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Pollution Prevention Fencing Geocomposite

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ABSTRACT
Silt fences have been in use on construction sites in the United States and elsewhere to protect nearby water bodies from sediments carried by rainwater. Like other geosynthetic applications, silt fences are evolving technologically and becoming more important for environmental protection.
A new series of geocomposites used to manufacture silt fences with much improved environmental protection capabilities has recently been developed and is being tested in the United States. This new generation of silt fences has dual function: to temporarily control sedimentation and to absorb or adsorb pollutants from storm water. Different reactive silt fence configurations, composed of particular capturing layers, can capture at least one of hydrocarbons, heavy metals, phosphates, volatile organic compounds (VOCs), trichlorobenzenes (TCBs), nitrates, arsenic, mercury, mineral oil, oil, polychlorinated biphenyls (PCBs), non-aqueous phase liquids (NAPLs), and polycyclic aromatic hydrocarbons (PAH).
This paper will provide an introductory explanation regarding the use of silt fences and related regulations. It will focus on a particular configuration to capture hexavalent chromium (Cr (VI)), lead (Pb), uranium (U), mercury (Hg) and selenium (Se) from contaminated water. It will describe the development and functioning of the reactive silt fence, its components, geosynthetic characteristics, discuss its capabilities and testing. It will also provide performance and general comparisons to older generation silt fence products. Besides the additional function, improvements were also made to the general setup of the system in order to minimize potential structural failures; such enhancements will be described as well.

1. INTRODUCTION

1.1 Definition of Silt Fences

Silt fences are temporary filtration devices used to prevent off-site damage by minimizing sediment from leaving the construction site. They are considered as a structural erosion control measure typically used in combination with other measures as part of an erosion control plan.

They are comprised of a filtering fabric (burlap, plastic filter plastic, etc.) attached to posts, sometimes a wire mesh or other reinforcing elements are added to the structure for improved stability. The system is typically installed along the perimeter of the site and the bottom of the filtering fabric is embedded in an anchor trench.

1.2 Functioning

The silt fence is installed along the perimeter of the controlled area to intercept runoff water. The upstream runoff moves across the fabric, which functions as a filter to retain soil particles. Therefore, the filter material must exhibit good flow capability while also being able to retain fine sediment.

As described by Koerner (2012) silt fences initially allow the free passage of water through the fabric plane. With time, sediments start clogging the fabric, in turn coarser sediment particles start to deposit at the toe of the fence. Subsequently, water carrying finer sediments starts to move higher until it gets above the clogged zone and it can again flow through the fabric at a higher elevation. This cycle takes place until equilibrium is achieved (see Figure 1).

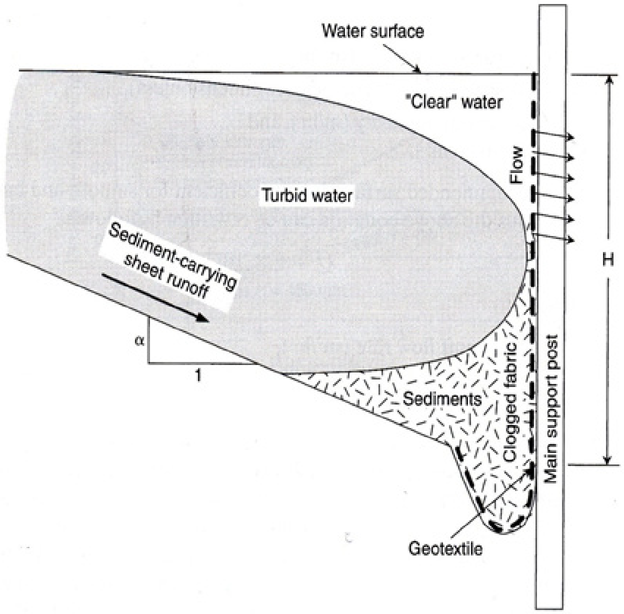

Figure 1. Cross section of geotextile silt fence and suggested manner in which system functions (from Koerner 2012).

The functioning of a silt fence therefore has two contradictory requirements: 1) the openings of the filtering fabric need to be large enough to allow good flow capability; 2) the filtering fabric openings need to retain upstream fine soil particles.

Also important for its proper functionality, a silt fence mounting structure needs to be stable not to collapse due to hydrostatic and sediment accumulation loads. Furthermore, the filtering fabric needs to resist high tensile stresses due to the same loads while not suffering dislodgment or excessive deformation.

1.3 Traditional Silt Fences

State and federal agencies have distinct regulations and guidelines for erosion control measures. In this paper, we will use The Department of Environmental Protection (DEP) of Pennsylvania state as reference for the description of silt fence types and requirements.

The DEP of Pennsylvania describes on its Erosion and Sediment Pollution Control Program Manual (2012) two main types of silt fences: a) silt fence (filter fabric fence) and b) super silt fence (super filter fabric fence).

Silt fence main type a) has three subtypes: standard silt fence, reinforced silt fence and silt fence reinforced by staked straw bales. Each of these has slightly different configurations regarding the exposed height and supporting components. Super silt fence main type has no subtype. The main configuration parameters for each type are summarized on Table 1.

Table 1. Summary of Pennsylvania's DEP silt traditional silt fence types.

Types	Subtypes	Fabric Width (cm)	Exposed Fabric Height (cm)	Differential Structural Component	Post/Stake Minimum Embedment (cm)
Silt Fence	Standard	76	46		46
	Reinforced	107	76	Fabric reinforced with mesh (polypropylene or steel). Stake anchoring wire.	46
	Reinforced with Straw Bales	107	76	Continuous row of straw bales for improved stability.	46
Super Silt Fence	N/A	107	84	Fabric reinforced with chain link fence, tension wire and attached to aluminum or heavy-duty galvanized posts.	91

The manual establishes the maximum permissible slope length to be treated by the silt fence according to its type and to the grade of the slope. The minimum required fabric specifications are the same for all fence types, the parameters are shown on Table 2.

Table 2. Pennsylvania's DEP Fabric Properties for Silt Fence.

Fabric Property	Minimum Acceptable Value	Test Method
Grab Tensile Strength (N)	534	ASTM D 4632
Elongation at Failure (%)	20 Max. (at 534 N)	ASTM D 4632
Mullen Burst Strength (kPa)	1,379	ASTM D 3786
Trapezoidal Tear Strength (N)	222	ASTM D 4533
Puncture Strength (N)	178	ASTM D 4833
Slurry Flow Rate ($l/min/m^2$)	12	ASTM D 5141
Equivalent Opening Size (sieve #)	30	ASTM D 4751
Ultraviolet Radiation Stability (%)	80	ASTM D 4355

1.4 Typical Failures

A few types of silt fence failures can be routinely observed. They may include situations where the fabric tears off from the stakes, the stakes get pushed over, the water flows underneath the fence (undercutting by erosion), the ponding level overtops the fence, and the fabric suffers excessive deformation. Figures 2 through 5 illustrate some of these situations.

Figure 2. Typical Failure

Figure 3. Typical Failure

Figure 4. Typical Failure

Figure 5. Typical Failure

2. POLLUTION PREVENTION SILT FENCE

The following sections of this paper will discuss the improvements made to older generation silt fences. The new version was developed to offer the additional function of absorbing or adsorbing pollutants from storm water (besides the function of sediment control).

2.1 Description of the System

The main objective of the creation of the new silt fence herein described was to develop a system configured for capturing pollutants while still providing a high performance sediment control. Attention was also placed on providing a construction with improved resistance to typical failures.

The fence filtering pollutant capture element is a composite comprised of three elements: a backing layer for structural resistance, a core pollutant-capturing layer and a fabric-filtering layer. The configuration has high strength to resist typical rip, tear and puncture failures. The ultraviolet (UV) resistance is also higher than the first-generation products. In order to prevent overturning, an anti-push spade was developed to integrate the mounting stakes.

The nonwoven filtering layer defines the flow capacity for the silt fence, defining the lowest hydraulic flow of the composing layers. The core layer defines the targeted pollutants to be absorbed/adsorbed. Differently from the conventional silt fences that are omnidirectional, the improved device needs to have the filtering layer facing the incoming water flow.

As described in Section 1.2, typical silt fences work by ponding sediment-laden water. This allows sediment to settle out while slowly releasing water though the geotextile. This slow release of water is called seepage. As the sediment clogs the fabric, the water rises going through regions of the fence that are still open for flow. Therefore, the area available for filtering slowly diminishes requiring maintenance or replacement of the fence. The new generation of silt fences has an improved performance in relation to this dynamic filter-ponder effect. The design was developed to resist blinding and keep seeping. For a dynamic filter-ponder, blinding is caused by the buildup of sediment during the transition from filter to ponder. An unique course textured non-woven was specifically designed to resist blinding and functions as a pre-filter for the system. The final geocomposite exhibits a soft and yielding surface that compresses as the hydrostatic pressure increases and decompresses as the pressure alleviates. As this decompression takes place, the textile suddenly rebounds (approximately 0.5 mm) breaking up the slurry cake and allowing seepage to continue. The test results discussed ahead will illustrate the fact that the new design shows a much smaller change in flow over time in comparison to the traditional type of devices.

2.2 Geocomposite Filtering Element

Different types of media can be used to assemble the pollution prevention silt fencing geocomposite. The targeted pollutants for different media types are hydrocarbons, heavy metals, phosphates, volatile organic compounds (VOCs), trichlorobenzenes (TCBs), nitrates, arsenic, mercury, mineral oil, oil, polychlorinated biphenyls (PCBs), non-aqueous phase liquids (NAPLs), and polycyclic aromatic hydrocarbons (PAH).

A variety of elements are already under consideration to be used as media to target the pollutants mentioned above, but for the purpose of this paper, only one media type will be discussed (the others are under testing to assess manufacturing feasibility). One of the challenges for developing these devices is the feasibility of applying natural materials, already used for site remediation, in vertical applications as in a silt fence. Issues like the development of an efficient assembly method, the relatively small treatment thickness, clogging potential, etc., need to be resolved.

The issues cited above were resolved for the filter media herein discussed and the geocomposite is already being used for the production of pollution prevention silt fences. The pollutant-capturing layer is a plant based cellulose layer that captures viscous site pollutants like diesel, bar oil, motor oil and hydraulic fluid. Studies have shown that the core fibers can effectively remove high percentage of heavy metals as Cr (VI), Pb, U, and Hg from contaminated water. When these fibers are treated with an enhancement solution, they can also capture Se.

The pollutant-capturing layer is generally configured to capture elements through absorption or adsorption. Adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. This process creates a film of the adsorbate on the surface of the adsorbent. This differs from absorption, in which a fluid (the absorbate) is dissolved by or permeates a solid, or liquid (the absorbent). Adsorption is a surface-based process while the absorption involves the whole volume of the material. Adsorption is a surface phenomenon. The specific media herein under discussion functions as an adsorbent.

2.3 Structure Robustness

As mentioned in Section 1.4, typical silt fences are prone to different types of structural failure. This is in many instances due to loads that the fence cannot withstand. An effort was made on developing the new device to account for such loads and provide a structure robust enough to resist the required mechanical and environmental conditions.

The back layer of the geocomposite does not limit the hydraulic flow and allow for the use of heavy-duty staples for fixing the fence mounting stakes. The composite geotextile also exhibits higher resistance to rip, tear and puncture failures than the typical requirements; test results are shown on Table 3.

Table 3. 2018 ASTM Test Results for 3-layer pollution prevention composite geotextile

Test	Composite Geotextile
Grab Tensile Strength ASTM D 4632, MD (N)	1,801
Elongation ASTM D 4632, MD (%) at 1,801 N	21
Grab Tensile Strength ASTM D 4632, CMD (N)	934
Elongation ASTM D 4632, CMD (%) at 934 N	9
Puncture Strength ASTM D 4833 (N)	996
Trapezoidal Tear ASTM D 4533, MD (N)	632
Trapezoidal Tear ASTM D 4533, CMD (N)	600
Mullen Burst Strength ASTM D 3786 (N)	3,376
Apparent Opening Size ASTM D 4751 (mm)	0.14-0.17

The geocomposite resulted in a sturdy fabric that does not require a reinforcing layer for stability. A typical detail showing the silt fence elements is shown in Figure 6.

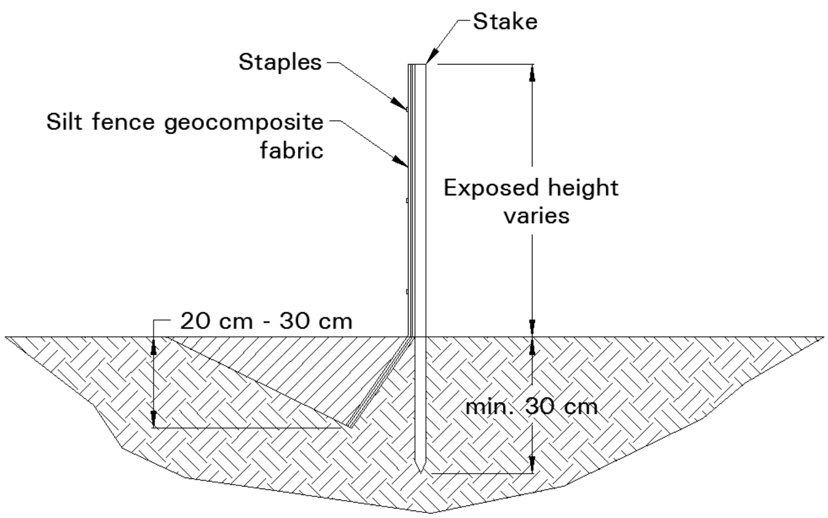

Figure 6. Pollution prevention silt fence elements

3. PERFORMANCE TESTS

Silt fence performance testing is typically carried out using ASTM D 5141, Standard Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device using site-specific soil. This test is preferred due to the smaller scale of the testing apparatus versus using ASTM D 7351, Standard Test Method for Determination of Sediment Retention Device (SRD) Effectiveness in Sheet Flow Applications, which requires much larger equipment, and much more water and soil to conduct the test.

3.1 ASTM D 5141 Test Methodology

This test determines the filtering efficiency and flow rate of a filtration component such as a silt fence, silt barrier, or SRD. The filtering efficiency is presented as a percentage of the retained sediment captured by the silt fence, silt barrier, or

SRD; with the flow rate measured as the rate of sediment-laden water passing through the silt fence, silt barrier, or SRD during the 25-minute test duration.

The testing apparatus consists of a channeled flume, which is 125 cm (49.2 inches) long by 85 cm (33.5 inches) wide with sides of 30 cm (11.8 inches) as shown in Figures 9 through 11. The channeled flume is elevated at the back with an 8% slope to ensure flow through the filter sample. The filter sample size is 1 m (3.3 feet) long by 0.3 m (12 inches) wide and is securely placed at the down slope of the flume. The test to characterize the material under discussion was performed using an initial flow volume of 50 liters of clear water to pre-wet the filter media followed by three cycles of a mixture of 50 liters of clear water mixed with 150 grams of a silty clay. The sediment-laden water passing through the filter sample was collected, and the sediment separated and heat dried in an oven for an hour at a temperature of 103 ˚C to 105 ˚C. The collected dried sediment weight was compared to the initial mass of 150 grams to obtain the filtering efficiency. The flow rate through the filter sample was determined by the volume of water collected during the 25-minute test.

Figures 7 and 8 compare the performance filtering and flow efficiencies of the new improved silt fence (Siltron®) to a traditional silt fence (Silt-Saver® type BSRF-P1). A comparison of the average flow rates show that the new improved silt fence has almost three times the flow rate to that of the traditional assembly. The high flow rate through the new improved silt fence indicates that there is a significant reduction of water ponding behind the fence reducing not only the stress on the composite but also reducing the potential for an overtopping failure, while maintaining a high filtering efficiency.

When considering the filtering efficiency, the new device achieved an average value of 96.0%. This was after five consecutive runs where the sediment is allowed to accumulate behind the fence. The traditional fence resulted in an average value of 97.9%. However, on this case, the test was completed after three runs (versus five) and the behavior could be affected by additional accumulation of sediment, elevation of seeping water, structural integrity, etc. Therefore, a direct comparison of the filtering efficiency may be deemed as inconclusive.

With typical woven and nonwoven silt fences, the combined high flow and high efficiency filtering is not seen, either one is present, but not both. Pennsylvania´s erosion and sediment control manual mentioned as reference on section 1.3, particularly does not provide a requirement for filtering efficiency while other agencies may, typically with a minimum value of 80%.

Sediment Control Test Results via ASTM D 5141

Client: MKB Company TRI Log #: 791 Date: 2/6/2019 Temperature, C: 14 Technicians: GM

Sample ID	Composition	Specimen #	Soil Type	Test Configuration (Vertical or Horizontal)	Specimen Width, cm	Flow Volume (L)	Distance from SRD to the edge of water behind SRD at end of 25 min (mm)	Flow Rate ($m^3/m^2/min$)	Flow Rate (GPM/ft^2)	Initial Mass of Soil (g)	Final Mass of Soil (g)	Filtering Efficiency (%)
Pollution prevention silt fence	Orange Non-Woven Geotextile	1	Clear Water	Vertical	81	50	0	0.966	23.716	0	0.00	n/a
			Silty Clay	Vertical	81	50	0	0.199	4.878	150	10.69	92.9
			Silty Clay	Vertical	81	50	20	0.055	1.353	150	7.89	94.7
			Silty Clay	Vertical	81	50	221	0.046	1.125	150	4.10	97.3
			Silty Clay	Vertical	81	50	495	0.033	0.815	150	4.02	97.3
			Silty Clay	Vertical	81	50	630	0.027	0.662	150	3.58	97.6
		Avg						0.072	1.767	150	6.06	96.0

Figure 7. Test results for the pollution prevention fence

Sediment Control Test Results via ASTM D 5141

Client: Silt Saver TRI Log #: 665 Date: 1/12/2018 Temperature, C: 17 Technicians: JWS/AMH

Sample ID	Composition	Specimen #	Soil Type	Test Configuration (Vertical or Horizontal)	Specimen Width, cm	Flow Volume (L)	Distance from SRD to the edge of water behind SRD at end of 25 min (mm)	Flow Rate ($m^3/m^2/min$)	Flow Rate (GPM/ft^2)	Initial Mass of Soil (g)	Final Mass of Soil (g)	Filtering Efficiency (%)
Traditional silt fence	NW Geotextile Silt Fence	1	Clear Water	Vertical	81	50	0	1.050	25.766	0	0.00	n/a
			Silty Clay	Vertical	81	50	382	0.036	0.883	150	3.32	97.8
			Silty Clay	Vertical	81	50	608	0.026	0.644	150	2.93	98.0
			Silty Clay	Vertical	81	50	774	0.019	0.468	150	3.37	97.8
		Avg						0.027	0.665	150	3.21	97.9

Figure 8. Test results for a traditional silt fence

Figure 9. Typical upstream view with sediment-laden discharge

Figure 10. Typical downstream view with sediment-laden discharge

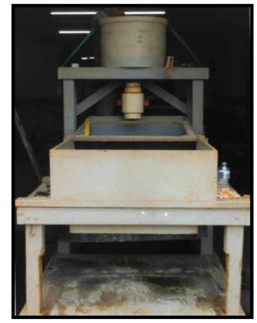

Figure 11. Testing Apparatus

4. CONCLUSION

Traditional silt fences are filtering devices that have been in use as part of erosion control plans for a long time; their sole function is to minimize the amount of sediment leaving the construction site. The development of geocomposite production technologies has made it possible to assemble different materials (fibrous, granular, etc.) in layered systems with multiple functions. In the case of silt fences, it is possible to add the pollutant filtering function with the use of different medias, targeting a myriad of site pollutants.

This paper focused on a geocomposite already commercialized, which is comprised of a back layer for structural resistance, a cellulose pollutant-capturing layer and a fabric-filtering layer. It compared the minimum requirements for silt fences provided by Pennsylvania´s state to the enhanced parameters achieved by the new generation device. The results reflect a structurally robust silt fence, with higher resistance to hydrostatic loads and typical failures with the additional pollutant filtering function.

The pollution prevention fencing geocomposite herein discussed adsorbs Cr (VI), Pb, U, Hg and Se from contaminated water. As manufacturers improve the manufacturing of geotextile composites, other types of media will possibly be added as pollution prevention silt fences targeting other pollutants. These developments represent an important environmental benefit, which is the protection of water bodies receiving runoff from nearby contaminated sites.

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