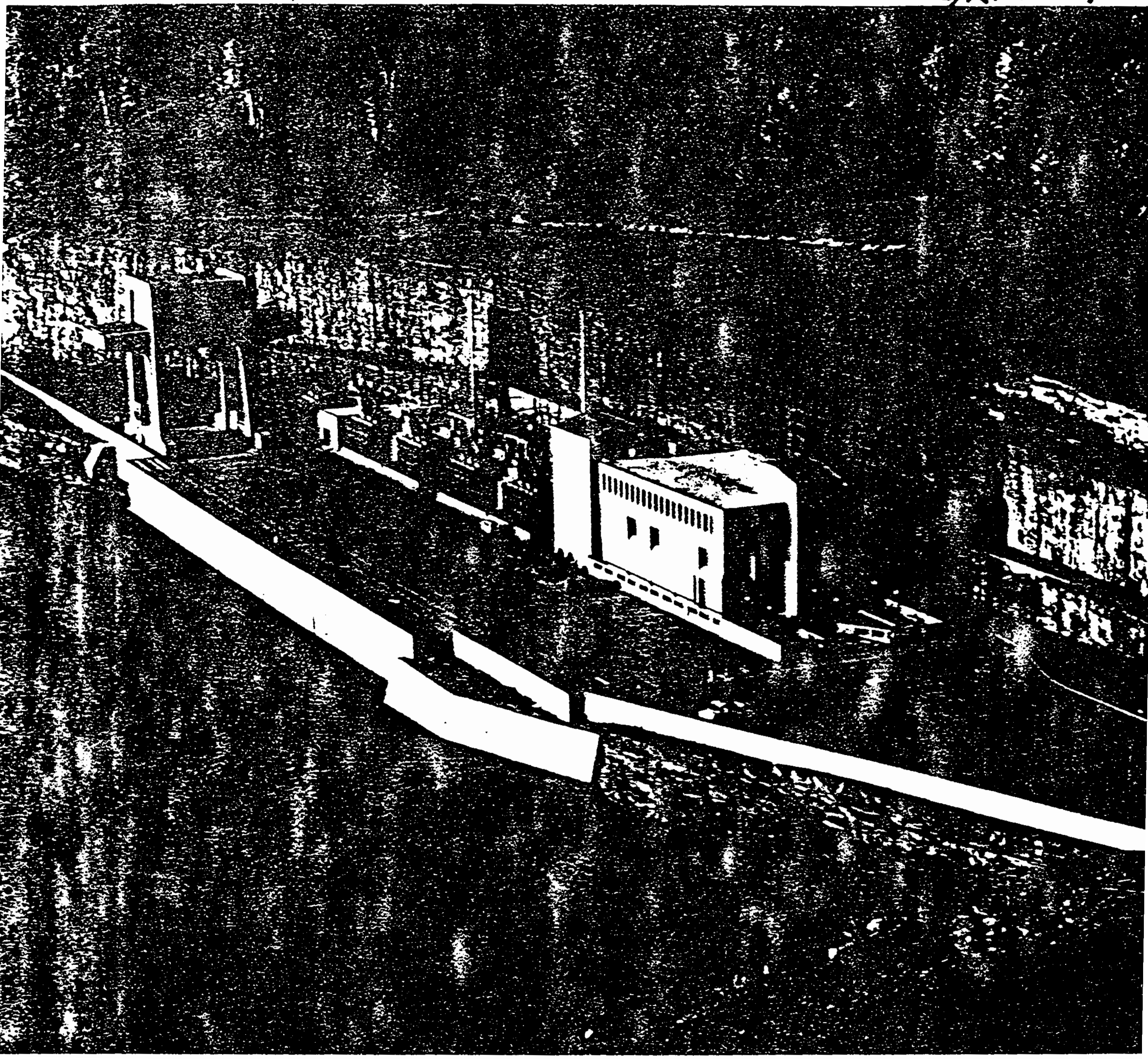
United States Committee On **Large** Dams

USCOLD

GRAHAM



Use Of Geosynthetics In Dams

Eleventh Annual USCOLD Lecture Series

White Plains, New York April 1991

BUREAU OF RECLAMATION EXPERIENCES WITH GEOMEMBRANES IN DAM CONSTRUCTION

W. R. Morrison[1], E.W. Gray Jr.,[1] J. M Cyganiewicz,[1] and P. G. Grey[1]

INTRODUCTION

In recent years, there has been a dramatic increase in the use of geosynthetic materials in seepage and pollution control applications both in the United States and worldwide. These materials were developed for use in applications where conventional construction materials are not available, or cannot be used because of weather conditions, time constraints (for example, minimum downtime to accomplish the work), limited access etc. Geosynthetic materials include geomembranes (flexible membrane linings, plastic linings, etc.), geotextiles (filter fabrics, construction fabrics, etc.), geogrids, geowebs, synthetic drainage composites, and erosion control blankets. This paper describes several recent Reclamation geomembrane installations related to embankment dams. These include:

1. The Mt. Elbert Forebay Reservoir, East Slope Power System, Fryingpan-Arkansas Project, Colorado

2. San Justo Reservoir, San Felipe Division, Central Valley Project, California

3. Emergency Spillway, Cottonwood Dam No. 5, Collbran Project, Colorado

MOUNT ELBERT FOREBAY RESERVOIR MEMBRANE LINING

Background

During the summer of 1980, Reclamation installed approximately 117 hectares of geomembrane in the Mt. Elbert Forebay Reservoir near Leadville, Colorado, figure 1. The purpose of the geomembrane was to reduce seepage through a previously constructed compacted earth lining.

The forebay reservoir and adjacent Mt. Elbert pumped-storage powerplant are part of the East Slope Power System of the Fryingpan-Arkansas Project. The original reservoir, built under contract between 1975 and 1977, was formed by constructing a small dike in the open southwest corner and a 27-m high-zoned earth embankment across the open north side of a topographic depression. A ridge, composed of glacial deposits overlying weakly indurated formation materials, forms the south side of the reservoir and separates it from lower Twin Lakes Reservoir. A portion of the side of the ridge facing lower Twin Lakes had been geologically mapped as an ancient landslide.

[1]Bureau of Reclamation, PO Box 25007, Denver, Colorado 80225-0007

Figure 1. Aerial view taken June 1980, looking south across the forebay reservoir. The first portion of placed geomembrane is visible in the near right side of the reservoir and the processing plant is located in the center of the reservoir area. Also, the inlet-outlet structure (upper left-hand corner), forebay dam (foreground), slope protection material around the perimeter of the reservoir, and subgrade areas being prepared by the contractor are visible.

Considerable concern had been expressed that seepage from the reservoir might reactivate the slide, and a 1.5-m thick compacted earth lining was placed under the entire reservoir. Water was introduced into the forebay to a depth of 7.5 m during the period of November 1977 through March 1978. Water levels in several of the piezometers and observation wells located in the side of the ridge between the forebay reservoir and the powerplant began to rise shortly after completion of this first introduction of water into the forebay. By the summer of 1979, the water level had risen nearly 2.4 m in one well and up to 2.0 m in several others. Since other wells either had not responded or had experienced water level decreases, the continuous rise experienced in some wells was considered attributable to water in the forebay, rather than cyclical changes in the groundwater level.

Because the original 1.5-m thick compacted lining failed to provide adequate seepage control, a decision was made to dewater the reservoir and install a flexible membrane lining over the entire forebay bottom and side slopes.

At that time, the installation at Mt. Elbert constituted the world's largest single-cell flexible membrane lining application and represented a milestone in the use of geosynthetic materials in the United States, if not in the world. Also, to meet Reclamation's time schedule for power on-line, the installation had to be accomplished in one construction season to allow sufficient time to fill the reservoir and conduct acceptance tests on the pump-generating units and other accessory equipment in the powerplant.

Construction

Specifications for the membrane lining were issued in January, 1980 (Reclamation 1980 a); the contract for installation was awarded April 16, 1980, and installation was completed September 20, 1980. The principal features covered by the specifications for the lining work included: removing all existing reservoir slope protection; excavating and processing the top 0.6 m of the compacted earth lining; placing a 150 mm processed earth subgrade; manufacturing, fabricating, testing, and installing the geomembrane; placing a 0.45 m earth cover over the geomembrane; and replacing the slope protection materials.

The specifications provided alternate bidding schedules for installation of one of the following three lining materials: 1.14-mm reinforced chlorinated polyethylene (CPER), 1.14-mm reinforced chlorosulfonated polyethylene (RCSPE), and 2.0-mm high density polyethylene (HDPE). The contractor selected CPER because of its availability to meet the construction schedule.

This geomembrane was of three-layer construction consisting of two equal thicknesses of chlorinated polyethylene (CPE) laminated to a middle layer of 10 by 10 1,000-denier polyester scrim. The specified physical properties requirements for this geomembrane are given in table 1.

Table 1

Test methods and Physical Properties Requirements for CPER Lining

Property	Test Method	Minimum Requirement
Thickness	ASTM: D 751-79	1.04 mm
Breaking Strength each direction	ASTM: D 751-79 Grab Method A	890 N
Tear strength each direction	ASTM: D 751-79 Tongue Tear Hethod B	334 N
Bonded seam strength in shear strength.	ASTM: D 751 -59 Grab Method A	Equals Parent breaking
Bonded seam strength in peel	ASTM: D 1876-78	No spec requirements
Dimensional stability (percent change, maximum)	ASTM: D 1204-78 1 hour at 100 °C	2 percent
Low temperature bend	ASTM: D 2136-78 3 mm mandrel; 4 hours at -4 ° C	Pass
Hydrostatic resistance	ASTM: 0751-79 Method A	2.07 MPa
Ply adhesion	ASTM: D 413-76	1400 N/m

The membrane lining was factory fabricated into 'blankets,' each 1300 m^2 in size and weighing approximately 2268 kg. Two shapes of blankets were furnished: 61 by 21 m containing 14 factory seams made with a Leister tm hot-air gun, and 30 by 43 m containing 28 factory seams made dielectrically. The latter blankets were installed on the side slopes in order to avoid making field seams at or near the toe of the slope. To install the membrane lining, labor crews unfolded and positioned the blankets as shown on figure 2. Adjacent blankets were overlapped a minimum of 150 mm. A three-man crew thoroughly cleaned the contact surfaces with cleaning solvent and then applied the manufacturer's bodied solvent CPE adhesive to a minimum width of 100 mm. After the field seams were tested and approved, a cap strip was applied over the field seam. A 0.45 m protective earth cover material was then placed over the geomembrane, figure 3.

Details of the construction work and the quality assurance program conducted during the installation of the flexible membrane lining are summarized in the literature listed in the references at the end of this paper (Morrison, et. al., 1981, Reclamation 1980b, Reclamation 1981, Frobel and Gray 1984).

Performance

After completion of the membrane lining installation in 1980, the reservoir was refilled beginning in January 1981. By June 1981, the reservoir had been filled to elevation 2940 m. Since that time, the reservoir has remained above elevation 2935 m except for short periods of pool drawdown.

Piezometers and observation wells installed in the hillside south of the reservoir continue to be monitored. Several of the observation wells which began to rise during initial filling began a gradual decline as soon as the reservoir was drained in 1979. Others continued to rise primarily due to time lag and did not show signs of leveling off and declining until well after the lining was installed and the reservoir refilled. At the time of this writing, the water levels in the observation wells in the hillside south of the reservoir continue to decline. The foundation beneath the Mt. Elbert Forebay Dam on the north side of the reservoir is still not saturated. Inclinometers installed along the south side have not indicated any movement of the old landslide mass. Also, the riprap on the side slopes has remained stable with no evidence of sl'ippage.

Included in the specifications for the work was a 5-year maintenance warranty period on the membrane lining. To monitor the performance of the lining during the warranty period and for long-term research purposes, a special test section was installed in the forebay reservoir. The 6- by 30-m test section was installed at a location within the reservoir that would allow periodic access for retrieval of the membrane lining test coupons.

Figure 2. Installation of geomembrane on reservoir side slopes.

Figure 3. Placement of protective soil material on geomembrane.

Eleven test panels (or coupons) comprised the total test section. Each test panel was made up of all three types of seams used in the project which included hot air, dielectric, and bodied solvent adhesive field seams. The test panels were placed on a 50-mm layer of fine sand directly above the Mt. Elbert Forebay membrane lining and then covered with the same 0.45 m of earth cover. Thus, the panels can be extracted and tested without disturbing the original CPER membrane lining. Test panels were retrieved on a yearly basis for the first 5 years, in 1987 after 7 years of reservoir exposure, and in 1990 after 10 years of reservoir exposure.

In addition to the tests listed in table 1, large-scale hydrostatic pressure resistance tests were conducted on the coupon samples. This test was developed by Reclamation (Hickey 1969, Frobel, 1981). The procedure is now being adopted by ASTM Committee D-35, on Geotextiles, Geomembranes and Related Products. For the Mt. Elbert evaluation, the coupon samples were tested over a 10-to 20-mm aggregate subgrade at a hydrostatic head of 43 m which was the same pressure that was used on samples of the unaged membrane lining material during acceptance testing in 1980.

Original test specimens were taken from the same blanket samples as those used to fabricate the test section. Thus, results from extracted coupons can be compared directly with the test results obtained for the original blanket material.

Test results are summarized in tables 2 to 5. Generally, any significant changes in the CPER lining and seams occurred within the first 3 years of service. There has been very little change through the additional 7 years of reservoir exposure. Specific details of the tests results are summarized in a paper presented earlier this year at Geosynthetics '91 (Morrison and Gray 1991).

To obtain additional information on the aging characteristics of the Ht. Elbert membrane lining, laboratory water immersion tests were conducted on random samples of the 1.14-mm CPER lining and the 0.5-mm CPE sheet material used in the manufacture of the membrane lining. The reinforced material specimens with both sealed and unsealed edges were immersed to determine if there were any major differences due to possible water wicking through the exposed scrim. The samples were immersed in Denver laboratory tapwater for 5 years. The temperature of the running tapwater varied between 10 and 15 °C during this immersion period. Samples were removed yearly for testing. The same tests listed above except breaking strength and large-scale hydrostatic testing were conducted on the CPER samples. For the CPE sheet material, the following tests were conduced:

1. Weight changes
2. Breaking strength (ASTM D 882)
3. Elongation at break (ASTM D 882)
4. Tear resistance (ASTM D 1004, Die C)

Test results conducted on random samples of the 1.14-mm CPER during the 5-year laboratory water immersion period are summarized in table 6. The testing of sealed versus unsealed edges showed no major differences in mechanical properties due to possible water wicking through the exposed scrim. Consequently, only the test results for the specimen with unsealed edges are presented in table 6. The results generally paralleled those observed for the field samples. The moisture absorption for the laboratory immersion samples leveled off around 21 percent as shown in figure 4.

Test results for 0.5-mm CPE materials are summarized in table 7. The moisture absorption was similar to that noted for the reinforced material. It appeared that the moisture absorption caused some softening of the material as reflected in a reduction in its tensile and tear strength properties.

Summary

Results of studies conducted on the geomembrane installed in 1980 in the Mt. Elbert Forebay Reservoir indicate that the material is performing satisfactorily after 10 years of service. The studies involved continuous monitoring of the instrumentation on the ridge between the forebay reservoir and powerplant, and periodic retrieval of coupon samples from the field test section for laboratory testing and evaluation.

Continuous monitoring of the instrumentation on the hillside has indicated no movement of an old landslide mass. Water levels in observation wells and piezometers in the hillside continue to decline from levels reached during or shortly after first filling of the reservoir following installation of the geomembrane lining. Results of laboratory tests conducted on the coupon samples indicate that the lining has experienced some water absorption resulting in a decrease in its strength properties. The water absorption has caused some weakening of the polyester reinforcing scrim, the bond between the CPE and scrim, and the CPE to CPE bond. Most of the changes in the strength properties occurred within the first 3 years of service and are not considered detrimental to the overall integrity of the lining. In fact, the retained strengths of all the geomembrane's mechanical properties are above the minimum specification requirements for the original unaged material except for the seam shear strength. The lower shear strength of the seams, however should not affect the integrity of the lining with regard to seepage control.

As part of the construction work in 1980, an extensive quality assurance (QA) program was developed and conducted in an attempt to obtain a top quality installation. Prior to this time, QA programs for flexible membrane lining work were generally very minimal, and in some cases nonexistent. The installation at Mt. Elbert was a major milestone with respect to advancing the state-of-the-art on the use of geomembranes for seepage control, both in the United States and worldwide.

Table 2. Mt Elbert Test Section Results After One Veer of Exposure

Property	Specification Requirement	Hot Air Sew panel: Original data	Hot Air Sew panel: One year data (rage)	Hot Air Sew panel: Percent change	Dielectric ream pard: Original data	Dielectric ream pard: One year data (range)	Dielectric ream pard: Percent change
Weight gain (percent)				8.62			8.62
Mullen burst (kPa)	2070	2958.0	2868.3 2724-2930	-3.0	2764.9	2571.8 2482-2655	-7.0
Tear strength (kN)	0.33	0.33	0.33 0.30-0.38	1.0	0.30	0.35 0.29-0.40	17.1
Ply adhesion (kN/m)	1.40	1.59	1.28 1.21-1.33	-20.5	1.87	1.41 1.38-1.44	-24.8
Breaking strength (kN)	0.89	1.26	1.33 1.21-1.40	4.9	1.26	1.25 1.18-1.30	-1.4
Bonded seam shear (kN)	0.89	1.33	0.90 0.82-0.97	-32.2	1.23	0.56 0.50-0.61	-54.1
Bonded seam peel (kN/m)	NR***	6.13	5.06 4.92-5.85	-17.4	6.92	6.06 5.83-6.20	-12.4
Adhesive field seam shear (kN)	NR***	1.34	1.21 ** 1.15-1.26	-9.9	1.34	1.22 * 1.16-1.30	-8.9
Adhesive field seam peel (kN/m)	NR***	6.04	6.30 ** 5.32-7.63	4.3	6.04	5.88 * 5.60-6.60	-2.6

* - Field ream with cap strip

** . Field seam without cap strip

*** - Not required

Table 3. Mt Elbert lest Section Results After Three Years of Exposure

Property	Specification Requirement	Hot Air #em panel Original data	Hot Air #em panel Three year data (range)	Hot Air #em panel Percmt change	Dielectric #em panel Original data	Dielectric #em panel Three year data (range)	Dielectric #em panel Percent change
Weight gain (percent)				15.60			15.60
Mullen burst (kPa)	2070	2999.3	2716.6 2551-2758	-9.4	2813.2	2392.6 2241-2482	-14.9
Tear strength (kN)	0.33	0.35	0.30 0.28-0.32	-15.4	0.28	0.30 0.28-0.32	5.3
Ply adhesion (kN/m)	1.40	1.51	1.21 1.14-1.23	-19.7	1.84	1.30 1.23-1.37	-29.5
Breaking strength (kN)	0.89	1.26	0.99 0.94-1.04	-21.7	1.26	0.66 0.58-0.75	-47.5
Bonded seam shear (kN)	0.89	1.34	0.61 0.59-0.63	-54.6	1.22	0.56 0.48-0.59	-54.5
Bonded seam peel (kN/m)	NR***	5.69	4.13 3.99-4.27	-27.4	7.37	5.73 5.46-5.95	-22.3
Adhesive field seam shear (kN)	NR***	1.34	0.95 ** 0.89-0.10	-29.2	1.34	1.01 * 0.89-1.14	-24.6
Adhesive field seam peel (kN/m)	NR***	6.04	5.39 ** 5.17-5.92	-10.7	6.04	5.85 * 3.66-8.09	-3.2

* - field seam with cap strip
** - field seam without cap strip
*** - Not required

Table 4. Mt Elbert Test Section Results After Seven Years of Exposure

Property	Specification Requirement	Hot Air seam panel: Original data	Hot Air seam panel: Seven year data (range)	Hot Air seam panel: Percent change	Dielectric seam panel: Original data	Dielectric seam panel: Seven year data (range)	Dielectric seam panel: Percent change
Weight gain (percent)				16.90			16.90
Mullen burst (kPa)	2070	2923.5	2840.7 2758-2965	-2.8	2985.5	2558.0 2448-2655	-14.3
Tear strength (kN)	0.33	0.32	0.32 0.27-0.35	-1.6	0.31	0.27 0.26-0.28	-13.4
Ply adhesion (kN/m)	1.40	1.61	1.24 1.21-1.28	-22.8	1.79	1.37 1.26-1.42	-23.5
Breaking strength (kN)	0.89	1.26	0.91 0.77-1.17	-27.7	1.26	0.77 0.75-0.80	-38.7
Bonded seam shear (kN)	0.89	1.34	0.59 0.52-0.65	-55.9	1.21	0.49 0.48-0.50	-59.5
Bonded seam peel (kN/m)	NR***	6.06	3.38 3.22-3.59	-44.2	6.46	3.75 3.61-3.82	-42.0
Adhesive field seem shear (kN)	NR***	1.34	1.17 ** 1.07-1.22	-12.6	1.34	1.09 * 0.98-1.18	-18.3
Adhesive field seem peel (kN/m)	NR***	6.04	6.51 ** 5.71-7.20	7.8	6.04	7.74 * 6.81-8.98	28.1

* - Field seam with cap strip
** - Field seam without cap strip
*** - Not required

Table 5. **Mt Elbert** Test **Section Results** After Ten Years of **Exposure**

Property	**Specification Requirement**	Hot Air seam panel: **Original** data	Hot Air seam panel: **Ten year** data (range)	Hot Air seam panel: **Percent change**	Dielectric seam panel: **Original** data	Dielectric seam panel: **Ten** year **data (range)**	Dielectric seam panel: **Percent** change
Weight gain (percent)				ND			ND
Mullen burst (kPa)	2070	2923.5	2392.6 2344-2448	-18.2	2895.9	2302.9 2275-2379	-20.5
Tear strength (kN)	0.33	0.29	0.30 0.27-0.33	1.1	0.33	0.29 0.27-0.31	-12.8
Ply adhesion (kN/m)	1.40	1.54	1.47 1.44-1.52	-4.2	1.77	1.65 1.58-1.75	-6.9
Breaking strength (kN)	0.89	1.26	1.01 0.89-1.10	-20.3	1.26	0.89 0.69-1.06	-29.3
Bonded **seam shear** (kN)	0.89	1.28	0.78 0.74-0.81	-39.3	1.16	0.55 0.51-0.58	-52.8
Bonded seam peel (kN/m)	NR***	5.38	[illegible] 3.87-5.03	[illegible]	7.84	3.61 3.40-3.[illegible]	-54.0
Adhesive field **seam** shear (kN)	NR***	1.34	1.18 ** 1.09-1.27	-12.0	1.34	1.09 * 1.00-1.13	-18.6
Adhesive field seam peel (kN/m)	NR***	6.04	5.46 ** 4.66-6.69	-9.6	6.04	6.09 * 4.52-8.12	0.9

* - **Field seam** with cap strip
** - Field **seam without** cap strip
*** - Not **required**

Table 6. Water Immersion Test Results - 1.14 mm CPER

Property	Original data (range)	One year data (range)	Percent change	Three year data (range)	Percent change	Five year data (range)	Percent change
Weight gain (percent)	-	-	15.58	-	19.25	-	21.07
Mullen burst (kPa)	2909.7 (2448-3075)	2330.5 (2275-2413)	-19.9	2706.3 (2551-2861)	-7.0	2526.3 (2344-2655)	-13.2
Tear strength (kN)	0.35 (0.24-0.44)	0.43 (0.41-0.44)	20.2	0.43 (0.42-0.43)	20.3	0.37 (0.35-0.40)	5.1
Ply adhesion (kN/m)	1.54 (1.31-1.73)	1.24 (1.19-1.30)	-19.3	1.51 (1.47-1.54)	-2.3	1.38 (1.33-1.42)	-10.2
Hot Air seam shear (kN)	1.19 (0.89-1.37)	0.61 (0.60-0.63)	-48.7	0.93 (0.89-0.97)	-22.1	0.60 (0.60-0.60)	-49.3
Hot Air seam peel (kN/m)	5.50 (4.64-6.81)	4.82 (4.52-5.06)	-12.4	6.01 (5.78-6.22)	9.2	3.64 (3.57-3.69)	-33.8
Dielectric seam shear (kN)	1.30 (1.00-1.41)	0.64 (0.62-0.66)	-51.0	0.89 (0.89-0.89)	-31.7	0.77 (0.77-0.77)	-40.6
Dielectric seam peel (kN/m)	6.74 (6.01-7.49)	5.80 (5.69-5.92)	-14.0	4.11 (3.94-4.20)	-39.0	4.10 (3.96-4.25)	-39.2
Adhesive seam shear (kN)	1.23 (1.21-1.25)	1.15 (1.12-1.18)	-6.5	1.32 (1.29-1.36)	7.4	1.20 (1.14-1.25)	-2.7
Adhesive seam peel (kN/m)	5.38 (4.01-7.41)	5.22 (4.76-6.13)	-2.9	6.02 (5.60-6.30)	12.1	5.24 (4.69-5.69)	-2.6

Table 7. Water Immersion Test Results - 0.50 mm CPE

Longitudinal test direction

Property	Original data	One year Test value	One year Percent change	Three year Test value	Three year Percent change	Five year Test value	Five year Percent change
Ueight gain (percent)			16.9		20.4		20.9
Tensile strength (kN/m)	6.39	5.76	-9.9	5.59	-12.6	5.39	-15.6
Elongation (percent)	490.0	692.0	0.4	198.0	1.6	493.0	0.6
Modulus (kN/m)	1.91	0.93	-51.4	1.21	-34.9	1.63	-11.7
Tear strength (N)	18.68	12.01	-35.7	12.01	-35.7	15.57	-16.7

Transverse test direction

Property	Original data	One year Test value	One year Percent change	Three year Tat value	Three year Percent change	Five year Test value	Five year Percent change
Ueight gain (percent)			16.9	-	20.4		20.9
Tensile strength (kN/m)	5.53	4.78	-13.6	4.59	-17.1	4.47	-19.3
Elongation (percent)	587.0	587.0	0.0	581.0	-1.0	568.0	-3.2
Modulus (kN/m)	1.69	0.93	-37.6	0.91	-38.8	1.17	-21.2
Tear strength (N)	18.24	13.79	-24.4	14.23	-22.0	17.35	-4.9

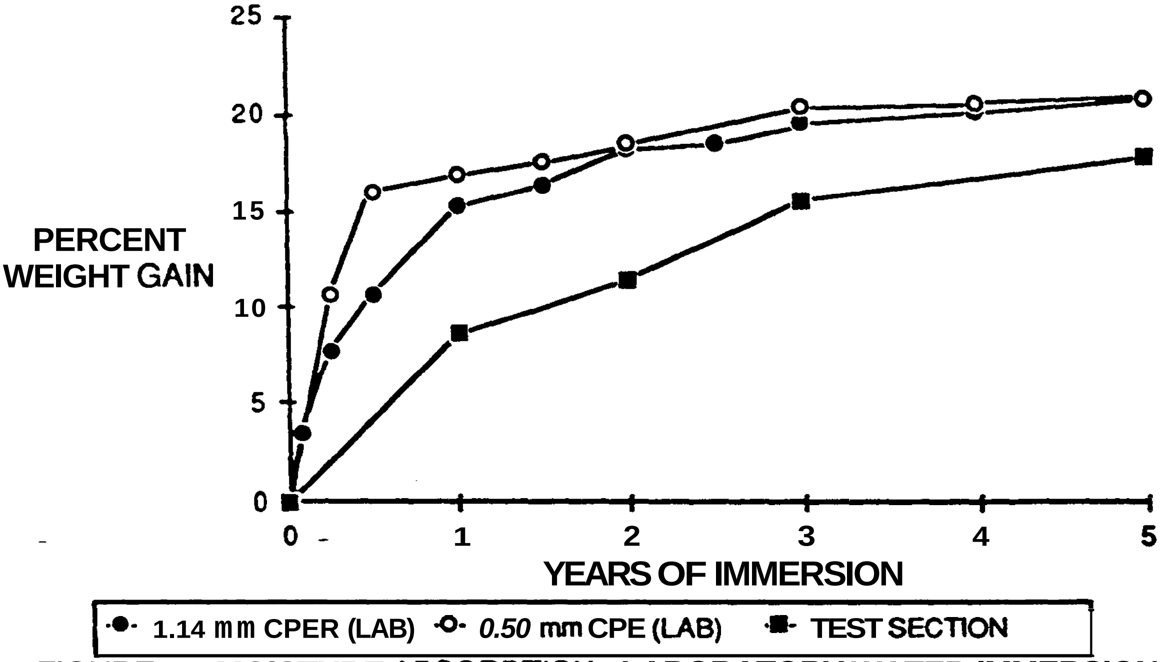


FIGURE 4. **MOISTURE ABSORBTION - LABORATORY WATER IMMERSION TESTING AND MT. ELBERT TEST SECTION RESULTS**

SAN JUSTO RESERVOIR MEMBRANE LINING

Background

San Justo Reservoir near Hollister, California, was constructed by Reclamation as an off stream storage facility to' provide water for irrigation and municipal purposes. Because the facility is located near both the San Andreas and Calaveras faults, special earthquake design considerations were used (Cyganiewicz 1986). Construction of the reservoir was completed in 1985.

The reservoir, shown in figure 5, is formed by two earthfill structures: a dam to the west and a dike to the north. It is filled and releases are made by an inlet-outlet works located in a tunnel through the east side of the reservoir. An emergency spillway is located near this structure and is provided strictly as a guard against overfilling of the reservoir.

Several large beds of clean sand are located within the reservoir site. In addition to loss of water, the increased seepage through the sand beds could increase the potential for landslides on the downstream portions of natural ridges which enclose the reservoir. Consequently, the decision was made to install a geomembrane over sloping portions of the reservoir containing the impervious sand beds. In flatter areas where natural impervious soil covers the sand beds, a supplemental 2-meter-thick earthfill blanket of clay was placed in lieu of the membrane lining.

Construction

The following geomembranes were included as options in the specifications (Reclamation 1984): 1.0-mm high density polyethlene-alloy (HDPE-A), 0.91-mm CPER, 0.91-mm RCSPE, and 1.14-mm polyvinyl Chloride (PVC). The linings were required to meet the material properties as listed in National Sanitation Foundation (NSF) Standard No. 54, 'Flexible Membrane Liners" (NSF 1985). The contractor selected the HDPE-A geomembrane.

Approximately 190,000 m^2 of geomembrane were installed for seepage control at 6 locations within the reservoir. An aerial view of several of these sites is shown in figure 6.

The HDPE-A liner was produced in rolls about 6-m wide by 200-m in length. the roll goods were shipped to the jobsite where they were unrolled on the prepared subgrade as shown in figure 7, and then joined using extrusion fillet welding as shown in figure 8. The geomembrane was secured at the toe and top of the slope in a v-shaped anchor trench as shown in figure 9.

During installation some problems were encountered with excessive thermal expansion of the geomembrane resulting in large waves and wrinkles in the liner as shown in figure 10. This wrinkling and

Figure 5. Aerial view of San Justo Reservoir. Several large beds of clean sand can be seen within the reservoir.

Figure 6. Aerial view showing installation of geomembrane at several sites within the San Justo Reservoir.

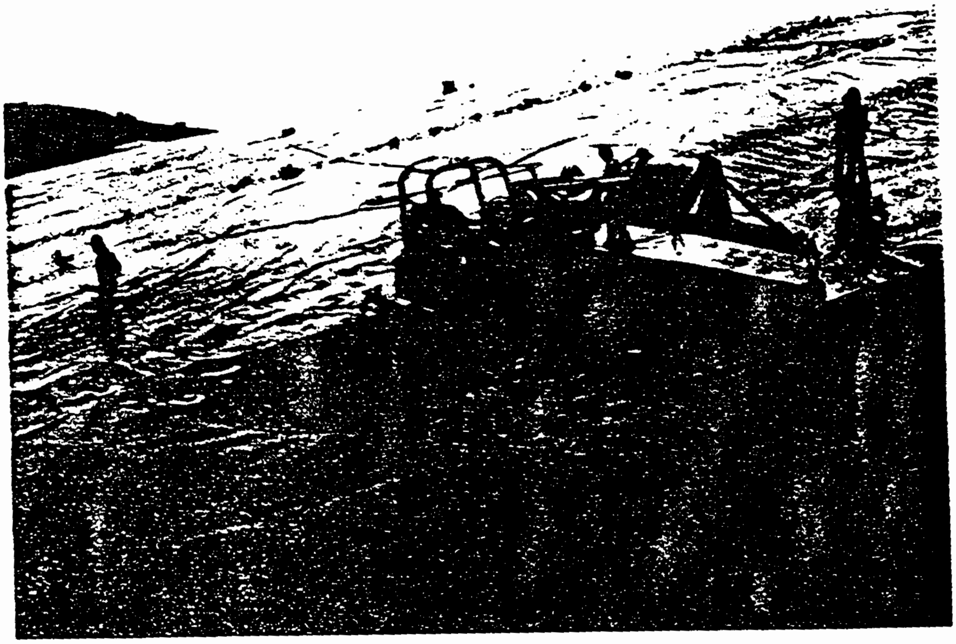


Figure 7. Unrolling HDPE-A geomembrane liner was produced in rolls about 6-m wide by 200-m in length.

Figure 8. Field seaming geomembrane using a hot-extruded fillet weld. Worker at right is cleaning and wire brushing overlapped area to be seamed.

waviness led to some permanent folds in the liner after the protective soil cover was placed. This condition is shown in figure 11. Folded samples were included in the coupon monitoring section to determine the long-term effect of the creases on the performance of the lining.

To protect the geomembrane from the elements, mechanical drainage, and vandalism, an earth fill cover consisting of a 0.5-m layer of semi-pervious material, 0.15-m layer of bedding material, and a 0.3-m layer of cobbles was placed over the liner.

In 1990, an additional 6100 m^2 of geomembrane were installed over another sand lens in the bottom of the reservoir (Reclamation 1990a). For this work, a 1.5-mm HDPE geomembrane was used since HDPE-A is no longer being manufactured.

Performance

In February 1986, unusually heavy rainfall occurred in the reservoir. During and immediately following the rainfall event, slippage of portions of the earthfill cover occurred. A total of eight separate areas experienced slippage affecting 4 hectares of cover material and exposing 1.2 hectares of geomembrane. Several areas experiencing slippage are shown in figures 12 and 13.

A study was performed to determine the as-constructed slopes on which the liner failed. In general, failures occurred on slopes steeper than 4:1 (horizontal:vertical). Interestingly, some areas with slopes as steep as 2.5:1 did not exhibit stability problems.

To support analytical studies and to aid in designing of an acceptable remedial modification, a laboratory test program was undertaken to determine the frictional resistance of the soil on the geomembrane. Samples of various types of soils and geomembranes were tested in a standard direct shear apparatus.

Geomembrane materials tested included:

1. Original material (smooth).
2. Original material scored with a wire brush
3. Original material sandblasted
4. Texturized material
5. Original material with an attached geogrid.

Soil materials used in the test included the original material covering the membrane (soil A), material representing the sand underlying the membrane (soil C), and materials representing proposed cover materials (soils B_1, and B_2).

Figure 11. Waviness shown in figure 10 led to some permanent folds in geomembrane after protective soil cover uas placed.

Figure 12. View showing slippage of protective soil cover.

The physical properties of the soils used in the test program are shown on figure 14. The results of the testing are shown on table 8. Also, included in the table are some of the details of the test apparatus and test procedures.

Utilizing these test results, stability analyses were completed and indicated that any of the modified geomembranes described above would be stable on the slopes under the loadings imposed. The analyses also indicated that a thicker cover material generally lowered the safety factor.

During the summer of 1987, a remedial construction program was initiated to repair the exposed areas of geomembrane (Reclamation 1987). Seven of the eight areas were repaired by sandblasting the top surface of the exposed liner to enhance the frictional resistance followed by covering it with a 0.15-m layer of pervious sand and gravel bedding and a 0.3-m layer of cobbles. Careful quality control ensured that there would be no damage to the geomembrane during sandblasting operations. For the remaining slide area, the existing geomembrane was removed and replaced with a texturized HDPE geomembrane and covered with bedding and cobbles.

The filling of San Justo Reservoir was initiated in the latter part of 1987 and was completed in March of 1988. A close inspection of the geomembrane area after initial filling indicated no signs of instability.

To monitor the performance of the geomembrane, a coupon monitoring section was installed in the reservoir. The monitoring section consists of 10 coupon samples (1.5- by 1.5-m) of the 1.0 mm HDPE-A liner. Each test coupon contains a field seam, and as previously mentioned the samples were placed in a folded condition. One coupon sample was removed after 2,3,4 and 5 years of burial, and the following tests were conducted on both folded and unfolded portions of the sample:

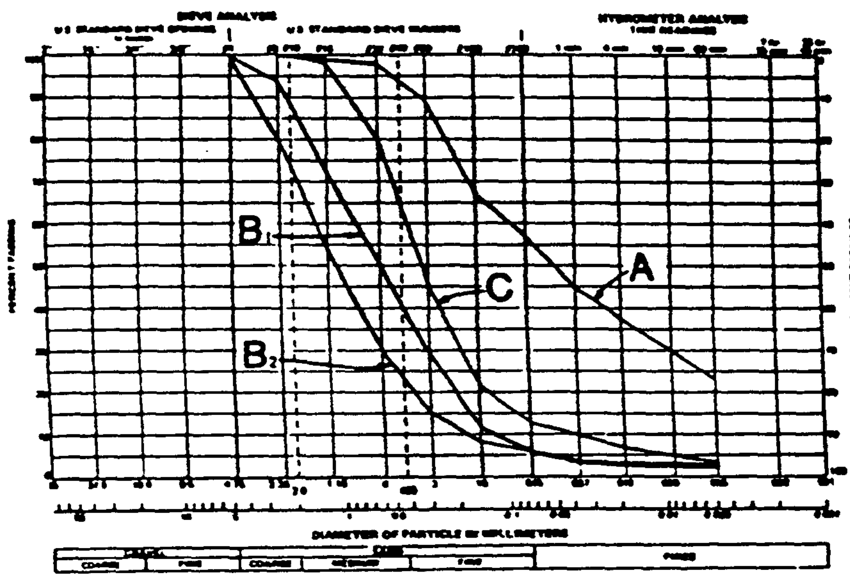
Breaking strength (ASTM D- 638)
Tear strength (ASTM 0-1004, Die C)

In addition, shear and peel tests were conducted on the seam samples.

Test results summarized in table 9, indicated that there was very little change in the tensile and tear properties of the geomembrane after 5 years of burial. Also, it appeared that there was no adverse effect from the lining being folded. The folded tensile and tear specimens were examined under a 5x magnification before being tested and there was no evidence of cracking. In addition, the field seam exhibited good retention of shear and peel strength properties after 5 years of burial..

To obtain additional information on the aging characteristics of the San Justo geomembrane, laboratory aging test were conducted on random

Figure 13. View showing exposed geomembrane after slippage of protective soil cover.



SOIL	PLASTICITY INDEX	SPECIFIC GRAVITY	CLASSIFICATION
A	15	2.65	CL
B_1	N.P.	2.65	SP-SM
B_2	N.P.	—	SP
C	N.P.	2.67	SW-SM

Figure 14. Gradation of protective soil cover.

Table 8. Results of Interface Frictional Tests

Soil *	Frictional resistance						
	Smooth	Sandblasted	Wire brush	Geogrid	Texturized	Embossed	Soil only (2)
A (wet)	N/A (19°)	(1) 28° (28°)	28° (30°)				
B_1		30° (31°)		32° (36°)	32° (36°)		33° (39°)
'32		26° (26°)	28° (29°)			32° (32°)	38° (38°)
C (wet)	21° (21°)	28° (28°)					
(moist)	20° (22°)						
(dry)	26° (29°)						

(1) Values are given for large strain and peak (parenthesis) results. Values at large strain were used for analyses except where unavailable **(N/A)**.

(2) Test results using direct shear apparatus on soil only.

Testing details:
- Shear box size - 4 inch x 4 inch
- Time of saturation - 1 to 3 days
- Normal applied pressure - 2, 5, 10 psi
- Placement densities - 40 % to 60 % relative density
- Strain rate - 0.005 inches/minute

*Classification	
A	CL
B_1	SP-SM
B_2	SP
C	SW-SM

Table 9. Test results for San Justo Geomembrane Coupon Samples

Property		Original data	2-year data	5-year data
Tear resistance, lbf (folded)		-----	26.1	32.9
Tear resistance, lbf (unfolded	L	36.8	26.6	31.3
	T	33.7	29.2	34.6
Breaking strength lbf/in (folded)		-----	113	155
Ultimate elongation, % (folded)		-----	671	679
Breaking strength, lbf/in (unfolded)	L	199	141	189
	T	197	152	177
Ultimate elongation % (unfolded)	L	774	739	790
	T			
Seam shear strength lb/in		------	97	116
Seam peel strength lb/in		------	85	96

Table 10. Results of Laboratory Aging Studies Conducted on San Justo Geomembrane

Test Duration	Test Condition: 73 °F, 50 % RH						Test Condition: Water Immersion						Test Condition: Heat aging at 100 °F					
	Tear Strength, lbf		Breaking Strength, lbf/in		Ultimate Elongation, %		Tear Strength, lbf		Breaking Strength, lbf/in		Ultimate Elongation, %		Tear Strength, lbf		Breaking Strength,		Ultimate Elongation, %	
	F	U	F	U	F	U	F	U	F	U	F	U						
Original	---	31.8	---	199	---	774	---	31.8	---	199	---	774	---	31.8	---	199	---	774
52 weeks	32.2	32.7	198	196	836	800	33.0	32.0	201	199	818	785	32.4	33.4	206	204	833	813
104 weeks	31.5	28.6	210	191	788	788	32.5	32.2	200	216	818	840	33.6	33.8	198	191	827	784
156 weeks	32.5	34.4	200	209	806	810	333	32.9	199	184	811	803	34.7	33.4	203	203	832	846
208 weeks	34.2	33.9	191	213	785	831	34.5	32.2	204	208	802	815	34.1	35.6	193	202	779	829
260 weeks	33.9	34.1	192	196	817	783	33.9	35.9	192	205	798	808	34.5	35.6	210	204	858	808

F denotes - folded
U denotes - unfolded

samples of the HDPE-A lining. Both folded and unfolded tensile and tear specimens were subjected to the following aging conditions.

1. Room temperature (23 °C, 50 percent relative humidity)

2. 37 °C oven aging

3. Water immersion in Denver laboratory tapwater. The temperature of running tapwater varied between 10 and 15 °C during the immersion period.

The laboratory aging study was conducted for 5 years, with the tensile and tear specimens being removed and tested on a yearly basis.

Test results are summarized in table 10. These results indicated that as with the field samples there was very little change in tensile and tear strength properties. Also, the samples exhibited no adverse effect from being folded.

EMERGENCY SPILLWAY, COTTONWOOD DAM No. 5

Background

In response to a Corps of Engineers' survey of non-Federal dams completed in 1981 which indicated some of the structures had inadequate spillway capacity, Reclamation initiated a study to evaluate the possible use of a geomembrane as one method of increasing the spillway capacity. Of the more than 63,000 dams inventoried in the Corps' survey, over 8,800 were examined. More than 2,900 (33 percent) of the examined dams were evaluated as unsafe. Of these, 81 percent were deficient because their spillways were too small to pass the estimated maximum floods. This reflects the difference between present-day design flood criteria contained in the "Recommended Guideline for the Safety Inspection of Dams" and the criteria in vogue at the time the dams were constructed (Corps of Engineers 1975, USCOLD 1982).

Embankment dams are particularly sensitive to failure caused by overtopping, both during construction and while in service. However, inadequate spillway capacity is not the only cause of overtopping failure. There have also been many cases where dams were overtopped because of gate failure (Londe 1983).

These potential hazards can be avoided by adding an emergency spillway with the required discharge capacity. However, in many situations, the cost for a conventional concrete-lined spillway or even a rock-lined compacted-earth spillway would be prohibitive.

The investigation on using geomembranes started with an evaluation of the feasibility of various applications for low-head structures.

Locations where the consequences of failure would not be serious were given primary consideration. Some potential applications included:

- The many low-head earth dams of the Bureau of Indian Affairs, National Park Service, and other Department of the Interior Agencies for which the USBR has some responsibility
- New low-head earth dams
- Low-head dikes on large reservoirs
- Saddles suitable for emergency overflow where erosion could be a problem
- Side channels for low-head embankments
- Canal wasteways
- Diversion structures
- Drop structures
- Improvements to existing emergency/auxiliary spillways

The primary objective of the study is to develop design criteria material specifications, construction procedures, and cost data to assist in the selection, design, and construction of geomembrane-lined emergency/auxiliary spillways for low-head structures. With experience in low-head structures, the potential for high-head structures can be evaluated.

Cottonwood Dam No. 5, located' in western Colorado, was selected as the site for the initial study. This dam is 1 of 17 small private reservoirs of the Collbran Project that was constructed on Grand Mesa, near Grand Junction, Colorado. These reservoirs, which are filled during the spring runoff, regulate the runoff from small streams. This stored water is released on demand for hydroelectric power and irrigation.

A Reclamation Safety Examination of Existing Dams (SEED) report recommended that Cottonwood Dam No. 5 be breached and reconstructed. This recommendation provided the opportunity for the implementation of the flexible membrane emergency spillway study. The earth dam is 137 m wide and 5.8 m high at elevation 3050 m.

Field Study

Construction of the emergency spillway at Cottonwood Dam No. 5 was completed in the summer of 1985. Information on the construction as well as other pertinent data related for the study are presented in the summary report (Timblin et. al., 1988).

A synopsis of the spillway design considerations is listed below.

1. The spillway was aligned to pass through the more plastic soil materials on the right abutment to provide additional erosion protection if needed.

2. Two grade sills were provided: One at the upstream end of the membrane liner to provide flow control and prevent piping, the other at the downstream end to prevent head-cutting back into the spillway.

At the grade sills, the membrane was attached to the concrete with redwood furring strips and nails to distribute the load evenly across the sheets and to prevent separation from the grade sills.

3. The edges of the liner along the sides and the upstream edge of the transverse joints were placed in trenches, and backfilled with compacted soil.

4. Transverse joints between adjacent sheets were not bonded. This prevented stress buildup in one sheet from being transferred to another.

5. A protective cover of 150 mm of noncohesive material was placed over the geomembrane to protect it from foot, animal, and vehicle traffic.

6. The alignment was chosen so that there are no discharges along the toe of the dam.

7. Inflow design flood is the 100-year flood. This results in a design discharge of 1.13 m^3/s.

8. Flow passes through the critical depth at the upstream grade sill; therefore, the flow is super critical over all areas protected by the flexible membrane liner.

9. The channel bottom width is 3.66 m with 2:1 side slopes and a depth of 0.91 m (to provide freeboard).

10. The assumed Manning's numbers are "n" = 0.025 for the protective cover in place, and "n" = 0.015 for the geomembrane.

11. Energy dissipation is to be provided by a natural hydraulic jump, which should form over the downsteam riprap protection.

12. Riprap is sized to resist movement caused by velocities associated with the design discharge.

Some surplus 0.9-mm-Hypalon lining material from another nearby job was available for installation in the spillway. A small quantity of material was purchased to complete the installation. The physical properties of this geomembrane material are given on table 11.

Table 11

Test Method and Physical Properties Requirements for Hypalon Lining

Property	Test Method	Minimum Requirement
Thickness	ASTM: D751-79	0.91 mm
Breaking strength each direction	ASTM: D 751-79 Grab Method	890 N
Tear strength each direction	ASTM: D 751-79 Tongue Tear Method B	265 N
Bonded seam strength in shear	ASTM: D 751-59 Grab Method A	710 N
Bonded seam strength in peel	ASTM: D 1876-78	Ply Separation in plane of scrim or 2.6 kN/m
Dimensional stability (percent change, maximum)	ASTM: D 1204-78 1 hour at 100 °C	2 percent
Low temperature bend	ASTM: D 2136-78 3 mm mandrel; 4 hours at -40 °C	Pass -
Mullen burst	ASTM: D 751-79 Method A	1.71 MPa
Ply adhesion	ASTM: D 413-76 Machine Method	1220 N/m

Before construction, 2-year water immersion and outdoor exposure tests were conducted on samples of the Hypalon to be used in the field study. Although some properties changed, these changes were considered insignificant.

An operation test was conducted in July 1986. To provide the necessary reservoir level to conduct the test, the gate to the primary outlet structure was closed and flashboards were installed in a weir in the gate chamber that is used as a service spillway. Sandbags were placed in the emergency spillway to increase the effective height of the reservoir above the emergency spillway crest by approximately 0.5 meters.

The operational test was conducted for approximately 3 1/2 hours. At the beginning of the test, the reservoir level behind the sandbags in the emergency spillway was about 0.3 meters. During the test, the discharge was estimated to be 0.6 to 0.7 m^3/s, and the maximum velocity estimated to be 6 to 8 m/s. These velocities are higher than anticipated and may be attributed to a Manning's number that was lower than the assumed value of 0.015. Consequently, some additional studies should be conducted to obtain design data for establishing a Manning's number for spillways with flexible membrane linings.

The spillway operated essentially as expected, i.e., the soil cover was washed away until the membrane on the bottom was exposed. From then on, gradual erosion of the cover on the sides of the spillway continued for a few centimeters up the sides. Even though the flow carried much abrasive material, stones, and a few cobbles approximately 100 millimeters in diameter, little or no erosion of the membrane was observed. Only one small tear, approximately 75 millimeters long, was found; we suspected that this occurred during construction. A fist-sized stone found under the membrane (original foundation material) at this location was probably responsible for the tear. This tear was visible during the operation of the spillway but did not appear to increase in size.

The overlapped field joints of the membrane functioned well. Immediately after the test, the overlapped joints were inspected. The exposed portion of the geomembrane was wet from the flows; however, the portion under the overlap was completely dry. There was no evidence of accumulated tensile strain from one sheet to another. As expected, the membrane was installed with some wrinkles to help it conform to the subgrade. These wrinkles, did not cause any problems during the operation of the spillway.

Specific observations and results of the field test, in terms of the study objectives, are summarized:

1. The flow placed no noticeable serious strain on the geomembrane, and the overlapped joints helped avoid accumulation of tensile load along the spillway. Any uplift pressures were accommodated by the overlapped joints. The amount of uplift was minimal.

2. The geomembrane experienced little or no abrasive damage from the cover material as it was washed away.

3. The simple method of securing the membrane in 1- by 0.5-m trenches filled with compacted soil was successful.

4. The soil cover proved successful in preventing mechanical damage to the geomembrane for the 10 months of exposure as a buried membrane lining. The cover was stable on the 2:1 side slopes.

5. As a precaution, the downstream hydroelectric facilities were protected from damage by the soil cover material by bypassing the turbid flow. However, this was necessary for only a few minutes as the stream quickly cleared up.

6. The velocity exceeded the expected 4 to 5 m/s and reached perhaps 6 to 8 m/s. Even at these higher velocities and with the wrinkled liner damage, distress, or cavitation was not observed.

7. Reasonable care must be taken to prepare the subgrade free of rocks and stones. If suitable material is not available for construction of the subgrade, a layer of fine-grained material will be needed under the geomembrane.

8. Aging and durability were not problems in the early field test, and none are expected because the normal early aging observed in the 2-year materials tests shows adequate retention of materials properties.

Future designs should be improved by curved bottom cross sections rather than the usual flat bottom of a trapezoidal section. This would minimize the amount of cover washed away at low flows. This concept could be expanded by providing vegetated earth cover that can handle flood flows with minimal erosion and not require recovering the spillway after each operation. Studies have recently been completed in England on the reinforcement of steep grassed waterways [Hewlett et., al.1985]. This may have application in Reclamation work, but would depend upon local soil and climatic conditions. To prevent the membrane from being torn by logs, trees, or branches, installation of a log boom upstream of the spillway should be considered.

SUMMARY

Reclamation has successfully used geomembranes in several seepage control applications in embankment dam construction. Besides the installations described in this paper, there have been several other geomembrane applications. These include:

1. Installation of a geomembrane as an impervious element in the raised embankment at Pactola Dam which is located in the Black Hills of South Dakota. It should be noted that the use of a geomembrane significantly reduced impact from borrow area development in a National

Forest area and from highway traffic congestion. The installation was competed in 1987 (Lippert and Hammer 1989).

2. Black Mountain Operating Reservoir, Central Arizona Project. During the past summer, this reservoir was constructed and lined with a geomembrane. A concrete cover was placed over the membrane in the bottom of the reservoir to provide a hard surface for cleaning operations. A coarse aggregate material was placed on the 3:1 side slopes. To protect the geomembrane from damage during cover placement as well as to provide a better frictional surface, a nonwoven geotextile was installed over it on the side slopes. (Reclamation 1989)

3. Installation of a geomembrane to reduce seepage through the right abutment at Ochoco Dam, Crooked River Project, Oregon (Reclamation 1990b). Approximately 2.5 hectares of a texturized HDPE lining was installed earlier this year.

As more experience and data become available on the slope stability of geosynthetic lining systems, the soil cover slippage problems encountered at San Justo Reservoir should be reduced. Also, industry is now beginning to develop products containing recycled materials such as ground rubber tires for use as a cushioning or protective layer for geomembranes. Eventually the development of this type product may . reduce subgrade preparation allowing for more rapid installation.

In addition to geomembranes, Reclamation has also used other types of geosynthetic materials in embankment dam construction. Examples of some of these applications include:

1. Installation of geogrids this past summer at Davis Creek Dam, Nebraska. (Engemoen and Hensley 1989) This coupled with the use of soil-cement on the downstream slope will permit a steeper embankment which will result in reducing the construction costs. After the dam is put in service and performance data become available, a Reclamation report will be prepared on this installation.

2. Use of a prefabricated drainage composite at Jackson Lake Dam, Wyoming, to increase drainage in the dam foundation densified by dynamic compaction. Also at Jackson Lake Dam, the downstream slope was protected by a reinforced grass slope, and a geogrid was placed across the base of the dam to minimize cracking in case of a earthquake.

It is expected that as new geosynthetic products are developed there will be an increase in their uses in hydraulic construction. However, the increased use will have to be tempered with prudent designs and effective quality assurance/quality control programs.

REFERENCES

Bureau of Reclamation 1980a. Specifications No. DC-7418, Mt. Elbert Forebay Reservoir Membrane Lining, Fryingpan-Arkansas Project, Colorado

Bureau of Reclamation 1980b. Construction Considerations, Mt. Elbert Forebay Reservoir Membrane Lining, Fryingpan-Arkansas Project, Colorado

Bureau of Reclamation 1981. Design Summary for Mt. Elbert Forebay Reservoir Membrane Lining, Fryingpan-Arkansas Project, Colorado

Bureau of Reclamation 1984. Specifications No. DC-7617, San Justo Dam, Central Valley Project, California

Bureau of Reclamation 1987. Specifications No. 20-C0300, Membrane Liner Modification - San Justo Reservoir, San Felipe Division, Central Valley Project, California

Bureau of Reclamation 1989. Specifications No. DC-7786, Tucson Aqueduct, Black Mountain Operating Reservoir, Tucson Division, Central Arizona Project, Arizona

Bureau of Reclamation 1990a. Specifications No. 20-C-357, Geomembrane and Drainage, San Justo Reservoir, San Felipe Division, Central Valley Project, California

Bureau of Reclamation 1990b. Specifications No. 1-CC-10-05220, Ochoco Dam Modification, Crooked River Project, Oregon

Corps of Engineers 1975. Recommended Guidelines for Safety Inspection of Dams, Office of the Chief of Engineers, Department of the Army, Washington D.C.

Cyganiewicz, J. M., 1986. San Justo Reservoir, USCOLD Newsletter March 1986

Engemoen W., and P. Hensley 1989. Reinforced 1:1 Slopes at Davis Creek Dam, USCOLD Newsletter, November 1989

Frobel R. K. 1980. Design and Development of an Automated Hydrostatic Flexible Membrane Test Facility, Bureau of Reclamation Report No. REC-ERC-80-9

Frobel R. K. and E. W. Gray Jr., 1984. Performance of the Fabric-Reinforced Geomembrane at Mt. Elbert Forebay Reservoir, Proceedings of International Conference on Geomembranes, Denver, Colorado, vol. 2, pp 421-426

Hewlett, H.W.M., L. A. Buarman, M.E. Bramley, and E. Whitehead 1985, Reinforcement of Steep Grassed Waterways, Construction Industry Research and Information Association, Technical Note 120, London, England ckey M.E. 1969. Investigations of Plastic Films for Canal Linings, Bureau of Reclamation Research Report No. 19

ppert T. L., and 6. G. Hammer 1989. The Use of a Geomembrane in Heightening Pactola Dam, Water Power and Dam Construction, February 1989

Londe M.P., 1983. Lessons from Earth Dam Failures, News and Views, British National Committee on Large Dams, August 1983

Morrison, W. R., E. W. Gray Jr., D. B. Paul, and R. K. Frobel 1981. Installation of Flexible Membrane Lining in Mt. Elbert Forebay Reservoir, Bureau of Reclamation Report No. REC-ERC-82-2

Morrison W. R., and E. W. Gray Jr. 1991. Performance of Mt. Elbert Forebay Reservoir Flexible Membrane Lining after 10 years of Service, Geosynthetics '91. Atlanta, Georgia, February 1991

National Sanitation Foundation 1985. Standard No. 54, Flexible Membrane Liners, Ann Arbor, Michigan

Timblin, L. O. Jr., P. G. Grey, B. C. Muller, and W. R. Morrison 1988. Emergency Spillways Using Geomembranes, Bureau of Reclamation Report No. REC-ERC-88-1

USCOLD, 1982. Dam Safety Practices and Concerns in the United States, Boston MA, April 1982