, the most cost effective configuration incorporates only two tiebacks along the entire R.O.W. Consequently, the recommendation is made to install two silt fence tiebacks approximately every 250 ft. Each of the two silt fence tiebacks, in conjunction with a silt fence length of 250 ft., has a total storage volume of approximately 28,000 gallons. The combined storage volume of both the silt fence and silt fence tiebacks at a 250 ft. spacing is 56,000 gallons which is greater than the required 43,340 gallons.

In conclusion, the development of the storm water runoff volume Excel™ spreadsheet gives designers a quick and easy to use tool for predicting the storm water runoff from a watershed or construction site. Using the typical cross section data from the highway construction project, the designer is then able to use the silt fence storage volume Excel™ spreadsheet to create a graph of silt fence length versus total storage volume for various slopes. Equipped with this data, the designer or inspector is able to then determine the proper placement frequencies of silt fence tiebacks along highway construction projects. The key in this determination is maintaining a balance between the storm water runoff and the available storage behind the silt fence installation lengths. The overall intent is to provide design guidelines that are flexible enough to be adapted to individual construction projects on a case by case basis. This design guideline was used in the following chapter to determine the number of silt fence tiebacks installed on the small-scale erosion control model.

CHAPTER SIX

SMALL-SCALE EROSION CONTROL MODEL

TESTING AND RESULTS

6.1 INTRODUCTION

To establish the effectiveness of the silt fence tieback design guidelines, a small-scale erosion control model was used to simulate soil erosion and sediment transport along the R.O.W. of a highway construction project. The total suspended solids (TSS) leaving the model was measured and compared for two different silt fence configurations. The two testing configurations consisted of a silt fence installed linearly without tiebacks along the R.O.W. versus a silt fence installed linearly along the R.O.W. with silt fence tiebacks and are shown in Figure 6.1 and Figure 6.2 below:

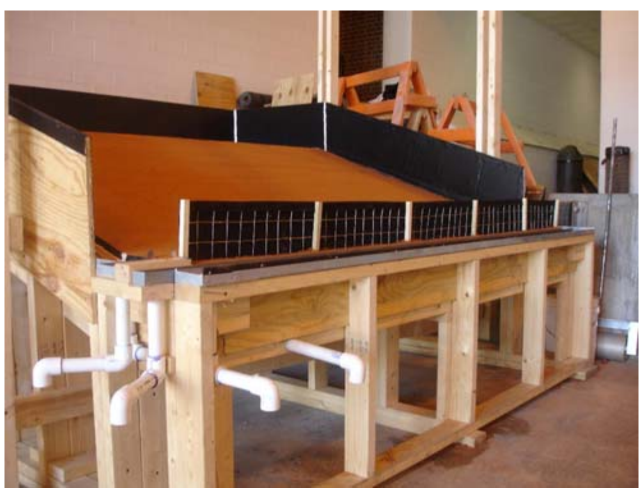


Figure 6.1 Silt Fence Configuration No. 1: Silt Fence Without Tiebacks.

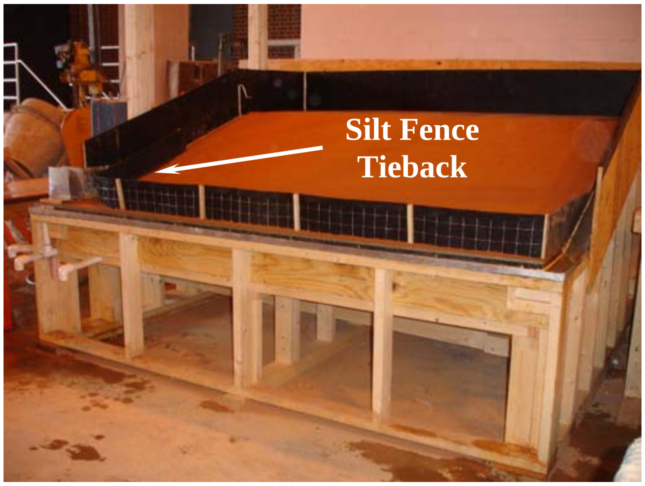


Figure 6.2 Silt Fence Configuration No. 2: Silt Fence With Tiebacks.

The primary objectives of conducting small-scale experiments with the above mentioned silt fence configurations were:

1.) To determine the TSS leaving a typical highway construction project for both the linear silt fence installation and the linear silt fence installation incorporating silt fence tiebacks.

2.) To determine the reproducibility of each testing configuration on the small-scale erosion control model.

3.) To determine the overall effectiveness of utilizing silt fence tiebacks in reducing the TSS leaving a typical highway construction project.

The small-scale experiments consisted of five trials highlighted in Table 6.1 below:

Table 6.1 Testing Trials

Test Trial No.	Type of Installation	Number of Tiebacks	Ditch Slope (%)	Storm Intensity (in/hr)
1	Silt Fence w/o Tiebacks	0	2.0	3.0
2	Silt Fence w/o Tiebacks	0	2.0	3.0
3	Silt Fence w/o Tiebacks	0	2.0	3.0
4	Silt Fence w/ Tiebacks	1	2.0	3.0
5	Silt Fence w/ Tiebacks	1	2.0	3.0

Note: w/ = with
w/o = without

Overall, four different data sets were collected during each trial using two different silt fence configurations. The first set of data consisted of the TSS as a function of time measured at the toe of slope collection system (toe of fence) and the down-slope (through fence) collection system. Data from each collection system was collected and summed to calculate the TSS magnitude as a function of time. The data provides an in-depth look at the sediment transport process along the silt fence at the toe of slope and through the silt fence on a typical highway construction project at any point in time during a specified rainfall event.

The second set of data consists of the changes in the cumulative TSS throughout the duration of the test. This data set is of particular importance as it identifies the magnitude of TSS that are being transported off of a highway construction project at any point in time during a particular storm event.

The third data set consists of charting the total volume of rainfall as a function of time collected in the rainfall overflow collection system, infiltration collection system, toe of slope collection system, and down-slope (through fence) collection system. The flow measurements from the four collection systems will be totaled at the end of the simulation to ascertain the rainfall volume as a function of time.

Finally, the fourth data set will highlight the changes in cumulative total volume throughout the test's duration. The ultimate goal is to obtain mass balance between the rainfall volume applied by the rainfall simulator during the experiment with the cumulative total volume collected and volume of water remaining on the model at the conclusion of the experiment.

6.2 TESTING METHODOLOGY

To minimize the experimental variability associated with the small-scale erosion control model, it is vital that the same testing methodology be followed for each of the five trials.

6.2.1 Model Setup

Prior to each trial, the poorly graded sand base material was removed and replaced following the technique described in section 4.2.3.3. In addition, the silt fence was installed in accordance with the technique described in section 4.2.4.3. Finally, the poorly graded sand base material was completely saturated prior to beginning each experiment. By beginning each trial from a saturated condition, the potential rainfall lost due to infiltration decreases, thereby increasing the erosion rates and modeling the worst case scenario. A strict adherence to this process ensured that the original conditions were replicated, as closely as possible, prior to conducting each test trial.

6.2.2 Testing Procedure

Each trial began with the opening of the gate valve that controls flow to the rainfall simulator. The valve was opened to allow for a maximum rainfall storm intensity of 3.0 in./hr. In order to simulate this intensity, the gate valve was opened until the flow rate recorded at the flow meter equaled 2.0 gallons per minute (gpm). At this point, the time for the testing and data collection commenced.

Prior to starting the data collection for the first configuration (i.e. Silt fence w/o tieback installation [test trials No. 1-3]), each of the four collection systems were equipped with containers for collecting rainfall volumes. The total volume in the infiltration collection system, toe of slope collection system, and down-slope (through fence) collection system was collected at two minute intervals throughout the testing duration. The runoff from the rainfall overflow collection system was collected at the end of the testing. The containers were stored chronologically from the beginning of the test until completion. Upon completing the simulation, the following post simulation data collection process was initiated for test trials No. 1-3:

1.) Infiltration Containers: the total volume collected in each of the infiltration containers (No. 1-15) was measured and recorded at two minute intervals.
2.) Toe of Slope Containers: the total volume collected in each of the toe of slope containers (No. 1-15) was measured and recorded at two minute intervals. Next, the volume was poured through a No. 200 sieve to separate the large suspended solids from the fine suspended solids in the solution. The sieve weight with large suspended solids was measured and recorded. Finally, fifteen small 24-ml samples of the volume passing the No. 200 sieve were

taken from the toe of slope containers to determine the amount of fine suspended solids as a function of time.

3.) Down-slope Containers: the total volume collected in each of the down-slope containers (No. 1-15) was measured and recorded at two minute intervals. Fifteen separate small 24-ml samples of the volume were taken from each of the 15 containers to determine the TSS in each container.

4.) Rainfall Overflow Collection Container: the total volume collected in the rainfall overflow collection container was measured and recorded at the conclusion of the test.

5.) Remaining Rainfall Container: the volume of water remaining on the model was collected, measured, and recorded at the conclusion of the test.

The data collection for the second configuration (i.e. Silt fence w/tieback installation [test trials No. 4-5] is similar to the first configuration with the exception that there is no flow accumulating in the toe of slope collection system as a result of the tieback installation. Therefore, only the remaining three collection systems were equipped with containers for collecting the volumes. The total volume in the infiltration collection system and down-slope (through fence) collection system was collected at two minute intervals throughout the testing duration. The rainfall overflow collection system was collected at the end of the testing period. The containers were stored chronologically from the beginning of the test until completion. Upon completing the testing of the model, the following post simulation data collection process was initiated for test trials No. 4-5:

1.) Infiltration Containers: the total volume collected in each of the infiltration containers (No. 1-15) was measured and recorded at two minute intervals.

2.) Down-slope Containers: the total volume collected in each of the down-slope containers (No. 1-15) was measured and recorded at minute intervals. Next, the volume was run through a No. 200 sieve to separate the large suspended solids from the fine suspended solids in solution. The sieve weight with large suspended solids was measured and recorded. Finally, fifteen small 24-ml samples of the volume passing the No. 200 sieve were taken from each of the 15 individual containers to determine the concentration of fine suspended solids.

3.) Rainfall Overflow Collection Container: the total volume collected in the rainfall overflow collection container was measured and recorded at the conclusion of the test.

4.) Remaining Rainfall Container: the volume of water remaining on the model was collected, measured, and recorded at the conclusion of the test.

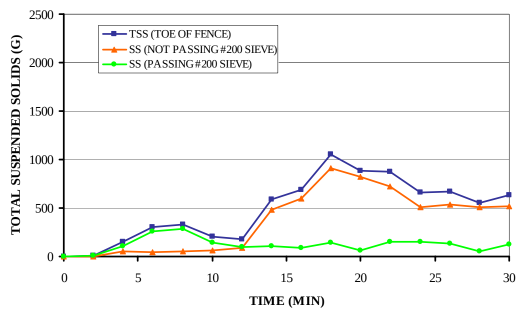
6.3 SILT FENCE PERFORMANCE WITHOUT TIEBACKS

6.3.1 Test Trials No. 1-3

The results of test trial No. 1-3 are summarized into four data sets: i.) TSS versus time, ii.) cumulative TSS versus time, iii.) total volume versus time, and iv.) cumulative total volume versus time.

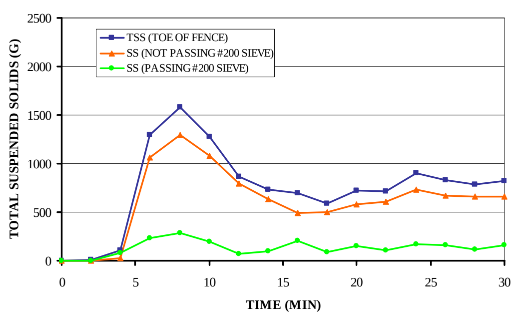
6.3.1.1 Data Set No. 1: TSS Versus Time

The first data set, TSS versus time is determined by summing the amount of TSS discharged along the toe of fence and through the fence at discrete two minute intervals throughout the duration of the test. Figure 6.3 illustrates the magnitude of TSS collected at two minute intervals along the toe of fence for test trials No. 1-3. Figure 6.4 represents the magnitude of TSS collected at two minute intervals that passed through the fence for test trials No. 1-3. The overall TSS as a function of time for test trials No. 1-3 is displayed in Figure 6.5. The results of this data clearly show the magnitude of sediment transport along the toe of slope and through the silt fence on a typical highway construction project at the collection intervals during the specified rainfall event.

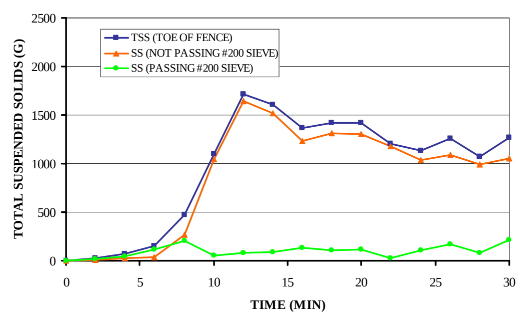


Note:
Test trial No. 1 was not completely saturated at start of test trial

a.) Test Trial No. 1

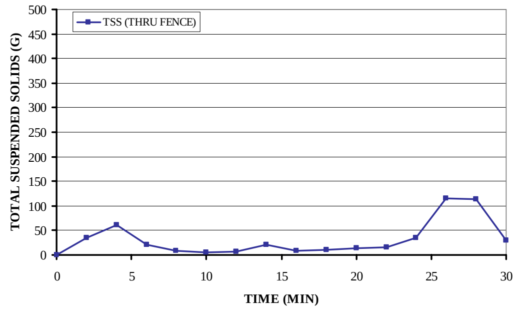


b.) Test Trial No. 2

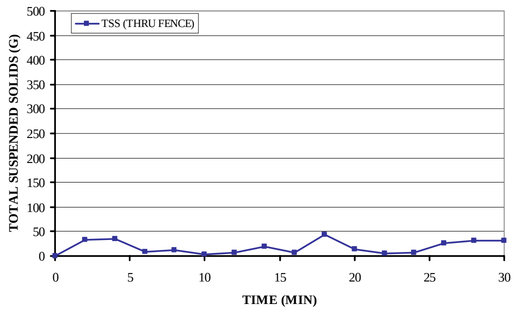


c.) Test Trial No. 3

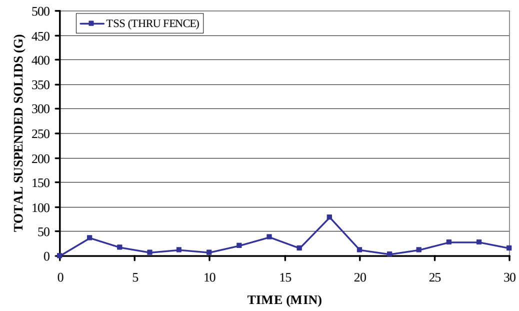
Figure 6.3 TSS vs. Time (Toe of Fence).



a.) Test Trial No. 1

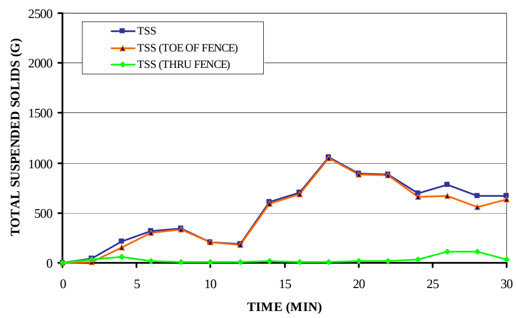


b.) Test Trial No. 2

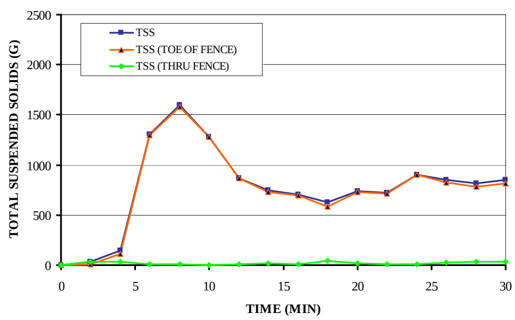


c.) Test Trial No. 3

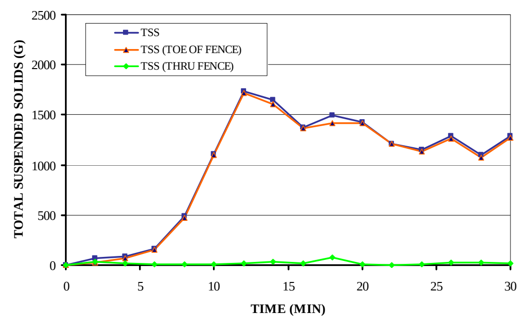
Figure 6.4 TSS vs. Time (Through Fence).



a.) Test Trial No. 1



b.) Test Trial No. 2

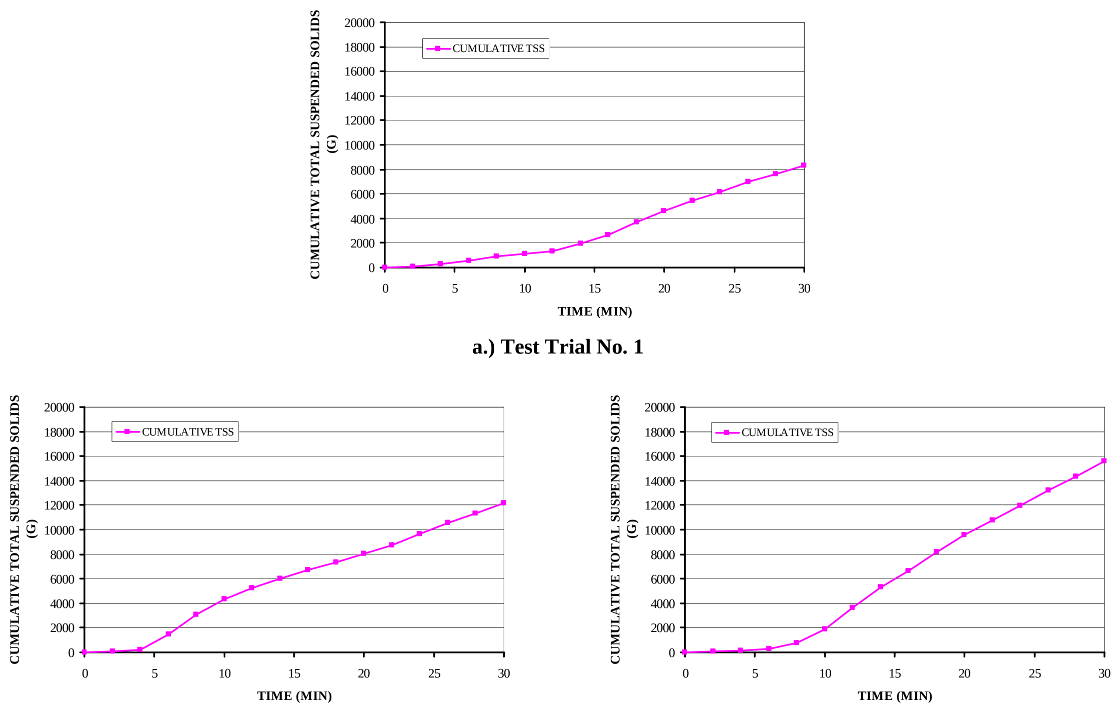


c.) Test Trial No. 3

Figure 6.5 TSS vs. Time.

6.3.1.2 Data Set No. 2: Cumulative TSS Versus Time

The second data set, cumulative TSS versus time identifies the cumulative TSS that are being transported off of a highway construction project at each two minute interval during the storm's duration. Figure 6.6 depicts the cumulative TSS being transported at each two minute interval during the testing for test trials No. 1-3.



a.) Test Trial No. 1

b.) Test Trial No. 2

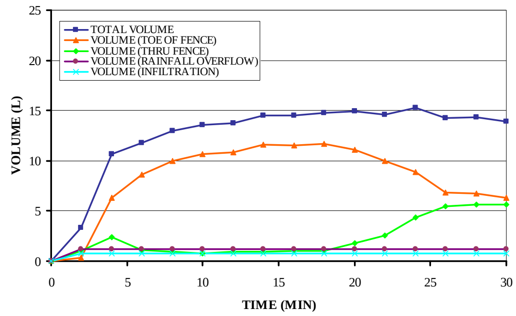
c.) Test Trial No. 3

Figure 6.6 Cumulative TSS vs. Time.

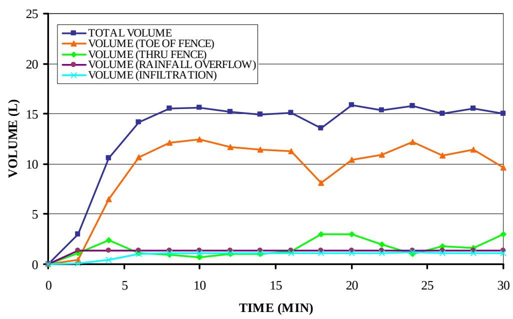
6.3.1.3 Data Set No. 3: Total Volume Versus Time

The third data set, total volume versus time, depicts the incremental volume of rainfall collected in the rainfall overflow collection system, infiltration collection system, toe of slope collection system, and down-slope (through fence) collection system at two minute intervals during the test's duration. The individual volumes from each collection systems are totaled to attain the total volume collected at each two minute interval.

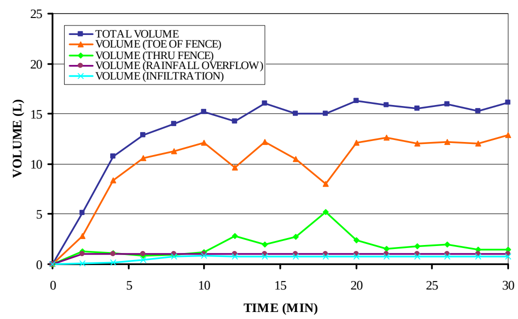
Figure 6.7 reflects the total volume collected on the model at two minute intervals for test trials No. 1-3.



a.) Test Trial No. 1



b.) Test Trial No. 2

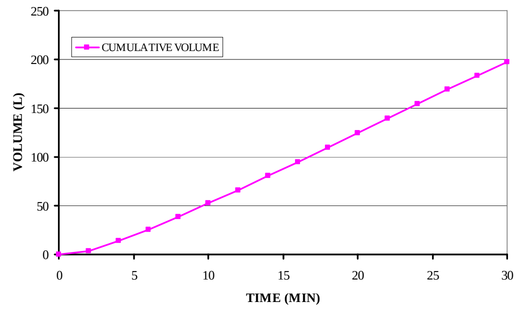


c.) Test Trial No. 3

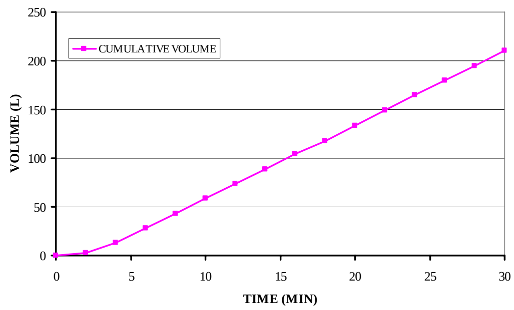
Figure 6.7 Total Volume vs. Time.

6.3.1.4 Data Set No. 4: Cumulative Total Volume Versus Time

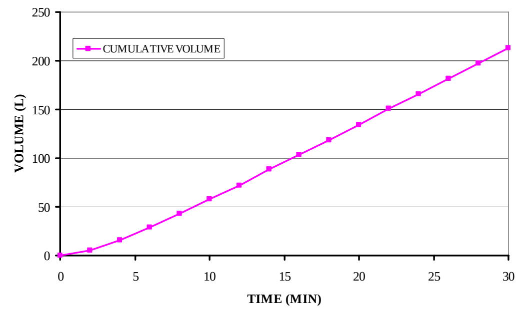
The fourth data set, cumulative total volume versus time, depicts the cumulative volume of rainfall collected in the rainfall overflow collection system, infiltration collection system, toe of slope collection system, and down-slope (through fence) collection system at each two minute interval during the storm's duration. Figure 6.8 reflects the cumulative total volume collected at each two minute interval for test trials No. 1-3.



a.) Test Trial No. 1



b.) Test Trial No. 2



c.) Test Trial No. 3

Figure 6.8 Cumulative Total Volume vs. Time.

6.3.2 Comparison of Test Trials No. 1-3

To evaluate the results of test trials No. 1-3, the four data sets collected from all three tests were plotted on one graph. This provided the ability to i.) identify distinct trends or patterns in the data, ii.) locate possible outliers and develop explanations for the deviations, and iii.) determine the reproducibility of the model in attaining reasonably accurate results on a consistent basis.

6.3.2.1 TSS Versus Time Comparison

Figure 6.9 contains the combined results of test trials No. 1-3 in respect TSS versus time.

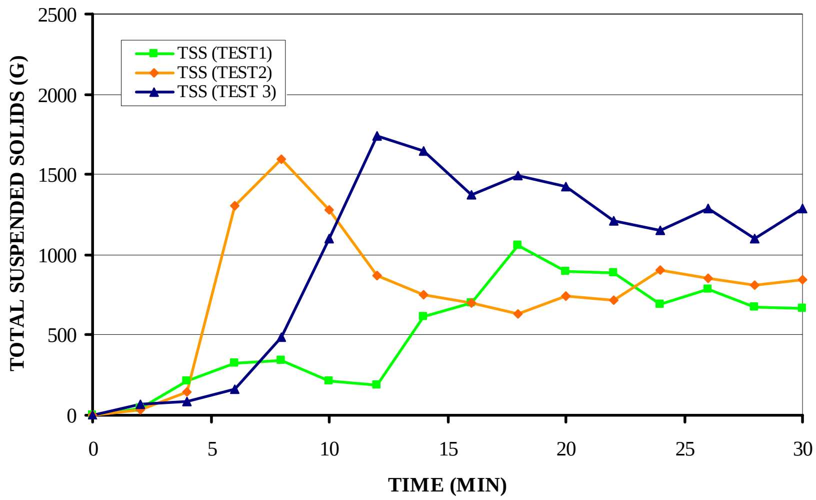


Figure 6.9 TSS vs. Time for Tests No. 1-3.

From Figure 6.9, it is apparent that there is a moderate amount of variability in the TSS being transported on the model for the three tests. However, the three data sets have several similarities or trends. In general, the TSS transported are negligible at the beginning of the test, increase rapidly to a maximum, and then taper back down to equilibrium. The obvious differences are in the time it takes to reach the maximum, the magnitude of the maximum TSS, and the final equilibrium value. After careful analysis of the testing trials, there are a number of factors which influence testing variability which include: i.) the variability in initial moisture content of the base material, ii.) variations in compaction, iii.) the fluctuations of precipitation from the rainfall simulator, and iv.) the randomness associated with the erosion process.

6.3.2.2 Cumulative TSS Versus Time Comparison

Figure 6.10 contains the combined results of test trials No. 1-3 in respect to cumulative TSS versus time.

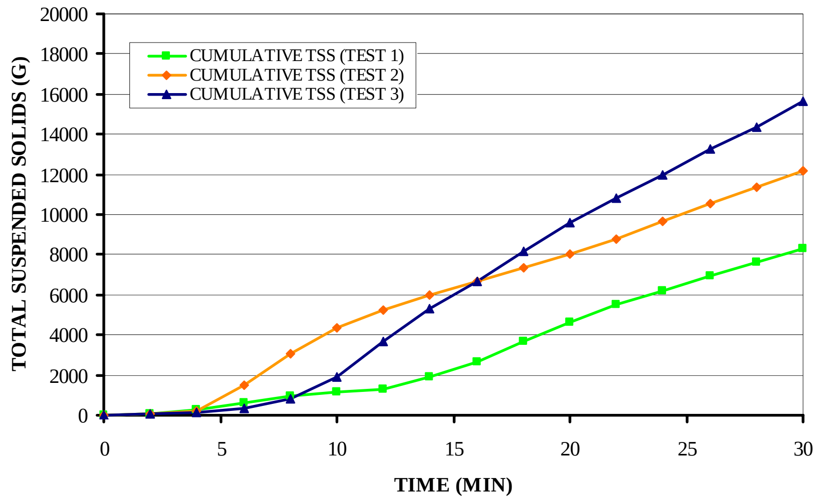


Figure 6.10 Cumulative TSS vs. Time for Tests No. 1-3.

The importance of Figure 6.10 is that it provides a closer look at the ranges of cumulative TSS being transported off of the model during the test. From the data obtained in test trials No. 1-3, the TSS transported was 8,300 g, 12,195 g, and 15,628 g respectively. The average TSS transported over the storm's duration is 12,041 g. The TSS observed from the test trials ranged within approximately ± 30% of the average TSS. Additionally, the test results show that there is an initial delay in TSS being transported off of the model and at approximately ten minutes the relationship becomes linear.

6.3.2.3 Total Volume Versus Time Comparison

Figure 6.11 contains the combined results of test trials No. 1-3 in respect to volume of rainfall versus time.

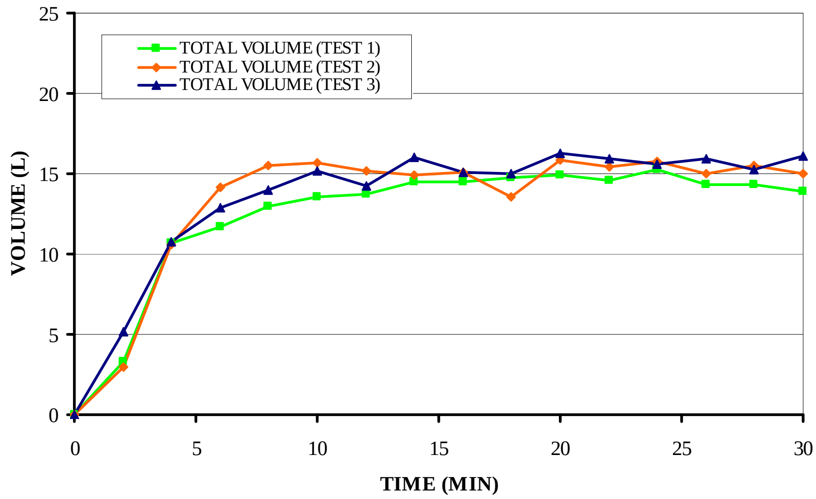


Figure 6.11 Total Volume vs. Time for Test No. 1-3.

Figure 6.11 is important to the study as it illustrates that the total volume measured from the four collection systems at any two minute interval during each of the tests is almost identical. Although there are minor fluctuations in each contributing collection system between the three test trials, ultimately all of the rainfall being applied to the model is accounted for therefore verifying mass balance. The minor variations can be attributed to two primary factors which include i.) the variability in initial moisture content of the base material and ii.) the fluctuations of precipitation from the rainfall simulator.

6.3.2.4 Cumulative Volume Versus Time Comparison

Figure 6.12 contains the combined results of test trials No. 1-3 in respect to cumulative volume of rainfall versus time.

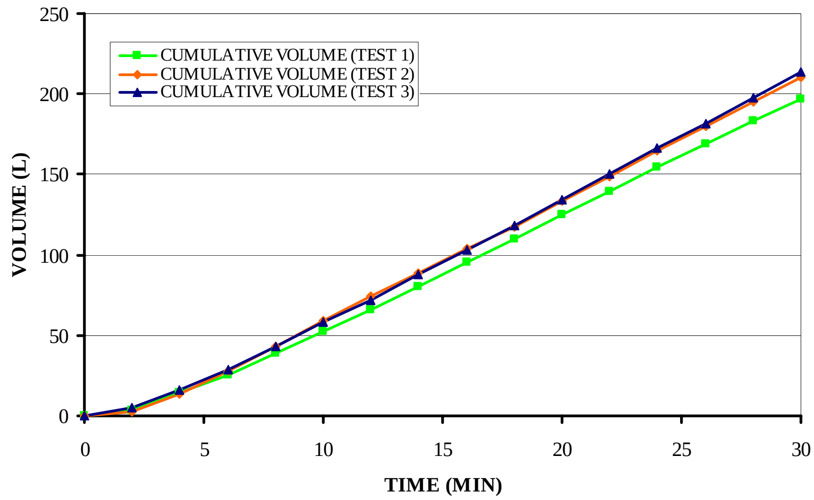


Figure 6.12 Cumulative Volume vs. Time for Tests No. 1-3.

For each of the three test trials, the flow rate during the test was 2 gpm for the 30 minute test duration resulting in approximately 60 gallons (227.1 liters) of water. Figure 6.12 depicts the cumulative volume measured from the four collection systems during the entire duration of the test. To attain mass balance, it was necessary to continue to collect water left in the model after stopping the testing. This volume was measured, summed with the cumulative volume in the collection systems, and then compared to the estimated volume applied to determine the mass balance. The results are shown below in Table 6.2.

Table 6.2 Test Trials No. 1-3: Mass Balance

Test Trial	Collection System Volume (l)	Model Volume (l)	Total Volume (l)	Estimated Volume Applied (l)	Mass Balance Closure Error (%)
1	197.2	12.4	209.6	227.1	-7.7
2	210.1	10.5	220.6	227.1	-2.9
3	213.4	16.5	229.9	227.1	+1.2

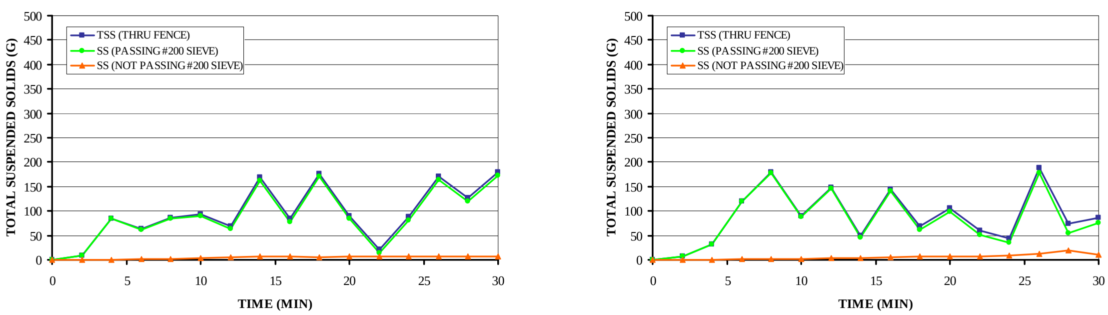
6.4 SILT FENCE PERFORMANCE WITH TIEBACKS

6.4.1 Test Trials No. 4-5

The results of test trial No. 4-5 are summarized into four data sets: i.) TSS versus time, ii.) cumulative TSS versus time, iii.) total volume versus time, and iv.) cumulative total volume versus time as discussed in the introduction.

6.4.1.1 Data Set No. 1: TSS Versus Time

The first data set, TSS versus time is determined by measuring only the TSS that passes through the fence at two minute intervals during the duration of the test. The installation of the silt fence tieback creates a detention basin and eliminates flow along the toe of slope of the silt fence. Consequently, no measurements in the toe of slope collection system were taken. Figure 6.13 illustrates the TSS transported through the fence at two minute intervals during test trials No. 4-5. The results of this data clearly show the sediment transport process through the silt fence on a typical highway construction project at the two minute intervals during the specified rainfall event.

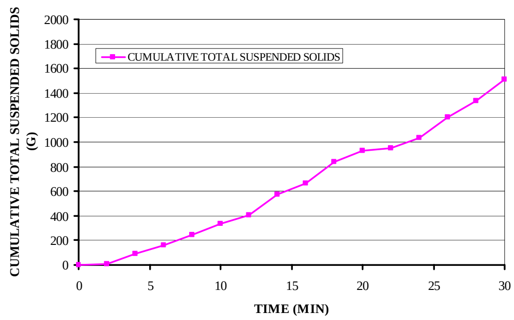


a.) Test Trial No. 4 **b.) Test Trial No. 5**

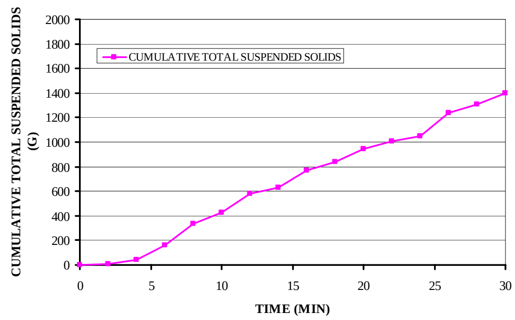
Figure 6.13 TSS vs. Time (Through Fence).

6.4.1.2 Data Set No. 2: Cumulative TSS Versus Time

The second data set, cumulative TSS versus time identifies the cumulative TSS that are being transported off of a highway construction project at each two minute interval during the storm's duration. Figure 6.14 depicts the cumulative TSS being transported at each two minute interval during the testing for test trials No. 4-5.



a.) Test Trial No. 4

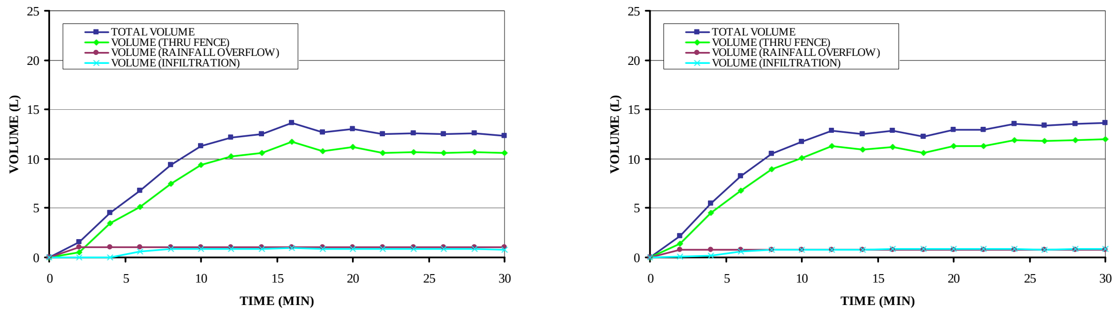


b.) Test Trial No. 5

Figure 6.14 Cumulative TSS vs. Time.

6.4.1.3 Data Set No. 3: Total Volume Versus Time

The third data set, total volume versus time, depicts the incremental volume of rainfall collected in the rainfall overflow collection system, infiltration collection system, and down-slope (through fence) collection system at two minute intervals during the test's duration. The individual volumes from the collection systems are totaled to attain the total volume collected at each two minute interval. Figure 6.15 reflects the total volume collected on the model at two minute intervals for test trials No. 4-5.

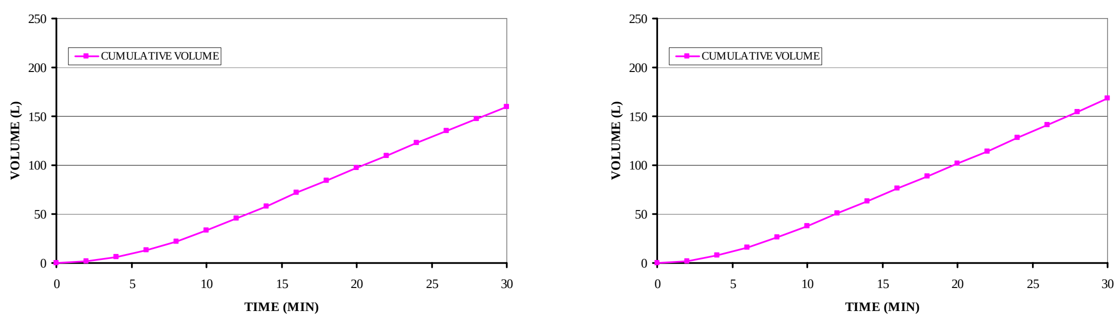


a.) Test Trial No. 4 b.) Test Trial No. 5

Figure 6.15 Total Volume vs. Time.

6.4.1.4 Data Set No. 4: Cumulative Total Volume Versus Time

The fourth data set, cumulative total volume versus time, depicts the cumulative volume of rainfall collected in the rainfall overflow collection system, infiltration collection system, and down-slope (through fence) collection system at each two minute interval during the storm's duration. Figure 6.16 reflects the cumulative total volume collected at each two minute interval for test trials No. 4-5.



a.) Test Trial No. 4 b.) Test Trial No. 5

Figure 6.16 Cumulative Total Volume vs. Time.

6.4.2 Comparison of Test Trials No. 4-5

In order evaluate the results of test trials No. 4-5, the four data sets collected from the two test trials were plotted on one graph. This is advantageous as it facilitates in i.)

identifying distinct trends or patterns in the data, ii.) locating possible outliers and developing explanations for the deviations, and iii.) determine the reproducibility of the model in attaining reasonably accurate results on a consistent basis.

6.4.2.1 TSS Versus Time Comparison

Figure 6.17 contains the combined results of test trials No. 4-5 in respect to TSS versus time.

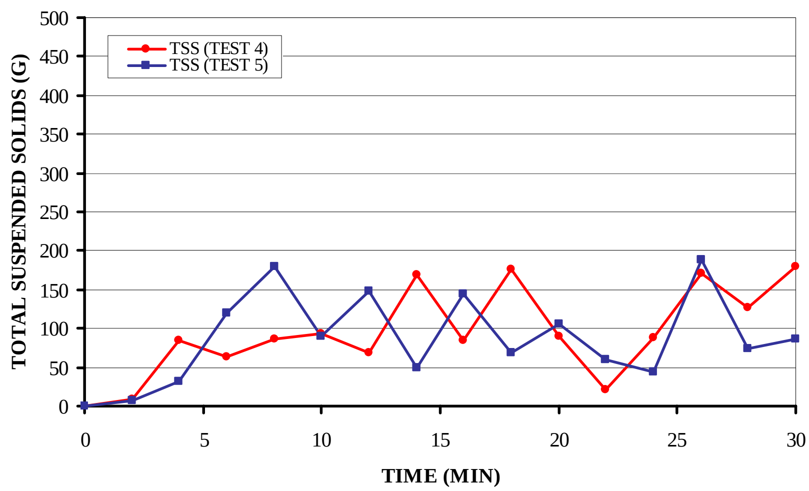


Figure 6.17 TSS vs. Time for Tests No. 4-5.

Figure 6.17 illustrates that the TSS being transported off the model for the two tests falls within a small range at each two minute interval during the tests. If the scale of this figure were increased to that of the scale used in trial tests No. 1-3, the data would illustrate a linear relationship. However, this scale was chosen to demonstrate that the amount of TSS leaving the model initially starts small and quickly reaches an equilibrium primarily fluctuating between 125 to 175 g. Some of the variability associated with this measurement may have been introduced in the measuring method. A small container with a capacity of 24-ml was chosen for sampling. After conducting the post processing of the samples, it became apparent that small deviations in filling the samples to the full level may create sampling errors that tend to be magnified due to the small size of the container. A recommendation is made to use larger containers for sampling during future testing. This will result in a reduction within the range of TSS measured during the testing.

6.4.2.2 Cumulative TSS Versus Time Comparison

Figure 6.18 contains the combined results of test trials No. 4-5 in respect to cumulative TSS versus time.

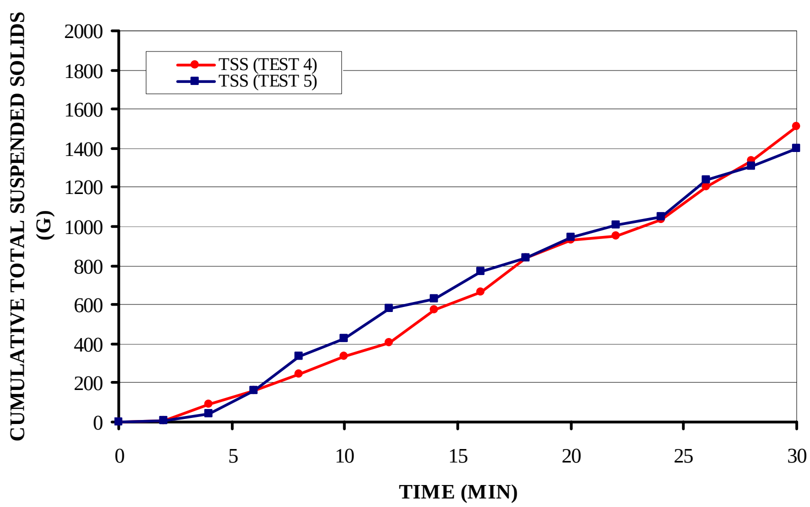


Figure 6.18 Cumulative TSS vs. Time for Tests No. 4-5.

Figure 6.18 illustrates that both test trials No. 4-5 have approximately the same linear growth in cumulative TSS leaving the model throughout the test. Despite the variations in the TSS measured from one time interval to another as shown in Figure 6.17, the variations appear to offset each other in each case resulting in nearly identical test results. From the data obtained in test trials No. 4-5, the TSS over the test duration ranged from 1,398 to 1,512 g. The average TSS transported over the storm's duration is

1,455 g. The TSS observed from the test trials ranged within approximately ± 4% of the average TSS. Additionally, the test results show that there is an initial delay in TSS being transported off of the model and at approximately five minutes the relationship becomes linear.

6.4.2.3 Total Volume Versus Time Comparison

Figure 6.19 contains the combined results of test trials No. 4-5 in respect to volume versus time.

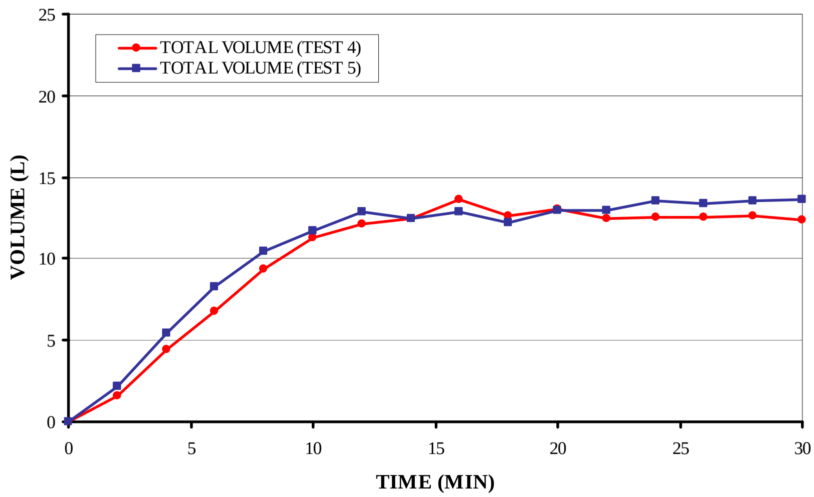


Figure 6.19 Total Volume vs. Time for Tests No. 4-5.

Figure 6.19 is important as it demonstrates that the total volume measured from the three collection systems at any two minute interval during the tests is almost identical. Although there are minor fluctuations in each contributing collection system between the two test trials, ultimately all of the rainfall being applied to the model is accounted for verifying mass balance. The minor variations can be attributed to two primary factors which include i.) the variability in initial moisture content of the base material and ii.) the fluctuations of precipitation from the rainfall simulator.

6.4.2.4 Cumulative Volume Versus Time Comparison

Figure 6.20 contains the combined results of test trials No. 4-5 in respect to volume versus time.

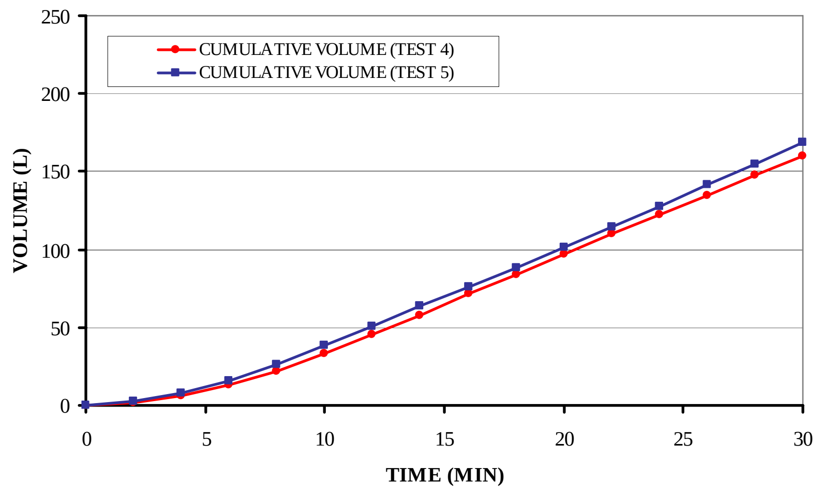


Figure 6.20 Cumulative Volume vs. Time for Tests No. 4-5.

For each of the two test trials, the flow rate during the test was 2 gpm for the 30 minute test duration resulting in approximately 60 gallons (227.1 liters) of water. Figure 6.20 depicts the cumulative volume measured in the three collection systems at each two minute interval during the entire duration of each test. To attain mass balance, it was necessary to continue to collect water remaining in the model after stopping the testing. This volume was measured, summed with the cumulative volume in the collection systems, and then compared to the volume applied to determine the mass balance. The results are shown below in Table 6.3.

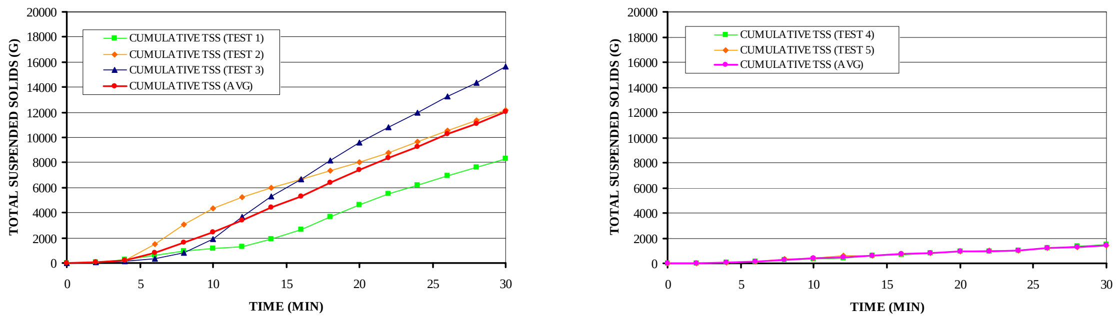
Table 6.3 Test Trials No. 4-5: Mass Balance

Test Trial	Collection System Volume (l)	Model Volume (l)	Total Volume (l)	Estimated Volume Applied (l)	Mass Balance Closure Error (%)
4	159.9	49.8	209.7	227.1	-7.7
5	168.5	47.6	216.1	227.1	-4.8

The relatively small mass balance closure errors obtained for configuration No. 1 (Silt fence w/o tiebacks) in test trials No. 1-3 and for configuration No. 2 (Silt fence w/tiebacks) are extremely important, a definite accomplishment, and strength of this research. Overall, the small-scale erosion control model is able to obtain over a 92% mass balance closure between the rainfall applied to the model and storm water runoff collected in the four collection systems. As a result, the research team is extremely confident in the data collected on this complex erosion control model. The error in mass balance can be attributed to a number of factors to include: i.) the variability in water supply, ii.) the accuracy of the flow meter, iii.) spillage occurring during sampling or handling, iv.) measurement error, and v.) whether the soil was fully saturated at the beginning of the test. Due to the small closure error, the small-scale erosion control model is unique compared to other laboratory models that have conducted erosion studies because it allows the potential to verify mass balance. The design of the small-scale erosion control model is progressive as it allows the research team to track exactly where and accurately quantify the rates that rainfall applied to the model reaches the four collection systems during the testing period.

6.5 OVERALL EFFECTIVENESS OF SILT FENCE TIEBACKS

In order to determine total reduction and percentage reduction attributed to the silt fence tieback, the average cumulative TSS as measured in test trials No. 1-3 for installation configuration No. 1 (Silt fence w/o tiebacks) will be compared against the average cumulative TSS measured in test trials No. 4-5 for installation configuration No. 2 (Silt fence w/tiebacks). Figure 6.21 contains the average TSS for both configurations.



a.) Configuration No. 1: Silt Fence w/o Tiebacks **b.) Configuration No. 2: Silt Fence w/Tiebacks**

Figure 6.21 Cumulative and Average TSS vs. Time.

The TSS for the first configuration, test trials No. 1-3, ranged from 8300 g to 15,628 g. The average TSS transported over the duration of the test was 12,041 g. The TSS for the second configuration, test trials No. 4-5, ranged from 1,398 to 1,512 g. The average TSS transported throughout the duration of the storm event was 1,455 g. The average TSS for both configurations are represented below in Figure 6.22.

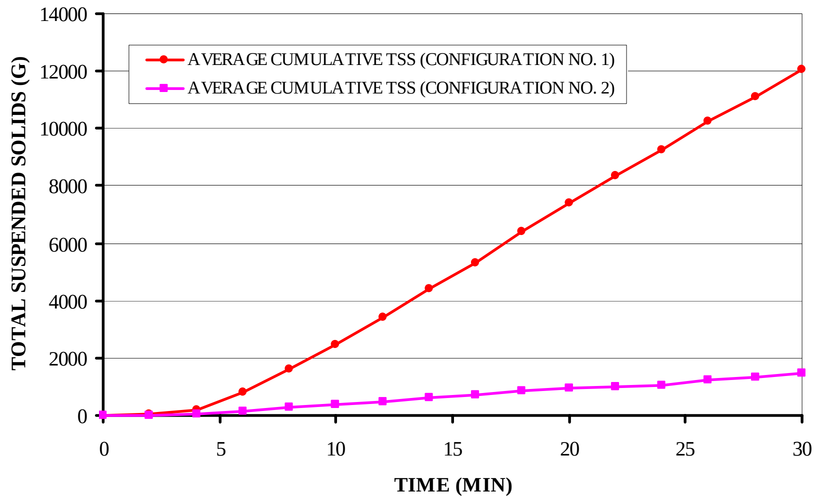


Figure 6.22 Average Cumulative Volume vs. Time.

The drastic differences in the average cumulative TSS being transported off of the construction site between the two silt fence configurations became quite apparent after comparing photographs taken during the testing of the small-scale erosion control model. Figure 6.23 and Figure 6.24 clearly illustrate the differences in the flow pattern of the storm water runoff along the toe of the silt fence during the testing.

Figure 6.23 Configuration No. 1: Flow Pattern Along the Toe.

Figure 6.24 Configuration No. 2: Flow Pattern Along the Toe.

The use of silt fence tiebacks resulted in an average reduction in TSS of 10,586 g. Equation 6.1 below can be used to compute the percentage reduction in TSS due to the utilization of silt fence tiebacks.

$$\%TSS_{REDUCTION} = \frac{TSS_{AVG(CONFIG2)} - TSS_{AVG(CONFIG1)}}{TSS_{AVG(CONFIG2)}} * 100 \qquad (6.1)$$

where: $\%TSS_{REDUCTION}$ = percent reduction (%)
$TSS_{AVG(CONFIG1)}$ = average TSS [configuration No. 1] (g.
$TSS_{AVG(CONFIG2)}$ = average TSS [configuration No. 2] (g.)

Using equation 6.1, there is an 88% reduction in TSS being transported off of the construction site due to the installation of silt fence tiebacks.

Finally, the large reduction in TSS being transported off of the construction sites due to the installation of silt fence tiebacks is quite visible from photographs taken at the conclusion of the testing. Figure 6.25 and Figure 6.26 show the final erosion and deposition patterns that occurred during the testing of the small-scale erosion control model for both silt fence installation configurations.

Figure 6.25 Configuration No. 1: Final Results.

Figure 6.26 Configuration No. 2: Final Results.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

This research project focused on three specific goals: i.) to construct a small-scale erosion control model that replicates typical highway construction sites, accommodates the simulation of varying rainfall intensities, and ultimately allows for the extensive testing of various erosion control BMPs at a small-scale, ii.) to develop guidance for silt fence tieback designs to assist designers and inspectors in the proper placement of silt fence tiebacks along highway construction projects, and iii.) to test the tieback design guidelines on the small-scale erosion control model and quantifying the reductions of the total amount of sediment leaving highway construction sites. The successes, shortcomings, and recommendations for future work in all three areas will be addressed in the following sections.

7.2 SMALL-SCALE EROSION CONTROL MODEL

The primary objective of this research effort was to construct a small-scale erosion control model that is representative of a typical highway construction project. This small-scale erosion control model permits various storm events to be simulated and is also flexible enough to allow testing of a multitude of erosion control BMPs. Overall, the final model constructed for this research project met all of these objectives. As the model was constructed, there were very few deviations from the original construction drawings. Preliminary testing revealed a few deficiencies that were corrected to include: i.) the replacement of the roadway asphalt surface in order to remove surface irregularities, ii.) the scoring of roadway edge to improve sheet flow onto fill slope, and iii.) the addition of aluminum flashing along the side of the fill slope to hinder the transfer of sediment into the overflow collection system. The test trials resulted in an erosion pattern, sediment transport, and sediment deposition similar to that observed while conducting the preliminary site investigation of typical highway construction projects. Overall, the model performed well during the test trials and will allow future research and testing of other BMPs (e.g. temporary vegetation, waddles, check dams, and flocculants). If future funding becomes available, a recommendation is made to address the shortcomings of the rainfall simulator. Currently, the rainfall simulator only meets three of the six main criteria listed in section 4.2.2. Modifications to the existing rainfall simulator would help improve the realistic simulation of a rainfall event resulting in a closer approximation of the natural erosion process and a higher accuracy in simulating the TSS transport occurring on highway construction projects.

7.3 SILT FENCE TIEBACK DESIGN GUIDELINES

The secondary goal of the research project involved developing a silt fence tieback design guide to assist designers and inspectors in the proper placement of silt fence tiebacks along highway construction projects. The methodology used in developing silt fence tieback guidelines centered upon using the SCS (Curve Number) method to estimate the amount of storm water runoff from a construction site during a specified storm event per unit length of roadway and attaining a balance with the computed storage capacity of the silt fence per unit length of silt fence. Ultimately, this design approach successfully resulted in the creation of an Excel™ spreadsheet program that predicts both the total storm water runoff and the storage capacity per unit length of silt fence installation for each unique highway construction project. Equipped with this information, the user is then able to select the tieback configuration that is most appropriate for the particular site. In most cases, the designer will select the most cost effective silt fence tieback configuration that achieves the required storage using the least amount of tieback installations. However, if there are physical site constraints, the designer is afforded the option of checking multiple tieback configurations that will work on the site. As a result, the tieback design program is a very effective tool for assisting designers and inspectors in effectively installing silt fence tiebacks along highway construction projects. However, it must be understood that silt fence tiebacks are typically designed to contain the runoff from small storm events (e.g. < 2 years). Similar to other BMPs, large storm events will exceed a silt fence's storage capacity resulting in failure to contain sediment.

7.4 OVERALL EFFECTIVENESS OF SILT FENCE TIEBACKS

The final goal of this research centered on conducting test trials on the small-scale erosion control model to determine the effectiveness of using silt fence tiebacks in reducing the TSS leaving highway construction sites. The TSS for the first configuration, test trials No. 1-3, ranged from 8300 g to 15,628 g. The average TSS transported over the duration of the test was 12,041 g. The TSS for the second configuration, test trials No. 4-5, ranged from 1,398 to 1,512 g. The average TSS transported throughout the duration of the storm event was 1,455 g. The use of silt fence tiebacks resulted in an average reduction in TSS of 10,586 g and an 88% reduction in TSS being transported off of the construction site.

7.5 USEFULNESS TO THE PRACTICE

The results obtained from this research clearly demonstrate the effectiveness of utilizing silt fence tiebacks on a small-scale model in reducing the TSS leaving a typical highway construction project. A significant reduction in TSS solids entering our waterways from highway construction projects will reduce i.) the clogging of reservoirs, lakes, and harbors, ii.) the loss of recreational areas and wildlife habitat, and iii.) the impairment of water necessary for human consumption as well as for plants, animals, and fish to live (Fifield, 2004). As a result, it is imperative that construction projects incorporate the necessary temporary control measures required to contain sediment on the construction site. This research fills a gap in the general knowledge in regards to designing and installing silt fence tiebacks. The development of the silt fence tieback design spreadsheet provides a quick field reference useful for state, city, and county engineers and inspectors to use in designing and inspecting silt fence tieback installations along highway construction projects. The formulation of an easily understood and accurate design guide gives these professionals a design mechanism for scientifically designing and inspecting silt fence tie backs as an erosion control measure that will provide an effective means of minimizing sediment transport during construction efforts.

7.6 RECOMMENDED FURTHER RESEARCH

7.6.1 Small-Scale Erosion Control Model

The testing conducted on the small-scale erosion control model established that the erosion patterns observed on the model are representative of those found on typical highway construction projects. However, the testing trials in this research focused on simulating a 3 in/hr rainfall intensity, using a poorly graded sand as a base material, and fixing the road and ditch slope at 2%. With the model constructed, further research needs to be conducted on the effect that the rainfall intensity, different soil types, and the variation that road and ditch slopes have on the TSS being transported off of the model. Equipped with the results of this future research, it is possible to develop simplified, quick reference silt fence tieback nomographs for any municipality. Using predetermined highway cross sections and a design storm, a total storm water runoff nomograph can be generated. Given the length of the fill slope on the highway construction project, the nomograph will tell the designer the total storm water that must be stored behind the silt fence tieback configuration. Using the total storm water quantity, the designer can then use a silt fence tieback nomograph to determine the appropriate number and placement of silt fence tiebacks. This nomograph will take into account different soil types in the area and various ditch slopes. Ultimately, the designer must ensure that the storage capacity behind the silt fence tiebacks selected for installation is greater than the storm water runoff generated by the storm event.

In addition, the testing conducted on the small-scale erosion control model did not result in any undercutting of the toe of slope along the silt fence installation. Future research must consider the possibility that higher ditch slopes may result in greater velocities occurring at the toe of the silt fence. These increased velocities may result in greater erosive action on varying soil types and ultimately result in a failure occurring at the toe of the silt fence. The maximum length before the installation of a tieback may ultimately not be governed by the length at which simultaneous overtopping and bypassing occurs, but by the length at which undermining of the toe of the silt fence begins to occur.

Finally, this research focused specifically on one BMP, the use of silt fence along highway construction projects. The model has the ability to allow future research and testing of numerous other BMPs such as temporary vegetation, waddles, check dams, and flocculants.

7.6.2 Field-Scale Erosion Control Testing Facility

Within the State of Alabama, there is a defined need for the development of a field-scale erosion control testing facility. This facility would be capable of testing current BMPs, determining their overall effectiveness, and developing proper installation procedures and maintenance requirements. An ideal location for such a facility is the NCAT test track owned by Auburn University. The NCAT Facility, shown in Figure 7.1 below, is a 1.7-mile oval test track built on 390 acres of land that was purchased by Auburn University to perform full-scale Accelerated Pavement Testing (APT). The facility is located approximately 30 minutes from Auburn University in Opelika, Alabama and is a closed access facility.

Figure 7.1 NCAT Test Facility.

The NCAT test track facility mirrors the natural conditions experienced on roadway construction projects encountered throughout the State. This is an ideal facility as it will allow the researchers to identify test sections that are representative of real world conditions, install the appropriate BMPs, and closely monitor the overall effectiveness of the BMPs.

The data obtained from the tests conducted at the field-scale erosion control testing facility could be compared to the results obtained from the small-scale models. After the data collection is completed, an analysis could be conducted to determine the validity of the small-scale test findings to determine if correlations can be drawn and scaled accordingly. The close correlation of the model data to actual field data would allow the researchers to develop a very cost efficient means of testing future BMPs.

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APPENDICES

APPENDIX A

ALABAMA DEPARTMENT OF TRANSPORTATION (ALDOT) BMPS

ALABAMA DEPARTMENT OF TRANSPORTATION (ALDOT) BMPs

Currently, the Alabama Department of Transportation (ALDOT) has adopted the following BMPs, in order of dependence, for sediment control during construction operations: 1.) Temporary Seed and Mulch, 2.) Temporary Mulch only, 3.) Solid Sod, 4.) Vegetated Buffer, 5.) Silt Fence, 6.) Hay Bales, 7.) Wattles, 8.) Drainage Sumps, 9.) Sand Bags, 10.) Silt Saver™, 11.) Rip Rap Ditch Check, 12.) ALDOT No. 1 Aggregate, 13.) Floating Basin Boom, 14.) Flocculents, 15.) Brush Barrier. These BMPs can be utilized for soil stabilization, inlet protection, sediment barriers, or ditch checks. In the following sections we will briefly review the design details of the abovementioned BMPs.

TEMPORARY SEEDING AND MULCH | TEMPORARY MULCH ONLY:

a. Temporary Seeding Application

b. Mulching Application

Temporary seeing and mulch is a form of soil stabilization that allows for the establishment of fast-growing annual vegetation from seed on disturbed areas. Temporary vegetative cover is an economical form of erosion control for up to one year and reduces the amount of construction site sediment transport. ALDOT stipulates specific seeds for temporary seeding that are dependent upon the time of year.

Mulching is the application of plant residues such as straw or other suitable materials to the soil surface. Mulch protects the soil surface from the erosive force of raindrop impact by holding soil in place and reduces the velocity of overland flow. When used simultaneously with temporary seeing, mulch provides an environment that helps seedlings germinate and grow by conserving moisture, protecting against temperature extremes and controlling weeds. This method helps to establish temporary plant cover on disturbed areas of the construction site. Mulch also maintains the infiltration capacity of the soil reducing the rate of overland flow. Mulch can also be used as an independent BMP application in unseeded areas to protect against erosion throughout the construction effort, until final grading and shaping can be accomplished. ALDOT limits temporary mulching to cereal grain straw (oats, wheat, or rye.).

These BMP applications will also reduce problems associated with mud and dust production from bare soil surfaces during construction. (Alabama Handbook et al, 153).

SOLID SOD:

Sodding is the use of a transplanted vegetative cover to provide immediate erosion control in disturbed areas. Sodding is well suited for stabilizing erodible areas such as grass-lined channels, slopes around storm drain inlets and outlets, diversions, swales, and slopes and filter strips that cannot be established by seed or that need immediate cover. (Alabama Handbook et al, 147).

VEGETATED STRIP:

A vegetated strip is a wide belt of vegetation maintained to allow infiltration, the interception of sediment, and the reduction of storm water flow and velocity. Filter strips can consist of either preserved vegetation or created by planting specified vegetation. These strips need to be strategically located on the contour as they are only effective in intercepting overland sheet flow (Alabama Handbook et al, 267).

SILT FENCE:

a. Sediment Barrier

ALDOT requires silt fence be installed on construction sites as required by the plans. Silt fence consists of a geo-textile filter fabric that meets the requirements of AASHTO M288, supported by posts placed in a way as to control sheet flow from disturbed sites. Its purpose is to retain sediment from small areas by providing detention time that allows for the deposition of suspended particles (Smolen et al., 1998 and EPA 600/R-04/184, 2).

Silt fence can be used as sediment barriers, ditch checks, or inlet protection devices on ALDOT projects.

Silt fence used as sediment barriers are

b. Ditch Check

c. Inlet Protection

temporary structures used across a landscape to reduce the quantity of sediment that is allowed to travel farther down slope and leave the construction site (Alabama Handbook et al, 287).

A silt fence used as a ditch check is a temporary dam constructed across a swale or drainage ditch to reduce the velocity of storm water runoff. The purpose of this practice is to reduce velocity and pond storm water runoff allowing sediment to deposit behind the silt fence ditch check.

Silt fence used for drop inlet protection is a temporary woven geotextile barrier placed around a drop inlet to prevent sediment from entering storm drains during construction. This practice is suitable for inlets with a drainage area of 1 acre or less and an approach slope of 1% or less. (Alabama Handbook et al, 263).

HAY BALES:

a. Ditch Check

b. Sediment Barrier

Hay bales create temporary sediment traps used for smaller drainage areas that are formed by an excavation and are designed to capture and hold sediment-laden runoff, trapping the sediment. Hay bales essentially create a ponding basin allowing deposition to occur. Hay bales are comprised of one row or more of anchorched straw bales which intercept and detain small amounts of sediment (Alabama Handbook et al, 323).

Hay bales can be used as either a ditch check or a sediment barrier on ALDOT construction sites. ALDOT specifies that hay bales may either be hay or straw containing 5 cubic feet of material and having a weight of not less than 35 pounds with a minimum length of 3 feet.

SILT SAVER™:

a. Silt Saver

b. Inlet Protection

The silt saver is an approved ALDOT erosion control measure used for inlet protection. The silt saver consists of a geotextile cover that is supported by a frame constructed of partially recycled, high molecular weight high-density polyethylene copolymer (HDPE). It is primarily installed over open catch basins to prevent construction site sediments from entering and polluting storm water within the basin drainage system.

WATTLES:

a. Inlet Protection

Wattles are temporary erosion and sediment control barriers and filters comprised of interwoven biodegradable plant material such as straw, coir, or wood shavings in biodegradable or photodegradable netting. Wattles have cylindrical cross sections that are 8 to 20 inches in diameter and 25 to 40 feet in length.

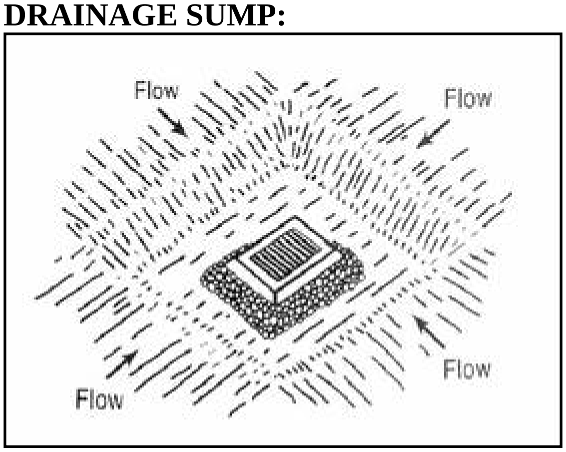
ALDOT specifies that wattles can be used as inlet protection devices, ditch checks, and sediment barriers on construction sites.

b. Sediment Barrier

The two main purposes of wattles are to: i.) reduce slope length; and ii.) trap sediment. Wattles stabilize slopes by shortening the slope length and by slowing, spreading, and filtering overland water flow. With the installation of wattles, sheet erosion is prevented, as well as rill and gully development, both of which occur when runoff flows uninterrupted down a slope. Storm water runoff also carries sediment and seeds off slopes as it gathers velocity. Wattles capture that sediment and retain it on site enabling seeds to settle and germinate, aiding the revegetation process.

c. Ditch Check

DRAINAGE SUMP:



a. Inlet Protection

ALDOT allows drainage sumps to be used as a sediment basin at discharge points or for inlet protection.

Where sediment retention is required, a drainage sump can be constructed below the ditch bottom elevation at discharge points allowing adequate detention time for suspended solids to settle out of the storm water runoff and deposit within the sump itself.

Drainage sumps used for inlet protection are basically an excavated drop inlet constructed by excavating around the approaches to the storm water drain inlet. The removed soil allows storm water to accumulate and for sediment to settle, consequently reducing the amount of sediment entering the storm drainage network during construction (Alabama Handbook et al, 259)

SAND BAGS:

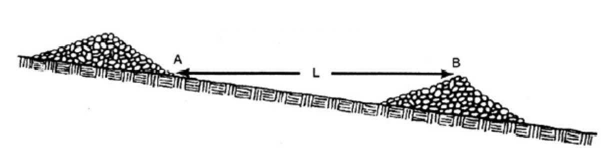
a. Sediment Barrier

Sand bags are a form of erosion control that is used on construction sites to contain sediment and to prevent sediment transport beyond the limits of the site. Sand bags can be utilized to provide inlet protection, act as a ditch check, or be installed as a sediment barrier.

ALDOT's special provisions specify that sand bags may be made of cotton, burlap, or any other approved material which will adequately confine the sand. Each bag must have a volume of approximately 1 cubic foot.

RIP RAP DITCH CHECK:

a. Rip Rap Ditch Check

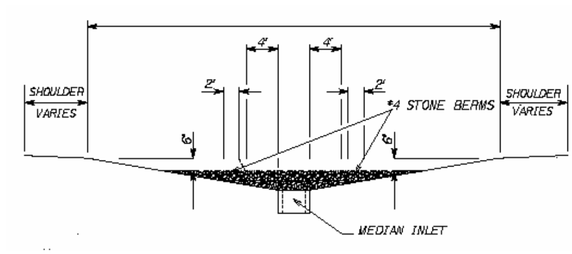


b. Ditch Check (Elevation View)

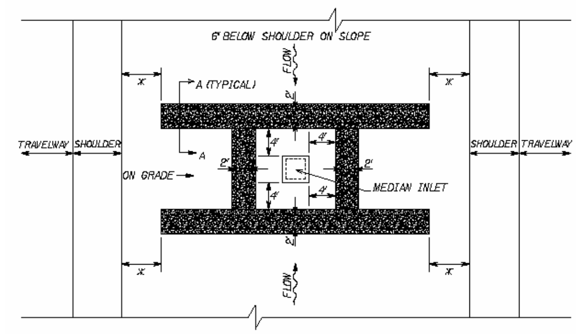
A rip rap ditch check is a small barrier or dam constructed across a swale, drainage ditch, or other area of concentrated flow for the purpose of reducing channel erosion. Channel erosion is reduced because ditch checks flatten the gradient of the flow channel and slow the velocity of channel flow. Most ditch checks are constructed of rock, but hay bales, silt fence, wattles, and other materials may be acceptable by ALDOT.

This practice applies in small open channels and drainage ways, including temporary and permanent swales. It is not to be used in a live stream. Situations of use include areas in need of protection during establishment of grass and areas that cannot receive a temporary or permanent non-erodible lining for an extended period of time. (Alabama Handbook et al, 165).

TEMPORARY COARSE AGGREGATE:



a. Inlet Protection (Elevation View)



b. Inlet Protection (Plan View)

ALDOT utilizes temporary coarse aggregate, such as ALDOT No. 1 and No. 4 aggregate types to stabilize construction entrances, to provide adequate inlet protection, and as ditch check material.

FLOATING BASIN BOOM:

a. Turbidity Barrier

Floating basin booms consist of a heavy duty reinforced fabric (geotextile material) attached on the upper side to floatation members and an anchorage system ballasted on the lower side with chains or weights to form a bottom-tensioned floating curtain boom. The floating basin boom minimizes sediment transport from a disturbed area that is adjacent to or within a body of water. The barrier provides sedimentation protection for a watercourse from up-slope land disturbance activities where conventional erosion and sediment controls cannot be used, or from dredging or filling operations within a watercourse. The practice can be used in non-tidal and tidal watercourses where intrusion into the watercourse by construction activities has been permitted and subsequent sediment movement is unavoidable. (Alabama Handbook et al, 273).

FLOCCULENT(s):

a. Soil Stabilization

Chemical erosion control on construction sites usually involves a powder, or a water soluble anionic polyacrylamide (PAM) product. PAM is used to minimize soil erosion caused by water and wind. PAM is typically applied with temporary seeding and or mulching on areas where the timely establishment of temporary erosion control is so critical that seeding and mulching need additional reinforcement. It may be used alone on sites where no disturbances will occur until site work is continued and channel erosion is not a significant potential problem (Alabama Handbook et al, 73).

BRUSH | FABRIC BARRIER:

a. Sediment Basin

Brush barriers are a dam-like temporary structure constructed of selected brush, limbs and small trees from clearing operations overlaid with a geo-textile filter fabric. This practice creates a temporary sediment basin and is best implemented on sites with small drainage basins. (Alabama Handbook et al, 255).

APPENDIX B

F-405 SERIES IN-LINE FLOWMETER SPECIFICATION

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- Rod guided float
- Strong polypropylene float stops (guide rod holders)
- Permanently silkscreened direct reading dual scale
- Permanently silkscreened white back reflector for enhanced readability
- Annealed for added strength and chemical resistance.

View a larger image...(28k)

Specifications:

- Pipe Sizes available:
  - 1/4" Female NPT
  - 3/8" Female NPT
  - 1/2" Female NPT
- Maximum Temperature (on most models):
  - 150°F / 65°C at 0 pressure
- Maximum Pressure:
  - 150 psig / 10.3 Bar at 70°F/21°C
- Accuracy:
  - +/- 5% Full scale
- Max. Pressure Drop:
  - 2 PSI
- Dimensions:
  - Height: 8-3/16 inches
  - Width (diameter): 1-1/4 inches
- Flow ranges (dual scale reading). These are some of our most popular flow ranges.
  The files below can be printed to see actual size of scale.

  Liquid Ranges:
  - .025 - .250 GPM / .1 - 1 LPM (PDF)
  - .1 - 1 GPM / .4 - 4 LPM (PDF)
  - .2 - 2 GPM / 1 - 7.5 LPM (PDF)
  - .3 - 3 GPM / 1 - 11 LPM (PDF)
  - .5 - 5 GPM / 2 - 20 LPM (PDF)

  Air Ranges:
  - 0.2 - 2.0 SCFM / .4 - 3.2 M^3/HR (PDF)
  - 1 - 12 SCFM / 2 - 20 M^3/HR (PDF)
  - 2 - 20 SCFM / 4 - 34 M^3/HR (PDF)

Calculate for your Specific Gravity. (Liquid only) Web tool.

Please call the factory for other calibrations (such as air), or check ordering information.

Wetted material:

Chemical Resistance guide for standard and optional wetted materials.
Chemical Resistance.

- Meter tube:
  - Cast Acrylic Rod
- Adapters / Float Stops:
  - Polypropylene, reinforced with aluminum stress rings for added strength
- Float:
  - 316 Stainless Steel -or- Hastelloy C-276 -or- PVC, depending on calibration
- Guide Rod:
  - 316 Stainless Steel
- O-ring
  - Viton

See our full line of Acrylic Tube Rotameters.

phone: 714-893-8529 | fax: 714-894-9492
Contact us (e-mail): Sales | Tech Support | Webmaste

APPENDIX C

1/8HH-3.6 SW FULLJET NOZZLE SPECIFICATION

Square / Oval Pattern Full Cone Nozzles

Ordering Number: 1/8HH-3.6SQ
Description: FullJet Spray Nozzles, Square Spray, Small Capacity

Image is representative only, actual part may vary.

▶ Printable Page ▶ Add to RFQ

Common Applications

Cooling and quenching, Product washing, Air and gas washers, Scrubbers, Liquor washers, Dust control, Fire protection

Design Features

Smaller capacity, square spray FullJet nozzles feature a solid cone-shaped spray pattern with a square impact area and spray angles of 40° to 82°. They produce a uniform spray of medium to large drops across their entire spray area and over a wide range of pressures and flow rates. This uniform spray distribution is the result of a unique vane design with large flow passages and superior spray control characteristics.

- Well suited for installations requiring complete coverage of rectangular areas or spray zones. *Model G-SQ and GG-SQ nozzles feature removable caps and vanes that allow the removal and inspection of these components without the removal of the nozzle body from its header or manifold.*
- *The sides of the square spray pattern are offset approximately 20° to 25° from the groove positions of the nozzles, depending upon spraying pressure and spray distance.*

Specifications

Nozzle Inlet Connection	Male NPT
Capacity @ 40 psi	0.69
Nozzle Type	HH
Inlet Connection (inches)	1/8
Capacity Size	3.6SQ
Material	Brass
Length (inches)	7/8
Hex (inches)	1/2
Net Weight (oz)	1/2
Orifice Diameter Nom.	.063
Spray Angle @ 7 psi	40
Spray Angle @ 20 psi	52
Spray Angle @ 80 psi (degrees)	47
Maximum Free Passage Diameter	0.05
Capacity Size (SQ)	3.6
Spray Pattern	Square
Minimum PSI	5
Maximum PSI	150
Accessories	Split-eyelet Connector, Adjustable Ball Fittings, Strainers, Check Valves

Experiments in Spray Technology

ISO 9001 14001

Spray Nozzles — Spray Control — Spray Analysis — Spray Fabrication

APPENDIX D

SKAPS W200 WOVEN GEOTEXTILE FABRIC SPECIFICATION

SKAPS Industries • Commerce, GA • Pendergrass, GA

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SKAPS W200

Woven Geotextiles

SKAPS geotextile fabrics are woven polypropylene materials offering optimum performance when used in stabilization applications. Produced from first quality raw materials, they provide the perfect balance of strength and separation in styles capable of functioning exceptionally well in a wide range of performance requirements. Unless indicated below, all listed properties are Minimum Average Roll Values:

:: Go Back ::

PROPERTY	TEST METHOD	UNIT	M.A.R.V. (Minimum Average Roll Value)
Weight (Typical)	ASTM D5261	oz/yd^2 (g/m^2)	4.0 (136)
Grab Tensile	ASTM D4632	lbs (kN)	200 (.889)
Grab Elongation	ASTM D4632	%	15
Trapezoid Tear Strength	ASTM D4533	lbs (kN)	75 (0.333)
Puncture Resistance	ASTM D4833	lbs (kN)	90 (.400)
Mullen Burst	ASTM D3786	psi (kPa)	400 (2756)
Permittivity*	ASTM D4491	sec^{-1}	.05
Water Flow*	ASTM D4491	gpm/ft^2 ($l/min/m^2$)	5 (203)
A.O.S.*	ASTM D4751	U.S. Sieve (mm)	50 (.300)
U.V. Resistance	ASTM D4355	%/hrs	70/500

* At the time of manufacturing. Handling, storage, and shipping may change these properties.

PACKAGING	
Roll Dimension (W x L) - Ft	12.5x432 / 17.5 x 309
Square Yards per Roll	600
Estimated Roll Weight - lbs	180

APPENDIX E

ALDOT STANDARD SILT FENCE DETAIL

(SEE MAP POCKET ON BACK COVER)

APPENDIX F

SKAPS GT 135 WOVEN GEOTEXTILE FABRIC SPECIFICATION

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SKAPS GT-135

Nonwoven Geotextiles

SKAPS **GT-135** is a needle-punched nonwoven geotextile made of 100% polypropylene staple fibers, which are formed into a random network for dimensional stability. SKAPS GT-135 resists ultraviolet deterioration, rotting, biological degradation, naturally encountered basics and acids. Polypropylene is stable within a pH range of 2 to 13. SKAPS GT-135 conforms to the physical values listed below:

:: Go Back ::

PROPERTY	TEST METHOD	UNIT	M.A.R.V. (Minimum Average Roll Value)
Weight (Typical)	ASTM D5261	oz/yd^2 (g/m^2)	3.5 (119)
Grab Tensile	ASTM D4632	lbs (kN)	90 (.401)
Grab Elongation	ASTM D4632	%	50
Trapezoid Tear Strength	ASTM D4533	lbs (kN)	40 (.178)
Puncture Resistance	ASTM D4833	lbs (kN)	60 (.267)
Mullen Burst	ASTM D3786	psi (kPa)	185 (1275)
Permittivity*	ASTM D4491	sec^{-1}	2.2
Water Flow*	ASTM D4491	gpm/ft^2 ($l/min/m^2$)	150 (6095)
A.O.S.*	ASTM D4751	U.S. Sieve (mm)	50 (0.3)
U.V. Resistance	ASTM D4355	%/hrs	70/500

* At the time of manufacturing. Handling, storage, and shipping may change these properties.

PACKAGING	
Roll Dimension (W x L) - Ft	12.5/15 x 360
Square Yards per Roll	500/600
Estimated Roll Weight - lbs	130/155

ALABAMA DEPARTMENT OF TRANSPORTATION
Bureau of Research and Development
1409 Coliseum Boulevard, Montgomery, Alabama 36130-3050
Phone: (334) 353-6940 FAX: (334) 353-6960
Internet: http://www.dot.state.al.us

Bob Riley
Governor

Joe McInnes
Transportation Director

July 12, 2005

Mr. Anurag Shah
Quality Control Manager
Skapps Industries
316 S. Holland Dr.
Pendergrass, GA 30567

RE: PEB 1499 – Skapps GT 135 (Silt Fence)

Dear Mr. Shah:

The Alabama Department of Transportation (ALDOT) Product Evaluation Board (PEB) reviewed your request in the July 5, 2005, PEB Meeting. The board approved the referenced product. This product will be added to List II-3, in the ALDOT, Materials, Sources, and Devices with Special Acceptance Requirements Manual.

If you have additional questions, please call Ms. Michelle Owens or Mr. Billy Bullard at (334) 353-6940.

Sincerely,

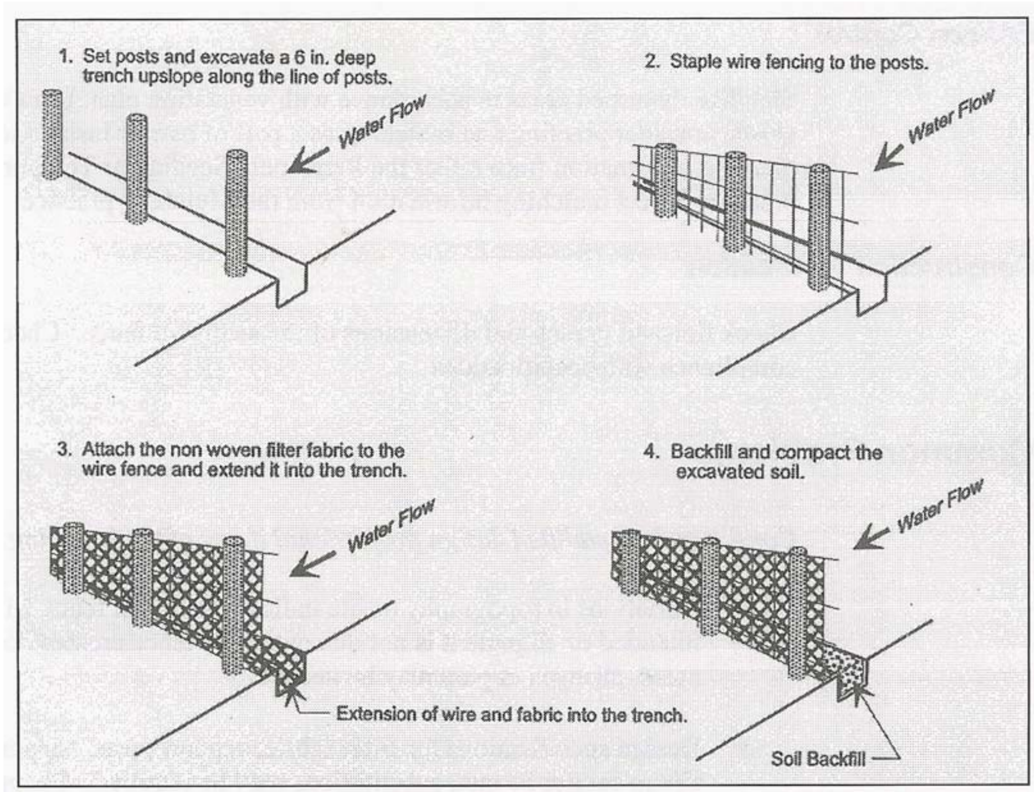
Lamar S. Woodham Jr.
Chairman, Product Evaluation Board

LSW/JWB/MO/BRB

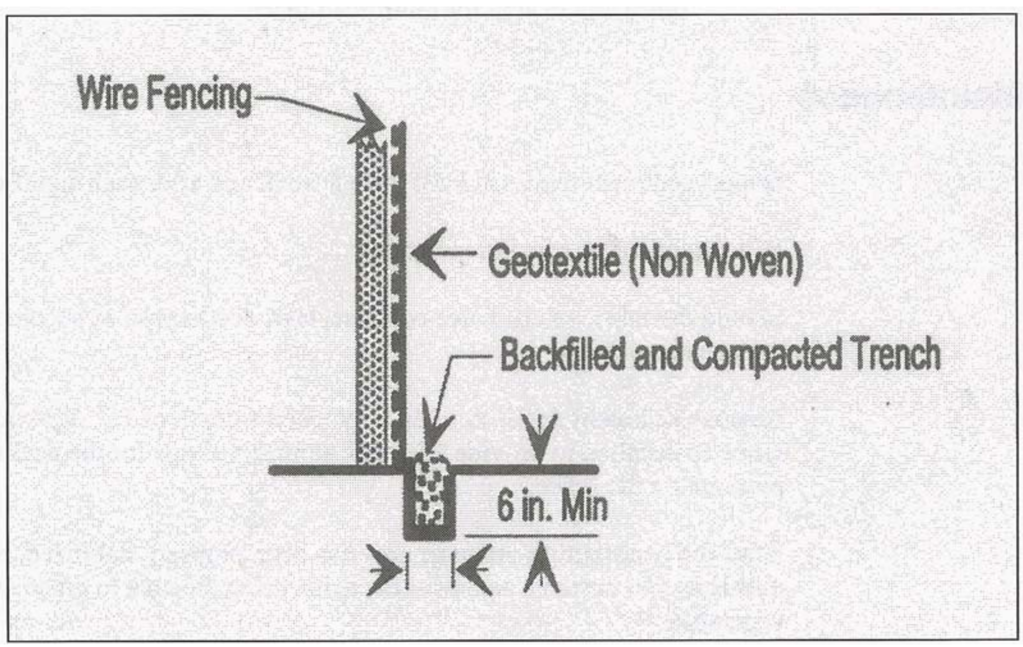
cc: File

APPENDIX G

SILT FENCE INSTALLATION DETAILS



1. Set posts and excavate a 6 in. deep trench upslope along the line of posts.
Water Flow
2. Staple wire fencing to the posts.
Water Flow
3. Attach the non woven filter fabric to the wire fence and extend it into the trench.
Water Flow
Extension of wire and fabric into the trench.
4. Backfill and compact the excavated soil.
Water Flow
Soil Backfill



Wire Fencing
Geotextile (Non Woven)
Backfilled and Compacted Trench
6 in. Min

APPENDIX H

CURVE NUMBERS FOR SCS METHOD

Table 4.5 Runoff Curve Numbers for Hydrologic Soil Cover Complexes[a]

Land-Use Description and Cover	Average Imperviousness (%)	Hydrologic Conditions	Hydrologic Soil Groups			
			A	B	C	D
Residential lot size[b]						
0.05 ha (⅛ acre)	65		77	85	90	92
0.10 ha (¼ acre)	38		61	75	83	87
0.15 ha (⅓ acre)	30		57	72	81	86
0.20 ha (½ acre)	25		54	70	80	85
0.4 ha (1 acre)	20		51	68	79	84
Paved parking lots, driveways, etc.[c]			98	98	98	98
Streets and roads						
Paved with curbs and storm sewers			98	98	98	98
Gravel			76	85	89	91
Dirt			72	82	87	89
Commercial and business	85 (av.)		89	92	94	95
Industrial districts	72		81	88	91	93
Open spaces, lawns, golf courses, cemeteries, etc.						
Good condition, grass cover on 75% or more of the area			39	61	74	80
Fair conditions, grass cover on 50 to 75% of the area			49	69	79	84
Fallow						
Straight row		—	77	86	91	94
Row crops						
Straight row		Poor	72	81	88	91
Straight row		Good	67	78	85	89
Contoured		Poor	70	79	84	88
Contoured		Good	65	75	82	86
Contoured and terraced		Poor	66	74	80	82
Contoured and terraced		Good	62	71	78	81
Small grain						
Straight row		Poor	65	76	84	88
Straight row		Good	65	75	83	87
Contoured		Poor	63	74	82	85
Contoured and terraced		Poor	61	72	79	87
Contoured and terraced		Good	59	70	78	81
Close-seeded legumes[d] or rotational meadow						
Straight row		Poor	66	77	85	89
Straight row		Good	58	72	81	85
Contoured		Poor	64	75	83	85
Contoured		Good	55	69	78	83
Contoured and terraced		Poor	63	73	80	83
Contoured and terraced		Good	51	67	76	80

Table 4.5 ***Continued***

Land-Use Description and Cover	Average Imperviousness (%)	Hydrologic Conditions	Hydrologic Soil Groups A	B	C	D
Pasture or range, contoured		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
		Poor	47	67	81	88
		Fair	25	59	75	83
		Good	6	35	70	79
Meadow, grass		Good	30	58	71	78
Woods or forestland		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		—	59	74	82	86

Source: Soil Conservation Service (1975).

[a] Antecedent soil moisture conditions AMC II.

[b] Curve numbers are computed assuming that the runoff from the house and driveway is directed toward the street, with a minimum of roof water directed to lawns where additional infiltration could occur. The remaining pervious areas (lawns) are considered to be in good pasture conditions for these curve numbers.

[c] In some warmer climates of the country, a curve number of 95 may be used.

[d] Close-drilled or broadcast.