COLLINS, T. G. and NEWKIRK, D. D.
Crown Zellerbach Corporation, Camas, Washington, USA

The Use of Geotextile Fabrics in Pond Construction Beneath an Impermeable Membrane (Geomembrane)

Utilisation de géotextiles sous une membrane imperméable dans la construction des bassins

Geotextiles are commonly being used as underlining for geomembranes in pond construction. The geotextile provides puncture protection, gas release and abrasion resistance. This paper describes field usage of geotextile/geomembrane systems and outlines field experiments conducted to define a geotextile selection process. Laboratory tests were developed and are described that proved capable of readily defining pass/fail criteria for various combinations of geotextile/geomembrane/soil/load conditions. It was found that thick, needlepunched, nonwoven fabrics in a weight range of 400-600 g/m^2 provide the optimum combination of strength, durability and lateral transmissivity to perform satisfactorily as an underlining in large pond construction.

On utilise couramment les géotextiles comme doublures de fond de géomembranes dans la construction de bassins. Les géotextiles protègent contre les perforations, l'échappement de gaz et les frottements. Ce rapport décrit comment les mécanismes des géotextiles/géomembranes sont utilisés sur les chantiers, et trace les grandes lignes des expérimentations menées en vue de définir un processus de sélection de géotextiles. Il est décrit ici les essais en laboratoire que l'on a réussi à mettre au point pour permettre de définir commodément d'après des critères précis l'acceptabilité de diverses conditions pour les combinaisons de géotextiles/géomembrane/sols/charges. On a pu trouvé que des matériaux épaix, poinconnés à l'aiguille, non-tissés, dans la gamme de poids de 400 à 600 grammes par mètre carré donnent la meilleure combinaison de résistance, durabilité et facilité de transmission latérale, qui permet leur emploi comme doublures de fond dans la construction de grands bassins.

INTRODUCTION

The use of geotextile fabrics in combination with geomembranes (impermeable linings) has been rapidly gaining in worldwide recognition and importance to the design engineer. There are two primary applications developed at this time requiring the use of heavyweight ($\geq$400 g/m^2) geotextile fabrics: (a) for abrasion and puncture protection of geomembranes in solid waste landfills--including bottoms, sidewalls and covers, and (b) for both puncture protection and gas relief beneath geomembranes in liquid containment ponds. This report will deal primarily with the latter application as specified and utilized in the United States market.

Geomembranes of varying chemical composition are well established products for pond linings (1) and are being increasingly specified by design engineers--particularly for containment of toxic wastes (e.g., sodium cyanide solution catch basins in a gold ore heap leaching process). Additionally, recent studies at Texas A&M University have shown that the containment of organic fluids (basic, neutral polar and neutral nonpolar) and organic acids have been demonstrated to cause substantial increases in the permeability of clay liners (2). This evidence will undoubtedly cause an even more frequent use of geomembranes in the future. However, this increased use of geomembranes heightens several functional concerns of the designer. First, the membrane manufacturers are very explicit in requiring that the installation contractor prepare the subgrade in a finished manner that is extremely smooth in order to prevent the possibility of puncture by sharp rocks or stones protruding up into the lining. Second, many subgrades contain organic wastes that emit gasses during decomposition which can be trapped beneath the lining and cause sections of the membrane to lift and float within the pond structure. Third, since many lined ponds are constructed over existing cracked surfaces such as concrete or asphalt, wind and water forces cause severe abrasion of the geomembrane by the spalled or rough textured surface. Each of these three real and potentially catastrophic problems can be eliminated by the use of a porous, yet strong, geotextile underlining fabric.

A relatively thick, porous nonwoven geotextile comprised of polypropylene (or polyester in nonalkaline environments) can easily be placed between the subgrade (base) and geomembrane to provide a cushion against puncture, provide a lateral conduit for release of trapped subgrade gasses and provide abrasion protection against a rough surface. In addition, the geotextile fabric provides a clean environment for field seaming of the geomembrane panels which reduces the incidence of pond leakage caused by blowing sand or soil fouling the chemically bonded seams.

This paper will describe several installations using geotextiles in combination with geomembranes and detail laboratory procedures developed to aid in the selection of the proper geotextile for the intended end-use.

FIELD EXAMPLES

In 1980, a uranium ore processing plant was being constructed in central New Mexico. Within this complex were three leachate evaporation ponds that totaled over 70 acres in size. The porous subsoil and sulfuric acid leachate required the use of a butyl rubber lining material (geomembrane) having both cushion and gas relief protection. The owner/designer considered two alternative designs for the underlining system: (1) 30.5 cm of treated sand, or (2) a 400 g/m^2 spun-bonded needlepunched, nonwoven polypropylene geotextile fabric. The geotextile fabric was selected because it provided all of the required properties of strength, permeability and thickness and it was less costly to place than the sand. Fibretex Grade 400 geotextile fabric (3) marketed by Crown Zellerbach Corporation was chosen and installed on this project in August 1980. All three ponds were subsequently filled with leachate and have operated since that time without interruption.

Figure 1. Photograph of Butyl Geomembrane Being Installed Over Polypropylene Geotextile.

Recent governmental EPA regulations on the storage of toxic fluids have recommended the use of double-lined ponds or expensive monitoring systems to insure against any possible leakage of the contained fluid into the surrounding water table. Thick, heavyweight geotextile fabrics are now being specified as the separation member between two geomembranes (Figure 2A) to act as a collection medium for lost fluid, to provide a space for leakage monitoring and to aid in the protection of the lower membrane during placement of the upper membrane. The geotextile is particularly effective on steep slopes (>2:1) where sand is often impossible to place.

Another common use for geotextiles is to provide an abrasion-resistant layer over existing cracked concrete surfaces or rough textured asphalt (Figure 2B). The larger cracks (>0.5 cm) are filled with grout or asphalt and then the geotextile is placed, with adjacent panels overlapped (30 cm). The geomembrane is then placed directly over the geotextile with care to insure that all exposed rough surfaces are well padded. Particular attention should be directed to the pond's top edges where wave action can be most severe.

In all three examples, the geotextile and geomembrane are securely planted together in a trench at the top of the berm and then backfilled and compacted to prevent eventual pull-out.

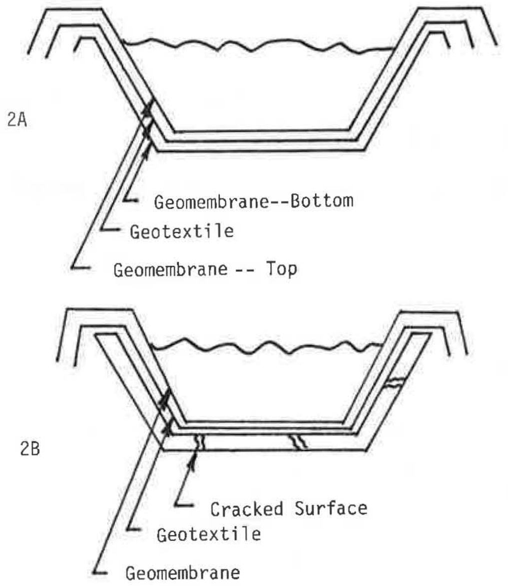

Figure 2. Installation of Geotextile in (A) Double-Lined Pond and (B) Rough Surfaced Pond.

FIELD TESTS FOR CUSHIONING

In an attempt to define a selection process that would identify the correct geotextile for puncture protection from heavy wheel loads, a field evaluation was conducted at an open pit coal mine in West Virginia. At this site, a polyvinyl chloride (PVC) geomembrane was used to contain and cover a large quantity of overburden removed from the mine. Since large ore trucks would be traversing areas underlined with the geomembrane, there was concern that puncture might occur thus releasing acidic runoff into the surrounding water supply. The use of a geotextile to protect the geomembrane from puncture was therefore investigated.

For the test, the base soil was leveled with a bulldozer, covered with 0.1 m of clean fill, and then compacted with three passes of a roller. The base was very "springy" under the roller movement, indicating unstable subsurface conditions. The geotextiles used in this study were needlepunched, spun-bonded polypropylene nonwoven fabrics with basis weights of approximately 400 g/m^2 (Geotextile A) and 600 g/m^2 (Geotextile B). These were cut into test strips of approximate dimensions: 1.2 m by 4.6 m. The fabric samples to be used under the liner were laid on the soil parallel to each other and separated by 0.6 m gaps. A single large piece of 0.51 mm (20 mil) PVC geomembrane was then placed over the geotextile samples and the soil. The fabric samples to be laid over the geomembrane were then put in place and their positions outlined with spray paint to allow identification of fabric position after the test when the soil overburden would be removed. The geotextile samples and exposed geomembrane were covered with fill so that, after compaction, there were 0.53 m of soil and crushed rock over the membrane. A four-wheel, 45,350 kg (50 ton) ore carrier was then run repeatedly over the test area. The wheels sank to within 0.15 m of the membrane. The soil was removed and damage to the geomembrane evaluated. Table 1 indicates the arrangement of geotextile samples over and under the geomembrane and the degree of damage resulting from the ore carrier wheel load. It is clear that the geotextile provided significant protection to the geomembrane thus significantly reducing puncture damage. The best protection was provided by Geotextile B (600 g/m^2) on the top and Geotextile A (400 g/m^2) under the geomembrane. Use of a single layer of Geotextile B on the top of the membrane or Geotextile A both above and below the membrane yielded slightly poorer results. Use of one layer of Geotextile B, on top of the liner, gave somewhat less protection. The degree of protection correlated directly with increasing fabric basis weight, thickness and protection from both sides. Test locations where the membrane was afforded no geotextile protection showed varying degrees of damage, with some showing complete membrane disintegration. This field trial clearly demonstrated the utility of thick needlepunched nonwoven fabrics to reduce the propensity of geomembrane puncture failure and pointed up the need for top and bottom layers where very heavy loading over poor subsoil are encountered.

TABLE I

FIELD TEST--GEOTEXTILE PROTECTING GEOMEMBRANE FROM PUNCTURE WHEN SUBJECTED TO LOADING FROM 45,000 Kg (50 TON) ORE CARRIER

Test Location	Identity and Position of Geotextile(1) Over Geomembrane	Under Geomembrane	Extent of Puncture Damage
1	B	A	None
2	None	B	Some
3	B	None	Very Slight
4	A	None	Slight
5	None	A	Some
6	A	A	Very Slight
7	None	None	Varying Degrees Up to Membrane Disintegration

(1) Geotextiles A and B are needlepunch spun-bonded polypropylene nonwoven fabrics of basis weight 400 g/m^2 and 600 g/m^2, respectively.

LABORATORY TESTS FOR CUSHIONING

Field trials as described above are too expensive and too time consuming for use in screening the performance of many different geomembrane-geotextile combinations. Therefore, a laboratory test method was developed that could simulate cyclic compression loading of the geomembrane against the soil-aggregate environment of interest. After subjection to the aggregate environment, the degree of damage was quantitatively determined by measuring the degree of air leakage through the geomembrane sample. The required load and number of cycles to simulate ore transport or equipment movement over the proposed site was achieved using an Instron testing machine cycling to the required compression load.

This test method was used to simulate geomembrane abuse expected during transport and dumping of ore onto a containment site used for heap leaching of gold ore. The experimental assembly of aggregates, geotextiles, and geomembrane mounted on the compression cell of an Instron testing machine is shown in Figure 3. The geomembrane, unprotected or covered top and/or bottom with geotextile, was placed on a 2 cm thick layer of 2 cm diameter aggregate. A 4 cm thick layer of finer, 0.5 cm diameter aggregate was then placed on the top of the membrane. Quartzite gold ore from a New Mexico mine was used as the aggregate. The assembly was placed on top of the compression cell of an Instron testing machine. A solid steel cylinder, 103 cm^2 in area and protected with a rubber gasket material was attached to the Instron crosshead bar to deliver compression force to the top of the aggregate assembly. The testing machine was then allowed to cycle 18 times/minute between 68 and 363 kg (150 lbs and 800 lbs) load to deliver 258 kPa - 1378 kPa (37.5 psi - 200 psi) compression force to the aggregate covering the plastic membrane. After cycling 30 minutes, the system was disassembled for damage evaluation. The system was then reassembled and cycling continued for a second 30-minute period. Damage was evaluated both visually and by measuring air flow under 69 kPa (10 psi) pressure through the geomembrane with a Sheffield Porosimeter.

Figure 3. Apparatus to Estimate Geotextile Protection of Plastic Pond Liner Membrane During Aggregate Compression Loading.

Geomembrane resistance to failure was found to be dependent upon geomembrane type, geomembrane caliper, type of geotextile used for cushioning and basis weight of that geotextile. Results for a wide selection of geomembranes, both unprotected and protected top and bottom with geotextiles, are summarized in Table 2. The utility of nonwoven geotextiles to increase geomembrane resistance to failure from aggregate cutting, puncture and abrasion was clearly demonstrated. The liners tested included low density polyethylene (LDPE), medium density polyethylene (MDPE), high density polyethylene (HDPE), alloy of high density polyethylene (HDPE) and ethylene propylene rubber (EPDM), polyvinylchloride (PVC), oil resistant polyvinylchloride, chlorosulfonated polyethylene (CSPER, with polyester fiber reinforcement) and chlorinated polyethylene rubber (CPER, with polyester fiber reinforcement). In most cases, two calipers of each type of plastic liner were tested. The effectiveness of no geotextile or Geotextiles C, A, and B, respectively, needlepunched spun-bonded polypropylene nonwoven fabrics having 300 g/m^2, 400 g/m^2, and 600 g/m^2 basis weights were evaluated.

The results in Table 2 suggest significant differences in the resistance of plastic liners to aggregate damage and significant differences in the degree of protection afforded by the different basis weights of the geotextile. The three 1.52 mm (60 mil) plastic liners tested showed significant resistance to failure even without geotextile protection. However, the use of Geotextile C (300 g/m^2) seemed to provide some protection for 1.52 mm (60 mil) LDPE and MDPE. All other plastic membranes besides the 1.5 mm (60 mil) products failed without geotextile protection. Geotextile C (300 g/m^2) on both sides yielded promising results with HDPE 0.76 mm (30 mil), LDPE 0.76 mm (30 mil) and CPDE 0.76 mm (30 mil). Note however that the latter two liners had failures in one of two replicates with Geotextile A (400 g/m^2) used on both sides. Geotextile A on both sides yielded sufficient protection to minimize leakage through MDPE 0.76 mm (30 mil), Alloy (HDPE + EPDE) 0.76 mm (30 mil), Alloy 1.02 mm (40 mil), PVC 0.51 mm (20 mil) and PVC 0.76 mm (30 mil). Geotextile C on both sides protected CSPER 0.91 mm (36 mil). The PVC oil resistant liner was the most difficult to protect using geotextiles.

Geomembrane protection via a single layer of geotextile above the membrane was also explored. The most promising results were seen with use of a single layer of Geotextile B (600 g/m^2) where a significant reduction in leakage was observed for all the geomembranes except PVC 0.51 mm (20 mil), PVC 0.76 mm (30 mil), and PVC oil resistant 0.76 mm (30 mil). Note that these results suggest that the compression cycling test for 1080 cycles was somewhat more extreme than the field test described above. In that experiment one layer of Geotextile B over 0.51 mm (20 mil) PVC provided a very high degree of protection.

Limited experimentation using this cyclic compression test method was carried out to compare the effectiveness of different types of geotextiles to protect several different types of geomembranes during 30 minutes of cyclic compression loading against aggregate. Table 3 compares results for the unprotected membrane; the membrane protected with Geotextile D, a spun-bonded, nonwoven polypropylene fabric of 136 g/m^2 basis weight and caliper of 0.38 mm (15 mils); and the membrane protected with Geotextile C, a needlepunched, spun-bonded polypropylene fabric of 300 g/m^2 basis weight and caliper of 2.29 mm (90 mils). As seen above, the unprotected geomembrane failed in all cases. Response for geomembranes covered top and bottom with the geotextiles was dependent upon both the type of geomembrane and the type of geotextile. For CPER (polyester fiber reinforced) both types of geotextiles provided acceptable protection. However for LDPE, MDPE, and CSPER (polyester fiber reinforced), the thick needlepunched nonwoven geotextile yielded much greater protection than observed with the thin nonwoven. For the two PVC liners neither geotextile afforded sufficient protection to prevent significant damage as indicated by air leakage. However, use of Geotextile A , the 400 g/m^2 analog of Geotextile A, protected both geomembranes.

Cyclic compression testing was also used to compare the cushioning effectiveness of geotextiles versus sand to protect the geomembrane. Results for a 0.76 (30 mil) PVC and a 0.91 mm (36 mil) CSPER (polyester reinforced) geomembrane are shown in Table 4. Both fail without protection. Similar protection was observed using one inch of sand under the membrane or a layer of Geotextile C, 300 g/m^2 basis weight nonwoven on the top and bottom of the membrane. Thus, with either of these systems, CSPER did not fail but PVC was severely damaged. Both geomembranes were protected by use of Geotextile A, 400 g/m^2 basis weight nonwoven.

Thus, a laboratory test method was developed to simulate geomembrane and geotextile-geomembrane resistance to repetitive loading such as generated by dumping or transport in heap leach mining. This method used cyclic compression loading generated by a tensile testing machine to subject the candidate geomembrane system to the cutting, punching, and abrasive action of the aggregate. Results demonstrated that geomembrane type, geomembrane caliper, geotextile caliper, and geotextile basis weight were important factors that determine resistance to damage. The cyclic compression loading method was also used to compare the relative protecting or cushioning effectiveness of sand and geotextiles. Conclusions from this test method were in agreement with limited field evaluations that also identified geotextile basis weight and caliper as important factors to preventing geomembrane failure.

GAS TRANSMISSION

Gas build-up under the geomembrane with possible flotation or rupture of the membrane can be prevented by use of a thick, nonwoven geotextile to allow gas transmission to the outside. Fluid permeability in the plane of the geotextile determines its utility in this application. Planer air permeability values were obtained via modifying a Frazier apparatus (4) by placing a piece of plastic film over the fabric so air flow was made to move through the plane of the fabric. The geotextile was held under 44.8 kPa (6.5 psi) compression pressure to simulate the force of 4.6 m (15 feet) of water down on the geomembrane and fabric. A pressure difference of 124 Pa was maintained through the fabric. Since the Frazier apparatus is calibrated for air movement through an area 156 cm^2 (4.91 in^2) the indicated air flow must be adjusted for the cross-sectional area of the geotextile that the air actually moves through. This area is determined by the diameter of the apparatus and the fabric caliper under the compression force. Thus, the resulting permeability was the flow per cross-sectional area of the fabric. Multiplication by caliper gave air transmission per linear dimension of fabric edge. Air transmission values for several fabrics are shown in Table 5. While these values are useful to rank geotextiles, it is unclear how well they predict the flow of gas from the center of the pond through the fabric to the edge of the pond. For a 4.6 m (15 ft) deep pond, there is a 44.8 kPa (6.5 psi) pressure differential to drive the gas compressed in the fabric out through the edge. Further work to quantify the gas transmissivity of geotextiles such as has been done by Koerner and Sankey with water as the fluid (5) seems justified.

TABLE 2

GEOMEMBRANE PUNCTURE RESISTANCE--GEOTEXTILE PROTECTION ON BOTH SIDES OF THE MEMBRANE. RESULTS AFTER 60 MINUTES OF CYCLIC COMPRESSION LOADING, 1080 CYCLES TOTAL

Geomembrane		Geomembrane puncture resistance as indicated by minimized air flow (cm³/min) through the membrane after cyclic compression loading. Protection by indicated geotextile(1)			
Type	Caliper	Unprotected Membrane	Fabric C (300 g/m²)	Fabric A (400 g/m²)	Fabric B (600 g/m²)
Low Density Polyethylene (LDPE)	0.76 mm (30 mil)	400+	2.0	98 3.0(2)	2.0
Low Density Polyethylene	1.52 mm (60 mil)	17	2.0	2.0	No Result
Medium Density Polyethylene (MDPE)	0.76 mm (30 mil)	400+	201	2.0	2.0
Medium Density Polyethylene	1.52 mm (60 mil)	37	2.0	3.0	No Result
High Density Polyethylene (HDPE)	0.76 mm (30 mil)	400+	0.0	0.0	0.0
High Density Polyethylene	1.52 mm (60 mil)	2.0	1.0	400 1.0(2)	0.0
Alloy of High Density Polyethylene and Ethylene Propylene Rubber (Alloy)	0.76 mm (30 mil)	400+	311	2.0	1.0
Alloy of High Density Polyethylene and Ethylene Propylene Rubber	1.02 mm (40 mil)	400+	245	0.0	0.0
Polyvinyl Chloride (PVC)	0.51 mm (20 mil)	400+	400+	3.0	1.0
Polyvinyl Chloride	0.76 mm (30 mil)	400+	400+	2.0	1.0
Oil Resistant Polyvinyl Chloride	0.76 mm (30 mil)	400+	328	148 2.0(2)	176 2.0(2)
Chlorinated Polyethylene Rubber With 10x10, 1000 Denier Polyester Fiber Reinforcement (CPER)	0.87 mm (35 mil)	400+	2.0	400+ 3.0(2)	3.0 1.0(2)
Chlorosulfonated Polyethylene Rubber With 10x10, 1000 Denier Polyester Fiber Reinforcement (CSPER)	0.91 mm (36 mil)	400+	107	233	0.0

(1) Geotextiles A, B, C are needlepunched, spun-bonded polypropylene nonwoven fabrics of indicated basis weight.
(2) Results from a second experiment.

TABLE 3

COMPARISON OF GEOTEXTILES TO IMPROVE PUNCTURE RESISTANCE OF GEOMEMBRANE--RESULTS AFTER 30 MINUTES OF CYCLIC COMPRESSION LOADING, 520 CYCLES TOTAL

Geomembrane	Geomembrane puncture resistance as indicated by minimized air flow (cm³/min) through the membrane after cyclic compression loading. Protection by indicated geotextile.		
	Unprotected Membrane	Geotextile D(1) Both Sides of Liner	Geotextile C(2) Both Sides of Liner
LDPE, 0.76 mm (30 mil)	400+	400+	2.0
MDPE, 0.76 mm (30 mil)	400+	400+	21
PVC, 0.76 mm (30 mil)	400+	400+	302
PVC, Oil Resistant 0.76 mm (30 mil)	400+	400+	302
CPER, 0.87 mm (35 mil) (10x10, 1000 denier polyester fiber reinforcement)	400+	4.0	2.0
CSPER, 0.91 mm (36 mil) (10x10, 1000 denier polyester fiber reinforcement)	400+	400+	1.0

(1) Geotextile D is a spun-bonded polypropylene nonwoven fabric of basis weight 136 g/m² and 15 mil caliper.

(2) Geotextile C is a needlepunched spun-bonded polypropylene nonwoven fabric of basis weight 300 g/m² and 90 mil caliper.

TABLE 4

USE OF GEOTEXTILES OR SAND TO IMPROVE PUNCTURE RESISTANCE OF GEOMEMBRANES--RESULTS AFTER 30 MINUTES OF CYCLIC COMPRESSION LOADING, 520 CYCLES TOTAL

Geomembrane	Geomembrane puncture resistance as indicated by air flow (cm³/min) through the membrane after compression loading. Protection by indicated geotextile.		
	Unprotected Membrane	Sand 1" on Bottom Side of Liner	Geotextile C(1) Both Sides of Liner
PVC, 0.76 mm (30 mil)	400+	400+ 400+(2)	302
CSPER, 0.91 mm (36 mil) (10x10, 1000 denier polyester fiber reinforcement)	400+	2.0	1.0

(1) Geotextile C is a needlepunched, spun-bonded polypropylene nonwoven fabric of basis weight 300 g/m² and 90 mil caliper.
(2) Results from a second experiment.

TABLE 5

GEOTEXTILE PLANER GAS PERMEABILITY--
MODIFIED FRAZER METHOD(1)

Geotextile--Basis Weight(2)	Gas Transmission: Per Meter of Fabric Edge (L/s-m)	Gas Transmission: Per Foot of Fabric Edge (ft^3/min ft)
E-150 g/m^2	0.59	0.38
F-200 g/m^2	0.79	0.51
C-300 g/m^2	1.67	1.08
A-400 g/m^2	1.32	0.85
B-600 g/m^2	2.11	1.36
G-500 g/m^2	1.05	0.68
H-300 g/m^2	0.96	0.62

(1) Fabric under 44.8 kPa (6.5 psi) compression to simulate 4.5 m (15 ft) of water. Pressure difference of 124 Pa was present through the fabric.

(2) Geotextiles E, F, C, A, B are needlepunched, spun-bonded polypropylene nonwoven fabrics. Geotextile G is needlepunched, spun-bonded polyester nonwoven fabric. Geotextile H is a needlepunched staple polypropylene nonwoven fabric.

SUMMARY AND CONCLUSIONS

Both field and laboratory tests have been conducted in order to optimize geotextile fabric properties for use as underlining in geomembrane pond construction. The geotextile has been demonstrated to be functionally useful as a cushion against puncture, as a gas release medium and as an abrasion resistant layer over rough surfaces. Laboratory test methods were developed which simulate field puncture problems, various combination of geotextile/geomembrane were evaluated and test data reported. From this work, it can be concluded that a thick, nonwoven, needle-punched polypropylene geotextile can be used to provide the essential protection functions noted above for pond construction. Commercial use of geotextiles as pond underlining can be expanded without fear of failure or deterioration if care is exercised in the geotextile/geomembrane selection.

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