APPENDIX – I. REFERENCES

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APPENDIX – II. SYMBOLS USED

E = Young's modulus
K = stiffness
υ = Poisson's Ratio
R = outside radius of the ring-foot

Geotextile Separators For Hike And Bike Trail

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Abstract: Intrusion of surface aggregate into the underlying soil of hike and bike trails creates undesirable conditions for trail users and exacerbates the problem of trail rutting. A study is underway to evaluate the effectiveness of geotextile separators for rails-to-trails applications. Non-woven needle-punched and spunbonded geotextiles were placed between the subsoil and the aggregate surface in three test sections along a trail. The test sections are being monitored for visible intrusion of aggregate into the subsoil, drainage of surface water off the trail, and enhanced performance and durability of the aggregate surface compared to control sections. Destructive samples of the geotextile separator and aggregate were taken and tested periodically to evaluate field performance of the geotextiles. The characteristics of the surface aggregate and geotextile separators, installation of the three test sections, and results of performance monitoring and laboratory testing activities are described herein. The findings indicate the geotextile separators to be performing well and the test sections have maintained a well-drained, smooth surface after one and a half years. The performance of these sections vastly exceeded that of the control (no separator) sections.

INTRODUCTION

The objective of this effort is to demonstrate the advantages of using a geotextile separator on hike and bike trails. This requires documentation of a higher quality, longer lasting surface course along with decreased frequency for maintenance of the trail surface. The ultimate goal is to demonstrate that a geotextile separator can be beneficial to both trail users and owners. Geotextiles are normally used in pavements to provide separation and filtration (Koerner, 1998). The separator function in pavements has been well documented by Black and Holtz

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(1999) in their article assessing the performance of geotextile separators five years after installation. In the application presented herein, the geotextile is installed between the subsoil and aggregate to prevent the subsoil and aggregate from mixing (Figure 1). This design reduces the amount of rutting and muddy spots.

The City of Columbia Missouri Parks and Recreation Department maintains 7.5 km of a hike and bike trail, constructed on the former Missouri-Kansas-Texas (MKT) railroad line (Figure 2). The MKT trail connects to the KATY trail, also a rails-to-trails project, which stretches approximately 240 miles across Missouri from Sedalia to St. Louis.

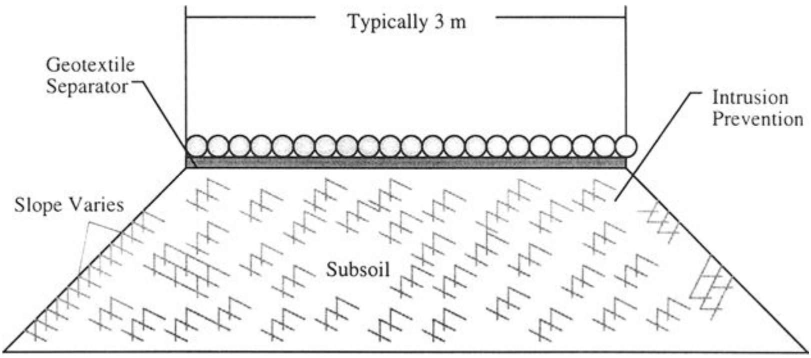

Figure 1: Typical Cross-Section of Geotextile Stabilized Area of the MKT Hike & Bike Trail.

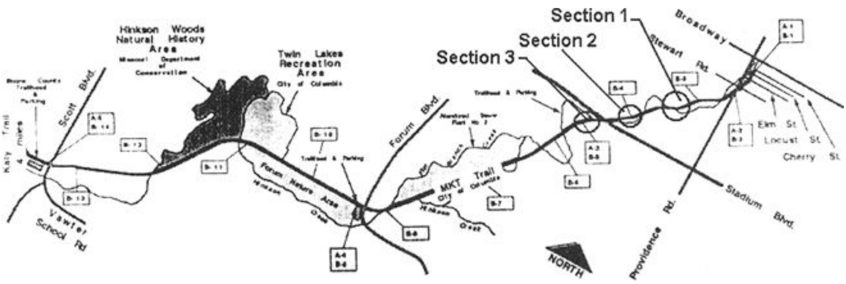

Figure 2: The 7.5 km MKT Trail Hike and Bike Trail Maintained by Columbia (Missouri) Parks and Recreations Department.

Railroad ballast, outcrop rock, and clayey soils make up the subsurface of the trail. The trail surface (10 mm crushed limestone) is generally five to ten centimeters thick placed directly on the subsurface to provide a firm surface for trail users to run, walk, or bicycle.

Several problem areas have been encountered on the trail. Excessive rutting occurs where users repeatedly travel along the same paths. Intrusion of aggregate into the underlying soil causes water to pond and muddy spots on the trail surface. Aggregate also tends to wash off the sides of the trail leaving only fines on the trail surface.

Columbia Parks and Recreations Department annually places fresh aggregate on the entire trail and quarterly performs spot maintenance along portions of the trail. Approximately $17,000 (U.S., 1999) is spent per year on labor and aggregate to upkeep the 7.5 km MKT trail (Griggs, 1998). The overall objective of this project is to demonstrate the reduction in long-term maintenance cost and improvement in the trail's surface performance by introducing the use of a geotextile separator.

PRE-INSTALLATION TESTS

Laboratory tests were performed on samples of the MKT trail aggregate to determine its classification and to investigate the performance of two geotextiles for filtration purposes. Aggregate used for the trail is a 10-mm crushed limestone from Boone Quarry in Columbia, Missouri. The two geotextiles used include a non-woven needle-punched geotextile and a non-woven spunbonded geotextile.

Sieve analyses (ASTM D422) and Atterberg limits tests (ASTM D424) were performed on samples of the MKT aggregate to determine its grain size distribution and soil classification according to the Unified Soil Classification System (USCS) (ASTM D2487). The fine-grained portion of the aggregate was determined to be non-plastic. The grain-size distribution for the surface aggregate is shown in Figure 3. The aggregate is dually classified as a poorly graded sand and silty sand (SP-SM) with eleven percent of the aggregate passing the #200 sieve (0.075mm).

A laboratory test was performed to evaluate whether the finer particles from the aggregate would migrate into or through the candidate geotextiles. A loose sample of aggregate (dry unit weights varied from 3.72 kN/m^3 to 5.29 kN/m^3) was placed in a rigid-wall permeameter over a geotextile. Aggregate was subsequently removed and divided into thirds. Sieve analyses were performed on each third to establish baseline data ("Pre-Test") taking into account segregation due to sample preparation (Figure 4). A new sample of aggregate was then placed in the mold and a constant-head permeability test was performed. The average hydraulic conductivity was measured to be 0.014 cm/s. After the permeability test, the aggregate was retrieved from the permeameter and divided into thirds. Sieve analyses were again performed on each third to determine the degree of particle migration through the sample and into the geotextiles (Post-Test). The fine particles tended to migrate in the direction of flow. Some fines passed through the geotextiles but the majority stayed in or on the geotextiles. As shown in Table 1, the non-woven needle-punched geotextile collected more fines within the geotextile compared to non-woven spunbonded. The fines within the geotextile may result in a slight reduction in the permittivity of the geotextile; however, a slight reduction is not expected to diminish the performance of the geotextile as a separator.

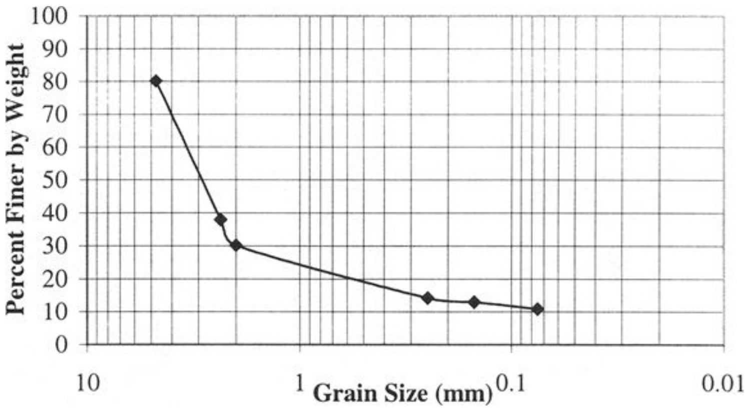

Figure 3: Grain Size Distribution Curve of a Sample of Trail Surface Aggregate.

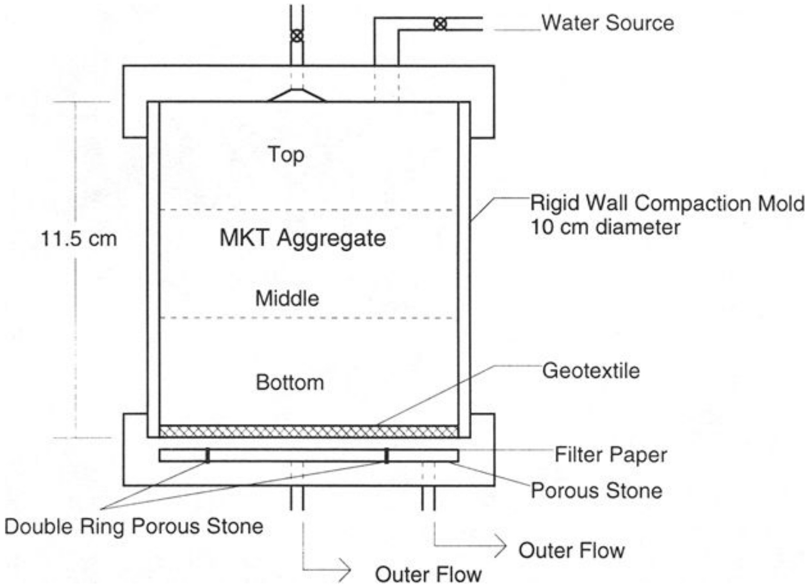

Figure 4: Test Setup to Evaluate Migration of Aggregate Fines Into and Through the Underlying Geotextile Separator.

Table 1: Dry Mass of Geotextiles Pre- and Post-Test.

Geotextile	Dry Mass of Geotextile		
	Pre-Test (g)	Post-Test (g)	Post-Test Fines Shaken From GT (g)
Non-woven Needle-punched	1.3	11.3	4.7
Non-woven Spunbonded	1.1	13	1.3

FIELD INSTALLATION OF GEOTEXTILE SEPARATORS

In June 1998 three test sites were selected and installed along the MKT trail for evaluation of geotextile separator performance. Test sections were selected to meet one or more of the following criteria:

- the aggregate had a history of intruding into the subsoil,
- water was ponding on the surface, or
- excessive rutting was occurring.

Each test section is approximately 30-m long by 3-m wide (Figure 2). The control sections are located at the end of each test section and are approximately 3-m long. Columbia Parks and Recreation staff and researchers from the University of Missouri-Columbia performed the installation. The installation procedure consisted of removing the top 5-10 cm of aggregate and subsoil using a box scraper. Each section was checked for debris that could puncture the geotextiles. Next, the geotextile was cut to size (≈ 30-m by 3-m) and placed directly on the subgrade of each test section. A non-woven needle punched geotextile (172 g/m^2) was installed in test sections 1 and 2. A non-woven spunbonded geotextile (132 g/m^2) was installed in section 3 (Figure 2). Wrinkles were removed from the geotextile. The surface aggregate was placed using a 10-ton dump truck. The truck traveled backwards while placing the aggregate so that it did not travel directly on the exposed geotextile. Aggregate was then manually distributed over the sections to ensure a uniform cross-section and compacted using a 1-ton walk-behind vibratory roller.

After installation, depth measurements and representative samples of aggregate were taken at four or five locations along each test section. Visual observations during installation indicated that the aggregate was uniformly mixed of large and fine particles. Sieve analyses were performed on the samples to quantify any variation of grain-size distribution along the test sections (Figure 5). The percentage of finer particles did not vary as greatly as that of the coarser particles. Table 2 shows the in-place aggregate course thickness that ranged from 2.5-cm to 7.6-cm depending on the test section.

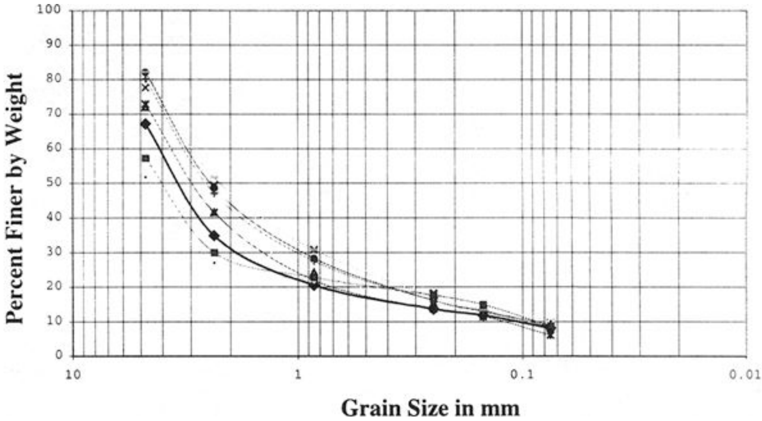

Figure 5: Grain Size Distribution Curves for the Surface Aggregate Sampled Along Various Locations During Installation of the Test Sections.

Table 2: Depth Measurements for each Test Section

Site	Depth (cm)		
	Average	Low	High
1	5.0	2.5	7.6
2	5.5	5.0	6.4
3	4.0	2.5	5.0

FIELD PERFORMANCE

Monthly visual observations were taken of the three test and control sections for one and a half years (July 1998 through November 1999). The sections are performing very well compared to the control sections (sections without geotextiles). There is no sign of intrusion of aggregate into the underlying soil. Rutting and water ponding has decreased in the geotextile-separated sections. In the control sections, the aggregate is covered with soil and the amount of loose lying aggregate has significantly reduced compared to the time of installation indicating that the unstabilized section aggregate has intruded into the subsoil which has lead to frequent ponded water and rutted sections.

Destructive samples were taken to investigate the possible migration of fines through the geotextiles - both from the subsoil upward and aggregate fines downward. The permittivity of the sampled geotextiles was measured to assess any clogging that might have developed due to migration of fines into or onto the geotextile. The samples were taken from the three test sections approximately one year after installation. The depth of surface aggregate at the time of installation and the depth after one year are shown in Table 3. The surface course thickness at Site 2 decreased while the thickness increased at Sites 1 and 3. It is most likely that the increase in thickness was due to scattering of surface aggregate due to trail user activity; although, the Parks Department did add aggregate to some non-test sections during this time.

Table 3: Surface Aggregate Course Thickness Taken at the Time of Installation and One Year After Installation.

Site	Surface Aggregate Thickness		
	Installation (cm)	At 1 year (cm)	Change in Thickness (cm)
1B	5	5.4	0.4
2A	6.4	4.13	-2.27
2B	5	3.02	-1.98
2C	5	3.02	-1.98
3A	2.5	4.45	1.95
3B	3.8	5.08	1.28
3C	5	5.72	0.72

The masses of the exhumed geotextiles were measured and the results are shown in Table 4. The non-woven needle-punched geotextile had a minimal amount of mass gain over time while the spunbonded geotextile, in some cases, quadrupled it's mass. The increased mass of the geotextile is a result of fines collecting in and on the geotextiles. Table 5 shows that the percentage of voids filled by migrating soil is less for the needle-punched geotextile than the spunbonded geotextile. This indicates that the needle-punched geotextile would clog at a slower rate and would be a better geotextile to use with this type of aggregate in this application.

Table 4: Dry Mass of Geotextiles at Time of Installation and Destructive Sampling.

Site	[1]Geotextile Type	Area (cm^2)	Mass at Installation (g/m^2)	Mass at Destructive Sampling (g/m^2)	Mass of Soil Gained (g/m^2)	% Mass Gain
1B	NP	169.1	172	183.4	11.4	6.6
2A	NP	173.6	172	155.5	-16.5	-9.6
2B	NP	321.5	172	174.0	2.0	1.2
2C	NP	338.7	172	239.1	67.1	39
3A	SB	81.1	132	518.1	386.1	293
3B	SB	251.6	132	230.5	98.5	75
3C	SB	169.1	132	201.1	69.1	52

[1]NP = Non-woven Needle-punched, SB = Non-woven Spunbonded

Table 5: Percentage of Geotextile Voids Filled with Soil.

Site	Geotextile Type	Area (cm^2)	Volume of Voids in Geotextile (cm^3)	Mass of Soil (g)	Volume of Soil (cm^3)	% Voids Filled
1B	NP	169.1	22.0	0.189	0.071	0.3
2A	NP	173.6	22.6	0.194	0.073	0.3
2B	NP	321.8	41.9	0.360	0.136	0.3
2C	NP	338.7	44.1	0.379	0.143	0.3
3A	SB	81.1	2.0	0.091	0.034	1.7
3B	SB	251.6	6.2	0.282	0.106	1.7
3C	SB	169.1	4.2	0.189	0.071	1.7

For each destructive sampling location, the surface aggregate, geotextile, and underlying soil were exhumed and in situ balloon density tests (ASTM D2167) were performed (Table 6). Sieve analyses were also performed on the surface aggregate and underlying soil to evaluate the migrations of fines after one year of field exposure. The amount of fines on the geotextiles increased over time. The mass of the geotextiles increased with time as shown in Table 4; indicating that the fines migrated into the geotextile. Clogging of the geotextile may occur if the fines continue to increase over time. The subsoil fines may also have migrated upwards toward the geotextile. Alternatively, part of the increase in fines may be a result of slight variation in sampling locations, degradation of aggregate particles, or collection of fines from other sources.

Table 6: Unit Weights from Destructive Sampling.

	Moist Unit Weight		Dry Unit Weight	
Site	Above Geotextile (g/mm^3)	Below Geotextile (g/mm^3)	Above Geotextile (g/mm^3)	Below Geotextile (g/mm^3)
2B	2.07	1.81	1.98	1.69
2C	1.82	1.79	1.76	1.66
3B	--	2.22	--	2.12

Typically, the underlying soil had a greater amount of fines than the surface aggregate. Data in Table 4 indicate that fines are being collected on the geotextile. A thin residue of fine particles covering the subsoil was observed after removing the destructive samples indicating that fines also traveled through the geotextile. The water contents at sites 3A, 3B, and 3C of the surface aggregate and underlying soil are all practically the same (Table 7). The water contents taken from sites 1B, 2A, 2B, and 2C vary significantly between the underlying soil and the surface aggregate (Table 7). Samples of sites 1B, 2A, 2B, and 2C were taken a few days after a significant rainfall occurred. Surface aggregate contained about half as much water as the underlying soil indicating that the geotextile is not clogging but rather allows the water from the surface aggregate to quickly drain from the surface thereby reducing the effects of ponding and improving the surface of the trail.

Table 7: Water Contents of Surface Aggregate and Subsoil

Site	Water Content: Surface Aggregate (%)	Water Content: Subsoil (%)
1B	5	9.1
2A	3.3	6.5
2B	4.3	7.4
2C	3.6	7.6
3A	4	5.8
3B	5	4.7
3C	3.8	6.2

Permittivity tests were also performed on the exhumed geotextiles in accordance with ASTM D4491 (Table 8). Fines were shaken off the surface of the geotextile before permittivity tests were performed. The values in Table 8 therefore represent internal permittivity and not in situ conditions. For the non-woven needle-punched geotextile, there was a consistent decrease in the permittivity for the exhumed geotextiles compared to new material. The decrease ranged from 20 to 30 percent of the original permittivity. Fines migrating into the geotextile are believed to have caused the reduction in permittivity; however, when the exhumed geotextile was held up to the light it appeared much thinner than the new geotextile.

The permittivity tests on the exhumed non-woven spunbonded geotextile resulted in one decreased permittivity and one increased permittivity (Table 8). No conclusions can be extended until additional samples of the spunbonded material are exhumed and tested.

Table 8: Permittivity Results

Material	Site	[1]Manufacturer's Permittivity (sec^{-1})	New Permittivity (sec^{-1})	Exhumed Permittivity (sec^{-1})
Non-woven Needle-punched	1B	1.5	1.1	0.81
	2A	1.5	1.1	1.0
	2B	1.5	1.1	0.83
	2C	1.5	1.1	0.83
Non-woven Spunbonded	3A	0.70	0.36	--
	3B	0.70	0.36	0.29
	3C	0.70	0.36	0.52

[1]Geotechnical Fabrics Report, 1998 Specifier's Guide, Vol. 15, No. 9.