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COLLEGE OF ENGINEERING

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Development of a Test Facility to Evaluate the Optimal Design of BMPs for Managing Environmental Problems at Construction Sites

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ABSTRACT

The following document is the final report for ALDOT Project 930-655 which summarizes the design and construction of the Auburn University – Erosion and Sediment Control Testing Facility (AU-ESCTF) along with several intermediate-scale, full-scale, and field-scale research efforts performed during the project period. This report contains separate design briefs and research briefs providing an overall summary of the individual efforts conducted under this research project. Each brief is intended to be read as a separate document, and this final report is the compilation of all design and research briefs developed as a result of this research effort. The complete details and results associated with each research element are fully documented in the master's theses reference at the conclusion of this section. The report is divided into the following sections:

Auburn University – Erosion and Sediment Control Testing Facility (AU-ESCTF): Overview

- Evaluation of the Water Introduction System
- Evaluation of the Sediment Introduction System
- Geotechnical Evaluation of the Earthen Section
- Summary of Water Profile Mapping Methods

Design Brief: Silt Fence Tieback Design Tool for Highway Construction Installations

Research Brief: Field Evaluation of Silt Fence Tieback Systems at a Highway Construction Site

Research Brief: Use, Application, and Evaluation of Anionic Polyacrylamide (PAM)

Research Brief: Performance Evaluation of Polymer-Enhanced Soft Armoring

Research Brief: Evaluation of Hydromulches as an Erosion Control Measure

Master's Thesis References:

1. Halverson, J.L. "*Use of a Small-Scale Erosion Control Model in the Design of Silt Fence Tiebacks*", M.S. Thesis, Auburn University, 2006.
2. McDonald, J.S. "*Evaluation of Erosion and Sediment Control Best Management Practices: Use of Silt Fence Tieback Systems and Anionic Polyacrylamide on Highway Construction Sites*", M.S. Thesis, Auburn University, 2007.
3. Shoemaker, A.L. "*Evaluation of Anionic Polyacrylamide as an Erosion Control Measure using Intermediate-scale Experimental Procedures*", M.S. Thesis, Auburn University, 2009.
4. Wilson, W.T. "*Evaluation of Hydromulches as an Erosion Control Measure Using Intermediate-Scale Experiments*", M.S. Thesis, Auburn University, 2010.
5. Donald, W.N. "*Development of a Large-Scale Erosion and Sediment Control Testing Facility*", M.C.E. Report, Auburn University, 2010.

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Auburn University-Erosion and Sediment Control Testing Facility (AU-ESCTF): Overview

The AU-ESCTF is a research facility designed to test sediment and erosion control products and practices typically used on highway construction sites. The facility has the capabilities of: (1) testing erosion control practices (e.g., straw mulch, hydromulch, polyacrylamide, polymer-enhanced soft armoring, etc.) at an intermediate-scale using simulated rainfall, and (2) testing erosion and sediment control practices (e.g., ditch checks and inlet protection) at a large-scale using simulated channelized flow applications to meet the testing and product evaluation needs of the Alabama Department of Transportation (ALDOT). The 2 ¼ acre facility is located at the National Center for Asphalt Technology (NCAT) as shown in Figure 1.

Figure 1: Satellite Image and Aerial Photo of the NCAT Test Track and AU-ESCTF Location.

The facility has a testing area dedicated to performing intermediate scale testing in a laboratory setting (Figure 2(a)) as well as a testing area dedicated to performing large-scale testing Figure 2(b)).

INTERMEDIATE-SCALE TESTING

The intermediate scale testing area is capable of testing various erosion control practices on plots ranging from 2 ft wide and 4 ft in length to 4 ft wide and 8 ft in length. The rainfall simulator is 10 ft in height and uses a pressure regulator to simulate various storm events along with a solenoid valve to immediately turn on or off the water supply. Several experiment have been performed at in intermediate scale and are summarized in the research briefs found in this report.

LARGE-SCALE TESTING

Three test channels were constructed for the large-scale testing area. Two are designated as ditch check testing channels while the third is used for inlet protection testing as shown in Figures 3(a) and 3(b). The two ditch check testing channels are comprised of four sections: 1) the water/sediment introduction system; 2) the permanently lined section which is plated with sheet metal; 3) the earthen section where each ditch check is installed; and 4) the concrete conveyance channel where test waters are sampled after passing the test area and then conveyed to the sediment basin for treatment before discharging to the lower retention pond.

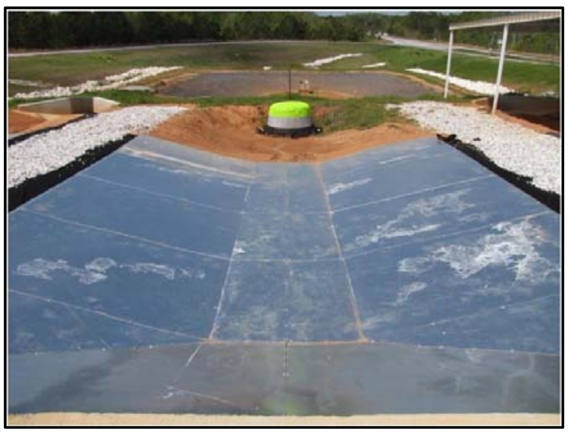
(a) Intermediate-scale testing area

(b) Large-scale testing area

Figure 2: AU-ESCTF Test Facility.

Testing is performed using three pumps rated to pump 0.56 cfs each. The test being performed delegates known flow rates (e.g. low (0.56 cfs), medium (1.12 cfs), or high (1.68 cfs)) based upon the number of pumps that are engaged during a particular test. When testing a device's functionality as a sediment control device, a hopper with a hydraulically driven conveyor belt is used to supply sieved sediment into the test water creating sediment-laden flow as shown in Figure 4. The sediment hopper is a 2 cy fertilizer spreader that has been modified to satisfy the sediment discharge needs of the facility. The chute and the conveyor belt of the hopper have been extended to provide direct delivery of sediment into the water discharged from the water introduction system.

(a) Straw wattle ditch check test



(b) Inlet protection channel

Figure 3: AU-ESCTF Test Channels

ASTM D 7208-06 Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion was modified to develop the testing protocol for ditch check testing. These procedures can be found in Appendix A of this report.

Each ditch check will be evaluated structurally using non-sediment laden water. This allows the researchers to observe the performance of a ditch check's installation under the standard testing conditions. If deficiencies are observed in the installation based on mapped water velocity, erosion and undermining profiles, the installation is reevaluated, modified, and retested.

Figure 4: Water/Sediment Introduction System

If the recommended installation practice is sufficient or when a new installation practice is determined to be adequate, the sediment retention capabilities of the ditch check will be evaluated under sediment-laden flow conditions. To determine a ditch check's effectiveness as a sediment control device, the ditch check is installed per the determined best installation practice from the clean water test. Sampling is performed during this test to evaluate the ditch check's ability to reduce turbidity and total suspended solids (TSS). Erosion and deposition patterns will be documented to determine soil retention or losses behind the ditch check device. Pre-conditions, during, and post testing documentation will be performed including photographs and video. Each test will be performed a minimum of 3 times. Once all testing has been completed and data collected and evaluated, a standard summary report documenting the testing for the particular device will be developed and submitted to ALDOT for review.

The following sections outline the two basic systems that are used during the large-scale testing efforts. These systems include: (1) Water Introduction System, and (2) Sediment Introduction System. Each system was independently tested, evaluated to verify the performance during large-scale tests.

Additional information on the geotechnical testing procedures of the earthen section to ensure repeatability when the section is prepared prior to each test is summarized.

Lastly, an evaluation of the water velocity data collection procedure along with preliminary results is also included.

Auburn University – Erosion and Sediment Control Testing Facility: Evaluation of the Water Introduction System

The water introduction system consists of three Northstar® 3" semi-trash pumps. Each pump is specified by the manufacturer to pump at a maximum rate of 15,850 gal/hr (0.59 cfs). These pumps are set up in series and pump from the collection pond to a 40.1 ft^3 (300 gal.) polypropylene trough. This trough has been modified with three openings specifically designed to accommodate flow from each pump, (i.e. when only one pump is pumping water, the lowest opening is being fully used, when two pumps are pumping water, two openings are being fully used, and when three pumps are pumping water, all the openings are fully discharging). Figure 5(a) shows the outlet configuration and the respective water levels when the pumps are operating in series.

(a) corresponding flow rates per opening

(b) Max. flow when all 3 pumps are operating

Figure 5: Polypropylene Trough Openings and Flow Levels at Various Flow Conditions.

Figure 5(b) illustrates the condition when all three pumps are engaged, and all three openings on the trough are being used to discharge the flow.

The purpose of this report was to verify the pumping rate of the water introduction system, and establish the flow measurement system that can be used to measure any flow condition. The pump flow rates were therefore determined by first calculating the volume of the trough to the bottom of the first trough opening. This volume was estimated to be 20.4 ft^3. The time required to fill the trough to this volume by each pump was recorded and reported in Table 1. This task was repeated five times per pump to collect data and establish an average time to fill the trough, which was 36.5 seconds. This corresponds to an average flow rate of 0.56 cfs. This is very close to the manufacturer specified flow rate of 0.59 cfs. Therefore, the measured flow rate of 0.56 cfs will be used as the true pumping rate in all subsequent analysis.

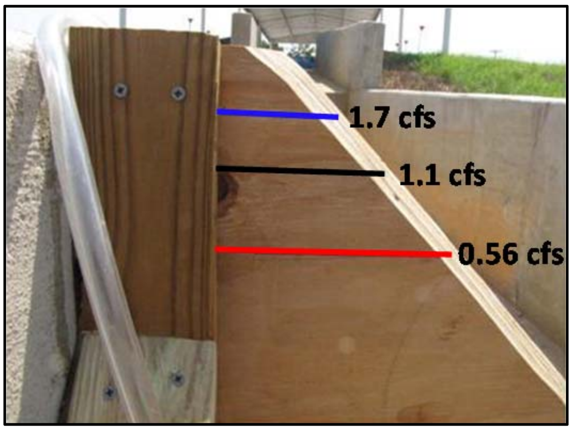
Table 1: Flow Rate Determination for Each Pump (Trough Volume = 20.4 ft^3)

Pump	Time (sec.)	Q (cfs)	Avg. Q (cfs)
Left	36.82	0.55	**0.57**
	34.87	0.59	
	35.84	0.57	
	35.38	0.58	
	35.47	0.58	
Middle	37.81	0.54	**0.55**
	36.96	0.55	
	36.32	0.56	
	36.35	0.56	
	37.00	0.55	
Right	36.13	0.56	**0.55**
	37.22	0.55	
	36.62	0.56	
	37.25	0.55	
	37.19	0.55	
AVERAGE	**36.48**	**0.56**	

The pumping rates evaluated from the data collected in Table 1 were used to evaluate the performance of a 90° sharp crested v-notch weir which was installed in the concrete channel, as shown in Figure 6(a).

The purpose of the 90° sharp crested v-notch weir was two-fold: (1) to evaluate the performance of the weir equation and (2) as a secondary means of determining the flow rates of the three pumps. Figure 6(b) illustrates the heights on the 90° sharp crested v-notch weir that correspond with the three flow rates of 0.56, 1.1, and 1.7 cfs.

(a) Installation of weir in concrete channel



(b) water level heights for various flow rates

Figure 6: 90° Sharp Crested V-notch Weir.

The general expression for flow over a 90° sharp crested v-notch weir is given in Equation 1 (Brater et al, 1995):

$$Q = 1.34 \tan(\theta/2)\, H^{2.5} \qquad (1)$$

where,

H = height (m)

Q = flow rate (m^3/s)

For a 90° sharp crested v-notch weir, the corresponding formula is:

$$Q = 2.44\, H^{2.5} \qquad (2)$$

where,

H = height (ft)

Q = flow rate (ft^3/s)

A plot of the 90° sharp crested v-notch weir equation used to determine flow rates is shown in Figure 7. The average Q (i.e. 0.56) from Table 1 along with the respective flow rates with two pumps (i.e., 1.1 cfs) and three pumps (i.e., 1.7 cfs) discharging have been plotted with respect to the measured heights shown in Figure 6(b). Figure 7 shows that the weir equation was able to predict the known flow rates.

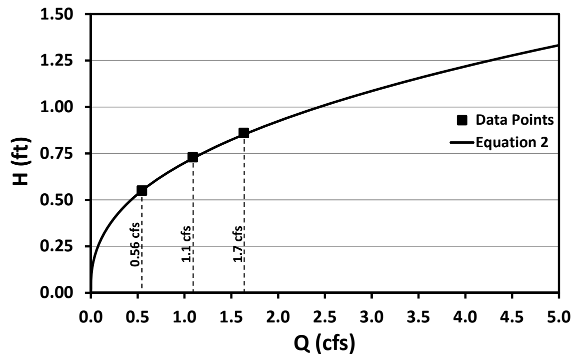


Figure 7: Test Data vs. Weir Equation.

SUMMARY

The purpose of this report was to determine the actual pump discharge rates and ensure the reproducibility of the water introduction system that is to be used when testing ditch check practices under channelized flow conditions. Two methods were used to verify the pumping rates for each pump: (1) volumetric flow rate evaluation and (2) using a 90° sharp crested v-notch weir.

Both methods used for evaluating pump flow rates indicate that the flow rates of 0.56, 1.1 cfs, and 1.7 cfs are achievable and reproducible.

REFERENCES

1. *Brater E.F., HW. King, J.E. Lindell, and CY. Wei, (1995) Handbook of Hydraulics 7th Edition, McGrawHill.*

Auburn University – Erosion and Sediment Control Testing Facility: Evaluation of the Sediment Introduction System

The discharge rate of the sediment hopper, shown in Figure 8, was evaluated to determine the rate that sediment will be discharged into the water/sediment introduction system during sediment-laden testing. The sediment that will be used for testing was sieved and only contains material passing a 4.75 mm sieve (No. 4). The soil was then stored in the sediment storage building to be protected from rain while it was allowed to dry.

Figure 8: Conveyor Belt and Modified Chute of Sediment Hopper Discharge System.

The sediment hopper is a 2 cy fertilizer spreader that has been modified to satisfy the sediment discharge needs of the facility. The chute and the conveyor belt of the hopper have been extended to provide direct delivery of sediment into the water discharged from the water introduction system. The hopper has a hydraulically driven aggregate conveyor belt as seen in Figure 9.

Figure 9: Conveyor Belt and Modified Chute.

The conveyor belt is controlled by the hydraulic system of a walk-behind mini skid-steer Bobcat. Figure 10(a) illustrates the hydraulic hose connections to the drive chain of the sediment discharge system. The speed of the conveyor belt is controlled by the Mini-skid steer's throttle controls shown in Figure 10(b).

To determine the rate at which sediment is discharged from the hopper, dry tests were performed. These tests consisted of fully loading the hopper with sediment and discharging this sediment over a 25 minute period. Sediment was collected in pre-weighed bins in fifteen second intervals at the beginning of every minute over a 25 minute period.

(a) Hydraulic Hose Bobcat|Hopper Connections.

(b) Mini-skid Steer Bobcat Hydraulic Drive System.

Figure 10: Hydraulic Controls of the Sediment Discharge System.

The sediment was weighted to determine the mass collected in 15 seconds. Each test was repeated three times to evaluate the reproducibility of the system. Each mass recorded for a 15 second interval was divided by 15 seconds to calculate the discharge rate of the hopper. The discharge rates for all three tests were averaged to determine the average discharge rate with respect to time and all data is summarized in Table 2.

Table 2: Average Sediment Hopper Discharge

Time (min)	Average Mass (kg)	Avg. Mass /15 sec	Standard Deviation
1	15.0	1.0	0.10
2	13.8	0.9	0.02
3	13.4	0.9	0.05
4	15.2	1.0	0.18
5	15.5	1.0	0.09
6	16.3	1.1	0.15
7	16.5	1.1	0.12
8	15.7	1.0	0.01
9	17.3	1.2	0.23
10	17.3	1.2	0.26
11	18.7	1.2	0.26
12	17.5	1.2	0.12
13	16.7	1.1	0.06
14	17.8	1.2	0.06
15	18.2	1.2	0.10
16	17.5	1.2	0.15
17	17.8	1.2	0.03
18	18.2	1.2	0.13
19	18.6	1.2	0.02
20	19.1	1.3	0.15
21	20.9	1.4	0.09
22	20.9	1.4	0.10
23	22.0	1.5	0.11
24	21.8	1.5	0.09
25	22.7	1.5	0.13
	Average =	**1.2**	**kg/sec**
	Standard Deviation =	**0.2**	**kg/sec**

Figure 11 illustrates the average discharge rates over time over the course of 25 minutes.

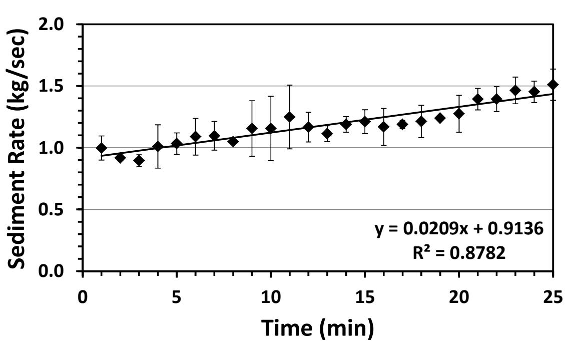


Figure 11: Sediment Hopper Discharge Rate.

The data shown in Figure 11 was fitted with a linear regression line and exhibits an R^2 of 0.88. Figure 11 also shows error bars indicating standard deviations and variability within the system. Sediment discharge rates increase over the duration of the test which is attributed to weight of the soil decreasing in the hopper over time and lessening the weight on the conveyor belt.

SOIL ANALYSIS

The soil to be used for the initial round of testing was attained from the Birmingham, AL area. The characteristics of the soil classify it as a poorly graded sand (SP). Figure 12 illustrates the grain size distribution and Table 3 displays the results of the sieve analysis.

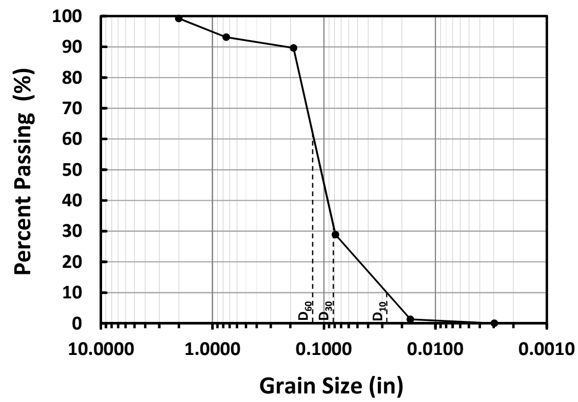


Figure 12: Birmingham Soil Grain Size Distribution.

Table 3: Sieve Analysis of Birmingham Soil

Sieve	Apparent Opening Size (in)	Mass Retained (lbs)	Percent Retained (%)	Percent Passing (%)
2"	2.00	0.00	0.00	100.00
0.75"	0.75	0.04	0.79	99.96
#4	0.19	0.32	6.08	99.64
#10	0.08	0.18	3.51	99.46
#40	0.02	3.16	60.75	96.30
#200	0.00	1.43	27.57	94.87
Pan	Pan	0.07	1.30	94.80

CONCLUSIONS

The purpose of this summary was to determine the sediment discharge rate from the hopper and show reproducibility of the system that will be used for ditch check testing purposes. Three tests were conducted in which the hopper was fully loaded and discharged over the course of 25 minutes. Sediment was collected in a pre-weighed bin for 15 seconds, every minute, and weighed. These weights were used to determine an average discharge rate of 1.2 kg/sec. The trend line and relatively high R^2 value indicate that the discharge rate is reproducible and consistent over time.

Auburn University Erosion and Sediment Control Testing Facility: Geotechnical Evaluation of Earthen Section

The soil used in the earthen section of the test channel was classified using the USGS Soil Classification System. The particle size distribution of the soil is shown in Figure 13.

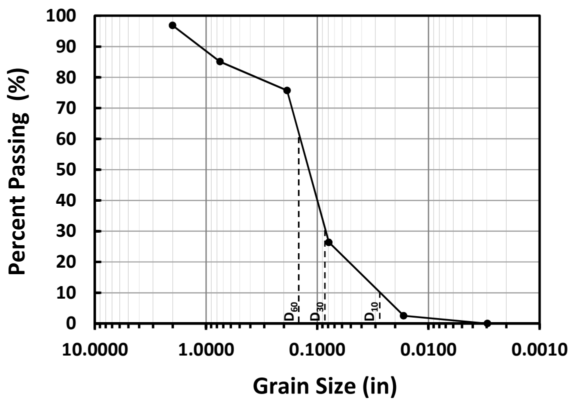


Figure 13: Grain Size Distribution for Earthen Section.

Table 4 displays the sieve analysis of the soil used for the earthen section. Using the data shown in Table 4 and Table 5; the soil used for testing within the earthen section of the channel has been classified as a poorly graded sand (SP).

Table 4: Sieve Analysis of Earthen Section Soil

Sieve	Apparent Opening Sizes (in)	Mass Retained (lbs)	Percent Retained (%)	Percent Passing (%)
2"	2.0000	0.00	0.00	100.00
0.75"	0.7500	0.17	3.17	96.83
#4	0.1870	0.64	11.75	85.09
#10	0.0787	0.51	9.36	75.72
#40	0.0167	2.68	49.34	26.38
#200	0.0030	1.29	23.86	2.52
Pan	Pan	0.14	2.52	0.00

Table 5: Properties of Earthen Section Soil

SP (Poorly Graded Sand)	
D_{60} = 0.14 in	C_u= 4.24%
D_{30}= 0.085 in	C_c= 1.56%
D_{10}= 0.033 in	% Gravel= 14.91%
LL= 31	PL= 16

Note: D_{60}, D_{30}, or D_{10} = soil particle diameter at which 60%, 30%, or 10% of the mass of a soil sample is finer
C_u/C_c = coefficients of uniformity/curvature
LL = liquid limit = the percent water content of a soil at the arbitrarily defined boundary between the semi-liquid and plastic states
PL = plastic limit = the percent water content of a soil at the boundary between the plastic and semi-solid states

The moisture-unit weight relationships were also determined for this soil. A Standard Proctor Test was performed to determine the maximum dry density (ρ_{dmax}) and the optimum moisture content (OMC) for the soil. Figure 14 and Table 6 illustrate the results of this test. The ρ_{dmax} determined was 123.8 lbs/ft^3 and the OMC was determined to be 10.9%.

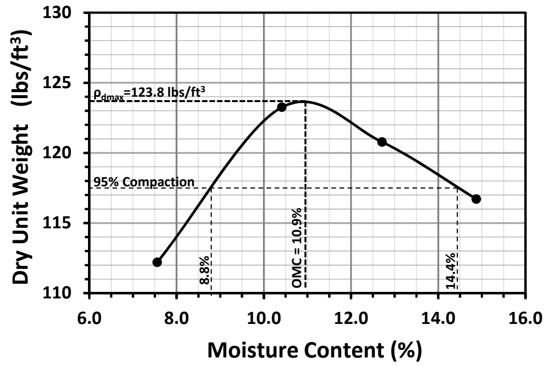


Figure 14: Proctor Curve for Earthen Section Soil.

The dry unit weight for 95% compaction was calculated to be 117.5 lbs/ft^3 with a moisture content (MC) ranging from 8.8-14.4%.

Table 6: Proctor Test Data for Earthen Section Soil

n	Wet Soil Mass (lbs)	Dry Soil Mass (lbs)	Water Content (%)	Bulk Density (lb/ft^3)	Dry Density (lbs/ft^3)
1	4.02	3.74	7.56	120.68	112.20
2	4.54	4.11	10.41	136.09	123.25
3	4.54	4.03	12.71	136.13	120.77
4	4.47	3.89	14.87	134.07	116.71

An upright rammer hammer with a compaction plate of 14 by 11.5 in., a blow count of 600 plows per minute and a compaction force of 2,700 lbs is used to compact the earthen section between tests. A test was performed on 09/01/11 and the earthen section had to be redressed before installing a 20 in straw wattle. In place density was taken using a density drive hammer and thin walled Shelby tubes. Five samples were taken every 3 ft along the center line of the earthen section and processed to determine the average in-place density of the earthen section after compaction. The average in-place density was 117.5 lbs/ft^3 while the average MC was determined to be 10.01%.

REFERENCES

1. ASTM Standard D698, 2007, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort,* ASTM International, West Conshohocken, PA, 2007, DOI: 10.1520/D0698-07E01, www.astm.org

Auburn University Erosion and Sediment Control Testing Facility: Summary of Water Velocity Profile Mapping Methods

One of the major goals of a ditch check installation is to reduce the channel velocity and thus reduce the channel erosion potential. Therefore, during each ditch check BMP evaluation test, the velocity of the water will be measured and a velocity profile will be mapped based on measured data. Figure 15 illustrates the use of a stagnation tube to measure the static head of the flow at three points along each cross-section. Using this simple tool, the velocity is calculated using Equation 1.

$$v = \sqrt{2gh} \qquad (1)$$

where,

v = water velocity (ft/sec)
g = gravitational constant (ft/sec^2)
h = measured velocity head (ft)

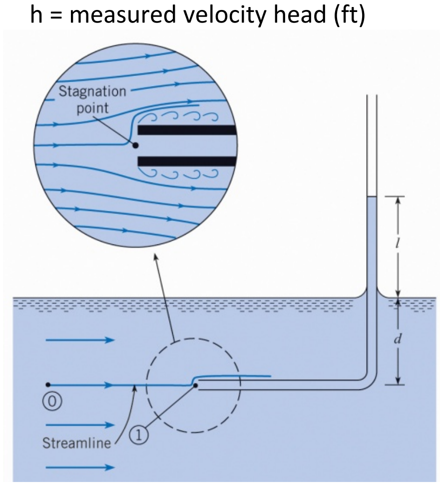


Figure 15: Stagnation tube to measure the velocity in an open channel flow (Crowe et al., 2009).

In our test bed, measurements will be taken at eight cross sections (i.e. CS1 thru CS8). Figure 16 illustrates the cross section locations of the measured velocities.

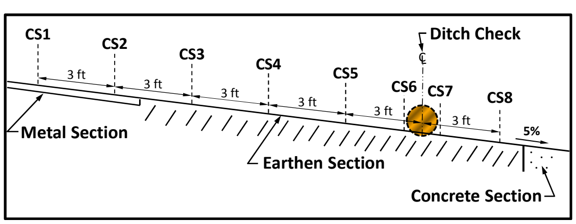


Figure 16: Ditch Check Measurement Cross Sections.

CS1 thru CS5 are spaced 3 ft apart. The center line of the ditch check is located 3 ft from CS5 and CS8. CS6 and CS7 are located directly in front and behind the face of the ditch check, respectively as illustrated in Figure 16.

Three velocity measurements, at approximately 1 inch below the water surface will be taken during each test at each cross-section once a steady-state condition is observed. Points 4, 5, and 6 in Figure 17 are the locations of the velocity measurements taken for each cross section. These measurement points are spaced 1 ft apart. The measurements are averaged for each cross section. The average velocities will be used to develop the velocity profile for the ditch check being tested.

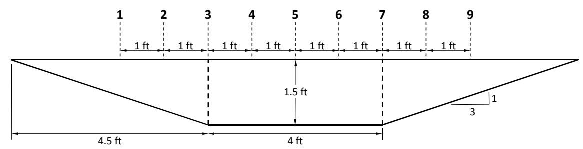


Figure 17: Measurement Points for Each Cross Section

Velocity in uniform open channel flow can be calculated using Manning's equation (Akan, 2009) shown as Equation 2.

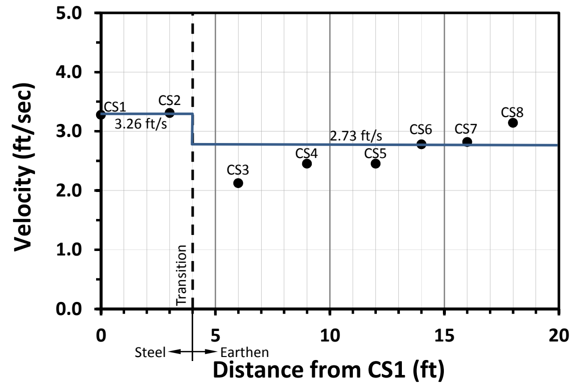
$$v = \frac{1.49}{n}(A/P)^{2/3} S_o^{1/2} \qquad (2)$$

where,

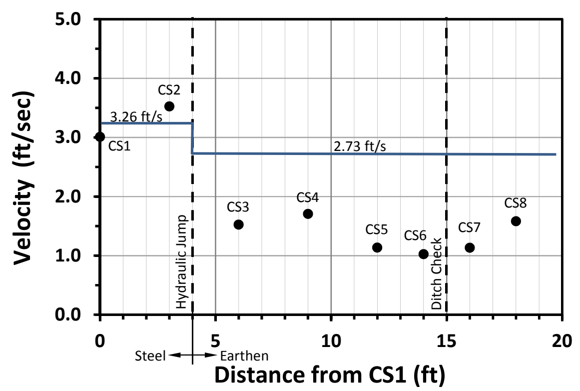
v = normal flow velocity (ft/s)
n = Manning's roughness coefficient
A = cross sectional flow area (ft^2)
P = wetted perimeter (ft)
S_o = channel bottom slope

Given a flow rate of 0.56 ft^3/s and the channel geometry as shown in Figure 17, calculated uniform flow velocity in the sheet metal section of the channel is 3.26 ft/s using n = 0.012, and calculated uniform flow velocity in the bare, earthen soil section is 2.73 ft/s using n = 0.016.

Figure 18(a) displays the velocity profile of the ditch check test channel during a bare soil control condition (i.e., no ditch check installed) during a 0.56 ft^3/s test. Figure 18(b) displays the measured velocity profile of the ditch check test channel with a 20 in. straw wattle installed during a 0.56 ft^3/s test. The wattle was staked-in according to ALDOT specifications and keyed-in 2 inches into the channel bottom.



(a) Bare Soil Control



(b) 20" Straw Wattle Installed

Figure 18: Velocity Profile of Channel Cross Sections.

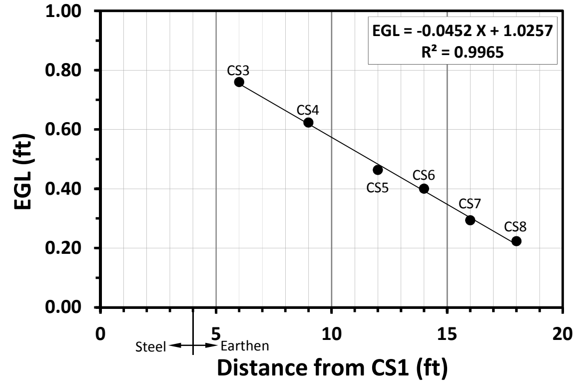
Using the collected velocity data, the energy slope (S_f) of the water profile is then plotted as specified by ASTM D 7208-06. The energy gradient line (EGL) is defined as Equation 2 (Akan, 2009, Crowe et al., 2009).

$$EGL = WSE + v^2/2g \qquad (3)$$

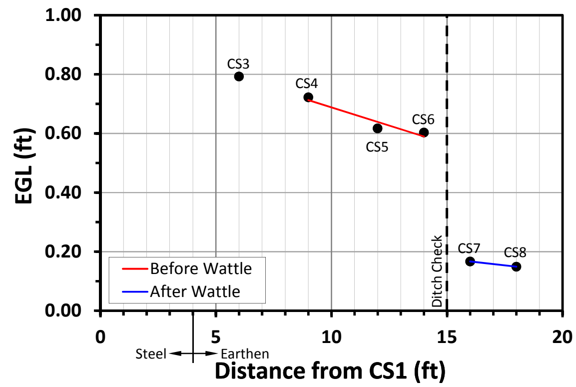
where,

EGL = energy grade line (ft)
WSE = water surface elevation (ft)
v = average water velocity (ft/sec)
g = gravitational constant (32.2 ft/sec^2)

Figure 19(a) displays the energy slope (S_f) of the test flow for a bare soil control condition with no wattle installed. Figure 19(b) displays the S_f of the test flow for a 20" straw wattle installed during the 0.56 cfs test. These figures display only the cross-sections located within the earthen section to remove any bias resulting from the two different surfaces which is apparent in Figure 18(a) for differences in cross section 2 to cross section 3.



(a) Bare Soil Control



(b) 20" Straw Wattle Installed

Figure 19: Energy Slope Profiles of Cross Sections.

Comparison of Figures 17(a) and 17(b) as well as Figures 18(a) and 18(b) illustrate the wattle's velocity and energy reduction capabilities. Velocity distribution along the channel will be mapped for every test. This data will be used to comparatively analyze the performance of various devices and installation practices.

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3. Chow V. T. 1959. "Open Channel Hydraulics", McGraw Hill.
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Design Brief: Silt Fence Tieback Design Tool for Highway Construction Installations

The purpose of this brief is to describe a design tool that uses a rational approach for designing silt fence tieback installations at highway construction sites. The design tool employs a hydrological model to estimate the volume of runoff water generated by the watershed and balances the water with the storage capacity of the silt fence installed with a tieback. Firstly, the Soil Conservation Service (SCS) method is used to estimate the amount of stormwater generated during a design storm event. Then, using the cross sectional data from a highway construction project, a graph is generated to estimate the storage volume available behind a silt fence for various ditch and highway slopes. Using these data, the designer can determine the proper placement frequencies of silt fence tiebacks along a linear highway construction project. This brief provides details of the design tool and the mathematical procedures used throughout this design procedure. An example problem is also provided to illustrate its practical applicability.

DESIGN METHODOLOGY

The design tool developed for determining an adequate silt fence tieback design requires designers to input project specific parameters such as: (1) curve numbers (CN), (2) a precipitation amount for a 2-yr, 24-hr storm, and (3) geometric properties of found onsite. Figure 1 provides an illustration of the design tool interface that a designer would use to determine the total stormwater runoff volume and a corresponding silt fence tieback storage capacity for the area under consideration. The mathematical procedures used to compute the abovementioned values are described below using two design steps.

Design Step 1: Methodology for Predicting Stormwater Runoff Volume

To determine the stormwater runoff volume, the SCS method was used. According to this method, the relationship between excess rainfall, P_e, and total rainfall, P, on a 24-hour basis is computed using the expression (*1*):

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (1)$$

where:

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

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

$$I_a = 0.2S \quad (2)$$

Using Equation 2, Equation 1 can be modified as:

$$P_e = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (3)$$

The maximum potential retention is related to the CN by the following relationship:

$$S = \frac{1000}{\text{CN}} - 10 \quad (4)$$

where:

S = maximum potential retention (in.), and
CN = curve number.

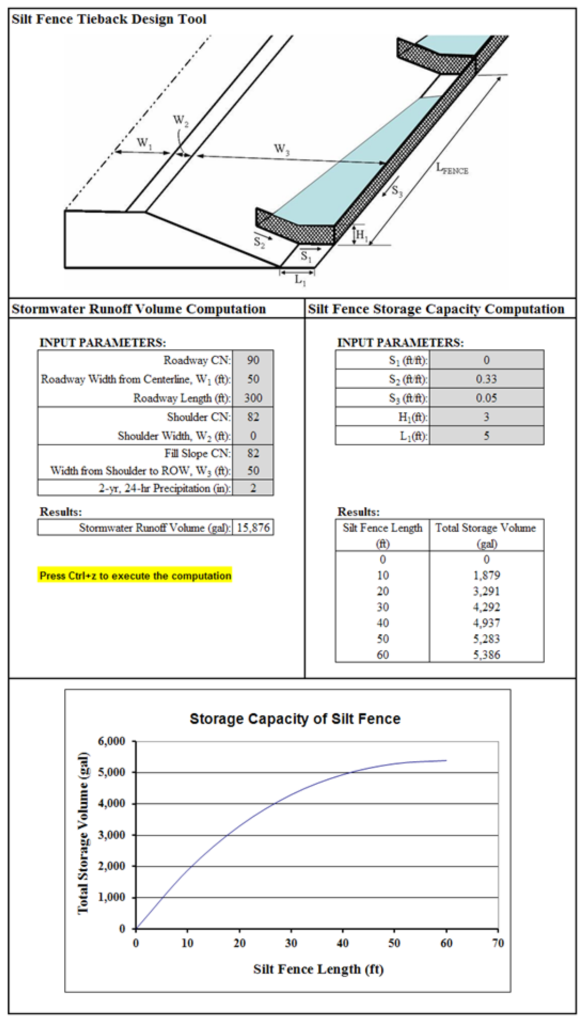

Figure 1: Silt Fence Design Template.

The runoff CN for varying land uses needs to be selected from the appropriate hydrological table.

After computing the maximum potential retention, *S*, and the initial abstraction, I_a, the excess rainfall, P_e, from a storm event is calculated using Equation 3. The total volume of stormwater runoff flowing over the watershed under consideration is obtained by multiplying the excess rainfall by the watershed area using the formula:

$$V_{total} = \frac{\left(P_e \times A_{\text{watershed}}\right)}{12} \tag{5}$$

where:

V_{total} = total volume of stormwater runoff (ft^3),
P_e = excess rainfall (in.), and
$A_{\text{watershed}}$ = area of watershed (ft^2)

To simplify the computation of the stormwater runoff volume from a typical highway construction site, the following procedure has been incorporated into the design tool. The parameters required from the designer or inspector includes site specific data such as the roadway geometry, the design storm precipitation for the local project, and the CN values associated with hydraulic characteristics of the watershed area that the silt fence is being design to contain.

The geometry of the construction site is required to compute the area of the watershed under consideration. The parameters required by the designer when computing the area of the watershed include the width of the roadway, shoulder, and fill slope, along with the length of the section that the silt fence is being installed. The watershed area is calculated using Equation 6 as,

$$A_{\text{watershed}} = \left(W_1 + W_2 + W_3\right) \times L_1 \tag{6}$$

where:

$A_{\text{watershed}}$ = area of watershed (ft^2),
W_1 = roadway width (ft),
W_2 = shoulder width (ft),
W_3 = fill slope width (width from shoulder to ROW) (ft), and
L_1 = length of the fill section (ft.).

The second parameter required by the designer is the amount of rainfall that can be expected from a 24-hr storm event, P, that the project might experience based upon historical local rainfall data.

The final parameter required to compute the volume of runoff that can be expected on-site, are the CN for the typical project cross-section. The CN for a typical highway construction site is a weighted average combining the hydrological characteristics of the roadway, the shoulder and the fill slope on the project. The weighted CN value is computed using the equation,

$$CN_{\text{weighted}} = \frac{\left[\left(CN_1 \times W_1\right) + \left(CN_2 \times W_2\right) + \left(CN_3 \times W_3\right)\right]}{\left(W_1 + W_2 + W_3\right)} \tag{7}$$

where:

CN_{weighted} =weight average of watershed curve numbers,
CN_1 = roadway curve number,
CN_2 = shoulder curve number, and
CN_3 = fill slope curve number.

Design Step 2: Methodology for Predicting Silt Fence Storage Capacity

The second component of the general design tool methodology for determining the proper placement of silt fence tiebacks along a highway construction project is to compute the storage volume behind the silt fence system per linear foot of silt fence installed along the ROW. The storage volume calculations are based on the silt fence installation concepts shown in Figure 2. The silt fence tieback should be anchored into an elevation equal to or greater than the top height of the silt fence at the toe of slope, as illustrated in Figure 2. This is an optimal design for installing the tieback configuration because, as demonstrated in Zech et al. (*2*), this design ensures: (1) that stormwater runoff will accumulate behind the tieback, (2) that the stormwater runoff will not be able to bypass around the toe of the silt fence tieback, and (3) that simultaneous failure will occur over the top of the silt fence along the ROW 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 and hence increases the silt fence installation length prior to requiring a tieback along the ROW.

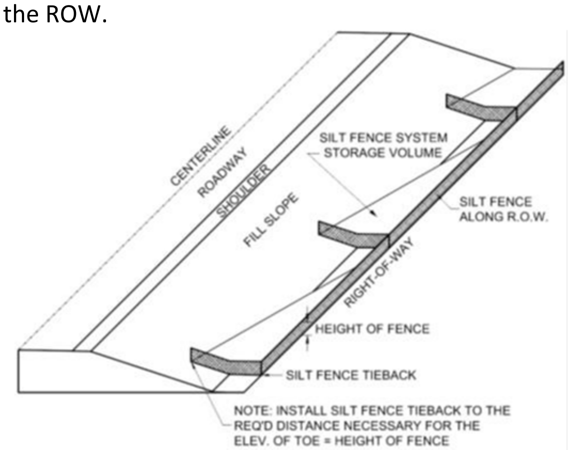

Figure 2: Silt Fence Tieback Configuration.

Figure 3 illustrates the required design parameters that must be known a priori to determine the length of silt fence required to calculate the cumulative total storage volume per linear foot along the silt fence installation. To estimate the silt fence length that is adequate to impound the stormwater runoff, the design requires the existing ground slope (S_1), the fill slope (S_2), the ditch slope (S_3), the length of the existing ground (L_1), the unit length of fence (L_3), and the height of the silt fence (H_1). These geometric parameters are used to numerically compute the length of silt fence and the number of tiebacks required to contain the runoff volume generated from the watershed for a typical highway construction site. The computations are integrated into the spreadsheet design tool program.

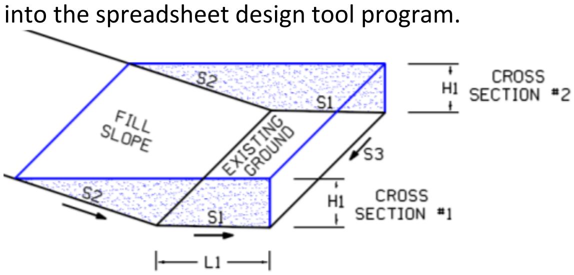

Figure 3:Required Typical Section Data per Unit Length of Silt Fence.

The spreadsheet calculations use various geometric parameters to determine the total silt fence storage volume for project-specific conditions. The length of the silt fence is segmented into typical cross-sectional elements, shown in Figure 3, to compute the volume of water contained within one unit length of silt fence (L_3). The unit length of silt fence (L_3) represents infinitesimal longitudinal increments arbitrarily selected by the designer. The unit length is selected based upon the desired amount of accuracy required by the designer for computing the total storage volume. Once the area of water was calculated per unit length of silt fence for two cross sections, the values are averaged and multiplied by the unit length of silt fence to determine a cumulative volume per unit length. As the length of silt fence increases toward the upslope end, the height of the water decreases at face of the silt fence. Eventually the height of the water at the toe of the silt fence will diminish to zero, signifying the maximum storage volume of the silt fence system has been obtained. Once this parameter is met, the incremental volumes are summed to compute the total cumulative volume attained by the silt fence length and tieback configuration. From these numerical calculations, a graph is developed by plotting the silt fence length versus cumulative volume per unit silt fence length. The graph provides an estimate for the linear length of silt fence that will satisfy a specific total storage volume requirement. The use of the design tool for implementing this method is shown in the example below.

Example Problem: Part A - Computation of Stormwater Runoff Volume

The U.S. Environmental Protection Agency (EPA) states that silt fence should be designed to withstand the runoff from a 2-year, 24-hour storm event (*14*). 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 (*3*). With this information, the first part of the design methodology can be applied by inputing project specific characteristics to determine the total amount of stormwater runoff.

For this example the width of roadway, shoulder, and fill slope along with the length of the section under consideration is 12 ft, 4 ft, 34 ft, and 500 ft, respectively. The Soil Conservation Services (SCS) curve numbers (CN) for the roadway, shoulder, and fill slope can be selected by the designer from the appropriate hydrological table (*1*). The CN values, assuming soil group B in this example, for the roadway, shoulder, and fill slope are 98, 85, and 82, respectively.

After inputting project specific data into design tool, the design can press 'CTRL-Z' to execute the first part of the design methodology. The total runoff volume for the 2-year, 24-hour design storm is 5,794 ft^3 or 43,340 gallons. Now the designer must input additional project specific characteristics to determine the required length of silt fence that will contain the computed stormwater volume prior to installing a tieback.

Example Problem: Part B - Computation of Silt Fence Storage Capacity

The second part of the methodology is to design a tieback silt fence system that can effectively contain this runoff volume. For this example the various slopes present on the project site are stipulated as a ditch slope (S_3) of 1%, an existing ground length (L_1) of 6 ft, a fill slope (S_2) of 3:1, an existing ground slope (S_1) of 2%, and a silt fence height of 3 ft. After inputting this geometry into the design tool, the designer can again execute the program for the numerical calculations to be performed to determine the volume of runoff a particular silt fence system can contain per unit length of silt fence installed.

For this example, the spreadsheet was used further to calculate the total silt fence storage volume for various project ditch slope situations beyond 1% for a 2%, 3%, 4%, and 5% condition. We plotted the output of silt fence length versus total storage volume for these various slopes using the cross section data assumed in the example problem. The example ditch slope of 1% is illustrated as the bold line. Figure 4 is a graph for this problem and it provides the storage capacity of the silt fence system versus the silt fence length for various possible ditch slopes. It should be noted in Figure 4 that as the ditch slope increases, the storage volume capacity of the silt fence tieback system decreases. Therefore, as the ditch slope increases, the designer will need to install tiebacks more frequently over longer runs of silt fence.

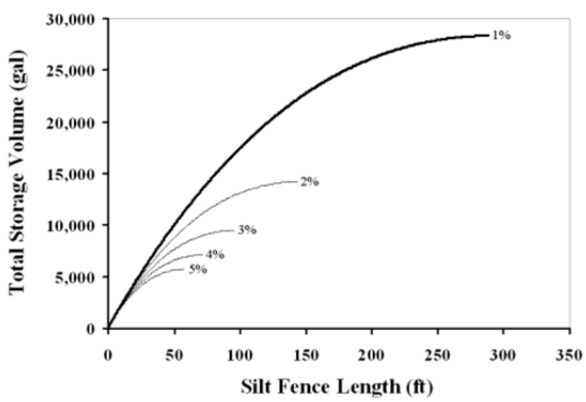

Figure 4: Example Problem: Total Storage Volume vs. Silt Fence Length.

Table 1 provides the storage capacities of the tieback system at pre-determined, fixed incremental lengths. The data from Table 1 may be directly used, instead of the graph illustrated in Figure 4, to evaluate and select the appropriate silt fence design.

From Figure 4 and Table 1, it is clear that the longest length of a silt fence that can be installed at a 1% ditch slope prior to installing a tieback before failure occurs is 300 ft. Additionally, the maximum storage volume that 300 ft of silt fence can hold is approximately 28,300 gallons.

Example Problem: Part C - Computation of Tieback Frequency

From the SCS-CN method, the total runoff volume for the 2-year, 24-hour example design storm is 43,340 gallons. In the example problem definition, the watershed length was 500 ft. From the Figure 4, there are a number of alternative tieback configurations that can be selected to effectively contain the stormwater runoff on the construction site. However, the most cost effective configuration incorporates only two tiebacks along the entire 500 ft ROW. 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 27,875 gallons. The combined storage volume of both the silt fence and silt fence tiebacks at a 250 ft spacing is 55,750 gallons which is greater than the required 43,340 gallons, therefore effectively containing the stormwater runoff flowing over the example watershed.

Table 1: Silt Fence Tieback Storage Capacities

Silt Fence	Ditch Slope (%)				
Length (ft)	1	2	3	4	5
50	9,928	8,700	7,565	6,523	5,575
100	17,400	13,046	9,444		
150	22,694	14,166			
200	26,093				
250	27,875				
300	28,333				

Notes: The values appearing above the solid line represent the actual storage volumes achieved by the corresponding silt fence length. The values appearing below the solid line represent the maximum storage volume attainable for a given slope and silt fence length.

CONCLUSIONS

This brief provides design guidance centered upon using the SCS-CN method to estimate the amount of stormwater runoff from a construction site during a specified storm event and attain a balance with the computed storage capacity of the silt fence system per unit length of silt fence. This tool will help a designer in selecting the tieback configuration and interval spacing that is most appropriate for the construction site conditions.

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2. Novotny, Vladimir. *Water Quality: Diffuse Pollution and Watershed Management*. New York: John Wiley & Sons, Inc., 2003.
3. Zech, W.C., Halverson, J.L., and Clement, T.P. *Evaluating the Effectiveness of Various Types of Silt Fence Installations to Control Sediment Discharge from Highway Construction Sites.* Submitted, ASCE Journal of Hydrologic Engineering, 2006.
4. United States Department of Commerce. *Technical Paper No. 4: Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years*. Weather Bureau, Washington: D.C., 1963.

Research Brief: Field Evaluation of Silt Fence Tieback Systems at a Highway Construction Site

In this research brief, the performance of a silt fence system with tiebacks (a.k.a., "j-hooks") was investigated to determine its effectiveness as a sediment control technology at highway construction sites over multiple rainfall events. The data presented provide a qualitative perspective showing sediment migration over time along with the occurrence or lack of failures among two silt fence systems tested. The results from this field test exhibit that silt fence tieback systems are more effective in containing eroded sediment from construction sites and also reduce the risk of silt fence system failures than traditional linear silt fence systems.

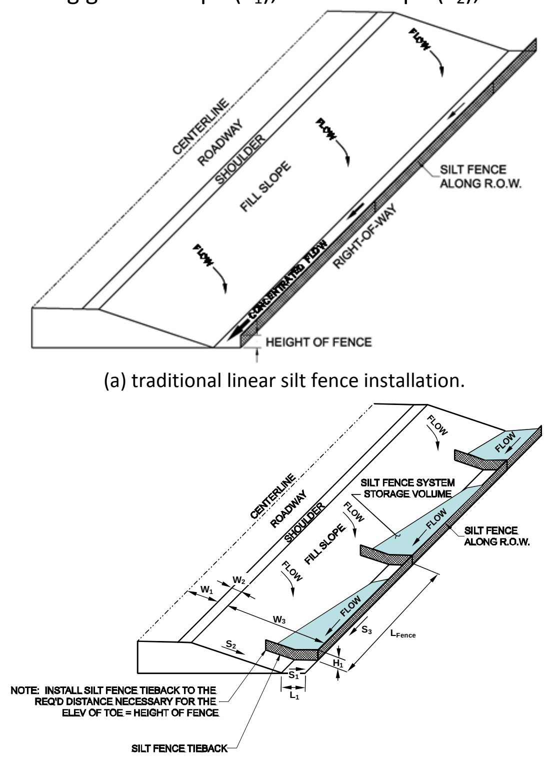
INTRODUCTION

One method of preventing sediment from leaving construction sites is the use of silt fences. The primary purpose of a silt fence is to serve as a sediment barrier where sheet flow can be detained allowing sediment to settle out of suspension. Silt fences are typically installed around the perimeter of a construction site, serving as the final barrier to capture and retain sediment within the area of disturbance. Traditionally on highway construction sites, long stretches of linear silt fence are installed parallel to the road as illustrated in Figure 1(a). However, research suggests that tying the linear length of fence back into the fill slope intermittently to form small detention basins is a more effective design (Barrett et al. 1995; Robichaud et al. 2001; Stevens et al. 2004; Zech et al. 2007; Zech et al. 2008). These silt fence tieback systems, commonly referred to as "j-hooks", can be an effective solution to controlling sediment discharge from highway construction sites. A silt fence tieback, or "j-hook", system is created by turning the downslope end of the linear silt fence back into the fill slope and extending the end of the fence up the slope to an elevation higher than the top of the fence at the toe of the slope. Figure 1(b) illustrates a properly designed silt fence tieback system on a typical highway construction site.

The purpose of this brief is to summarize a field study performed to evaluate the in-field performance of a silt fence tieback system designed according to the methodology proposed by Zech et al. (2007) compared against a traditional linear silt fence system at a highway construction site.

Storage Capacities of Silt Fence Tieback Systems

When designing silt fence tiebacks, one important factor to consider is the system's stormwater storage capacity. This storage capacity is a critical factor in designing an effective tieback system that can accommodate a design rainfall event. Important parameters that determine the storage capacity of a tieback system include the height of the fence above the existing ground (H_1), existing ground width (L_1), existing ground slope (S_1), road fill slope (S_2), ditch slope (S_3), and the linear length of fence between tiebacks (L_{FENCE}). Figure 1(b) illustrates a typical silt fence tieback section incorporating the parameters to be considered when computing the storage capacity of a design under consideration. During a rainfall event, the tieback section shown in Figure 1(b) serves as a temporary storage area to detain sediment laden stormwater runoff. The temporary impoundment of stormwater runoff allows sediment and other transported pollutants to be retained on site as a result of particles settling out of suspension. This act of deposition will lead to higher quality water leaving the construction site since it contains less suspended and bedload sediment.



(a) traditional linear silt fence installation.

(b) silt fence tieback installation

Figure 1: Comparison of Silt Fence Installations.

For a heavy rainfall event in which the runoff volume exceeds the storage capacity behind the silt fence tieback, the system will experience an overtopping condition. This scenario can be the result of improper tieback spacing, poor silt fence installation practices, or an unforeseen rainfall event exceeding the design storm under consideration. Therefore, the procedure for calculating the storage capacity of silt fence tieback systems is a critical design consideration to contain the runoff generated by the anticipated design storm. The purpose of this brief is to develop a comprehensive understanding of the in-field performance of a properly designed and installed silt fence tieback system.

PROJECT SITE DESCRIPTION

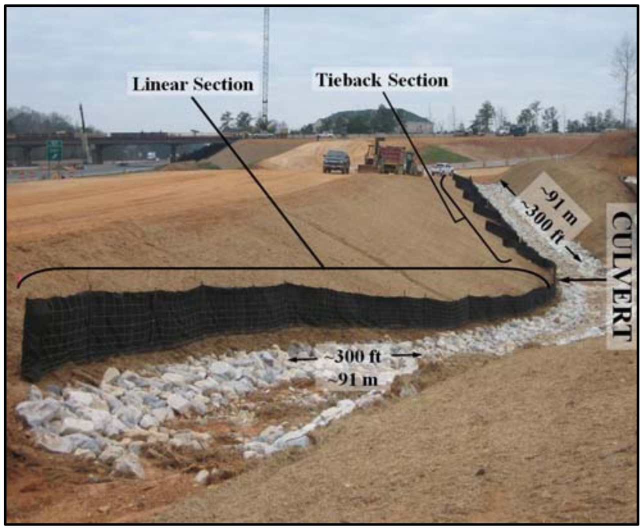
The silt fence tieback design methodology was used to design a tieback system for a 2 in. design storm on an ALDOT highway construction site located in Auburn, AL. The USEPA suggests that silt fences should be designed to withstand a 2-yr, 24-hr storm event (*USEPA, 1998*), which would yield approximately 4 inches rain in Auburn, AL. However at this field site, due to limited right-of-way (ROW), the silt fence systems had to be installed on the fill slope and did not contain an 'existing ground' component detailed in the design methodology. This site constraint made it impractical to install a silt fence tieback system to detain a 2-yr, 24 hr volume of approximately 4 inches. Therefore, engineering judgments were exercised to design a system that could detain 2 inches of rain. It is important to note the goal of this field test effort was to test the effectiveness of a silt fence tieback system versus a traditional linear silt fence system designed for the same conditions.

Site Description. The field test site used for this research was located on an ALDOT highway construction site (32°36'18", 85°24'42") at Exit 57 on I-85 in Auburn, AL. This site contained approximately a 600 ft. symmetrical vertical curve section of road with a 3H:1V fill slope with riprap ditch at the bottom along the ROW having approximately 5% longitudinal gradient. For testing purposes, the road was divided into two approximately equal 300 ft. sections using the crest of the curve as the division point. A 300 ft. linear stretch of silt fence was installed on half of the 600 ft. roadway section and silt fence tiebacks were installed on the other half. Figure 2 shows various views of the field test site after installation of the two silt fence scenarios at either side of the culvert, which is the point of reference. Figure 2(a) shows the site from the upslope end of the linear silt fence section exhibiting the limits of the entire experiment. Figure 2 (b) shows the linear silt fence section and Figure 2(c) illustrates the silt fence tieback section, both photographed from the culvert. The distance from the edge of the road to the ROW was 50 ft. at the crest of the curve. The roadway was unpaved at the time of the experiment; therefore, a single CN value of 82 was used for the roadway and fill slope sections. This CN value is representative of a dirt road with a Natural Resources Conservation Service (NRCS) Hydrologic Soil Group (HSG) classification of B. The HSG B classification corresponds to a soil with a final infiltration rate ranging from 0.15 to 0.3 in/h.

Tieback Design. As stated in the earlier section, the first component in the design methodology is to compute the storage capacity of the individual silt fence tieback sections. Figure 3 shows a graph developed from the design methodology illustrating the total storage capacity as a function of tieback spacing for this particular field test site. The maximum length of an individual tieback for this specific test site is 60 ft. with a maximum storage capacity of approximately 267 ft^3 per tieback.

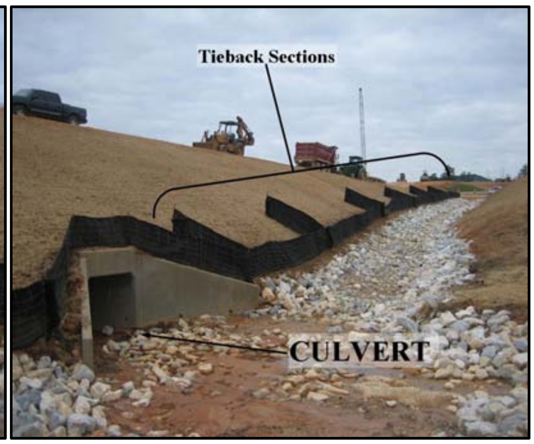
The next component in the design methodology is to compute the amount of stormwater that will be produce by the design rainfall event. Computations following the Zech et al. (2007) design methodology estimated a total stormwater runoff volume of 1,622 ft^3 for the 2 in. design rainfall event. To accommodate this runoff volume, 3 tieback design configurations were considered. The first tieback design configuration consisted of five tiebacks spaced at 60 ft intervals providing 1,335 ft^3 of storage which was less than the computed stormwater runoff volume generated. The second tieback configuration consisted of six tiebacks spaced at 50 ft. intervals providing 1,612 ft^3 of storage each. Finally, the third scenario consisted of ten tiebacks spaced at 30 ft intervals providing a total storage volume of 2,362 ft^3. For ease of installation and cost effectiveness, the research team decided to use the second scenario consisting of six tiebacks spaced every 50 ft, since the storage volume provided by this scenario was approximately the total stormwater runoff volume produced by the selected design storm.

Performance Data for Linear Silt Fence System. The linear silt fence system was monitored over the four individual storm events. Each storm event was compared against the initial condition of the relative ground profile established after installation.



(a) View of the entire site with two types of silt fence systems installed on either side of the culvert.

(b) Linear silt fence section.



(c) Silt fence tieback section.

Figure 2: Experimental Test Site.

The sedimentation profiles of the linear system obtained from measurements taken from the erosion pins installed along the fence is shown in Figure 4. The four separate ground profiles plotted indicate the level of erosion or sedimentation occurring over the study period.

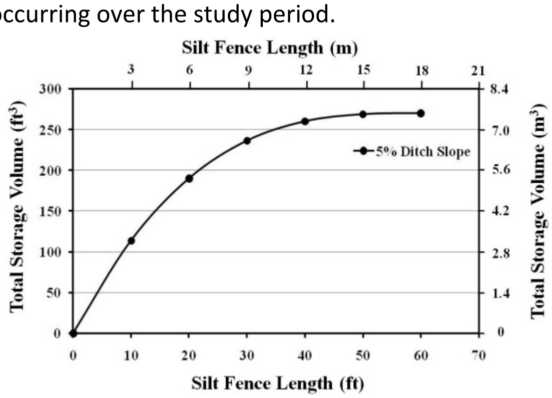
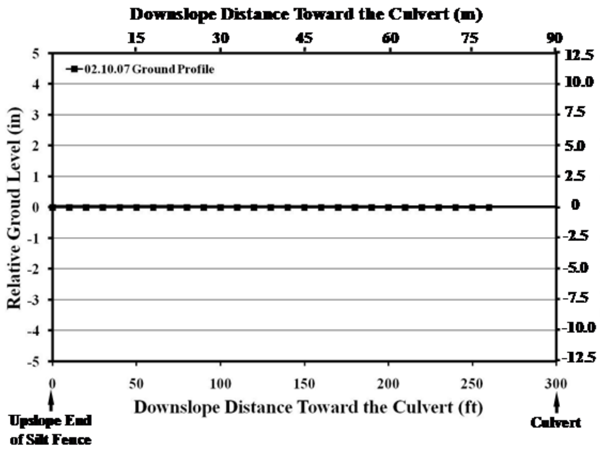
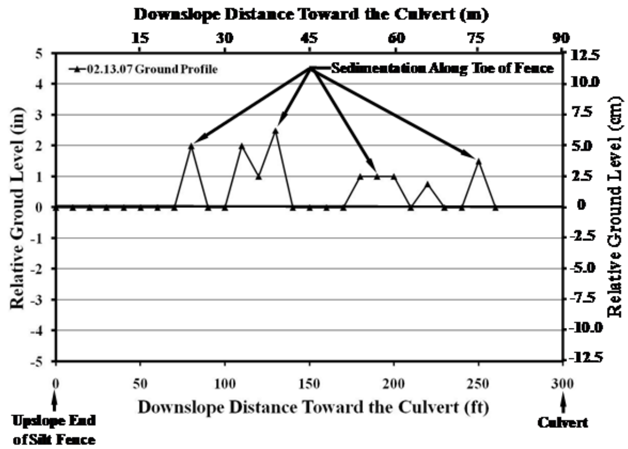


Figure 3: Capacity of Silt Fence Tieback System

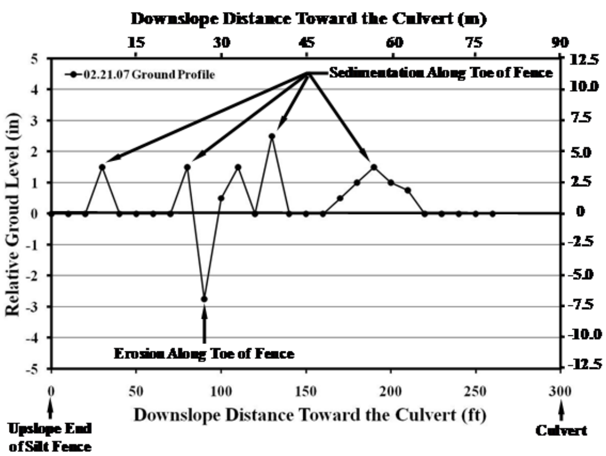
The first ground profile serves as the datum for establishing measurements at various points; this is represented by a horizontal line indicating the relative ground profile before installing the silt fence. This base ground profile in Figure 4(a) was established immediately after installing the erosion pins, after the installation of the silt fence. The second relative ground profile shown in Figure 4(b) illustrates the amount of sedimentation (or lack thereof) that occurred along the toe of the silt fence after the first rainfall event. Figure 4(c) shows the sediment profile after the second rainfall event when the site experienced a cumulative rainfall amount of 1.5 inches. The last profile illustrates the performance of the linear system after the occurrence of the fourth rainfall event and a cumulative rainfall amount of 4.4 inches. These sediment profiles show sediment migration occurring along the toe of the fence and help identify the occurrence of various failure modes.



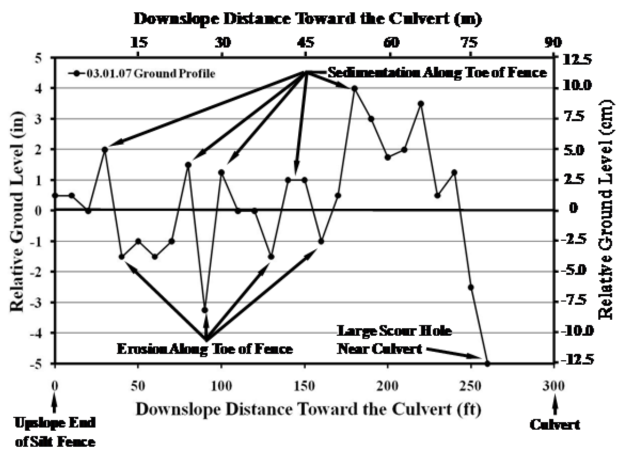
(a) Initial Condition



(b) 1.0 inch Cumulative Rain



(c) 1.5 inches Cumulative Rain



(d) 4.4 inches Cumulative Rain

Figure 4: Erosion/Sedimentation Levels Along the Fence of the Linear System.

Multiple photographs of the linear silt fence system after the fourth storm are shown in Figure 5. An overall view of the entire linear silt fence system highlighting areas of interest is shown in Figure 5(a). Figure 5(b) illustrates multiple areas on the upslope end where toe erosion occurred resulting from concentrated flow, exposing the bottom of the silt fence. Figure 5(c) depicts a section of the linear silt fence system that experienced sediment accumulation against the face of the fence. Finally, Figure 5(d) shows a toe erosion condition at the downslope end of the fence that resulted in a scour hole. The scour hole undercut the silt fence allowing sediment to be transported beyond the limits of the fence. This was the result of high velocity, concentrated flow that occurred along the toe of the fence during the storm. The scouring effect, along with the undercutting of the toe will allow sediment laden runoff to flow underneath the fence migrating beyond the ROW of the project.

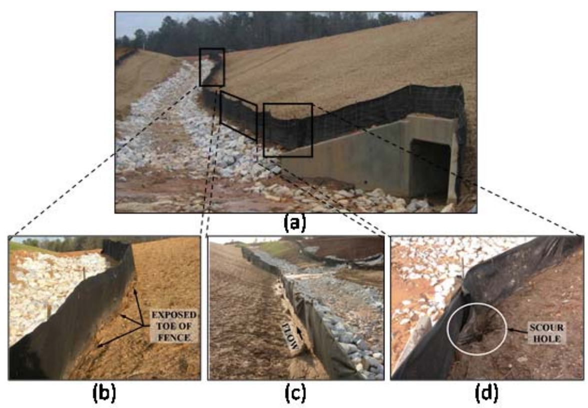
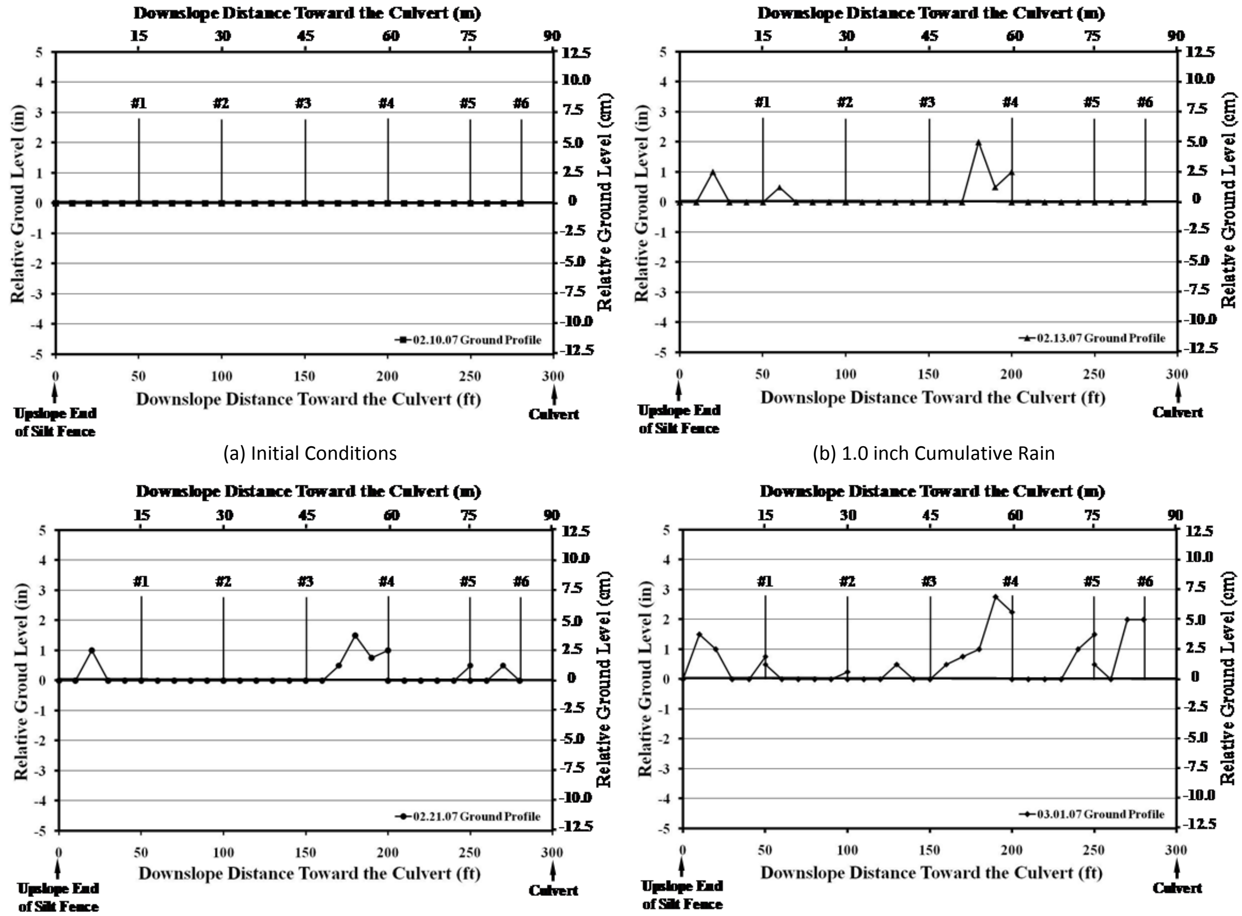


Figure 5: Linear Silt Fence After 4th Rainfall Event.

Performance Data for Silt Fence Tieback System. The silt fence tieback system was monitored, similar to the linear silt fence system, over the four rainfall events. The relative ground profile established for the tieback system is shown in Figure 6(a). Similar to Figure 4, Figure 6(b) through Figure 6(d) display three other separate ground profiles illustrating



(a) Initial Conditions (b) 1.0 inch Cumulative Rain

(c) 1.5 inches Cumulative Rain (d) 4.4 inches Cumulative Rain

Figure 6: Erosion/Sediment Profile Along the Fence of the Tieback System.

erosion and sedimentation levels at the test site over the storm events.

Photographs of the silt fence tieback system illustrating overall performance after the occurrence of the fourth rainfall event are shown in Figure 7. Figure 7(a) provides a viewpoint of the entire silt fence tieback system with the individual tieback sections labeled 1 through 6 beginning from the upslope end of the system to the downslope end. Figure 7(b) through Figure 7(g) depict the performance of each individual tieback section within the system to illustrate the containment capabilities of each section, which is a measure of system performance.

After the first three rainfall events, the tieback system performed as expected by impounding stormwater runoff from its contributing drainage areas. The impoundment of the sediment laden runoff allowed suspended sediment to settle out of suspension. This was evident from the visible mud line along the fence at the downslope end of the tieback sections 3, 4, and 5 (Figure 7(d), 7(e), and 7(f) respectively) and is illustrated quantitatively by the profiles shown in Figure 6. The temporary detention basins created by the tieback system also distributed the total sediment load throughout the system and prevented erosion along the toe of the fence by prohibiting concentrated flow to travel long linear distances along the fence. This is also illustrated by the erosion/sedimentation profile along the fence shown in Figure 6. The profiles do not indicate a single location where the ground profile along the fence after the first three rainfall events eroded below the original ground profile before installation of the tieback system.

As mentioned previously, the fourth rainfall event that occurred during the research effort was larger than the first three with a total rainfall depth of 2.5 in. This exceeded the design rainfall event for the tieback system by ½ inch, but overall, the tieback system still performed as expected. Four of the six tieback sections were structurally stable, however, the fence in two of the sections (Figure 7(e) and 7(f)) experienced partial structural failure due to excessive loads caused by heavy sedimentation and impounded water during the rainfall event. These near structural failures would not have occurred if the steel support posts of the silt fence system were closer together (i.e. 5 ft apart versus 10 ft) at the downslope end of the tieback sections.

(a) Silt Fence Tieback System (6 sections)

(b) Section 1

(c) Section 2

(d) Section 3

(e) Section 4

(f) Section 5

(g) Section 6

Figure 7: Performance of Silt Fence Tiebacks.

Even though these sections nearly failed structurally due to excessive loads, they still captured the eroded sediment from their contributing drainage areas. This can be seen from the heavy sedimentation shown in Figure 7(b) through 7(g) and from the sediment profile shown in Figure 6. After this event, extra steel posts spaced closer were installed at the potential failure locations to provide added structural support and prevent future structural failures from occurring. During the heavy fourth rainfall event, there were still no instances of erosion along the toe of the fence.

SUMMARY AND CONCLUSIONS

The erosion and sedimentation profiles shown in Figure 4 and Figure 6 and the digital pictures shown in Figure 5 and Figure 7 illustrate that both the silt fence linear systems and tieback systems performed as expected in respect to erosion and sedimentation. The tieback system performed as expected by distributing the total sediment load between the six tieback sections and preventing erosion from occurring along the toe of the fence. The linear system, on the other hand, experienced concentrated flow along the fence which led to heavy sedimentation, scouring at the downslope end of the system, and erosion along the toe of the fence at many upslope locations. Also a comparison of the data shown in Figure 4 and Figure 6 illustrates that the tieback design was an improved design due to its ability to contain sediment on site by impounding sediment laden stormwater runoff and minimizing the chances of any failure modes from occurring.

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Research Brief: Use and Application of Anionic Polyacrylamide (PAM)

The United States Environmental Protection Agency has recently stayed the 2009 effluent limitation guidelines pertaining to turbidity levels of construction site stormwater discharge. Suspended sediment is the primary pollutant prevalent in runoff waters exiting construction sites with exposed and disturbed land. In this brief, the effectiveness of a chemical stabilizer, known as anionic polyacrylamide (PAM), to prevent erosion and promote sedimentation was examined using different application methods (i.e., dry vs. liquid). The effectiveness of Silt Stop 712, a PAM manufactured by Applied Polymers Systems, was tested using different application methods at three different rates (i.e. 15, 25, and 35 lbs/acre). Intermediate-scale testing procedures were applied that mimic interrill erosion and sediment detachment scenarios similar to a highway embankment with a compacted 3:1 fill slope. Our results show that 'dry PAM' treatments applied at the manufacturer recommended rate (35 lbs/acre) were capable of reducing turbidity by 97% and net soil loss by approximately 50%. Conversely, 'liquid PAM' treatments applied at the same rate (35 lbs/acre) followed by a drying period of 48 hours prior to experimentation reduced turbidity by approximately 69% and soil loss by 76%. Based on these results it was concluded that: (1) 'dry PAM' applied directly to the surface at the manufacturer's recommended rate was more effective as a sediment control (turbidity reduction) measure, and (2) 'liquid PAM' applied directly to the surface at the manufacturer's recommended rate and allowed to dry for 48 hours prior to rainfall is a more effective erosion control measure. It is important to note that neither application method (i.e., dry or liquid) applied by itself on bare soil was able to reduce both erosion and turbidity related problems simultaneously. Further research focusing on PAM application methods combined with ground cover practices should be conducted to identify more effective erosion and sediment control practices to use at construction sites. The results discussed in this brief are qualified by several factors such as scale, slope, soil type, soil compaction, rainfall simulation, and rainfall intensity. Therefore, extending the results and conclusions for interpreting field scale performance would require further site and product-specific testing.

INTRODUCTION

Environmental implications of sediment-laden discharges from highway construction sites is a growing concern since it could result in fish kills, degradation of aquatic habitats, and capacity reduction of navigable waterways. Furthermore, there is growing pressure from regulatory agencies and the public to test and install better practices for controlling erosion from construction sites The United States Environmental Protection Agency (USEPA) has recently stayed the 2009 effluent restrictions regulating turbidity levels in stormwater discharge exiting construction sites to be less than or equal to 280 nephelometric units (NTUs) (*3*). As a result of this action, the USEPA continues to reevaluate effluent discharge data from construction sites to establish a new numeric limit. Therefore, a clear need stills exists for (1) developing best management practices (BMPs) that can be employed as erosion and sediment control measures, and (2) scientifically analyzing and evaluating BMPs' overall effectiveness in reducing erosion rates and turbidity levels.

One such practice is known as polyacrylamide (PAM) which is a chemical stabilizing technique that can assist in reducing erosion and promoting sedimentation of sediment-laden stormwater runoff. Anionic PAM is a negatively charged chemical that when applied to soil surfaces, bonds with soil particles to help maintain soil structure and reduce erosion. In addition to acting as an erosion control measure, PAM also serves as a binding agent to flocculate soil particles that have become detached during the erosion process. This flocculation of fine particles occurs when the negative charge of PAM polymers combine together with suspended soil particles. The resulting increase in combined particle sizes aids flocculation. Therefore, PAM applied as a chemical stabilization technique has the potential to assist in reducing erosion and improving sedimentation caused by stormwater runoff.

This research brief presents the results of intermediate-scale experiments conducted to evaluate the performance of different PAM application methods (i.e., dry vs. liquid PAM) on compacted, 3:1 slopes, and recommendations pertaining to the use of PAM as an erosion and/or sediment control measure at highway construction sites.

MATERIALS AND METHODS

Intermediate-scale test plots used for experiments were constructed from pressurized timber, measuring approximately 4 ft x 2 ft x 3 in. A gutter system was connected to the end of each test plot to collect runoff from the test plots into sampling containers as seen in Figure 1.

Test Plot Preparation

The testing soil used for experimental purposes was obtained from a local construction site in Auburn, Alabama. Soil analyses indicated the soil was well graded with a 58.6% sand, 12.5% silt, and 28.9% clay soil composition. The test soil was compacted in two test plots to 95% of the maximum density, meeting the Alabama Department of Transportation (ALDOT) *Standard Specification for Highway Construction* (*1*). Proctor curves were developed and it was determined that moisture contents ranging between 12 and 19% could achieve the desired 95% compaction level. The test soil was added to the test plots in two, 1 in. lifts and were compacted using hand tamps to obtain the required compaction level. Each test plot was mounted on adjustable sawhorses to provide a test slope of 3:1 as shown in Figure 1.

Figure 1: Experimental Setup.

Rainfall

To simulate runoff, synthetic rainfall was generated using a rainfall simulator, which was installed at a height of 10 ft as shown in Figure 1. Using the Christiansen Uniformity Coefficient (*2*), the rainfall simulator was calibrated, verified, and we determined that a uniform rainfall distribution for an area representing the location of the two test plots was produced. We designed a rain regime based on the ALDOT stormwater inspection guidelines as well as the amount of cumulative rainfall experienced by central-Alabama during a 2 year, 24 hour rain event, which produces between 4 and 4.5 inches of rainfall. To produce this much rainfall, we designed rainfall regimes consisting of four, 15 minute rain events that result in 1.1 in of rainfall per event, exceeding the established baseline of 0.75 inches required for inspection. All four rain events in total produced a rainfall intensity of 4.4 in/hr; representative of the 2 year, 24 hour rain event. Between each event, 15 minutes of no rainfall was allocated to allow sufficient time to collect all relevant data.

Polyacrylamide

A standard soil analysis was conducted to determine the best PAM formulation for the soil type used in this study. The objective of this analysis is to select a PAM that would produce optimum protection against erosion and promote sedimentation. Applied Polymer Systems, Inc., performed the soil analysis and selected Silt Stop™ 712 as the appropriate polymer at an application rate of 25 to 35 lbs/acre.

PAM treatments at the manufacturer recommended upper and lower application rates (i.e., 25 and 35 lbs/acre) were tested; in addition to a much lower rate (i.e., 15 lbs/acre). We also explored the effectiveness of two application methods: (1) dry PAM granules applied directly to the soil surface, and (2) an aqueous PAM solution (i.e., dry PAM dissolved in water), herein referred to as 'liquid PAM' applied at the same rate as dry PAM (i.e., 15, 25, and 35 lbs/acre) using a backpack sprayer with built-in agitation. Test plots treated with 'liquid PAM' at the above mentioned rates were not permitted to dry prior to the start of the experiment. This allowed an examination of whether liquid PAM requires a drying period for improved performance; furthermore, this scenario simulated a 'worst-case' scenario (e.g., rainfall beginning shortly after initial application of PAM treatments). This scenario was applied to both dry and liquid PAM treatments. Additional tests were conducted to examine liquid PAM applied only at 35 lbs/acre with a 48-hour drying period before initiating rainfall.

RESULTS AND DISCUSSION

Through the duration of the research and following each test run, the following data was collected: (1) surface runoff volume, (2) instantaneous turbidity, and (3) amount of soil eroded from test plots. Infiltration from the plots was minimal due to the high level of compaction, resulting in elimination of this parameter. Data were collected every minute throughout each 15 minutes rainfall event. All above-mentioned data collected for each individual treatment was averaged and reported herein.

Turbidity

Instantaneous turbidity was collected every minute of an experimental duration. The turbidity was measured using an ANALITE NEP 160 turbidity meter with an ANALITE NEP 260 probe, ranging 0 to 4,000 NTUs. Immediately after the runoff was collected and weighed, the samples were agitated to ensure homogeneity prior to measurement and are summarized in Figure 2.

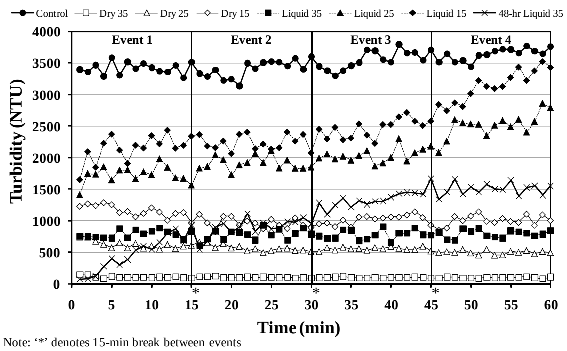
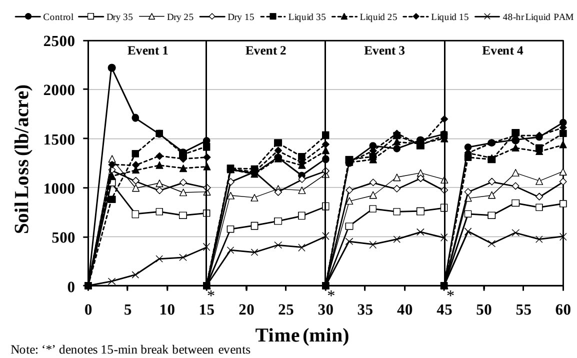


Figure 2: Instantaneous Turbidity of Surface Runoff over Time for Different Treatment Methods.

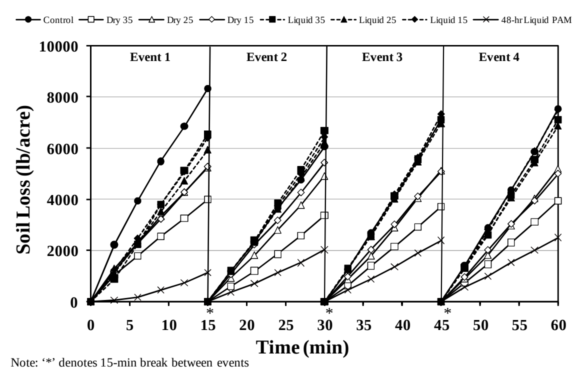
Over the duration of the experiment, dry PAM, applied at the rate of 35 lbs/acre, was able to reduce turbidity levels and maintain consistently low turbidity readings yielding reductions of approximately 97% for all events, when compared to the control. As PAM application rates decreased, initial turbidity measurements increased. This trend continued for all PAM treatments. 'Liquid 25 and 15' experienced a noticeable increase in turbidity approximately 40 minutes into the rain regime's duration, with a greater increase occurring for event 4. This increase of initial turbidity was identified as the point at which these PAM treatments were no longer effective in reducing turbidity, as PAM treatments were being washed away by surface runoff. It was observed that the '48-hr liquid 35' initial performance was similar to dry 35 PAM, but it quickly began to yield turbidity levels that were similar to liquid PAM treatments without a drying period. This trend continued during the first two events, but subsequent events (i.e. event 3 and event 4) showed that turbidity was higher than that was recorded using the liquid PAM without a drying period. On average, '48-hr liquid 35' reduced turbidity levels approximately 69% when compared to the control. 'Dry 35' was the only treatment in this study capable of obtaining USEPA's proposed effluent limit of 280 NTU when evaluating initial turbidity of runoff.

Soil Loss

Soil from each event was collected using Hayward single-length filter bags with one micron sized pores for every three minute period throughout each 15 minute event duration. Following the filtration process, the silt-laden bags were oven dried for 24 hours, then carefully emptied and weighed to determine soil loss. Figure 3(a) shows the recorded soil loss versus time and Figure 3(b) shows the cumulative soil loss for each test. The control and dry PAM treatments experienced an initial surge of sediment contained within the runoff. Following this surge, eroded soil levels achieved a steady state and remained relatively constant throughout the four tests. It was observed that dry PAM treatments consistently produced levels of sediment that were less than the bare soil. The application rate of 35 lbs/acre performed better than the 25 and 15 lbs/acre treatments in reducing the amount of eroded soil from the plots. When compared to the control, 'dry 35' reduced soil losses by approximately 50% across all four events. Other application rates of dry PAM were also capable of reducing soil loss with measurements ranging from 10 to 30% reductions. The three 'worst-case' liquid PAM applications had soil losses similar to that of the control, indicating that these treatments provided almost no benefit in reducing the amount of erosion.



(a) Soil Loss vs. Time



(b) Cumulative Soil Loss vs. Time

Figure 3: Soil Loss over Time for all Treatments.

The '48-hr liquid 35' treatment experienced greatly reduced soil loss when compared to the control by an average reduction of approximately 76%. This shows that the liquid PAM treatment which was allowed to dry for 48 hours out performed 'dry 35' by approximately 28%. This indicates that when liquid PAM was applied with a drying period, it was capable of performing better than dry PAM as an erosion control measure. This is because the treatment had time to adequately bond with the soil surface to provide protection against erosion.

Turbidity vs. Soil Loss

One of the main objectives for this research was to determine differences between the performance quality of dry and liquid PAM treatments. By examining the previous results, two general trends were observed: (1) dry PAM treatments were substantially more effective at promoting sedimentation than liquid PAM and (2) liquid PAM treatments that had been given time to dry were more capable at reducing erosion than dry PAM applications. These factors can be observed in Figure 4.

It was observed that dry PAM applications were more effective as a sediment control measure; this was deduced by examining turbidity versus time measurements. Dry PAM treatments are grouped together towards lower turbidity levels (200 NTU to 1,400 NTU). The groupings of data are also more aligned vertically, rather than horizontally, indicating that a relatively more consistent range of turbidity was achieved, while variations occurred in the amount of eroded soil. This range of turbidity increases as application rates decrease, indicating that lower application rates were not as effective as promoting sedimentation.

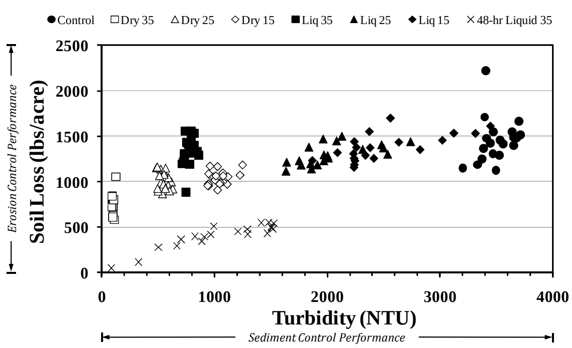


Figure 4: Avg. Turbidity vs. Soil Loss.

Conversely, liquid PAM treatments were more distributed over turbidity measurements, while more consistent levels of soil loss were achieved, especially as observed with '48-hr liquid 35' treatment. This relationship between turbidity and soil loss indicated which treatments performed better as either an erosion or sediment control measure. The liquid PAM applications, specifically the '48-hr liquid 35', were much more efficient at reducing soil loss during the storm duration however the treatment exhibited decreased performance throughout the test duration. Dry PAM, specifically applied at 35 lbs/acre, and was tightly grouped around lower turbidity levels, indicating that this treatment measure was more effective at promoting sedimentation.

We attribute these results to the molecular properties of PAM and the polymer's interaction with soil particles. PAM becomes 'active' once introduced to water (i.e. rainfall or dissolved in water). Once PAM molecules are active, they bond with soil particles. Different application methods (i.e., dry and liquid treatments) dictate when this bonding occurs. When dry granules of PAM are applied directly to the soil surface, the granules first become active when rainfall and surface runoff is initiated. As runoff passes by the PAM granules, they are activated and the PAM molecules are slowly and consistently being introduced into the runoff. As these active PAM molecules are present in the surface runoff, they begin to bond with suspended soil particles, which promote flocculation and sedimentation, resulting in decreased turbidity levels, as observed in this research. For liquid PAM treatments, when the treatment is being prepared, the dry granules are added to water creating an aqueous solution of PAM. While the dry granules are being dissolved in water, the PAM molecules are activated. Once the aqueous PAM solution is complete, the liquid PAM is sprayed onto a test plot and the PAM molecules begin bonding with soil particles on the soil surface, providing a thin layer of protection. As rainfall was initiated, '48-hr liquid 35' was capable of maintaining the structure of the soil surface, resulting in low amounts of eroded soil initially. However, once PAM activates, it cannot 'reactivate', so as PAM begins to degrade and is washed away by surface runoff, it was incapable of acting as an effective sedimentation control measure by bonding with the suspended soil particles, such as the dry PAM applications performed. Once the protective layer of PAM is washed away, test plots are effectively 'untreated' and resulted in higher turbidity levels compared to dry PAM applications.

Conversely, liquid PAM treatments that were not given time to dry had recorded turbidity levels that were lower than '48-hr liquid 35' (31.2 kg/ha). Since these treatments were not given time to dry, the molecular bonding with the soil surface did not adequately form. Therefore, liquid PAM treatments were washed off without the means to provide protection on the soil surface against erosion. However, the PAM molecules were still active and were able to bond with suspended soil particles in the surface runoff and act as a more effective sedimentation control measure than the '48-hr liquid 35' (31.2 kg/ha) treatment.

Therefore, liquid PAM (when allowed to dry) performed better as an erosion control measure and dry PAM treatments performed better as sediment control measures by improving water quality and reducing turbidity levels.

Summary of Results

Figure 5 summarizes the average percent reductions in turbidity and soil loss across all four events and for all soil treatments normalized to the bare soil control. As previously indicated, 'dry 35' was most effective in reducing turbidity levels on average by 97% and it was the best sedimentation control measure. Conversely, '48-hr liquid 35' minimized the effect of erosion by reducing the soil loss by 76%; this was the best erosion control option. 'Liquid 15' performed the worst for both sediment and erosion control with reductions of 35% and 4%, respectively.

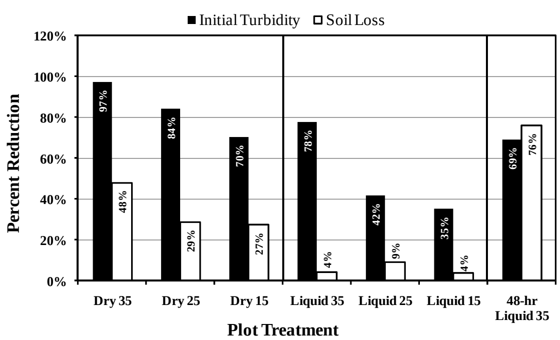


Figure 5: Avg. Percent Reductions of Turbidity and Soil Loss Compared to the Bare Soil Control.

CONCLUSIONS

The main objective of this study was to evaluate the performance that different PAM application methods, using an anionic PAM, had on interrill sediment detachments from steeply sloped embankments at highway construction sites. Intermediate-scale designs and procedures were employed to test effectiveness of various application rates of dry and liquid PAM on compacted, 3:1 slopes. Test plots treated with dry PAM were observed to promote sedimentation, reducing turbidity levels more effectively than liquid PAM treatments. Dry PAM, at an application rate of 35 lbs/acre, on average generated a 97% reduction in turbidity when normalized to the control data. Turbidity levels for dry PAM treatments provided consistent readings, which illustrated that these treatments were capable of acting as a long-term sediment control measure. The lower application rates (i.e., 15 and 25 lbs/acre) of liquid PAM treatments without a drying time were observed to lose effectiveness after about 40 minutes. Liquid PAM that had been given 48 hours to dry prior to rainfall was more effective in reducing soil erosion when compared to other PAM treatments since it provided an average of 76% reduction in soil loss compared to the control data. However, this treatment was unable to provide a similar level of protection against turbidity. Experimental results indicated that dry PAM was most effective as a sediment control measure and liquid PAM applications with a drying a period performed better as an erosion control measure.

In summary this brief indicates that PAM by itself is not effective in simultaneously reducing both erosion and turbidity levels at a construction site. Therefore, PAM should be used in conjunction with additional technologies. The use of PAM coupled with ground cover practices has the potential to drastically reduce the amount of eroded soil from construction sites while improving overall water quality of stormwater discharges from construction sites into the environment. Further research is warranted to determine which combination of technologies will provide the optimal level of protection to control soil loss and sedimentation problems related to highway construction sites. The results discussed in this brief are qualified by several factors such as scale, slope, soil type, soil compaction, rainfall simulation, and rainfall intensity. Therefore, extending the results and conclusions for interpreting field scale performance would require further site and product-specific testing.

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Research Brief: Performance Evaluation of Polymer-Enhanced Soft Armoring

Construction fill slopes on highway projects present a unique environmental challenge that involve prevention of erosion and the associated transport of sediment by stormwater runoff, prior to the establishment of a vegetative stand. The objective of this research brief is to discuss the use of a polymer-enhanced soft armoring technique as a temporary erosion and sediment control measure on compacted 3:1 fill slopes that are common in highway construction applications. Polymer-enhanced soft armoring consists of installing a soft, pliable open-weave mat (i.e. jute, coir, coconut, hemp, burlap, etc.) on the disturbed soil surface along with a site-specific, dry-granular polyacrylamide (PAM). The addition of PAM allows the chemical treatment to bond with soil particles, thereby enhancing the stability of the surface. This research uses intermediate-scale testing procedures under simulated rainfall conditions. We evaluated the effectiveness of a polymer-enhanced soft armoring consisting of an open-weave, jute matting with PAM applied at a rate of 35 lbs/acre. Through comparative analyses, the performance of the soft armoring was quantified against the following conditions: (1) bare soil, (2) open-weave jute matting, and (3) open weave, jute matting with dry, granular PAM applied at 35 lbs/acre (polymer enhanced soft armoring). Data collected include surface runoff volumes, turbidity values, and the total amount of eroded soil. Results of the analyses help understand the performance of the polymer-enhanced soft armoring technique in preventing erosion and reducing the amount of sediment in stormwater runoff. The results discussed in this brief are qualified by several factors such as scale, slope, soil type, soil compaction, rainfall simulation, and rainfall intensity. Therefore, extending the results and conclusions for interpreting field scale performance would require further site and product-specific testing.

INTRODUCTION

Sediment-laden stormwater discharge from highway construction sites is a growing concern in the construction industry. According to the United States Environmental Protection Agency's (USEPA's) *Storm Water Phase II Final Rule Fact Sheet Series,* sediments from construction site runoff is one of the most widespread pollutants affecting rivers and streams. The 2000 National Water Quality Inventory reported sedimentation impairs 84,503 river and stream miles, with construction site sedimentation runoff rates 10 to 20 times greater than those of agricultural runoff, and about 1,000 to 2,000 times greater than those of forest land runoff (*3*). In 2008, the USEPA proposed more stringent effluent limitation guidelines, mandating construction sites to reduce initial turbidity levels to 280 NTU, which has recently been stayed (*4*). This new proposed effluent limitations guideline has generated considerable momentum within the construction industry to establish a scientific approach to evaluate the effectiveness of best management practices (BMPs) in reducing erosion rates and turbidity levels.

This research brief presents the performance evaluation of a novel BMP, known as *polymer-enhanced soft armoring*, which consists of installing a soft, pliable open-weave mat (i.e. jute, coir, coconut, hemp, burlap, etc.) on a disturbed soil surface followed by an application of soil-specific polyacrylamide (PAM) on top of the matting. The applied PAM is expected to react with various minerals within the soil to form a highly erosion-resistant surface that would aid in the attachment of the particulate to the matting surface (*2*).

MATERIALS AND METHODS

Intermediate-scale test plots used for experiments were constructed from pressurized timber, measuring approximately 4 ft x 2 ft x 3 in. A gutter system was connected to the end of each test plot to collect runoff from the test plots into sampling containers as seen in Figure 1.

Test Plot Preparation

The testing soil used for experimental purposes was obtained from a local construction site in Auburn, Alabama. Soil analyses indicated the soil was well graded with a 58.6% sand, 12.5% silt, and 28.9% clay soil composition. The test soil was compacted in two test plots to 95% of the maximum density, meeting the Alabama Department of Transportation (ALDOT) *Standard Specification for Highway Construction* (*1*). Proctor curves were developed and it was determined that moisture contents ranging between 12 and 19% could achieve the desired 95% compaction level. The test soil was added to the test plots in two, 1 in. lifts and were compacted using hand tamps to obtain the required compaction level. Each test plot was mounted on adjustable sawhorses to provide a test slope of 3:1 as shown in Figure 1.

Figure 1: Experimental Setup.

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To simulate runoff, synthetic rainfall was generated using a rainfall simulator, which was installed at a height of 10 ft as shown in Figure 1. Using the Christiansen Uniformity Coefficient (*4*), the rainfall simulator was calibrated, verified, and we determined that a uniform rainfall distribution for an area representing the location of the two test plots was produced. We designed a rain regime based on the ALDOT stormwater inspection guidelines as well as the amount of cumulative rainfall experienced by central-Alabama during a 2 year, 24 hour rain event, which produces between 4 and 4.5 inches of rainfall. To produce this much rainfall, we designed rainfall regimes consisting of four, 15 minute rain events that result in 1.1 in of rainfall per event, exceeding the established baseline of 0.75 inches required for inspection. All four rain events in total produced a rainfall intensity of 4.4 in/hr; representative of the 2 year, 24 hour rain event. Between each event, 15 minutes of no rainfall was allocated to allow sufficient time to collect all relevant data.

Polyacrylamide

A standard soil analysis was conducted to determine the best PAM formulation for the soil type used in this study. The objective of this analysis is to select a PAM that would produce optimum protection against erosion and promote sedimentation. Applied Polymer Systems, Inc., performed the soil analysis and selected Silt Stop™ 712 as the appropriate polymer at an application rate of 25 to 35 lbs/acre. We determined that dry PAM applied at 35 lbs/acre would be the application rate used in this study. The 35 lbs/acre was converted to the necessary application rate for test plots, equivalent to 0.006 lbs/acre.

Polymer enhanced soft armoring

The polymer enhanced soft armoring selected for experimental analysis consists of an open weave jute matting installed on bare soil with an application of dry, granular PAM applied at 35 lbs/acre.

The experimental study examined bare soil conditions, and two different treatments: (1) open-weave jute matting on bare soil without PAM [herein referred to as 'jute matting w/o PAM'], and (2) polymer-enhanced soft armoring, which is open-weave jute matting on bare soil with an application of dry PAM at 35 lbs/acre, herein referred to as 'jute matting w/dry 35'.

RESULTS AND DISCUSSION

Through the duration of the research and following each test run, the following data was collected: (1) surface runoff volume, (2) surface runoff mass, (3) instantaneous turbidity, (4) runoff samples (turbidity vs. time), and (5) amount of soil eroded from test plots. Infiltration from the plots was minimal due to the high level of compaction, resulting in elimination of this parameter. Surface runoff volume, mass, and instantaneous turbidities were collected every minute throughout each 15 minutes rainfall event. All above-mentioned data collected for each individual treatment was averaged and reported herein.

Turbidity

Instantaneous turbidity was collected every minute of an experimental duration. The turbidity was measured using an ANALITE NEP 160 turbidity meter with an ANALITE NEP 260 probe, ranging 0 to 4,000 NTUs. Immediately after the runoff was collected and weighed, the samples were agitated prior to measurement and are summarized in Figure 2.

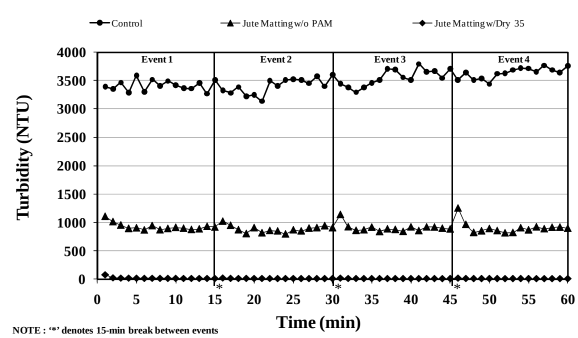
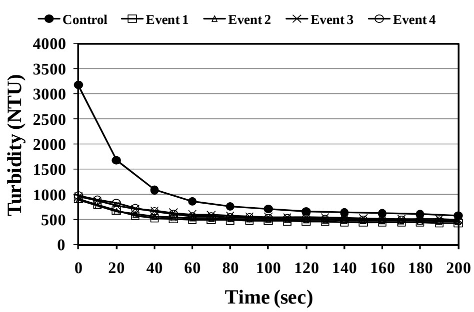


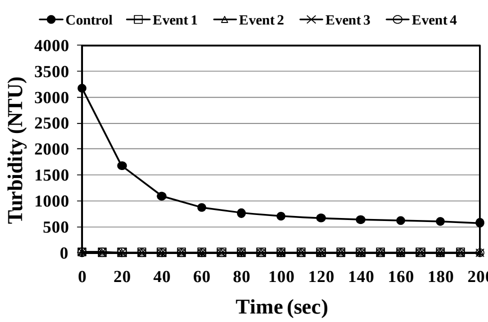
Figure 2: Instantaneous Turbidity of Surface Runoff Over Time for Different Treatment Methods.

Prior to averaging the instantaneous turbidity readings, all data was observed and checked for consistency to assure an accurate analysis of testing results. Figure 2 illustrates 'Jute Matting w/Dry 35' performed the best, yielding turbidity reductions of approximately 100% for all events, when compared to the control (bare soil). The jute matting without PAM on bare soil was also very consistent in controlling turbidity, reducing turbidity levels by a calculated 74% in comparison to the control.

During the experiment, after the instantaneous turbidities were recorded, grab samples were collected every 10 minutes from each 15 minute rainfall event to examine the rate at which suspended solids settled. Figure 3 depicts changes in average turbidity for each treatment. The 'Jute Matting w/Dry 35' was capable of yielding a turbidity rate that was consistently lower than the 'Control' by approximately 3,500 NTUs and lower than the 'Jute matting w/o PAM' by approximately 1,000 NTUs. 'Jute Matting w/Dry 35' was also the only treatment in this study capable of obtaining USEPA's proposed effluent limit of 280 NTU.



(a) Jute Matting w/o PAM



(b) Jute Matting w/Dry 35

Figure 3: Settling Pattern of Runoff Water.

Soil Loss

Soil from each event was collected using Hayward single-length filter bags with one micron sized pores for every three minute period throughout each 15 minute event duration. Following the filtration process, the silt-laden bags were oven dried for 24 hours, then carefully emptied and weighed to determine soil loss. Figure 4 represents the recorded soil loss versus time and for each test. There was an initial surge in sediment runoff, as shown in the control data in Figure 4; however following the surge, steady-state conditions were achieved and the sediment flow rate was relatively constant for the remainder of the tests. The data collected from this research revealed that minimal soil eroded when the jute matting was used. Both the jute matting and the polymer-enhanced soft armoring technique experienced minimal soil loss from test plots. When compared to the control, 'Jute Matting w/o PAM' reduced soil losses by approximately 98%, and the 'Jute Matting w/Dry 35' PAM reduced soil losses by approximately 100%.

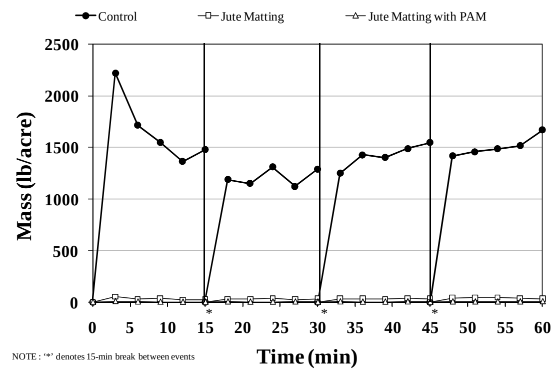


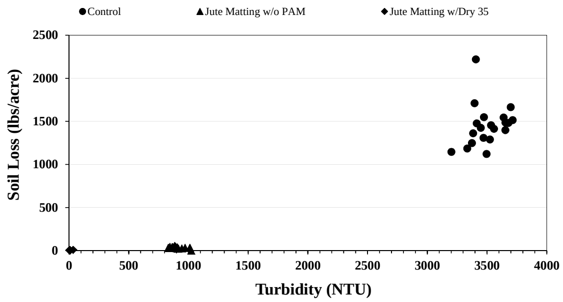
Figure 4: Soil Loss Over Time.

Turbidity vs. Soil Loss

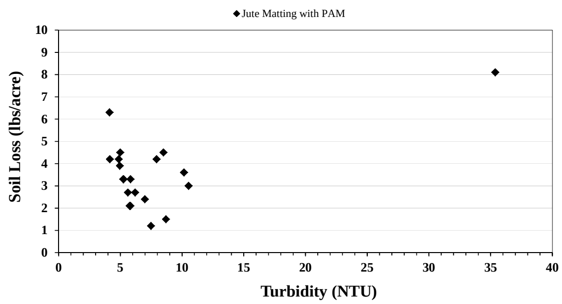
Previous results for this study confirmed the effectiveness of polymer-enhanced soft armoring technique, however by plotting average turbidity versus eroded soil in Figure 5(a) and 5(b), we are able to observe a trend with each treatment. Figure 5(a) shows that the 'jute matting w/dry 35' controlled erosion and turbidity simultaneously with little variability in data collected. This practice created an effective erosion and sediment control treatment in comparison to the 'Jute Matting' and the control. Figure 5(b) shows an exaggerated scale to illustrate the erosion reduction and sedimentation results associated with the polymer enhanced soft armoring technique.

Summary of Results

Figure 6 is a chart summarizing the percent reductions achieved in soil loss and turbidity for all four events and the two soil treatments normalized to the bare soil control. With close to 100% reduction in turbidity and soil loss, the polymer-enhanced soft armoring ('Jute Matting w/Dry 35') was ranked as the most effective treatment. 'Jute Matting w/o PAM' had a soil loss percent reduction of 98% and a turbidity percent reduction of 74% when compared against the control.



(a) All results w/bare soil control



(b) Polymer Enhanced Soft Armoring Results

Figure 5: Avg. Turbidity vs. Soil Loss.

CONCLUSIONS

The main objective of this study was to determine the performance of jute matting on bare soil and jute matting with dry granular polyacrylamide (PAM) as erosion and sediment control measures on slopes representative of a typical highway embankment. Jute matting with an appropriate, soil-dependent application of PAM, also known as *polymer enhanced soft armoring technique* was developed by Applied Polymer Systems, Inc. It is an attempt to find an optimal solution for both erosion and sediment control. Based on the literature review, to the best of our knowledge, this is the first time an intermediate-scale testing has been completed to scientifically determine the feasibility of these BMP techniques. The intermediate-scale tests were conducted on a 3:1 (H:V) slope and were compacted prior to the application of jute matting or PAM. Test plots with jute matting were observed to reduce soil loss, but did not meet the USEPA proposed effluent limitation guidelines of 280 NTUs. The jute matting, when compared to the control, generated about 74% reduction in turbidity, and about 98% reduction in soil loss. However, once dry granular PAM was applied at 35 lbs/acre to the jute matting, both soil loss and turbidity levels were optimally controlled. The jute matting with PAM applied at 35 lbs/acre indicated close to 100% reduction in both turbidity and soil loss levels.

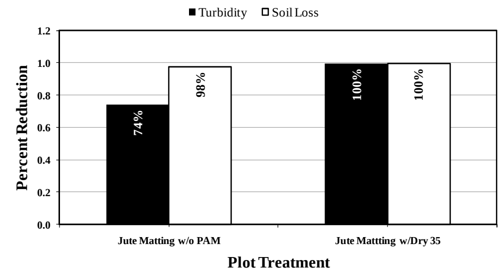


Figure 6: Avg. Percent Reductions of Turbidity and Soil Loss Compared to the Bare Soil Control.

Our experimental results indicated that jute matting was effective in controlling soil loss; however, with dry granular PAM (applied at 35 lbs/acre), both soil loss and turbidity were effectively controlled. Therefore, it is concluded that the polymer-enhanced soft armoring is an effective erosion and sediment control measure when using jute matting in conjunction with an application of soil-specific, dry granular PAM. *The results discussed in this brief are qualified by several factors such as scale, slope, soil type, soil compaction, rainfall simulation, and rainfall intensity. Therefore, extending the results and conclusions for interpreting field scale performance would require further site and product-specific testing.*

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Research Brief: Evaluation of Hydromulches as an Erosion Control Measure

The hydraulic application of mulches, known as hydromulching, is one of the most widely used erosion control practices in construction. Although mulching fill slopes for erosion control is not a new practice, new technologies and innovations in the hydromulch industry have given way to the development of several high performance erosion control products. The purpose of this research brief is to discuss the results of intermediate-scale tests conducted to evaluate the performance of four hydromulches: (1) Excel® Fibermulch II, (2) GeoSkin®, (3) HydraCX2®, and (4) HydroStraw® BFM and compare them to the performance of two conventional straw practices, crimped or tackified, and a bare soil control. Each treatment was subject to simulated rainfall, which was divided into four 15 minute rainfall events, producing a total cumulative rainfall of 4.4 inches, representative of a 2-year, 24 hour storm event. To determine the overall performance of each treatment, initial turbidities and soil loss measurements were consistently collected from plot runoff. According to experimental results, when normalized to the bare soil (control) condition, all six practices tested were successful in controlling erosion. HydroStraw BFM was the only product capable of achieving sediment control standards prescribed by both USEPA (280 NTUs) and ADEM (50 NTUs above background turbidity levels) ELGs. For all other treatments, sediment control additives such as polyacrylamide (PAM) are encouraged to be used in conjunction for effective erosion and sediment control. The results discussed in this brief are qualified by several factors such as scale, slope, soil type, soil compaction, rainfall simulation, and rainfall intensity. Therefore, extending the results and conclusions for interpreting field scale performance would require further site and product-specific testing.

INTRODUCTION

Discharge of sediment-laden stormwater from active construction sites, such as highway construction projects, is a growing concern in the construction industry (*Zech et al. 2007, 2008*). The United States Environmental Protection Agency (USEPA) labels such discharge as nonpoint source (NPS) pollution and is defined as land runoff, precipitation, atmospheric deposition, seepage or hydrologic modification that does not meet the legal definition of 'point source' in section 502(14) of the Clean Water Act. According to the USEPA's *Storm Water Phase II Final Rule Fact Sheet Series* (*2008*), sedimentation from construction site runoff is one of the most widespread pollutants affecting rivers and streams. In an effort to reduce erosion and sedimentation, the USEPA had implemented a numeric limitation of 280 nephelometric units (NTUs) to be phased in over a four year period, beginning in August of 2011, for construction sites that disturb 20 or more acres at a time (*USEPA, 2009c*), which has recently been stayed. In addition to federal guidelines, the Alabama Department of Environmental Management (ADEM), with authority given by the federal government, has implemented effluent limitation guidelines (ELGs) forbidding construction sites in the state of Alabama to exceed runoff turbidities of 50 NTUs above background levels (2011). These federal and state guidelines have encouraged the construction industry to establish a scientific approach to evaluating the performance of erosion and sediment control practices in reducing erosion rates and turbidity levels.

The primary objective of this research effort was to use intermediate-scale plots to test the erosion and sediment control performance of the following surface cover treatments: (1) conventional straw, crimped, (2) conventional straw, tackified, (3) Excel Fibermulch II, (4) GeoSkin, (5) HydraCX^2, and (6) HdyroStraw BFM on a compacted, 3:1 slope.

MATERIALS AND METHODS

Intermediate-scale test plots used for this research effort were 4 ft x 2 ft x 3.5 inches and constructed from pressurized timber. An aluminum flume was connected to the end of each test plot to collect runoff from the test plots into sampling containers as seen in Figure 1.

Test Plot Preparation

The testing soil used for experimental purposes was obtained from a local construction site in Auburn, Alabama. Soil analyses indicated the soil was well graded with a 67.5% sand, 2.5% silt, and 30% clay soil composition. The test soil was compacted in two test plots to 95% of the maximum density, meeting the Alabama Department of Transportation (ALDOT) *Standard Specification for Highway Construction* (2008). Proctor curves were developed to determine a moisture content ranging between 5% and 23% was required to achieve the desired 95% of the maximum density. The test soil was added to the test plots in one, 3 in. lift and compacted using hand tamps to obtain the required compaction rate. After completing the compaction effort, the 3 inch compacted surface was then scoured with a rake approximately ¼ inch in depth. Each test plot was mounted on adjustable sawhorses to provide a test slope of 3:1 as shown in Figure 1.

Figure 1: Compaction and Setup Procedures.

Rainfall

A rainfall simulator was used to generate rainfall to create runoff on the intermediate-scale plots. The rainfall simulator was installed at a height of 10 ft as shown in Figure 1. The simulator was calibrated, verified, and the Christiansen Uniformity Coefficient was used to ensure uniformity of the rainfall distribution was achieved over the test plots. We established a rain regime based on ALDOT stormwater inspection guidelines as well as the amount of cumulative rainfall experienced by central-Alabama during a 2 year, 24 hour rain event, which produces between 4 and 4.5 inches of rainfall. We designed rainfall regimes consisting of four, 15 minute rain events that result in 1.1 in of rainfall per event, exceeding the established baseline of 0.75 inches required for inspection. All four rain events in total produced a rainfall intensity of 4.4 in/hr; representative of the 2 year, 24 hour rain event. Between each event, 15 minutes of no rainfall was allocated to allow sufficient time to collect all relevant data.

Conventional Crimped Straw Application

Conventional straw was applied to the test plots at an application rate of 4000 lbs/acre to each test plot, which was equivalent to 333 grams/plot. Depicted in Figure 2, the proper amount of dry, conventional straw was weighed and evenly applied by hand to the compacted and tilled test plot. After proper application of the conventional straw, the next task was to crimp the conventional straw into the soil. To simulate a crimping wheel, a prototype was constructed from wood and is 2 ft in length by 3.5 inches in height, and ¼ inch thick. Using a rubber mallet, the wooden crimper was positioned horizontally along the box plot and struck uniformly into the soil until it was approximately 1 inch deep, as shown below in Figure 2. The conventional straw was crimped every two inches, as specified by ALDOT (*2008*).

Conventional Straw w/Tackifer Application

The type of tackifier used in this research was *Hytac*® *II* mixed at a rate of 52.8 oz per 600 to 700 gallons, and applied at a rate 1.1 oz/1000 ft^2. This is approximately 0.075 to 0.088oz/gallon, and ¼ gram/plot/0.038 L. The tackifer was equally applied to both test plots onto the conventional straw using a backpack sprayer. After tackifer application, the test plots were placed under ultra-violet-ray heat lamps for 48 hours to allow the tackifier to bond and dry to the straw and soil.

Figure 2: Conventional Straw Mulch Plots.

HYDROMULCH APPLICATIONS

To ensure that intermediate-scale application of hydromulch simulated field applications, it was decided to use a TurfMaker® 380 hydroseeder, for applying each hydromulch product. An experimental procedure was developed to allow the researcher performing the hydromulch applications to have the capability of quantifying the sprays necessary to achieve manufacturer specified application rate. Table 1 shows a summary of the number of sprays necessary to achieve the manufacturer's specified application rate for each hydromulch product. After the test plots were sprayed with the manufacturer specified application rate of the hydromulch, the test plots were dried for 48-hrs under the ultraviolet heat lamps.

RESULTS AND DISCUSSION

Data collection from intermediate-scale experiments allowed researchers to observe and evaluate the

Table 1: Determined Number of Sprays For Hydromulch Products Tested

Hydromulch Product	Manufacturer Required Dry Application Rate (lbs/acre)	Equivalent Test Plot Required Dry Application Rate (g/plot)	Averaged Factors	Minimum # of Sprays Required
GeoSkin	2000	~167	10.1	6
HydraCX^2	3500	~292	9.7	7
Excel Fibermulch II	2000-2500	~167-209	9.3	9
HydroStraw	3000	~250	8.9	3

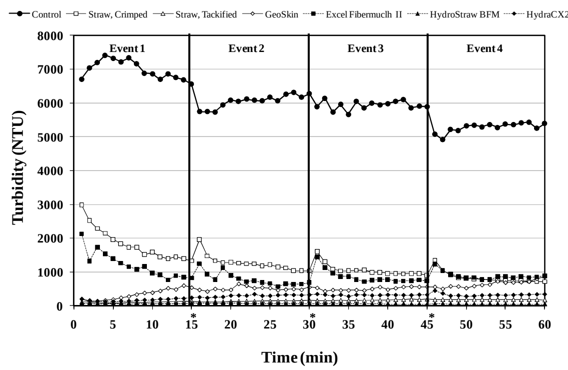
performance of conventional straw (crimped or tackified) and four hydromulches (Excel Fibermulch II, GeoSkin, HydraCX^2, and HydroStraw BFM) as an erosion and sediment control measure. Data collection included: (1) surface runoff, (2) initial turbidity, and (3) soil loss.

Turbidity

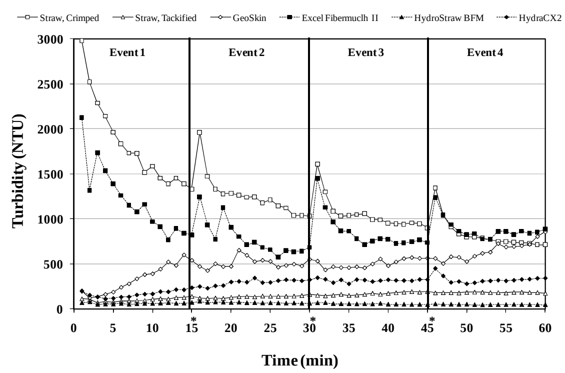
Instantaneous turbidity was collected every minute during each experiment. The turbidity was measured using an ANALITE NEP 160 turbidity meter with an ANALITE NEP 260 probe, ranging 0 to 8,000 NTUs. Immediately after the runoff was collected and weighed, the samples were agitated prior to measurement and are summarized in Figure 3. Initial turbidity measurements collected, allowed researchers to rank treatments; from most to least effective in reducing turbidity when normalized to bare soil (control) conditions, the ranked treatments in this research effort are (1) HydroStraw BFM, (2) straw, tackified, (3) HydraCX^2, (4) GeoSkin, (5) Excel Fibermulch II, and (6) straw, crimped, with reductions of 99%, 98%, 95%, 92%, 85%, and 80% respectively. The straw treatments without tackifiers, conventional straw, crimped and Excel® Fibermulch II, experienced the 'first-flush' phenomenon, receiving an initial surge of concentrated sediment in the runoff, which steadily reduced over time. Contrarily, the hydromulches and straw with tackifier were observed to slowly lose their effectiveness over the four rainfall events as the chemical bonds in the tackifying agents began to deteriorate.

Soil Loss

Soil samples were collected from test plot runoff every 3 minutes for all experiments conducted. Samples were filtered and oven dried for 24 hours. Figure 4(a) is representative of the average values of eroded soil for each treatment during an experiment's duration. It was observed that all treatments had significantly less levels of sediment when compared to the bare soil control.



(a) All cover practices with the control

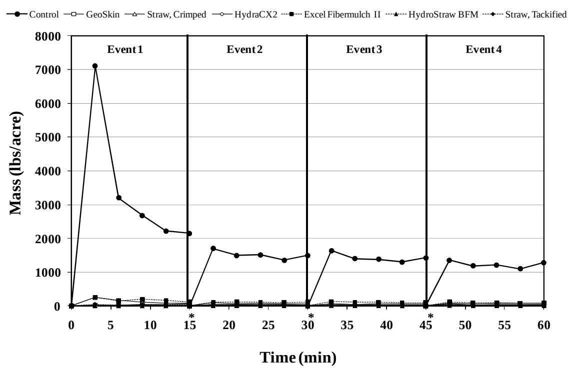


(b) All cover practices with/out the control

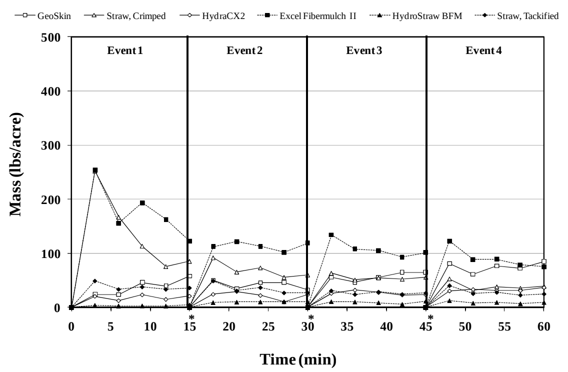
Note: '*' denotes 15 minute break in between tests

Figure 3: Avg. Turbidity of Runoff vs. Time.

The control condition and the treatments without a tackifying agent (i.e. 'Straw, Crimped' and Excel Fibermulch II) experienced an initial surge of sediment within the runoff, as discussed above. This is most likely due to a 'first flush effect' from the beginning of a rainfall event. However, the treatments with tackifiers did not have this surge; a steady increase in soil loss over time for each rainfall event was observed for these treatments. As shown in Figure 4(b), the most effective treatment in reducing soil loss was HydroStraw BFM. After the first rainfall event, it was observed that soil loss measurements remained consistent for the remainder of the experiment.



(a) All cover practices with the control



(b) All cover practices with/out the control

Note: '*' denotes 15 minute break in between tests

Figure 4: Average Soil Loss vs. Time.

To determine the relationship between the average recorded initial turbidities (essentially indicative of sediment control performance) and average measured soil loss (which is indicative of erosion control performance) values were plotted together, illustrated in Figure 5. Average soil loss and initial turbidity values for the bare soil control produced an outlying group of high sediment yield and turbidity values making it difficult to distinguish the performance of the other treatments tested therefore it is not shown on the figure.

As illustrated in Figure 5, HydroStraw BFM was highest performing treatment in comparison to the other six treatments. The conventional straw with an application of a tackifying agent was the second most effective treatment. The relationship between initial turbidities can be used as a method to determining overall performance of a treatment from an erosion and/or sediment control perspective. Patterns and consistencies in erosion and sediment control are also revealed when using this method to plot treatments. For example, Excel Fibermulch II and 'Straw, Crimped' have plotted values with a wider variability in comparison to the other treatments, showing signs of inconsistencies in product performance. Overall, significant reductions in both soil loss and initial turbidity are observed for each treatment when compared to the bare soil control.

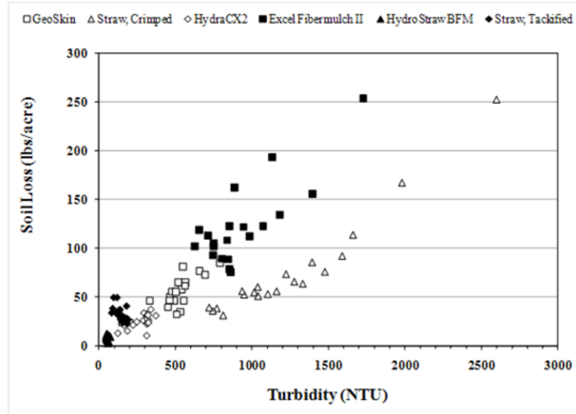


Figure 5: Average Turbidity vs. Soil Loss.

Turbidity vs. Soil Loss

Figure 6 is a chart summarizing the average percent reduction of turbidity and soil loss for each treatment normalized to the bare soil control in this research effort. Soil loss reduction results included 100%, 99%, 98%, 97%, 96%, and 94% for HydroStraw BFM, HydraCX^2, straw-tackified, GeoSkin, straw-crimped, and Excel Fibermulch II respectively. Initial turbidity reductions included 99%, 98%, 95%, 92%, 85%, and 80% for HydroStraw BFM, straw-tackified, HydraCX$^{2®}$, GeoSkin, Excel Fibermulch II, and straw-crimped, respectively.

Overall, it was observed that HydroStraw BFM was the most effective erosion and sediment control practice. This was observed using recorded and analyzed turbidity measurements, and soil loss masses estimated from test plot runoff.

SUMMARY AND CONCLUSIONS

Fourteen experiments were conducted to examine the erosion and sediment control effectiveness of 6 surface cover practices: (1) conventional straw, crimped, (2) conventional straw, tackified, (3) Excel Fibermulch II, (4) GeoSkin, (5) HydraCX^2, and (6) HydroStraw BFM. Performance was evaluated using data collection from experiments, which included surface runoff volume and mass and initial turbidity. Initial turbidity measurements were recorded from samples that were collected every minute of each four, 15 minute rainfall events. Representative of initial sediment control, researchers were able to rank the 6 treatments in order from most to least effective according to an averaged percent reduction when normalized by the bare soil condition: (1)

HydroStraw BFM [99% reduction], (2) straw, tackified [98% reduction], (3) HydraCX^2 [95% reduction], (4) GeoSkin [92% reduction], (5) Excel Fibermulch II [85% reduction], and (6) straw, crimped [80% reduction].

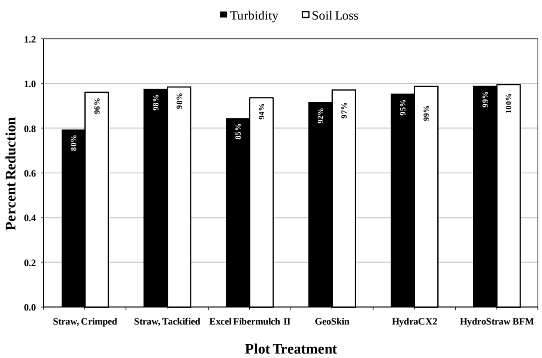


Figure 6: Average Percent Reduction of Treatments Compared to Control.

The erosion and sediment control practices without tackifiers, conventional straw, crimped and Excel® Fibermulch II, experienced a heavy concentration of sediment in the runoff during the first two rainfall events, which is known as the 'first flush phenomenon'; however each treatment steadily improved sediment control over time. Contrarily, the surface cover practices with tackifying agents provided excellent initial sediment control, but over the four rainfall events the chemical bonds began to deteriorate, showing a steady decrease in performance.

Soil loss was determined from runoff that was collected every 3 minutes, filtered, oven dried for 24 hours, and weighed to provide quantitative erosion control results. Researchers observed approximately 100%, 99%, 98%, 97%, 96%, and 94% for HydroStraw BFM, HydraCX^2, straw-tackified, GeoSkin, straw-crimped, and Excel Fibermulch II respectively.

Results from this research effort suggest that conventional straw crimped or tackified as well as hydromulches are effective erosion control measures, when applied at the proper application rates. As a sediment control measure in the state of Alabama, HydroStraw BFM was the only product capable of achieving both USEPA (280 NTUs) and ADEM (50 NTUs above background turbidity levels) ELGs. For all other treatments, sediment control additives such as polyacrylamide (PAM) are encouraged to be used in conjunction for optimal erosion and sediment control on construction sites with 3H:1V compacted fill slopes.

The results discussed in this brief are qualified by several factors such as scale, slope, soil type, soil compaction, rainfall simulation, and rainfall intensity. Therefore, extending the results and conclusions for interpreting field scale performance would require further site and product-specific testing.

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APPENDIX A: Proposed Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion*

*The following test procedure is an adaptation of ASTM D 7280 – 06. This test procedure has been modified to adapt to Alabama Department of Transportation (ALDOT) sediment control performance evaluation needs of temporary ditch check devices and practices. All differences between the proposed procedures and the actual ASTM D 7280-06 are shown in red.

1. Scope

1.1. This test method covers the guidelines, requirements, and procedures for evaluating the ability of temporary ditch checks to protect earthen channels from stormwater-induced erosion. Critical elements of this protection are the ability of the temporary ditch check to:

1.1.1. Slow and/or pond runoff to encourage sedimentation, thereby reducing soil particle transport downstream;

1.1.2. Trap soil up stream of structure; and

1.1.3. Decrease soil erosion.

1.2. This test method utilizes full-scale testing procedures, rather than bench-scale simulation, and is patterned after conditions typically found on ALDOT highway construction sites during or at the conclusion of earthwork operations, but prior to the start of revegetation work. Therefore the test method considers only unvegetated conditions.

1.3. This test method provides a comparative evaluation of a temporary ditch check to baseline bare soil conditions under controlled and documented conditions.

1.4. The values stated in this standard are reported in English units.

2. Referenced Documents

2.1. *ASTM Standards*: D 6460 Test Method for Determination of Erosion Control Performance in Protecting Earthen Channels from Stormwater-Induced Erosion

2.2. *Other standard operation procedures*: Standard procedure for determining Total Suspended Solids (TSS).

3. Terminology

3.1. *Definition of Term Specific to This Standard*

3.1.1. *temporary ditch check (in erosion control)*, n – a non-permanent barrier consisting of rocks, straw bales, excelsior logs, wattles, silt dikes, silt fence or other materials installed or constructed across a drainage way, swale, or other ephemeral waterway to reduce flow velocity, decrease erosion, and promote soil retention.

4. Summary of Test Method

4.1. The performance of a temporary ditch check in reducing stormwater-induced erosion is determined by subjecting the material to simulated water flow in a controlled and documented environment.

4.2. Key elements of the testing process include:

4.2.1. Calibration of the stormwater simulation equipment;

4.2.2. Preparation of the test channel;

4.2.3. Documentation of the temporary ditch check to be tested;

4.2.4. Installation of the temporary ditch check;

4.2.5. Performance of the test;

4.2.6. Collection of hydraulic, topographical, and associated data;

4.2.7. Analysis of the resultant data; and

4.2.8. Reporting.

5. Significance and Use

5.1. This test method evaluates temporary ditch checks and their means of installation to:

5.1.1. Reduce soil loss and sediment concentrations in stormwater runoff under conditions of varying channel conditions and soil type; and

5.1.2. Improve water quality exiting the area disturbed by earthwork activity by reducing suspended solids.

5.2. This test method models and examines conditions typically found on ALDOT highway construction sites involving earthwork activities with onsite drainage conveyance.

5.3. This test method is a performance test. It is a comparative tool for evaluating the erosion control characteristics of different temporary ditch checks and can be used for quality control to determine product conformance to project specifications. Unique project-specific conditions may be taken into consideration due to precision inconsistent possible from differences in soil and other environmental and geotechnical conditions.

6. Apparatus

6.1. *Water Delivery System* – The water delivery system includes a system of three ~0.6 cfs pumps, three 3 inch hoses, four 4 inch valves for controlling flow rate and a weir system to achieve the desired hydraulic conditions. The water control system shall regulate the flow.

6.2. *Water Source* – The water source will be ponded stormwater collected from runoff of the asphalt parking lot upgrade from the facility. Stormwater will be collected in a 28,000 ft^3 retention pond with a riprap inlet and outlet channel.

6.3. *Soil Loss and Deposition Measurement System* – Pre and post testing elevations will be measured using lateral, level string lines that stretch across the width of the test channel. Manual measurements will be taken and documented in each test log.

6.4. *Velocity Probe* – A velocity probe capable of measuring point velocities to an accuracy of ± 0.1 ft/s shall be used to identify flow conditions during test operation. Probes including electromagnetic, spinning cup, propeller and static tube devices may be implemented during testing and will be reported in the test log.

6.5. *Water Sampling* – Sampling of sediment laden test water will be performed mechanically using ISCO water samplers, or manually using a scoping rod and sampling bottle capable of sampling 250 ml of test flow.

6.6. *TSS Vacuum Pump System* – A vacuum pump system as described in the TSS determination standard operating procedure will be utilized to determine TSS.

6.7. *Miscellaneous* – Other miscellaneous equipment including meteorological equipment and camera or video recorders may also be used to document each test.

***7.* Procedure**

7.1. *Test Channel Preparation:*

7.1.1. The test channels are designed specifically to meet ALDOT ditch check testing needs and differ from this standards test specifications. Rather than using a completely earthen channel, the trapezoidal channels shall be plated with a smooth surface to reduce erosive forces on the channel from the water delivery system resulting in unnatural erosion at the water introduction area. A 10-20 ft long earthen section will be used to install and test each ditch check device and practice. The length of the earthen section will be reported in the test log.

7.1.2. The test channel will be constructed conventional earthwork placement techniques similar to procedures outlined in Test Method D 6460. Compaction of the bed material will be performed to create a stable subgrade. The channel surface will be plated with a minimum of 18 in thick veneer of soil using native soils to Alabama. The soil used will be characterized to obtain the soil gradation. The soil will be placed in 6 in. lifts and compacted to 90 ± 3% of standard Proctor density in accordance with Test Method D 698.

7.1.3. The test channel will not be constructed to ASTM D 6460 as called for by ASTM D 7208. These standards call for a 2 ft wide channel bottom with 2:1 H:V side slopes. The test channel has been constructed to represent ALDOT typical design practices. Therefore, tests will be performed using a 4 ft wide channel bottom with 3:1 H:V side slopes. The longitudinal slope of the test channels are approximately at a 5% grade as specified by these standards.

7.1.4. The test reach begins 30-40 ft downstream of the water delivery system depending on the ditch check being tested and the size of the earthen section. Measuring points of cross sections using level string lines at 2 ft longitudinal increments upstream and downstream of the ditch check within the deposition and scour zones will be used for each test. Nine lateral measurements will be taken across each string line. Five measurements of the channel bottom and two measurements on each side slope will be performed for each string line. Measurements from the string line to the channel bottom and sides slopes shall be performed before and after each test to determine soil loss and gain throughout the effected channel section.

7.1.5. Once compaction of the test reach is completed, the test reach will be raked and hand tamped to produce a smooth section for each test. Ensure that the soil is free from obstructions or protrusions, such as roots, large stones, or other foreign material.

7.1.6. If the channel has been used previously for a test series, discard the soil carried out of the channel, and obliterate any rills and gullies. Spread new soil of the same type across the channel and blend (rake or tilled) into the surface. After each test the channel will be prepared to previous compaction specifications.

7.2. *Calibration:*

7.2.1. The water delivery system shall be calibrated to ensure the weir system used to vary flow rate is accurate. An ISCO sampler equipped with a flow meter and a V-notch weir will be used to determine the flow rate of the water delivery system.

7.3. *Pre-Test Documentation:*

7.3.1. A test folder will be maintained for each test cycle including information on:

7.3.1.1. Site conditions;

7.3.1.2. Soil conditions;

7.3.1.3. Meteorological data;

7.3.1.4. Temporary ditch check product type, description, and installation procedure; and

7.3.1.5. Photo documentation.

7.3.2. Any other supplemental information and documentation thought to be of relevant significance to the test shall also be included.

7.3.3. All soil used for testing will be documented based on soil classification [Unified Soil Classification System]; standard proctor moisture-density relationship; 'K' factor; and gradation.

7.3.4. Air temperature, wind speed and precipitation will be included in all meteorological data

7.3.5. The product type and description information will include the manufacturer name, the product name, product description, and product specifications dimensions.

7.4. *Test Set-Up:*

7.4.1. The temporary ditch check will be installed in the channel after any needed calibration and channel preparation has been completed. The installation of the ditch check will be documented, including: orientation on the bed and side slopes (longitudinally or laterally); placement (orientation of faces of device); termination details; joint details; and anchor type and installation pattern. The ditch check will be placed across the channel bottom perpendicular to the flow direction and extended up the side slopes far enough so ponded water cannot erode around the temporary ditch check.

7.4.2. The elevation of the channel surface will be measured using the reference level sting lines to determine any resulting deposition and/or scour. The location of ditch check will be measured with reference to the channel sheet metal lining upstream and concrete conveyance channel downstream. A platform walkway will be placed across the channel at the location of each cross section to be measured to ensure the channel is not disturbed before or after testing. Elevation measurements for each test cross-section (nine total) at specified locations will be taken. Elevations measurements for additional cross-sections directly in front and behind each temporary ditch check shall also be taken to measure deposition and/or scour directly adjacent to the ditch check structure.

7.4.3. Photo documentation of the channel and test set up will be performed prior to testing.

7.5. *Test Operation and Data Collection:*

7.5.1. The following test data will be included: operator name and title, time duration of test flow, flow depths, and measured velocities.

7.5.2. Water surface elevation measurements will be performed at the centerline point of each test cross-section and directly in front and behind the temporary ditch check as soon as flow reaches a steady-state, uniform condition. Velocity measurements at the centerline point of each test cross-section using the velocity probe will be performed. Three velocity measurements will be made at differing heights at the centerline to get an average velocity for the cross-section. Photographs and/or videotaping will be performed during the test.

7.5.3. Sampling of test flows will be performed every minute during testing. Sampling will take place at the entrance of sediment laden flow into the test channel and directly downstream of the temporary ditch check. Samples will be marked sequentially and stored throughout testing until the samples are analyzed.

7.5.4. Flow rate will be based upon test being performed.

7.5.5. Test duration shall be a maximum of 30 minutes or until the ditch check has become dislodged.

7.5.6. At the conclusion of each test, the channel surface elevation measurements shall be performed at the same locations along the level string lines as the pre-test measurements using the platform walkway.

7.5.7. General observations regarding the condition of the tested temporary ditch check as well as the test area of the channel shall be performed at the conclusion of the data collection. Photographic documentation will be used to record the temporary ditch check's post test condition.

7.5.8. The temporary ditch check will be carefully removed with as little disturbance of the soil as possible. General conditions of the scour patterns will be noted.

7.5.9. Photographic documentation will be used to record the post test channel condition.

7.5.10. Three replications for each ditch check test will be performed.

***8.* Calculation**

8.1. *Discharge* – The discharge will be determined for each flow using the weirs of the water delivery system.

8.2. *Test Data:*

8.2.1. Analysis of the test data involves the following variables, total discharge, velocity, flow depth and energy slope.

8.2.2. The total discharge will be determined using the weir system as previously calibrated. The flow rate for each level string line will be calculated using the following continuity equation:

$$Q = V_{avg} A$$

Where:
Q = discharge, ft^3/sec
V_{avg} = average velocity of the three centerline velocity measurements taken during testing, ft/sec, and
A = cross-sectional area of flow, ft^2

8.2.3. The energy slope, S_f, will be determined by fitting a regression line through the energy grade line elevation determined at each of the level string line cross-sections, as follows:

$$S_f = WSE + V_{avg}^2 / 2g$$

Where:
S_f = energy slope
WSE = water surface elevation
V_{avg} = average velocity of the three center line velocity measurements taken during testing, ft/sec, and
g = gravitational constant, 32.2 ft/sec^2

8.2.4. Soil loss will be calculated using the Clopper Soil Loss Index (CSLI) while soil deposition will be calculated using the Soil Aggradation Index (SAI) from the topographical data collected during channel bed elevation measurements. The change in the channel topography will be used to define the performance of the temporary ditch check. Areas of soil loss will be quantified as "cut" while areas of sediment deposition will be quantified as "fill."

8.2.4.1. *Clopper Soil Loss Index*:

$$CSLI = (C_T / A_T) \times 100$$

Where:
$CSLI$ = Clopper Soil Loss Index, in,
C_T = total cut, ft^3, and
A_T = wetted channel area, ft^2

Soil Aggradation Index:

$$SAI = (F_T / A_T) \times 100$$

Where:
SAI = Soil Aggradation Index, in,
F_T = total fill, ft^3, and
A_T = wetted channel area, ft^2

9. Report

9.1. The following minimum information shall be reported for each test:

9.1.1. General information including: test facility location, date, time and operator(s),

9.1.2. Test channel used for testing

9.1.3. Test channel preparation

9.1.4. Calibration data and analysis

9.1.5. Materials documentation including temporary ditch check material and anchor description

9.1.6. Test set-up activities including trenching (if applicable), anchor pattern, and average anchor density (anchor per unit area),

9.1.7. Test operation and data collection (including "raw" data such as measured discharge for each test flow), and

9.1.8. Analysis (including hydraulic conditions, time elapsed TSS concentrations, CSLI, and SAI compared to a bare soil data set contacting a minimum of three replications).