DESIGNING, TESTING, AND INSTALLING A POLYPROPYLENE GEOMEMBRANE CAPPING SYSTEM FOR LOW-LEVEL RADIOACTIVE INTERIM STORAGE PILES

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ABSTRACT

Piles created for temporary storage of low-level radioactively contaminated soil and rubble (LLRSR) must be adequately covered to prevent wind-blown dust and debris from contaminating surrounding areas. The piles must also be protected from water infiltration to prevent groundwater contamination caused by leachate. Because an interim pile could be in place for several years until final disposal arrangements are made, its cap must be designed to last at least 5 to 10 years, and possibly as long as 25 years. Because these covers are generally exposed geomembrane systems, they must be designed to withstand forces caused by high wind (uplift and movement against the pile). In addition, the capping system must resist climatic stress, puncturing (hail and debris), and tensile fatigue at tie-down areas.

The design procedure includes an in-depth wind uplift analysis as well as technical and practical considerations to prevent damage from restraint (tie-down), pullout, puncture, and environmental stress. The design incorporates a unique ballasting system consisting of a polypropylene rope and sleeve restraint system integrally attached to the polypropylene geomembrane and tied down to the pile using concealed helical anchors spaced on a grid pattern over the pile. Laboratory tests used in the design analysis include large-scale multiaxial seam/restraint testing, seam and sleeve mechanical peel testing, and tensile, tear, and puncture resistance testing. This system has been successfully installed and is in use.

INTRODUCTION AND BACKGROUND

Under the jurisdiction of U. S. Department of Energy, interim storage piles created from 1981 through 1987 in New Jersey for temporary storage of low-level radioactively contaminated soil and rubble (LLRSR) were covered by then-available geomembranes such as Hypalon™ and ethylene propylene diener monomer (EPDM). These materials required chemically bonded field seams and required use of concrete blocks, sandbags, and/or rubber tires as ballast to prevent damage to the covers under wind-induced uplift forces. In spite of continuous maintenance, pile covers at two sites were wind damaged in 1991 and 1992. This prompted an investigation and a study to find a reliable, durable, and economical capping system. Visual inspection of these damaged covers revealed that the chemically bonded seams were becoming brittle and less effective because of exposure to weather. This phenomenon also made any repair work very difficult. Results of subsequent laboratory tests also demonstrated that the peel strengths of weathered, chemically bonded seams were significantly less than the peel strengths of non-weathered chemically bonded seams.

Based on the results of the "Capping Options Study" by the author (1), a new cover system was designed that consists of a thermally welded polypropylene geomembrane equipped with a unique ballasting system. The capping system is described in detail in the following paragraphs.

CAPPING SYSTEM FEATURES

The capping system discussed in this technical paper was installed at the Middlesex Sampling Plant in Middlesex, New Jersey. The system consisted mainly of a scrimmed geomembrane reinforced with a series of ballasting ropes, which in turn were tied down to the pile with concealed helical anchors spaced on a grid pattern covering the entire pile (see Fig. 1).

Helical Soil Anchors

Helical soil anchors used for ballasting the geomembrane cover were made of 19-mm- (0.75-in.-) diam steel rods welded to a 152-mm- (6-in.-) diam steel helix segment. The upper ends of the rods were finished into a circular eye, which facilitated installation of the anchors into the pile using mechanical devices and also permitted easy connection of the anchors to the ballasting rope.

Geotextile

To protect the geomembrane from sharp objects and stones, a 4.3-mm (170-mil), needlepunched, nonwoven, polypropylene geotextile was placed over the entire pile surface before installation of the geomembrane.

Geomembrane

The geomembrane used consisted of 1.14-mm (45-mil) fire retardant polypropylene reinforced with high-strength woven polyester scrim. The reinforced polypropylene was selected because of its high tensile strength, high environmental stress crack resistance, low permeability for radon gas, and low thermal coefficient of expansion and because field seams can be bonded by a fusion welding process. The geomembrane was installed on top of the geotextile.

Some of the physical properties of 1.14-mm (45-mil) reinforced polypropylene (pp-45R) (listed in Ref. 2) are compared with those of 1.52-mm (60-mil), high-density polyethylene (HDPE-60), 1.02-mm (40-mil) very low density polyethylene (VLDPE-40), and 1.02-mm (40-mil) unreinforced polypropylene (PP-40) in Figs. 2 through 7. (Figs. 2 through 7 appear courtesy of JPS Elastomerics Corp.)

Ballasting Ropes

Polypropylene ballasting ropes, 9.5 mm (0.375 in.) in diameter, were attached to the underside of the geomembrane and traversed across the shorter width of the pile. The ropes were attached at 3.71 m (12.17 ft) on centers (o.c.) to the underside of the geomembrane by positioning the rope

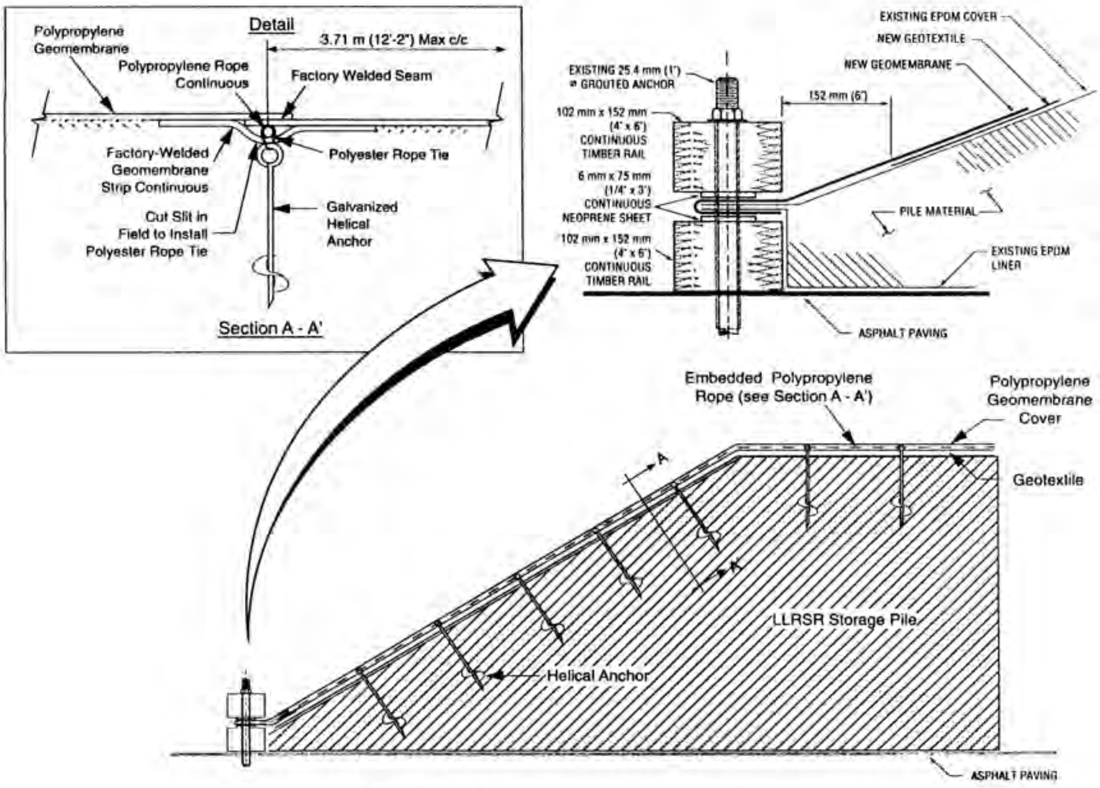
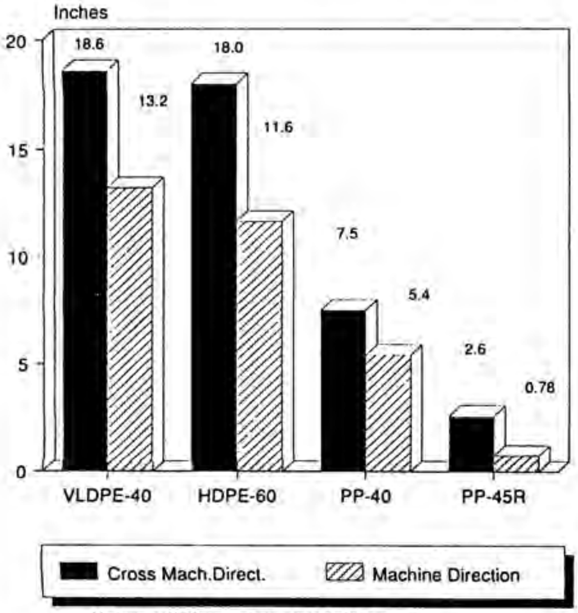


Fig. 1. Typical anchoring system for geomembrane.

between the geomembrane and a 152-mm (6-in.) wide capping strip made of the same material as the geomembrane. The capping strip was thermally welded to the geomembrane to secure the rope. The rope, in turn, was tied to the top of the helical soil anchors to ballast the geomembrane cover.

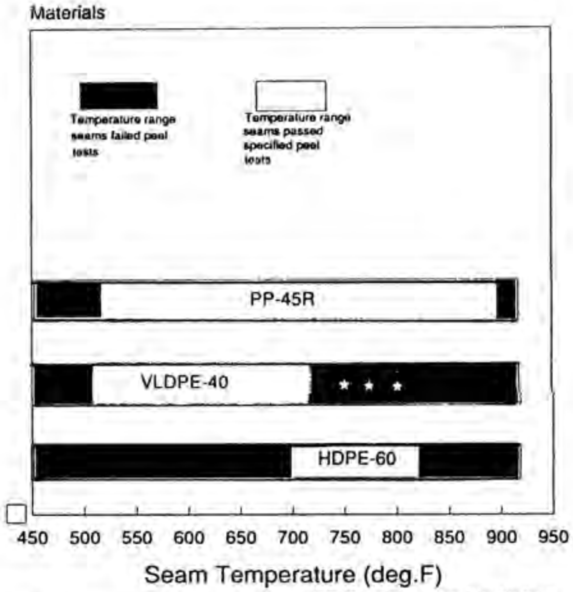


Maximum and Minimum displacement per 100 ft. length of geomembrane when exposed to a 90 deg. F temperature change (68-158 deg.F)

Fig. 2. Comparison of typical expansion & contraction rates per 90 deg. temperature change.

Rope Ties

Solid-braided polyester rope ties, 9.5 mm (0.375 in.) in diameter, were used to secure the polypropylene ballasting ropes to the helical anchors. (See the details in Fig. 1.)



Welder speed of (12'/min., pressure of 250 psi)

PP-45 maintains consistent values without failure, i.e. brittle fractures★or peels

Fig. 3. Seaming temperature window (wedge welder).

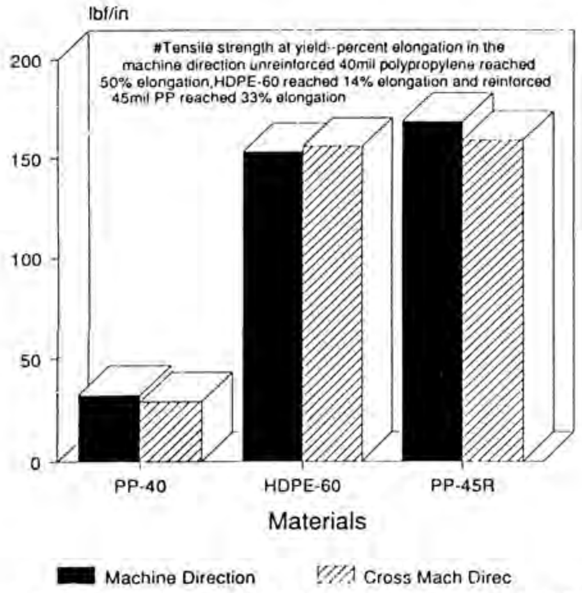


Fig. 4. Tensile strength at yield (polypropylene ASTM D-4885).

DESIGN APPROACH

Analytical Evaluation

The objective of this evaluation was to qualify the 1.14-mm (45-mil) reinforced geomembrane and helical anchors for the loading conditions described below. The Bechtel/PMB SeaStar nonlinear finite element computer program was used for the analysis. SeaStar is a specific extension of the ANSR computer program, which was developed at the University of California, Berkeley. SeaStar has been used for years in the design and analysis of offshore platforms supported with cables. In this analysis, version P3.01 was used on an IBM RISC 6000 work station. For the analysis reported here, the SeaStar was specifically validated with two verification problems.

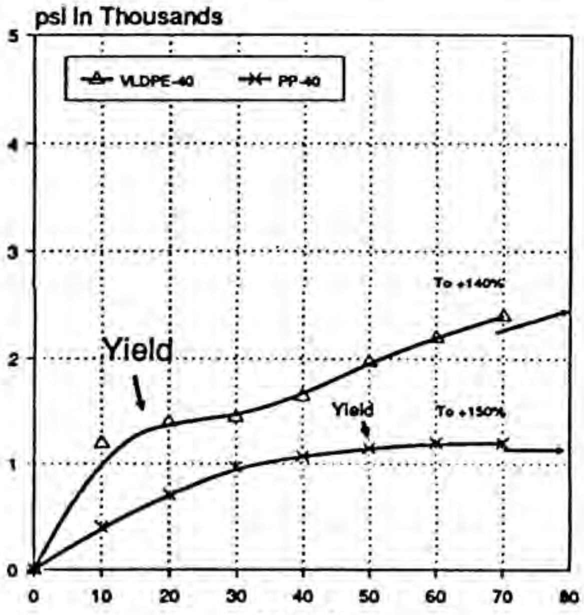


Fig. 6. Multiaxial strain %.

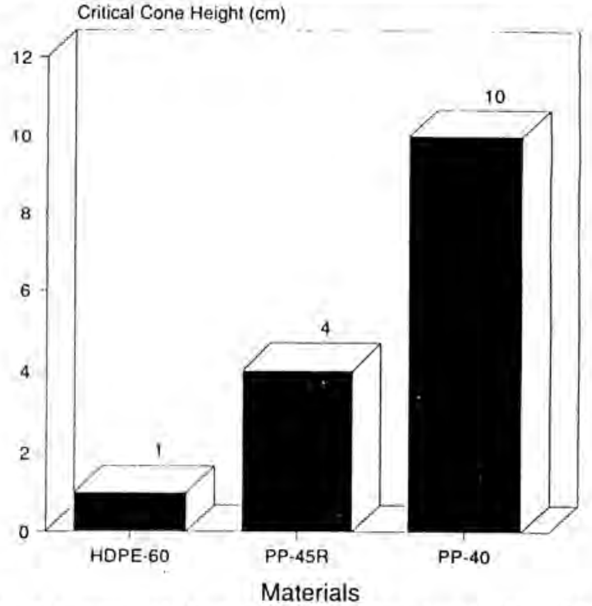


Fig. 5. Large scale hydrostatic puncture test (GRI/GM3).

Loading Condition

A strong wind of 137 km/h (85 mph) was considered in the analysis. In accordance with ANSI 58.1, the wind stagnation pressure at a height of 9.14 m (30 ft) above ground is 68.35 kg/m^2 (14.0 psf) for exposure B. For suction wind load on flat roof, a factor of 0.7 was applied. Therefore, in accordance with ANSI 58.1, an upward wind suction load of 47.85 kg/m^2 (9.8 psf) was applied to the pile cover. The code does not consider the changes of interior air volume due to structural deformation. However, in the pile cover design the enclosed air volume would be changed significantly by extension of the geomembrane. By assuming that the storage pile consisted of 25 percent of air volume and following the gas pressure-temperature law, it was found that a vertical displacement of 25.4 mm (1 in.) at the center of the cover would increase the air volume by 0.45 percent; this would decrease the interior pressure from the atmospheric pressure by

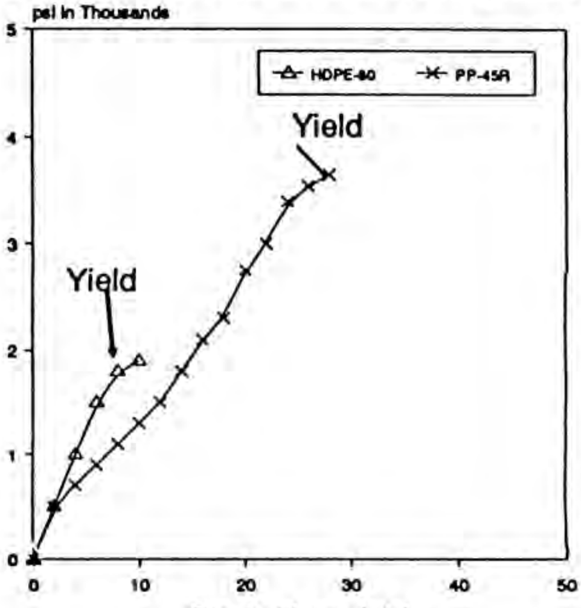


Fig. 7. Multiaxial strain % to yield.

47.85 kg/m^2 (9.8 psf). This calculation indicated that a small upward vertical displacement in the geomembrane would eliminate the suction pressure on the cover completely. This also implied that if a large upward displacement occurred, it would reduce the interior pressure to a level even lower than the external wind pressure and could result in an additional positive downward pressure on the cover. Because of this self-limiting behavior on the upward movement, the pile cover can never induce a large upward displacement from suction pressure. Therefore, the code suction pressure on a flat roof was considered inappropriate for the design of the pile cover. Accordingly, the significant wind load to which the cover is actually subjected is not a suction pressure but an upward positive pressure on a ruptured panel.

Analytical Model

The polypropylene geomembrane panels were available in 1.93-m (76-in.) widths. The panels were anchored at 3.71 m (12.17 ft) o.c. in one direction and 3.05 m (10 ft) o.c. in the other direction to limit the anchor loads to approximately 453.7 kg (1,000 lbs). Figure 8 shows a typical 3.71-m x 3.05-m (12.17-ft x 10.0-ft) section of the panel analyzed to determine forces on the helical anchors. The section was divided into 20 elements, and the wind force was applied at each of the node points. Except at the anchors, every node was modeled free in the vertical (+ Z) direction. All elements were considered truss elements.

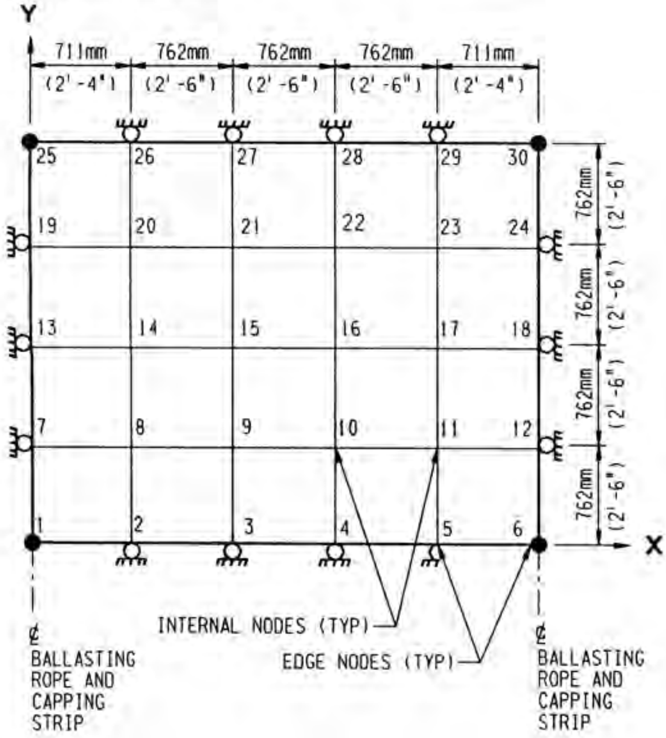


Fig. 8. Analytical model.

Forces in Helical Anchors (using Manual Calculations)

- Wind load on internal nodes:
  0.762 m x 0.762 m x 47.85 kg/m^2
  = 27.8 kg
- Wind load on edge nodes:
  27.8/2 = 13.9 kg
- Total upward vertical wind load:
  - at internal nodes = 12 x 27.8 = 333.6 kg
  - at edge nodes = 14 x 13.9 = 194.6 kg
  - geomembrane weight = 23.9 = −23.9 kg

  Total = 504.3 kg
  = (1,111 lbs)

Forces in Helical Anchors (using Computer Analysis)

TABLE I
Vertical Displacement

Node Point	Disp. cm (in.)	Node Point	Disp. cm (in.)
2	26.67 (10.5)	3	39.62 (15.6)
4	39.62 (15.6)	5	26.67 (10.5)
7	24.13 (9.5)	13	31.50 (12.4)
14	47.24 (18.6)	15	57.40 (22.6)
16	57.40 (22.6)	17	47.24 (18.6)
18	31.50 (12.4)	19	24.13 (9.5)

- Rope and Geomembrane Tension: (in direction Y)
  - Rope tension = 2 x 60.57
    = 121.1 kg
  - Tension in capping strip = 2 x 43.33
    = 86.7 kg
  - Tension in edge strip = 2 x 116.15
    = 232.3 kg
  - Total tension = 121.1 + 86.7 + 232.3
    = 440.1 kg
- Geomembrane Tension: (in direction X)
  - Tension in edge strip = 2 x 162
    = 324 kg
- Tension in Geomembrane at Anchor: (in direction Y)

  Anchor Force, F_1 = 2 x 440.1 x 24.13/80
  = 265.50 kg

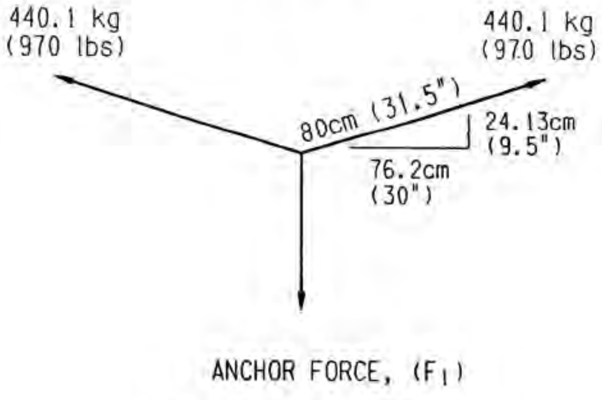


Fig. 9. Anchor force (F_1).

- Tension in Geomembrane at Anchor: (in direction X)

  Anchor Force, $F_2 = 2 \times 324 \times 26.67/75.95$
  $= 227.50$ kg
  Total Anchor Reaction $= 265.5 + 227.5$
  $= 493$ kg (1,087 lb)

This figure is comparable within 2 percent to the manual calculation. Geomembrane stresses were found to be within allowable limits.

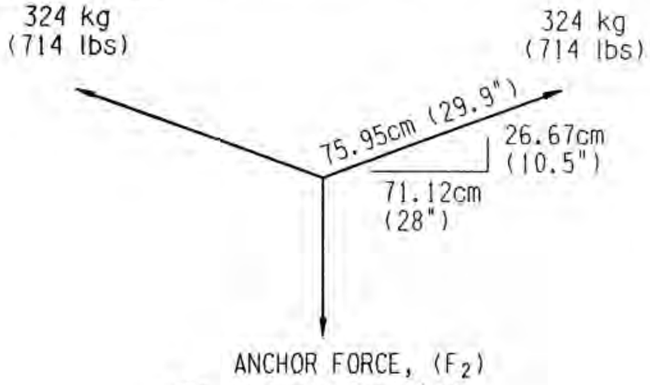


Fig. 10. Anchor force (F_2).

Evaluation of Helical Anchors:

The anchor pullout capacities were calculated based upon varying conditions of soil and different anchor sizes.

The pullout resistance results from:

- The weight of the soil in the cone above the helix, and
- Shear strength along the cone surface above the helix.

The following equations were used for calculating the anchor pullout capacities:

Angle of internal friction $= \phi$
Cohesion of soil = c
Density of soil $= \gamma$
Diameter of helix = d
Depth to anchor = H

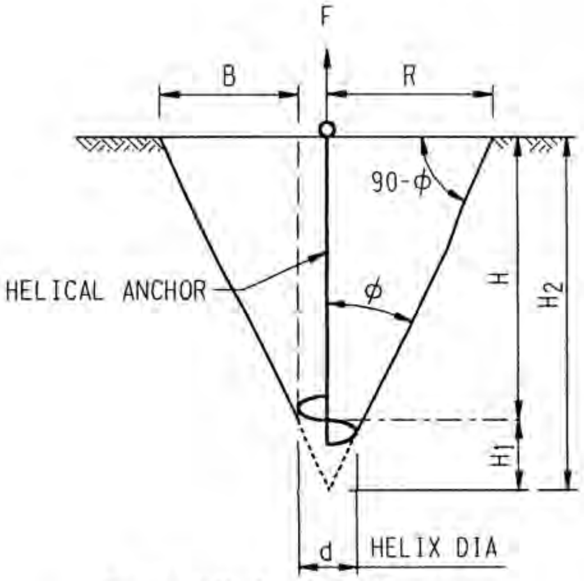


Fig. 11. Helical anchor failure cone.

$$Tan\,(90-\phi) = \frac{H}{B} \qquad (1)$$

Therefore:

$$B = \frac{H}{Tan\,(90-\phi)}$$

$$\text{and } R = B + \frac{d}{2}$$

$$H_2 = H + H_1 \text{ (Large Cone)}$$

$$\text{and } r = \frac{d}{2}$$

$$H_1 = rTan\,(90-\phi) \text{ (Small Cone)}$$

Weight of soil = W = unit weight x volume of soil

$$W = \gamma V \qquad (2)$$

Volume of soil above helix = V

$$V = V_L - V_S$$

$$V_L = \frac{1}{3}\pi R^2 H_2$$

(Volume of large cone)

$$V_S = \frac{1}{3}\pi r^2 H_1$$

(Volume of small cone)

Therefore:

$$V = \frac{1}{3}\pi\,(R^2H_2 - r^2H_1) \qquad (3)$$

$$W = \gamma\frac{1}{3}\pi\,(R^2H_2 - r^2H_1) \qquad (4)$$

Shear resistance = S_R = surface area x cohesion

$$S_R = S\,x\,c \qquad (5)$$

Surface area of truncated cone $S = S_L - S_S$

(Surface area of large cone minus surface area of small cone)

$$S_L = \pi R\sqrt{R^2 + H_2^2}$$

$$S_S = \pi r\sqrt{r^2 + H_1^2}$$

$$S = \pi\,(R\sqrt{R^2 + H_2^2} - r\sqrt{r^2 + H_1^2}) \qquad (6)$$

$$S_R = c\pi(R\sqrt{R^2 + H_2^2} - r\sqrt{r^2 + H_1^2}) \qquad (7)$$

Anchor capacity = F = (weight of soil + shear resistance)

$$F = W + S_R \qquad (8)$$

The calculated anchor pullout capacities were compared with actual field tests, and the results were found comparable.

PERFORMANCE TESTING

Geomembrane Material Testing

Upon receipt of the 45-mil FR polypropylene geomembrane material from the manufacturer and before fabrication, the tests indicated in Table II were performed using Instron's Services IX Automated Materials Testing System 1.19 (Model 1011) to confirm the material's compliance with the specifications.

Seam Testing

Because the polypropylene material is chemically inactive, seams were made with an automatic thermal welding

TABLE II

Geomembrane Material Testing

Property & Test Method	Specification Values	Actual Average Values		
		Specimen 1	Specimen 2	Specimen 3
• Thickness mm (mil) - ASTM D-751	1.04 (41.0)	1.05 (41.5)	1.08 (42.5)	1.06 (41.9)
• Roll Width m (in.) - ASTM D-751	1.92 (75.75)	1.94 (76.25)	1.93 (76.0)	1.94 (76.2)
• Dim. Stability (%) - ASTM D-1204	2%	1.17%	1.17%	1.17%
• Breaking Strength kg (lb) - ASTM D-751	113.4 (250)	134.2 (295.7)	133.8 (294.9)	133.9 (295.2)
The test results indicated that the supplied 1.14-mm (45-mil) FR polypropylene material was acceptable.				

settings to obtain a minimum value of 5.36 kg/cm (30 lb/in.) for peel strength and a minimum value of 17.86 kg/cm (100 lb/in.) for bonded seam strength. Five specimens 25.4 mm (1 in.) wide were prepared for peel tests, and three specimens 51 mm (2 in.) wide were prepared for bonded seam tests. The specimens were tested in accordance with ASTM D413 (as modified by Appendix A, Part 5 of NSF 54, 1991) for peel strength, and in accordance with ASTM D751 for bonded seam strength. After several trial combinations, it was learned that a machine setting of approximately 538°C (1,000°F) heat and 2.74 m/min (9 ft/min) speed produced the desired results, as indicated in Tables III and IV.

TABLE III

Results of Peel Strength Test

Specimen Number	Displacement at Max. Load mm (in.)	Load/Width at Max. Load kg/cm (lb/in.)	Stress at Max. Load kg/cm² (psi)
1	13.18 (0.5189)	7.14 (40.00)	62.5 (888.9)
2	13.28 (0.5227)	6.83 (38.25)	59.8 (850.0)
3	15.29 (0.6269)	7.77 (43.50)	68.0 (966.7)
4	14.99 (0.5900)	7.28 (40.75)	63.7 (905.6)
5	11.25 (0.4428)	6.79 (38.00)	59.4 (844.4)
Mean:	13.72 (0.5402)	7.16 (40.10)	62.6 (891.1)

Helical Anchor Testing

To provide a reasonably accurate strength value of helical anchors for design purposes, the pullout capacities of a series of helical anchors were determined by field tests. Helical anchors of 152-mm (6-in.) helix diameter and of various lengths ranging from 610 mm (24 in.) to 1,220 mm (48 in.) were installed in the waste storage pile. The setup used for the pullout tests is shown in Fig. 12. The load at which the anchor showed no appreciable change in the vertical displacement was termed its pullout capacity for that soil condition. These tests were performed at about 20 locations on the pile to cover various waste soil conditions. Results of some of the tests are shown in Tables V through XI.

Wind Uplift Pressure Test

This test method (described in Ref. 3) was designed to measure the overall stability of the cover assembly on its supports and to evaluate the ultimate strength of the individual components in the completed cover under static conditions that simulate the uplift loads imposed by wind forces on the cover system. The full-scale, 9.14-m x 10.97-m (30-ft x 36-ft) cover specimen employed for this test was sufficiently large so that the means of securing the perimeter of the sample (see Fig. 13) had virtually no effect on the ultimate behavior of the assembly during testing.

Design and Operations of Test Apparatus

- The wind uplift pressure test was arranged to generate air pressure at pre-established pressure levels to the underside of the cover assembly (test panel). This

TABLE IV

Bonded Seam Strength Test Results

Specimen Number	Displacement at Yield mm (in.)	Load at Yield kg/cm (lb/in.)	Stress at Yield kg/cm² (psi)	Strain at Yield m/m (in./in.)
1	23.4 (0.92)	23.8 (133.00)	103.9 (1478)	0.1150
2	22.9 (0.90)	24.2 (135.7)	106.0 (1508)	0.1125
3	24.1 (0.95)	23.4 (133.7)	104.5 (1486)	0.1188
Mean:	23.5 (0.92)	23.8 (134.1)	104.7 (1490)	0.1154
The test results indicated that the machine settings were acceptable for obtaining the desired joint strengths.				

Fig. 12. Helical anchor field test in progress.

TABLE V
Test No. 1
For 152-mm-diam x 610 mm
(6-in.-diam x 24 in.) Long Anchor

Initial Load kg (lb)	Final Load kg (lb)	Displacement mm (in.)
231.4 (510)	231.4 (510)	5.1 (0.2)
453.7 (1000)	435.6 (960)	7.6 (0.3)
521.8 (1150)	503.6 (1110)	10.2 (0.4)
621.6 (1370)	603.5 (1330)	10.2 (0.4)
Soil Conditions: Hard with dense clayey/silty gravel.		

TABLE VI
Test No. 2
For 152-mm-diam x 762 mm
(6-in.-diam x 30 in.) Long Anchor

Initial Load kg (lb)	Final Load kg (lb)	Displacement mm (in.)
190.6 (420)	186.0 (410)	2.5 (0.1)
272.2 (600)	267.7 (590)	5.1 (0.2)
394.7 (870)	381.1 (840)	7.6 (0.3)
503.6 (1110)	490.0 (1080)	7.6 (0.3)
576.2 (1270)	553.5 (1220)	7.6 (0.3)
676.0 (1490)	653.4 (1440)	10.2 (0.4)
Soil Conditions: Hard with dense clayey/silty gravel.		

TABLE VII
Test No. 3
For 152-mm-diam x 610 mm
(6-in.-diam x 24 in.) Long Anchor

Initial Load kg (lb)	Final Load kg (lb)	Displacement mm (in.)
267.7 (590)	258.6 (570)	3.8 (0.15)
317.6 (700)	308.5 (680)	5.1 (0.2)
517.2 (1140)	503.6 (1110)	7.6 (0.3)
598.9 (1320)	585.3 (1290)	7.6 (0.3)
Soil Conditions: Hard with dense clayey/silty gravel.		

TABLE VIII
Test No. 4
For 152-mm-diam x 762 mm
(6-in.-diam x 30 in.) Long Anchor

Initial Load kg (lb)	Final Load kg (lb)	Displacement mm (in.)
245.0 (540)	235.9 (520)	5.1 (0.2)
376.6 (830)	367.5 (810)	6.4 (0.25)
603.4 (1330)	589.8 (1300)	7.6 (0.3)
Soil Conditions: Hard with dense clayey/silty gravel.		

cover assembly, when secured in place, formed and sealed the top of the pressure vessel.

- The test apparatus measured 9.3 m x 11.3 m (30.5 ft x 37 ft). The 1.14-mm (45-mil) FR polypropylene geomembrane was mechanically fastened at the perimeter to the concrete floor using 50-mm x 100-mm (2-in. x 4-in.) lumber fastened at 305 mm (12 in.) o.c. (see Fig. 13). Eight 12-mm- (0.5-in.-) diam steel anchors with eyelets were fastened to the concrete floor in a 3.66-m x 3.05-m (12-ft x 10-ft) grid pattern. The 9.5-mm- (0.375-in.-) diam polypropylene rope was tied to the anchor eyelets using steel quick links.
- The air supply into the sealed vessel was provided by an inlet manifold constructed with 100-mm- (4-in.-) diam PVC pipe. The pipe penetrated the concrete floor and served as the air inlet on the bottom of the pressure vessel. A 6-mm- (0.25-in.-) diam tube on the bottom of the vessel was connected to a manometer. A bead of caulking material was placed between the geomembrane and concrete to minimize air leakage.
- Pressurized air was supplied to the inlet manifold by a pressure blower capable of generating 36.81 m^3/min (1,300 ft^3/min). The air flow was regulated by a manually operated variable frequency drive. Pressure readings were obtained from a water filled manometer.
- Air was introduced beneath the cover assembly in accordance with the pressure schedule noted in Table XII. For each test, the cover was maintained at each level of pressure for a period of 5 minutes or until the failure occurred.

FABRICATION, INSTALLATION, AND TESTING

Fabrication

To keep the number of field seams to a bare minimum and to locate the field seams to best suit the pile configuration, panel layout drawings were developed. Each panel was given a unique identification number. The panels were fabricated with a minimum of 51-mm- (2-in.-) wide weld in the shop after seam samples were tested as described earlier. Panel seams and capping strip seams were tested by the air lance testing method in accordance with ASTM D4437. After fabrication, the panels were individually accordion-folded in both directions. This facilitated the installation of panels without unnecessary repositioning, disturbance of the pile surface, and needless soiling of the edges to be bonded in the field. Coupons for future destructive testing were also welded on the panels located on the pile slope.

Installation

The surface of the existing pile cover was cleaned of ballasts, standing water, and debris before placement of the

TABLE IX
Test No. 5
For 152-mm-diam x 762 mm
(6-in.-diam x 30 in.) Long Anchor

Initial Load kg (lb)	Final Load kg (lb)	Displacement mm (in.)
172.4 (380)	158.8 (350)	5.1 (0.2)
317.6 (700)	304.0 (670)	7.6 (0.3)
467.3 (1030)	449.2 (990)	10.2 (0.4)
594.4 (1310)	576.2 (1270)	10.2 (0.4)

Soil Conditions: Hard with dense clayey/silty gravel.

TABLE X
Test No. 6
For 152-mm-diam x 914 mm
(6-in.-diam x 36 in.) Long Anchor

Initial Load kg (lb)	Final Load kg (lb)	Displacement mm (in.)
544.5 (1200)	508.21 (1120)	2.5 (0.1)
907.4 (2000)	553.5 (1220)	9.7 (0.38)
907.4 (2000)	753.2 (1660)	12.7 (0.5)

Soil Conditions: Hard with dense clayey/silty gravel.

TABLE XI
Test No. 7
For 152-mm-diam x 1067 mm
(6-in.-diam x 42 in.) Long Anchor

Initial Load kg (lb)	Final Load kg (lb)	Displacement mm (in.)
181.5 (400)	154.3 (340)	3.0 (0.12)
363.0 (800)	299.5 (660)	6.4 (0.25)
544.5 (1200)	435.6 (960)	9.7 (0.38)
680.6 (1500)	544.5 (1200)	15.7 (0.62)

Soil Conditions: Soft and wet (not watery) area.

Test results indicated that helical anchors with a 152-mm- (6-in.-) diam helix and lengths varying from 610 mm (24 in.) to 1,220 mm (48 in.), depending on the soil conditions, were required to obtain sustained load capacity of 545 kg (1,200 lb) with minimal displacement.

TABLE XII
Air Pressure and Displacement

Pressure kg/m^2 (PSF)	Cover Displacement mm (in.)
25.4 (5.2)	549 (21.6)
50.8 (10.4)	610 (24.0)
63.5 (13.0)	701 (27.6)
76.2 (15.6)	792 (31.2) (rope failed)

Test results indicated that the 1.14-mm (45-mil) reinforced polypropylene geomembrane capping system, when fabricated and installed as described in this paper, will sustain a maximum differential pressure of 63.5 kg/m^2 (13.0 psf). No damage to the geomembrane or seams was observed after this test. The mode of failure was a tensile failure of the 9.5-mm- (0.375-in.-) diam polypropylene rope at the anchor. Table XII summarizes the pressures and corresponding approximate cover displacements recorded during the test.

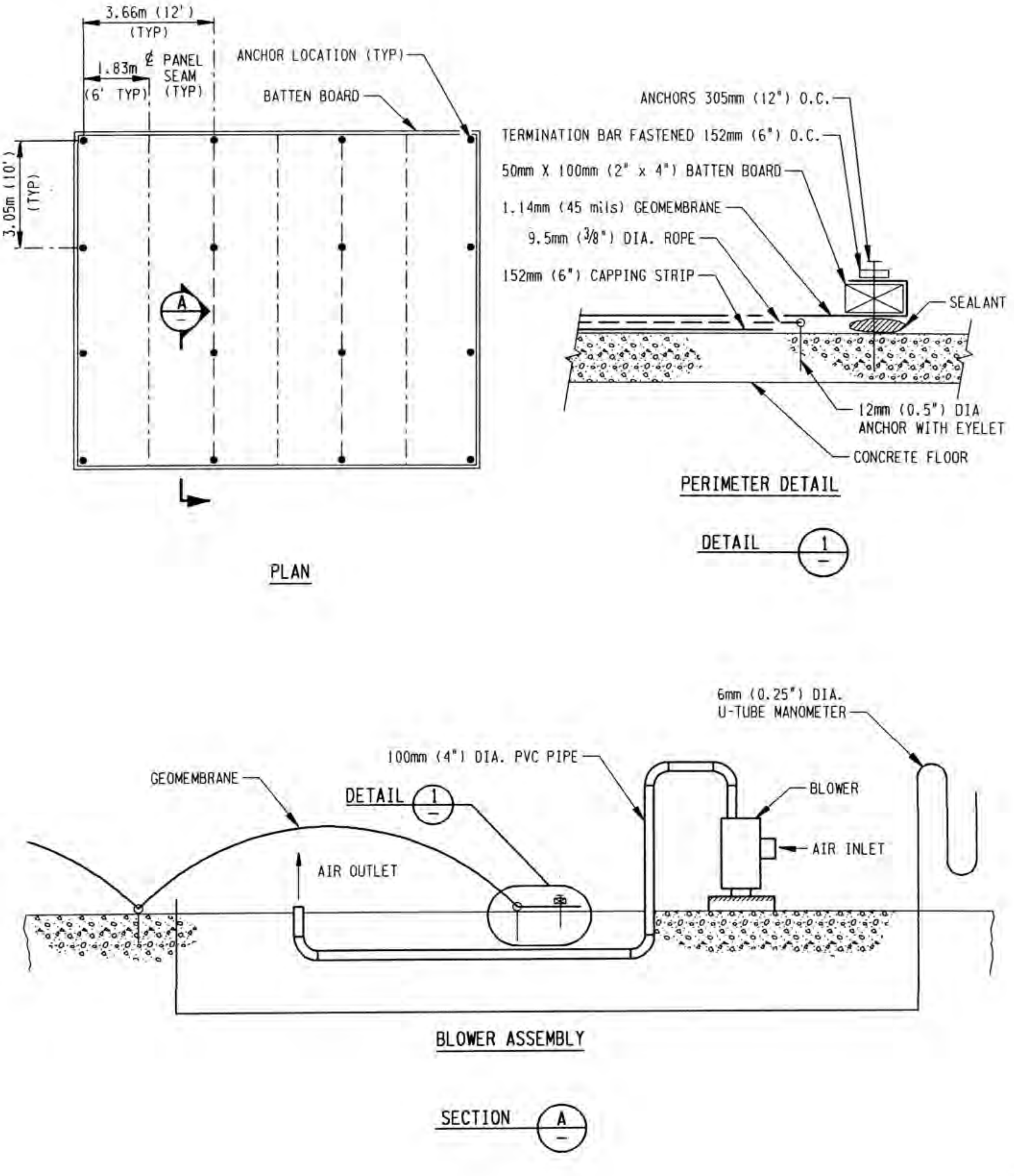


Fig. 13. Wind uplift pressure test.

new cover. The pile cover surface was divided into several areas designating a day's work. All cover installation activities, including installation of geotextile, geomembrane, ballasting system, and perimeter anchoring system, were completed on one designated area each day. After the pile surface was found satisfactory, geotextile panels were placed in the designated areas. Extra layers of geotextile were placed in low areas to level the surface. Starting from the foot of the pile, geomembrane panels were placed over the geotextile by a crew of 10 to 20 persons into the locations specified on layout drawings. The panels were then folded back to bring the capping strip containing ballasting rope to open view. Next, helical anchors were installed along the final position of the ballasting rope. Depending upon the condition of the soil at each helical anchor location, the longest size of helical anchor was installed with a power-driven hand tool. After the anchor was completely driven into the soil so that the eye was flush with the top surface of the existing cover, a slit [not more than 51 mm (2 in.) long] was made in the capping strip on both sides of the ballasting rope at the same location as the anchor eye. The ballasting rope was tied to the anchor eye with a 305-mm- (12-in.-) long, 9.5-mm- (0.375-in.-) diam polyester rope using a square knot and minimum slackness. This procedure was repeated for installing all panels in the designated area.

Before field seaming of the geomembrane panels was started, the weld areas were cleaned to remove all dirt, dust, moisture, and other foreign materials. To obtain the optimum seaming temperature and speed, test samples were made and tested as described earlier. After approval of the test samples, field seams were made. Additional destructive test samples were cut from the panel ends to reconfirm the field peel strength and bonded seam strength. The perimeter anchoring system was then installed. After each day's work, the free ends of geotextile and geomembrane were fully secured with tires to prevent any damage from winds and storms. This procedure was repeated for installing the entire pile cover.

Testing

After the cover was installed, a walkdown of the entire cover surface was conducted to visually inspect for any damage and unbonded seams. The damaged areas were repaired *with a hand*-held heat gun and a roller using rounded patches extending 152 mm (6 in.) beyond the puncture and with a minimum seam width of 51 mm (2 in.). All field seams were finally tested by the air lance testing method in accordance with ASTM D4437. In this test, air at a minimum pressure of 3.52 kg/cm^2 (50 psi) (gauge) was directed through a 2.38-mm (0.094-in.) nozzle, held not more than 51 mm (2 in.) from the seam edge and directed at the seam edge. Absence of fluttering of the seam edges indicated a good seam weld.

CONCLUSION

It was apparent from this case history that to obtain a geomembrane capping system that would be reliable, durable, resistant to wind damage, protective, and economical to construct, the features listed below are critical.

- Selection of reinforced polypropylene geomembrane.
- Use of thermally welded seams.
- Implementation of a unique ballasting system consisting of polypropylene rope and capping strip.
- Use of concealed helical anchors to tie down the geomembrane to the pile.
- Use of nonlinear finite element computer program for wind analysis.
- Performance testing to verify seam strengths and field testing to verify pullout capacities of helical anchors.
- Preparation of geomembrane layout to minimize the number of field seams.

ACKNOWLEDGMENTS

The authors wish to thank Richard T. Taylor and Peter Garrigus of JPS Elastomerics Corp. for making extra efforts in constructing a full-scale model of the polypropylene geomembrane capping system and performing the wind uplift test in a timely manner.

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