Final Report

Index Testing to Support the Stormwater Management Erosion and Sediment Control Laboratory

Work Performed for the Florida Department of Transportation

Submitted by

Manoj Chopra, Ph.D., P.E.
Marty Wanielista Ph.D., P.E.
Ikiensinma Gogo-Abite
Mike Hardin, E.I.

Stormwater Management Academy
University of Central Florida

Orlando, FL 32816

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16. Abstract

The main aim of this project was to support the Stormwater Management Academy Research and Testing Laboratory (SMARTL) with material index testing. In addition to testing erosion and sediment control products on the test beds in the field-scale laboratory, there was a strong need for conducting tests on the index properties of these products in a controlled laboratory environment, using the relevant established American Society for Testing and Materials (ASTM) and/or American Association of State Highway and Transportation Officials (AASHTO) standards. The goals of this project include: (a) confirming manufacturer product data (if available) and (b) providing additional material property data to the scientific community. This present research was aimed at performing index testing in conjunction with the ongoing project on establishing test beds and a rainfall simulator. There is a need to evaluate best management practices for sediment and erosion control, and to train designers, inspectors and contractors doing work for the Florida Department of Transportation (FDOT). Soil erosion is the reason for sediments found in streams, rivers, ponds and reservoirs. Suspended sediments and other pollutants in stormwater have created problems nationwide. Sediments that stay suspended can impair entire ecosystems, and sediments that eventually settle may need to be removed. It is also important to prevent soil erosion from being initiated in the first place using erosion control measures. A new Florida Manual for Erosion and Sediment Control for Designers and an accompanying Inspectors Manual have recently been developed and are in the implementation phase. This project sets up a laboratory at the University of Central Florida to perform index testing on materials and products used in erosion and sediment control. This project also applies the testing protocols to the determination of the material properties of two types of silt fence materials and to the dosage and toxicity testing of polymers used in erosion and sediment control.

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EXECUTIVE SUMMARY

The main aim of this project is to support the Stormwater Management Academy Research and Testing Laboratory (SMARTL) with additional materials testing. In addition to testing erosion and sediment control products on the test beds in the field-scale laboratory, there was a need for conducting tests on the index properties of these products in a controlled laboratory environment, using the relevant established American Society for Testing and Materials (ASTM) and/or American Association of State Highway and Transportation Officials (AASHTO) standards. There are two goals for this research:

1. Confirm manufacturer product data (if available).
2. Provide additional material property data to the scientific community.

Testing capabilities established by this project serve the missions of the Florida Department of transportation (FDOT) and SMARTL, and will be available to other state DOT laboratories to follow in an effective collaborative and cooperative effort. Specifically, a recent evaluation of the current sediment and erosion control programs of the FDOT has recommended allowing the use of hydraulically applied methods and products for erosion control (J. Fifield 2001). The Erosion Control Technology Council (ECTC) standards committee is attempting to define and establish product use standards, developing a list of index test methods for rolled erosion control products. These testing methodologies can be used to assist engineers and designers in material identification, classification and selection. To help accomplish this task, the committee has been collecting information on common index test methods used by mat and blanket manufacturers to describe their products (www.ectc.org). ASTM standards are referenced wherever possible.

This present research was aimed at performing a similar function for the State of Florida in conjunction with the ongoing project on establishing test beds and a rainfall simulator. This research addressed the following issues:

1. Product verification particularly in failed situations.
2. New product development using Florida based materials.
3. Modifications, adaptation, and improvements of materials and methods for existing products for Florida conditions.
4. Characterization of material properties of the soils and the products used in testing.
5. Validation of manufacturers' claims on strengths and other properties.

To maintain compliance with applicable regulations and protect Florida's natural resources, FDOT needs to evaluate best management practices for sediment and erosion control, and to train designers, inspectors and contractors doing work for the FDOT. Eroded sediments in stormwater have created environmental impacts nationwide, impairing ecosystems and requiring costly remediation. The prevention of soil erosion is the first line of defense against avoiding downstream impacts from turbid stormwater. This project sets up a laboratory at the University of Central Florida to perform index testing on materials and products used in erosion and sediment control.

As the first application of the index testing laboratory, the material properties of two types of silt fences, Type III and BSRF, are determined. Tests for the tensile strength, puncture resistance, apparent opening size and permittivity are conducted on these two materials. Where available, these results are compared to manufacturer's published values and/or FDOT minimum requirements.

Polymers have been found to be effective for several applications related to erosion and sediment control and will be recommended for use in the state of Florida on FDOT projects. In view of this recommendation, there was a need to conduct index testing related to the performance of polymers and their toxicity. The performance is evaluated by measuring turbidity for determining the polymers' effectiveness in the reduction of turbidity. The dosage testing for turbidity removal using PAM reveals that as mixing speed and mixing time increase, the efficiency of the turbidity removal increases but that there is a level of mixing speed and time at which the efficiencies will plateau. At that dosage, the addition of PAM, mixing speed and/or mixing time will not improve the efficiency. These optimum levels of mixing are presented in the form of efficiency tables.

The polymers were also tested for their toxicity levels utilizing fathead minnows to observe whether or not there were any acute or chronic toxic repercussions on downstream organisms and the related dosage values. Filtered sample toxicity test results suggested that there will be no resultant toxicity if the waste stream is filtered with a 100 micron filter before discharge. It is recommended that toxicity be tested for both the unfiltered case and the filtered case. Filtration reflects the field practice of using some matting material to settle out the residual polymer. The results presented for polyacrylamide (PAM) dosage and toxicity have shown that the PAM dosage can be properly determined for a site and, based on the dosage level and filtration, PAM residue in the field discharge water is expected to be of minimal toxic effect if the PAM is applied. On the other hand, it could also be toxic to aquatic life in the receiving bodies.

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1 INTRODUCTION

This project is aimed at supporting the current Florida Department of Transportation (FDOT) funded research project titled Stormwater Management Academy Research and Testing Laboratory (SMARTL) with additional materials testing capabilities. In addition to testing erosion and sediment control products on the test beds in the field-scale laboratory, this project conducted tests on the index properties of these products in a controlled laboratory environment, using the relevant established American Society for Testing and Materials (ASTM) and/or American Association of State Highway and Transportation Officials (AASHTO) standards. The goals for this research:

i. Establish a Florida focused testing laboratory for erosion and sediment control products used on transportation facilities

ii. Confirm manufacturer product data (if available)

iii. Develop sediment removal efficiency and toxicity testing protocols for polyacrylamide (PAM).

iv. Modifications, adaptation and improvements of materials and methods for existing products for Florida conditions

There are at least four different definable types of erosion each describing a more progressive level of erosion. They are rainfall impact, sheet erosion, rill erosion and gully erosion (FDOT 2002). Also, the amount of erosion and sedimentation rates depends on the types of soils, ground cover, erosion controls, soil porosity and velocity of wind and water movement impacting these areas.

Soil erosion is the reason for sediments found in streams, rivers, ponds and reservoirs. Sediment is produced when earth materials undergo disintegration and decomposition. Disintegration describes the process whereby geomorphologic forces break apart materials without changing the chemical compositions. Decomposition involves chemical degradation whereby the composition of the materials changes as well, usually through a process such as solution, hydration, oxidation or carbonation. This also includes biological processes (Wanielista, Kertsten and Eaglin 1997). The sedimentation transport impacts may be seen far downstream from where the erosion initially occurs (FDOT 2002).

Suspended sediments and other pollutants in stormwater have created problems nationwide. Sediments that stay suspended can impair entire ecosystems, and sediments that eventually settle may need to be removed. In either case, the costs to society are high, estimated to be as high as $13 billion or more each year (Fifield, Designing for Effective Sediment and Erosion Control on Construction Sites 2004). It is also important to prevent soil erosion so as to preserve precious croplands and fertile topsoil; otherwise, the results would be land degradation and loss of productivity (Wanielista, Kertsten and Eaglin 1997).

Construction activities, though relatively brief in their duration, can be a major source of sediment-laden stormwater runoff (Peluso and Marshall 2002). The problem of soil erosion becomes acute whenever land is disturbed for construction activities. It has been shown that the sediment erosion rate at a construction site can increase 10 to 20 times from the preconstruction condition (Fifield 2004).

Polyacrylamide is of special interest to the transportation community, being one of the few practical tools available to remove colloidal sediment from stormwater runoff within linear facilities. Northern areas of Florida, especially within the Florida Panhandle area, contain clay creating the potential for colloidal sediment runoff.

2 LITERATURE REVIEW ON INDEX TESTING

A review of the current literature in the areas geotextile testing, polyacrylamide application and dosage testing and polyacrylamide toxicity testing is presented in the following sections.

2.1 Geotextile Testing

Geotextiles are synthetic fibers made into flexible and porous fabrics by weaving – woven geotextiles or by matting – nonwoven geotextiles, (Koerner 1997). The abilities of geotextiles to enhance soil stability, to allow flow through them and to separate and reinforce soils have increased their use as erosion and sedimentation control products. However, standard test methods adopted from textile (clothing) test methods, such as Mullen Burst Strength (ASTM Standard D3786 2009) and Puncture Strength (ASTM Standard D4833 2007), have failed to provide prediction of field performance in civil engineering applications (TenCate 2009). To this end, the initial ASTM standard test methods adopted from textiles have been modified, and are constantly revised to meet acceptable field practices (Fannin, et al. 1996, Koerner 1997).

Geotextiles as erosion and sediment control barriers play the role of providing filtration of soil particles from leaving a site and yet allow the flow of water through them. The effectiveness of geotextile filters depends on the granularity of the protected soil, hydraulic conditions and geometry of the pore network or pore size distribution of the geotextile (Fannin, et al. 1996). In addition, certain variables such as strength, durability and weathering degradation have been of concern by the users of these products. The need to understand the mechanism of geotextiles in erosion prevention and sediment control functions and to adequately predict the field performances of geotextiles has led to studies on the available standard test methods' ability to predict performance. The geosynthetic industry has realized that the strength based ASTM Standard index tests adopted in the 1970s could not provide reliable prediction of a geosynthetic field performance (TenCate 2009).

Research studies on different test methods aimed at prediction of field performances of geotextiles are regularly being reported (Fannin, et al. 1996, Narejo 2003, Suits and Hsuan 2003, Chew, et al. 2003) and are considered by the relevant ASTM committee (Committee D35 on Geosynthetics). Available research studies have focused on the ultraviolet exposure, puncture resistance, filtration capability and strength of geotextiles in the field.

Current test methods for strength are based on three ASTM standard test methods based on the application of the geotextile. These are:

1. Grab tensile test (ASTM Standard D4632 2008) that measures the breaking load and elongation by the grab method and is excellent in verifying the quality and consistency of products in accordance with manufactures' specifications. However, its use as a design aid could provide misleading tensile strength values, as the tensile force requirements cannot be easily quantified and the approach to selecting required geotextile tensile strength is largely empirical.
2. Wide width tensile test (ASTM Standard D4595 2009) in which the test specimen is gripped along its full width and pulled slowly (unlike the grab test where only one inch is clamped by the jaws of the machine). This test tends to give a better

estimation of tensile strength than the grab test in woven geotextile fabrics; however, it does not represent a true design value for nonwoven geotextile fabrics.

3. Tension creep tests (ASTM Standard D5262 2007, ASTM Standard D6992-03 2009) used to determine the anticipated total elongation or time to rupture that may occur in geosynthetic fabrics under sustained loading conditions.

Tests on measuring the index friction angle of geotextile have shown that the ability of a geotextile to retain fines depends primarily on its apparent opening size (AOS), and the AOS recommendations of AASHTO's M288 specification may be unsuitable for proper geotextile application (Narejo 2003). Further review of the research found that, in most cases, geotextiles with an apparent opening size (AOS) less than 85percent size of soil would function adequately; however, previous studies indicated that for fine silt and clayey soils, the AOS of a geotextile should be less than as 0.5 times the 85percent size of the soil considered. The test device is basically a tilting table for measuring friction effects of surface characteristics.

Another concern about the geosynthetic materials is their durability amongst weathering conditions due to long-term outdoor exposure. Sunlight is well recognized as a dominant factor in degradation of many polymers including those used in geosynthetic (Suits and Hsuan 2003). The UV energy of the sunlight is sufficient to break chemical bonds of polymers, with the shorter wavelengths being more severe, which can greatly affect the stability of geotextiles. The research to access the photo-degradation of geosynthetics (Suits and Hsuan 2003) utilized two processes for testing degradation: Xenon Arc Weatherometer – uses a long, arc water cooled xenon lamp furnished with inner and outer filters as the light source; and the UV-fluorescent Weatherometer consisting of eight fluorescent UV lamps. The output of UV-florescent light source only emits light spectrum in the UV region where the energy is great enough to cause polymer degradation. The study revealed that Xenon Arc exhibited a higher degradation rate amongst geosynthetic fabrics than the UV-fluorescent Weatherometer.

The stability of geotextiles subjected to non-uniform flow and/or puncture is of utmost importance for erosion and sediment control fabrics. As silt fence, geotextiles are exposed to various types of loading and overburden stresses caused by storms and erosion. One assumes that the flow through the openings of geotextiles is uniformly one-dimensional. However, research (Chew, et al. 2003) reveals that the soil particle motion by cyclic loading is different from uni-directional wave loading. To test this, an apparatus that is capable of simulating cyclic flow conditions normal to the geotextile interface was developed. Though, the apparatus is originally intended to simulate cyclic wave regime at coastal revetment application, it could also be relevant to silt fence barriers with turbulent flows. Another aspect of the research was the creation of pre-cut holes to simulate punctured hole in the geotextile fabrics. The results show that there is a critical size of pre-cut hole, above which the filtration function could be impaired. While this finding is relevant to some applications of erosion control, it may or may not be true for silt fence application of geotextile fabrics. Therefore, the current water permeability of geotextile by permittivity test (ASTM Standard D4491-99a 2009) and apparent opening size (ASTM Standard D4751 2004) could not adequately predict the field performance of geotextile fabrics.

2.2 Polyacrylamide (PAM) Application and Dosage Testing

Several studies focused on the application of PAM and produced varying results. However, these research studies collectively allude to the fact that State and/or manufacturer's dosage recommendations need to be modified in order to acquire effective turbidity removal efficiencies. In a study conducted in North Carolina, PAM was utilized alongside mulch, seeding and various other methods for preventing sediment losses and reducing turbidity (Hayes, McLaughlin and Osmond 2005). Three active highway locations were used in this study. Different treatment schemes were determined and randomly assigned to three different active highway runoff sites. The treatment schemes were combinations of APS 705 polymer from Applied Polymer Systems, Soilfix which is a 90 percent PAM with a molecular weight of 16 mg mol^{-1} and a control location without any treatment.

The selected sites were covered with sod and fertilized according to the North Carolina Sediment and Control Planning and Design Manual of 2002. Each site was separated into plots where the erosion control application was combined with seed, mulch or nothing at all. PAM was applied on the site by pressurized garden sprayers and sprinkler cans. The sprayers were not used after the first site because the PAM solutions had to be de-ionized so much to achieve a reasonable spray pattern that it resulted in unreasonable application times. Runoff samples were collected after every rainfall event and measured for turbidity, using an Analite Nephelometer Model 152, and for total suspended solids after filtration.

The test results show that the application of PAM (APS 705) alone did not have statistically significant effects on the runoff and turbidity for any of the storm events that occurred, although increasing the rates of PAM tends to lessen both turbidity and sediment loss. A treatment combination of mulch and PAM showed no significant difference from the use of mulch alone. The study found that the addition of PAM to seeding/mulch has no significant effect, and the most pronounced results of turbidity reduction and sediment loss came from the application of seed/mulch. In conclusion, an increased dosage of PAM is needed to have a significant effect on turbidity and erosion control (Hayes, McLaughlin and Osmond 2005).

From another study conducted in North Carolina at an active roadway project in the mountainous area of the state, standard BMP's were used in combination with PAM and fiber check dams (FCD) to provide sediment control (McLaughlin, King and Jennings 2009). The test sites for the study were fitted with erosion control practices that complied with standard best management practices. This consisted of small sediment traps followed by rock check dams. The PAM treatment consisted of the addition of approximately 100 grams of PAM 705 powder lightly interspersed over the lower center portion of each fiber check dam and over a small section down slope. PAM was reapplied after every major storm event. Runoff samples were collected by portable water samplers programmed for flow-weighted sampling. Significant reductions in turbidity and total suspended solids were observed using the FCD, with increased performance when combined with PAM. The decrease in turbidity with greater flows was enhanced substantially with the addition of PAM to the fiber check dams and turbidity remained well below 50 NTU. A conservative cost analysis results reveal that the fiber check dam system is comparable in cost with the standard practice of installing a shallow sediment trap beside a rock check dam. The fiber check dam system coupled with the granulated PAM resulted in turbidities of less than 10 NTU (McLaughlin, King and Jennings 2009).

In a study to investigate the effectiveness of both powder and liquid forms of PAM, a range of erosion control methods were analyzed, specifically for a construction site environment (Soupir, et al. 2004). The methods investigated were dry and liquid application of polyacrylamide, hydroseeding and straw mulch. It was found that none of the treatments considered significantly decreased runoff volume. However, both half and full recommended dosage of aqueous PAM reduced runoff by 5 and 4 percent, respectively. But dry PAM, twice the recommended dosage of aqueous PAM, hydroseed application and straw mulch actually increased runoff volume. The most effective treatments in reducing TSS concentration and yield, in order of efficiency, were straw mulch, hydroseeding and dry PAM. The most effective treatment for reducing total phosphorus was the straw mulch, followed by the powdered PAM. The percent reductions in total phosphorus concentrations were 63percent with straw mulch and 38percent with the powdered PAM. Evidently, the straw mulch also performed to be the best treatment for total suspended solids reduction and sediment bound nitrogen loading. The half-recommended dosage of aqueous PAM was the best treatment for total nitrogen reduction. Improvements in aggregate stability achieved at low PAM application rates depend upon polymer charge density, soil moisture content and the type of exchangeable ion (Soupir, et al. 2004).

Study of specific erosion control application issues was conducted with the general intent of increasing infiltration rates on soils while reducing runoff and erosion using gypsum and PAM (Yu, et al. 2003). Seals formed at the soil surface, typically during rainstorms, limit permeability and increase runoff. It is suggested that PAM, used either as granular (dry) or water based solution, be distributed on the soil surface prior to the rainy season to reduce the sealing effect. The experiments were conducted on soils (silty loam-loess and sandy clay) from Israel, using a drip-type rainfall simulator. This simulator produces rainfall at a known constant drop size passed through a set of hypodermic needles positioned at a spacing of 20 mm × 20 mm pointed downward. During each simulated rain event, the infiltration water was captured by a graduated cylinder every 4 minutes and water volume was recorded as a function time.

It was noted that gypsum at the soil surface dissolves during the rainstorm and releases electrolytes into the soil solution resulting in reduced clay dispersion and seal formation. Spreading gypsum at the soil surface resulted in higher infiltration rates than the control treatment. The research also showed that the introduction of PAM on the upper 5 mm layer before exposing the soil to rain resulted in infiltration rates that correlated with control treatment. The combination of dry, granular PAM and gypsum significantly increased the infiltration rate on the silty loam. When rainwater comes in contact with the dry PAM and gypsum mixture, gypsum dissolves and increases the electrolyte concentration in the soil solution resulting in seal formation. Though the general intent was to reduce the chances of surface seal formation, it should be noted that sandy clay is less susceptible to seal formation than the silty loam. Similar to the situation with the silty loam, the introduction of PAM did not prevent seal formation, yet the mixture of PAM and gypsum showed remarkable infiltration results on the sandy clay. Ultimately, PAM solely mixed with the soil did not seem to increase the infiltration rates through the soils, but PAM was very effective in reducing soil losses. A mix of dry PAM with soil was most effective in the prevention of erosion, because it increased inter-particle bonding due to the long polymer chains (Yu, et al. 2003).

The effectiveness of both coagulation and flocculation were analyzed on turbidity removal from travertine, commonly known as natural stone, processing waters (Ersoy, et al. 2009).

Classical sedimentation tests were used to determine the proper coagulants, and the flocculation processes were simulated using a polyacrylamide based anionic polymer. Anionic polymers have become the most common materials used for water clarification and erosion control on construction sites.

The travertine powder used for the study was obtained from natural stone processing wastewaters. The specified amount of tap water was poured into a 500 mL graduated cylinder having 21 grams of natural stone powder. The graduated cylinder was then sealed and inverted twice. A polymer solution was diluted with de-ionized water to 0.1g/L concentration and placed in the cylinder using an adjustable automatic pipette. This was also sealed and inverted four times to ensure sufficient mixing. The new solution was left on a smooth and level surface to settle for 15 minutes.

Subsequently, a sample was taken from a depth of 12 cm below the surface and the turbidity was measured using a Scientifica Velp-115 turbidimeter. The relationship between the residual turbidity of the travertine suspension and the polymer was analyzed and the result showed that a minimal dosage is more efficient (Ersoy, et al. 2009).

The turbidity values are the result of many unsettled particles during the flocculation process. The anionic polymer as well as the natural stone powder carry the same negative charge which prevents the particles to attract each other and generate larger, settled particles, hence, making the solution more turbid. The results indicate that that it is not necessary to introduce much polymer to obtain turbidity reduction. The most efficient methods for the removal of turbidity from the natural stone processing wastewaters were by flocculation and coagulation combined with flocculation (Ersoy, et al. 2009).

2.3 PAM Toxicity Testing

Krauth, et al. (2008) studied the use of anionic polyacrylamide to determine the effectiveness of the product as well as the potential acute aquatic toxicity. All the sample collection areas were located on cotton fields that were irrigated using sprinklers in Arkansas. All analyses, including toxicity, were performed at the Arkansas State University Ecotoxicology Research Facility. Treated and untreated water samples were collected after three irrigation and three rain-induced runoff events. The study was concerned with the acute toxicity of the PAM stormwater pellets (SWPs) when used in the field. The water stream was exposed to nylon mesh bags filled with 50 pellets evenly distributed throughout the bag, each with a molecular weight of 10-14E6 g/mol. When simulating field conditions in the laboratory, concentrations of 30 and 45 mg/L of crushed PAM SWPs were added to hard water with a turbidity of 320-345 NTU. To determine the acute toxicity of this product in the field 48-hour tests using fathead minnows (*Pimephales promelas*) as well as water fleas (*Ceriodaphnia dubia*) were conducted. Both species were exposed to water collected from the area upstream of the point where the PAM was added and to water collected from an area downstream of the point where the PAM was added. Organisms of the same species were also exposed to hard laboratory water to provide a control. It was concluded that this PAM dosage did not have a significant effect on the toxicity of the water sample. After 48 hours, the test species did not have a significant decrease in survival when compared to the control. There also was no significant difference in the survival rate of the organisms in the treated runoff when compared to the untreated runoff (Krauth, et al. 2008). However, the chronic toxicity of the organisms was not examined.

Weston, et al. (2009) examined the toxicity of several forms of anionic polyacrylamide: granular, tablet, liquid, oil-based and a water based product. All five of these different products were dissolved in water to create stock solutions ranging from 500 to 1500 mg/L of each product. To create each stock solution the products had to be stirred vigorously on a magnetic stirrer for different amounts of time dependent on the product. The granular PAM was mixed for four hours, the tablet was mixed for one hour and all other products dissolved within a few minutes. Five different species of aquatic organisms were examined: *Hyalella azteca, Chironomus dilutes, Ceriodaphnia dubia,* fathead minnows and *Selenastrum capricornutum*. When testing the toxicity of the various products on fathead minnows (*Pimephales promelas*) four samples of each test solution concentration (0.18, 0.37, 0.75, 1.5, 3 and 6 mg/L) were created by diluting the stock solutions. This method can cause some uncertainty in the resulting concentrations due to solubility issues with the PAM. Acute and chronic toxicity were tested as per USEPA protocol with a roughly 80percent of the water changed daily.

Fathead minnows were only used in the testing of three of the five polyacrylamide products: the granular product, the soil-floc oil-based product and the PAM25 water-based product. The granular product showed no indication of toxicity with a 95percent survival rate at the highest test concentration of 100 mg/L. The LC50 values could not be determined, but was more than 100 mg/L. The survival rate at 100 mg/L was 95percent for the PAM25 water-based product and also a statistically significant 16percent reduction in biomass at the highest concentration. However, in the oil-based product, the fathead minnows had a significant mortality rate at the 1.5 mg/L concentration with an LC50 of 16.6 mg/L. There was also a 47 percent reduction in biomass at the highest concentration. This shows the importance of testing each different polymer mix.

Weston, et al. (2009) suggests that given the physical attributes of PAM solutions it is possible that the effects may, in some cases, be physical rather than chemical and that the PAM products increase the viscosity of the solution which may have put added stress on the test organisms. The study found that the oil-based product had a higher toxicity because of the oil content or its other ingredients the other non-oil-based products may lack. Overall, the “use of solid and water-based forms of PAM appear to provide the environmental quality benefits of PAM, such as reduced sediment transport to the surface waters and reduced off-site movement of nutrients, pesticides and microorganisms, with minimal toxicity concerns associated with the use of the products themselves” (Weston, et al. 2009).

Hall and Mirenda (1991) examined 34 different polymers for toxicity using both *Daphnia pulex* and fathead minnows. The source water utilized was wastewater effluent due to the rising concern around pollutants in the wastewater that was being treated. The purpose was mainly to study the acute toxicity of the polymers being added to the wastewater. This is important because often “the more significant sources of toxicity in effluent are refractory materials not broken down in treatment processes or process byproducts” (Hall and Mirenda 1991). Acute, static and nonrenewal toxicity tests were developed by the EPA (APHA; AWWA; WEF 2005) to establish the toxicity of the polymers. The pH (acidity or basicity) of the samples had to be kept within the range of 6.0-9.0 (USEPA 2002), but the majority of the polymers did not have a significant effect on the pH. As mandated by the EPA procedure, the dilution water controls had less than 10percent mortality.

Hall and Mirenda (1991) shows that a significant difference exists in the reaction of the fathead minnows to the cationic substances compared to the anionic substances. The LC50 values for most of the cationic polymers that were tested were less than 14 mg/L with 92percent being less than 5 mg/L and the LC50 values for most of the anionic polymers were greater than 20 mg/L. Overall, the toxicity of cationic polymers to the fathead minnows generally increases as positive charge density increased. However, it was noted that the increased level of toxicity could have been due to physical issues such as damaging or clogging gills rather than an actual chemical reaction. In general, the *Daphnia pulex* is 81percent more sensitive to the polymers than the fathead minnows (Hall and Mirenda 1991).

Pistole, Peles and Taylor (2008) focused on the introduction of three different kinds of stressors (copper, cadmium and salinity) to fathead minnows for two test periods, 24 and 96 hours. Fathead minnows were chosen for this experiment due to their ability to exhibit a constant pattern for metabolic reactions to stressors. Testing these three toxicants is important because of the likelihood of a human-induced situation involving these toxicants therefore changing the environment in which these organisms live. Metal ions, the toxicants being tested, have been "predicted to result in an increased metabolic rate that reflects greater energetic demands for processes such as damage repair and depuration" (Pistole, Peles and Taylor 2008). The fathead minnows used in this experiment were adults and held for two weeks before use. They were exposed to a 12 to 12 photometric period. Determination of the toxicant concentrations was done by exposing the organisms to preliminary tests which were conducted and then the concentrations used were developed for the experiment based on the death rates of the fathead minnows.

Pistole, et al. (2008) showed that the body mass of the fish did not alter significantly between the organisms exposed to copper, cadmium or salinity. The metabolic rate for the organisms increased slightly in the concentrations closer to the control. However, the metabolic rates decreased significantly in the highest concentrations. The research concludes that because of the lack of response at the 24 hour period, longer than 24 hours is needed for the organism to have a reaction to a pollutant. However, the long-term exposure to copper and cadmium increased the metabolic rate in fathead minnows which may reflect the process of damage repair. The increased metabolic rate can also reflect the energetic costs of apoptosis that results from exposure to some metals such as Cadmium (Cd).

Lopus, et al. (2009) examined the toxicity testing of polyaluminum chloride (PAC), a turbidity-reducing product, using several different organisms; algae, fathead minnows and zooplankton. The tested samples were collected from three areas representing urban runoff in the area and were each dosed with three different forms of PACs. Recent studies in the Lake Tahoe area have shown that using low intensity coagulant dosing (LICD) techniques to treat stormwater runoff with select polyaluminum chlorides (PACs) may effectively decrease phosphorus and turbidity levels in surface waters in conjunction with existing treatment of wetlands (Lopus, et al. 2009). The standard USEPA 3-species toxicity test was utilized.

The concentrations of the three PACs introduced to each species were determined using jar testing methods and the control was non-treated runoff diluted with de-ionized water to reach moderately hard specifications introduced by the EPA. Six different dosages were tested on the water samples, accounting for a range of under-dosed to overdosed conditions, with two duplicates for each dosage. The samples tested are both non-treated and coagulant treated stormwater samples from three different locations in the area: Ski Run, Stag and Tahoe City.

Lopus, et al. (2009) found that the control mean mortality was 4.9 percent, which is significantly less than the 72.25 percent mortality rate at Ski Run and the 100 percent mortality rate at Stag, but it was not significantly less than the mortality rate at Tahoe City. Although treated stormwater was significantly more toxic than control water across all sites coagulant dosing did not affect fish survival compared with non-treated stormwater across all sites. Overall, coagulant dosing did not significantly affect biomass of surviving fish when compared with non-dosed stormwater across all sites, but it significantly increased fish biomass compared with non-dosed stormwater at Ski Run.

Ankley and Villeneuve (2006) analyzed the past use of fathead minnows in toxicity testing as well as the present use, and determined whether or not fathead minnows would be adequate for the future needs of toxicity testing with the current issues facing mankind. Fathead Minnows have proven very useful in toxicity testing in the past and present due to their high tolerance to wide variety of water types. There are several toxicity tests which utilize the fathead minnows, all designed for different regulatory applications. They include the partial life cycle, 7-day larval survival and growth test, the short term lethality test, partial life cycle 30-day test, partial life cycle reproductive test and full life cycle test. The short term lethality test is commonly used to set the range of concentrations tested. The partial life-cycle test now also includes the early life-stage test because there is evidence that data from assays conducted during early development can be predictive of chemical effects in full-life cycle tests.

The majority of tests conducted currently are done with fathead minnows that are in the early stages of life, while not many tests focus on the end points of life or involve reproduction. Testing during reproductive stages as well as early development stages is important because the reproductive stage of a fathead minnow’s lifespan is also considered a sensitive effects window for certain toxicants. Over the past century, the fathead minnow has proven a very useful model for addressing needs in both research and regulation (Ankley and Villeneuve 2006).

Ankley and Villeneuve (2006) recommended that the knowledge of the genetic composition of the stock used would help to understand the response to the toxicant and also help to decrease variability in results. In addition, a standardization of diet would be helpful because diet is probably the most variable factor in fish testing among laboratories; and further knowledge of embryonic and larval development would help to design tests and test endpoints that are more useful in understanding the response. The research suggested that the future of toxicity tests with fathead minnows will depend on a carefully planned effort to define and describe the genome, proteome and metabolome of the species, and the responses of each to different classes of both chemical and nonchemical stressors.

TenEyck and Markee (2007) tested pollutants which are common chemicals used to treat wastewater: Nonylphenol (NP), Nonylphenol Monoethoxylate (NP1EO) and Nonylphenol Diethoxylate (NP2EO). These pollutants were tested to determine if these chemicals display any interactive toxicity. These chemicals are not found in the environment naturally and the major sources are treated municipal and domestic wastewater. These chemicals have been reported to be found in 35 surface water samples from the Great Lakes Basin and St. Lawrence River (TenEyck and Markee 2007). EPA standard methods for acute toxicity were utilized. Concentrations ranging from 1 µg/L to 600 µg/L were created using the chemicals being tested. Overall survival of fathead minnows was greater than or equal to 95 percent with water quality staying within the guidelines established by the EPA (1993) in all tests (TenEyck and Markee 2007). The test showed that surface water samples containing NP2EO were the least toxic and the samples containing NP were the most toxic. The LC50 (with a 95 percent CI) for NP was 92.4 µg/L, NP1EO had an LC50 of 328 µg/L and NP2EO had an LC50 of 716 µg/L. They also found that NP was the most toxic of the compounds tested and NP2EO was the least toxic. Also, based on the additivity model created, the combinations of NP plus NP1EO, NP plus NP2EO and NP plus NP1EO plus NP2EO should have had a higher joint toxicity than what was calculated from the data gathered.

3 WORK PERFORMED

This chapter documents the list of equipment installed and the subsequent testing conducted for establishing the Index Testing Laboratory in support of the soil erosion and sedimentation control test facility at the Stormwater Management Academy Research Testing Laboratory (SMARTL), University of Central Florida. The effort involved the establishment of the Index Testing Laboratory with the purchase of relevant equipments for corresponding ASTM and/or AASHTO standard test methods; and conducting tests on index properties of erosion and sediment control related products and soils in a controlled laboratory environment as per the relevant ASTM and/or AASHTO standard test methods. Furthermore, as the initial application of this laboratory, testing was conducted on the properties of two types on materials for onsite sediment control, such as (a) silt fence materials and (b) polyacrylamide (PAM). Detailed results are presented later in this chapter on the performance of two types of silt fences and the performance of several types of PAMs with respect to its dosage requirements and potential toxicity.

Laboratory equipment for testing soils and index properties of erosion and sedimentation control materials was purchased and set-up in accordance with the requirements of the relevant ASTM and/or AASHTO standard methods. Detailed list of ASTM and/or AASHTO standard test methods, associated test objectives and related equipment are presented in the next two sections. The Index Testing Laboratory is equipped to perform the listed ASTM and/or AASHTO standard testing methods.

3.1 ASTM D6461-99 Standard Specification for Silt Fence Materials

This specification provides the lists of standard test methods required for geotextile fabrics and associated components used in silt fence applications as vertical permeable interceptors designed to remove suspended sediment from overland, non-concentrated water flow.

3.1.1 ASTM D4632-91 (2008) Standard Test Method for Grab Breaking Load and Elongation of Geotextiles

This test is applied to determine the effective strength of the fabric, that is, the strength of the material in a specific width with the additional strength contributed by adjacent material (ASTM Standard D4632 2008).

List of Equipment

i. Universal tensile testing machine (30,000 pound load capacity)
ii. Screw action grip jaw faces measuring 1 in. by 2 in.
iii. United quick release adapter
iv. United special grip face 2″ H x 3″ W smooth

Figure 1 Apparatus for grab breaking load and elongation of geotextiles (tensile testing machine with quick release adapter and clamps) – ASTM D4632 and D5035

3.1.2 ASTM D5035-06 Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method)

This test method is applicable to both ravel strip and cut strip procedures. Ravel strip procedure is for determining the force required to break a specific width of fabric, and is useful for comparison of the effective strength of yarns in the fabric with the combined strength of an equal number of the same nonwoven yarns. The cut strip procedure is applicable to dipped or coated felted fabrics and nonwoven fabrics (ASTM Standard D5035-06 2008).

List of Equipment

i. Universal tensile testing machine (30,000 pound load capacity), see Figure 1
ii. Screw action grip jaw faces measuring 1 in. by 2 in.
iii. United quick release adapter
iv. Stainless steel pins

3.1.3 ASTM D4491-99a (2009) Standard Test Methods for Water Permeability of Geotextiles by Permittivity

This index test evaluates the volume of water that would pass through a geotextile under a given head of 50 mm (2 inches) over a particular cross-sectional area. Permittivity is an indicator of the quantity of water that can pass through a geotextile in an isolated condition (ASTM Standard D4491-99a 2009).

List of Equipment

i. Geotextile permeability system capable of maintaining a constant head of water on the geotextile, and capable of being used for falling head test
ii. Sample holders

iii. 2 liter beakers
iv. Sample blanking die
v. 12.5 gallon de-airing apparatus
vi. Digital indicator w/output and 0-20″ differential/gradient
vii. Electrically driven two-stage vacuum pump 120 volts

Figure 2 Apparatus for geotextile permittivity test (permittivity system, de-airing device and vacuum pump) – ASTM D4491

3.1.4 ASTM D4751-04 Standard Test Method for Determining Apparent Opening Size of a Geotextile

This index determines the apparent opening size (AOS) of a geotextile by sieving of glass beads through a geotextile. The test method reflects the approximate largest opening dimension available for soil to pass through, (ASTM Standard D4751 2004)

List of Equipment

i. AOS rotary sieve shaker system 120 volt
ii. 8″ AOS geotextile sample holder assembly
iii. 20 pound AOS test bead kit
iv. 50 pound container of AOS glass beads of varying sizes
v. Sieve set for re-claiming AOS glass beads

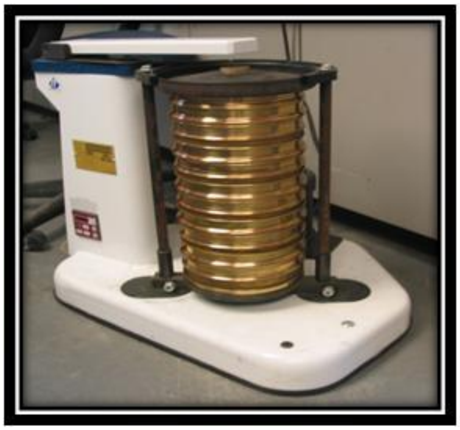
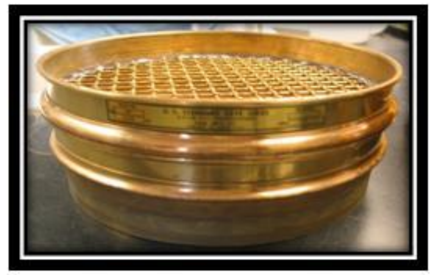
 

Figure 3 Apparatus for apparent opening size test on geotextiles (rotary sieve shaker and sieve set) – ASTM D4751

3.1.5 ASTM D4833-07 Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products

This test method is intended to establish an index value by providing standard criteria and as a basis for uniform reporting, (ASTM Standard D4833 2007).

List of Equipment

i. United tensile testing machine (30,000 pound load capacity)
ii. United puncture fixture and pneumatic action grips 1 kN
iii. Solid steel rod

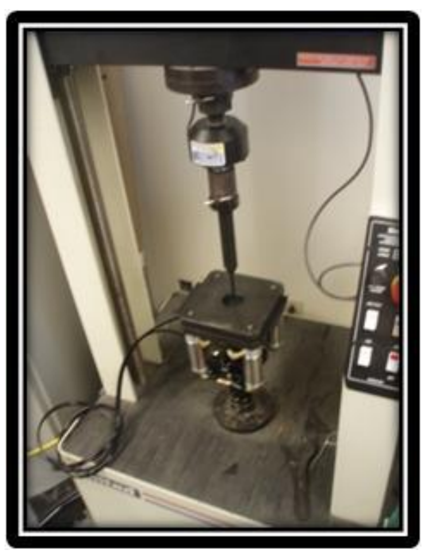


Figure 4 Apparatus for puncture test (Tensile/compression testing machine, clamp attachment and solid steel rod) – ASTM D4833

3.1.6 ASTM D1556-07 Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method

This test method is for determining the in-place density and unit weight of soils using a sand cone apparatus, and applicable for soils without appreciable amounts of rock or coarse materials in excess of 1 ½ inches (38 mm) diameter (ASTM Standard D1556 2007).

List of Equipment

i. Jar and detachable appliance consisting of a cylindrical valve with an orifice and a funnel
ii. Balance
iii. Field density base plate
iv. Density pick hammer, chisels, spoons and picks
v. Density sand (Ottawa sand)
vi. 1 gallon can

Figure 5 Apparatus for determining density/unit weight by sand cone method – ASTM D1556

3.1.7 ASTM D6938-08a Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

This test method is a rapid, nondestructive technique for in-place measurements of wet density and water content of soil and soil-aggregates and the determination of dry density (ASTM Standard D6938 2008).

List of Equipment

i. Nuclear density gauge

Figure 6 Apparatus for determining field moisture and density/unit weight by nuclear density gauge – ASTM D6938

3.1.8 ASTM D2434-68 (2006) Standard Test Method for Permeability of Granular Soils (Constant Head)

This test method is for determining the coefficient of permeability under a constant-head and for laminar flow of water through granular soils (ASTM Standard D2434-68 2006).

List of Equipment

i. Constant/falling head permeameter, 3 in. × 4.5 in.
ii. Accessories – timing device, thermometer, water faucet, balance, funnel, scoop, mixing pans, graduated cylinder

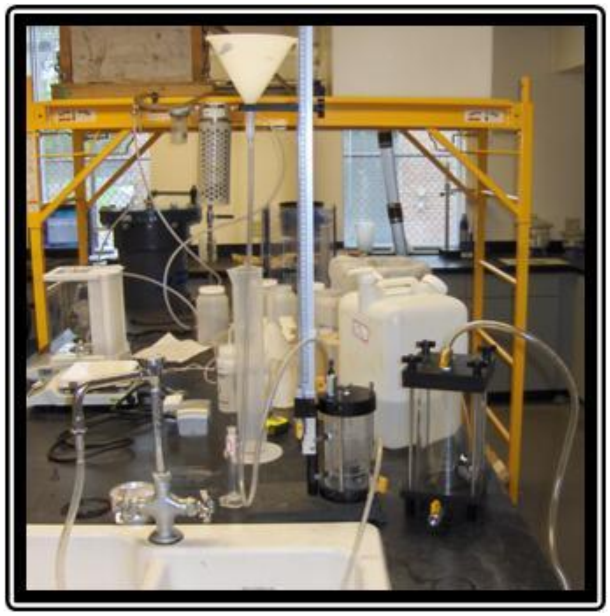


Figure 7 Apparatus for determining hydraulic conductivity of soils – ASTM D2434

3.1.9 ASTM D2216-05 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

This test method is the laboratory determination of the water (moisture) content of soil, rock and similar materials where the reduction in mass by drying is due to loss of water (ASTM Standard D2216 2005).

List of Equipment

i. Drying oven
ii. Balance
iii. Aluminum cans with lids
iv. Gloves, tongs, spatulas, scoop, knives

Figure 8 Apparatus for determining moisture content of soil – ASTM D2216 and D1140

3.1.10 AASHTO T88-00 (2004) Standard Method of Test for Particle Size Analysis of Soils

This test method is for the quantitative determination of the distribution of particle sizes of soils (AASHTO T 88 2004). The SMART laboratory is equipped to perform test only on particles retained on 75-µm (No. 200) sieve; however, access to equipment required for particles finer than 75-µm are available at the UCF geotechnical laboratory.

List of Equipment

i. 8″ brass full sieve set
ii. Portable sieve shaker
iii. Fine sieve brush
iv. Porcelain soil mortar
v. Rubber mallet
vi. Balance
vii. Blender

Chemicals

Sodium Hexametaphosphate

Figure 9 Apparatus for determining soil grain size analysis – ASTM D422

3.1.11 ASTM D1140-00 (2006) Standard Test Methods for Amount of Materials in Soils Finer than No. 200 (75-µm) Sieve

This test method is used to determine the amount of material finer than a 75-µm (No. 200) sieve by washing. Particles finer than 75-µm (No. 200) sieve are more efficiently and completely separated from larger particles by wet sieving than with dry sieving. For accurate determination of the percent finer than 75-µm this test method is recommended prior to dry sieving (ASTM Standard D1140-00 2006). This test method is an integral part of AASHTO T88.

List of Equipment

i. Double wall laboratory oven, see Figure 8
ii. Laboratory tongs
iii. Aluminum moisture box 2-1/2″ x 1-3/4″ and 3-1/2″
iv. Sieves
v. Weight balance scale

3.1.12 AASHTO T99-97; (ASTM D698-07^{e1}) Standard Test Methods for Moisture-Density Relations of Soils Using 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in) Drop

This test method describes laboratory compaction methods used to determine the relationship between molding water content and dry unit weight of soils (compaction curve) compacted in a 4 or 6 inch diameter mold with a 5.50-lb rammer dropped from a height of 12 inches producing a compactive effort of 12400 ft-lb/ft^3 (ASTM Standard D698 2007, AASHTO T 99-97 2001).

List of Equipment

i. Compaction hammer
ii. Standard compaction mold, 4 inches diameter
iii. Sample extruder
iv. Compaction straightedge, mixing pans, soil mixer, trowel, spoon, sieves
v. Balance
vi. Drying oven

Figure 10 Apparatus used in compaction test – ASTM D698

3.1.13 ASTM D854-00; AASHTO T100-06 Standard Method of Test for Specific Gravity of Soils

This test method determines the specific gravity of soil solids passing a sieve by means of a water pycnometer (ASTM Standard D854 2006, AASHTO T 100-06 2006).

List of Equipment

i. 8″ desiccators set
ii. Specific gravity bottle
iii. Graduated cylinder
iv. Volumetric flask, 500 mL
v. Balance
vi. Vacuum pump
vii. Evaporating dish, spatula, beaker

Figure 11 Apparatus for determining specific gravity of soil – ASTM D854

3.1.14 ASTM D4318-05; AASHTO T89-02; and AASHTO T90-00 (2004) Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils

This test method is used to characterize the fine-grained fractions of soils and to specify the fine-grained fraction of construction materials. In addition, it is used with other soil properties to correlate with engineering behavior such as compressibility, hydraulic conductivity, compactability, shrink-swell and shear strength (ASTM Standard D4318 2005, AASHTO T 89-02 2004, AASHTO T 90 2004).

List of Equipment

i. Liquid limit device
ii. Plastic dispensing bottle
iii. Flat grooving tool
iv. Evaporating dish, spatula, aluminum cans, No. 40 sieve
v. Aluminum moisture box 2-1/2 x 1-3/4″ and 3-1/2″
vi. Ground glass (plastic limit) plate
vii. Drying oven
viii. Balance

Figure 12 Apparatus for determining liquid limit and plastic limit of soil – ASTM D4318

In the same period of reporting, index tests were performed on silt fence materials, inlet protection materials, PAM (dosage and toxicity) and soils (in-situ and laboratory testing in accordance to the relevant ASTM and/or AASHTO standard methods). All tests were performed at SMARTL. The various procedures, results and discussions are presented in the following sections for index tests on two silt fence fabrics, and the dosage and toxicity of PAM.

3.2 Material Testing Using the Stormwater Management Academy Index Testing Laboratory

3.2.1 Application I: Silt Fence Testing

The Florida statewide stormwater rule requires the treatment of stormwater from all new development (FDEP 1988). The nature of construction activities accelerates soil erosion, sediment transport and the associated problems of sedimentation. For not violating Florida's water quality standard for turbidity, various performance standards for erosion and sediment control are designed to retain sediment on-site. One of such techniques is the use of barriers placed around construction sites for sediment containment and control. Barriers are basically designed to obstruct or prevent the passage of water. They function mostly to slow the velocity of flow and allow time for suspended particles to settle to the bottom. Common examples of barriers are silt fence, inlet barriers and diversion barriers.

Silt fences are geotextiles placed as temporary barriers to control sheet flow from disturbed lands. Commonly available silt fences are mostly woven, geosynthetic filtration fabrics supported at regulated intervals by wood or steel posts trenched into the ground to control sediments from leaving the site by slowing down the runoff flow velocity, filtering suspended sediments and allowing deposition of sediments. However, the commonly available silt fence barriers do not filter sediments out of runoff water (Florida E$SC 2007, Risse, Thompson and Governo 2007). To improve the performance efficiency of silt fences, Silt Saver, Incorporated introduced a new product known as belted strand retention fence (BSRF). BSRF is a nonwoven geotextile supported by wood post attached to the fence, and claims to offer several potential advantages (Risse, Thompson and Governo 2007). ASTM standard tests were conducted on both the new product and the existing, industry accepted product (Type III –), viz., a woven monofilament silt fence (Type III as per FDOT classification) and a belted strand retention fabric (BSRF), according to the following ASTM standard testing methods.

- D4632-08 Grab Breaking Load and Elongation of Geotextiles
- D4491-99A (rev. 2004) Water Permeability of Geotextiles by Permittivity.
- D4833-00 Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products
- D4751-04 Standard Test Method for Determining Apparent Opening Size of a Geotextile

Manufacturers' claims on both geotextiles and FDOT minimum specifications for silt fence barriers are presented as follows.

3.2.1.1 Type III Silt Fence

This is a circular woven polypropylene geotextile. The individual filaments are woven into a regular network such that filaments retain dimensional stability relative to each other. The geotextile is resistant to ultraviolent degradation and to biological and chemical environments normally found in soils. The Type III silt fence material used for the tests conducted at SMARTL was obtained from Absolute Erosion Control, Incorporated and manufactured by Assurene Corporation (ASR-1400). ASR-1400 is a polypropylene circular woven fabric, engineered geotextile stabilized to resist degradation due to ultraviolet exposure, non-biodegradable and resistant to chemicals, mildew and insects usually encountered in soils. The physical properties of ASR-1400, as listed by the manufacturers (Assurence Corp. 2006), are minimum average roll values (MARV) and are provided in Table 1.

Table 1 Manufacturer Recommended Physical and Hydraulic Properties of ASR-1400

Property	Unit	Test Method	Minimum Average Roll Value (English)
Weight Unit Area gsm(1)	g/m^2	ASTM D-5261	70
Weave			10 × 10
Grab Tensile	lb	ASTM D-4632	100
% Grab Elongation @ Yield	%	ASTM D-4632	15
Mullen Burst	psi	ASTM D-3786	220
Puncture	lb	ASTM D-4833	40
Trapezoidal Tear	lb	ASTM D-4533	40
UV Resistance @ 500 hours	%	ASTM D-4355	80
AOS(2)	US sieve No.	ASTM D-4751	30
Permittivity	sec^{-1}	ASTM D-4491	0.05
Flow Rate	gal/min/ft	ASTM D-4491	6

(1) Reported in SI units by Manufacturer
(2) maximum average roll values

3.2.1.2 Belted Strand Retention Fabric (BSRF) Silt Fence

The fabric used is a spunbond polyester material reinforced with a fiberglass scrim (coarse mesh-like material) or net, sandwiched in between layers. This process makes the fabric and the scrim as one. It is a nonwoven biodegradable fabric. BSRF silt fence material was obtained from Silt-Saver in Georgia. The manufacturers' reported physical and hydraulic properties of BSRF (Risse, Thompson and Governo 2007) are presented in

Table 2 below.

Table 2 Manufacturers' Specification of Physical and Hydraulic Properties for BSRF

Property	Unit	Test Method	Manufacturers Specification
Grab Tensile Strength-warp	lb	ASTM D-4632	95
Grab Tensile Strength-sewn	lb	ASTM D-4632	95
Elongation	%	ASTM D-4632	68
Apparent Opening Size	US Sieve No.	ASTM D-4751	70
Permittivity	s^{-1}	ASTM D-4191	
Flow Rate/Flux	gpm	ASTM D-5141	185
Ultraviolet Stability	% at 500 hours	ASTM D-4355	26.3

Table 3 presents FDOT recommended specifications for erosion control silt fence (FDOT Design Standards 2006) and Table 4, the ASTM specification for silt fence (ASTM Standard D6461-99 2007).

Table 3 FDOT Geotextile Criteria for Erosion Control Silt Fence (Type III E-1)

Test	Unit	Test Method	Standard Criteria
Permittivity	sec^{-1}	ASTM D-4491	0.05
AOS	US Sieve No.	ASTM D-4751	NA
Elongation nonwoven	%	ASTM D-4632	NA
Elongation woven	%	ASTM D-4632	NA
Grab Tensile Strength	kN (lb)	ASTM D-4632	0.40 (90)
Sewn Strength	kN (lb)	ASTM D-4884	0.36 (81)
Puncture	kN (lb)	ASTM D-4833	NA
Trapezoidal Tear	kN (lb)	ASTM D-4533	0.155 (35)
U.V. Resistance	% Retained	ASTM D-4355	80
U.V. Resistance	Hours	ASTM D-4355	500
Filtration Efficiency	%	ASTM D-5141	75
Flow rate	L^3/min	ASTM D-5141	0.3 gal.

Table 4 ASTM D 6461 Temporary Silt Fence Material Property Requirements

	Direction	Test Methods	Units	Supported Silt Fence	Unsupported Silt Fence	Type of Value
Grab Strength	Machine	ASTM D 4632	N (lbs)	400 (90)	550 (90)	MARV
	X-Machine			400 (90)	450 (90)	MARV
Permittivity		ASTM D 4491	sec^{-1}	0.05	0.05	MARV
Apparent Opening Size		ASTM D 4751	Mm (US Sieve #)	0.60 (30)	0.60 (30)	Max. ARV
Ultraviolet Stability		ASTM D 4355	% Retained Strength	70% after 500 hours of exposure	70% after 500hours of exposure	Typical

Subsequently, detailed procedures, results and discussions are presented on the different tests conducted on both BSRF and Type III silt fences.

3.2.2 ASTM D4632-08 – Grab Breaking Load and Elongation of Geotextiles

Test on the grab breaking load and elongation on BSRF and Type III silt fence materials were conducted in accordance with the ASTM D-4632-08 standard test method. The ASTM Standard describes the breaking load as the maximum force applied to a specimen in a tensile test carried to rupture and the elongation at break as the corresponding elongation. This test is applied to determine the *effective strength* of the fabric, that is, the strength of the material in a specific width with the additional strength contributed by adjacent material (ASTM Standard D4632 2008). This test method is applicable for testing geotextile specimen in both dry and wet conditions.

3.2.2.1 Specimen Preparation and Conditioning

As required by the ASTM D 4632 and where there is no reliable estimate available, fixed number of ten specimens for the machine direction and ten specimens for the cross-machine direction should be tested. Four groups of ten rectangular specimens cut 4 in. × 8 in. were used for the grab tests in the constant-rate-of-traverse (CRT) machine with the longer dimension parallel to the direction of load application for each silt fence. The groups were classified as:

- Dry condition with the longer dimension parallel to the machine direction (DMD)
- Dry condition with the longer dimension parallel to the cross-machine direction (DCMD)
- Wet condition with the longer dimension parallel to the machine direction (WMD)
- Wet condition with the longer dimension parallel to the cross-machine direction (WCMD)

Specimens tested in the wet condition were immersed in water at room temperature (70 ± 4ºF) to sufficiently wet them thoroughly. For the tests conducted on both silt fence materials, a minimum of 20 minutes was sufficient to thoroughly wet the specimens.

3.2.2.2 Test Apparatus and Procedure

The apparatus used for the test were UNITED Tensile Testing Machine of constant-rate-of-traverse (CRT) type interfaced with a computer and clamps having jaw face measuring 2 in. by 3 in. with the longer dimension parallel to the direction of load application. The testing procedure started by setting the clamps 3±0.5 inches apart, a load range of 1000 pounds at full-scale load and operating speed of 12±0.5 inches per minute. The test specimen was then firmly secured in the clamps spaced with the longer dimension parallel to the direction of load application, and specimen centrally located in the widthwise direction of the clamps. The CRT machine was started and continued to run until rupture of the material. The machine is then stopped and reset to the initial gage position for the next specimen in the same category. Measurements of the breaking load and elongation for every specimen were recorded and reported for each direction and moisture conditioning by the autographic recorder. The tests were continued until acceptable ten specimen breaks were observed. Decisions to discard or accept a break were based on the ASTM D 4632. However, for the test conducted on both silt fence materials, the fixed specimen number of ten breaks was achieved. Most breaks occurred above ¼ inch of clamp edge and at more than 80 percent of the average break load for the corresponding silt fence material which is within the acceptable criteria (ASTM Standard D4632 2008), see Figure 13c.

For the elongation testing on the silt fence materials, a pretension load of 0.5 pounds was applied on the specimens before the loading was continued until rupture. Measurements of extension (each applied incremental load) were recorded on the interfaced computer in the same test the breaking strength was determined. Figure 13 (a) through (d) show the testing machine, BSRF silt fence specimen placed in the clamp before and after rupture and the interfaced computer, respectively.

a

b

c

d

Figure 13 Grab test apparatus with BSRF sample before and after test

3.2.2.3 Results and Plots

Breaking load and apparent elongation were determined separately for the four groups: DMD, DCMD, WMD and WCMD. The breaking load was calculated by averaging the value of the breaking load for all accepted specimens of that group. The apparent elongation is the average extension at the breaking load for any specimen and is expressed as the percentage increase in length based on the initial nominal gage length of the specimen.

Table 5 presents the beak loads and strains with the computed averages, standard deviations and coefficient of variations (CVs) for BSRF silt fence.

Table 5 Grab strength and strain for BSRF silt fence

Test Number	Peak Load (lb)				Strain at Break Load (%)			
	Cross-machine Direction		Machine Direction		Cross-machine Direction		Machine Direction	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	154.63	167.48	111.98	133.77	38.62	28.63	35.49	40.69
2	168.15	162.60	142.95	132.21	33.99	33.17	44.23	35.79
3	148.20	163.91	129.90	119.39	40.09	35.49	39.87	32.81
4	161.37	172.08	132.31	130.82	38.12	33.57	41.91	33.25
5	174.28	178.96	110.34	127.55	39.99	29.40	33.61	36.28
6	154.64	187.55	138.63	140.53	39.67	34.44	37.93	37.26
7	178.34	189.88	132.80	136.82	40.70	31.44	44.04	38.73
8	170.51	180.57	135.17	143.21	40.90	30.71	40.37	35.66
9	170.51	163.06	123.25	123.53	37.09	31.88	37.67	34.03
10	151.14	165.73	141.23	141.21	33.97	37.38	43.03	41.70
Mean	**163.18**	**173.18**	**129.86**	**132.90**	**38.32**	**32.61**	**39.81**	**36.62**
Std. dev.	10.56	10.34	11.38	7.84	2.57	2.73	3.62	3.01
CV	0.065	0.060	0.088	0.059	0.067	0.084	0.091	0.082

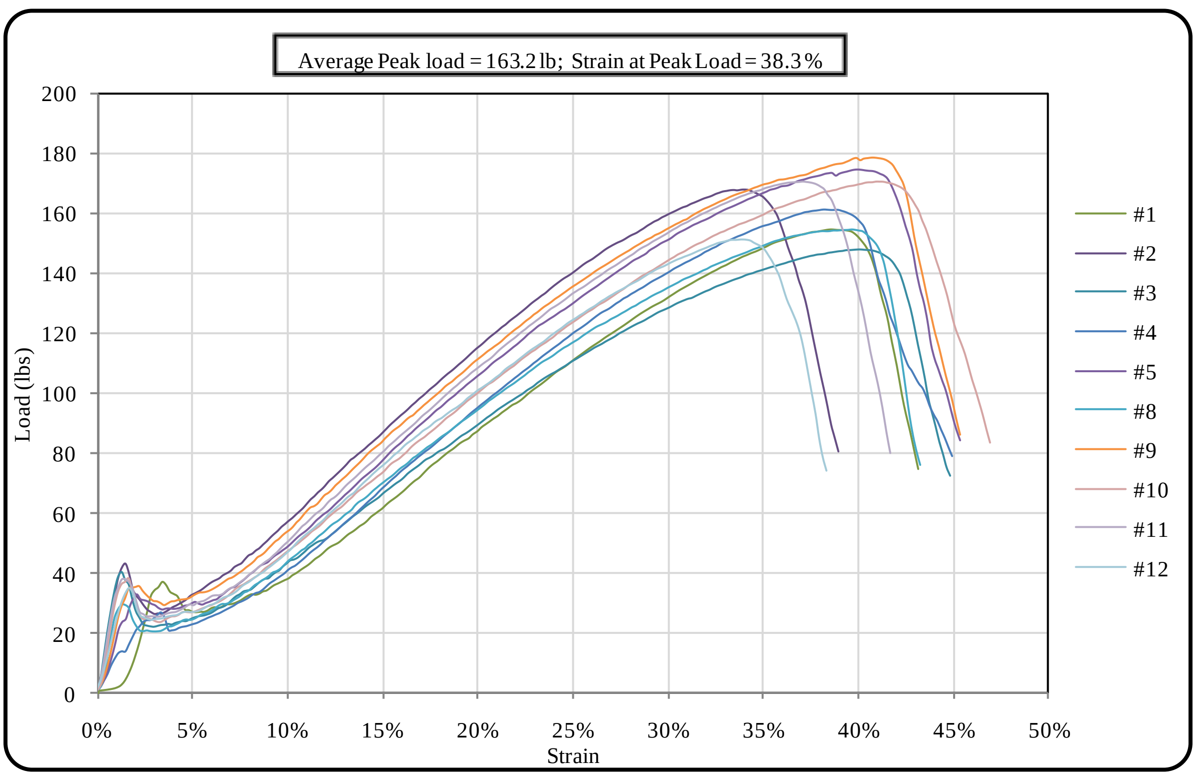


Figure 14 Load versus strain plot for dry, cross-machine direction (DCMD) on BSRF

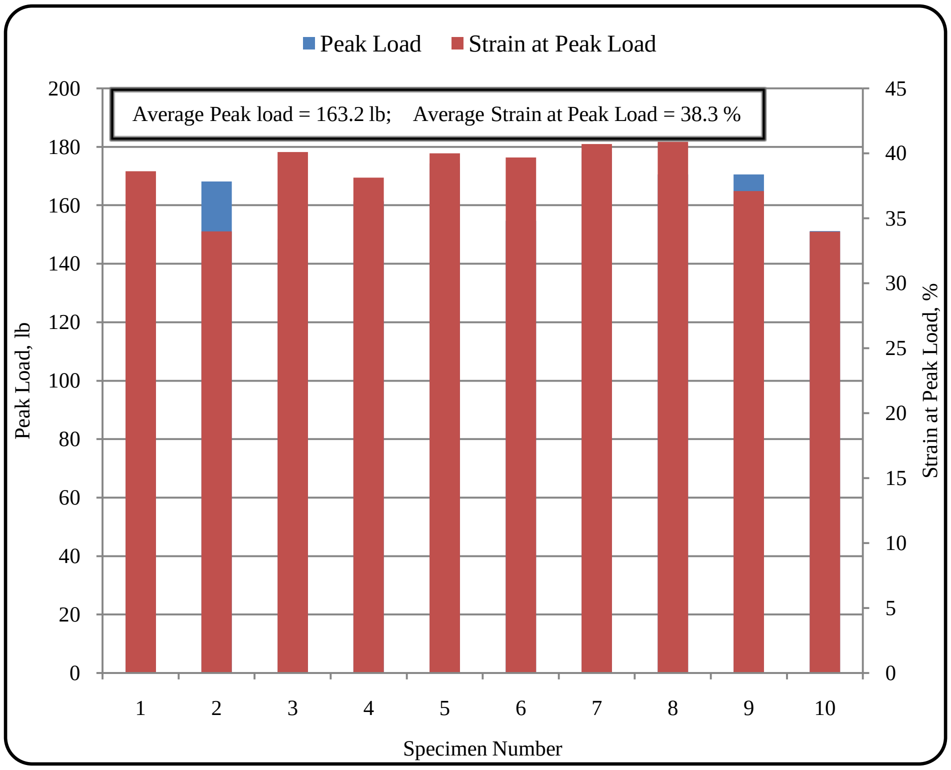


Figure 15 Peak Loads and corresponding strains for dry, cross-machine direction (DCMD) on BSRF

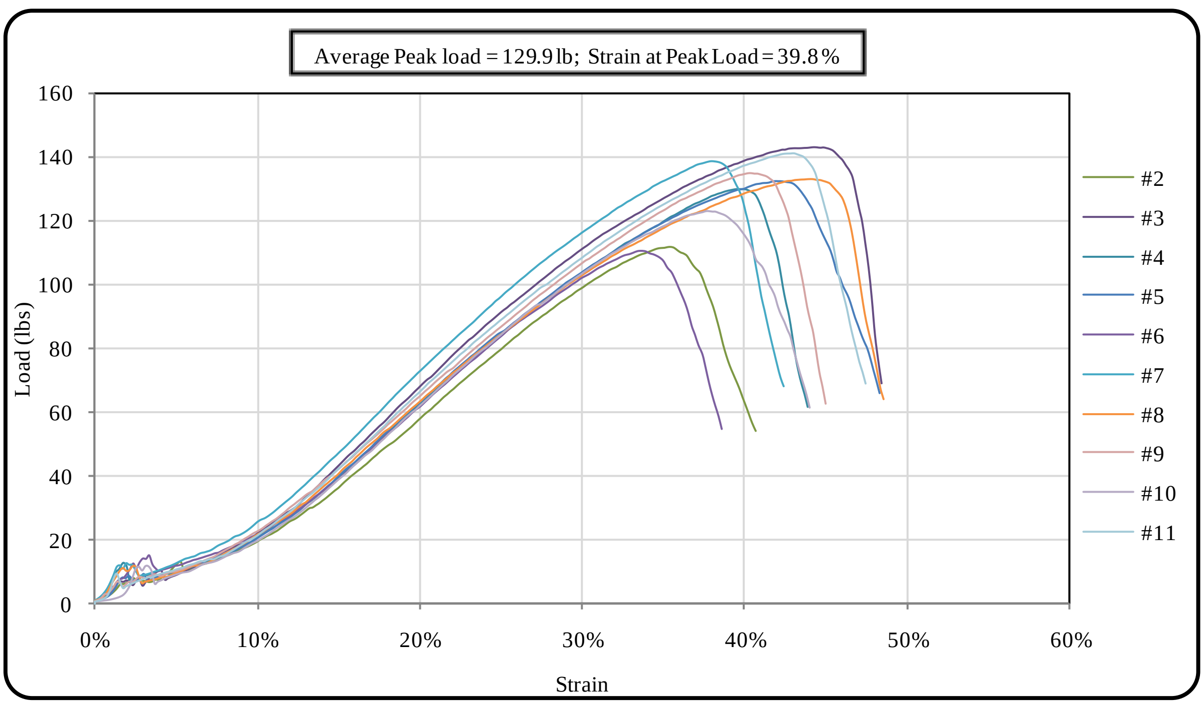


Figure 16 Load versus strain plot for dry, machine direction (DMD) on BSRF

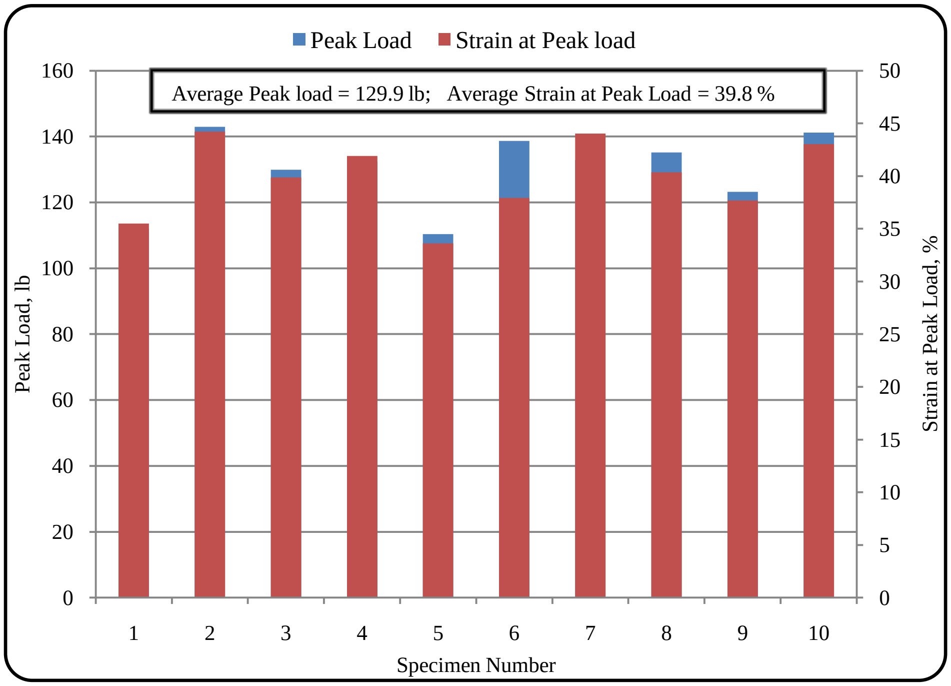


Figure 17 Peak Loads and corresponding strains for dry, machine direction (DMD) on BSRF

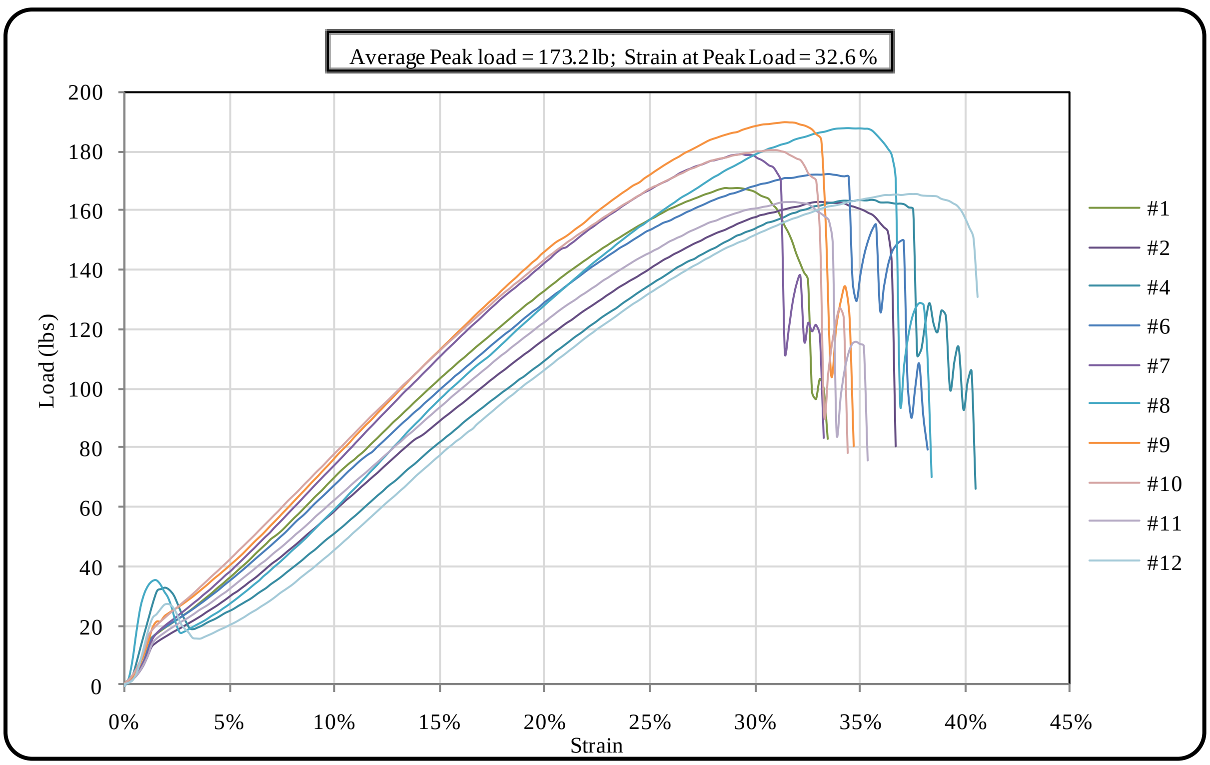


Figure 18 Load versus strain plot for wet, cross-machine direction (WCMD) on BSRF

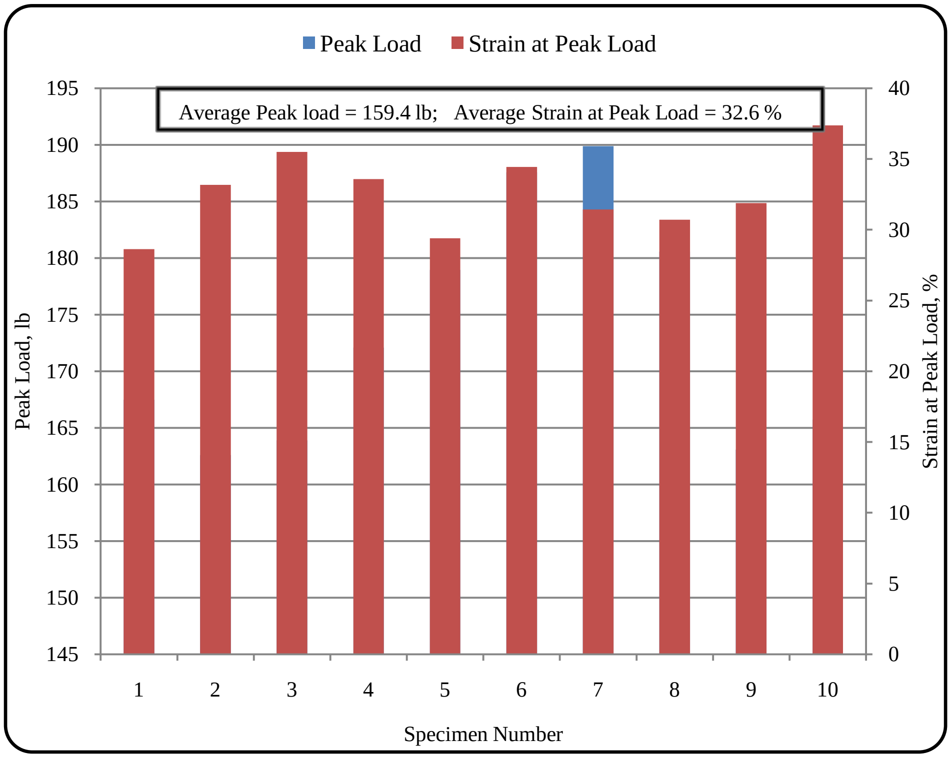


Figure 19 Peak Loads and corresponding strains for wet, cross-machine direction (WCMD) on BSRF

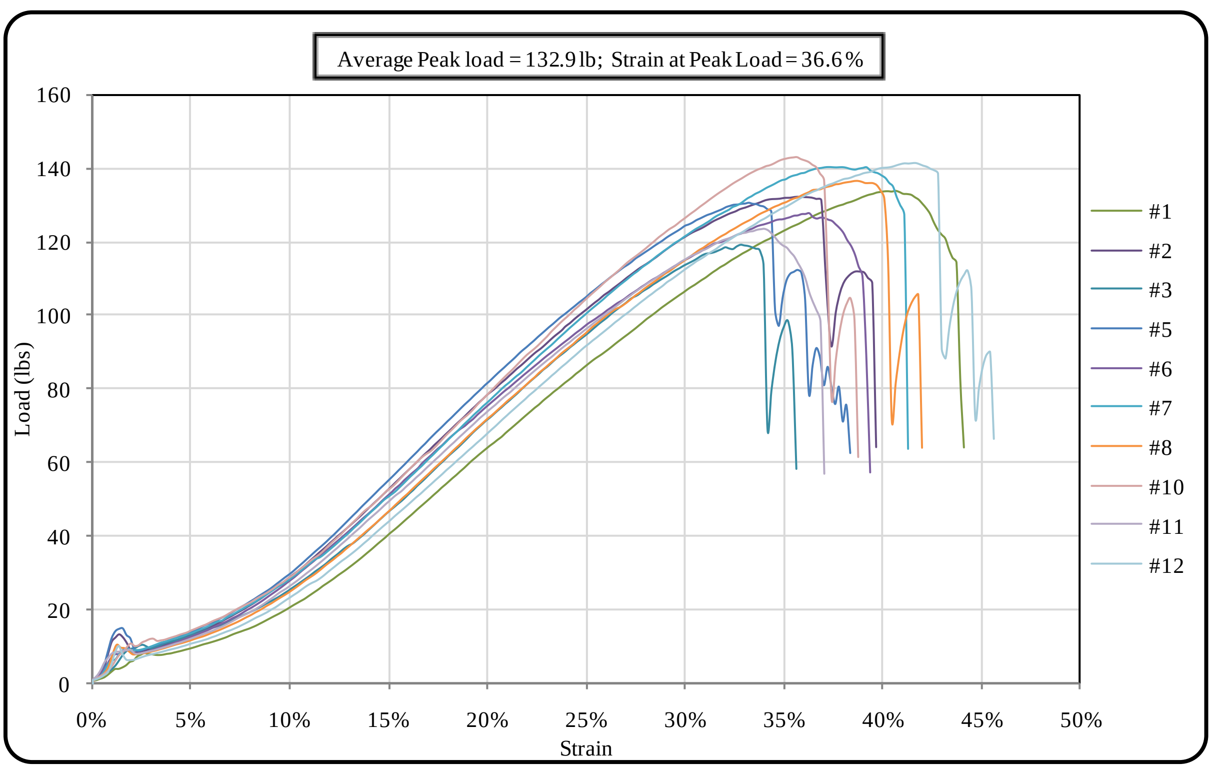


Figure 20 Load versus strain plot for wet, machine direction (WMD) on BSRF

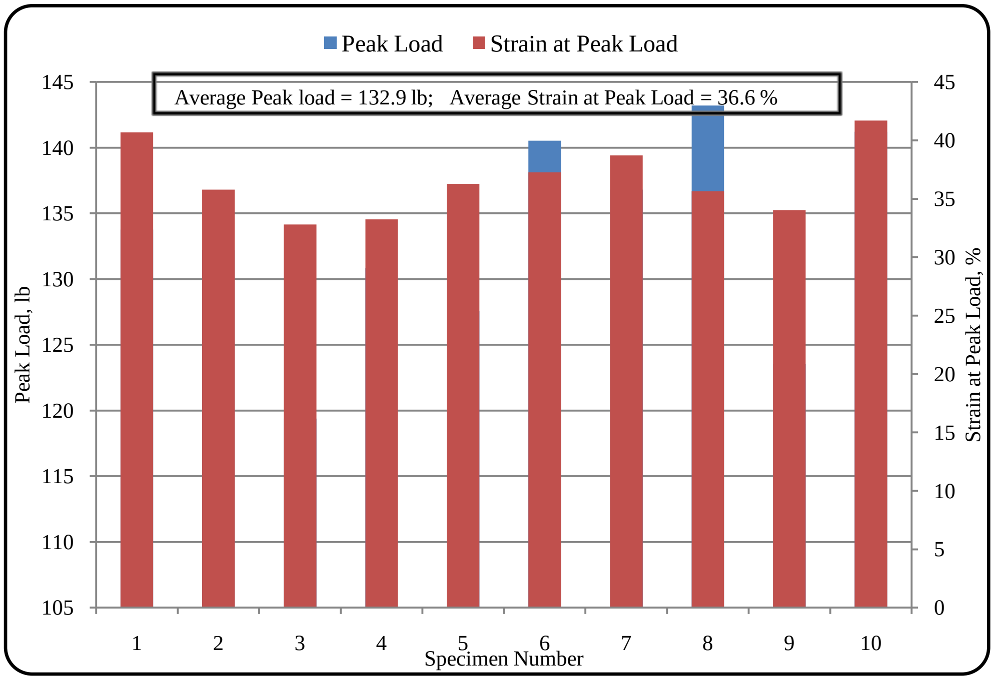


Figure 21 Peak Loads and corresponding strains for wet, machine direction (WMD) on BSRF

Grab tests on Type III silt fence were also conducted in both the machine and cross-machine directions. Table 6 presents the grab strengths and strains at peak load for Type III silt fence for ten specimens tested, and Figure 22 through Figure 29 show the plots of load versus strain and the peak loads and corresponding strains for the dry and wet conditions in both machine and cross-machine directions.

Table 6 Grab strength and strain for Type III silt fence

Test Number	Peak Load (lb)				Strain at Break Load (%)			
	Cross-machine Direction		Machine Direction		Cross-machine Direction		Machine Direction	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	151.80	106.84	111.99	117.17	9.31	5.95	9.71	9.06
2	137.45	97.78	134.08	83.59	7.62	8.77	8.09	4.20
3	144.97	98.71	154.35	131.55	6.65	9.70	7.35	10.85
4	158.74	86.84	158.38	84.13	11.51	4.13	8.52	9.69
5	118.41	87.97	126.69	118.59	3.82	7.24	7.74	7.51
6	122.68	134.79	145.21	123.01	9.49	7.83	9.26	6.41
7	132.66	129.35	162.24	139.24	4.07	6.78	6.92	9.16
8	148.95	167.97	162.60	174.11	5.54	6.51	7.45	6.77
9	150.07	178.93	159.32	141.63	8.48	7.03	9.92	7.57
10	167.39	138.80	140.16	99.03	7.48	6.69	7.04	5.06
Mean	**143.31**	**122.80**	**145.50**	**121.20**	**7.40**	**7.06**	**8.20**	**7.63**
Std. dev.	15.50	32.66	17.14	27.80	2.45	1.52	1.10	2.10
CV	0.11	0.27	0.12	0.23	0.33	0.22	0.14	0.28

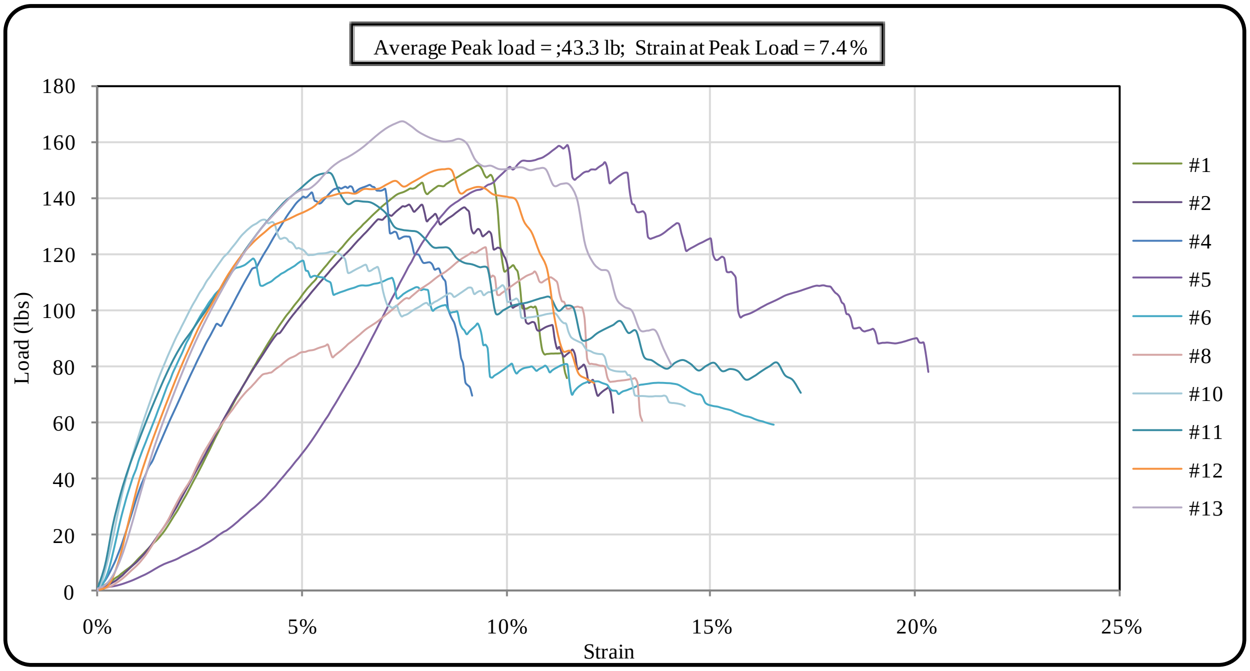


Figure 22 Load vs. strain plot for DCMD on Type III silt fence

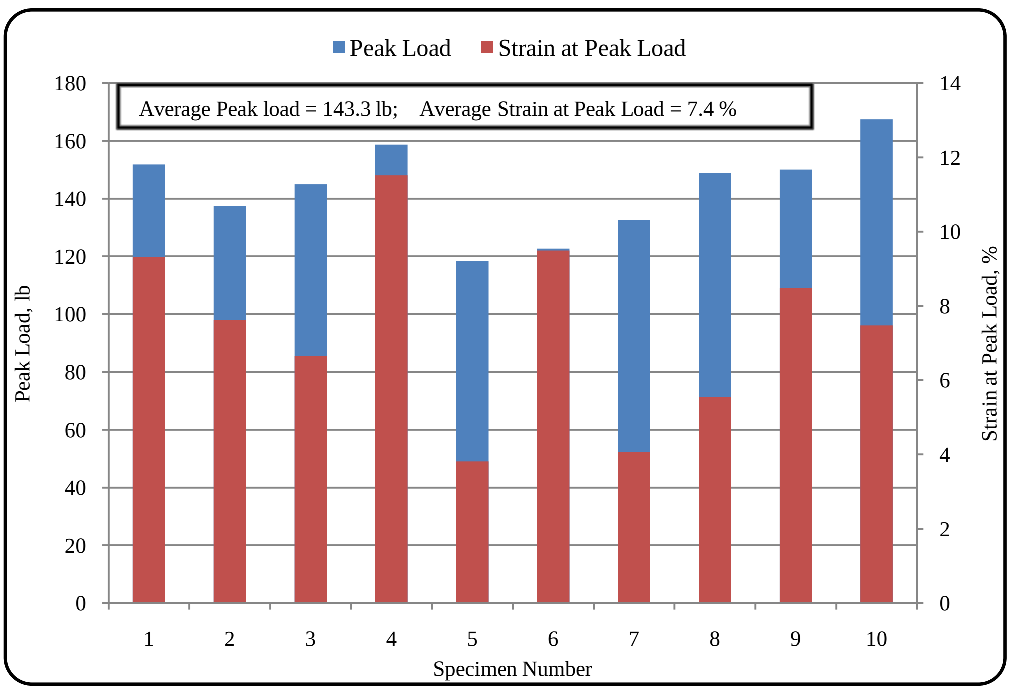


Figure 23 Peak loads and corresponding strains for DCMD on Type III silt fence

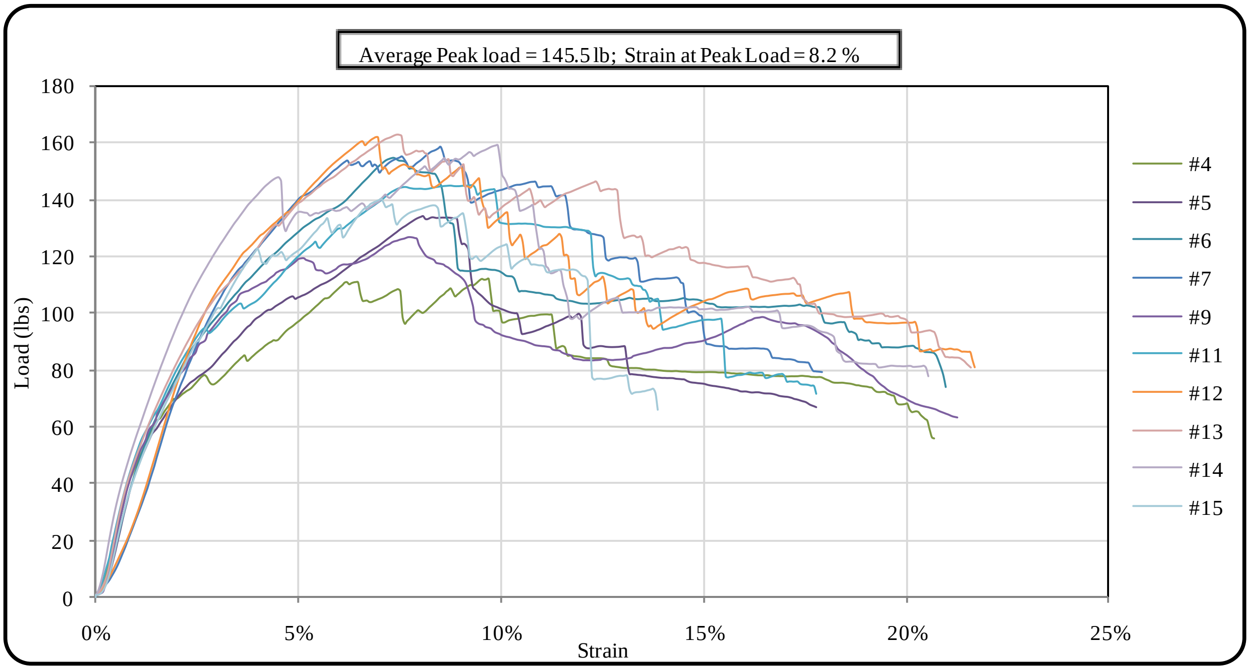


Figure 24 Load versus strain plot for DMD on Type III silt fence

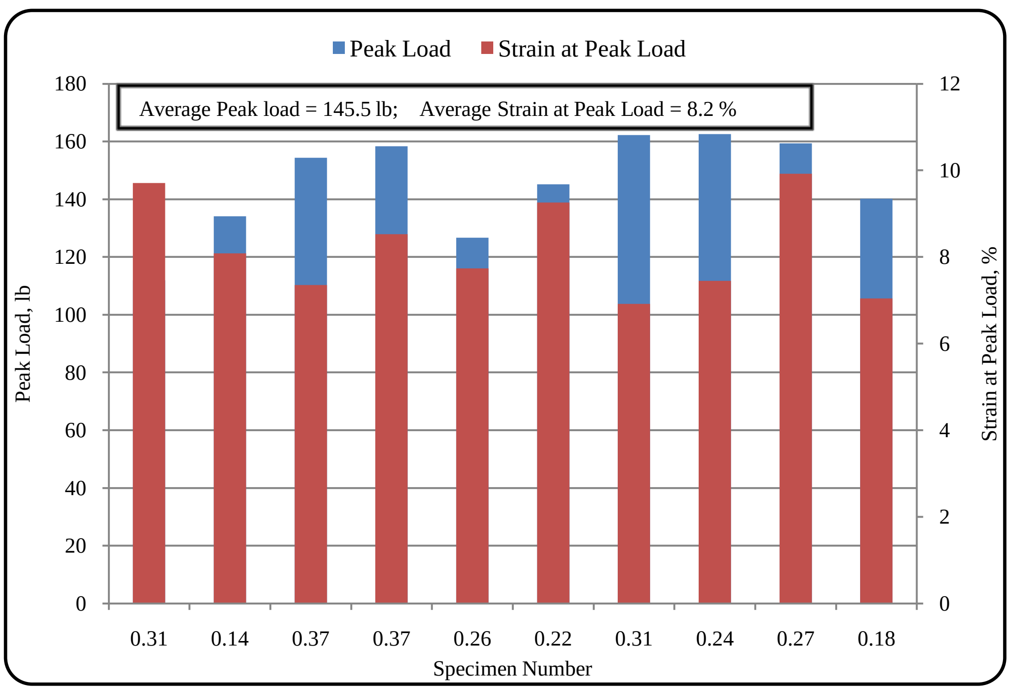


Figure 25 Peak loads and corresponding strains for DMD on Type III silt fence

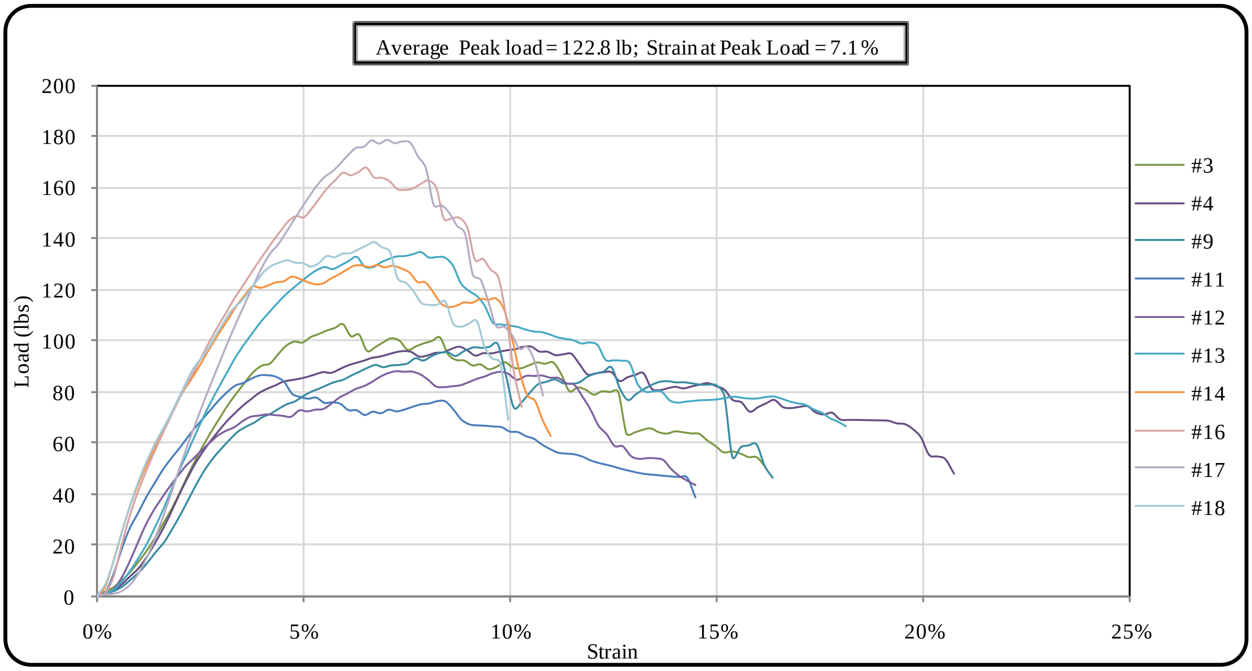


Figure 26 Load versus strain plot for WCMD on Type III silt fence

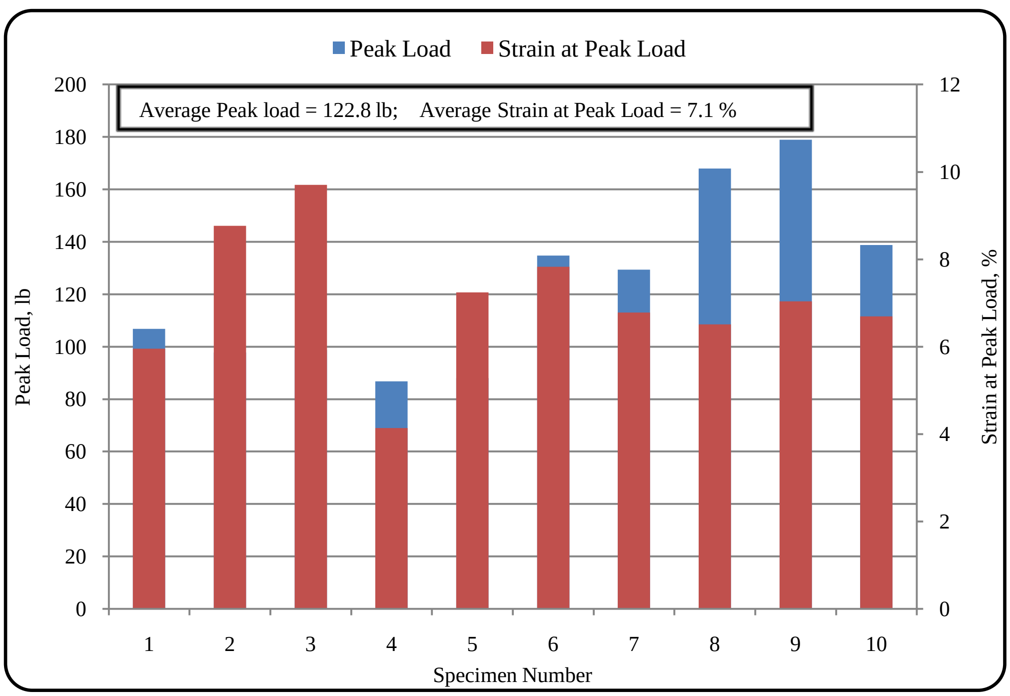


Figure 27 Peak loads and corresponding strains for WCMD on Type III silt fence

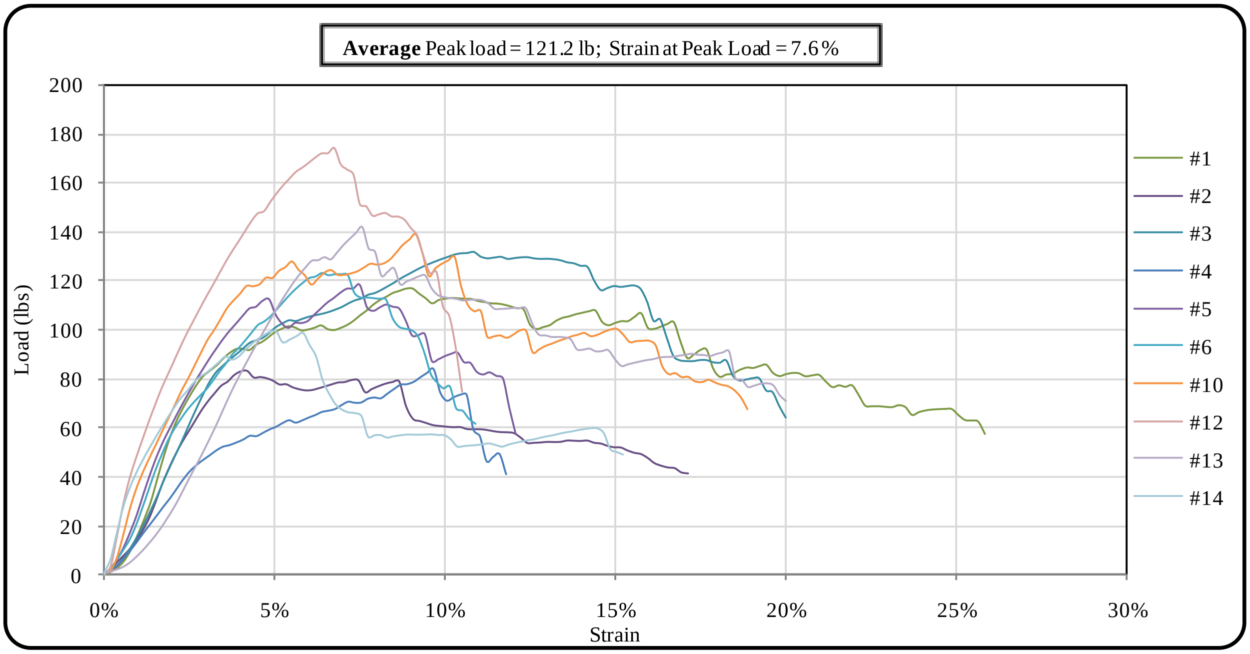


Figure 28 Load versus strain plot for WMD on Type III silt fence

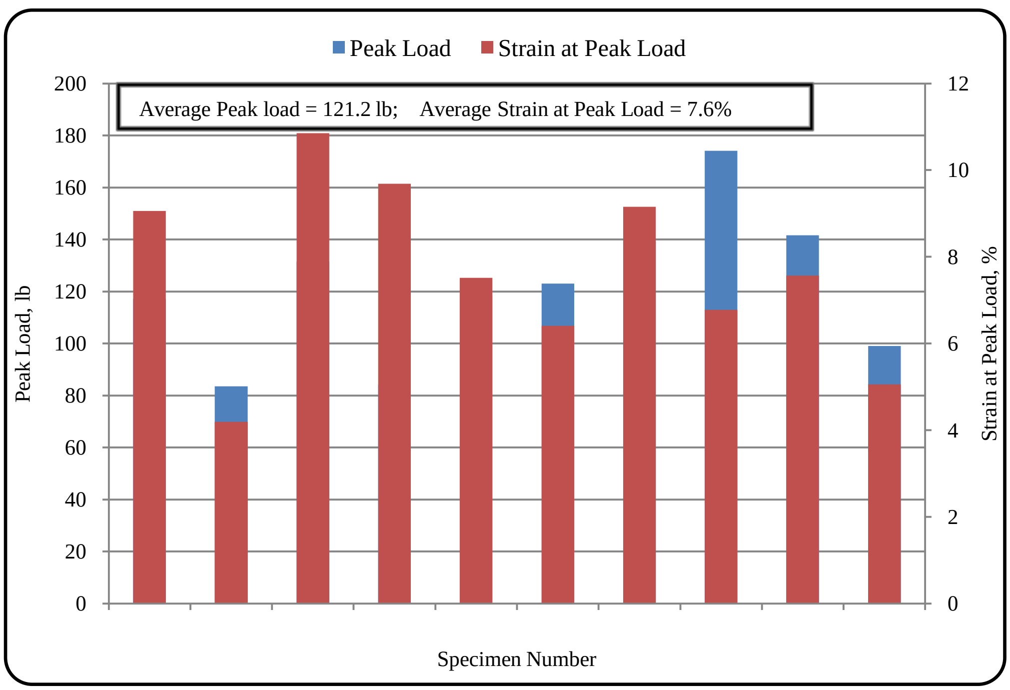


Figure 29 Peak loads and corresponding strains for WMD on Type III silt fence

3.2.2.4 Discussions

The tests were conducted to determine the grab strengths and elongations of Type III and BSRF silt fences using the grab method. It was not intended to compare both geotextiles, but test for quality control and acceptance. To determine if the results meet the minimum strength recommended by FDOT and ASTM standard specifications, statistical tests were conducted to show any statistically significant differences between test results for both geotextiles in both dry and wet conditions.

Tests were conducted to determine the proportion of the observed grab strength and elongation values that were within two standard deviations from the mean. Table 7 shows that the grab strength and strain at peak load from individual specimens of both silt fence barriers was 100 percent within two standard deviations from the mean when compared against the expected 95 percent based on the empirical rule and 75 percent based on the Chebyshev's rule for interpreting standard deviation. The respective grab strength coefficients of variation, statistical measure of the dispersion of data points in a data series around the mean, were 0.06 to 0.09 and 0.11 to 0.27 for BSRF and Type III, respectively. Similarly, the coefficients of variation of strain at peak load were 0.07 to 0.09 and 0.12 to 0.33 for BSRF and Type III, respectively. Such a low coefficient of variation indicates a distribution of low-variance. However, the frequency distribution of the samples might not be mound-shape, but asymmetric or skewed.

In cases where the distribution is not known, the Chebyshev's rule would be most appropriate for the interpretation of the results. In probability theorem, Chebyshev's theorem indicates that in any set of data sample or probability distribution, more than $(1-1/k^2)$ of the values are very close to the mean value; where k is a number greater than 1. It is most appropriate when the probability distribution is unknown for all data set which include sample or population. As an acceptance test for the test data set, all the values were above 75 percent required for Chebyshev's rule of two (k = 2) standard deviations from the respective mean values for both silt fence fabrics.

Table 7 Actual proportion within two standard deviations from the mean

Silt Fence	Condition	Grab strength		Strain at peak load	
		$\bar{y} \pm 2s$	*Actual proportion*	$\bar{y} \pm 2s$	*Actual proportion*
BSRF	DMD	(107.10, 152.61)	1.00	(32.58, 47.05)	1.00
	DCMD	(142.05, 1184.30)	1.00	(33.18, 43.45)	1.00
	WMD	(117.22, 148.59)	1.00	(30.60, 42.64)	1.00
	WCMD	(152.49, 193.87)	1.00	(27.14, 38.08)	1.00
TYPE III	DMD	(111.23, 179.78)	1.00	(5.00, 8.10)	1.00
	DCMD	(112.30, 174.32)	1.00	(2.49,12.30)	1.00
	WMD	(65.60, 176.81)	1.00	(3.43, 11.82)	1.00
	WCMD	(57.47, 188.12)	1.00	(4.02, 10.11)	1.00

3.2.2.5 Grab Strength

Table 8 presents the summary of the test results for both BSRF and Type III silt fences. These are the average values, standard deviations and coefficients of variation for the effective strength for Type III and BSRF in both wet and dry conditions, and machine and cross-machine directions. On the BSRF silt fence, the average grab strengths for the machine direction were 129.9 pounds and 132.9 pounds, and for the cross-machine direction 163.2 pounds and 173.2

pounds, in the dry and wet conditions, respectively. The difference in grab strength between the machine and cross-machine directions is due to the 0.5 in. × 1.0 in. rectangular orientation of the fiber reinforcement in the BSRF silt fence, the longer dimension is parallel to the cross-machine direction. However, statistical tests were conducted to show if there were significant differences in the grab strength and the corresponding grab elongations. The coefficients of variation were less than 1.0 for the different conditions and orientations of the BSRF silt fence, which show that the distribution has low-variance. That is, the dispersion of the test values from the calculated mean is minimal and the mean values truly represent the test results. An analysis of the coefficients of variation show that for BSRF the specimen data variations are similar, 6 percent, except for DMD having 9 percent data variation.

On the Type III silt fence, the average grab strengths for the machine direction were 145.5 pounds and 121.2 pounds, and for the cross-machine direction they were 143.3 pounds and 122.8 pounds, in the dry and wet conditions, respectively. The Type III silt fence is a woven geotextile with no significant difference in the orientation of the weaves; the differences cannot be explained without conducting statistical test. However, the coefficients of variation show a distribution of low-variance; for the machine and cross-machine directions, they were 11 and 12 percent, and 27 and 23 percents, for dry and wet conditions, respectively.

For further comparison of the results obtained in the grab tests, Student's t-test was conducted to explain the differences between the silt fence orientation and moisture conditions. The Student's *t*-test is recommended by the ASTM to compare test results from different laboratories and is considered appropriate to test for significant differences (ASTM Standard D4632 2008). However, the probability distribution is not readily known. An Analysis of variance (ANOVA) – a non-parametric test – was also conducted because of insufficient knowledge to assume any normality distribution which might lead to error in the statistical test outcomes.

Table 8 Summary results on grab strength and strain at peak loads for both silt fences

Silt Fence	**Test Condition**	**Grab Strength (lb)** Average	Standard deviation	Coefficient of variation	**Strain at peak load (%)** Average	Standard deviation	Coefficient of variation
BSRF	DCMD	163.2	10.6	0.06	38.32	2.57	0.07
	DMD	129.9	11.4	0.09	39.81	3.62	0.09
	WCMD	173.2	10.3	0.06	32.61	2.73	0.08
	WMD	132.9	7.8	0.06	36.62	3.01	0.08
Type III	DCMD	143.3	15.5	0.11	7.40	2.45	0.33
	DMD	145.5	17.2	0.12	6.55	0.78	0.12
	WCMD	122.8	32.7	0.27	7.06	1.52	0.22
	WMD	121.2	27.8	0.23	7.63	2.10	0.28

The Student's *t*-test and ANOVA tests were conducted on a significance level of 5percent ($\alpha = 0.05$) to determine if there are differences between each silt fence material tested in dry and wet conditions for both machine and cross-machine directions. Both test methods have same conclusions as could be seen in

Table 9 and

Table 10 for the Student's *t*-test and ANOVA, respectively.

Table 9 Student's t-test results on peak loads for BSRF and Type III silt fences

Silt Fence Material	Null Hypothesis, H_0	Alternative Hypothesis, H_1	Significance level, α-level	*p*-value	Decision
BSRF	DCMD = DMD	DCMD ≠ DMD	0.05	0.000	Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.000	Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.021	Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.382	Do not Reject H_0
TYPE III	DCMD = DMD	DCMD ≠ DMD	0.05	0.753	Do not Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.844	Do not Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.081	Do not Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.015	Reject H_0

Table 10 ANOVA test results on peak loads for BSRF and Type III silt fences

Silt Fence Material	Null Hypothesis, H_0	Alternative Hypothesis, H_1	Significance level, α-level	*p*-value	Decision
BSRF	DCMD = DMD	DCMD ≠ DMD	0.05	0.0000	Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.0000	Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.0463	Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.4943	Do not Reject H_0
TYPE III	DCMD = DMD	DCMD ≠ DMD	0.05	0.7676	Do not Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.9078	Do not Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.0896	Do not Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.0302	Reject H_0

The decisions from both Table 9 and

Table 10 show that the null hypotheses of equal means can be rejected and the alternative hypotheses accepted for BSRF silt fence between DCMD and DMD, WCMD and WMD, and DCMD and WCMD. However, the null hypothesis of equal means cannot be rejected for BSRF between DMD and WMD; so the assumption of equal means is acceptable. This implies that there are significant differences in the peak loads for BSRF silt fence material stressed in machine and cross machine directions for both dry and wet conditions. This is in agreement with the observation of the rectangular orientation of the fiber reinforcing strands in the geotextile. There is also statistically significant difference in the grab strength of dry and wet BSRF silt fence stressed along the cross-machine direction. However, the observed p-value on the BSRF between DCMD and WCMD is approximately equal to the significant level of 0.05, which could lead to a decision of *do not reject* the null hypothesis of equal means. No significant difference was observed when the BSRF silt fence was stressed in the machine direction, at a significance level of 0.05, in both dry and wet moisture conditions. It is statistically reasonable to assume that the moisture condition of the BSRF does not affect the grab strength at a significance level of 0.05.

Statistical test results on Type III silt fence show no significance difference in grab strength between DCMD and DMD, WCMD and WMD, and DCMD and WCMD. However, the null hypothesis of equal means for Type III between DMD and WMD can be rejected at a significance level of 0.05; so an assumption of unequal means is acceptable. The results show that the difference in the average means between machine and cross-machine directions of Type III silt fence, in both dry and wet moisture conditions, were not statistically significant. However, the results show that the hypothesis of equal means can be rejected for Type III between DMD and WMD, but cannot be rejected between DCMD and WCMD. This discrepancy from the earlier conclusion of no significant difference between machine and cross-machine direction of Type III silt fence could be attributed to the observed slippage from the clamps attached to the tensile testing machine. The observation of slippage and the resultant varying grip pressure of the clamps on the geotextile led to more specimens tested to acceptable results, which might have led to the statistical test rejection of equal means between DMD and WMD. More grab tests are recommended on the Type III silt fence with known grip pressure on the specimens to resolve the differences observed.

3.2.2.6 Strain at Peak Load

Table 8 presents the average values of the strain at peak load and the corresponding standard deviations and coefficients of variation for Type III and BSRF in both wet and dry conditions, and in machine and cross-machine directions. On the BSRF silt fence, the average strains at peak load for the machine direction were 29.7 percent and 27.7 percent, and for the cross-machine direction 29.2 percent and 25.4 percent, in the dry and wet conditions, respectively. The coefficients of variation show distribution with low-variance of 7 to 9 percent variability of the strain data series. The average strain values for Type III silt fence for the machine direction were 6.6 percent and 5.8 percent, and for the cross-machine direction 5.6 percent and 5.6 percent, in the dry and wet conditions, respectively. The coefficients of variation show a distribution of low-variance for the machine and cross-machine directions of 12 and 26 percents, and 34 and 23 percents for dry and wet conditions, respectively.

As with the grab strength, the Student's *t*-test and ANOVA tests were conducted on a significance level of 5percent ($\alpha = 0.05$) to determine if there are differences between each silt fence material tested in dry and wet conditions for both machine and cross-machine directions. Both test methods have same conclusions as could be seen in

Table 11 and

Table 12 for the Student's *t*-test and ANOVA, respectively, are shown below.

Table 11 Student's *t*- test results on strain at peak loads for BSRF and Type III silt fence

Silt Fence Material	Null Hypothesis, H_0	Alternative Hypothesis, H_1	Significance level, α-level	*p*-value	Decision
BSRF	DCMD = DMD	DCMD ≠ DMD	0.05	0.386	Do not Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.014	Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.003	Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.057	Do not Reject H_0
TYPE III	DCMD = DMD	DCMD ≠ DMD	0.05	0.217	Do not Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.540	Do not Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.760	Do not Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.458	Do not Reject H_0

Table 12 ANOVA test results on strain at peak loads for BSRF and Type III silt fences

Silt Fence Material	Null Hypothesis, H_0	Alternative Hypothesis, H_1	Significance level, α-level	*p*-value	Decision
BSRF	DCMD = DMD	DCMD ≠ DMD	0.05	0.299	Do not Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.006	Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.000	Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.046	Do not Reject H_0
TYPE III	DCMD = DMD	DCMD ≠ DMD	0.05	0.358	Do not Reject H_0
	WCMD = WMD	WCMD ≠ WMD	0.05	0.501	Do not Reject H_0
	DCMD = WCMD	DCMD ≠ WCMD	0.05	0.719	Do not Reject H_0
	DMD = WMD	DMD ≠ WMD	0.05	0.455	Do not Reject H_0

The decisions from both

Table 11 and

Table 12 show that the null hypotheses of equal means can be rejected and the alternative hypotheses accepted for BSRF silt fence between WCMD and WMD, and DCMD and WCMD. However, the null hypothesis of equal means cannot be rejected for BSRF between DCMD and DMD, and DMD and WMD; thus, the assumption of equal means is acceptable. This indicates that there are significant differences in the strains at peak loads for BSRF silt fence material strained in the cross machine directions for both dry and wet moisture conditions, and between machine and cross-machine direction in wet condition. However, there is no statistically significant difference in BSRF silt fence strained in the machine direction in both dry and wet moisture conditions, and between cross-machine directions in dry and wet conditions. Unlike the statistical test results on the grab strength, the corresponding strain values do not have same responses. Therefore, tests on the correlation between grab strength and strain at peak load for the different moisture conditions and orientation were conducted.

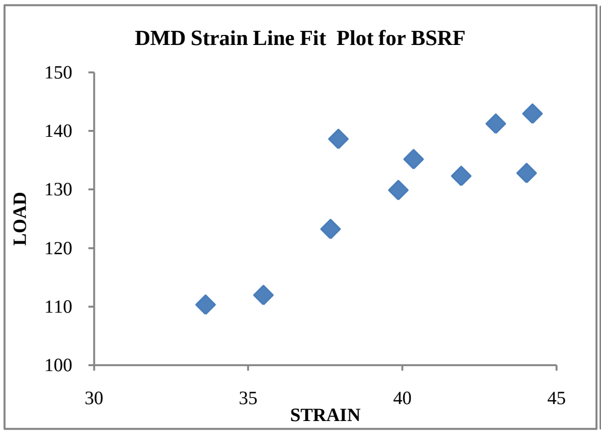
The test result, as shown in

Table 13, reveal that the 70 percent and 40 percent of the variance in grab strength and strain at peak load for BSRF is common for the dry and wet conditions in the machine direction. That is, 70 percent of strain at peak load is explained by the grab strength for DMD and 40 percent for WMD. However, only 5 percent and 7 percent of the variance in grab strength and strain at peak load is common for the dry and wet conditions in the cross-machine direction. That means high grab strength does not necessarily correspond to high strain at peak load. This could be the reason for the grab strength and strain at peak load not having similar responses to statistical tests for equal means. The results show that there is a higher correlation for BSRF silt fence when dry than wet in the machine direction, but the correlation is very weak in the cross machine direction.

Table 13 Correlation between grab strength and strain at peak load for both silt fences

Silt Fence Material	Condition	Pearson Correlation, R	R-squared	Adjusted R-squared
BSRF	DCMD	0.2259	0.0510	-0.0676
	DMD	0.8395	0.7048	0.6679
	WCMD	0.2549	0.0650	-0.0519
	WMD	0.6314	0.3987	0.3235
Type III	DCMD	0.4602	0.2117	0.1132
	DMD	0.2849	0.0811	-0.0337
	WCMD	0.0318	0.0010	-0.1239
	WMD	0.2220	0.0493	-0.0696

Statistical test results on Type III silt fence show no significant difference in strains at peak loads in all conditions and orientations, that is, between DCMD and DMD, WCMD and WMD, DCMD and WCMD, and DMD and WMD. This is in agreement with the grab strength test results as the Type III silt fences are woven with same synthetic material in both directions and therefore it strains equally. The correlation between grab strength and strain at peak load is weak for all cases of Type III silt fence with the common variances between both variables being between 5 to 21 percent. Hence, high grab strength does not necessarily correspond to high strain at peak load, nor does low grab strength correspond to a low strain at peak load. Plots of the correlations for both BSRF and Type III silt fences are shown in Figure 30 through Figure 33.



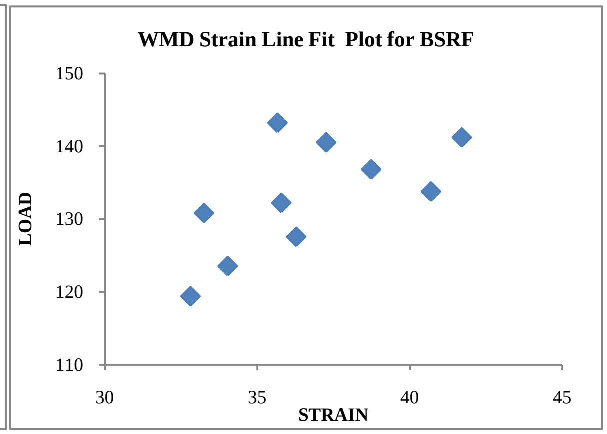
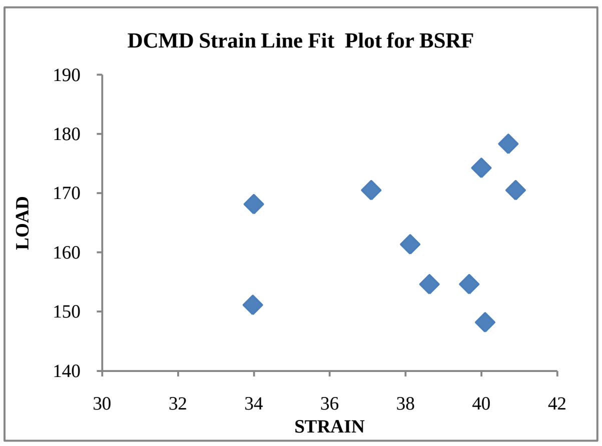


Figure 30 Correlation plot between grab strength and strain at peak load for DMD and WMD tests on BSRF



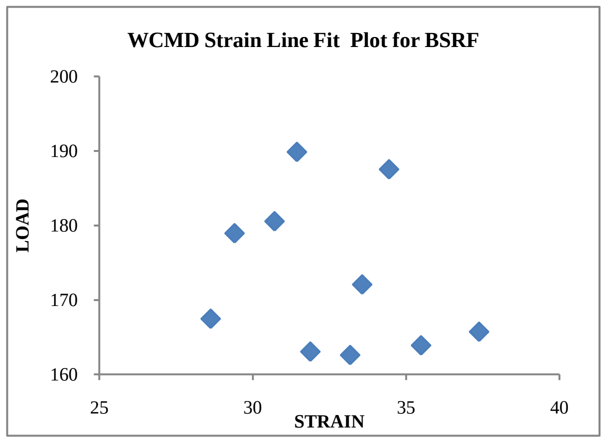
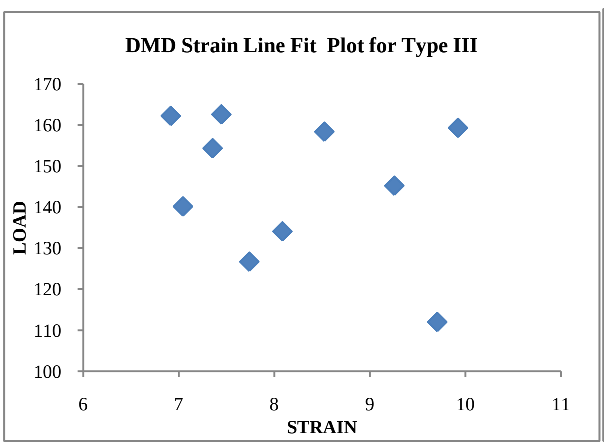


Figure 31 Correlation plot between grab strength and strain at peak load for DCMD and WCMD tests on BSRF



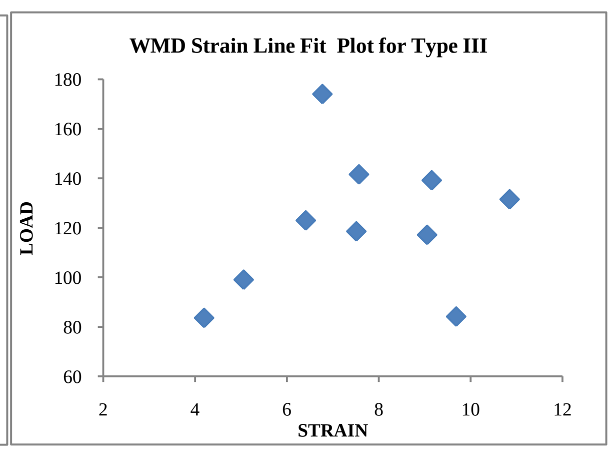


Figure 32 Correlation plot between grab strength and strain at peak load for DMD and WMD tests on Type III silt fence

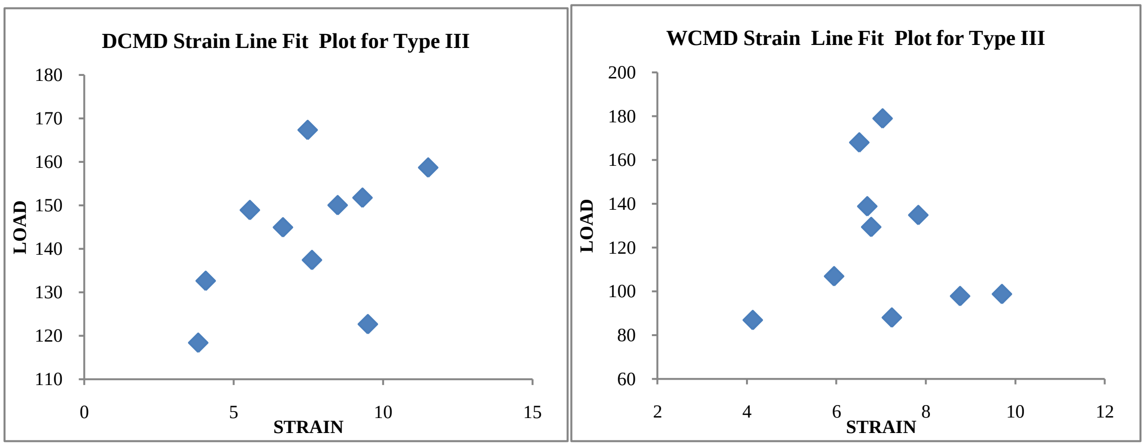


Figure 33 Correlation plot between grab strength and strain at peak load for DCMD and WCMD tests on Type III silt fence

3.2.2.7 Acceptance criteria

The tests were conducted to verify the manufacturer's specifications in Table 1 and

Table 2, and to check minimum recommendations of ASTM and FDOT in Table 3 and Table 4. Figure 34 and Figure 35 show the comparisons between the manufacturer's specifications, average test results and the FDOT and ASTM recommendations on woven and nonwoven silt fence. The observed grab strength for both silt fences were above the minimum recommendations and manufacturer's specifications. Similarly, the strain at peak load for Type III silt fence meets the minimum recommendations and specifications, but the BSRF were below the 68 percent manufacturer's specification.

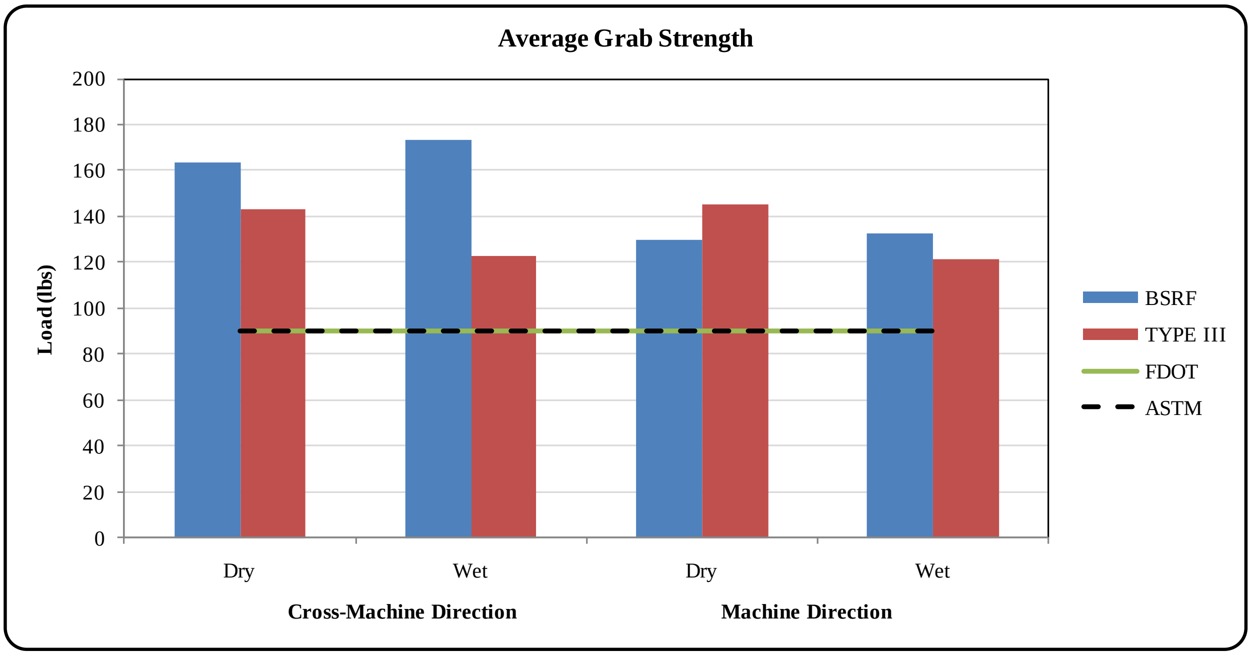


Figure 34 Comparisons of average grab strength results with specifications

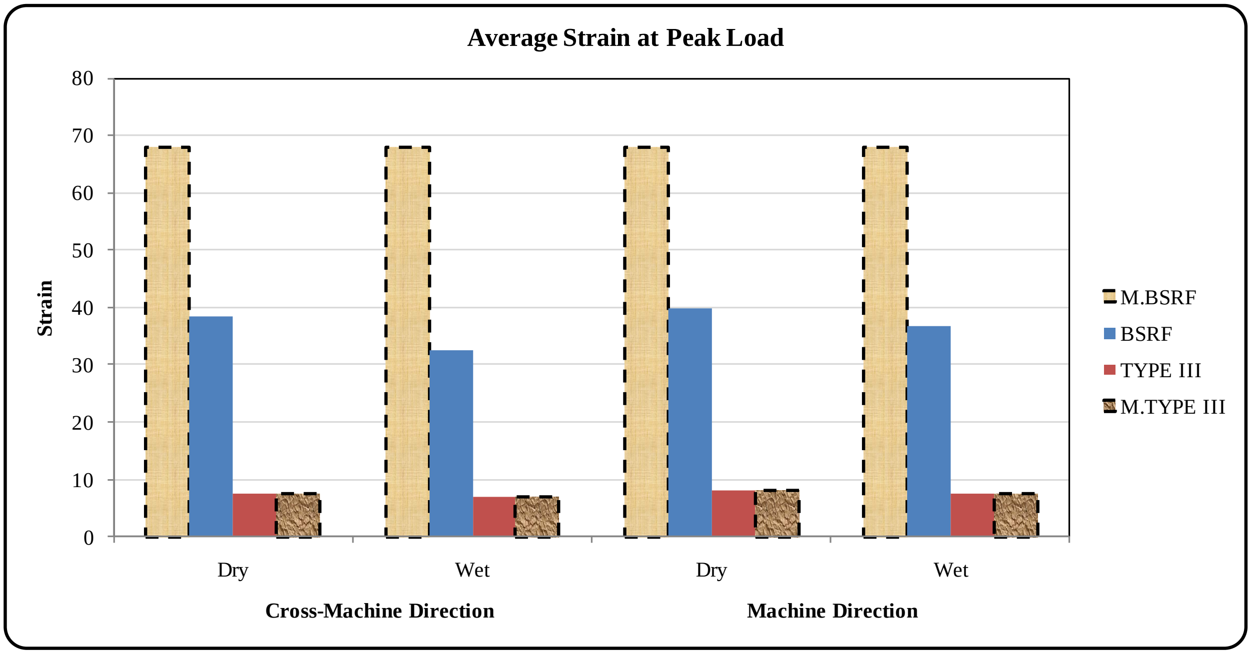


Figure 35 Comparisons of actual average strains at peak loads with manufacturers' specifications

(M stands for manufacturer)

3.2.3 D4833-00 $^{\varepsilon 1}$ 07 Standard Test Method for Index Puncture Resistance of Geomembranes, and Related Products

Tests on the index puncture resistance of the above mentioned silt fence materials were conducted in accordance of the ASTM D-4833-00$^{\varepsilon 1}$ 07 standard test method. This test method is intended to establish an index value by providing standard criteria and a basis for uniform reporting, (ASTM Standard D4833 2007). However, it is inappropriate for woven materials having large openings.

3.2.3.1 Specimen Preparation and Conditioning

Two groups of fifteen rectangular specimens cut 4.5 in. × 8 in. were used for the index puncture tests in the CRT machine for each silt fence material. Each group was classified based on the moisture conditions, that is, dry and wet. The specimens were cut from the sample rows of both geotextiles. Specimens tested in the wet condition were immersed in water at room temperature (70 ± 4ºF) to sufficiently wet them out thoroughly for at least 20 minutes.

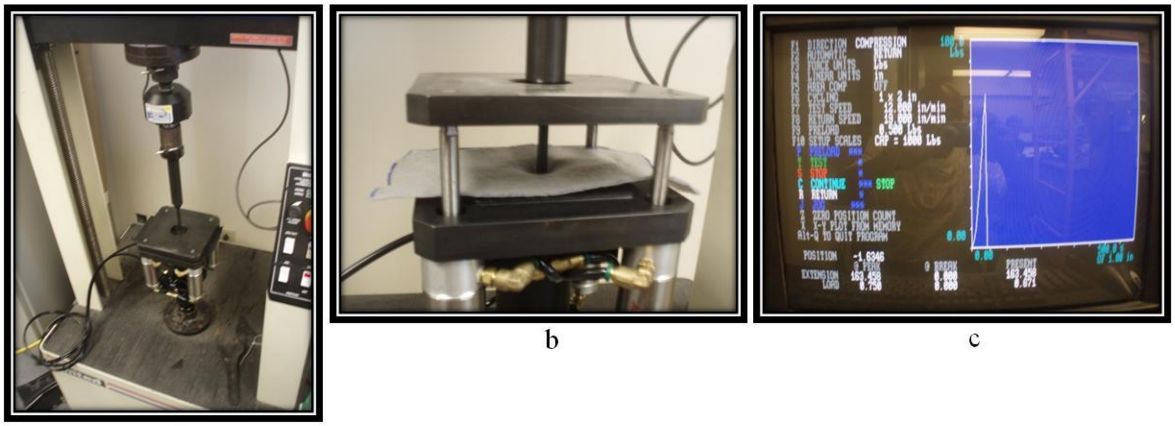
3.2.3.2 Test Apparatus and Procedure

The apparatus used for the test were UNITED tensile testing machine of constant-rate-extension (CRE) type interfaced with a computer, and rectangular clamps attachment having internal opening diameter of 1.8 inches capable of preventing slippage. The test was started by firmly securing the test specimen between the holding ring clamps attached to the CRE machine. The clamps are operated by pneumatic system with air pressure and having grooves on opposing surfaces to firmly secure the material. Connected to the CRE machine is a solid steel rod with a diameter of 0.315 inch having a flat end with 45º chamfered edge. For this test, the CRE machine was set to operate at speed of 12 ± 0.5 inches per minute with a load cell of 1000 pounds and a pretension load of 0.5 pounds applied by the steel rod on the test specimen. The CRE machine is then set to run until penetration of the test specimen and allowed to move 2 inches further downward. The machine is stopped and returned to the initial gage position for the next specimen in the same category. The interface computer records the resistance force per specimen extension until rupture for every specimen.

This process was repeated for every specimen and in both dry and wet conditions. The peak resistance force observed is recorded as the puncture resistance. Tests on the BSRF silt fence specimens produced double peaks because of the composite nature of the geotextile – the fiber mesh reinforcement. However, only the initial peak resistance force is recorded as the puncture resistance even when the second peak resistance force was observed to be higher. Figure 36 (a), (b) and (c) show the clamping arrangement, for BSRF silt fence specimen placed in the clamp during test, and the interfaced computer, respectively.

3.2.3.3 Results and Plots

Plots of the results for both silt fence materials are presented in Figure 37 through Figure 40. These are the recorded output of the resisting force of the specimen versus its extension until rupture. Two specimens (Type III 8 and Type III 9) show significant deviation in shape from the other specimens for Type III wet (see Figure 40). This was due to the steel rod penetrating slightly loosed woven strands of the silt fence, thus resulting in more extension before eventual rupture.



a b c

Figure 36 Index puncture resistance test set-up and fixtures

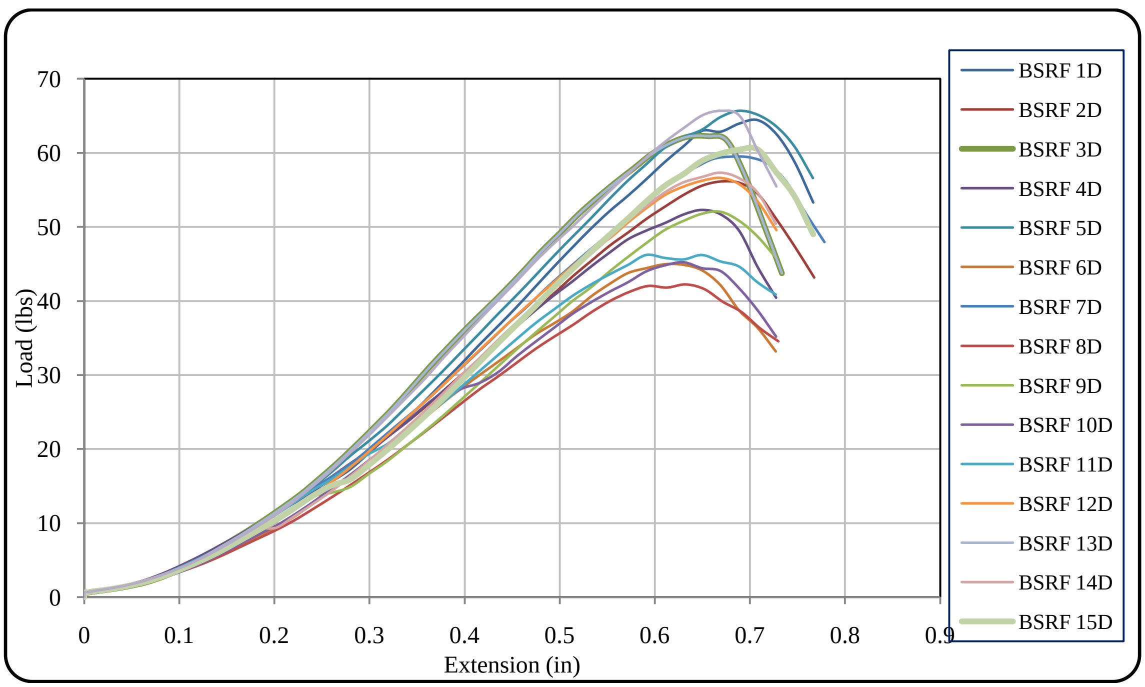


Figure 37 Puncture resistance plot for BSRF in dry condition

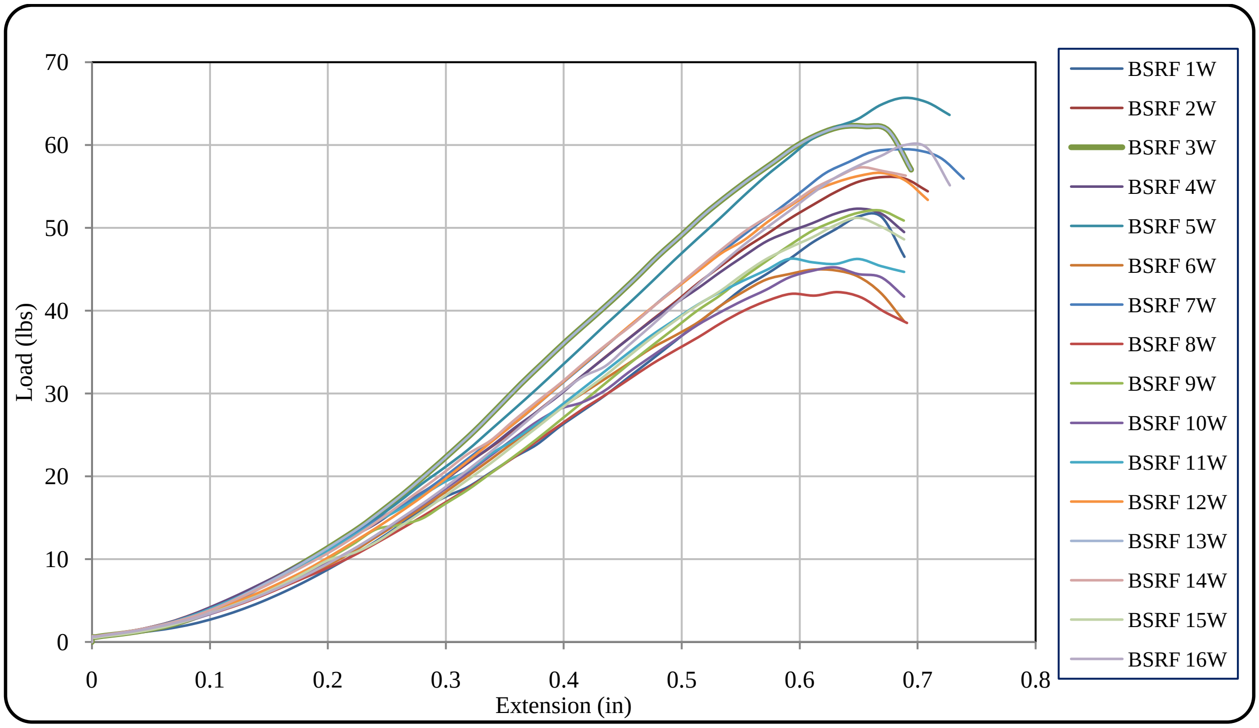


Figure 38 Puncture resistance plot for BSRF in wet condition

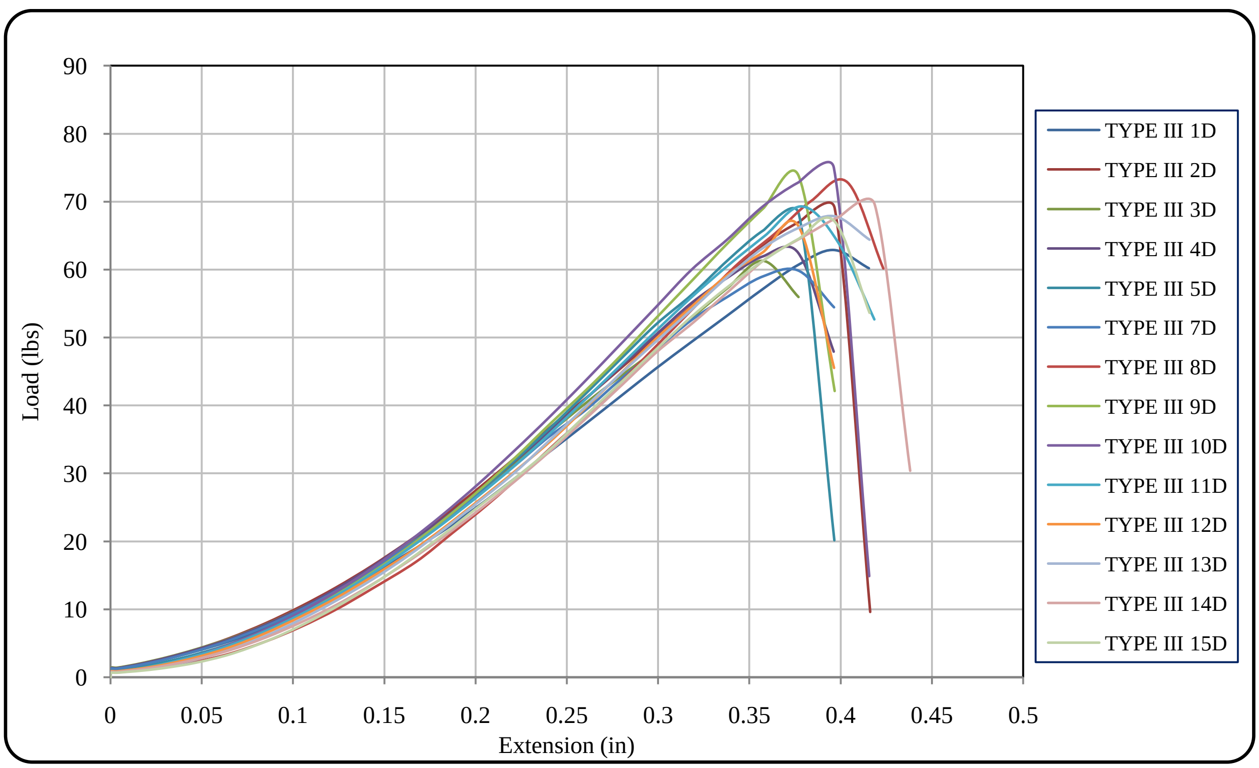


Figure 39 Puncture resistance plot for Type III in dry condition

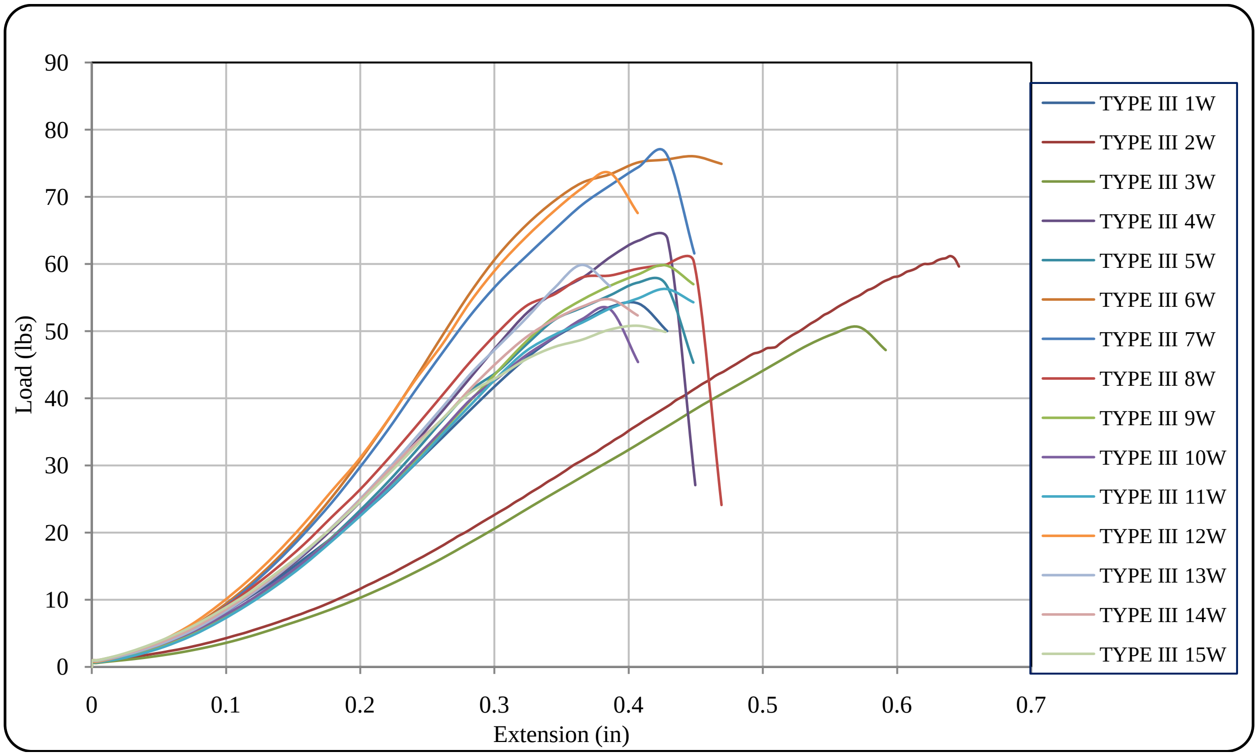


Figure 40 Puncture resistance plot for Type III in wet condition

Table 14 presents the puncture resistance values for all test specimens, and the respective averages, standard deviations and coefficient of variations. The puncture resistance ranged from 42.05 – 65.70 pounds for both dry and wet BSRF silt fence material with an average of 55.7 lbs and 54.1 pounds, respectively. For Type III silt fence, the puncture resistance ranged from 59.83 – 74.96 pounds and 50.61 – 76.49 pounds with averages of 67.5 lbs and 60.4 pounds for both dry and wet moisture conditions. The average puncture resistance, standard deviation and coefficients of variation were determined for both moisture conditions, separately.

Table 14 Summary Index Puncture Resistance Test Results for both BSRF and Type III Silt Fence Materials

Test Number	Puncture Load (lb)			
	BSRF		TYPE III	
	Dry	Wet	Dry	Wet
1	62.98	51.38	62.90	54.06
2	56.13	56.13	68.96	61.18
3	62.25	62.25	61.30	50.61
4	52.31	52.31	62.46	63.71
5	65.70	65.70	68.19	57.22
6	44.95	44.95	59.83	76.03
7	59.48	59.48	72.84	76.49
8	42.05	42.05	73.70	60.42
9	52.08	52.08	74.96	59.80
10	45.23	45.23	69.30	53.28
11	46.24	46.24	66.44	56.27
12	56.24	56.62	67.88	73.58
13	62.25	62.26	69.52	59.85
14	57.34	57.28	67.14	54.72
15	60.50	51.21	---	50.81
16	65.67	59.98	---	---
Count	16	16	14	15
Average	**55.71**	**54.07**	**67.53**	**60.54**
Standard deviation	7.76	7.04	4.62	8.56
Coefficient of variation	**0.139**	**0.130**	**0.068**	**0.141**
Minimum	42.05	42.05	59.83	50.61
Maximum	65.70	65.70	74.96	76.49

The coefficients of variation for the BSRF silt fence are 13.9 and 13.0 percents in the dry and wet moisture conditions, respectively. Variations of the puncture resistance are partly attributable to the point of penetration of the steel rod through the BSRF geotextile. The puncture resistance is higher when the steel rod makes contact with the fiberglass reinforcement, but lower puncture resistance when it contacts the polyester. For Type III silt fence, the coefficient of variation is 6.8 percent in the dry moisture condition and 14.1 percent in the wet condition (twice that of the dry). This was because immersion in water tends to ease penetration through the woven strands of the Type III geotextile.

Table 15 presents the proportion of the puncture resistance within two standard deviations from the mean for both silt fence materials in dry and wet conditions. All observed puncture resistances of the specimens of both silt fence materials were within two standard deviations from their respective means. These are above the expected 95percent based on the empirical rule and 75percent based on the Chebyshev's rule for interpretation of standard deviation. This shows that the test data variations are within probability theorem acceptance limits and thus, the mean values are true representations of the tests.

Table 15 Actual proportion within two standard deviations (s) from the mean (y)

Silt Fence Material	Condition	Puncture Resistance	
		$\bar{y} \pm 2s$	Actual proportion within 2 Standard deviation
BSRF	Dry	(40.18, 71.24)	1.00
	Wet	(39.99, 68.16)	1.00
TYPE III	Dry	(58.29, 76.77)	1.00
	Wet	(43.41, 77.66)	1.00

ANOVA statistical tests were conducted to test for any significant differences between the same silt fence materials tested in wet and dry conditions. As in the grab test analysis, ANOVA was used for this test because of insufficient knowledge to assume normality of the distribution. The ANOVA tests were conducted on a significance level of 5 percent ($\alpha = 0.05$) to determine if there are significant differences between a silt fence material tested in dry and wet conditions and between both silt fence materials. Results for the ANOVA tests are presented in

Table 16 and

Table 17 for the puncture resistances of BSRF and Type III silt fence materials.

Data from

Table 17 show that there was a significant statistical difference of the puncture resistance between the dry and wet moisture condition of Type III silt fence material at a significance level of α = 0.05. This may be due to the loose strands and slippage due to the presence of water on the geotextile when it was immersed in water. Slippage may be due to movement of the penetration rod between strands instead of puncture of the strand. For the BSRF silt fence material, the null hypothesis of equal means between dry and wet moisture conditions of the puncture resistance cannot be rejected at the significance level of α = 0.05, which is less than the *p*-value (0.54). There is no significant difference of the puncture resistance of BSRF silt fence between dry and wet moisture conditions. The moisture condition does not significantly affect the puncture resistance of BSRF silt fence.

Table 16 ANOVA test results on puncture resistance of silt fence materials in dry and wet conditions

Silt Fence Material	Condition	Null Hypothesis, H_0	Alternative Hypothesis, H_1	Significance level, α-level	*p*-value	Decision
BSRF	Dry	Dry = Wet	Dry ≠ Wet	0.05	0.5360	Do not Reject H_0
	Wet					
TYPE III	Dry	Dry = Wet	Dry ≠ Wet	0.05	0.0116	Reject H_0
	Wet					

Table 16 shows significant statistical difference of the puncture resistance between dry and wet BSRF and Type III silt fence materials. In both cases, the null hypotheses of similarity were rejected at a significance level of α = 0.05, inferring significant differences in the puncture resistance between both silt fence materials in dry and wet conditions.

Table 17 ANOVA test results on puncture resistance of silt fence materials in dry and wet conditions

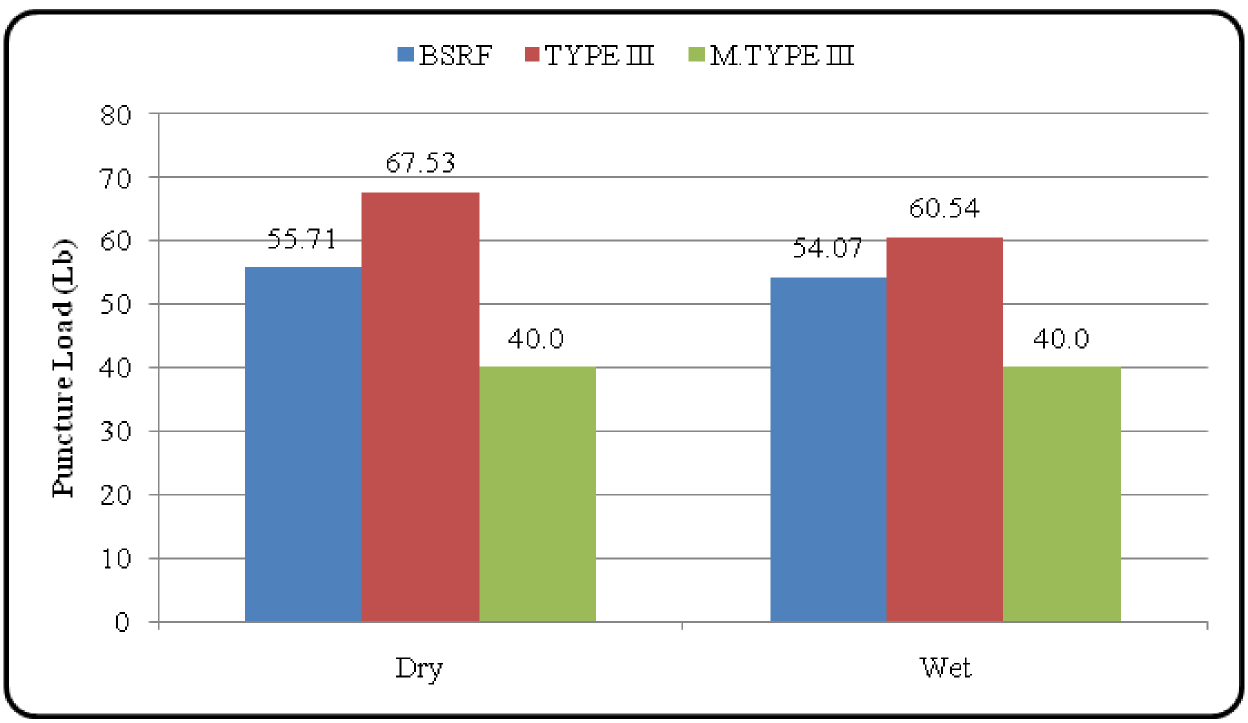
Condition	Silt Fence Material	Null Hypothesis, H_0	Alternative Hypothesis, H_1	Significance level, α-level	*p*-value	Decision
Dry	BSRF	BSRF = TYPE III	BSRF ≠ TYPE III	0.05	0.0000	Reject H_0
	TYPE III					
Wet	BSRF	BSRF = TYPE III	BSRF ≠ TYPE III	0.05	0.0287	Reject H_0
	TYPE III					

Acceptance criteriaTable 18 and Figure 41 show the comparison between the average test results and the manufacturer's specifications for Type III silt fence. The observed puncture resistance for Type III silt fence was above the manufacturer's specification. However, manufacturer's specification for the puncture resistance of BSRF silt fence is not available as the test was never conducted by the manufacturer. Both ASTM and FDOT do not have a minimum recommendation for silt fence puncture resistance.

Table 18 Average puncture resistances of BSRF and Type III silt fence materials

Silt Fence Type	Average Puncture Resistance (lb)	
	Dry	Wet
BSRF	55.71	54.07
TYPE III	67.53	60.54
*M.TYPE III	40.0	40.0

* M is manufacturer



*Manufacturer's specification for the puncture resistance of BSRF silt fence is not available.

Figure 41 Comparison of average puncture resistance between BSRF* and Type III silt fence barriers

3.2.4 D4751-04 Standard Test Method for Determining Apparent Opening Size of a Geotextile

Test on the apparent opening size (AOS) of the above mentioned silt fence materials were conducted in accordance of the ASTM D-751-04 standard test method. This index test determines the apparent opening size (AOS) of a geotextile by sieving glass beads through it. The index reflects the approximate largest opening dimension available for soil to pass through, (ASTM Standard D4751 2004).

3.2.4.1 Test Apparatus and Procedure

A mechanical sieve shaker was used for the test to induce both lateral and vertical motion to the particles on the sieve. The induced motions enable the glass beads to generate different orientations to the sieve surface for easy passage of particles smaller than the opening on the geotextile. In addition to the sieve shaker, apparatus used were sieve cover, five (5) sieve frames consisting of 8-inch diameter pans and sieves, spherical glass beads of different sizes, Explorer Pro (EP4102D) balance having accuracy of 0.01 grams and anti-static spray. See Figure 42 for AOS test apparatus and materials.

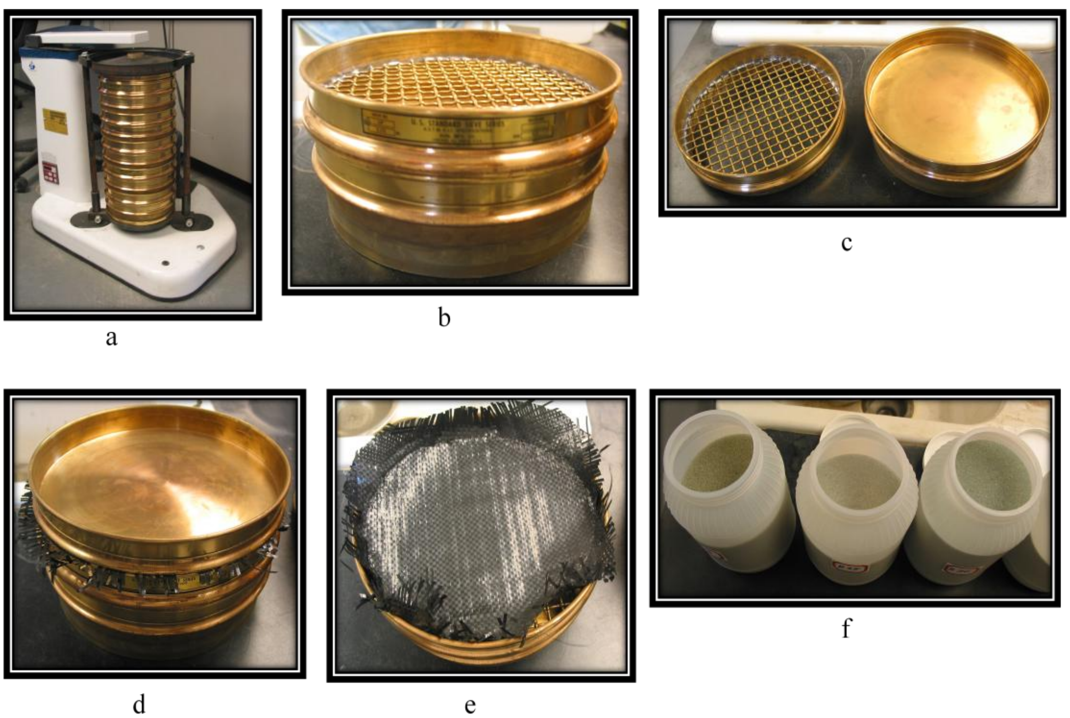


Figure 42 AOS Sieve shaker, sieve frame, glass beads and silt fence material

To test the apparent opening size of silt fence materials, five samples of each silt fence materials were cut and secured between sieve frames that they were taut and without wrinkles or bulges. Verified sizes of glass beads, weighing approximately 50 grams and starting with the smallest diameters, were placed at the center on the geotextile samples in the sieve frame. The sieve frames were covered and placed in the mechanical sieve shaker and vibrated for 10 minutes to induce jarring motion that forces the glass beads to pass through the geotextile samples.

Measurements of the weights of the glass beads retained on the specimen and those that passed through were recorded and the percentages of retained and passing were computed. This process was continued with larger glass bead sizes until the weight of beads passing through the specimen was 5 percent or less, for all five geotextile samples of both BSRF and Type III silt fence materials. Equation (1), (ASTM Standard D4751 2004) was used in the computation of the percentage of beads passing through each specimen.

$$B = 100\left(P/T\right) \tag{1}$$

where B = percentage of beads passing through specimen; P = mass of glass beads in the pan, grams; and T = total mass of glass beads used, grams.

3.2.4.2 Results and Plots

The average percent of glass beads passing through the specimen and the percent retained on the specimen were computed from the five samples for each geotextile at every bead diameter tested.

Table 19 and Table 20 present the calculated results for average percentage of glass beads passing and retained on the geotextile for the BSRF and Type III silt fence materials, respectively. The apparent opening sizes (AOS) were determined by plotting the percentage of beads passing specimen versus the bead size for every bead size used on each silt fence (Figure 43 and 44). The observed apparent opening sizes were 0.212 mm (Sieve #70) for BSRF and 0.71 mm (Sieve #30) for Type III (

Table 21).

Table 19 Average results of AOS test on BSRF silt fence material

U.S. Sieve No.	Bead diameter, (mm)	Average % passing, $O_{\%}$	Average % retained, $O_{\%}$	Average % loss
180	0.080	96.92	2.37	0.71
120	0.125	85.56	13.99	0.45
80	0.180	17.83	82.07	0.10
70	0.212	1.96	97.83	0.21

Table 20 Average results of AOS test on Type III silt fence material

U.S. Sieve No.	Bead diameter, (mm)	Average % passing, $O_{\%}$	Average % retained, $O_{\%}$	Average % loss
50	0.300	58.83	41.19	0.00
40	0.425	42.20	55.43	2.37
30	0.600	21.61	67.54	10.86
25	0.710	2.01	97.79	0.20

Table 21 AOS test result for BSRF and Type III silt fence materials

Silt Fence Material	AOS, O_{95}, (mm)	U.S. Sieve No.	Bead diameter, (mm)
BSRF	0.205	70	0.212
Type III	0.685	30	0.710

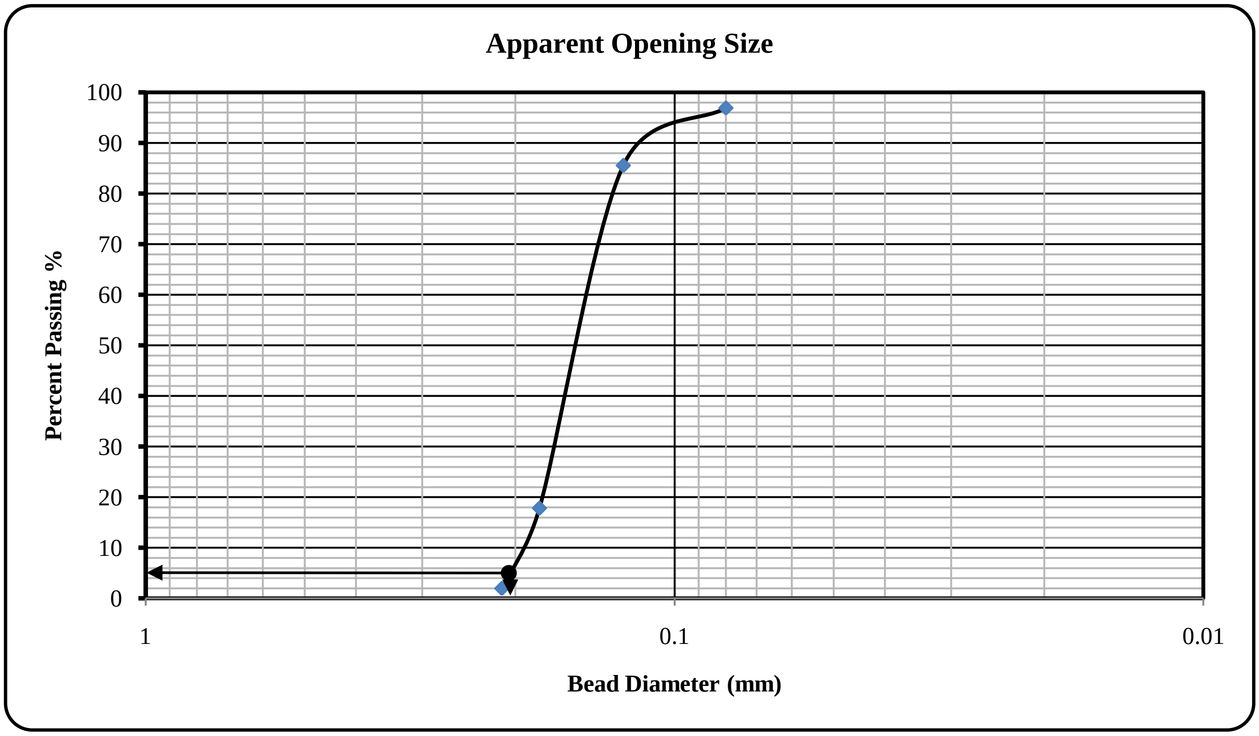


Figure 43 Plot of apparent opening size for BSRF silt fence material

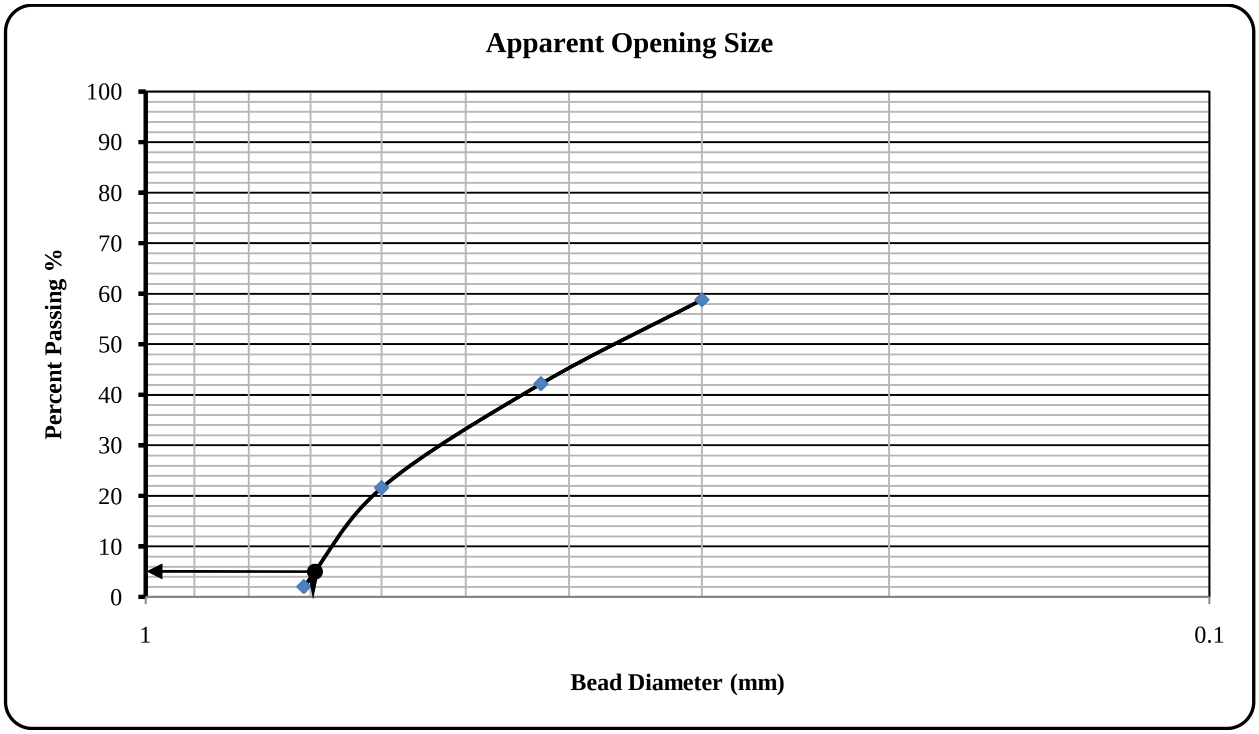


Figure 44 Plot of apparent opening size for Type III silt fence material

The AOS is determined by the number of U.S. standard sieve having nominal opening equal to or next larger than the bead diameter, in millimeter, as in

Table 22. The bead size designation is the retained-on size of the sieve pair used to size the beads. That is, AOS determined as No. 70 are beads that pass the No. 60 sieve and are retained on the No. 70 sieve.

Table 22 Glass bead sizes

Bead Size Range				**Bead Size Designation**	
Passing		**Retained**			
Opening size, mm	Sieve Number	Opening size, mm	Sieve Number	Opening size, mm	Sieve Number
2.00	10	1.70	12	1.70	12
1.40	14	1.18	16	1.18	16
1.00	18	0.85	20	0.85	20
0.71	25	0.60	30	0.60	30
0.50	35	0.425	40	0.425	40
0.355	45	0.300	50	0.300	50
0.250	60	0.212	70	0.212	70
0.180	80	0.150	100	0.150	100
0.125	120	0.106	140	0.106	140
0.090	170	0.075	200	0.075	200

Courtesy (ASTM Standard D 4751 2004)

3.2.4.3 Acceptance criteria

Table 23 shows the comparison between the average test results and the manufacturer's specification for Type III silt fence. The FDOT minimum requirements for the apparent opening size (AOS) for silt fence material is not yet specified. The observed AOS values for both BSRF and Type III silt fences meet both manufacturer's specifications and ASTM minimum recommendation.

Table 23 AOS test results, manufacturers' specification and recommendation

		U.S. Sieve No.	**Bead diameter, (mm)**
BSRF	Test	70	0.212
	Manufacturer	70	0.212
Type III	Test	30	0.600
	Manufacturer	30	0.600
FDOT		NA	NA
ASTM		30	0.600

3.2.5 D4491-04 Standard Test Method for Water Permeability of Geotextile by Permittivity

Test on the water permeability by permittivity of the above mentioned silt fence materials were conducted in accordance with the ASTM D-751-04 standard test method. This index test evaluates the volume of water that would pass through a geotextile under a given head over a particular cross-sectional area. Permittivity is defined as the "volumetric flow rate of water per unit cross sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile," and an indicator of the quantity of water that can pass through a geotextile in an isolated condition (ASTM Standard D4491-99a 2009). The nominal coefficient of permeability is obtained by the multiplication of permittivity by the thickness of the geotextile. Mathematical dimension of permittivity is presented in Equation (2) as

$$\psi = \frac{\left(L^3/T\right)L^2}{L} = \left(\frac{L}{T}\right)\cdot\left(\frac{1}{L}\right) = \frac{1}{T} = T^{-1} \tag{2}$$

This test method uses both the constant-head or falling-head test procedures. The falling head test is used when the flow rate through the geotextile is slow enough to allow the reading of head changes with time. When the flow rate is large that measurement of head change with time is difficult, then the constant head test is used. For the tests conducted on both BSRF and Type III silt fence materials, only the constant head test was performed.

3.2.5.1 Test Specimen Preparation and Conditioning

To avoid experimental errors due to air dissolved in water and to make test results reproducible, water from the mains in the laboratory was passed through a de-airing device (Figure 45b) under a vacuum of 28-inch of mercury to bring down the dissolved oxygen content. Prepared test water is drained slowly from the de-airing chamber into a 6-gallon plastic container, which is then lifted up using a pulley device, and discharged into a storage tank under slight vacuum until room temperature was attained. Four specimens (Figure 45c and d) from each silt fence material were cut to fit the testing apparatus (Figure 45a). For this test, the samples were 3-inches in diameter. The cut geotextile specimen is placed in a sample holder and secured tightly between the holder top and base, then immersed in de-aired water at room temperature (70 ± 4ºF) for 2-hours prior to testing.

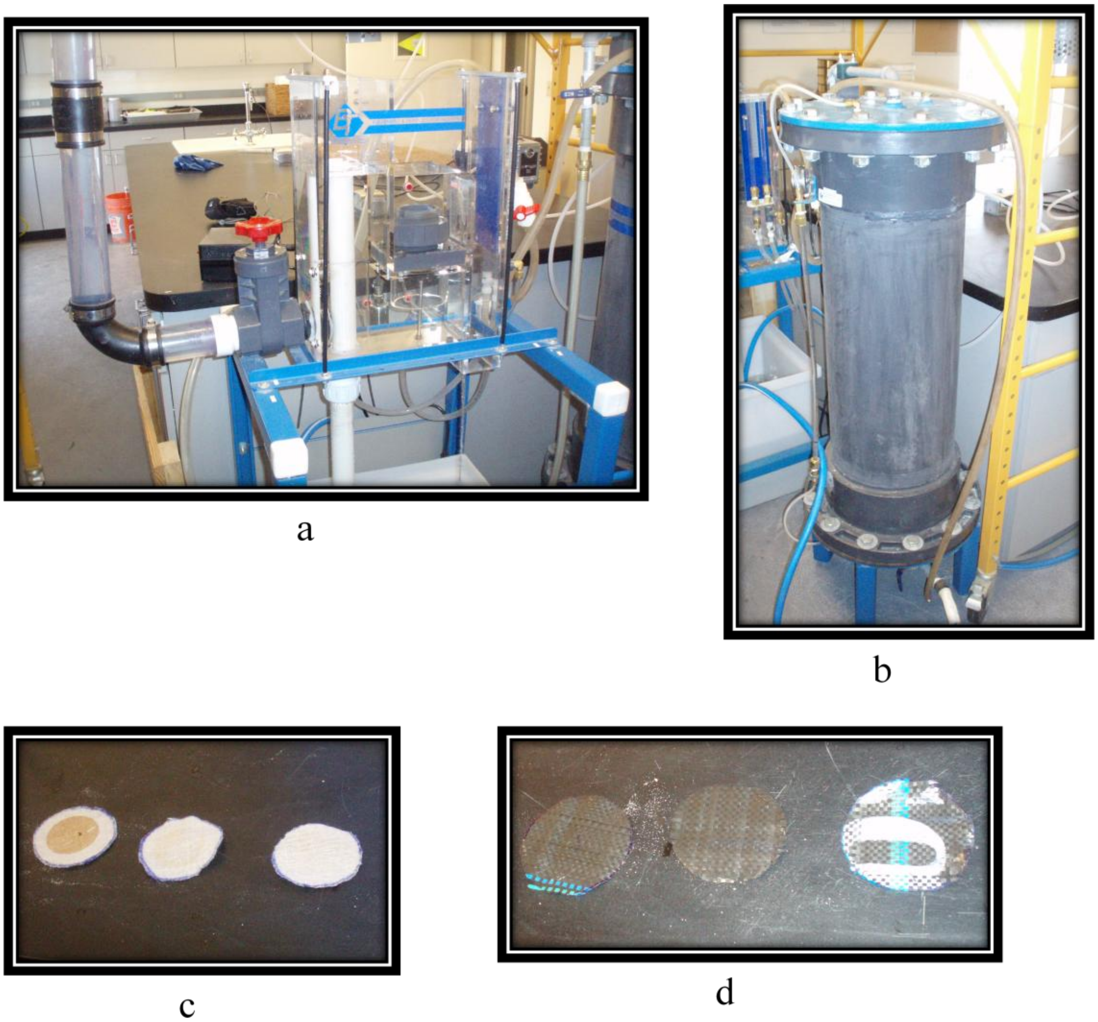


Figure 45 Permittivity testing apparatus, de-airing device and cut test specimens

3.2.5.2 Test Procedure

The permittivity testing device was assembled according to the manufacturer's specifications. The upstream head tube (B) was raised above the level of the downstream threshold and this allowed de-aired water to flow into the permittivity device enclosure (D) and filled to its threshold (overflow). The soaked sample in the sample holder was quickly and carefully removed from de-aired water and inserted perpendicular to the water surface and was securely screwed into its mount in the downstream sample area of the permittivity enclosure to allow for any air to escape. With de-aired water flowing into the system through the water inlet, the upstream tube (B) and the inlet throttle valve (A) were continually adjusted to produce a 50 mm (2-inch) head of water on the geotextile. Flow through the geotextile was allowed to stabilize after the establishment of the 50 mm (2-inch) head differential. Thereafter, water flow through the geotextile and out of the permittivity device enclosure (D) was collected for 30 seconds and the quantity of water measured. The following values were recorded: time (t), quantity of flow (Q) as collected from the drainage outlet and water temperature (T). Five readings per specimen were recorded for the four samples of each geotextile. A schematic drawing of the test setup is shown in Figure 46.

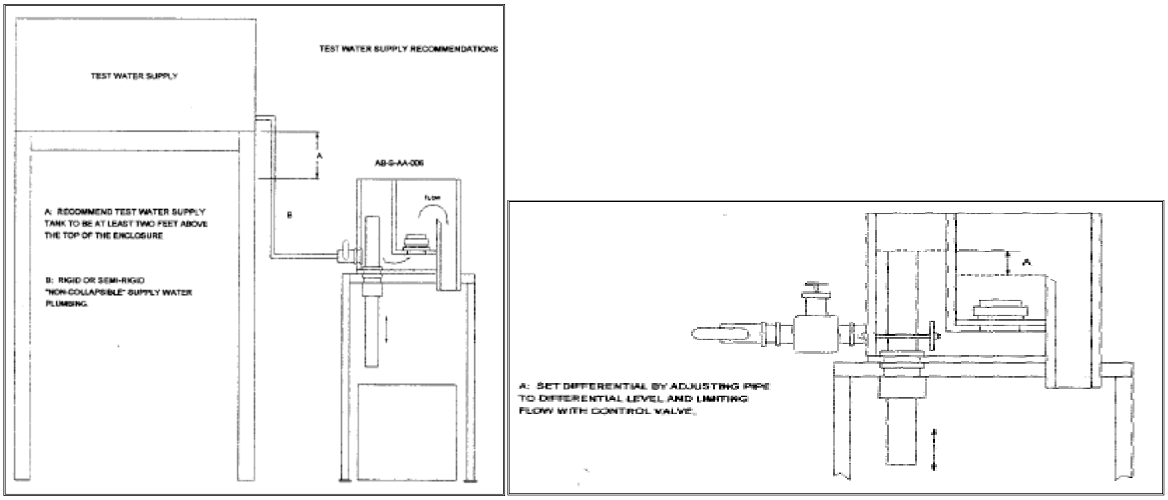


Figure 46 Constant head test setup of the permittivity device

After the first test specimen measurements were completed, the differential water head on the geotextile specimen was increased to 10 mm (⅜-inch) and the water was collected for 30 seconds and measured. The differential water head was then increased by 5 mm (3/16-inch) and the test procedure repeated until 75 mm (3-inch) of water head on the geotextile specimen in the permittivity device was attained. The volumetric flow rates versus head differentials was plotted to determine the region of laminar flow, which is the initial straight line portion of the plot.

3.2.5.3 Results and Plots

The permittivity of the geotextile is determined by this expression (ASTM Standard D 4491 1999)

$$\psi = QR_t / hAt \tag{3}$$

where ψ = permittivity, s^{-1}; Q = quantity of flow, mm^3; h = head of water on the specimen, mm; A = cross-sectional area tested area of specimen, mm^2; t = time of flow, sec; and R_t = temperature correction factor determined using Equation (4).

$$R_t = u_t / u_{20^\circ C} \tag{4}$$

where u_t = water viscosity at test temperature, millipoises; $u_{20^\circ c}$ = water viscosity at 20˚C, millipoises.

Computation of the permittivity of every geotextile specimen was based on the individual quantity of flow observed in the experiment. The permittivity computations were based on specimen's tested cross-sectional area of 2027 mm^2, 50 mm head of water on the specimen, and temperature correction factor of 1.11 and 1.05 for BSRF and Type III silt fence, respectively. In addition to the observed quantity of flow and computed permittivity values, the standard deviations and coefficient of variations within the individual test results of every specimen are presented in Table 24 and Table 25 for BSRF and Type III silt fence materials, respectively.

Table 24 Quantity of flow and permittivity of BSRF silt fence

Time (*t*), *s*	Test Number	*First Specimen*	*Second Specimen*	*Third Specimen*	*Fourth Specimen*	*Average*	*Standard Deviation*	*Coeff. of Variation*
Quantity of Flow (Q), mL								
30	1	7280	6085	8230	8110	7426.25	988.92	0.133
30	2	6550	6145	8460	7600	7188.75	1046.04	0.146
30	3	6415	5900	7930	7400	6911.25	921.16	0.133
30	4	6088	5810	7700	6800	6599.50	843.85	0.128
30	5	5680	5660	7400	6240	6245.00	815.58	0.131
Permittivity (ψ), s^{-1}								
30	1	2.647	2.213	2.993	2.949	2.701	0.36	0.133
30	2	2.382	2.235	3.076	2.764	2.614	0.38	0.146
30	3	2.333	2.146	2.884	2.691	2.513	0.33	0.133
30	4	2.214	2.113	2.800	2.473	2.400	0.31	0.128
30	5	2.066	2.058	2.691	2.269	2.271	0.30	0.131
Average Permittivity		2.328	2.153	2.889	2.629	**2.500**		
Standard deviation		0.216	0.072	0.153	0.264			
Coefficient of variation		0.093	0.034	0.053	0.100			
Minimum		2.066	2.058	2.691	2.269			
Maximum		2.647	2.235	3.076	2.949			

Table 25 Quantity of flow and permittivity of Type III silt fence material

Time (*t*), *s*	Test Number	*First Specimen*	*Second Specimen*	*Third Specimen*	*Fourth Specimen*	*Average*	*Standard Deviation*	*Coeff. of Variation*
Quantity of Flow (Q), mL								
30	1	315	240	292	380	306.75	58.04	0.189
30	2	335	230	292	385	310.50	65.76	0.212
30	3	360	225	285	377	311.75	70.30	0.226
30	4	335	223	284	380	305.50	67.55	0.221
30	5	340	223	280	375	304.50	67.01	0.220
Permittivity (ψ), s^{-1}								
30	1	0.109	0.083	0.101	0.131	0.106	0.02	0.189
30	2	0.116	0.079	0.101	0.133	0.107	0.02	0.212
30	3	0.124	0.078	0.098	0.130	0.108	0.02	0.226
30	4	0.116	0.077	0.098	0.131	0.106	0.02	0.221
30	5	0.117	0.077	0.097	0.130	0.105	0.02	0.220
Average Permittivity		0.116	0.079	0.099	0.131	**0.106**		
Standard deviation		0.006	0.002	0.002	0.001			
Coefficient of variation		0.048	0.032	0.018	0.010			
Minimum		0.109	0.077	0.097	0.130			
Maximum		0.124	0.083	0.101	0.133			

The average permittivity for the four specimens was determined as the permittivity value for each geotextile material. The average permittivity values for both BSRF and Type III silt fence materials are presented as 2.5 sec^{-1} and 0.11 sec^{-1}, respectively, in

Table 26. From the permittivity values for the four specimens and test sequence presented in Table 24 and Table 25, the permittivity values ranges between 2.06 to 3.08 and 0.08 to 0.13 for BSRF and Type III silt fence materials, respectively. The standard deviations (*s*) and coefficient of variations are 0.33 sec^{-1} and 13.02 percent for BSRF, and 0.023 sec^{-1} and 21.19 percent for Type III silt fence, respectively. Due to the variations observed, statistical analyses were performed to test for significant difference in the permittivity values among the specimens. Two Chi-squared tests for independence at significant level of 0.05 were conducted to test the null hypotheses (H_0):

1. The permittivity values from individual test on each specimen are more than ±5 percent from the average value; range (2.375 ~ 2.625) and (0.101 ~ 0.112) for BSRF and Type III silt fence materials, respectively;
2. The permittivity values from individual tests on each specimen are more than one standard deviation away from the average value range (2.162 ~ 2.838) and (0.086 ~ 0.127) for BSRF and Type III silt fence materials, respectively.

Table 26 Permittivity values for BSRF and Type III silt fence materials

Permittivity (ψ), s^{-1}		
Test Number	**BSRF**	**Type III**
1	2.328	0.1165
2	2.153	0.0789
3	2.889	0.0990
4	2.629	0.1311
Average	**2.500**	**0.106**
Standard Deviation	0.326	0.023
Coefficient of Variation	13.02%	21.19%

The alternative hypotheses (H_1):

1. The permittivity values from individual test on each specimen are within ±5 percent from the average value; range (2.375 ~ 2.625) and (0.101 ~ 0.112) for BSRF and Type III silt fence materials, respectively;
2. The permittivity values from individual test on each specimen are within one standard deviation from the average value range (2.162 ~ 2.838) and (0.086 ~ 0.127) for BSRF and Type III silt fence materials, respectively.

The Chi-square test was performed by first identifying the categorical variables (observed, *O*) as to how many are within the range of ±5 percent and/or one standard deviation away from the average value(s). Thereafter, the expected outcomes (*E*), the degree of freedom (*df*) computed by and the Chi-square statistics (χ^2) were computed by Equation (5), Equation (6) and Equation (7), respectively.

$$E = \frac{(Row_{Total})(Column_{Total})}{Total_{rows+columns}} \tag{5}$$

$$df = (No_{rows} - 1)(No_{columns} - 1) \tag{6}$$

$$\chi^2 = \sum \left[\frac{(O - E)^2}{E} \right] \tag{7}$$

Results for the first Chi-square test, that is on the permittivity values from individual tests on each specimen, are more than ±5 percent from the average value. The results are presented in

Table 27 and Table 28 for BSRF and Type III silt fence fabrics, respectively. The results for the second Chi-square test, which is on permittivity values from individual tests on each specimen, are more than one standard deviation away from the average value. They are presented in

Table 29 and Table 30 for both BSRF and Type III silt fence materials, respectively.

The Chi-square test results show that for significance level of 0.05, there is no significant difference among the individual specimen permittivity values and ±5 percent of the average permittivity values for both silt fence materials tested. In the second Chi-square test, one standard deviation away from the average value, BSRF individual specimen permittivity values show no significant difference. However, for Type III silt fence fabric, the null hypothesis is rejected and it is assumed that individual permittivity values are not beyond one standard deviation from the average value.

Table 27 Chi-square test #1 (±5 % range) for BSRF silt fence

H_0 =	Specimen permittivity value is beyond ± 5 % of the average permittivity	
H_1 =	Specimen permittivity value is within ± 5 % of the average permittivity	
df =	df = (col. - 1)(row - 1)	3
Chi-square statistics χ^2		2.222
Chi-square distribution from Table		7.815
Decision	Don't Reject H_0 because 2.222 < 7.815 for $\alpha = 0.05$	

Table 28 Chi-square test #1 (±5 % range) for Type III silt fence

H_0 =	Specimen permittivity value is beyond ± 5 % of the average permittivity	
H_1 =	Specimen permittivity value is within ± 5 % of the average permittivity	
df =	df = (col. - 1)(row - 1)	3
Chi-square statistics χ^2		3.158
Chi-square distribution from Table		7.815
Decision	Don't Reject H_0 because 3.158 < 7.815 for $\alpha = 0.05$	

Table 29 Chi-square test #2 (one standard deviation) for BSRF silt fence

H_0 =	Specimen permittivity value is beyond 1 s from the average permittivity	
H_1 =	Specimen permittivity value is within 1 s of the average permittivity	
df =	df = (col. - 1)(row - 1)	3
Chi-square statistics χ^2		3.333
Chi-square distribution from Table		7.815
Decision	Don't Reject H_0 because 3.333 < 7.815 for $\alpha = 0.05$	

Table 30 Chi-square test #2 (one standard deviation) for Type III silt fence

H_0 =	Specimen permittivity value is beyond 1 s from the average permittivity	
H_1 =	Specimen permittivity value is within 1 s of the average permittivity	
df =	df = (col. - 1)(row - 1)	3
Chi-square statistics χ^2		20.000
Chi-square distribution from Table		7.815
Decision	Reject H_0 because 20.00 > 7.815 for $\alpha = 0.05$	

Figure 47 and 48 show permittivity values plotted against the sequence of testing in each specimen for both silt fence materials. The plots were based on the permittivity values of every specimen and the average permittivity values of every testing sequence. The observed trend is a negative slope with declining permittivity values with every passing test for both silt fence materials. Based on the observations, regression analyses were conducted to show the trend mathematically and test the hypothesis of a negative slope in the permittivity values with testing sequence. The regression analyses were based on each test number and the calculated average permittivity value, see

Table 24 and Table 25. Figure 49 and Figure 50 show regression analysis plots for both silt fence materials. Equations (8) and (9) have the regression equations for line fits, respectively.

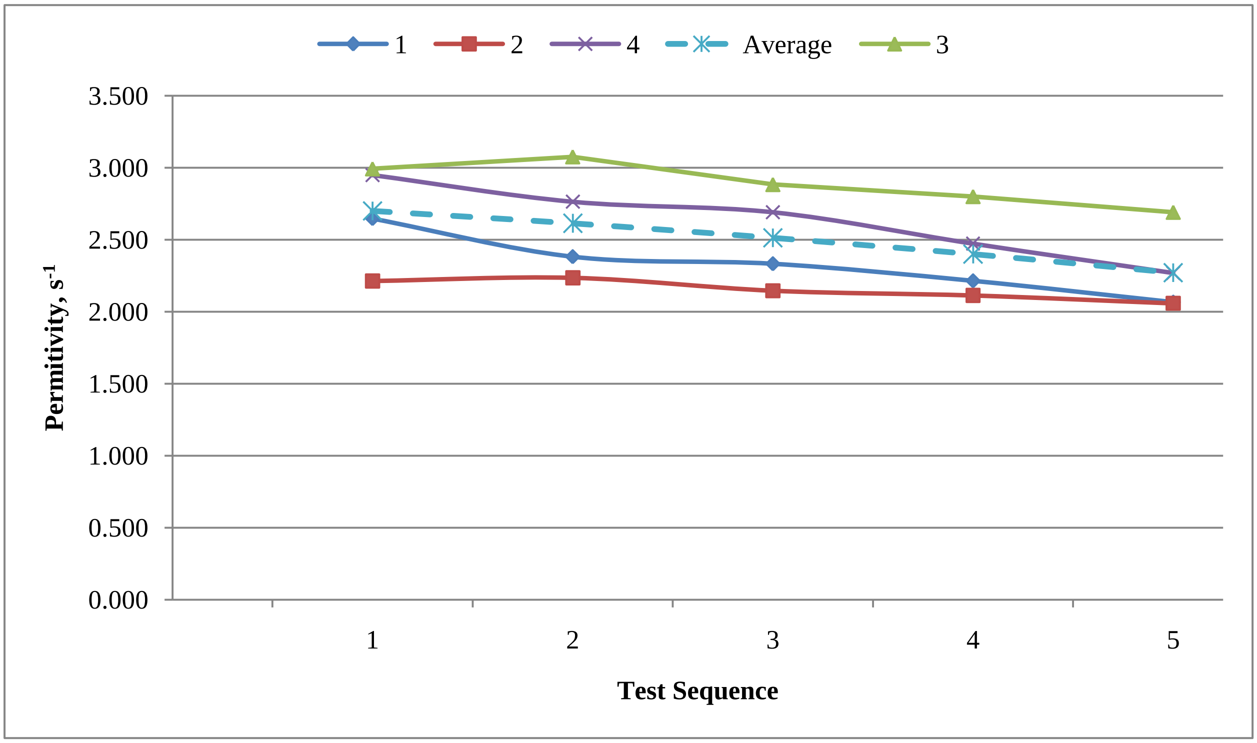


Figure 47 Plot of permittivity versus test sequence for BSRF silt fence material

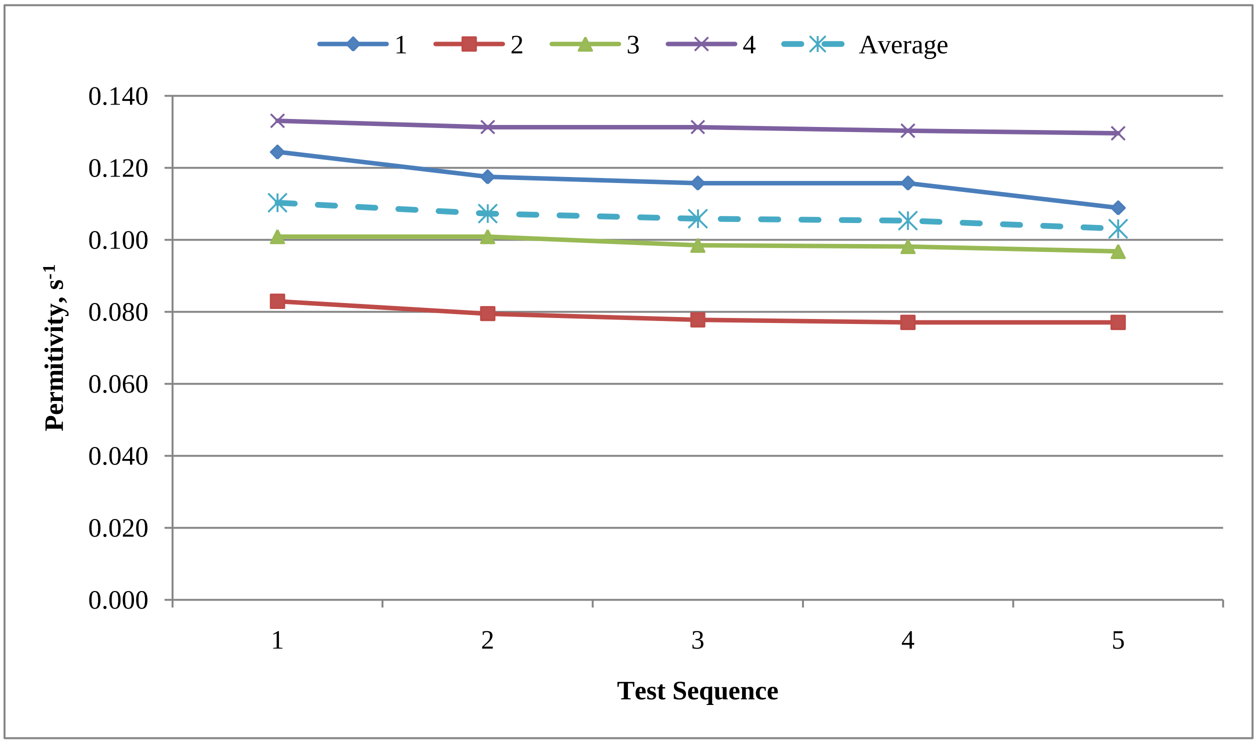


Figure 48 Plot of permittivity versus test sequence for Type III silt fence material

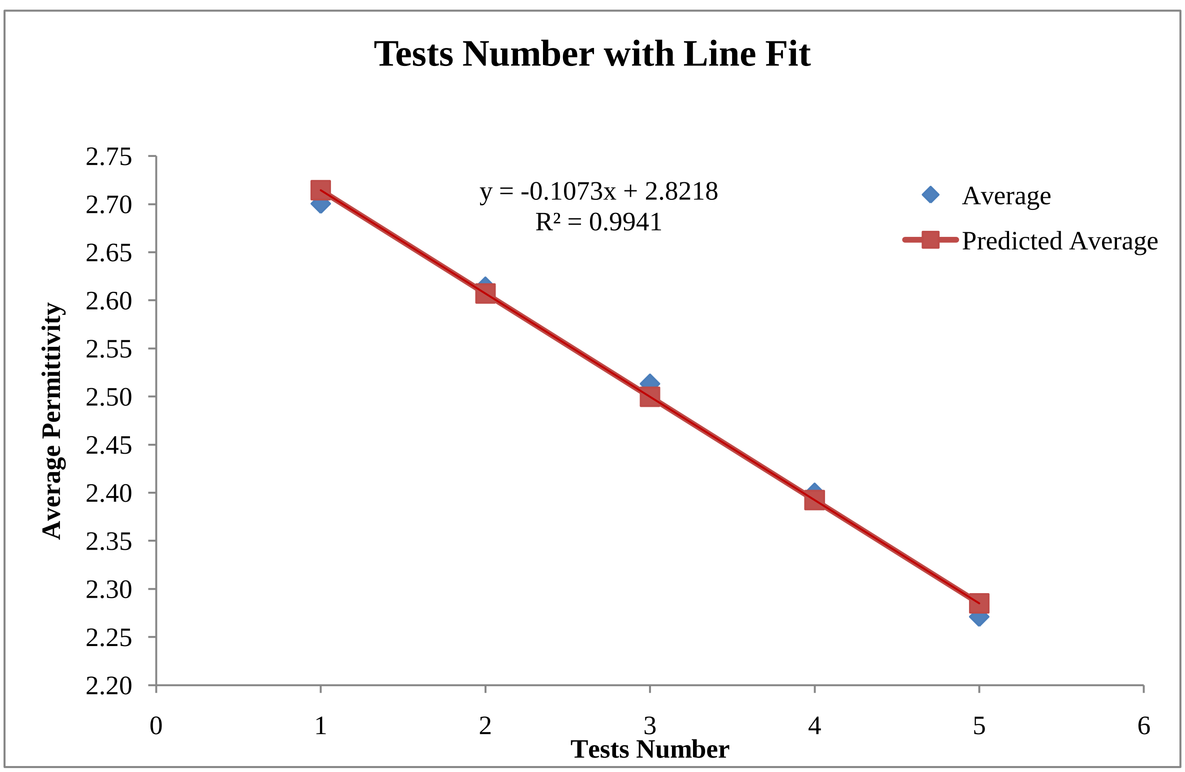


Figure 49 Permittivity regression plots for BSRF silt fence

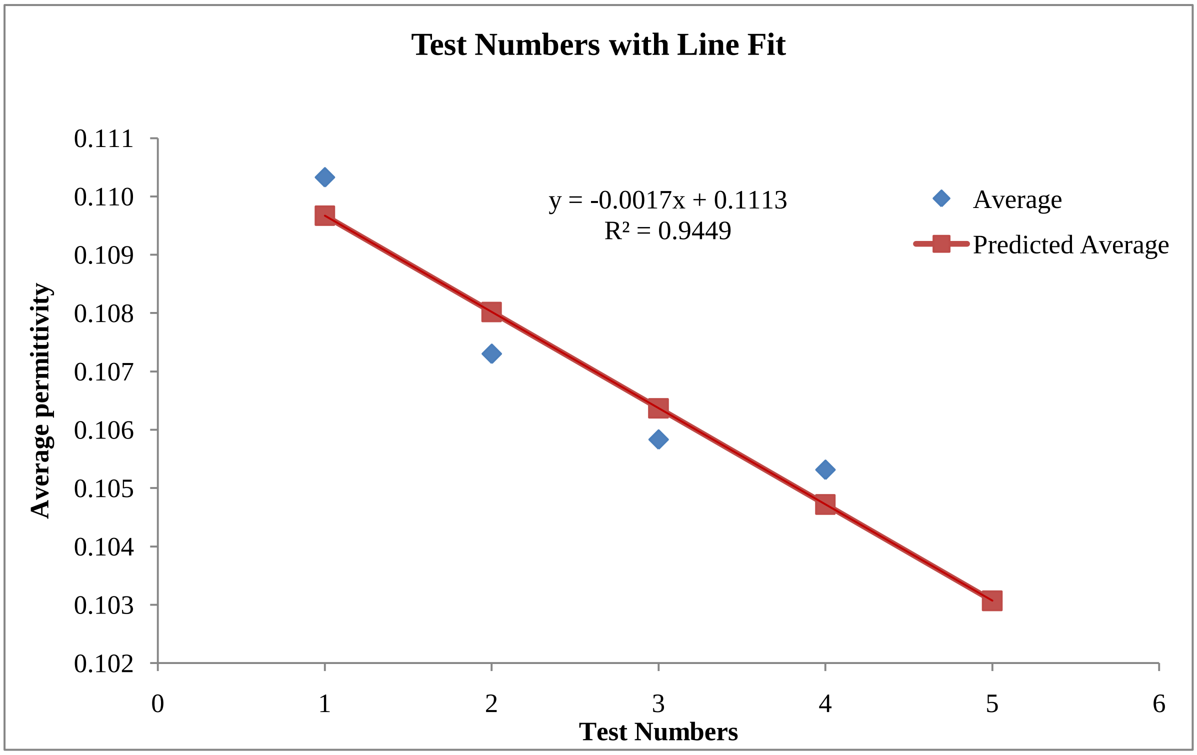


Figure 50 Permittivity regression plots for Type III silt fence

$$\psi_{predicted_{BSRF}} = 2.8218 - 0.1073\,(Test_{\#}) \qquad \textbf{(8)}$$

$$\psi_{predicted_{TypeIII}} = 0.1113 - 0.0017\,(Test_{\#}) \qquad \textbf{(9)}$$

Both mathematical expressions reveal a negative slope with each passing testing sequence. This is because of the presence of fine particles in the water that clog the silt fence openings with passage of time. Equations (8) and (9) estimate the average permittivity value of the respective silt fence for every testing sequence for the series of tests performed. The coefficients of determinations (R-squared) – a measure of how well the regression equations estimate the average observed permittivity values – are 0.9941 and 0.9449, and the adjusted R-squared values are 0.9921 and 0.9265 for BSRF and Type III silt fence materials, respectively. This shows that 99 percent or 93 percent of the variations of permittivity values can be explained by the regression equations, for either BSRF or Type III silt fence materials, respectively.

Table 31 and Table 32 present the regression data for BSRF or Type III silt fence materials, respectively.

Table 31 Regression test data for BSRF silt fence material

Test Specimens	***Regression Equation***	***Intercept***	***Predictor***	***R-Square***	***Adjusted R-Square***	***Std. Error***
First Specimen	y = -0.1332x + 2.7278	2.7278	-0.1332	0.9492	0.9322	0.0563
Second Specimen	y = -0.0431x + 2.2821	2.2821	-0.0431	0.8890	0.8520	0.0278

Third Specimen	y = -0.088x + 3.1528	3.1528	-0.0880	0.8322	0.7763	0.0721
Fourth Specimen	y = -0.1651x + 3.1244	3.1244	-0.1651	0.9791	0.9721	0.0441
Average	**y = -0.1073x + 2.8218**	2.8218	-0.1073	**0.9941**	**0.9922**	0.0151

Table 32 Regression test data for Type III silt fence material

Test Specimens	***Regression Equation***	***Intercept***	***Predictor***	***R-Square***	***Adjusted R-Square***	***Std. Error***
First Specimen	y = -0.0033x + 0.1263	0.1263	-0.0033	0.8762	0.8350	0.0023
Second Specimen	y = -0.0014x + 0.0831	0.0831	-0.0014	0.8129	0.7505	0.0012
Third Specimen	y = -0.0011x + 0.1024	0.1024	-0.0011	0.9209	0.8945	0.0006
Fourth Specimen	y = -0.0008x + 0.1335	0.1335	-0.0008	0.9248	0.8998	0.0004
Average	**y = -0.0017x + 0.1113**	0.1113	-0.0017	**0.9449**	**0.9265**	0.0007

The regression test data for each specimen and the average and median were computed and presented, where *x* is the test number sequence. The plots of only the average regression data were presented, because the ASTM Standard test method D4491 is based on the average computed permittivity values. However, the median regression data would have been conservative estimates, with lower coefficient of determinations (R-square) and adjusted R-squares of 0.9782 and 0.9710 for BSRF, and 0.9327 and 0.9103 for Type III silt fence materials, respectively.

3.2.5.4 Acceptance criteria

Figure 51 presents the comparisons between average test results, manufacturer's specifications, FDOT and ASTM specifications for silt fence. The observed permittivity for both silt fences were above the minimum recommendations and manufacturers' specifications. However, there was no manufacturer's specification for BSRF silt fence permittivity value.

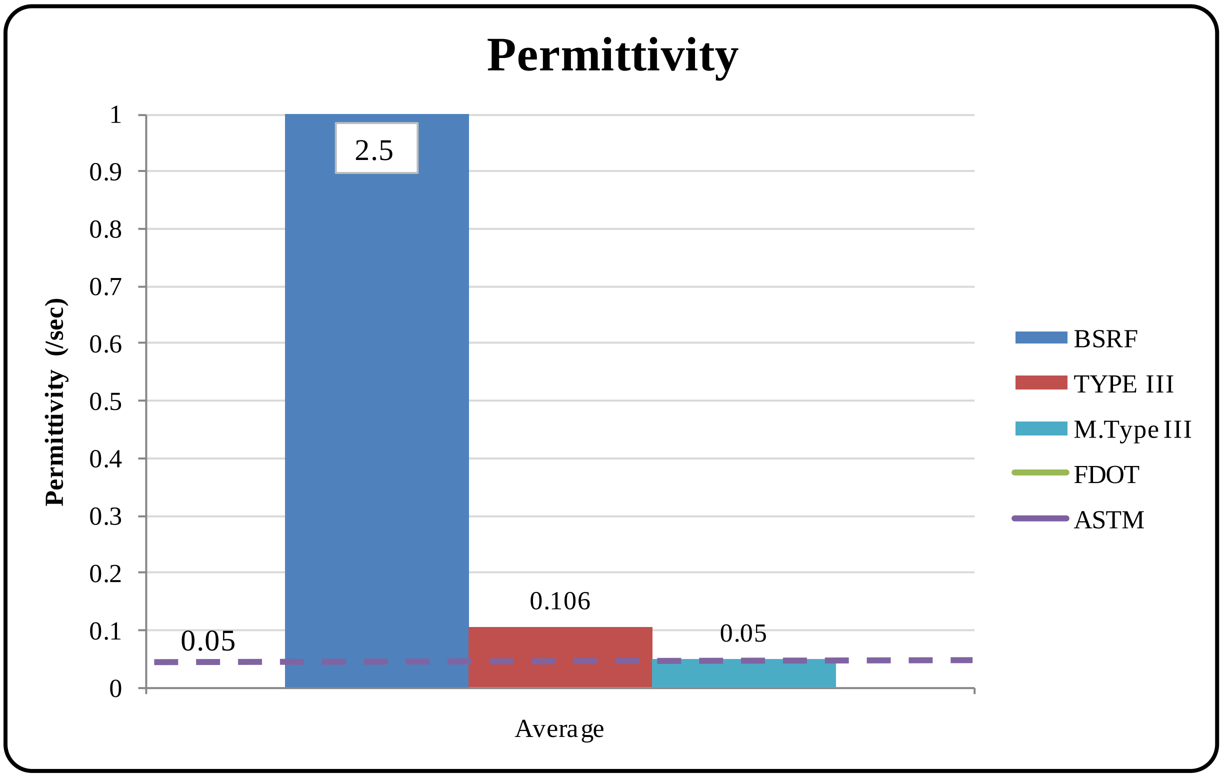


Figure 51 Comparison of permittivity values of silt fence materials

3.3 PAM Dosage Testing

3.3.1 Introduction

According to the Environmental Protection Agency (USEPA 1996), soil erosion is believed to be the biggest contributor to nonpoint source pollution in the United States. From a local perspective, rivers, lakes and streams across the United States are becoming more frequently damaged by sediment than any other pollutant (Hayes, McLaughlin and Osmond 2005). Disturbed, unprotected locations inevitably experience some level of erosion; be it from wind or due to stormwater runoff. More specifically, construction sites are amongst the most common areas to experience soil erosion due to the mandatory foundation tasks, such as excavation.

Polyacrylamide (PAM) is a high molecular weight polymer and is widely used to control erosion in furrow irrigated agriculture. It functions by increasing cohesion, by strengthening soil particles and by flocculating the suspended particles in the solution thereby creating larger aggregates and as a result decreases the transportability and helping particles to settle (Soupir, et al. 2004). Flocculation is essentially an aggregation process assisted by organic electrolytes such as polymers. The main intent is to settle the suspended colloidal particles in water/wastewater quickly, which typically settle slowly under normal conditions.

The increasing popularity of PAM within the industry forces the need for a more regulated implementation. By doing so, one can associate certain mixing durations and dosages to obtain a desired turbidity removal efficiency. The application of PAM also raises concerns of any implications it may have to the discharging environment. When any new chemical product, such as PAM, is introduced into the market, it is essential that it undergoes testing to reassure that it has no negative or toxic effect. One of the many ways to do so is to quantify toxic effects through toxicity testing, which tests species most sensitive to environmental change and observing and quantifying their response. Details on toxicity tests conducted on PAM discharge are reported in later sections.

Polymers have been included in a recently developed specification for erosion and sediment control in Canada and similar specifications may be adopted in the United States very soon. At a recent meeting of the FDOT/FDEP/WMD Erosion Prevention and Sediment Control Committee, it was determined that polymers have been found to be effective for several applications related to erosion and sediment control and will be recommended for use in the state of Florida on FDOT projects. In view of this recommendation, there is a need to conduct index testing related to the performance of polymers and their toxicity. The performance is evaluated by measuring turbidity, in terms of nephelometric turbidity units (NTUs), for determining the polymers' effectiveness in the reduction of turbidity.

Recommendations based on the testing performed at the Stormwater Management Academy Laboratory (SMARTL) at the University of Central Florida are presented here. Dosage calculations have been derived based on achieving certain turbidity reduction efficiency values. Dosage would remain constant as mixing speed and mixing duration are systematically increased. This test was repeated to encompass a wide range of dosages. The research staff at the Academy has also tested for PAM's toxicity levels utilizing fathead minnows to observe whether or not there were any acute or chronic toxic repercussions on downstream organisms and if so, at what dosage.

3.3.2 Test Method

Toxicological tests for polymers were conducted using one or all of the protocols listed below, as designated by the species selected by the appropriate regulatory authority. The test reports was intended to investigate if the polymer clarifier exhibits acceptable toxicity parameters set by all applicable standards:

- EPA/600/4-90/027F [acute testing];
- EPA/600/4-91/022 [seven day chronic testing];
- EPA 1/RM/13 [96 hr static bioassay]

The research conducted by (Ersoy, et al. 2009) most closely reflects the investigation completed by the Stormwater Management Academy at the University of Central Florida. The study was designed to formulate a testing procedure that could be used on site to determine the appropriate polymer for a specific site.

Clayey sand was used in the PAM dosage tests conducted at the Stormwater Management Academy Research Laboratory. Five grams of soil was mixed with 180 milliliters of de-ionized water to form turbid water and the initial turbidity was measured using the Hach 2100P Turbidimeter. The NTU values were greater than the capacity of the Hach 2100P Turbidimeter used. The solution was diluted with a factor of six (6) to determine the initial turbidity. Sixty (60) milliliters of the turbid sample was then placed in a 200 milliliter beaker and placed on a stir plate with a stir bar in the beaker to induce mixing between the polymer and the turbid solution at predetermined speed and time. A predetermined dosage of polymer (25, 50, 100, 150, 200 and 250 milligrams) were then dropped in solution already being mixed by the stir plate and stir bar. Mixing was continued for set time of 30, 45, 60, 75, 90 and 120 seconds. The polymer enhanced solution in the beaker was measured for final turbidity without filter and with filter of 35 and 64 microns. Filters were used to simulate the use of jute to trap settling flocculants caused by the polymer. This process was repeated for three times for a set of dosage and time. For example, turbidity results were obtained three times for a dosage of 50 mg of polymer at a contact time of 45 seconds. If the results appeared to heavily distort from each other, more than three trials were conducted. Turbidity removal efficiency for the polymer tested was calculated using Equation (10)

$$Efficieny(\%) = \left[1 - \frac{NTU_{final}}{NTU_{initial}}\right] \times 100 \qquad (10)$$

3.3.3 Test Results

A summary of turbidity reduction ratios for the different polymer block/log tested for the three test considerations are shown in subsequent charts/tables below and in the Appendix. Test reports include all details necessary to determine which polymer block/log will work on the specific soil or water type (pH, NTU_i, NTU_f, total hardness, phosphate, polymer block/log type). These results provide response due to random reaction time, mixing speed and polymer type and size adopted for these tests, factors that affected flocculation significantly. To this end, standardized reaction time, mixing speed and polymer concentration is proposed as a part of the testing protocol for conducting laboratory studies to establishing the correct polymer dosage that will react with and flocculate the sediment in a water sample. Figure 52 shows sample water prior to treatment and after treatment with PAM product.

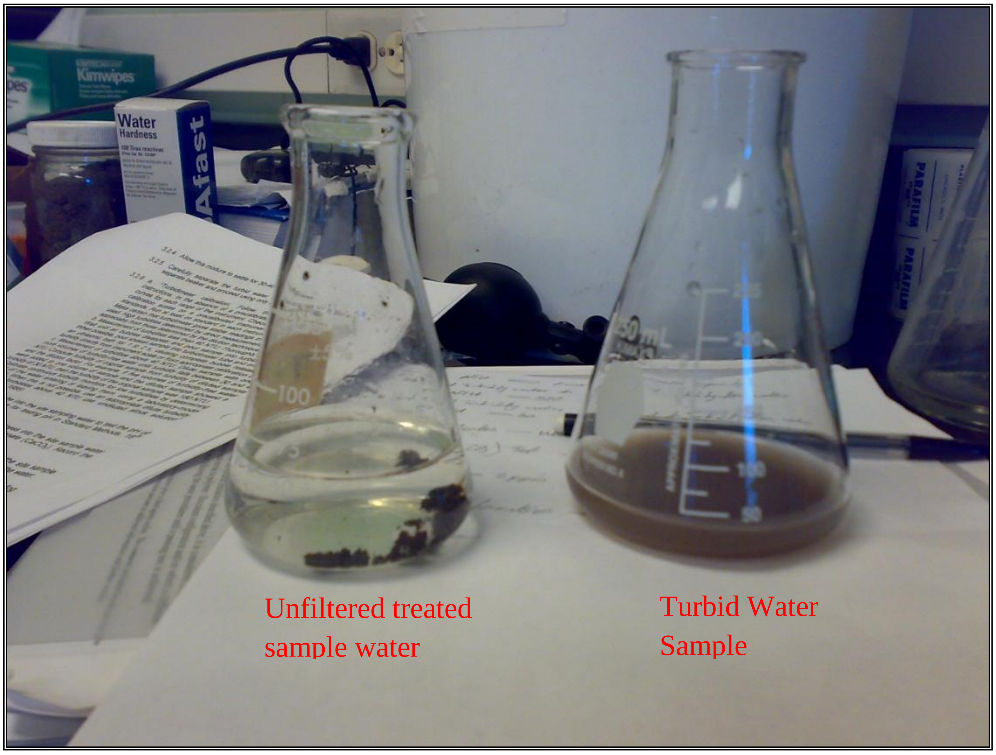


Figure 52 PAM treated and untreated water samples in beakers

For easier use in field applications, the mixing speed in revolutions per second and the mass of polymer obtained in the laboratory testing were converted to velocity and concentration, respectively. The conversion factors are

$1.0\,rev/\min = 0.0109\ ft/\sec$; and $1mg/60mg = 16.67\,mg/L$

A summary of the efficiencies obtained on the tests performed using powdered PAM (APS 745) is presented in

Table 33,

Table 34, Figure 53 and Figure 55. Tables and charts for other PAM products tested are presented in the appendix.

Table 33 PAM 745 @ 417 mg/L dosage; turbidity removal efficiencies relative to mixing time and speed

Efficiency with Time Speed							
Applied Polymer Concentration (mg/L)	*Mixing speed, ft/s*	1.4		2.6		3.8	
	Mixing Time, seconds	*w/o filter*	**filter*	*w/o filter*	**filter*	*w/o filter*	**filter*
417	30	59%	88%	91%	93%	96%	97.5%
	45	84%	91%	92%	95%	97%	97.8%
	60	96%	98%	96%	97%	98%	98.8%
	75	94%	97%	97%	98%	98%	98.5%
	90	93%	96%	97%	98%	99%	99.1%
	120	94%	96%	99%	99%	99.7%	99.7%

Table 34 PAM 745 @ 833 mg/L dosage; turbidity removal efficiencies relative to mixing time and speed

Efficiency with Time Speed							
Applied Polymer Concentration (mg/L)	*Mixing speed, ft/s*	1.4		2.6		3.8	
	Mixing Time, seconds	*w/o filter*	**filter*	*w/o filter*	**filter*	*w/o filter*	**filter*
833	30	74%	87%	84%	92%	90%	96%
	45	76%	87%	91%	95%	94%	96%
	60	89%	94%	92%	95%	96%	97%
	75	89%	95%	94%	96%	95%	97%
	90	92%	94%	93%	97%	95%	97%
	120	90%	94%	94%	96%		

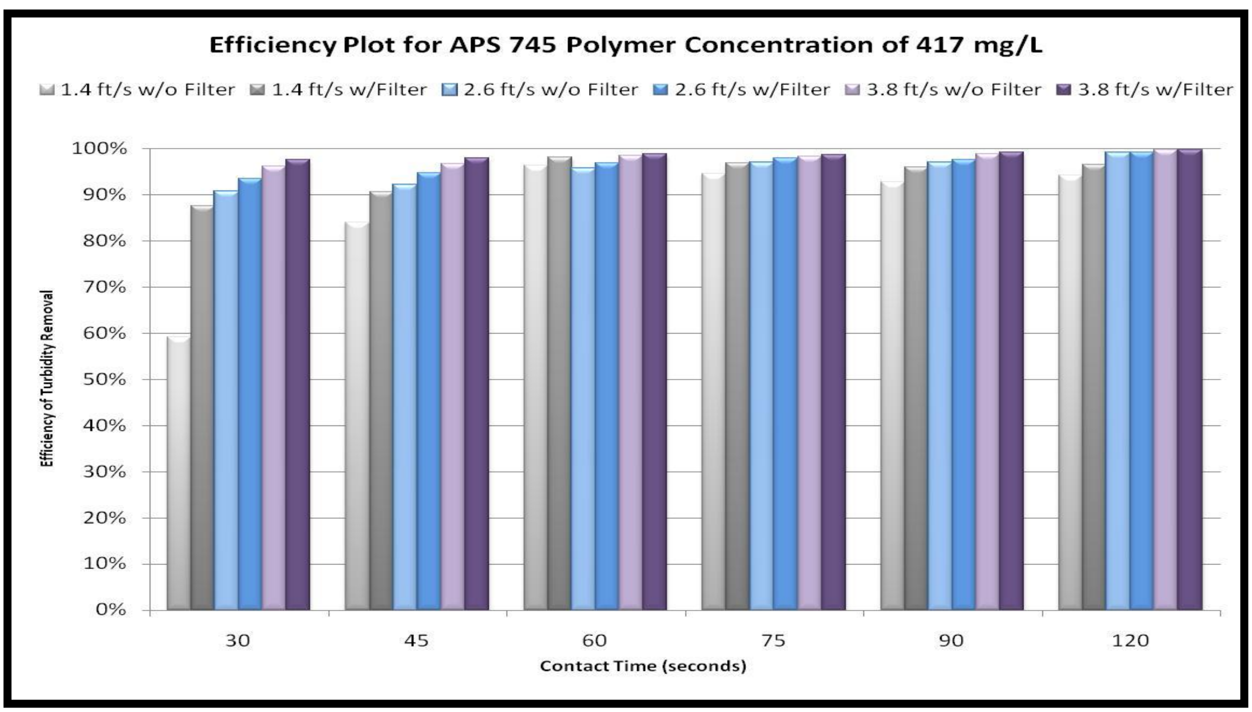


Figure 53 Plot of efficiencies for polymer APS 745 at a concentration of 417 mg/L

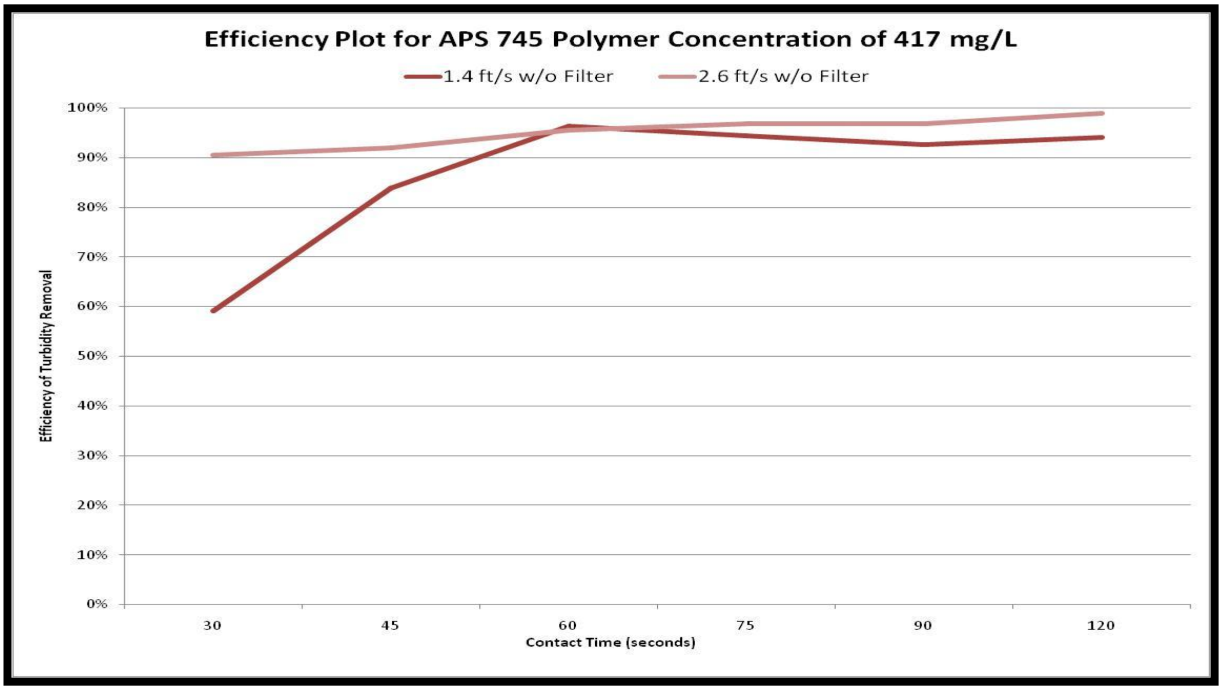


Figure 54 Line graph for APS 745 Polymer at concentration of 417 mg/L

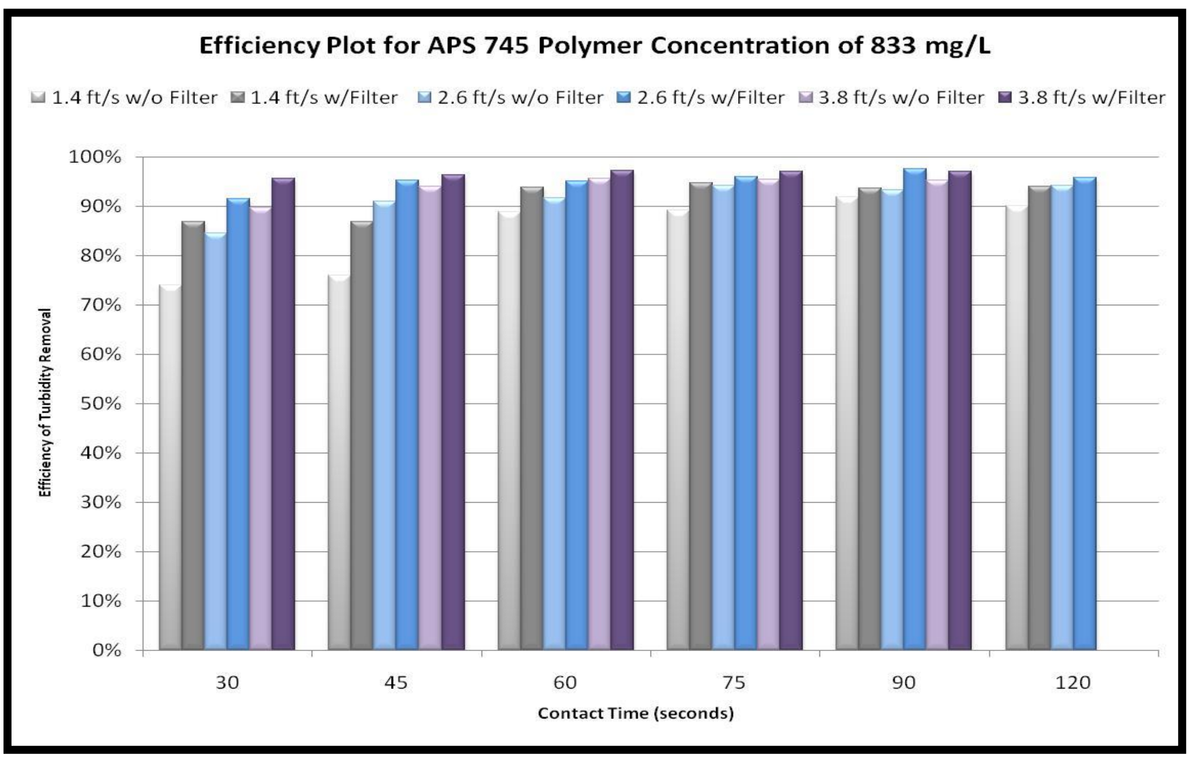


Figure 55 Plot of efficiencies for polymer APS 745 at a concentration of 833 mg/L

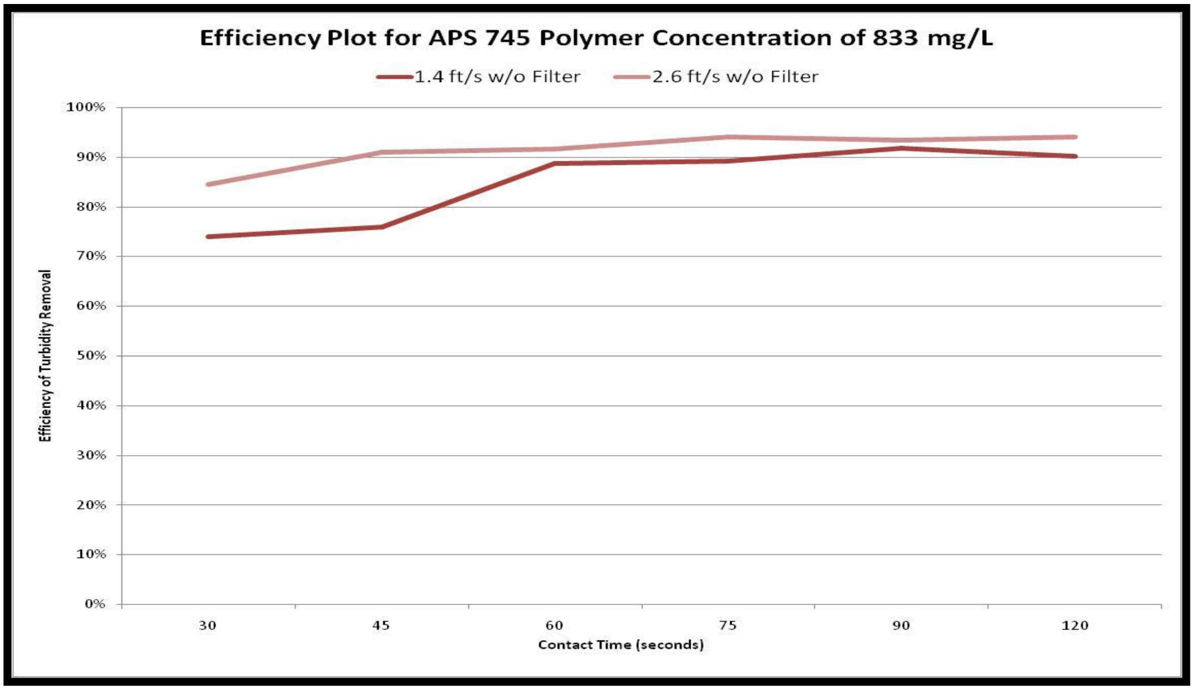


Figure 56 Line graph for APS 745 Polymer at concentration of 833 mg/L

As the research progressed, potential causes for error were periodically noted. A few things were subjective and not necessarily structured to be replicated continuously throughout the entire study. Examples of sources of error are moisture on fingers, different polymer block pieces possibly having different initial moisture contents, calibration of the turbidimeter and inadequate initial contact of the polymer to the solution during mixing. A major concern, particularly with polymer blocks, was the moisture of the polymer blocks. The polymer blocks lose moisture constantly as they are exposed to the environment, which in turn affects their performance.

3.3.4 Recommended Testing Procedure for PAM Dosage

The following are procedural recommendations for testing PAM.

Materials/Apparatus

1. Five (5) grams site specific soil or 180 mL turbid site water
2. If site water is not available, approximately 237 mL de-ionized water
3. Two (2) clear/transparent beakers or glassware capable of holding at least 180 mL of water with the soil from the site (Figure 52)
4. Polymer sizes to be tested:
    a. Blocks – 50, 100, 150, 200 and 250 mg
    b. Powder – 25 and 50 mg
5. pH meter or litmus paper
6. Nephelometric Turbidity Meter (NTU meter)
7. Water Quality Test Strips or meter for testing Total Hardness
8. PO_4^{-3} test strips or meter to test for phosphate

Procedure

1.1. Water sample only

1.1.1. Shake water sample to ensure water is uniformly mixed.

1.1.2. Allow insoluble material to settle for 60 seconds before drawing samples.

1.1.3. Carefully pour the muddy water into a second clear/transparent container taking care to not allow the sand and bulk of the heavier dirt to enter the second container.

1.1.4. Pour approximately 60 mL of this muddy water into a clean transparent beaker or glassware to test the polymer block/log with.

1.1.5. Turbidity measurement

1.1.5.1. Turbidimeter calibration – follow the manufacturer's operating instructions for the turbidimeter used.

1.1.5.2. Measurement of turbidities above meter capacity – dilute sample with one or more volumes of de-ionized (DI) water until turbidity falls within the meter capacity. Compute turbidity of original sample from turbidity of diluted sample and the dilution factor used. For example, if five volumes of DI water were added to one volume of sample and the diluted sample showed a turbidity of 50 NTU, then the turbidity of the original sample was 300 NTU.

1.1.6. Place the predetermined dosage of the PAM sample within beaker and then proceed to pour in 60 mL of the prepared sample water.

1.1.7. Place the beaker with PAM and solution on stir plate at predetermined mixing speed and record the time in seconds that it takes to cause particulate formation.

1.1.8. Filter the treated soil sample water through a predetermined filter media based on discharge requirements.

1.1.9. Take a final NTU reading of the filtered sample water by repeating step 1.1.5. Record this as NTU_f.

1.1.10. If this test does not meet the water quality requirements for the specific site being tested, repeat the test process using a different polymer until the water quality requirements are met. Discharge should not violate the state of Florida's water quality standards (WQS); turbidity shall not be greater than 29 NTU above background.

1.2. Soil sample only

1.2.1. Take five (5) grams of the soil to be tested.

1.2.2. Dry and mortar the five grams of soil to a fine dust and place into a transparent beaker or glassware capable of holding approximately 237 mL of de-ionized water or preferably water that is taken from the sampling site.

1.2.3. Repeat steps 1.1.1 to 1.1.10

1.2.4. Repeat this entire process for each polymer block/log tested as required.

In order to obtain the proper polymer type, all variables need to be accounted for prior to requesting any polymers from manufacturers. High or low pH can greatly affect flocculation.

Elevated calcium carbonate ($CaCO_3$) will affect polymer solubility. Cold temperatures may reduce reaction time and warm temperatures may increase reaction time. The subsequent steps are completed alongside turbidity removal to justify the polymer best suited for the site specific application.

1. Dip litmus paper or a pH probe into the site sampling water to test the pH of the water. Follow the procedure for testing pH in Standard Methods, 16^{th} Edition, 1985. Record the value.
2. Dip a water quality test strip for total hardness into the site sample water for five (5) seconds to test for calcium carbonate ($CaCO_3$). Record the value.
3. Dip a water quality test strip for phosphate into the site sample water for five (5) seconds to test for the amount of phosphate in the water.

3.4 PAM Toxicity Testing

3.4.1 Introduction

The introduction of polyacrylamide (PAM) began in the 1990's and since then has been used as a method for erosion and sediment control, particularly in construction areas. However, some of the PAM polymers have significant toxicity and affect the surrounding aquatic life, particularly the cationic and neutral polymers (Weston, et al. 2009)). The objective of any aquatic toxicity test is to estimate the *safe* or *no-effect* concentration of the substance being tested (USEPA 2002). The two different aspects of toxicity to be measured are acute (short-term) and chronic (long-term). Acute toxicity is defined as being relatively short-term focusing on a lethal response or other effect usually defined as occurring within four days. Chronic toxicity is defined as toxicity involving a stimulus that lingers or continues for a relatively long period of time and can be measured in terms of reduced growth, in addition to lethality (Standard Methods 2005). These toxicity tests provide information regarding the toxicant effects on environmental conditions for aquatic life and the effects of the polyacrylamide on dissolved oxygen (DO), pH, temperature, turbidity and other conditions that affect the organisms. Performing these tests will determine the potential toxic effect of the polyacrylamide and amount and type of treatment that can be safely applied on the intended area.

The methods presented in this report are the procedures recommended in Pimephales Promelas Larval Survival and Growth Test Method 1000.0 using fish commonly known as fathead minnows. The methods are for determining the potential chronic and acute toxicity due to a desired polymer. The procedures outlined below are taken from United State Environmental Protection Agency (USEPA) Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms, (USEPA 2002).

3.4.2 Procedure

The intent of this procedure is to determine the acute and chronic toxicity of different PAM mixes within the range of doses recommended for field application. The method selected, acceptable per the USEPA (2002) publication cited above for the determination of both chronic and acute toxicity, is a 7-day static renewal test with one water change halfway through the test or on day four. The water change was modified from what is recommended in the above EPA method since the toxicant studied is insoluble in water; this requires each tank to be prepared separately with mixing times of a minimum of one hour, an excessive time to prepare each of the twenty four test vessels. Since the dissolved oxygen didn't drop significantly in the four day period, it was determined an acceptable modification. The drop in dissolved oxygen was used to determine the acceptability of the test modification since the water change is intended to minimize the drop in dissolved oxygen. This is important since the health of the test organisms will be significantly affected if dissolved oxygen levels drop too much. The test organisms used in this toxicity test can be any of those recommended by USEPA and should be indigenous to the geographic region of interest. If there are no organisms listed by USEPA indigenous to the geographic region of study, alternatives should be suggested and used pending approval from the department issuing the NPDES permit, usually a state regulatory agency. Florida's NPDES permit issuing department is Florida Department of Environmental Protection (FDEP). The use of the fathead minnows (Pimephales Promelas) for toxicity testing for fresh water discharge in the state of Florida is acceptable as fathead minnows are indigenous to the area.

For the determination of potential toxicity of a particular polymer, it is necessary to examine 5 different polymer concentrations and a control. Each treatment is to be replicated a minimum of 4 times including the control per EPA protocol. Since this test is a measure of both acute and chronic toxicity, it is necessary to use organisms of a certain age, that is, larval stage or 24 – 48 hours old. This is to make sure that any developmental changes due to the toxicant can be observed.

Observations and measurements are recorded daily. The quality of water also must be monitored to ensure other factors, such as pH changes or low DO concentrations, are not causing mortality of the test organisms which can influence toxicity test results. Thus, the following parameters are to be measured daily and recorded into a data sheet: temperature, alkalinity, hardness and conductivity. DO and pH are to be measured twice a day and entered into a data sheet, once at the start of the day and once at the end of the day.

The water used in the toxicity test should be from the receiving water body. Samples should be sufficient volume to perform the toxicity tests. Water collected for use in toxicity testing should be used within 48 hours of collection and passed through 60-μm plankton net to remove organic matter and any possible parasitic organisms or pathogens that might affect the health of the test organisms.

Preparing the toxicant concentrations is to be done in a way slightly different from what is presented in the USEPA method. Due to the insolubility of some products requiring testing, it is necessary to prepare each tank concentration separately to ensure that each tank has the desired concentration: making a batch concentration and then applying dilution water will result in inaccurate concentrations as chunks or particles that do not dissolve may not transfer to the test tank resulting in higher or lower than expected concentrations. Additionally, the test water should be prepared to match stormwater discharge in the field as much as possible. For example, if a treated water stream is to be filtered before discharge, it is advantageous to test both unfiltered and filtered water samples. If the unfiltered sample does not produce toxic results within the range of intended use, filtered sample is not necessary.

The test organisms can be cultured in the lab or ordered from an outside culture facility of known and acceptable quality. If a lab is going to culture their own test organisms, it is necessary to perform simultaneous tests using a reference toxicant to ensure that the test organisms cultured in-house are of acceptable quality. If the test organisms are ordered from an outside source, investigators must be able to document the age and date of hatching as well as guarantee the correctness of species and their disease-free, healthy condition. Test organisms must all have hatched within 24 hours of each other.

Several factors affect the accuracy and repeatability of toxicity tests such as the health of the test organisms, source and quality of test water, food source and quality, laboratory conditions, experience level of laboratory technicians. It is for this reason that several, at least five, tests should be run using a reference toxicant such as those recommended by USEPA, that is, sodium chloride (NaCl), potassium chloride (KCl), cadmium chloride ($CdCl_2$), copper sulfate ($CuSO_4$), sodium dodecyl sulfate (SDS) or potassium dichromate ($K_2Cr_2O_7$). Using the data acquired from the reference toxicant tests, control charts are to be made and maintained by performing monthly tests with the reference toxicant to document test variability and show the precision of the lab using only the 20 most recent reference toxicant tests.

3.4.2.1 Testing Set-up

To begin the tests, prepare the test vessels (Figure 57) by cleaning them with soap and water and rinsing with de-ionized (DI) water at least twice. Allow the test vessels to air dry. Label all vessels for each concentration and replicate, and set the vessels up in a random layout in the laboratory. Add the collected receiving water from the field with the appropriate concentrations to the test vessels. For the polymers tested thus far by the Stormwater Management Academy, each tank was prepared separately and allowed to mix for a minimum of one hour before addition of test organisms. Allow the water temperature to equalize with the ambient lab temperature. Carefully add the test organisms one at a time in a random fashion to the test vessels. Test organisms should be 24 – 48 hours old and all hatched within a 24 hour window. Should any test organisms get damaged during transfer to test vessels discard the test organism and replace it with another. Continue until all test vessels have 10 test organisms.

Figure 57 Test aquarium tanks for toxicity tests on PAM

At the start of each day, the above mentioned water quality analysis is to be performed and recorded in the data sheets. After the water quality analysis is completed the test organisms are to be fed as much newly hatched brine shrimp as they can eat. Make note of any dead or sick test organisms on data sheet. At the end of the day, perform the required water quality analysis mentioned above and feed the test organisms in the same manner as at the beginning of the day.

On Day Four, the halfway point of the test, the test vessel water needs to be changed. Collect water from the field between 24 and 48 hours before the scheduled water change. Change the water in the test vessels in a similar manner as mentioned above for the preparation of the test water making sure to add the appropriate concentration to the appropriate test vessel. Place the test organisms back in the appropriate tank and feed as much freshly hatched brine shrimp as they can eat.

On the seventh day, all analysis and observations previously mentioned are to be repeated. At this time, if the control test vessels (tanks with no toxins) don't show a survival rate of at least 80 percent, the test is considered invalid and must be redone. All surviving test organisms are to be rinsed with DI water several times to wash off any debris, dried and weighed on a balance capable of measuring 0.0001g. Test organisms are to be oven dried for 6 hrs or 24 hrs at temperatures of $105^{o}C$ and $50^{o}C$ respectively. The fatality data is used for the determination of acute toxicity, LC50, while the dry weight data is used for chronic toxicity, NOEC and LOEC. Once all the data is collected, the necessary statistical analysis to determine the LC50, LOEC and NOEC using methods presented in USEPA Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, (USEPA 2002) may be performed.

Equipment/Materials

1. 60µm filter
2. 100mL beakers
3. 1L volumetric flask
4. 2.5 gallon tank (test vessel)
5. Stir plate
6. Magnetic stir bar
7. Crucible
8. Desiccators
9. Desiccant
10. Scale capable of measuring to 0.0001g
11. Brine shrimp eggs
12. Brine shrimp hatchery
13. Dissolved oxygen meter
14. pH meter
15. Conductivity meter

3.4.3 PAM Toxicity Test Results and Conclusions

Presented below in Table 35 and

Table 36 are the toxicity results of unfiltered and filtered samples performed thus far by the Stormwater Management Academy.

Table 35 PAM toxicity test results (untreated)

Toxicity Test Results Summary: PAM				
Product	Date	NOEC [mg/L]	LOEC [mg/L]	LC50 [mg/L]
706b	8/5/2009	210	420	577.3
740	8/19/2009	56.25	112.5	97.3
707	8/28/2009	900	NA	6198.0
730	9/9/2009	56.25	112.5	99.4
705	9/29/2009	112.5	225	296.6
712	10/9/2009	450	900	1218.4
745	10/20/2009	56.25	112.5	96.0

The results presented above show the chronic and acute toxicity of samples that have not been filtered. As can be seen from the PAM Type 745 toxicity in Table 35 and dosage results shown in the previous section of this report, toxic effects will occur for the suggested dosage when the samples are not filtered.

This shows that this product needs to be retested by filtering the sample before exposing the test organisms. The results from the filtered toxicity tests are presented below in

Table 36. Based on the filtered sample toxicity results, it can be seen that if the waste stream is filtered with a 100 micron filter before discharge, there will be no resultant toxicity. It is for this reason that toxicity must be tested for the unfiltered case as well as the filtered case and the filtered field application must not cause toxicity based on tested results.

Table 36 PAM 745 filtered toxicity test results

Summary: PAM Filtered with 100 micron				
Product	Date	NOEC [mg/L]	LOEC [mg/L]	LC50 [mg/L]
745	10/29/2009	900	NA	NA

4 RESULTS AND CONCLUSIONS

The Index Testing Laboratory was set up for providing laboratory support to the field-scale test beds and the other field-scale erosion and sedimentation control testing in the SMARTL at UCF, Orlando. To this end, some tests have been completed on silt fences, polyacrylamide (PAM), inlet protection products and soil properties. This report covers the tests on silt fence, and PAM dosage and toxicity. The test results from other products are being presented in other related reports. The Index Testing Laboratory is equipped to run some index tests as per ASTM standard test methods relevant to the erosion and sediment control test beds. Additional test equipment would be needed to perform other needed index tests, such as ultraviolet stability of geosynthetic fabrics. The laboratory is not equipped to conduct the ultraviolet stability test on geotextiles because of the high cost of the equipment. The SMARTL has arranged with FDOT State Material Laboratory for performing ultraviolet degradation tests when necessary.

The two tested silt fence products, BSRF and Type III, meet the minimum recommendations of FDOT and ASTM for the grab strength, permittivity and apparent opening size.

The dosage testing for turbidity removal using PAM reveals that as mixing speed and mixing time increase, the efficiency of the turbidity removal increases but that there is a level of mixing speed and time at which the efficiencies will plateau. At that dosage, the addition of PAM, mixing speed and/or mixing time will not improve the efficiency. These optimum levels of mixing can be obtained by referring to the efficiency tables, see

Table 33 and Table 34 and Table 37 through Table 40.

Filtered sample toxicity test results suggested that there will be no resultant toxicity if the waste stream is filtered with a 100 micron filter before discharge. It is recommended that toxicity be tested for the unfiltered case as well as the filtered case; thus, a similar field application based on tested results will likely not cause toxicity. The results presented for PAM dosage and toxicity have shown that the PAM dosage can be properly determined for a site and, based on the dosage level and filtration, PAM residue in the field discharge water is expected to be of minimal toxic effect if the PAM is applied. On the other hand, it could also be toxic to aquatic life in the receiving bodies.

Further tests need to be conducted on the use of silt fences, such as field simulation on the erosion beds to evaluate their performance, structural stability, flow rate and filtration capability. Another test of interest is the combination of erosion and sedimentation control products on the erosion beds, such as the use of PAM and silt fence, PAM and other turf mats, and the test of the index property of all products used. More PAM dosage and toxicity tests on other available polymer products are necessary to establish the relevant safe dosage concentration to reduce turbidity to acceptable levels before discharge to receiving water bodies.

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APPENDICES

Table 37 Turbidity removal efficiency results for APS 703d without filter

Block/Log weight (mg)	*Speed (ft/s)*	Without Filter					
		30 sec	45 sec	60 sec	75 sec	90 sec	120 sec
50	1.4	30%	37%	66%	93%	92%	95%
	2.6	44%	56%	61%	72%	68%	96%
	3.8	93%	97%	98%	97%	98%	94%
100	1.4	42%	49%	70%	76%	87%	94%
	2.6	25%	36%	55%	63%	94%	95%
	3.8	56%	76%	90%	95%	95%	96%
150	1.4	28%	49%	75%	71%	70%	88%
	2.6	36%	56%	59%	89%	95%	96%
	3.8	28%	83%	87%	94%	96%	97%
200	1.4	38%	61%	79%	87%	90%	94%
	2.6	23%	59%	92%	97%	97%	97%
	3.8	83%	94%	96%	98%	98%	98%
250	1.4	18%	51%	66%	72%	80%	92%
	2.6	63%	83%	94%	96%	96%	97%
	3.8	88%	96%	99%	98%	99%	99%

Table 38 Turbidity removal efficiency results for APS 703d with 35 micron filter

Block/Log weight (mg)	*Speed (ft/s)*	With Filter					
		30 sec	45 sec	60 sec	75 sec	90 sec	120 sec
50	1.4	45%	52%	68%	96%	95%	96%
	2.6	55%	62%	67%	76%	73%	99%
	3.8	95%	98%	99%	99%	99%	96%
100	1.4	56%	59%	77%	89%	90%	95%
	2.6	38%	44%	61%	75%	95%	96%
	3.8	68%	83%	92%	96%	95%	96%
150	1.4	36%	54%	84%	76%	75%	89%
	2.6	47%	64%	79%	90%	95%	97%
	3.8	39%	88%	90%	96%	96%	98%
200	1.4	48%	66%	87%	91%	92%	94%
	2.6	44%	73%	95%	98%	98%	98%
	3.8	87%	97%	97%	98%	98%	98%
250	1.4	40%	75%	83%	80%	87%	93%
	2.6	75%	90%	96%	97%	97%	98%
	3.8	92%	96%	99%	99%	99%	99%

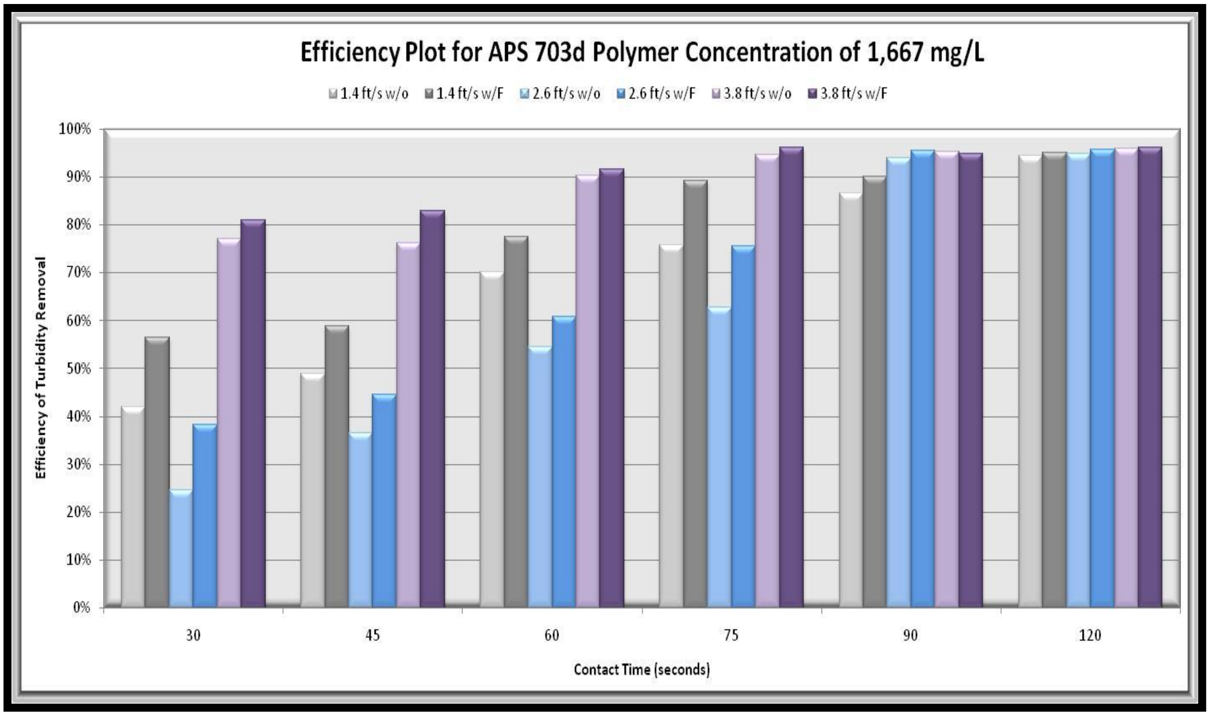

Figure 58 Plot of efficiencies for 1667 mg/L concentration of APS 703d PAM product

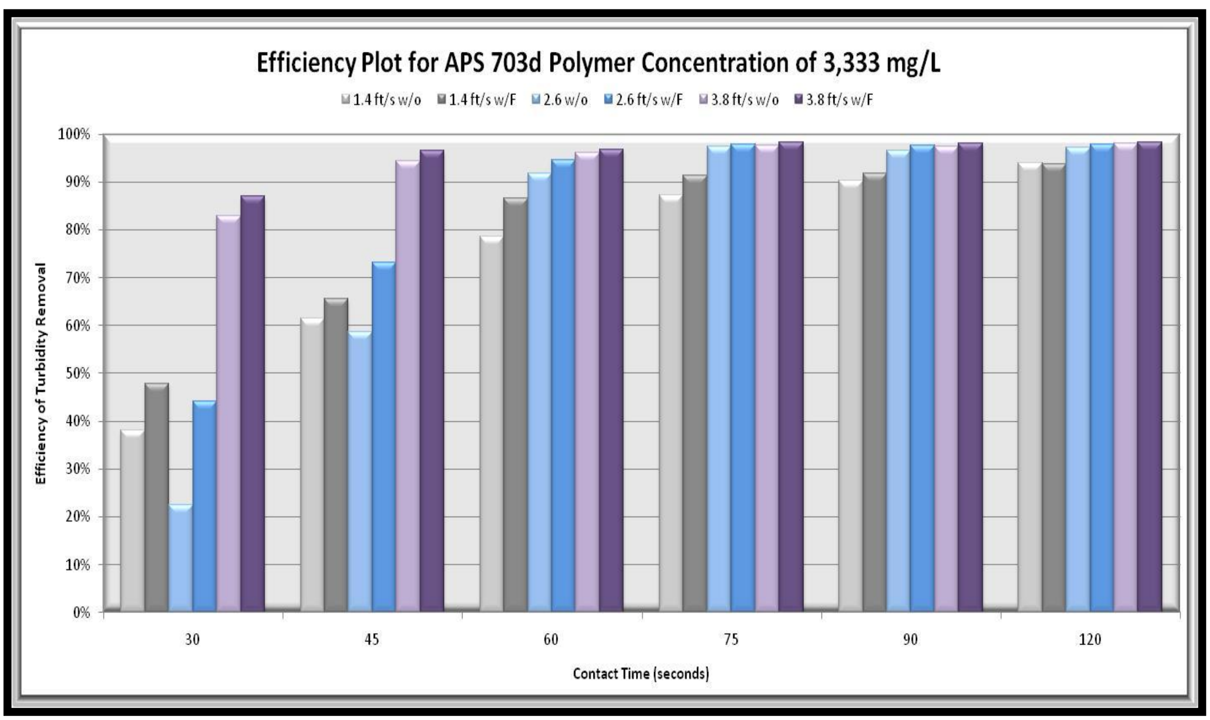

Figure 59 Plot of efficiencies for 3334 mg/L concentration of APS 703d PAM product

Table 39 Turbidity removal efficiency results for APS 705 without filter

Block/Log weight (mg)	*Speed (ft/s)*	Contact time					
		30 sec	45 sec	60 sec	75 sec	90 sec	120 sec
25	1.4	76%	82%	95%	96%	97%	99%
	2.6	97%	97%	98%	98%	99%	99%
	3.8	97%	99%	99%	99%	100%	100%
50	1.4	91%	94%	98%	97%	97%	98%
	2.6	94%	97%	96%	98%	99%	99%
	3.8	97%	98%	99%	99%	99%	99%

Table 40 Turbidity removal efficiency results for APS 705 with 35 micron filter

Block/Log weight (mg)	*Speed (ft/s)*	Contact time					
		30 sec	45 sec	60 sec	75 sec	90 sec	120 sec
25	1.4	84%	87%	97%	98%	98%	99%
	2.6	98%	98%	98%	98%	99%	99%
	3.8	98%	99%	100%	100%	100%	100%
50	1.4	95%	97%	98%	98%	98%	99%
	2.6	97%	98%	98%	99%	99%	99%
	3.8	98%	99%	99%	99%	99%	99%

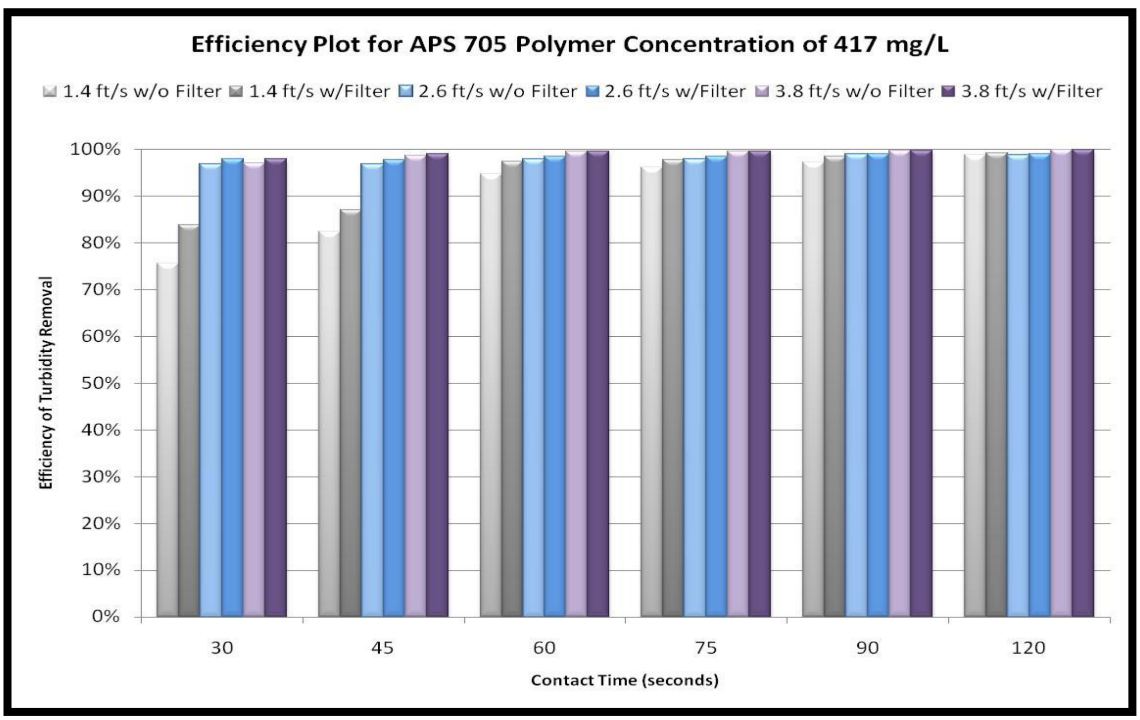

Figure 60 Plot of efficiencies for 417 mg/L concentration of APS 705 PAM product

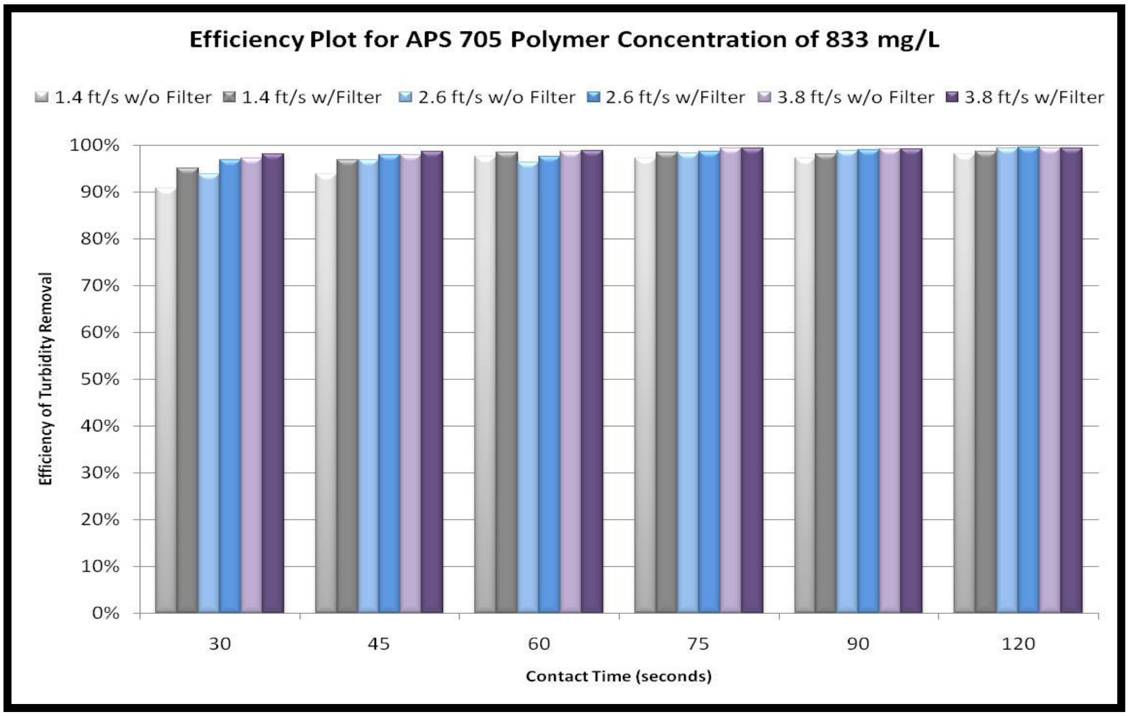

Figure 61 Plot of efficiencies for 833 mg/L concentration of APS 705 PAM product