

Field evaluation of geosynthetic protection cushions

These tests results are intended to assist designers involved in landfill construction using 60-mil-HDPE geomembranes and similar stone aggregate.

By Gregory N. Richardson, Ph.D.

The performance of contemporary lined landfills depends on the abilities of the leachate collection/removal system (LCR) to remove leachate and minimize the head acting on the liner, and on our ability to install the geomembrane component of a composite liner with minimal installation-related damage. Technical developments during the past five years, however, have increased the potential that these two goals are mutually exclusive. Research sponsored by the Environmental Protection Agency (EPA) and conducted at the Geosynthetic Research Institute (GRI) has highlighted the significant potential for clogging of the LCR by biological growth or mineral precipitation (Koerner and Koerner 1991). This has led to the use of larger aggregates within the LCR and an increased potential for installation damage to the geomembrane.

The field tests, conducted by G.N. Richardson & Associates (GNRA), Raleigh, N.C., were designed to evaluate a range of eight geosynthetic products and the degree of protection they provide to a geomembrane. The geosynthetic cushions included generic geotextiles (GT), geosynthetic clay liners (GCLs), a

double geotextile-faced geonet (GN2), heavy-weight-nonwoven geotextiles and a recycled-tire rubber matting specifically produced for cushion applications. Table 1 provides the physical properties of the geosynthetic cushions.

The test program was designed to determine the protection provided by the geosynthetic cushions under the following field conditions (bottom to top):

- a compacted clay liner (CCL) subgrade having a moisture content near optimum, and a maximum particle size less than 19 mm (0.75 inch),
- a 1.5 mm (60 mil) smooth HDPE geomembrane, and
- an LCR stone aggregate having an as-constructed thicknesses of 30 cm (12 inch) and 60 cm (24 inch), using an AASHTO # 57 stone (Table 2) having a maximum particle size less than 38 mm (1.5 inch).

The field tests

did not evaluate the impact of alternate geomembranes, maximum particle size in the clay layer or alternate stone gradations on the resulting damage to the geomembrane. The test results are intended to assist designers involved in landfill construction using 60-mil HDPE geomembranes and similar stone aggregate.

Two full-scale liner sections were constructed and test-loaded with 100 passes of a low-ground-contact pressure dozer and/or a fully loaded dump truck. The initial test strip was constructed using a 60-cm (2-foot) layer of #57 stone and represents the final stone section commonly provided around the primary LCR collection piping. The second test strip used a

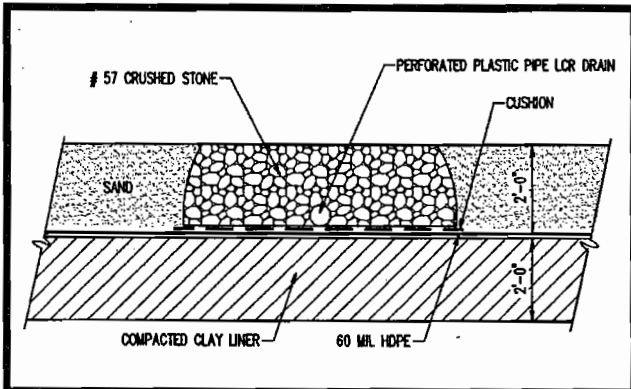


Figure 1. AASHTO #57 stone at the leachate collection removal system drainage line

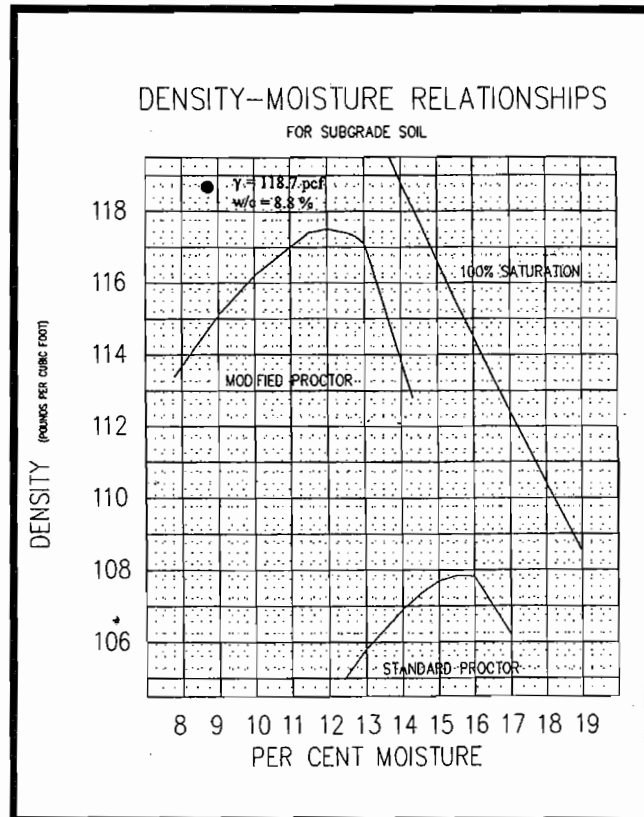


Figure 2. Density-moisture relationship for soil layer

30-cm (1-foot) layer of #57 stone and represents an interim stone section used when the full LCR system is constructed with #57 stone.

60-cm stone thickness test strip construction

The 60-cm stone thickness test strip simulates the common use of stone around the drainage pipes in the LCR system, as shown in **Figure 1**. The test strip consisted of a 6.67 m by 24.8 m (22 feet by 82 feet) flat area located at the Martin Marietta Aggregate quarry in Garner, N.C. A CCL subgrade was prepared by compacting a 8-inch-thick layer of a low plastic silt (ML) that was free of gravel size or larger particles. The soil was compacted to more than 100 percent density (ASTM D 1557) at a moisture content of dry of optimum to produce a stiffer, less yielding surface than associated with typical CCLs.

Field moisture-density tests were obtained immediately after compaction and are shown with the laboratory Proctor curves in **Figure 2**. The use of a modified Proctor compaction criteria produced a very stiff subgrade that increased the potential for localized puncturing of the liner by the stone. Proof-rolling the subgrade with a fully loaded water truck produced a depth of the rutting less than 6 mm (0.25 inch). After compaction and proof rolling, the test fill was rolled by a smooth steel drum to prepare it for the geomembrane.

A 1.5 mm (60 mil) smooth HDPE geomembrane supplied by GSE Lining Technology Inc., Houston, was immediately placed over the CCL to minimize the potential for desiccation. The location of each geosynthetic cushion was marked on the GM with a paint pencil. Each geosynthetic cushion ran the full width of the test strip, as shown in **Figure 3**. A control zone using no geosynthetic cushion also was included in the test. Then, the geosynthetic cushions were placed over the geomembrane at their respective locations and anchored with several shovels of the stone aggregate.

The stone aggregate used is a AASHTO #57 stone with the particle size gradation shown in Table 2. It is a washed crushed stone with angular particles (**Figure 4**), specifically selected for its high damage potential to the geomembrane.

Table 1. Properties of geosynthetic cushions

Fabric	Average ASTM D 3776 oz/yd ²	Thickness mil	Polymer filament form	Mullen Burst ASTM D 3776 psi	Con-Puncture psi	Cost per yard
Amoco 580	35	60	PP Staple	400	no available	\$0.80
Amoco 557	40	120	PP Staple	600	no available	\$1.20
Amoco 560	40	155	PP Staple	700	no available	\$1.90
Amoco 435 & 4657	20	200	PP Staple	750	no available	\$2.00
Claymax 345	30	100	PP Staple	no available	39	\$1.35
Claymax 206	27	200	no applicable	no applicable	no available	\$8.10
Geocomposite 24	20	280	Staple	no available	44	\$1.74
Geocomposite 2	39	375	Staple	no available	50	\$2.30
Geocomposite 6	64	106	Staple	no available	69	\$4.60
Huesker H4500	30	320	PP Staple	no available	140	\$9.00
Huesker H2000	58	420	PP Staple	no available	160	\$14.00
PeccoMat 250	25	250	no applicable	no applicable	76%	not available
PeccoMat 150	33	125	no applicable	no available	no available	\$7.00
Tensar GHD5	40	200	PP continuous	no available	no available	\$2.15

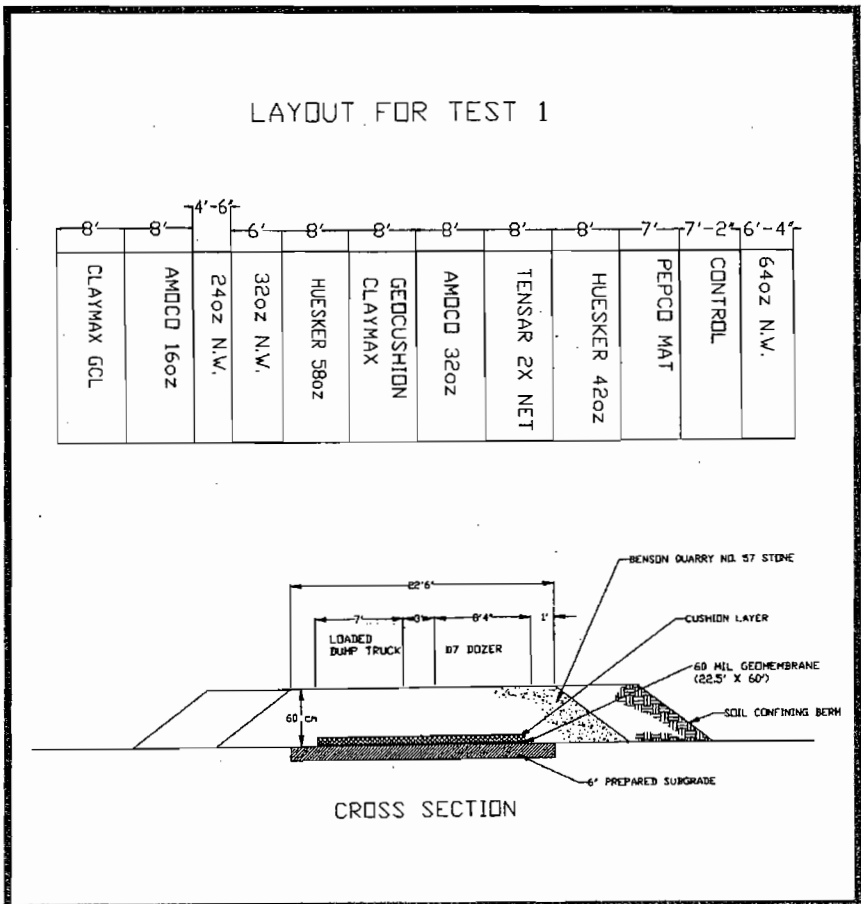


Figure 3. Test strip layout for the 60-cm-thick stone



Figure 5. Placement of AASHTO #57 stone

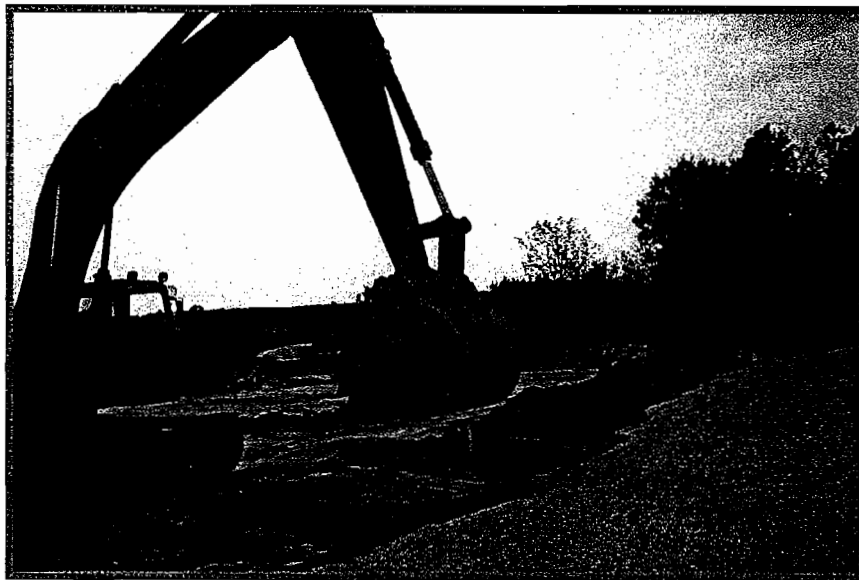


Figure 6. Soil-confinement berm

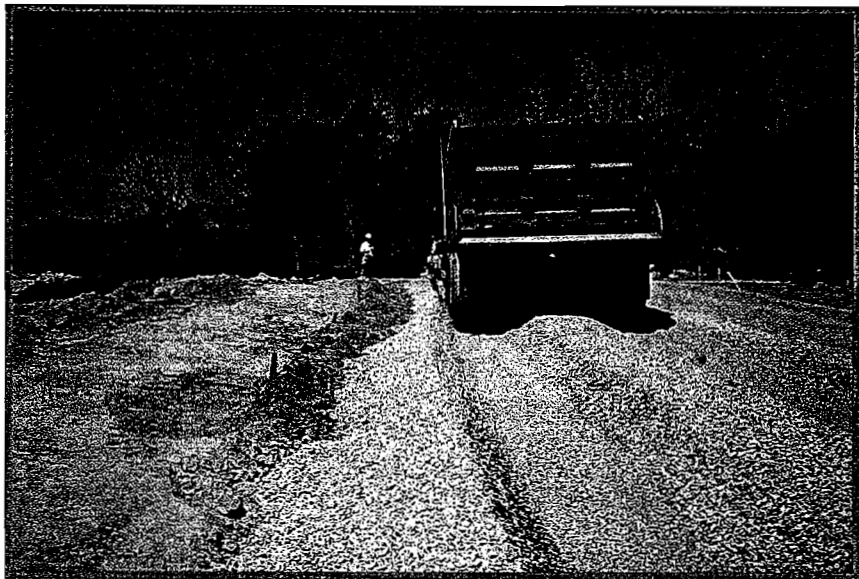


Figure 7. Rutting of stone by dump truck



Figure 4. AASHTO #57 Stone particle size and angularity

The stone, a metavolcanic granite aggregate, was quarried and crushed at the Martin Marietta Aggregate quarry in Benson, N.C. To avoid shifting of the geosynthetic cushions, the stone was placed and leveled using a large backhoe, operating from the side of the test strip (Figure 5). This placement technique is commonly employed to protect the LCR piping from traffic loading. Stone was placed to a uniform thickness of approximately 60 cm (24 inches).

To simulate common construction techniques, no special compaction effort was applied to the stone other than that provided by the construction equipment. After the stone placement was completed, a soil berm was constructed around the test strip to provide lateral confinement to the stone (Figure 6). This simulated the large lateral extent of the LCR systems in actual applications.

After placement of the stone, the GCL cushion section was flooded the day before testing to allow the bentonite to hydrate and simulate the worst-case field condition. Hydration of the bentonite was confirmed during tear-down of the test strip.

60-cm stone thickness test strip loading

Typical construction loadings were simulated by trafficking the completed test strip with a fully loaded dump truck (HS20 load) and a standard-tracked dozer (D7G). The dump truck had a maximum axle loading of 80 kN (18 kips) and tire pressures of approximately 690 kPa (100 psi). The rear tires produced an equivalent uniform vertical stress on the geomembrane of approximately 23 kPa (3.7 psi). Higher contact stresses may be caused locally from rutting of the stone by the truck, as shown in Figure 7. The speed of the truck was less than 8.3 km/hr (5 mph) and no significant braking was allowed while on the stone. This is consistent with conventional construction practice when less than 60 cm (2 feet) of cover exists over the geomembrane. The

dozer has a ground contact pressure of 73 kPa (10.6 psi), which produces an equivalent uniform vertical stress acting on the geomembrane of approximately 21 kPa (3.1 psi). The dozer was not allowed to turn while on the test strip. Both vehicles made 100 passes over the test strip in their respective traffic lanes (Figure 3). This allowed the impact of the truck and dozer to be independently evaluated.

During application of the 100 loading passes, the loaded dump truck created significant rutting of the stone, as shown in Figure 7. The depth of rutting at the completion of the test averaged less than 15 cm (6 inches). This rutting depth increased the geomembrane contact stresses by up to 60 percent. No stone rutting was generated by successive passes by the dozer.

Upon completion of the test, the stone was removed by first excavating a trench immediately adjacent to the test strip, then using a high-pressure water jet to move the stone off the cushions and into the trench. After removal of the stone and geosynthetic cushions, the individual sections of the geomembrane were separated and removed for inspection.

60-cm stone thickness test strip geomembrane-damage evaluation

The degree of installation damage at each geosynthetic cushion section was evaluated for (1) that portion of the liner that had not been loaded by the truck or

dozer, (2) that portion loaded by the truck and (3) that portion loaded by the dozer. Installation damage to the GM was evaluated as follows:

- visual inspection of the GM for scratches and localized dents,
- visual inspection of the scratches and localized dents on the GM for punctures, and
- comparison of wide-width tensile strengths (ASTM D 4595) at failure for the geomembrane.

Table 2. AASHTO #57 stone particle size gradation

Sieve size	AASHTO #57	As tested #57
1 1/2 inch	100	100
1 inch	95-100	96.1
3/4 inch		41.1
1/2 inch	25-60	4.7
#4	0-10	0.9
#8	0-5	
#20	0-0.6	

Note: Martin Marietta Aggregates, Materials Laboratory, April 24, 1995

Table 3

Results from Test One

100 passes with a loaded dump truck over 24 inches of #57 stone

Fabric	Sample	Percent original value			
		Yield Strain	Yield Load, lb	Ultimate Strain	Ultimate Load, lb
Pepco P250	A	94.7	680	12.5	1020
Pepco P250	B	92.9	755	11.9	1110
Geo composite 24 oz.	A	1.88	645	9.4	1110
Geo composite 24 oz.	B	2.38	630	10.6	1050
Geo composite 32 oz.	A	3.11	825	11.3	1120
Geo composite 64 oz.	A	2.71	710	11.3	1130
Geo composite 64 oz.	B	2.63	710	12.8	1120
Tensor Bonded Net	A	2.19	590	11.3	1055
Tensor Bonded Net	B	2.38	710	11.8	1110
Claymax 32 oz.	A	2.19	720	10.6	1120
Huesker 58 oz.	A	2.50	650	12.5	1120
Amoco 16 oz.	A	1.58	665	9.4	1200
Amoco 16 oz.	B	2.50	680	12.5	1110
Amoco 32 oz.	A	2.34	640	11.7	1125
Huesker 42 oz.	A	3.44	870	9.4	1110
No mat (truck)		2.50	680	11.8	1110
No mat (100 passes with a bulldozer)		1.88	620	12.3	1115
Claymax GCE	A	2.50	680	8.1	1040
Claymax GCE	B	2.31	825	10.6	1220
Average		2.49	699	10.88	1110
Standard Deviation		0.51	72	1.46	46

Results from Test Two

100 passes with a loaded dump truck over 12 inches of #57 stone

Fabric	Sample	Percent original value			
		Yield Strain	Yield Load, lb	Ultimate Strain	Ultimate Load, lb
Amoco 8 oz. A	A	1.75	520	13.1	1000
Amoco 8 oz. B	B	1.56	610	11.2	1080
Amoco 12 oz. A	A	1.56	460	6.9	1020
Amoco 12 oz. B	B	1.88	560	12.5	1040
Amoco 16 oz. A	A	2.19	580	9.4	1050
Amoco 16 oz. B	B	2.13	600	12.5	1050
Amoco 20 oz. (8 oz. & 12 oz.) A	A	1.94	590	12.5	1080
Amoco 20 oz. (8 oz. & 12 oz.) B	B	1.11	420	11.5	1070
Pepco P125		1.25	560	11.3	1090
No mat		1.25	360	15.6	970
Average		1.66	526	11.65	1045
Standard Deviation		0.36	81	2.19	37

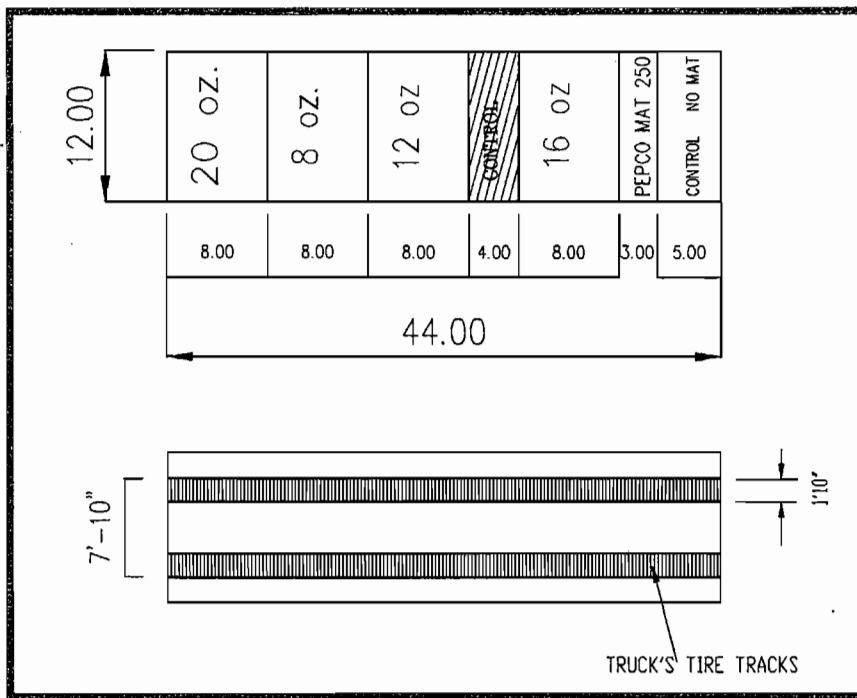


Figure 8. Test strip layout to evaluate potential geosynthetic cushions for service under 30-cm stone

The wide-width test data provided an indication of the stone induced damage to the geomembrane. The percentage of original yield load and strain, and ultimate load and strain retained in the exhumed samples is shown in Table 3. The yield loads and strains appear to be significantly impacted by even slight damage to the geomembrane. The ultimate loads and strains, which are an indicator of the serviceability of the geomembrane, are less impacted by the surface scratches resulting from the stone.

30-cm stone thickness test strip construction

A second, but smaller, test strip was performed to evaluate potential geosynthetic cushions for service under 30 cm (12 inches) of stone. This stone thickness has been proposed as an alternative to 60 cm (24 inches) of sand in the LCR. Typically, the 30-cm stone layer is covered with an operational cover layer to provide a minimum separation between the geomembrane and waste of 60 cm (2 feet). The 30-cm stone layer, therefore, is not exposed to long-term direct trafficking. Because of the excellent performance of the lighter cushions in the 60-cm test strip, the cushions were limited to non-wovens having a weight less than 24 oz. and to the recycled tire matting. The physical properties of the cushions are presented in Table 1, and the physical layout of the second test strip is shown in Figure 8.

Stone for the 30-cm test strip was placed by end-dumping the stone from a truck operating on top of the 30-cm stone layer, pushing the pile outward with a dozer, then repeating. This stone placement technique replicates the way area collectors would be constructed.

30-cm stone thickness test strip loading

After construction, vehicle loading was provided by 100 passes of the same loaded dump truck used in the 60-cm test. The 60-cm test had clearly shown that the truck produced more damage to the geomembrane than the dozer so no dozer loading was performed. As before, the truck was restricted in operation so that all passes of the truck were in a common lane. The passage of the loaded truck over the 30-cm stone layer produced significantly less rutting than had been observed during the 60-cm stone layer test. Although the pathway of the truck was clearly distinguishable at the completion of the test, maximum rut depth did not exceed 2.5 cm (1 inch). The normal stress produced by the truck on the surface of the geomembrane is approximately 65.5 kPa (11.4 psi).

30-cm stone thickness test strip geomembrane-damage evaluation

The stone for the second test fill was removed by water jetting in the same manner employed for the 60-cm stone test strip. After removal of the geosynthetic cushions, the geomembrane sec-

tions were visually inspected for scratches and localized dents. The geomembrane sections were then removed for further testing. Each scratch or localized dent was inspected for evidence of puncture. Visual evidence of actual punctures by the scratches or localized dents was readily found by examining the underside of the HDPE geomembrane. A vacuum box was available for questionable punctures, but it was not required for any of the test-strip geomembrane evaluations. Wide-width test data in Table 3 show that the yield loads and strains are significantly impacted by the stone induced damage, but the ultimate load and strains are only moderately impacted.

Geosynthetic-cushion test summary

Neither the 60-cm or 30-cm stone test strips produced a puncture of the HDPE geomembrane. The control sections, i.e., the section with no cushion, were visibly scratched and dented to a much greater extent than when even the lightest geosynthetic cushion was used. The wide-width tensile data obtained from the exhumed geomembranes is presented in Table 3. The visual evidence of geomembrane damage correlates well with the reduction in both strain and load at yield from the tests. Wide-width samples were oriented in the machine direction of the geomembrane and the "damage" centered within the gage length of the sample.

It is reasonable to conclude, therefore, that the reported wide-width values represent "worst-case" values and not average values. Note that the ductility, i.e., the strain at yield, and not the strength of the HDPE geomembrane was impacted by damage from the stone. The ultimate load and strains measured in the wide-width test were significantly less impacted by the stone-induced surface scratches. Correlation of visual inspection and wide-width data indicates that a 10 percent reduction in ultimate load should be considered the limit for acceptable surface damage.

Recommendations for selecting a geosynthetic cushion

The field testing presented in this study was limited to a specific stone gradation (AASHTO #57) and a specific geomem-

brane (HDPE). A more generalized procedure for the selection of a geosynthetic cushion has been developed at GRI (Wilson-Fahmy, et al., Narejo, et al., Koerner, et al.). This more generalized procedure does, however, contain specific empirical data and recommendations for the #57 stone and HDPE geomembrane used in this study. Based on the GRI study, Figure 9 presents the GNRA-recommended unit weight of geosynthetic cushion required to protect the HDPE geomembrane from a uniform normal stress acting on the cushion. This cushion weight provides a factor of safety of 3.0 and is intended to eliminate all potential damage to the geomembrane.

Data from the field tests conducted in this study have been added to Figure 9 for comparison to the GRI guideline. The percentage reduction refers to the reduction in ultimate load capacity in the tested samples. All of the tests conducted in this study were at normal stress levels and cushion unit weights such that the GRI data would predict no degradation of the geomembrane. The slight to moderate degradation of the geomembrane's ultimate-load capacity that did occur can be attributed to the difference in loading characteristics between the GRI study and the field test.

The GRI cushion procedure is based on hydrostatically applied normal loads. The normal stresses in the field study are dynamic and include significant horizontal-shear stresses in addition to the normal load. In the field test, the normal load occurs in a manner that can "work" a stone down through the plane of a cushion, actually pushing fibers away from the path of the stone. The GRI hydrostatic loading is an accurate model of what will occur due to static stresses generated by the weight of the waste over the liner, but the model underestimates the impact of construction and traffic-related dynamic loads.

The recommended design procedure for selection the unit weight of a geotextile cushion to protect 60-mil HDPE geomembrane from #57 stone modifies the GRI selection envelope at low normal stresses based on the field test observations. The revised design envelope is shown on Figure 9. The revised procedure implies that, for typical municipal solid waste landfills, the geosynthetic cushion unit weight is based on installa-

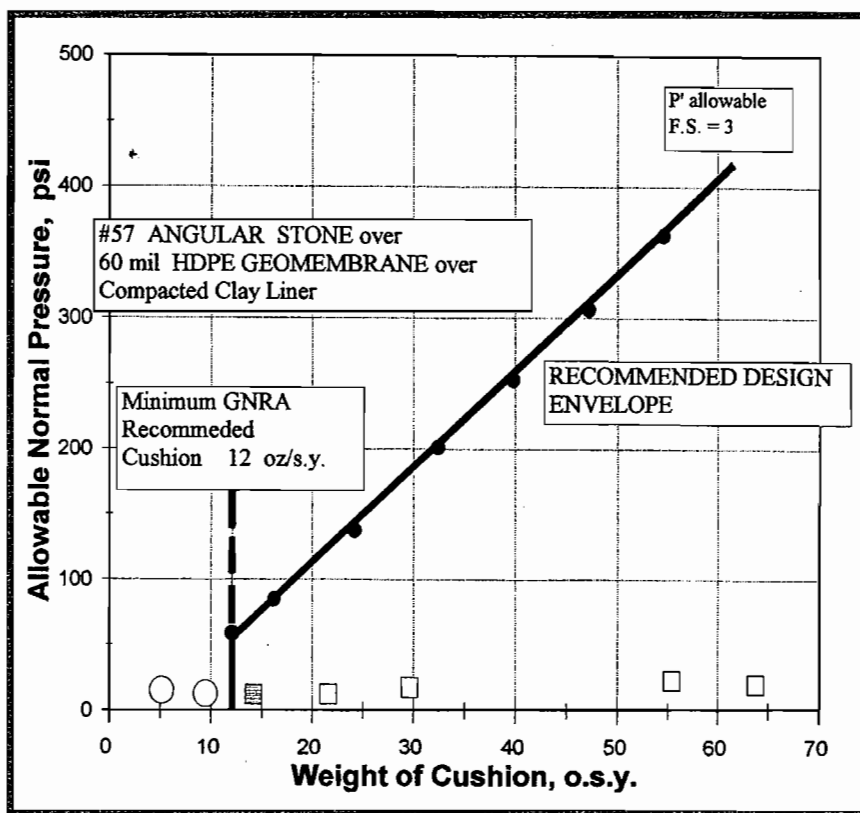


Figure 9. GNRA recommended weights for nonwoven cushions

tion and traffic loads for waste thicknesses less than 120 feet. For larger waste thicknesses, the design cushion unit weight is based on the normal stresses generated by the waste.

The recommended selection envelope is intended for nonwoven geotextiles only. The field test does, however, indicate the GCLs, geotextile-bonded geonets and recycled-rubber sheeting do provide acceptable protection of the geomembrane from installation damage. Design curves similar to Figure 9 could be developed for these geosynthetics using the generalized GRI procedure. In a similar manner, design curves for alternative stone particle sizes would require field testing to evaluate field-installation and traffic-related damage. It is felt, however, that the cushion selection procedure is conservative for stone gradations smaller than #57.

Readers are cautioned that the geosynthetic cushion selected based on Figure 9 is not intended to protect the geomembrane from damage caused by aggressive operation of tracked equipment on the stone. Limited field trials have shown that even the heaviest of the nonwovens does

not provide sufficient cushion to resist the large shearing forces generated when a tracked vehicle makes a sharp turn. The operation of tracked vehicles on the stone must be carefully monitored to prevent damage to the geomembrane, regardless of whether a cushion is used.

About the author Gregory N. Richardson, Ph.D., is principal of G.N. Richardson & Associates, Raleigh, N.C.

References

- Koerner, R.M. and G.M. Koerner, "Landfill Leachate Clogging of Geotextile (and Soil) Filters," prepared for U.S. Environmental Protection Agency, EPA/600/2-91/025, Cincinnati, 1991.
- Koerner, R.M., R.F. Wilson-Fahmy and D. Narejo, "Puncture Protection of Geomembranes—Part III: Examples," accepted for publication in Geotextile and Geomembranes, 1995.
- Narejo, D., R.M. Koerner and R.F. Wilson-Fahmy, "Puncture Protection of Geomembranes—Part II: Experimental," accepted for publication in Geotextile and Geomembranes, 1995.
- Wilson-Fahmy, R.F., D. Narejo and R.M. Koerner, "Puncture Protection of Geomembranes—Part I: Theory," accepted for publication in Geotextiles and Geomembranes, 1995.