Field evaluation of geosynthetic protective cushions: Phase 2

A follow-up to the authors' 1996 field test helps to further define recommendations for geosynthetic-cushion selection.

By Gregory N. Richardson and Sam Johnson

Geosynthetic cushions are used to protect geomembranes from installation damage during placement of drainage layers on the liner. These cushions have been actively evaluated and discussed both within the United States and internationally. The need for effective cushions is exacerbated by the gravel and stone used in the drainage layers to lessen the potential for biological clogging of the leachate-collection system.

Koerner et al. (1996) proposed the most rigorous design procedure for selecting a nonwoven geotextile cushion to protect high-density polyethylene (HDPE) geomembranes. Their procedure combines theory and laboratory hydrostatic-puncture tests, which use a truncated-cone puncturing device, on geomembranes (Hullings and Koerner 1991). A thorough review of this design procedure is beyond the scope of this paper. Suffice it to say that it allows the determination of the nonwoven weight required to protect a 60-mil HDPE geomembrane from damage related to a given stone size and normal service loads. The work described in this article was performed to ensure that the cushion also would adequately protect the geomembrane from construction-related loads.

The March 1996 *GFR* includes results from previous cushion field tests conducted by the authors. The earlier tests used a #57 stone (1.5 in.) placed at a thickness of 30 and 60 cm over the 60-mil HDPE geomembrane. This stone was trafficked upon by both a D7 dozer and a fully loaded dump truck (18-kip axle load). For each of the cushions evaluated, the entire geomembrane (approximately 8 by 23.8 ft) was recovered. However, only the most visibly damaged liner portions were sampled.

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Photo 1. Well-defined ruts caused by a loaded dump truck mark the traffic lane.

This study showed that a 12 oz/yd² nonwoven sufficiently minimized geomembrane damage caused by dozer tracking (i.e., nonturning) and dump-truck traffic on 12 in. of #57 stone cover. This observation was used to modify the geomembrane cushion-design procedure proposed by Koerner et. al. by adding a minimum acceptable cushion weight based on field-installation stresses. Phase 2 of this cushion study is reported here and extends the previous geomembrane-cushion work to include both a smaller stone size (North Carolina Department of Transportation [NCDOT] #78) and a more flexible reinforced and unreinforced geomembrane.

Additional field-cushion demonstration data reported since our initial paper is very limited, consisting of information previously presented by Reddy et al. (1996) for smooth 60-mil HDPE geomembrane. They placed 30 cm of both fine and medium (> 1 in.) stone aggregate over the geomembrane with and without an 8-oz/yd² nonwoven-geotextile cushion present. Loading was supplied by either a D4 or a D7 low ground-contact-pressure dozer used for both stone placement and surface operations.

In no instance was the geomembrane fully penetrated. The nonwoven-protected geomembrane provided an increase in average elongation at burst in the multi-axial tensile test (ASTM D 5617) compared to the unprotected material. The protected liner also showed increased average elongation and stress at break, as measured in the wide-width test (ASTM D 4885).

Phase 2 material components

Table 1 presents the particle-size gradations for the #57 and #78 stone used in the Phase Two cushion testing. This stone is a metavolcanic granite that produces a highly angular aggregate with a less elongated shape than the stone used in Phase 1 tests. The stone was quarried and crushed at the Martin Marietta quarry in Raleigh, N.C.

The same compacted-clay liner subgrade was used in Phase 2 as in the Phase 1 study. This clayey silt was compacted to a dry density of 106 pcf at a moisture content of 13.5%—drier than optimum. A very stiff subgrade resulted. The surface was smooth drum-rolled and carefully inspected; all visible stones of a size greater than 0.5 in. were removed to limit geomembrane damage.

Three geomembranes, all manufactured by Henderson, Nev.-based Serrot Corp., were used in Phase 2 tests:

- 60-mil smooth HDPE
- 60-mil unreinforced Metallocene geomembrane
- 60-mil reinforced Metallocene geomembrane.

The physical properties for the three geomembranes are presented in **Table 2. Figure 1** shows the geometry of the liners, as-placed in the Phase Two test.

Geosynthetic cushions tested in Phase 2 ranged from a 8 oz/yd² nonwoven to a 156 oz/yd² tire-chip-filled geotextile sandwich. The manufacturers, structure and unit weight for the evaluated geosynthetic cushions are presented on **Table 3 (p.46)**.

Phase 2 construction and loading

A dozer was used for conventional "mudwave"-type placement of a uniform 30-cm stone lift over the geomembranes. An additional wedge of stone was placed in a similar manner over the initial lift before the loaded dump truck began trafficking. Note that a number of geotextile samples were placed beneath the wedge of stone to provide data on geotextile survivability. The geotextile-survivability results are not reported in this article, since they were previously presented in *GFR* (Richardson 1998).

As shown on Figure 1, the dump truck followed two traffic lanes over each geomembrane unit. This compacted the stone-depth to a 1 to 3 ft (30 to 90 cm) layer above the geomembrane. Each lane was subjected to 100 passes of a loaded dump truck moving at approximately 5 mph. The traffic lane was demarcated by the well-defined ruts that quickly developed (see **Photo 1**). Rut depths in Phase 2 were similar to those experienced in Phase 1 trafficking. Note that this rutting was due exclusively to the lateral movement of the stone and not to furrowing of the subgrade soils. The rutting resulted in reported cover-stone depths which are conservative in that they are based on the as-constructed geometry and not the post-traffic geometry.

Geomembrane recovery and evaluation

In Phase 2, geomembrane recovery was made more difficult by the need to avoid damaging the geotextile-survivability samples. The stone within approximately 2 in. of the survivability samples had to be removed by a small backhoe modified with a "screed" welded to the teeth of the bucket, as shown on **Photo 2** (p. 46). The screed was used to carefully scrape thin layers of gravel from the test fill. The balance of the stone over the survivability samples was removed by hand shoveling.

TABLE 1. PARTICLE SIZE GRADATION FOR GRAVEL

Percentage of total by weight passing

Standard size	*1.5 in.*	*1 in.*	*¾ in.*	*½ in.*	*⅜ in.*	*#4*	*#8*	*#200*
NCDOT #57	100	95–100		25–60		0–10		0–0.6
#57 as tested		100	91	50		5	2	0
NC-DOT #78			100	98–100	75–100	20–45	0–15	0–0.6
#78 as tested				100	98	40	9	0

TABLE 2. GEOMEMBRANE PHYSICAL PROPERTIES

Property	**60 mil HDPE**	**Unreinforced Metallocene**	**Reinforced Metallocene**
Yield load, ppi	185	—	195+
Yield strain, %	14	—	38
Break load, ppi	—	82–100	—
Break strain, %	—	172–240	—

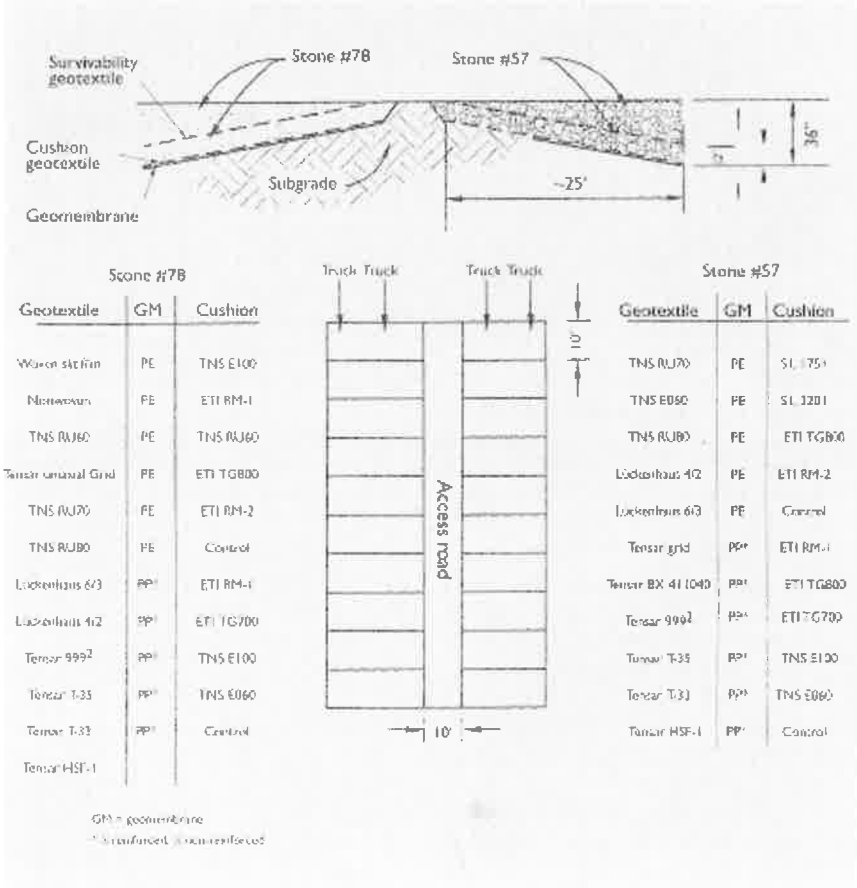

Figure 1. Cushion-test layout

After the survivability samples were extracted, the remaining 30-cm lift of stone was removed from the geomembranes with the same hand-shoveling technique used adjacent to the survivability samples. The cushion then was used to pull back the stone and make recovery simpler. No attempt was made to minimize cushion damage. This stone-removal technique differed from the water-cannon method used in Phase 1.

Each recovered geomembrane section was visually examined for stone-related damage. A vacuum box was made available for testing all regions with suspected penetration. Sampling was performed across those points that exhibited damage.

This sampling method emphasizes extreme damage levels and is not intended to portray typical damage. Sampling also focused on the unique loading paths that crossed each sample, which included truck loadings on stone thicknesses of approximately 16, 22, 26 and 34 in. above the cushion, as well as an area exposed only to dozer traffic during stone placement.

Thus it is possible to obtain at least four distinct service-condition samples from each geomembrane/cushion setup. **Tables 4, 5** and **6** provide the results of wide-width testing on the most visibly damaged portions of the shallower service zones for all geomembrane/cushion setups. As in Phase 1, all wide-width tests were oriented in the machine direction of the geomembrane, with the damage centered on the sample. A summary of the visual observations of the geomembrane condition in each service zone is also presented.

Supplemental geosynthetic-cushion testing

In addition to the traffic-damage study, several other tests were performed to evaluate geomembrane protection from exposure to the shear-type loading that is generated when a small to medium dozer turns sharply on the stone. Previous observations indicated that the 12 oz/yd² nonwoven did not provide adequate protection when a dozer turned sharply with only 12 in. of #57 stone cover.

The supplemental dozer-turning damage tests used approximately 22 ft (7 m) square sections of the smooth 60-mil HDPE geomembrane with 12 in. (30 cm) of lightly trafficked and uncompacted #57 and #78 stone cover. Four different cushion sections were used:

- A control test with no cushion protection
- Synthetic Industries 16 oz/yd² nonwoven cushions
- Synthetic Industries 32 oz/yd² nonwoven cushions
- Tensar 120 oz/yd² tire-chip/geotextile composite cushion.

Supplemental geosynthetic-cushion sections were loaded using a D7 dozer that tracked to the center of the section and made a single 90-degree turn in place. It then tracked and turned 90 degrees to move off the section (see **Photo 3**, p.49). This single-turn loading is a typical maneuver that a dozer operator may use during stone placement. Currently, most specifications discourage such turns, but these rely on third-party inspectors to control or limit such activity. Field measurements indicated that, after the single turn, the initial 12 in. vertical separation between the tracks and the geomembrane was reduced to 2.5–4.0 in.

After each section was loaded, the stone was removed using the backhoe screed and hand shoveling to expose the entire geomembrane. The material was visually inspected for tears or punctures caused by the turning. This was most conveniently done by turning the geomembrane over and examining the lower and essentially undisturbed face. None of the "turning" geomembranes were punctured, and only the control geomembrane without a cushion was very visibly damaged. Geomembranes protected by the geotextile had faint scratches in the surface that resembled those that medium sandpaper (120 grit) under moderate pressure might create. The geomembranes protected by the composite tire-chip cushions had no visible damage to either face of the geomembrane. However, the 2.5–4 in. stone layer that remained under the dozer at the test's completion meant that the system could not have sustained an additional turn.

Cushion test summary

The work of Reddy et al. (1996) indicates that installation damage has a greater effect on the yield and ultimate strain and stress levels from wide-width tests than from the multi-axial test. The impact on yield stress and strain values was greater in our Phase 1 installation-damage data than in Reddy's work. This may reflect the higher contact stresses generated by the truck used in our Phase 1 testing as compared to the low ground-contact-pressure dozer used by the others.

The sensitivity of yield values to installation damage in Phase 2 remained obvious for the HDPE and the reinforced-Met-

Photo 2. A modified screed was used to remove aggregate without damaging underlying samples.

TABLE 3. GEOSYNTHETIC CUSHION PROPERTIES

Manufacturer/name	Structure/polymer	Weight, oz/yd²
TNS E060	Nonwoven/polypropylene	6
TNS E100	Nonwoven/polypropylene	10
ETI TG700	Nonwoven/polypropylene	8
ETI TG800	Nonwoven/polypropylene	12
ETI TG1000	Nonwoven/polypropylene	16
ETI RM-1	Tire chip/nonwoven composite	120
ETI RM-2	Tire chip/nonwoven composite	156
Synthetic Industries 1751	Nonwoven/polypropylene	16
Synthetic Industries 3201	Nonwoven/polypropylene	32

allocene geomembranes. However, the unreinforced-metallicized geomembrane did not exhibit a yield point in the wide-width test. As a result, the break values must be used for comparison.

The HDPE geomembrane-damage data on Table 4 indicates a decrease in yield force and increase in yield strain when nonwoven cushions of less than 12 oz/yd^2 are used for both the #78 and #57 stone. The Metallocene geomembrane data included on Tables 5 and 6 do not show a similar reduction for the lighter cushions.

It should be noted that the Metallocene geomembranes were early production samples that had visible flow marks in the surface, and therefore a greater nonuniformity of thickness and resulting wide-width strength. This is thought to contribute to the scatter in the strength measurements. However, it is clear that even without a geosynthetic cushion, both Metallocene geomembranes survived the stone placement with minimal or no damage.

Geosynthetic cushion recommendations

The Phase 2 testing allows us to extend our previous Phase 1 recommendations to include the finer #78 stone and alternative geomembranes. As in Phase 1, these recommendations use the more generalized procedure developed at GRI for selection of a geosynthetic cushion (Wilson-Fahmy et al. 1996, Narejo et al. 1996 and Koerner et al. 1996). The Phase 1 and 2 field installation-test data is used to provide a lower bound to the service-load relationships developed by the institute. A factor of safety of 3.0 is maintained for the service-load portion of the recommendation to minimize long-term damage to the geomembrane.

Figure 2 presents the nonwoven cushion-design envelopes recommended for the smooth 60-mil HDPE geomembrane and the reinforced Metallocene for both #57 and #78 stone. GRI's earlier work using the truncated-cone test showed that the scrim-reinforced "flexible" geomembranes act very similarly to the more rigid HDPE in puncture tests (Koerner 1998). Figure 2 therefore treats the reinforced geomembrane like the rigid HDPE but reduces the minimum geotextile cushion to a 6 oz/yd^2 nonwoven to reflect the better installation survivability of the reinforced Metallocene geomembrane.

TABLE 4. WIDE-WIDTH TESTING RESULTS FOR SERROT 60 MIL HDPE

Cushion	78M stone				57 stone			
	Depth = 16 in.		Depth = 22 in.		Depth = 16 in.		Depth = 22 in.	
	Yield (ppi)	*Yield (%)*	*Yield (ppi)*	*Yield (%)*	*Yield (ppi)*	*Yield (%)*	*Yield (ppi)*	*Yield (%)*
TNS E060 6 oz/yd^2	162	23	171	23				
	160	24	188	23				
TNS E100 10 oz/yd^2	169	16	227	16				
	164	20						
ETI TG 800	178	13	183	13	172	18	168	19
	172	14	187	14	180	19	171	19
ETI TG 1000					171	19	171	18
					189	20	175	19
ETI RM-1	174	13	182	13				
	186	14	185	14				
ETI RM-2	183	14	183	14	177	18	173	19
	178	19	182	18	177	19	176	19
SI 3201					176	19	168	19
					185	18	174	18
Control	177	20	176	19	173	19	175	18
	173	19	166	16	164	18	177	18

ETI = Evergreen Technologies Inc. SI = Synthetic Industries

TABLE 5. WIDE-WIDTH TESTING RESULTS FOR SERROT REINFORCED METALLOCENE

Cushion	78 M stone				57 stone			
	Depth = 16 in.		Depth = 22 in.		Depth = 16 in.		Depth = 22 in.	
	Yield (ppi)	*Yield (%)*	*Yield (ppi)*	*Yield (%)*	*Yield (ppi)*	*Yield (%)*	*Yield (ppi)*	*Yield (%)*
TNS E060 6oz/yd^2	172	30	180	32	186	32	198	30
	189	35	166	27	141	30	188	32
TNS E100 10 oz/yd^2	176	32	193	42	207	38	201	35
	188	32	193	43	202	36	194	31
ETI TG 700	152	29	154	31	177	30	168	28
	142	30	168	29	181	31	164	31
ETI TG 800					183	85	166	28
					183	82	191	32
ETI RM-1	162	31	166	32	187	31	189	34
	171	32	169	30	194	33	196	35
Control	204	37	212	41	164	30	208	39
	209	33	201	36	187	32	173	31

ETI = Evergreen Technologies Inc.

TABLE 6. WIDE-WIDTH TESTING RESULTS FOR SERROT UNREINFORCED METALLOCENE

Cushion	78 M stone				57 stone			
	Depth = 16 in.		Depth = 22 in.		Depth = 16 in.		Depth = 22 in.	
	Break (ppi)	*Break (%)*	*Break (ppi)*	*Break (%)*	*Break (ppi)*	*Break (%)*	*Break (ppi)*	*Break (%)*
TNS E060 6 oz/yd^2	67	41	63	86	58	242	65	53
	76	333	101	375	64	145	63	170
TNS E100 10 oz/yd^2	73	465	62	310	78	585	66	77
	95	613	58	163	61	74	63	72
ETI TG 700	61	87	63	92	65	67	66	77
	63	88	59	88	74	477	92	550
ETI TG 800					63	74	65	74
					84	580		
ETI RM-1	59	240	66	424	98	539	65	67
	62	70	58	256	64	72	64	72
Control	82	275	61	102	61	72	79	538
	61	84	56	244	66	77		

ETI = Evergreen Technologies Inc.

Unfortunately, we currently cannot create a similar nonwoven cushion-design chart for the more flexible unreinforced geomembrane. The curves for such cushion types, as presented by Koerner, are based on empirical measurement of the hydrostatic failure pressure vs. cushion mass per unit area for a range of truncated-cone heights. This pioneering research has not been duplicated for more flexible geomembranes.

Work by Hullings and Koerner (1991) has shown that the nonwovens do not provide the same degree of protection to flexible geomembranes because the strains at failure, e.g., the cone height, are so large that the geotextiles have failed at such strains. However, our tests do indicate that flexible geomembranes can survive installation beneath #57 and #78 stones with little or no cushion required. The use of Figure 2 for the more flexible geomembranes is therefore very conservative.

In the Phase 2 test, the tire-chip composite cushions provided such a high level of protection that none of the geomembranes which they protected experienced any visual damage during either the traffic or dozer-turning tests. Such cushions would provide an unparalleled level of protection to the geomembrane and would be ideal beneath primary leachate-collection pipes with their coarse rock-collection covers.

However, the dozer-turning test demonstrates that even the cushion composites are at risk if a dozer is allowed to freely operate on the stone surface above the cushions. No moderate-to-hard turning of a dozer should be allowed atop the stone. Like the flexible geomembrane, we lack the empirical measurement of the hydrostatic-failure pressure vs. cushion mass per unit area for a range of truncated-cone heights to allow development of a design chart similar to Figure 2 for the tire chip-composite cushion.

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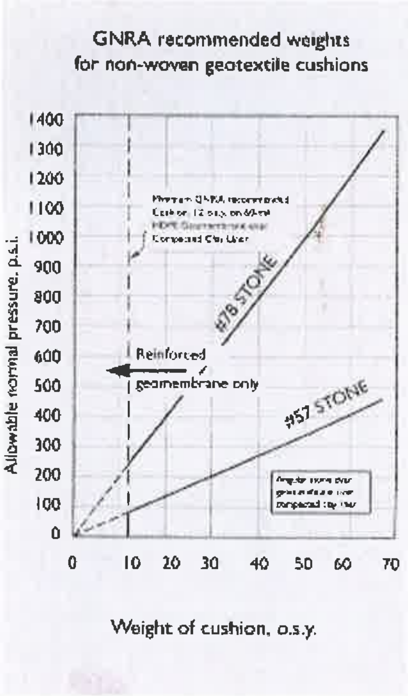

Figure 2. Recommended nonwoven cushion-design envelopes.

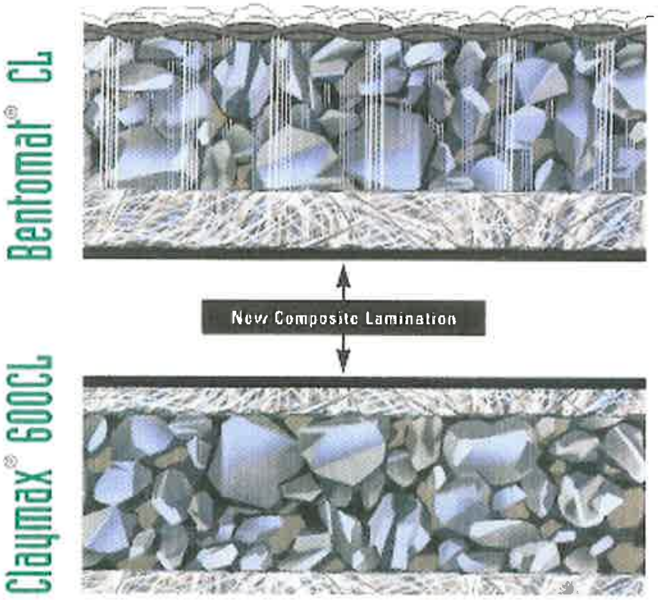


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Photo 3. A D7 dozer makes a typical stone-placement maneuver.

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