BELTED STRAND RETENTION FABRIC: AN ALTERNATIVE TO SILT FENCES FOR EROSION AND SEDIMENT CONTROL

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Abstract. In this study SiltSaver belted strand retention fence was compared with traditional type C silt fence with the goal of determining if it would be acceptable for use as a sediment barrier in Georgia. ASTM standard methods were used to evaluate flow through and sediment removal efficiency using three different site specific soils. For flow without sediment, there were no statistical differences, although the BSRF showed a slightly higher flow rate than the type C fence that was tested. Flow rates with sediment were generally 30% to 85% lower on the BSRF than the type C fence with the greater differences observed with the finer particle sizes and the double concentration runs. This indicates the influence of the soil particles on the flow rate and may suggest that the sediment trapped behind the fence is controlling the flow rate more than the fence itself. The results from the analysis of the effluent and sediment removal efficiency indicated that the BSRF was more effective at retaining the sediment behind the fence. Both the suspended solids content and the turbidity of the effluent was lower using the BSRF fence material than the Type C fence material for all test conditions. Sediment removal efficiencies for the BSRF were significantly higher for all three tested soils at both the single and double concentration. Additional tests were conducted using variations of the ASTM standard and these tests showed similar trends. Testing also indicated that the design of the supporting apparatus was sufficient for holding the materials. While no testing program can provide results to prove an application will function under all conditions that will be encountered in the field, our testing indicates that the SiltSaver BSRF should be an effective alternative to standard Type C silt fence.

INTRODUCTION

Sediment has been recognized as one of the largest the contributors to water quality impairments in Georgia and most of the United States. Historically, soil erosion was primarily considered an agricultural issue, however, construction sites are receiving more attention as more land is being developed and there is greater awareness for water quality issues. In fact, new regulations have been developed at the State and Federal level that require all construction sites greater than one acre to develop stormwater pollution prevention plans that include appropriate sediment and erosion control. While numerous erosion and sediment control products and practices are being used in the field to reduce soil loss from construction sites, there are few scientific studies that have evaluated the effectiveness of most of these practices. A common concern of both the users and developers of erosion and sediment control products is the difficulty in comparing the performance of the different devices. Few standardized tests are available and independent laboratories at universities or manufacturing facilities do not use consistent procedures so that results can be compared. Improving technologies and insuring minimum standards are met for approving new technologies will be difficult if standardized test methods are not available.

Silt fences are one of the most commonly utilized erosion and sediment control practices. Most silt fences are constructed of woven geotextile fabrics that are reinforced and supported by wood or metal posts. Silt fences reduce sediment transport off-site through filtration and by impounding runoff to increase sedimentation. SiltSaver, Inc. has introduced a belted strand retention fence that is made of spunbound polyester fabric reinforced by fiberglass scrim and supported by wooden posts that are directly attached to the fence. This offers several potential advantages including the use of biodegradable fabric and supports and potentially having improved effectiveness.

The purpose of this project was to test Silt-Saver Belted Silt Retention Fence (BSRF) against a industry standard erosion control measure, (i.e. Type C Silt Fence) under a controlled bench experiment to compare the sediment restraining properties and flow through rates of BSRF to the industry standard. Dimensional and structural analysis was also conducted but will not be reported here.

Literature Review

While studies in the area of silt fence testing are limited, the processes and controlling parameters are well understood. A silt fence initially removes silt and sand particles from overland flow through filtration of the large particles. As the larger particles block the pores in the silt fence, runoff begins to pond behind the fence and sedimentation occurs. Wyant (1981) conducted one of the first comprehensive studies on silt fence using a flume with an 8% slope, several fabric types, and a variety of soils. His work led to development of ASTM D5141. Wyant (1981) found that flow rates ranged from 0.0004 m^3/m^2/min to 3.5 m^3/m^2/min (0.01 gal/ft^2/min to 86 gal/ft^2/min) and average sediment removal efficiencies for all of fabrics ranged from 92% for the silty soil to 97% for the sandy soil. Other research on sediment reduction caused by silt fences in laboratory settings have shown the total suspended solids removal ranges from 85% to 100% (Kouwen, 1990; Barret et al. 1998). Thiesen (1992) concluded that the apparent opening size of the fabric affects the storage capacity of the fence as well as particle deposition upstream of the fabric. Other studies contradict this and suggest that pore clogging will minimize the impact of apparent opening size.

Barret et al., 1998 evaluated the performance of several different geotextiles in the lab and field. The field studies indicated that silt fences had little influence on the turbidity of the discharged runoff and that essentially no sediment removal was attributable to filtration by the fabric. Using flumes in the lab, total suspended solids removal rates of 68% to 90% were observed and the removal efficiency was correlated to the average detention time of the runoff impounded behind the fence. Flow rates through the fabrics under field conditions were reported to be two orders of magnitude lower than would be calculated using standard ASTM index characteristics of the fabrics due to clogging of the fabric with sediment. Sherry et al., (2000) drew similar conclusions by examining two woven fabrics with a tight weave and an open weave in a flume study.

While the work of Wyant (1981) led to the development of ASTM standard D5141 (Standard test method for determining sediment removal efficiency and flow rate of a geotextile for silt fence application using site-specific soil, ASTM, 2004), only one report could be found in the literature where this test method was used. Henry and Hunnewell, 1995 used this standard test method to evaluate potential geotextile candidates for use in a remediation project involving dredged sediment. They reported flow rates ranging from 0.063 m^3/m^2/min to 0.026 m^3/m^2/min and sediment removal efficiencies of 45.5% to 72.8% using the standard test method on non-woven polyester and polypropylene geotextiles using dredged spoil that was primarily silt and clay sized particles.

Requirements and specifications for silt fence materials vary across the United States. Often, either the State department of transportation or the regulatory agency responsible for sediment and erosion control will require that geotextiles meet certain physical requirements, that the support systems be designed to meet predetermined specifications, and, in some locations, soil particle retention requirements are given. These requirements are usually based on "past experience" (National Highway Institute, 1998). The Geosynthetic Design and Construction Guidelines (National Highway Institute, 1998) suggest that site specific design of the hydraulic properties is not practical and the use of general standard specifications for nominal Apparent Opening Size (AOS) and permittivity is preferable. As an alternative, they suggest the use of performance tests including ASTM standard D 5141 for measuring site specific flow rate and filtering efficiency. They suggest using a minimum performance standard of 75% sediment retention efficiency and a flow rate of at least 0.1 L/min/m^2. It also states that the physical and mechanical properties of the geotextile should insure that it is strong enough to support the pooled water and sediment behind the fence. The report clearly states that these specifications are not based on research but on the properties of existing geotextiles which have performed satisfactory in silt fence applications. These specifications are listed in Table 1.

In Georgia, the State Soil and Water Conservation Commission regulates sediment and erosion control and publishes a manual of approved practices and products. While silt fence specifications are not listed, it references the Georgia Department of Transportation (GA DOT) as the agency responsible for approving geotextiles for silt fence applications. The Georgia DOT guidelines (not published) closely resembles the National specifications in FP-03 although they are not identical. Table 1 lists these requirements as well as measured results supplied by the manufacturer of the BSRF.

Table 1 Physical and Hydraulic Properties and specifications for geotextiles to be used in silt fence applications.

		Specifications		Reported Values	
Property	**Unit**	**GDOT Type C**	**FP03 Type C**	**BSRF Mfr Spec**	**BSRF GADOT test**
Grab Tensile Strength-warp	lbs	260	125	95	127
Grab Tensile Strength-warp	lbs	180	102	95	99
Elongation	%	<40	<50	68	>67
Apparent Opening Size	Sieve size	30	30	70	NA
Permittivity	s^{-1}		0.05		
Flow Rate/Flux	gpm	70		185	103
Ultraviolet stability	% at 500 h	80	70	[illegible]	

METHODS

Initial testing was conducted according to ASTM Standard D5141-96(2004). A watertight flume was constructed using aluminum and pressure treated plywood using specifications of ASTM D 5141. The flume was supported at an 8% grade. The test geotextile was fastened securely along the entire length of three sides of the flume opening to ensure that the geotextile had no wrinkles or loose sections across the entire cross section. Two different geotextiles were tested. One was a polyester belted strand retention fabric (BSRF) supplied by SiltSaver, Inc. The other was a woven polypropylene geotextile that is approved for use as a Type C silt fence (Willacoochee Industrial Fabrics, Style 2098). Manufacturer's specifications on the Type C approved fence state an apparent opening size of #40 sieve (0.425 mm) and a water flow rate of 2,035 L/min/m^2 (50 Gal/ min/sq. ft.) which is typical of geotextiles used in Georgia.

Three soils types were selected for use in developing slurry mixtures. The soils were chosen to represent the variety of textural properties commonly found in Georgia and to test material effectiveness at containing sediment derived from various parent materials. To represent the diversity in Georgia, a Cecil (sandy clay loam to clay), Tifton (sand to sandy loam), and Fannin (loam to silt loam) series were selected. Test soils were collected in the field from the upper 10 cm of the soil profile and air dried and sieved through a 2 mm sieve prior to testing. Three concentrations were used for the testing: 0 ppm (clear), the concentration set forth in the standard, 2890 ppm (standard), and double the standard concentration, 5780 ppm (double).

Three concentrations of sediment laden water were mixed in a 50 L holding container on top of the flume. Zero (0), 150, and 300 grams of dry test soil were added to 50L of tap water within the top holding container to mix the clear, standard and, double concentrations. The temperature of the solution was recorded so that the viscosity of the water could be standardized. The solution was thoroughly mixed using a mechanical stirring device (paint stirrer on a 4 amp drill) for one minute to ensure a uniform mix. While continuously mixing the solution, a 150 ml depth integrated sample was taken in order to measure the initial turbidity of the sediment laden water. After one minute of mixing the sediment solution was released from the container into the upper end of the flume. The timer was started at release of the water. The holding container was then rinsed using 2 L of water allowing the rinse water to enter into the upper end of the flume.

The flow of water through the geotextile was timed and recorded until no water remained behind the geotextile or 25 minutes had elapsed. In cases where 25 minutes elapsed and water remained behind the geotextile, distance from the geotextile to the edge of the water up the flume was measured. All the filtrate passing through the flume was collected into a 100 L plastic container. Collected filtrate was then agitated with a stirrer for one minute. After one minute of stirring, a 500 ml depth integrated sample was taken to measure suspended solids and turbidity of the leachate.

The ASTM standard provides equations for calculating suspended solids, sediment removal efficiency, and flow rate. These equations were used to calculate suspended solids and sediment removal efficiency. Minor changes were made for the double concentration runs to account for increased sediment. The equations for the flow rate that were given in the ASTM standard were determined to be incorrect and ASTM was contacted to derive new equations.

Each test consisted of a clear, single, and double concentration run on a single section of geotextile. The test was run in triplicate for each soil type on both geotextiles for a total of 18 tests. After each test was completed, the test geotextile was removed from the flume, dried and saved. The top holding tank, the flume, gutter, and collector were then cleaned using tap water to remove any remaining sediment. A new section of geotextile was then fastened securely along the entire length of 3 sides of the flume for the next test.

During initial testing, it was noted that most of the sediment settled out of the flow relatively quickly and that a test conducted at a higher slope might provide a better indication of the fabric properties. In follow up testing, the flume was raised to simulate a 60% slope. This produced more hydraulic head A few adjustments were necessary to accommodate the new angle. The brace that secured the holding tank was modified to level the tank. The gutter that channeled the leachate into the 100L plastic container had to be removed and replaced with flashing. The flashing allowed the leachate to freefall into a new plastic container that was wider than the flume. The new receptacle was calibrated so the volume of leachate collected could be calculated by the depth of leachate in the container. The same timing and sampling procedure was used for the 60% slope as the 8%. Testing at the higher slope was only conducted for the silt loam soil. Again each test included a clear, single and double concentration run per geotextile material. The test was run in triplicate for each fence for a total six tests.

Captured samples from each of the tests were analyzed for total suspended solids and turbidity. Total suspended solids were analyzed using the standard method set forth in Methods for the Examination of Waster and Wastewater (Greenberg at al., 1998). Whatman 934-AH glass micro fiber filters and sample volumes of 100ml were used for the procedure. Turbidity was run on a HF scientific DRT 100B. The instrument was zeroed using DI water. Samples bottles were shaken vigorously for 10 seconds. A small subsample was poured into the instrument cuvette and capped. The subsample was again shaken vigorously for 10 seconds and placed in the instrument of measurement. A 10 second average was taken for the reading. The subsample was then discarded and the cuvette was rinsed thoroughly with DI water. This process was repeated for each sample.

SAS analysis of variance (ANOVA) was used for statistical analysis to determine differences between the treatments. Since the primary purpose of the testing was to determine differences between the type C silt fence and the BSRF, comparisons were made using the difference between the test parameter for type C and BSRF and using a standard T-test (α=0.05) to determine if the difference was significantly different from 0. Each set of data was plotted to determine if it was normally distributed and was logarithmically transformed if not.

RESULTS AND DISCUSSION

Table 2 presents results for the comparison of flow rates through the geotextile materials for the ASTM Standard test method. For the clear flow conditions, there were no statistical differences between the flow rates although the BSRF showed a slightly higher flow rate than the type C fence that was tested. Average flow rates through the BSRF were 0.512 $m^3/m^2/min$ (12.6 $gal/ft^2/min$) or about 20% more than the type C fence. The flow rates with sediment were consistently higher for the Type C fence on the runs at both the single and double concentrations. Flow rates through the BSRF ranged from 0.047 $m^3/m^2/min$ (1.15 $gal/ft^2/min$) for sand and the standard concentration to a low of 0.0005 $m^3/m^2/min$ (0.012 $gal/ft^2/min$) for the silt or clay at the double concentration. These values were within the range of those reported in Wyant, 1981. Flow rates were generally 30% to 85% lower on the BSRF than the type C fence with the greater differences observed with the finer particle sizes and the double concentration runs. The flow rates were at least an order of magnitude lower for both fence materials for the silt and clay runs than the sand runs. These results indicate the influence of soil particles on flow rate and may suggest that sediment trapped behind the fence is controlling the flow rate more than the fence itself. This also would be consistent with the results of other research that suggests that the apparent size opening is not a reliable indicator of flow rate under field conditions.

Table 3 Average flow rates measured in initial trails.

		Flow Rate ($m^3/m^2/min$)[a]		
		Clear	Single	Double
Sand	BSRF	0.6753	0.0470 *	0.0015 *
	Type C	0.4560	0.1072	0.0098
Silt	BSRF	0.4544	0.0014	0.0005 *
	Type C	0.4265	0.0022	0.0015
Clay	BSRF	0.4163	0.0016	0.0005 *
	Type C	0.3881	0.0023	0.0021

[a] All reported flow rates are average of three replicates.
* Indicates that the difference between the BSRF and Type C value was significantly different than 0 at the 95% confidence level.

Table 2 Measured effectiveness data for initial trails.

		Effluent S_S Conc. (ppm)	Turbidity (NTU)	% Reduction in Turbidity	F_E
Single Concentration					
Sand	BSRF	46.0 *	25.5 *	57.9 *	98.4
	Type C	92.3	43.3	25.4	96.8
Silt	BSRF	161.3 *	77.7	81.3	94.4 *
	Type C	365.7	167.0	57.7	87.3
Clay	BSRF	76.7 *	83.2 *	81.7 *	97.3 *
	Type C	300.7	220.7	51.2	89.6
Double Concentration					
Sand	BSRF	73.3 *	43.3 *	54.9 *	98.7
	Type C	163.0	77.0	30.9	97.2
Silt	BSRF	166.7 *	92.7 *	90.1 *	97.1 *
	Type C	608.7	359.3	57.7	89.5
Clay	BSRF	139.3 *	138.3 *	83.8 *	97.6 *
	Type C	509.3	452.7	45.0	91.2

* Indicates that the difference between the BSRF and Type C value was significantly different than 0 at the 95% confidence level.

The results from the analysis of the effluent and sediment removal efficiency indicate that the BSRF was more effective at retaining the sediment behind the fence (Table 3). Both suspended solids and turbidity in the effluent were lower using the BSRF fence material than the Type C fence material for all three soils at both influent concentrations. In most cases (9 of 12 comparisons), these differences were statistically significant. Differences were greater for the double concentrations and the finer soils. Turbidity levels in the effluent passing through the BSRF were 41% (Sand at standard concentration) to 74% (silt at double concentration) lower for the BSRF than the Type C silt fence. It is interesting to note that while the turbidity levels increased as particle size got smaller for both fence materials, suspended solids getting through the fences were greater for the silt runs than the clay runs. This is probably due to the fact that clay particles contribute to turbidity but are very light compared to the silt particles.

All of the measured sediment removal efficiencies were high for both fence materials (lowest was 87%). These high efficiencies may be attributed to low slope gradient and the extended holding time created under these conditions. Much of the released sediment settled out of suspension prior to reaching the fence materials. Sediment removal efficiencies were significantly higher for the BSRF on all three tested soils at both the single and double concentration. They were also consistently higher for the runs at the double concentration than those at the concentration suggested in the standard. While the sediment removal efficiency data seems to indicate that both materials were effective, if reduction in turbidity is used as a measure of effectiveness, the BSRF functioned statistically better. It is commonly accepted that silt fences provide for little treatment of turbidity, especially on finer soils. For these runs, type C fence provided 25% (Sand, standard concentration) to 58% (Silt, both concentrations) reductions in turbidity while the BSRF provided 55% (Sand, double concentration) to 90% (Silt, double concentration) reductions in turbidity. Clearly, the BSRF removed more of the turbidity causing particulate matter.

The results of the tests conducted using the ASTM standard method indicated differences between the fence materials, however, it did not test the materials under "worst case" conditions because very little fabric was exposed to flow (maximum depth of slurry behind the fence was only 0.097 m (3.8 inches)) and the low slope did not allow significant hydraulic head to occur. To test how the fence materials would react when exposed to higher flow rates, the flume was elevated to a slope of 58% and the same procedures were used to evaluate both fence materials. The only other modifications to the ASTM procedure was that the total volume of slurry passing the fence was measured and recorded instead of measuring the distance of ponded water behind the fence after 25 minutes so new equations were derived to calculate the flow rate.

The results from the runs at the 58% slope are shown in table 4. This test was only conducted using the silt loam soil since that soil produced the poorest results in the standard ASTM test and "worst case" conditions were desirable. Flow rates in this test were slightly higher for the BSRF than the Type C silt fence using clear water as well as at the standard and double sediment concentrations, however these differences were not statistically significant.

Table 4 Results from tests conducted at higher slope on silt loam soil. All values are average of three runs.

Fence type	Run	Flow Rate ($m^3/m^2/min$)	Susp. Solids (ppm)	Turbidity (NTU)	F_e
BSRF	Clear	0.4054			
	Standard	0.0149	290 *	130 *	89.97*
	Double	0.0084	447 *	197 *	92.26 *
Type C	Clear	0.3747			
	Standard	0.0084	474	171	83.59
	Double	0.0068	860	322	85.12

* Indicates that the difference between the BSRF and Type C value was significantly different than 0 at the 95% confidence level.

Interestingly, the calculated flow rates for the clear runs were slightly lower than the tests on the 8% slope while the flow rates for both of the runs with sediment were higher than the corresponding runs at the 8% slope. Under these conditions the maximum depth of slurry ponded behind the fences increased from 0.097m to 0.26 m (3.8 inches to 10.2 inches). It appears that either this increase in hydraulic head or the increase in turbulence changed the flow characteristics of both fence materials. The flow through the BSRF increased significantly for these runs while the Type C fence exhibited close to the same flow rate.

While the flow rate was higher for the BSRF than the type C silt fences at the 58% slope, it continued to provide greater sediment retention. For both the single and double concentration, suspended solids and turbidity of the effluent were significantly lower for the BSRF than the Type C silt fence (Table 4). Both fence materials showed higher levels of solids and turbidity in the effluent than the corresponding tests conducted on the 8% slope. Likewise, the sediment removal efficiency and turbidity reductions were lower for these tests than the similar tests at 8% slope (figures 7 and 8). The BSRF continued to show significantly higher sediment removal efficiencies and turbidity reductions than the Type C fence material. Under these conditions, which may be more representative of an extreme event, the BSRF removed 61% and 74% (for the standard and double concentration respectively) of the turbidity while the Type C fence averaged 46% and 53%.

SUMMARY

In this testing, the flow rates and sediment removal efficiencies for BSRF and type C silt fence were measured and evaluated using an ASTM standard method and a modified ASTM standard method conducted at a much greater slope. Measured flow rates for both the BSRF and the type C fence materials were well within the range of commonly reported values and varied considerably depending on soil type, sediment concentration, test method used, and fence material. Flow rates through the BSRF were higher for clear water but lower for sediment laden water for the tests conducted using the ASTM standard methods. However, further testing using a steeper flume or the modified testing apparatus indicated higher flow rates through the BSRF than the type C approved materials for flow containing sediment. While there were differences between the flow rates of the two materials, neither consistently exhibited higher flow rates across the conditions tested. Conversely, all of the test data indicated that the BSRF consistently removed greater amounts of sediment from the flow. Measured sediment removal efficiencies were higher for the BSRF than the type C fence and ranged from 94% to 98% for the tests conducted using

ASTM standards. Using the ASTM standard methods, turbidity reductions of 58% to 82% were obtained using BSRF while the type C fence material removed 25% to 58% of the turbidity. Based on these analysis, it appears that the BSRF would provide similar flow rates to commonly used type C materials and greater sediment removal and sediment retention capabilities.

LITERATURE CITED

ASTM, 2004. Standard Test Method for Determining Filtering Efficiency and Flow Rate of a Geotextile for Silt Fence Application Using Site Specific Soil. Designation D5141-96 (2004). ASTM International.

Barrett, M.E., J.F. Malina, and R.J. Charbeneau, 1998. An Evaluation of Geotextiles for Temporary Sediment Control. *Water Environment Research* 70(3): 283-290.

Britton, S.L., K.M. Robinson, B.J.Barfield, and K.C. Kadavy, 2000. Silt Fence Performance Testing. ASAE Annual International Meeting Paper no. 002162.

Greensburg, Arnold, et al., 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. Washington D.C.: American Public Health Association, 1998. pp 2-57,2-58.

Henry, K.S. and S.T. Hunnewell, 1995. Silt Fence Testing for Eagle River Flats Dredging. Special Report 95-27 U.S. Army Corps of Engineers Cold Regions Research & Engineering Laboratory. Available from NTIS, Springfield, Virginia 22161.

Kouwen, N., 1990. Silt Fences to Control Sediment Movement on Construction Sites, Report MAT-90-03. Research and Development Branch Ontario Ministry of Transportation, Downsview, Ont. Canada.

Theisen, M.S. 1992. The Role of Geosynthetics in Erosion and Sediment Control: An Overview. *J. Geotextiles and Geomembranes* 11:535-549.

U.S. Department of Transportation, Federal Highway Administration, National Highway Institute, 1998. Geosynthetic Design and Construction Guidelines, NHI Course 13213, Publication No. FHWA HI-950038. Washington, DC. Pgs 121-139.

U.S. Department of Transportation, Federal Highway Administration, FP-03. Standard Specification for Construction of Roads and Bridges on Federal Highway Projects. Section 714, p. 657.

U.S. Environmental Protection Agency, Standard Methods for the Evaluation of Water and Wastes.

Wyant, D.C., 1981. Evaluation of Filter Fabrics for use as Silt Fences. *Transportation Research Record* 832: 6-12.

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