Evaluation of Silt-Saver Belted Strand Retention Fabric for use as a Replacement for Type C Silt Fence

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Executive Summary

Currently, Georgia does not have well defined procedures for approving erosion control BMP's for field use. In this study we developed a process for comparing Silt-Saver belted strand retention fence with a traditional type C silt fence with the goal of determining if it would be acceptable for use as a sediment barrier in Georgia. To accomplish this, testing was conducted to determine flow rates and efficiency of sediment removal for both types of fences. While these performance indicators would show if the fabric materials were at least as good as existing materials, structural testing was also needed to insure that the design of the structural support would withstand the forces that would be expected under normal field applications. This was accomplished using modeling efforts with field verification.

ASTM standard methods were used to evaluate flow through and sediment removal efficiency. Since these standards suggest using the site specific soils, testing was conducted using the predominant series of sand, silt loam, and clay soils in Georgia. 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 sediment concentration suggested in the standard and double concentrations for all three soils. 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 commonly reported in the literature. 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. 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. 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.

The results from the analysis of the effluent and sediment removal efficiency using the ASTM standard 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 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. 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. 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 solution prior to reaching the fence materials. Sediment removal efficiencies for the BSRF were significantly higher for all

three tested soils at both the single and double concentration. Sediment removal efficiencies 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 the reduction in turbidity is used as a measure of effectiveness, the BSRF functioned much 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.

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 for 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. 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. 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 this increase in hydraulic head, pore space blockage by sediment, or increases in turbulence changed the flow characteristics of both fence materials. 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. 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. The BSRF continued to show significantly higher sediment removal efficiencies and turbidity reductions than the Type C fence material.

While the two flume tests met the testing needs, one additional test was conducted to determine if a more simplistic method of measuring the sediment removal efficiency and flow rate would produce comparable results. Using an easily constructed apparatus made of standard PVC piping, additional runs were made with the silt loam soil. Using this method, measured flow rates were higher for both materials. This was probably due to the fact that a greater hydraulic head was established behind the silt fence. The flow rates for clear water were slightly higher for the Type C silt fence than the BSRF, however, the flow rates with the standard concentration of sediment were slightly lower for the silt fence. Results from this test also indicated very similar trends with the suspended solids and turbidity of the effluent as well as the sediment removal efficiency and the reduction in turbidity. The BSRF tended to trap more sediment than the type C silt fence in this test as well. Measured values of sediment removal efficiencies and turbidity reductions for both the BSRF and the Type C silt fence were nearly the same as those measured using the ASTM standard test method. Since this testing apparatus is much easier to construct and since the tests are easier to conduct, this procedure may offer advantages over the standard test method that should be investigated further.

Structural analysis and load testing were used to assess the adequacy of the design to withstand loads associated with extreme flow conditions. Grab tests of tensile load using ASTM standard methods indicated that test specimens withstood tensile loads of approximately 92 lbs in the lateral direction and 114 lbs in the longitudinal direction with little difference between the values under wet and dry conditions. These values corresponded well with manufacturer’s data. Tensile strength testing was also conducted using slower loading rates that would be commonly encountered under field conditions. Under these conditions, measured peak loads in the longitudinal direction ranged from 292 to 324 lbs. The material often stretched 75 to 80% of its original length and failure was characterized by fraying of the material rather than breaking. Field testing of the material indicated that this material and the associated support system could withstand overtopping by sediment enriched flow when installed according to manufacturer’s recommendations. Deflections of both the posts and the fabric material were measured throughout the loading process and used to verify modeling results obtained by the STARDYNE finite element program.

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. Results indicate that the belted strand retention fence provided improved sediment removal efficiency and lower turbidity than standard type C silt fence and that it can withstand extreme loads and overtopping without structural failure.

Introduction

Sediment has been recognized as one of the largest 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 (U.S. Environmental Protection Agency, 2000) that require all construction sites greater than one acre to develop storm water 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 analysis was also conducted to determine the maximum loads that would be expected on typical sediment barrier applications and compared to the maximum load that BSRF could withstand.

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. He concluded that the high trapping efficiencies of the fabrics could be attributed to the majority of the tests consisting of non-woven fabric types and the low flow rates.

Previous 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 to the 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. They found that as the impounded volume increase, the removal efficiency would improve. Increasing the flow rate, the sediment concentration, or the tightness of the weave on the woven fabrics would improve the performance of silt fence mainly by increasing the ponding of water.

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.

Improper installation and maintenance are commonly reported problems with silt fences (Carpenter and Sprague, 2004). Silt fences can undercut, overtop, or flank because inadequate attention is given to installation and maintenance. Undercutting and flanking usually occur due to improper installation. Overtopping can occur when silt fences are improperly located in concentrated flow conditions or when the flow rate through the fence is inadequate.

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.

It suggests using standard specifications for several properties such as grab strength, elongation, and ultraviolet stability. These specifications are listed in the U.S. Department of Transportation, Federal Highway Administration Report FP-03, Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects. 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. For silt fence fabric specifications, 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	**ASTM Test Method**	**Units**	**GADOT Type A**	**GADOT Type C**	**FP03 Type A**	**FP03 Type C**	**BSRF Mfr Spec**	**BSRF GADOT test**
Grab Tensile Strength-warp	D4632	lbs	120	260	91	125	95	127
Grab Tensile Strength-warp	D4632	lbs	100	180	91	102	95	99
Elongation	D4632	%	<40	<40		<50	68	>67
Apparent Opening Size	D4751	Sieve size	30	30	30	30	70	NA
Permittivity	D4491	s^{-1}			0.05	0.05		
Flow Rate/Flux	D4491	gpm	25	70			185	103
Ultraviolet stability	D4355	% at 500 hrs	80	80	70	70	26.8	

Materials and Methods

ASTM D5141Tests

Initial testing was conducted according to ASTM Standard D5141-96(2004). A watertight flume was constructed using aluminum and pressure treated plywood using specifications from Figure 1 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 (Table 2). 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. Not only do these soils represent predominate series in Georgia, but they also include the variety of erodibilities and clay contents that we typically see in Georgia soils. 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).

Table 2 Textural analysis of soils used in testing.

Soil Texture	% Sand	% Silt	% Clay
Sand	88	8	4
Silt Loam	22	64	8
Clay Loam	30	40	30

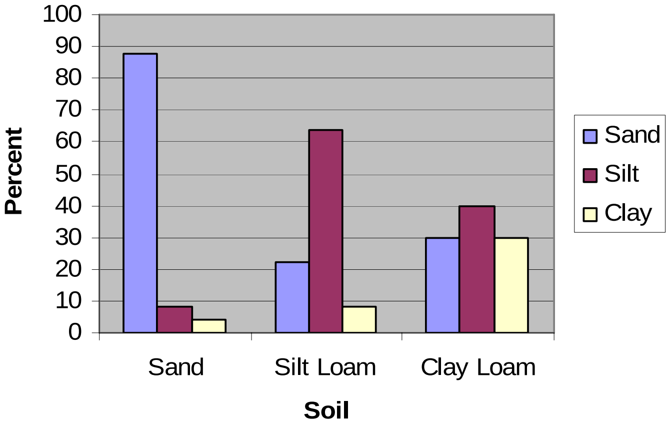

Figure 1 Comparison of Soil Textures used in this study.

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. The equations for suspended solids and sediment removal efficiency were given as:

$$S_s = \frac{(\mathrm{A - B}) \mathrm{x}\, 1000}{\mathrm{C}} \tag{1}$$

Where:
S_s = Suspended solids, ppm,
A = weight of filter plus residue,
B = weight of filter, and
C = sample size, mL.

$$F_E = \frac{2890 - S_s}{2890} x100 \quad (2)$$

Where:
F_E = Sediment removal efficiency (Note: the ASTM Standard refers to this as filtering efficiency, however, the term of sediment removal is used in this report since it is more representative), and 2890 represents the sediment placed behind the geotextile.

The 2890 in equation 2 was changed to 5780 for the double concentration runs. The equations for the flow rate that were given in the ASTM standard were determined to be incorrect. Through consultation with the standard developers, the following equations were derived to calculate flow rate (F_T) through the geotextile specimen in $m^3/m^2/min$:

For complete drainage in less than 25 minutes:

$$F_T = 0.606 / t \quad (3)$$

or for incomplete drainage:

$$F_T = \frac{0.05 - 0.000000034X^2}{0.082 - 0.000068X} / t \quad (4)$$

Where:
t = time for flow in minutes, and
X = distance from the geotextile to the edge of the water behind the geotextile in mm.

Since there was very little temperature variation in the room over the testing period (temperature ranged from 21.7±0.4 °C), a correction for the viscosity of water was made using the average temperature rather than the individual runs as outlined in equation 5 of the standard.

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.

Figure 2 Experimental set up for flume testing.

Modified ASTM D5141 Tests

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 58% 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 58% 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.

Rapid Filtering Test

In addition to flume testing, an additional structure and test method were constructed to determine if an easier method would produce similar results. PVC piping was used to construct an apparatus consisting of a 7 L holding tank placed on top of a valve. Attached below the valve was a 0.356 m (14 inch) section of 10.2 cm (4 inch) diameter PVC pipe which ran perpendicular to the ground. A 45° elbow was attached to the bottom of the pipe. A 17.8 cm (7 inch) diameter section of geotextile was tightly fastened to the open end of the elbow with a ring clamp. A plastic container was placed below the opening to collect the leachate as shown in Figure 3.

Figure 3 Test apparatus used for additional testing.

For this test, 21 grams of soil was added to 7 L of tap water in order to make the standard concentration, 2890 ppm. The temperature of the water was recorded and the soil laden water was mixed with a small paint stirrer for 1 minute. While still mixing, a depth integrated sample was taken to measure the initial turbidity of the water. At this point the valve was opened and the timer started. An additional 100 ml of water was used to rinse any remaining sediment from the holding container.

The flow of slurry was timed until the leachate began to drip into the plastic container or 25 minutes had elapsed. If 25 minutes elapsed the total volume of leachate collected was measured and recorded. The leachate was then agitated for 1 minute with a small paint stirrer and a depth integrated 500 ml sample was taken to measure the suspended solids and turbidity of the leachate. Clear and standard concentrations were run for each geotextile material using the silt loam soil. The fence was replaced after each test. Each test was done in triplicate for each geotextile.

Analysis Methods

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 were used for the procedure. Sample volumes of 100 ml were used for this testing. 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 ($\alpha=0.05$) 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

ASTM D5141 Tests

Table 3 and Figures 4-6 present results for the comparison of flow rates through the geotextile materials. 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 the initial trail.

		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.

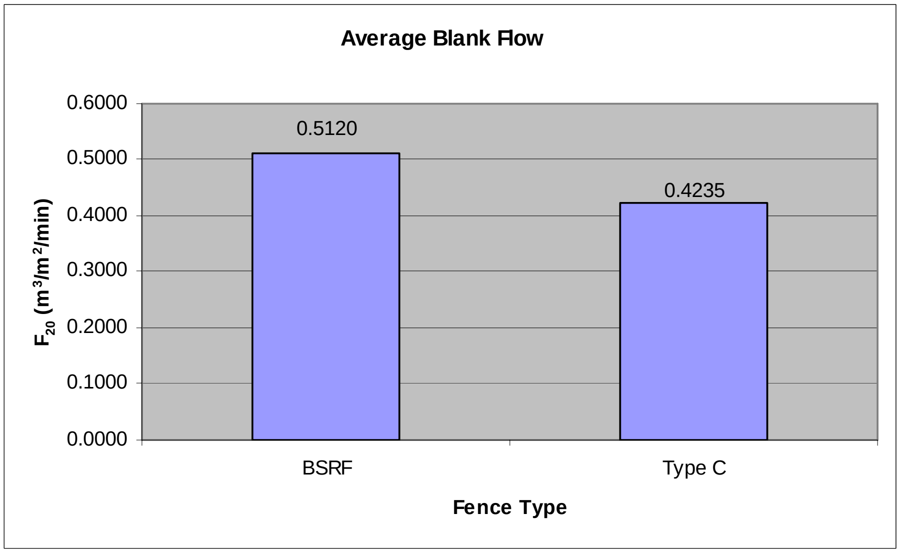

Figure 4 Average flow rates of clean water through each fence material using ASTM standard methods. Each bar represents the average of nine replicates.

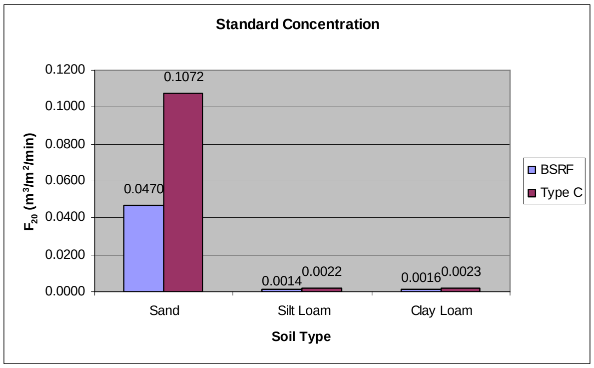

Figure 5 Average measured flow rates for the initial trails. Each bar represents the average of three replicates.

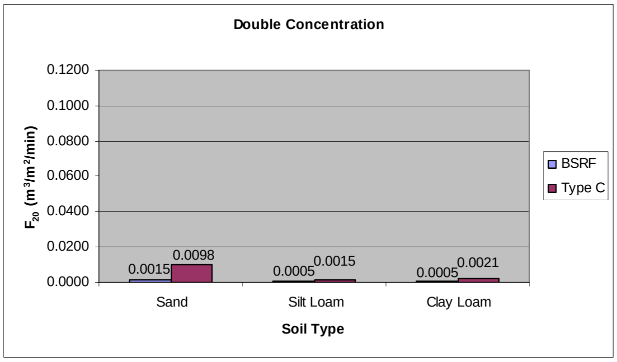

Figure 6 Average measured flow rates for the initial trails each using higher sediment concentrations. Each bar represents average of three replications.

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 4). 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 (Figures 7 and 8). 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.

Table 4 Measured effectiveness data for the initial trail.

		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.

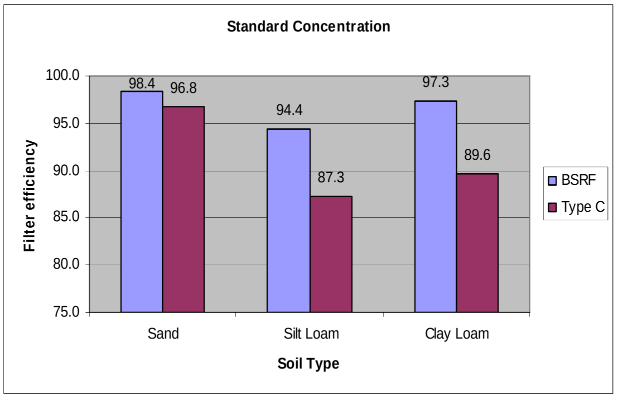

Figure 7 Measured sediment removal efficiency for the initial trail at standard concentrations.

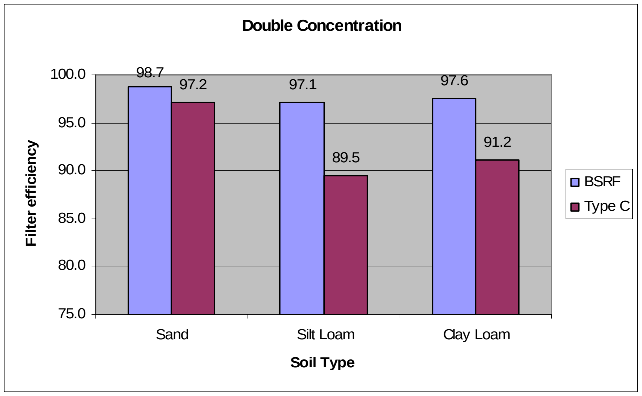

Figure 8 Measured sediment removal efficiency for the initial trail at double concentrations.

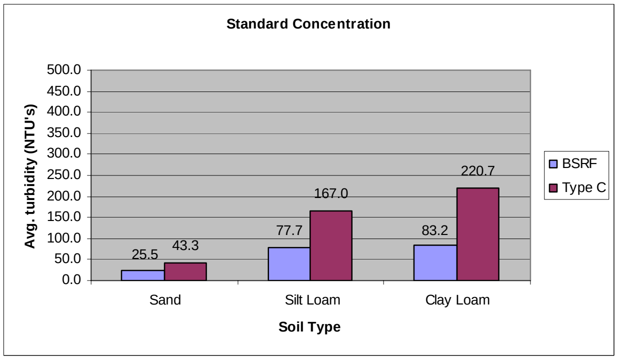

Figure 9 Turbidity of effluent measured in the initial trail at standard concentrations.

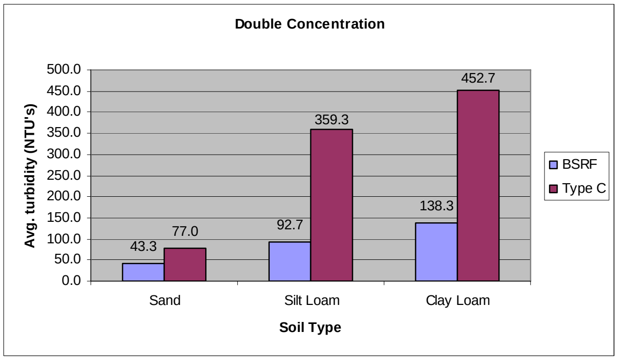

Figure 10 Turbidity of effluent measured in the initial trail at standard concentrations.

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ASTM D5141 Modified Tests

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 for 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 were 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 and the following equations were derived and used to calculate the flow rate:

For complete drainage in less than 25 minutes:

$$F_T = 0.2252 / t \tag{5}$$

or for incomplete drainage:

$$F_T = \frac{Vnet}{0.222} / t \tag{6}$$

Where:
t = time for flow in minutes,
Vnet = total flow that passed through the fence barrier in cubic meters, and
0.222= the area of fence material exposed to flow.

The results from the runs at the 58% slope are shown in Table 5 and Figures 11-13. 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. 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.

Table 5 Results from runs conducted at 58% slope. All values are average of three replicates using the silt soil.

Fence type	Run	Flow Rate ($m^3/m^2/min$)	Suspended Solids (ppm)	Turbidity (NTU)	F_e	%Reduction in Turbidity
BSRF	Clear	0.4054				
	Standard	0.0149	290 *	130 *	89.97*	61 *
	Double	0.0084	447 *	197 *	92.26 *	74 *
Type C	Clear	0.3747				
	Standard	0.0084	474	171	83.59	46
	Double	0.0068	860	322	85.12	53

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

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 5). 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 12 and 13). 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%.

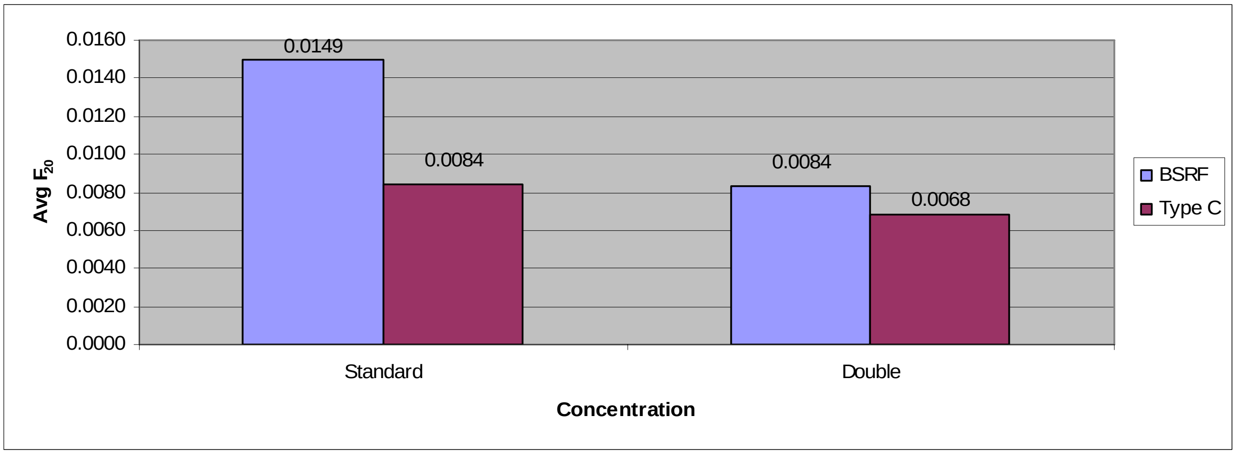
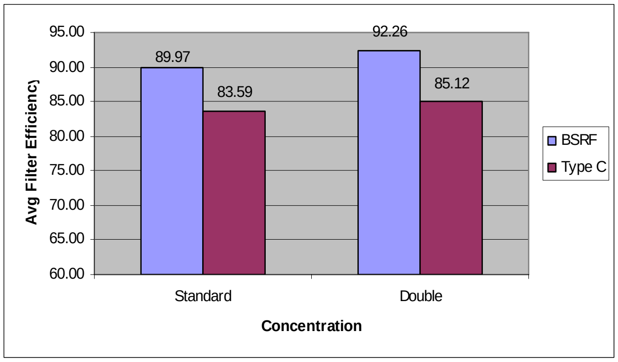


Figure 11 Average calculated flow rates ($m^3/m^2/min$) for each run at the 58% slope.



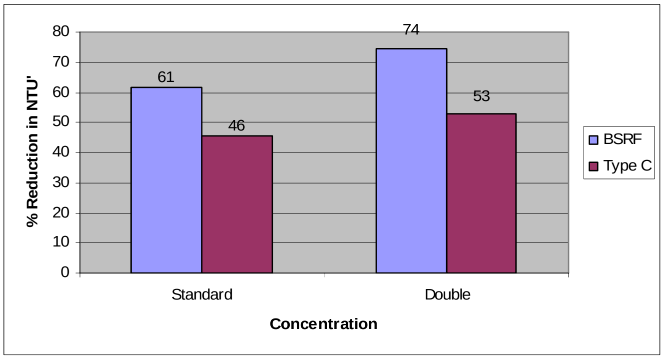


Figure 12 Average Filtering Efficiency for each run at the 58% slope.

Figure 13 Average percentage reduction in turbidity for each run at the 58% slope.

Rapid Filtering Test

While the two flume experiments met testing requirements, one additional test was conducted to determine if a more simplistic method of measuring the sediment removal efficiency and flow rate would produce comparable results. Using the easily constructed apparatus shown in Figure 3, additional runs were made using the silt loam soil. These runs were only conducted at the standard concentration. Flow rates were simply calculated by dividing the volume of flow collected (m^3) by the area (m^2) and the time over which it was collected (minutes with maximum of 25 minutes). The measured flow rates were higher using this method (Tables 6 and 7). This was probably due to the fact that a greater hydraulic head was established behind the silt fence. On these runs, the flow rates for clear water were slightly higher for the Type C silt fence than the BSRF, however, the flow rates with the standard concentration of sediment were slightly lower for the silt fence. This contradicted results of the clear water tests conducted on the flume and the results of the standard concentration tests conducted at the 8% slope but was consistent with the tests conducted at higher slopes. Results from this test also indicated very similar trends with the suspended solids and turbidity of the effluent as well as the sediment removal efficiency and the reduction in turbidity (Table 8). The BSRF trapped more sediment than the type C silt fence in this test as well. Measured values of sediment removal efficiencies and turbidity reductions for both the BSRF and the Type C silt fence were nearly the same as those measured using the ASTM standard test method. Since this testing apparatus is much easier to construct and since the tests are easier to conduct, this procedure may offer advantages over the standard test method that should be investigated further.

Table 6 Results from the tests conducted on the modified pipe apparatus for the Silt Loam Soil. Each value represents the average of three replicates.

Fence Type	Run	Flow Rate ($m^3/m^2/min$)	Suspended Solids (ppm)	Turbidity (NTU)	F_e	% Reduction in Turbidity
BSRF	Clear	2.5493				
	Standard	0.0314	148 *	61 *	94.87 *	82 *
Type C	Clear	2.7337				
	Standard	0.0266	350	130	87.89	60

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

Table 7 Comparison of average flow rates ($m^3/m^2/min$) for each method using the Silt Loam Soil. Each value represents the average of three replicates.

Fence	**Run**	**Flume at 8%**	**Flume at 58%**	**Simple Test**
BSRF	Clear	0.4544	0.4054	2.5493
	With Sediment	0.0014	0.0149	0.0314
Type C	Clear	0.4265	0.3747	2.7337
	With Sediment	0.0022	0.0084	0.0266

Table 8 Comparison of average sediment removal efficiency and percent reduction in turbidity using the silt loam soil at the standard sediment concentration. Each value represents the average of three replicates.

Fence	**Sediment removal Efficiency**			**%Reduction in Turbidity**		
	Flume at 8%	**Flume at 58%**	**Simple Test**	**Flume at 8%**	**Flume at 58%**	**Simple Test**
BSRF	94.4	90.0	94.9	81	61	82
Type C	87.3	83.6	87.9	58	46	60

Structural Testing

While the tests associated with effectiveness of the fabric itself indicate that the BSRF should provide improved filtration over Type C fabrics, the entire system including the structural support needs evaluation prior to being approved. The BSRF is a new, innovative application in that it is entirely constructed of biodegradable materials, eliminates the need for wire mesh backing, and has an entirely different mechanism for securing the fabric to the support structure. We evaluated the structural integrity of this system by measuring the tensile strength of the fabric under a variety of conditions, by conducting field tests to insure that the fence system would allow over-topping of water without failure, and by developing and applying a finite element model to the system and using that model to evaluate conditions that could not be tested.

Grab Test of Tensile Strength

Grab tests using ASTM Standard D4632-91 (ASTM, 2003) were conducted on the silt-saver test fence material in both a wet and dry state. A grab test is a tensile test in which the specimen is loaded until breaking. This testing was not conducted on the Type C fence material because tensile strength of these materials are commonly reported in the literature and would be expected to greatly exceed those of the BSRF. Specimens of BSRF 10.1 cm long by 5.1 cm wide (4 in. long and 2 in. wide) were cut out of silt saver fence material. Since the BSRF fabric has a strengthening fiber added to it in the longitudinal direction, the tensile strength would be expected to be higher in this dimension. Therefore, specimens were cut both in the longitudinal direction (4 inch long dimension in the longitudinal direction) and in the lateral direction (4 inch long dimension in the lateral direction) of the material. Tests in the wet state were done by first soaking the material in water for 20 minutes and immediately testing it in the near-saturated state.

According to the standard test method, the duration of the test must not be longer than 20±3 seconds. If the specimen breaks outside of this time range then the specimen is not considered acceptable. The grab tests were done using an Instron test machine which monitored both the applied load to the member as well as the amount of stretching of the member. The results of these tests are shown in Tables 9-12. Figure 14 shows the test apparatus, Figure 15 summarizes the results of these tests and Figure 16 shows a typical result from one of the runs.

Table 9 Results of grab breaking load tests conducted under wet conditions in the longitudinal direction of fabric.

Test	Duration (s)	Cross-Head Speed (in/min)	Peak Load (lbs)
1	18	12	103
2	17	12	102
3	18	12	105
4*	15	12	96
5	17	12	113
6*	15	12	118
7*	16	12	122
8	20	11	132
9	19	11	129
10	17	11	128
11*	30	5	93
12*	34	5	104
13*	11	18	98
14*	18	18	106
Average (all tests)			116.0 ± 12.3
Average (only tests that meet duration requirement)			110.6 ± 13.0

* These tests do not meet the required time duration for a grab test of 20 seconds, ± 3 seconds.

Table 10 Results of grab breaking load tests conducted under wet conditions in the lateral direction of fabric.

Test	Duration (s)	Cross-Head Speed (in/min)	Peak Load (lbs)
1*	24	10	93
2*	25	10	100
3	20	12	93
4	21	12	92
5	20	12	78
6	21	12	98
7	19	12	106
8	21	11	94
9	22	11	82
10	22	11	102
11	20	5	92
12	22	5	78
Average (all tests)			92.3 ± 8.6
Average (only tests that meet duration requirement)			91.5 ± 9.1

* These tests do not meet the required time duration for a grab test of 20 seconds, ± 3 seconds.

Table 11 Results of grab breaking load tests conducted under dry conditions in the longitudinal direction of fabric.

Test	Duration (s)	Cross-Head Speed (in/min)	Peak Load (lbs)
1*	15	16.5	116
2*	13	15	106
3*	14	14	107
4	18	12	111
5*	15	12	101
6	19	10	116
7	20	10	107
8	20	10	125
9	21	10	122
10	20	10	104
11	19	10	114
12	20	10	104
Average (all tests)			111.1 ± 7.3
Average (only tests that meet duration requirement)			112.9 ± 7.4

* These tests do not meet the required time duration for a grab test of 20 seconds, ± 3 seconds.

Table 12 Results of grab breaking load tests conducted under dry conditions in the lateral direction of fabric.

Test	Duration (s)	Cross-Head Speed (in/min)	Peak Load (lbs)
1	17	18	89
2	19	17	94
3*	15	17	88
4	17	17	93
5*	15	17	93
6*	16	17	101
7*	16	16.5	106
8*	16	16.5	88
Average (all tests)			94.0 ± 6.0
Average (only tests that meet duration requirement)			92.3 ± 1.9

* These tests do not meet the required time duration for a grab test of 20 seconds, ± 3 seconds.

Figure 14 Testing apparatus and test specimen under load during the grab testing of BSRF fabric.

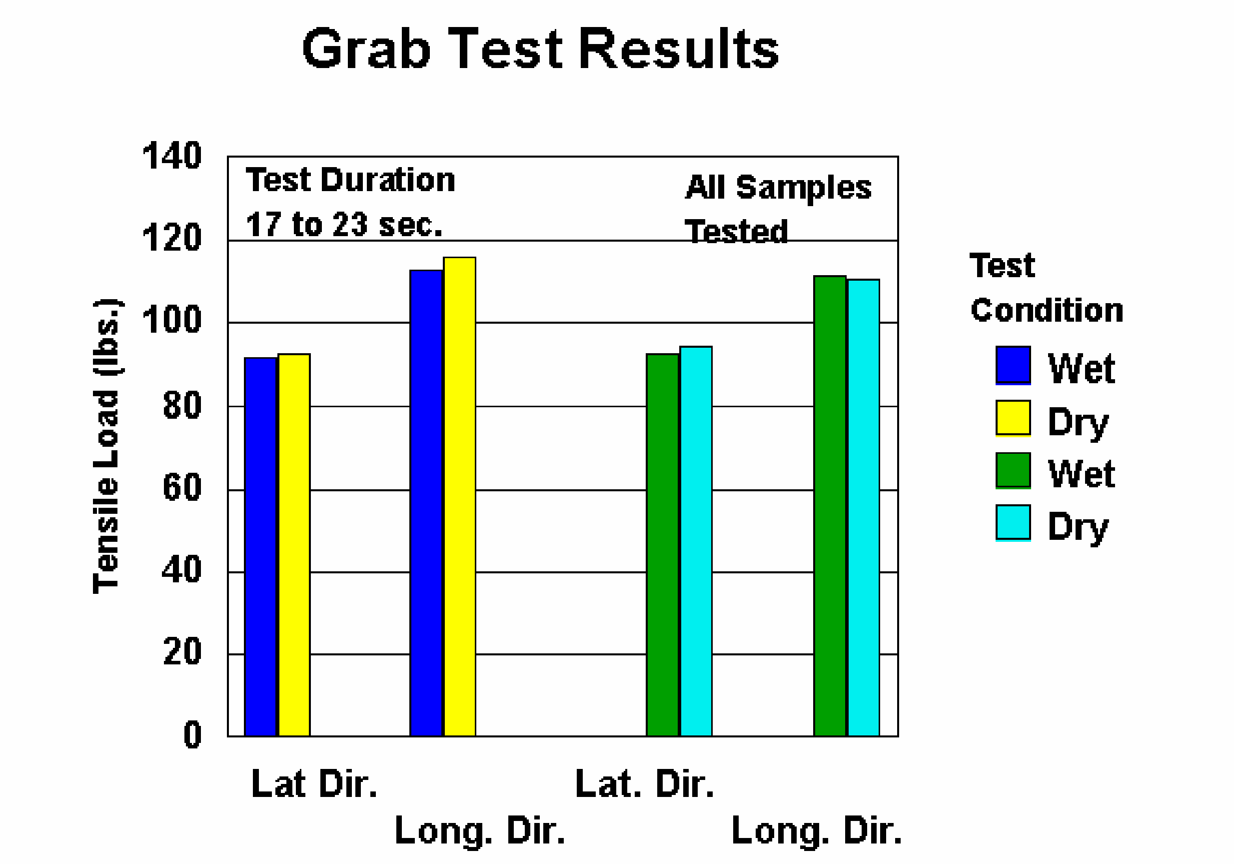


Figure 15 Summary of results of grab tests conducted to measure tensile strength.

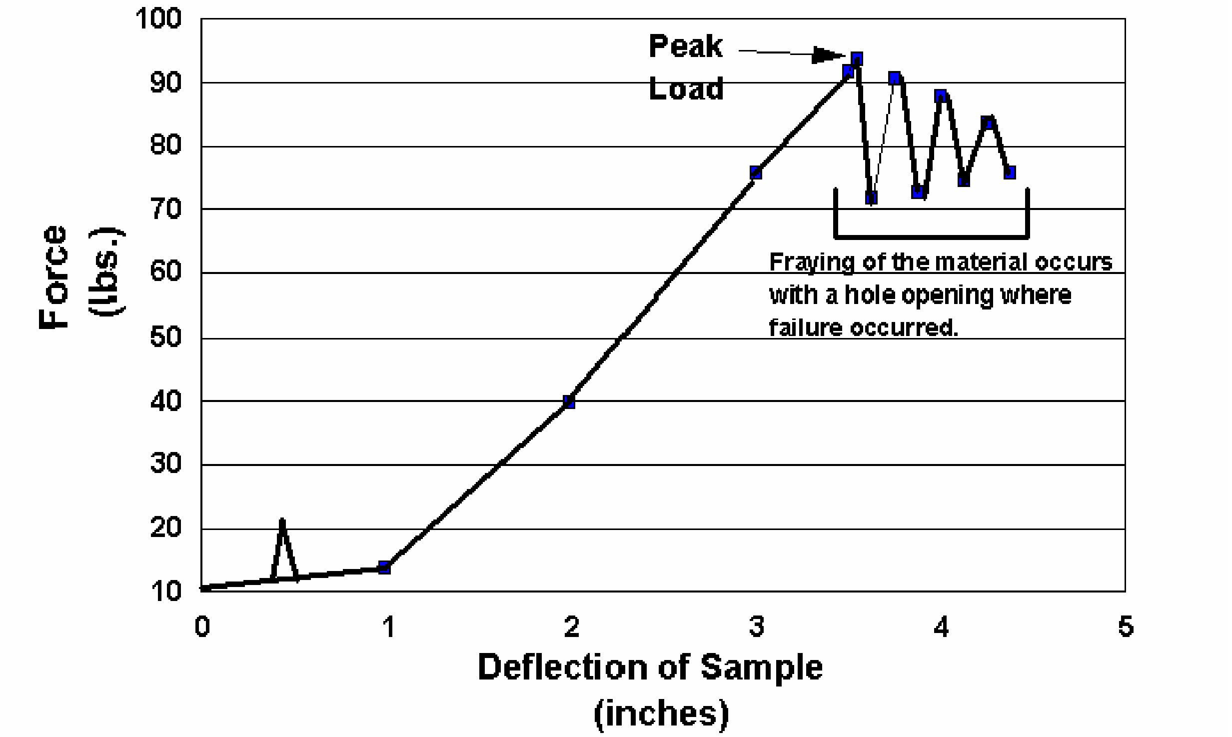


Figure 16 Example of grab test results showing typical deflection and fraying of BSRF materials.

The results of these tests indicate that there is a slight difference in strength in the material in the lateral and longitudinal direction. It appears that the weave of the strengthening fiber in the material given is not square but slightly rectangular and so the material is stronger in one direction than the other. During testing the samples usually stretched about 4 inches prior to failure. Failure was identified at a condition where the material could not carry any more load. At this point the material would fray but would not separate into two parts. The strengthening fiber in the material did not allow separation of the test sample into two parts. From these tests it did not appear that the strength of the material was affected by testing in either the wet or dry condition. The measured tensile strengths also agree closely with those provided by the manufacturer (Johns Manville, Inc.) for this same material.

While the standard method required a specified loading rate, silt fences would not be subjected to such rapid loading unless they were placed in concentrated flow. To determine if the loading rate influenced the measured strength, tensile tests were also conducted on the BSRF material in the longitudinal direction of the fabric at slow cross-head speeds. Speeds of 2 inches per minute were used during this testing. In this case the specimen was approximately 8 inches wide and 8 inches long. This procedure is similar to ASTM Standard test method 4595, however, the clamp arrangement was not identical to that used in the ASTM standard. During this testing, the fabric was also secured to the test apparatus in a slightly different manner as shown in Figure 14. The steel plates were used in order to distribute the load across the width of the material. When tests were performed in which these plates were not used. The test machine only loaded the center portion of the specimen and mirrored the results from the grab test condition in which a narrower sample of material was used. Tests were conducted under both wet and dry conditions. Tests were only conducted in the longitudinal direction of the fabric.

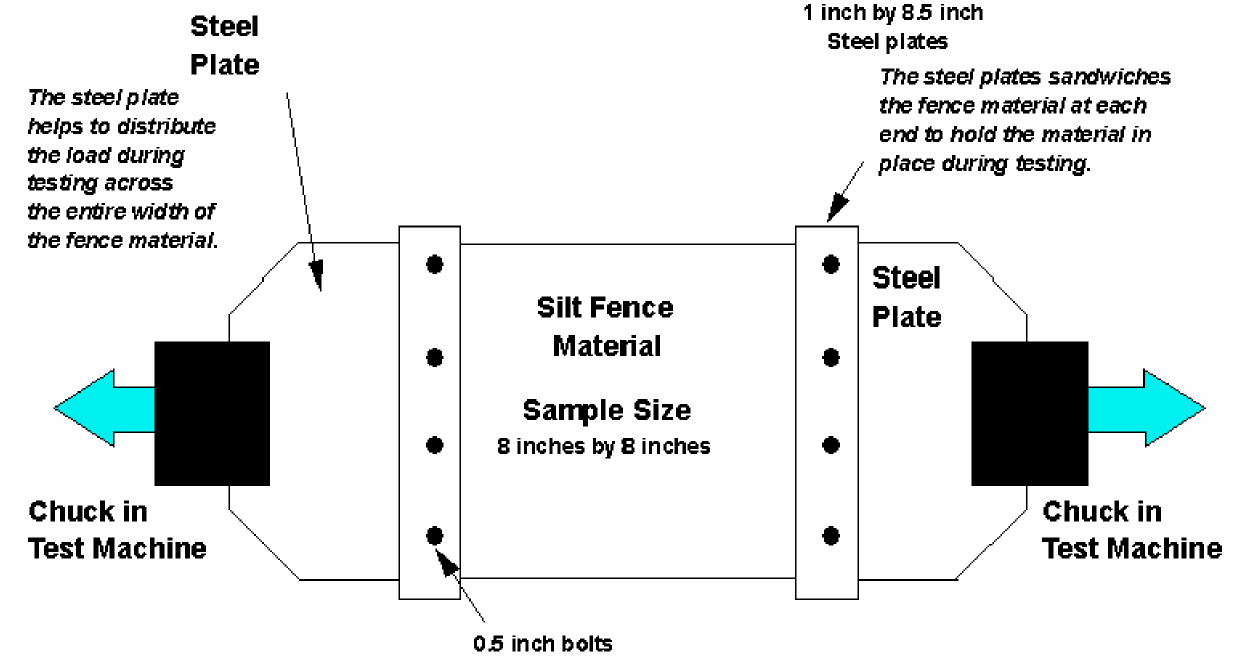


Figure 17 Testing set-up for modified tests conducted at lower loading rates.

Table 13 Results of grab breaking load tests conducted under slower loading rates in the longitudinal direction of fabric. Cross head speed was 2 inches per minute for all runs.

Test	Peak Load (lbs)
1 Dry	324
2 Dry	295
3 Dry	313
4 Wet	326
5 Wet	304
6 Wet	292
7 Wet	294
8 Wet	290
9 Wet	307
10 Wet	295
Avg. Dry	310.7 ± 14.6
Avg. Wet	301.1 ± 12.6

Measured peak loads were much higher for this test. The dry material was slightly stronger than the wet material, however, statistically there was no difference between testing of the material in either condition. As before, the material was loaded until it would not carry additional load but, the material never completely ruptured into two pieces. As before, the strengthening fiber in the material kept the sample from rupturing. While the material would fray at the point of failure, opening a large hole in the material, none of the samples broke into two parts. As in the grab test, the material was able to stretch large amounts prior to rupture, in most cases the material stretched about 75 to 80 percent of the original length of the material. For example, for the 8 inch test specimen, the final length after testing was approximately 14 inches.

While this test is not an official ASTM test, it may be more representative of the manner in which these materials are loaded in the field. The grab test which is used to describe the strength of these type materials is performed over a 20 second time period, therefore, rapidly loading the material in tension. As water backs up behind silt fences, it will probably not rise rapidly but rather at a fairly slow rate, therefore, loading the fence material at a slow rate. A slower test speed would seem to more appropriate to characterize the material, because that is probably the manner in which it is loaded in the field.

Georgia Department of Transportation specifications call for filter fabrics to have a minimum tensile strength of 100 lbs for Type A and Type B and 180 lbs for type C silt fence. While the BSRF did not meet the type C requirements under the standard loading methodology, it far exceeded it under a slower loading rate. The material also exceeded DOT specifications, which specify a maximum elongation of 40%, although it is unclear how and why these specifications were developed.

Field Testing Of Silt Saver Material

Tests were conducted in the field on December 20, 2005 on two replicates of BSRF systems installed on a disturbed construction site on land graded to a slope of approximately 2:1. The soil at the site resembled a eroded Cecil Clay loam and because of the previous grading, there was very little residue or cover. The fences were constructed and installed by persons from Silt Saver, Inc. knowledgeable about the proper installation of the fence system. Figure 18 shows the site and installation process.

Tests were performed to measure deflection of both the posts and the BSRF system at various depths of water. Deflection in this case is defined as the distance moved from the original position for either the post and/or BSRF fabric material To make these measurements, a wood frame was constructed in front of the fence system and was used as a reference system. Measurements were taken both before and during the tests to determine the relative distance of the posts and or the silt fence material from the reference frame. During testing, measurements were taken at points between the posts as well as points up and down the fence material. For both fence systems, posts were spaced approximately 4 feet from each other. During testing, water was applied by use of a fire hose to a mound of soil upgrade from the fence system. The water/soil mixture then flowed down the grade and was retained behind the silt fence as intended. Water was continuously applied during testing until the water/soil mixture retained behind the fence reached a depth of approximately 24 inches of water and overtopped the fence material. Measurements were taken of the deflection of the fence material for every 4 inches of water up to total depth of approximately 24 inches of water. Each test lasted approximately 30 to 45 minutes. While measures of flow rate or water quality were not made, with the exception of minor under cutting beneath the fence at depths of 20-22 inches, the filtered water passing through the fence appeared to have low turbidity.

Figure 18 Installation of the BSRF for field testing.

In Figures 19 to 22 are show the side profile and top profile measurements of the fence material during tests one and two. The measured data points are shown in the figures. The top profile of the fence material was measured at the top bar of the reference frame. The side profile was measured at the mid-point of the material half-way between the two side posts. With 24 inches of water behind the silt fence a mid-point deflection of approximately 12 inches was measured at approximately 8 inches above the ground. Even at these large deflections only a small amount of water was allowed through the fence. No damage, such as fraying or increased flow rates, of the material observed for either of the replications conducted. If fraying had occurred then a large hole in the material would have been observed and large amounts of the water and material retained by the fence would have flowed through the fence. Figure 23 shows the fence under load as the water begins to overtop the fence.

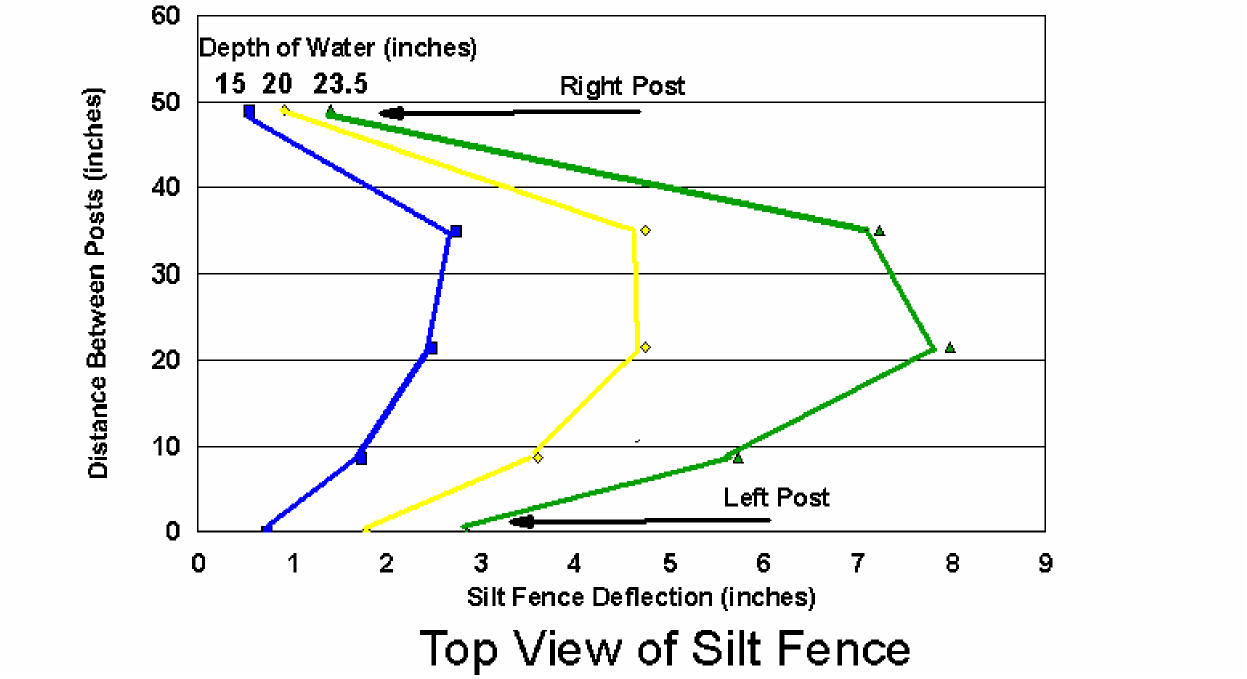


Figure 19 Silt fence deflection at 20 inches above ground level as measured during test 1.

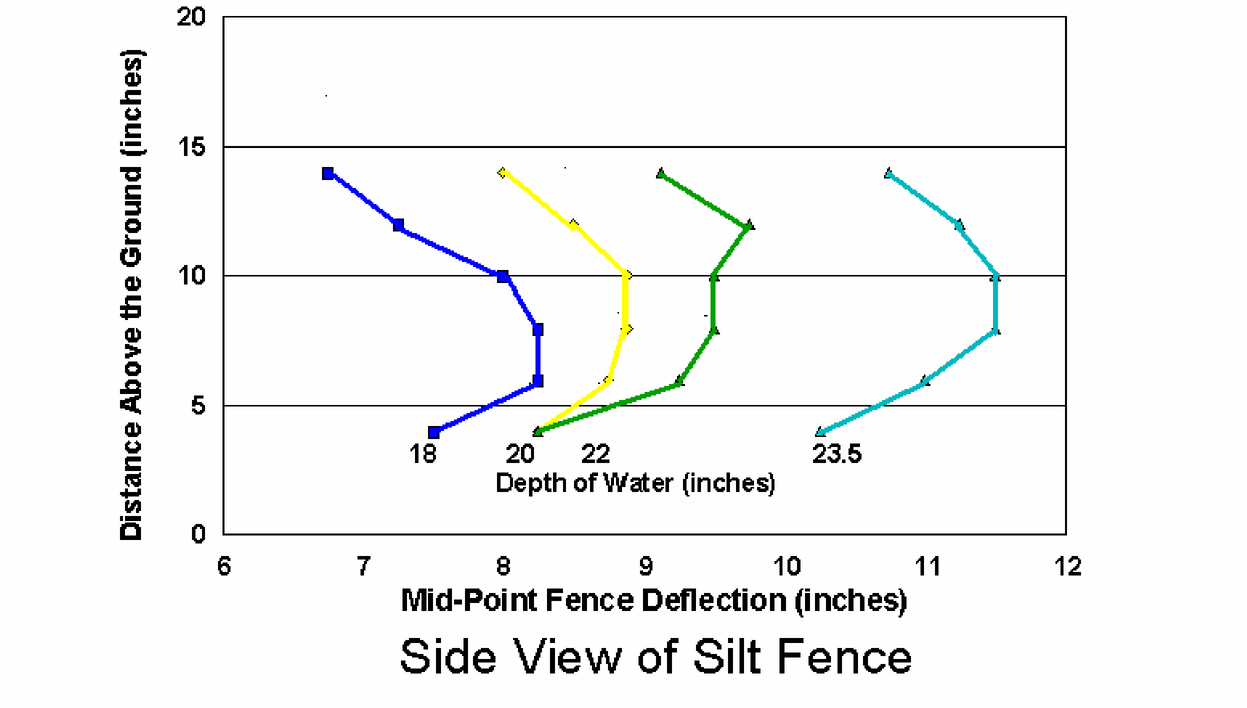


Figure 20 Silt fence deflection at midpoint between the posts as measured during test 1.

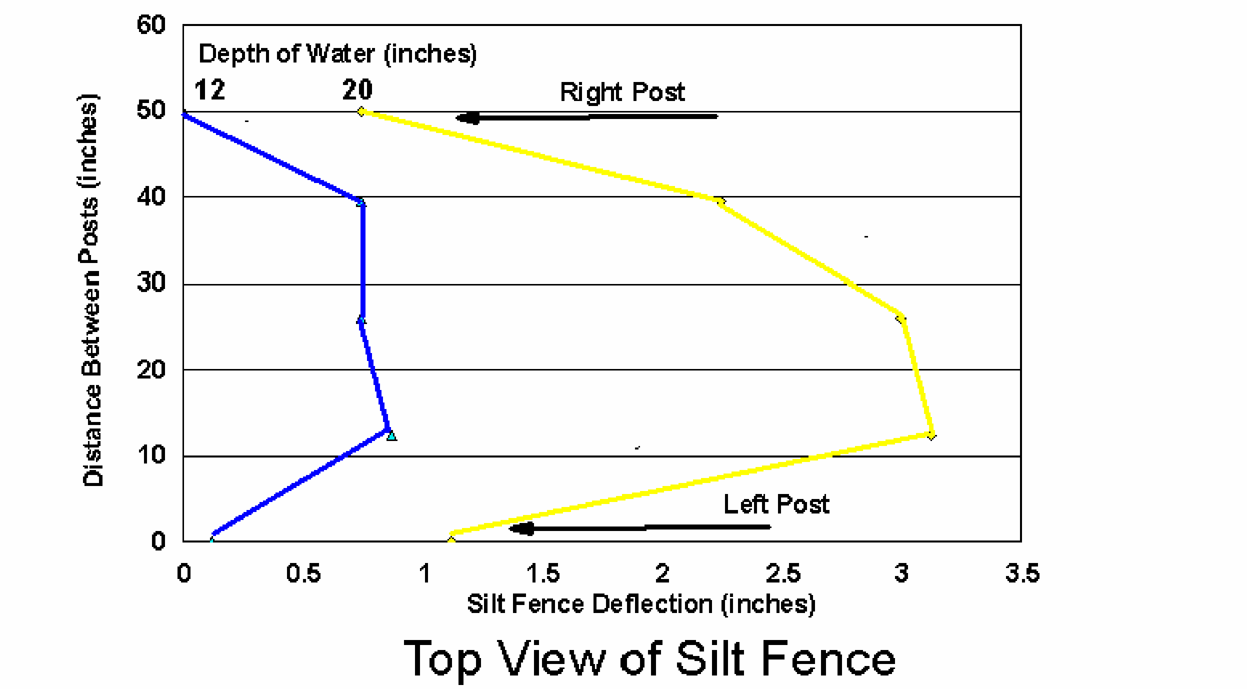


Figure 21 Silt fence deflection at 20 inches above ground level as measured during test 2.

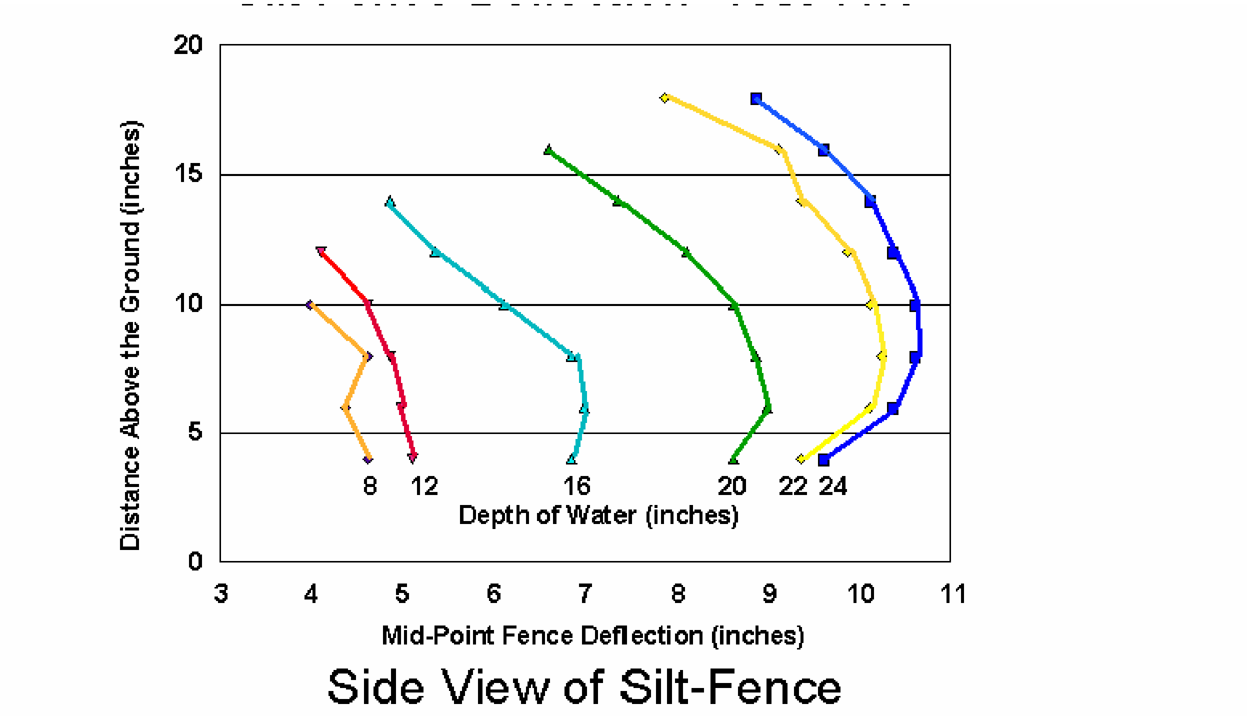


Figure 22 Silt fence deflection at midpoint between the posts as measured during test 2.

Figure 23 Photograph of BSRF as it approaches overtopping.

In these tests, the fence material had a mid-post deflection of about 12 inches. If an arc is drawn similar to the deflected shape of the fence (see Figure 24) in which a deflection of 12 inches is assumed at the middle, then the total length along the arc is about 57 inches. Based on these assumptions a strain (change in length/original length) of about 19% occurred in the silt fence material in that direction. A similar curve was drawn of the deflected shape of the fence material in the vertical direction (see Figure 25). This curve was constructed using the deflected points measured at the center-line of the cloth material. For this condition the silt fence material was originally 24 inches in length prior to deflection and approximately 34 inches in length along the deflected curve. This would indicate a strain of about 41% in the vertical direction of the cloth. While this might sound large, the fence material can be stretched large amounts and still retain its properties. Strains of greater than 75% were regularly observed during laboratory testing in which the material could stretch large amounts with no damage to the specimen. In the laboratory when damage did occur fraying of the material occurs in which a hole opens. However, the strengthening fiber constructed in the weave of the material provides extra strength such that total failure does not occur.

One explanation for the lack of fraying in the material is the manner in which the fence is constructed. The material is sandwiched between the post and a nailer strip and then stapled. This construction technique helps in distributing the load over the entire length of the post rather than at discrete points as would be the case if the material was just stapled without the nailing post attached. Without the nailing posts a large load would be transmitted at each point of attachment from the cloth through the post and fraying would be expected. In a similar fashion, in laboratory testing most of the fabric failure occurred where the loads were localized at a bolt attachment in the chucks. In laboratory testing the cloth was found to have a strength of approximately 40 lbs/inch in tension. If you assume this same strength over the entire length of the post then the material can have a total tensile load of 960 lbs. For a 4 ft. post spacing, approximately 500 lbs of lateral force is transmitted by the water retained by the fence. The fence in turn transmits this force through the fence material by tension. If you draw the force

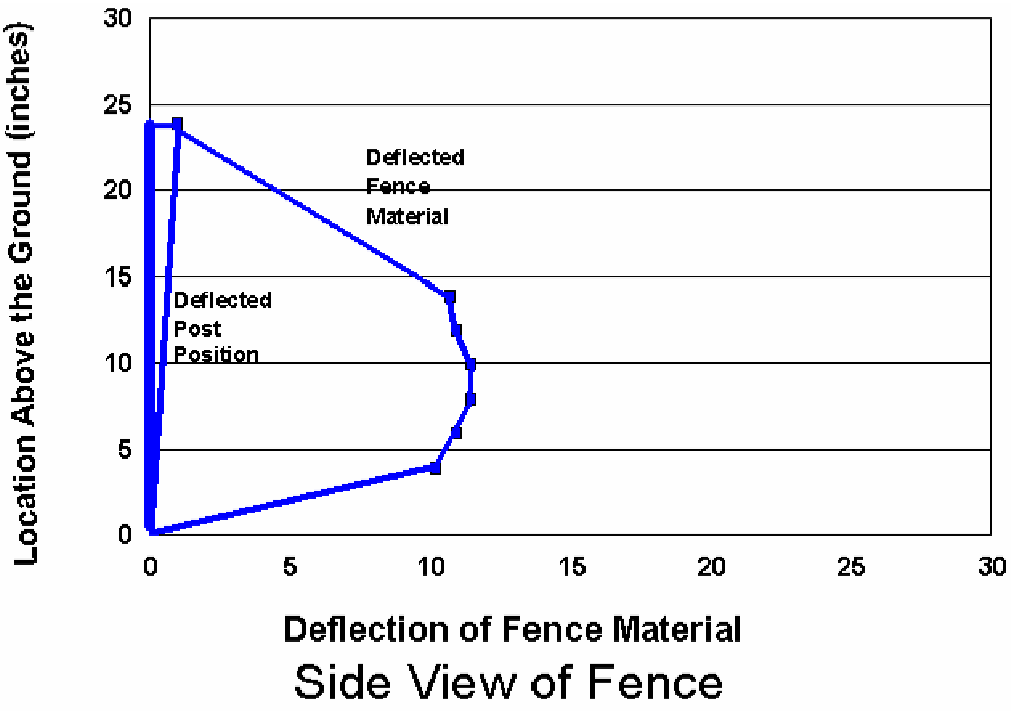


Figure 24 Profile of fence material at the centerline of the fabric when loaded with 24 inches of water.

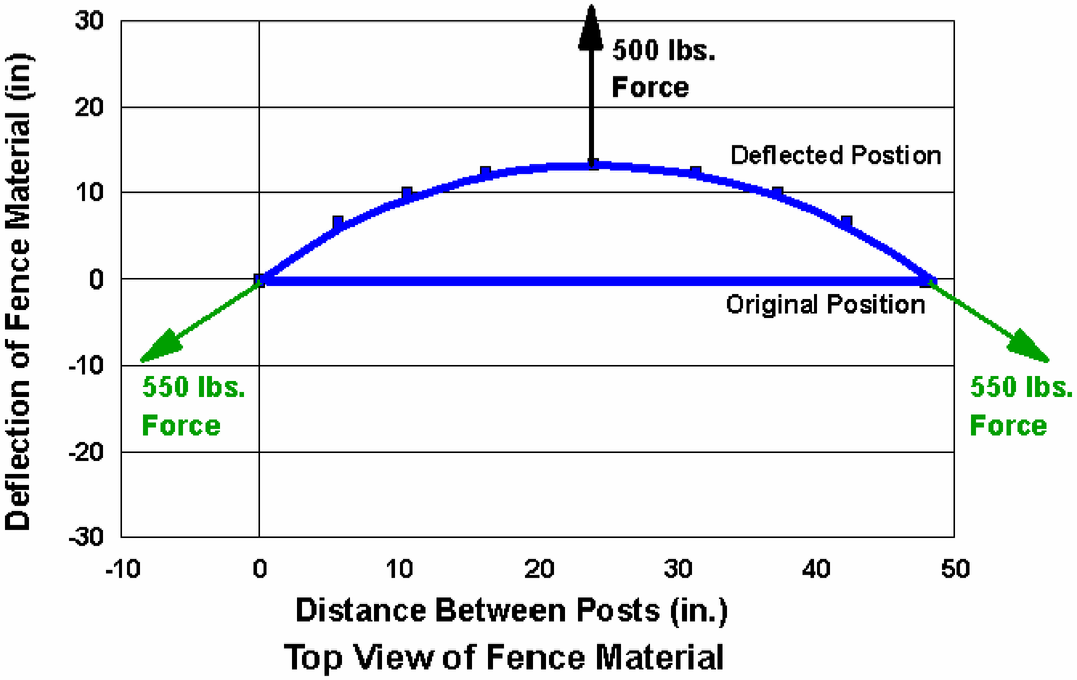


Figure 25 Profile of fence material looking down at it when loaded with 24 inches of water.

vectors (see Figure 25) of the forces acting on the fence and then the forces acting at both ends of the fence material you would have a tensile force in the fence material of about 550 lbs. If you take this value and spread this load out uniformly over the entire length of the post uniformly where the nailing strips occur then you would have approximately 23 lb/inch of force. The fence material when tested averaged about 40 lbs/inch. At 23 lb/inch of force the material could stretched about 50% of its original length. While more force occurs in the bottom portion of the fence than the top, it would be difficult to estimate how this distribution would occur over the height of the fence. Even if the total force is assumed to act only over 2/3 of the height of the fence nailing strip, this would give a tensile force of 34 lbs/inch, which is still below the tested strength of the material.

In the construction of the fence the posts are also leaned at approximately 5 degree angle with respect to the direction in which the loads will be applied to the fence. By leaning the posts inwards, the posts are not loaded only in bending and shear but also axially. This slight lean of the post transmits a small portion of the load axially through the long direction of the post rather than through shear and bending. During these tests the top of the posts deflected about 1.5 inches, with most of this deflection accomplished by rotation of the post in the soft soil.

Computer Modeling of Fence System

The Silt-Saver fence system was modeled using a STARDYNE finite element program. The fence material was modeled using rectangular elements and the posts were modeled using beam elements. Using the finite element model different configurations of post spacing at different depths of water were modeled. The weakness of this model is that exact stiffness properties of the fence material were not available and therefore could not be used in the model. While the stiffness of the fence material was estimated from the literature, these values did not take into account that a strengthening fiber existed in the material. In addition the program assumes a linear elastic element, which may not correspond to the properties of the fence material when deflected. However, even though weaknesses existed in the computer model, some general statements can be made involving these results.

Figure 26 shows the centerline deflections of the fence material at approximately 12 inches above the ground level. Both data from field testing as well as that predicted by the computer model are shown. The values shown are graphed as a function of the maximum deflection that occurred, with the maximum deflection existing at 24 inches of water. In both the field testing and the computer modeling of the fence system it became apparent that the deflection of the fence increased exponentially with the depth of water. Almost 60% of the maximum deflection occurred between a water depth of 16 and 24 inches. Of course this should not be that surprising in that the total force (post spacing of 4 ft. on center) acting on the fence system at a depth of water of 16 inches is only 220 lbs, while the total force acting on that same fence system at 24 inches of water is 500 lbs. Since deflection is related to the total force on the fence, then about 56% of the total deflection should occur between 16 and 24 inches of water. The computer model predicted a similar exponential trend to that of the field data. However, the computer model underestimated the percent deflection that occurred at the lower depths of water while overestimating the deflections at the greater depths. This is directly related back to the stiffness assumed for the fence material. However, other things also effected how the model reacted with respect to the field data. In constructing of the fence, the material is stretched and then stapled to the fence, this pre-tensioning of the fence material actually helps carry the loads applied to the fence material by the water. In the computer program no pre-tensioning was assumed because the magnitude of this pre-tensioning would have been hard to estimate.

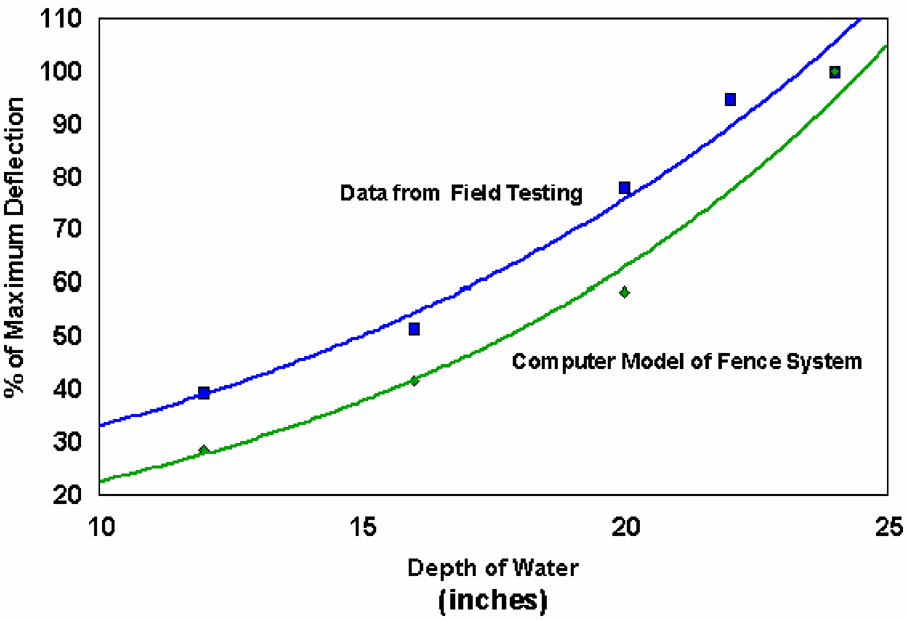


Figure 26 Comparison of results obtained from the field data with that from a finite element model of the system.

While the computer model only provides relative answers about how the fence material acts. It can show trends that would occur for different fence configurations. Figure 27 shows the relative deflections of a fence with 2 ft. post spacing to that of 3 ft. post spacing. Obviously, the variation in post spacing has a large effect on the deflection of the fence material. It can be seen that by changing the post spacing from 3ft. to 2 ft. the deflections were reduced in the fence material by over 40 percent.

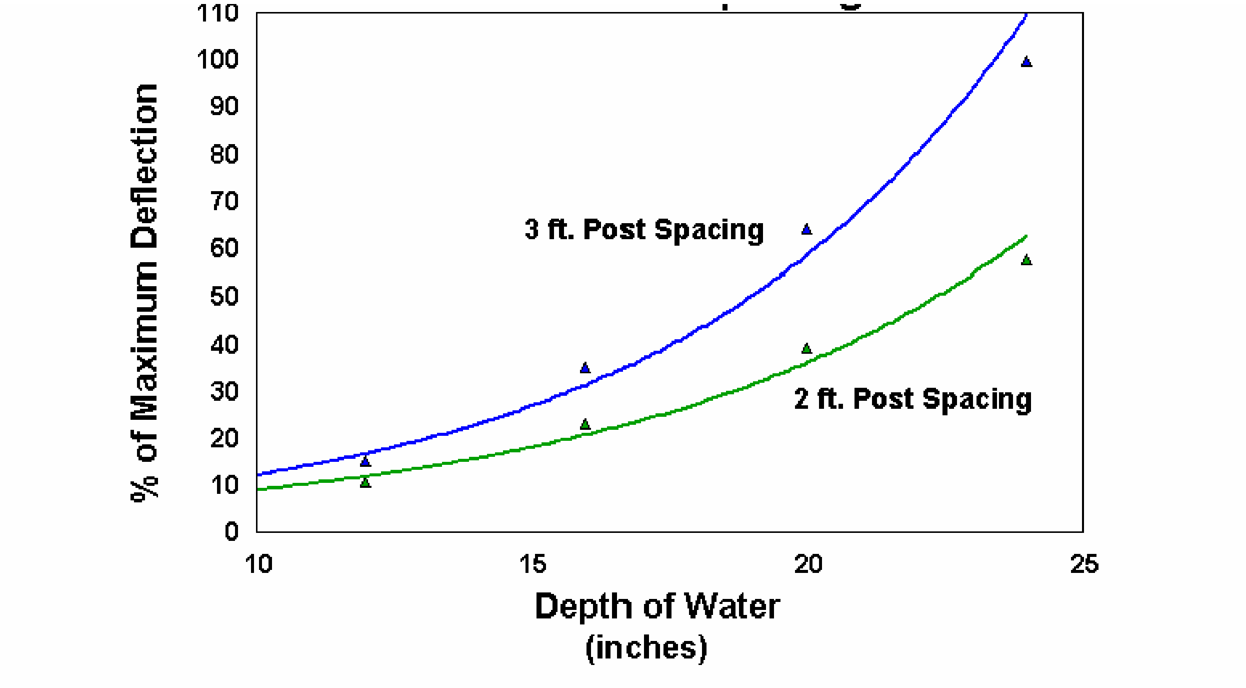


Figure 27 Relative deflection at the middle of the fabric under different post spacing scenarios.

Modeling was also done to compare a straight fence system to that which had both a straight fence and then side walls angling backwards at an angle of 60 degrees. In construction of these fences, it is not uncommon to arrange the fences in a similar orientation to contain water and silt material down a slope. During field testing the posts were also configured in a similar pattern. In looking at the results of a straight fence with 2 ft. post spacings to that of a fence with 2 ft. post spacings and wing walls angling backwards at 60 degrees, the maximum deflection of the fence material in the straight portion of the fence was reduced by about 20 percent based on the assumed loading. Just like the model, the fence is not comprised of individual panels which work independently of each other, but rather as a system of panels which work together to withstand the loading. Therefore, it is important to consider the entire system of panels as a structural system and look at how the load is transferred through the entire system. The effect of these wing walls angling backwards is to help carry the forces of the water retained by the wall. The loads caused by the water are transmitted back through these panels in tension and carried by other panels and posts within the system upgrade from the loading. With the modeling parameters established, this methodology could now be used to design many other alternative configurations and analyze the expected deflections without field testing.

Conclusions

In this testing, the flow rates and sediment removal efficiencies for BSRF and type C silt fence were measured and evaluated using three different test methods; the ASTM standard method, a modified ASTM standard method conducted at a much greater slope, and a simplified rapid filtering test using PVC pipes. 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 on all three soils 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.

All of the test data indicated that the BSRF consistently removed greater amounts of sediment from the flow. Measured sediment removal efficiencies were uniformly 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.

Structural testing was also conducted in the laboratory and field. While standard grab tests confirmed that the BSRF had lower tensile strength and did not meet Georgia DOT specifications, field testing indicated that the BSRF system should be capable of withstanding loads that would be normally encountered in the field due to its unique post arrangement and connection system. This summarizes the case for allowing the BSRF fabric fence as an or-equal alternative to traditional silt fence systems.

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