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Water Conservation Strategies Using Geosynthetics

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ABSTRACT: United States Bureau of Reclamation (Reclamation) frequently lines and rehabilitates open channels, dams, and reservoirs to conserve water and secure other benefits. Reclamation originally pioneered the development of lining technology from 1946 to 1962 when several studies were conducted to evaluate canal linings which were lower in cost than concrete. During those early years, 4,100 kilometers of lower cost linings and 680 kilometers of reinforced concrete linings were installed on Reclamation canals. Since then, a variety of new materials and new construction techniques have been developed and are currently being evaluated. This paper discusses Reclamation's experience with various flexible geomembranes including polyvinyl chloride (PVC), very low density polyethylene (VLDPE), a composite geotextile/low density polyethylene (LDPE)/geotextile, and polypropylene (PP) for use as seepage barriers in canals with traditionally acceptable subgrade conditions. In addition, alternative construction materials and techniques used to line rigorous canal subgrades will be discussed. Finally, the paper will briefly discuss Reclamation's use of geosynthetics in various dams and reservoirs.

1 INTRODUCTION

The United States Bureau of Reclamation (Reclamation) is charged with managing, and protecting water and related resources in an environmentally and economically sound manner. Conservation of water is not a new concern. As early as 1946, Reclamation began studies to investigate lining materials to control seepage from canals (Morrison and Starbuck, 1984). In the 1950's and 1960's, Reclamation began investigating plastic films (now referred to as geomembranes) as canal linings (Hickey, 1969). Geomembranes provide effective seepage control and are particularly useful when limited construction access, exposure to freeze/thaw cycling, and cold weather installation conditions exist. Reclamation continues to evaluate new materials and new construction techniques which reduce seepage, reduce erosion, and enhance water quality. Reclamation has recently applied findings from canal research to reservoir seepage control and embankment dam rehabilitation.

2 CANAL LINING

In recent years, Reclamation has conducted several studies on canal-lining technology. The Coachella Canal Lining Project used a new installation technique, underwater placement of a material Reclamation has used for over 20 years, polyvinyl chloride (PVC) geomembrane. In test sections on the Belle Fourche Project's South Canal, three new geomembrane materials are being evaluated as seepage barriers when placed over normal subgrades. These materials include: very low density polyethylene (VLDPE), a composite (geotextile/low density polyethylene (LDPE)/geotextile), and polypropylene (PP). The Deschutes Canal Lining

Demonstration Project is examining nontraditional material applications over extremely severe subgrade conditions of fractured basalt.

2.1 The Coachella Canal lining project

Reclamation conducted a research program to study methods and materials for the underwater placement of a geosynthetic flexible membrane lining system using a concrete protective cover (Morrison, 1990). The geosynthetic lining material was a 0.75-mm-thick PVC plastic lining with an overlayment of 115.3-g/m^2 nonwoven geotextile bonded to the lining on the side slopes. A 2.5-km-long test section was successfully completed in the Imperial Valley on the Coachella Canal near Niland, California, in 1991.

PVC plastic was selected for the underwater placement project because of its:

1. availability in large sheets (factory panels up to 30 m wide and 100 to 200 m long).
2. high flexiblity over a wide temperature range and therefore, it conforms well to the subgrade.
3. ease of field-splicing and repairing with solvent cement. PVC also has good puncture, abrasion, and tear-resistance properties.
4. 20 years of use by Reclamation and over 10 years of use in Alberta, Canada as a canal lining material (Weiner, 1987).

Initial installation identified problems when unanticipated subgrade conditions required modification of the paving equipment and PVC guidance system. Placement of the lining system resumed in February 1991, and eventually attained installation rates of over 400 m/day (Reclamation, 1993).

We believe that this technique for placing a concrete/plastic lining system may also be used in the dry to avoid the need for overexcavation in expansive shales or clays, gypsiferous, loessial, and high-sulfate soils.

2.2 Test sections on the South Canal, Belle Fourche Project, South Dakota

All test sections on the South Canal are installed over traditionally acceptable subgrade conditions, i.e., a firm, reasonably even and smooth surface with no offsets larger than 20 mm, no roots, sticks, or objectionable foreign matter.

2.2.1 VLDPE test section

A 150-m-long test section of 0.75-mm-thick VLDPE was installed in April 1987. This material was chosen for evaluation because it is as flexible as PVC, lighter in mass, and does not require a plasticizer which can migrate with time. In addition, VLDPE conforms well to the subgrade and has good puncture resistance. The disadvantage of VLDPE is that it requires specialized heat seaming equipment by experienced personnel. These specialized needs could add to the labor costs of installing VLDPE geomembrane.

The test section subgrade was prepared and the liner placed (Haverland, 1987). A longitudinal seam was fusion-welded down the centerline of the canal. Hot- air guns were used for patching, folds, and transverse seams. Six sets of two VLDPE test coupons were attached with butyl mastic tape to the top of the membrane on the left side slope. The coupons measure about 0.3-by 1.5-m, with one sample placed below the normal water line and the other sample equally divided above and below the normal water level. Table 1 reports the results of physical properties for the original VLDPE and then after 1 year, 2 years, and 5 years of service. As table 1 indicates, the performance data exhibit uniform material properties and no adverse effect from aging.

2.2.2 Composite test section (geotextile/LDPE/geotextile)

A 150-m-long test section of composite lining was installed on the South Canal in April 1990. This material is being evaluated with regard to the slope stability of soil cover over a geomembrane used on side slopes. The composite consists of a 118-g/m^2 needle-punched, nonwoven polypropylene geotextile, laminated to both sides of a 0.05-to 0.08-mm-thick, low density polyethylene (LDPE) liner.

The composite lining was furnished in rolls 3.6 m wide by 90 m long. To reduce the amount of field seaming,

Table 1 - Physical properties test results for very low density polyethylene. membrane lining on South Canal, Belle Fourche Project, South Dakota

Physical Property	Original	1 year of service		2 years of service		5 years of service	
		BWL	AWL	BWL	AWL	BWL	AWL
Thick-ness, mm (mils)	0.86 (33.8)	0.83 (32.7)	0.85 (33.3)	0.89 (35.2)	0.88 (34.5)	0.83 (32.8)	0.81 (32.0)
Breaking force N (lb_f)	490+ (110+)L	445+ (100+)L	445+ (100+)L	490+ (110+)L	490+ (110+)L	490+ (110+)L	490+ (110+)L
	445+ (100+)T	445+ (100+)T	445+ (100+)T	445+ (100+)T	490+ (111)T	445+ (100+)T	445+ (100+)T
Ultimate Elongation, percent	800+L 830+T	800+L 830+T	800+L 775+T	800+L 850+T	820+L 850T	820+L 830+T	830+L 850+T
Percent of specimens not breaking at machine elongation limit	80L 80T	80L 80T	60L 40T	60L 60T	60L 0T	80L 60T	100 L 80 T
Graves Tear resistance N (lb_f)	70.3 (15.8) L	65.3 (14.7)L	63.6 (14.3)L	85.4 (19.2)L	88.6 (19.9)L	70.2 (15.8)L	not determined
	74.8 (16.8)T	65.0 (14.6)T	65.0 (14.5)T	83.6 (18.8)T	79.1 (17.8)T	71.6 (16.1)T	62.2 (14.0)T

+ Indicates some specimens did not break at the limit of the testing machine movement.
BWL denotes below waterline, AWL denotes above waterline.
L denotes longitudinal direction, T denotes transverse direction.
Note: The tensile test was conducted in accordance with ASTM D-638; Type IV die, gauge length of 5 mm, and rate of grip separation of 5 mm/minute. The tear test was conducted in accordance with ASTM D-1004. Reported values are average of 5 specimens cut from the coupon in the direction indicated.

the rolls were plant-seamed and cut to form sheets wide enough (about 17 m) to cover the width of the canal and about 30 m in length. Preseaming was completed in the water district's warehouse and required no specialized equipment or skilled labor. The rolls were overlapped about 150-mm at the seams and sealed with a hot-applied rubberized asphalt adhesive. The adhesive was applied at a temperature of about 165 °C in a 40-mm bead in the overlapped area. The seam was then rolled with a rubber tire to tool the hot adhesive into the fabric of both layers, thus forming a watertight seam. Test coupons were installed as in the previous test section.

Laboratory test results of the composite material and a water immersion study of the field seams are summarized in tables 2 and 2a. As of March, 1994, the soil cover has remained stable on the 1.5 V to 1 H side slopes, and no visible seepage has occurred through the test section.

2.2.3 Polypropylene test section

A 150-m-long test section of 0.75-mm-thick unreinforced polypropylene (PP) was installed on the South Canal in April 1992. This material is being evaluated as an alternative to PVC because it is flexible without a plasticizer, conforms well to the subgrade, has good puncture resistance, and PP has the added advantage of having a lower coefficient of thermal expansion than VLDPE.

The PP geomembrane was pre-assembled into panels 20 m wide by 75 m long at the manufacturer's facility using wedge- welded seams. The panels were then folded, rolled, and shipped to the job site. Transverse field

Table 2 - Results of laboratory tests of composite lining installed on South Canal, Belle Fourche Unit, South Dakota.

Physical property	ASTM test method	Test results
Tensile strength, N/mm width (lb_f/in width)	D 882	6.4 (36.4) L 6.0 (34.3) T
Elongation, percent	D 882	30 L 62 T
Breaking force, N (lb_f)	D 751, Grade, method A	740 (166) L 580 (131) T
Graves, tear, N (lb_f)	D 1004	34.3 (7.7) L 28.5 (6.4) T
Tongue tear, N (lb_f)	D 751 as modified in Appendix A of NSF Standard No. 54	210 (47.1) L 100 (40.5) T
Hydrostatic resistance KPa (lb_f/in^2)	D 751, method A procedure 1	2090 (303)

L denotes longitudinal direction.
T denotes transverse direction.
NSF = National sanitation Foundation

Table 2a. - Results of laboratory tests conducted on field seam samples of composite lining installed on South Canal, Belle Fourche Unit, South Dakota.

seam property	Water immersion period				
	0 (original)	6 weeks	3 months	6 months	1 year
Shear					
N/mm	2.4	4.0	3.7	3.1	3.1
lbf/in	13.9	22.6	20.9	17.8	17.8
Peel N/mm	0.6	0.7	0.5	0.8	0.6
lbf/in	3.3	3.9	3.1	4.7	3.4

seaming was accomplished using a hot-air welder. Eleven sets of test coupons were installed on the side slope with each coupon containing both a factory and a field seam.

The first coupons from this section will be retrieved in the spring of 1994. No visible sign of seepage has occurred in this section.

2.3 The Deschutes Canal lining demonstration project

This project is evaluating the effectiveness of different lining materials and construction techniques in reducing seepage from canals with severe angular subgrade conditions (Swihart et al., draft 1994). The lining systems designed to accommodate the rigorous subgrade include combinations of geosynthetics, soil, concrete, elastomeric coatings, and sprayed-in-place foam.

The project, in the Upper Deschutes River Basin of central Oregon, has 10 test sections on the Arnold Canal and 8 sections on the North Unit Main Canal. Test sections range from 100 to 300 m in length and 1400 to 2800 m^2 in area.

Canals in this project have fractured basalt bottoms and typically lose 35 to 50 percent of their water to seepage. Preconstruction seepage rates were 1 to 2 orders of magnitude greater than seepage rates after lining. Pre-construction seepage rates ranged from 195 to 1280 L/m^2 day. Ponding tests completed about a year after the linings were installed showed seepage rates between 0 and 36 L/m^2 day; the majority of the seepage rates were less than 21 L/m^2 day. Reports will be prepared over the next 10 years to document durability and maintenance costs of the test sections. The information from this study may apply to other areas throughout the world where water conveyance systems are constructed through porous material.

3 USE OF GEOMEMBRANES IN RESERVOIR AND DAM LINING APPLICATIONS

The majority of Reclamation's research of seepage control membranes has been associated with canals. However, since the 1980's, lining technology has also been applied to reservoir construction and dam rehabilitation. Table 3 summarizes various sites where geomembranes have been used.

3.1 Reservoir lining

Reclamation's first reservoir lining occured in the Mount Elbert Forebay. Totaling 117 ha, this installation at the time was the world's largest single cell geomembrane installation (Reclamation, 1981).

The contractor selected 1.14-mm reinforced chlorinated polyethylene (CPER) as the lining material because of its availability to meet the construction schedule. Geomembrane test coupons were installed to monitor the performance of the geomembrane. The most recent coupon was retrieved in 1990 after 10 years in service (Morrison and Gray, 1991). Most of the changes in strength properties occurred within the first 3 years of service and are not considered detrimental to the overall integrity of the lining. The lining is performing as a watertight barrier. Performance data for the San Justo Reservoir (Morrison et al., 1991) and the Black Mountain Operating Reservoir (Comer and Straubinger, 1993) also indicate good geomembrane endurance properties.

3.2 Dam Rehabilitation

Reclamation's first use of a geomembrane in dam rehabilitation occurred with modifications to raise the embankment at Pactola Dam. A geomembrane was selected for

Table 3 - Summary of locations where geosynthetics have been used in Reclamation and Bureau of Indian Affairs Reservoirs and Dams.

Type	Location	When	Geomembrane	purpose
R	Mount Elbert	1980	1.14-mm CPER	Seepage control to prevent activating ancient landslide
R	San Justo	1985	1-mm HDPE-A	Seepage control of sand lens
R	Black Mountain	1990	1.14-mm PVC	Watertight liner to accomodate rapid drawdown
D	Pactola	1985-1987	1-mm HDPE	Seepage control to raise the embankment and protect against erosion
D	Cottonwood Dam Number 5	1986	0.9-mm CSPE	Erosion protection as a low-cost emergency spillway
D	Ochoco	1991	1.5-mm HDPE-T	Seepage control right abutment
D	Black Lake	1992	1.5-mm VLDPE-T	Seepage control right abutment talus deposit
D	Pablo	1993	1.5-mm HDPE-T	Seepage control upstream face of embankment

R= RESERVOIR, D= DAM, CPER=Chlorinated polyethylene reinforced, CSPE=Chlorosulfonated polyethylene reinforced, PVC=Polyvinylchloride, HDPE=High density polyethylene, HDPE-A=High density polyethylene alloy, VLDPE=Very low density polyethylene, -T denotes textured liner protection against erosion of the raised embankment because it would reduce the number of construction seasons, allow for heavy seasonal tourist traffic around the dam, and minimize unsightly borrow area development. (Morrison, 1984).

At Cottonwood Dam Number 5 a low-cost emergency spillway was constructed using a geomembrane with an erodible protective soil cover (Timblin et al., 1988).

In the 1990's geomembranes have been used to line pervious areas in aging embankment dams such as Ochoco, Black Lake, and Pablo Dams.

4 CONCLUSIONS

Reclamation has used geosynthetics in canals, dams, and reservoirs to effectively conserve water and protect against catastropic damage. These construction materials will likely see increased usage as their effectiveness is documented.

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