WATER OPERATION AND MAINTENANCE BULLETIN

No. 179 March 1997

IN THIS ISSUE. . .

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Bureau of Reclamation

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Cover photograph: *Bituminous geomembranes being installed near Altus, Oklahoma, May 1994.*

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SLIPPAGE OF SPILLWAY RADIAL GATE WIRE ROPES AT YELLOWTAIL DAM, MONTANA

by Tim Flanagan[1], Dennis Rosberg[2], and Connie Berte[3]

On July 13, 1995, while radial gate No. 2 was being raised to increase spillway discharge at Yellowtail Dam, the 25- by 64.4-foot gate suddenly closed. The gate had been open 7 inches prior to the raise. Examination revealed that all four wire ropes had come off the hoisting drums (two ropes per drum) and were under water in the spillway inlet channel. Two wire ropes on radial gate No. 1 may have pulled through the wire rope clamp 2 to 3 inches, as evidenced by paint marks, but had not become detached from the drum.

Further investigation provided clues about what had happened on gate No. 2. Divers were dispatched to help retrieve the cables for gate No. 2. Although the wire ropes were relatively new, having been replaced by in-house personnel approximately 2 years before the failure, about 3 feet of the end of each wire rope was badly frayed (figure 1). The steel wire rope clamps (figures 2 and 3) that had secured the wire ropes to the drums were still in place but were scarred from the ropes pulling out. The hose clamps that had encircled the ends of the ropes had come off and fallen to the bottom of the hoist enclosures. In addition, a lock washer was missing from the clamp on the right drum.

Conjecture as to why the wire ropes pulled out of the clamps has centered on a combination of factors. On the hoist drums, the machined grooves (that spiral around the circumference of the drum) taper to an end near the center of the drum, just past the clamp that anchors the rope ends to the drum. However, on the right drum, the grooves were not symmetrically machined, and the taper on one side ends approximately 2.5 inches prematurely when compared to the other taper (figure 4). In effect, the grooves were of different depth at the location of the wire rope clamp. This would tend to produce an uneven clamping force on the two rope ends, with the rope in the deeper groove receiving less force than the one in the shallower groove.

It is also thought that the clamping force may have been inadequate on all clamps because the bolts were torqued with the rope in an unstretched condition (as mentioned above, the ropes for gate No. 1 may have slipped 2 to 3 inches). Lifting the gates would elongate the ropes and reduce the diameter, which would reduce the clamping force on each rope. The missing

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lock washer may also have contributed to inadequate clamping force if the washer broke and fell off, leaving a gap between the bolt head and the clamp.

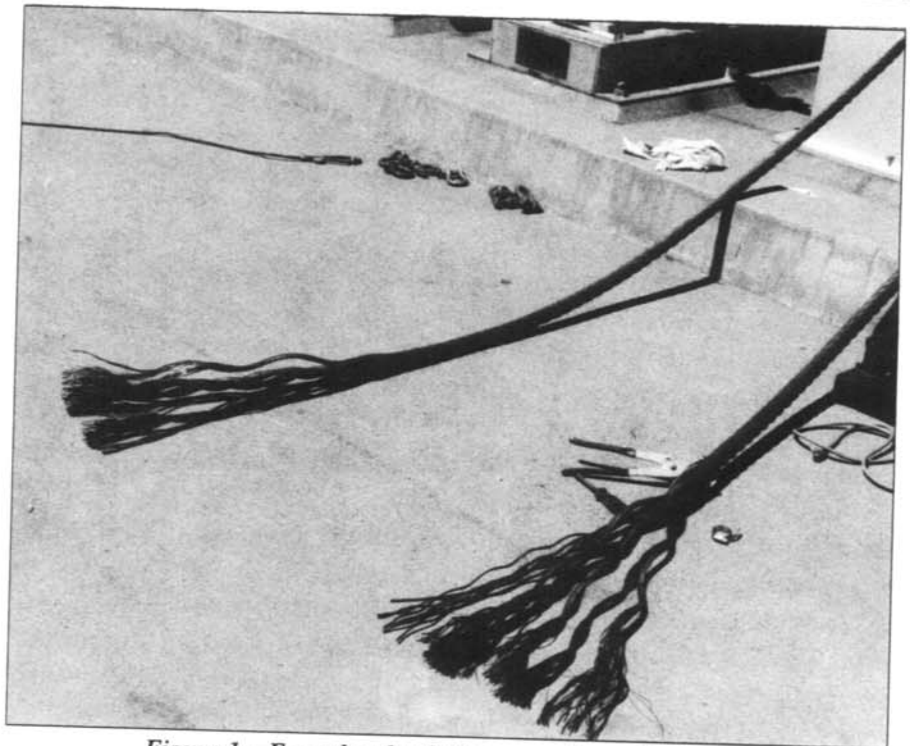

Figure 1.—Frayed ends of wire ropes that pulled out of wire rope clamps on hoist drums.

It is believed that one of these conditions, or a combination of conditions, led to the pullout. If one rope slipped at the clamping point, the other rope on the hoist would also slip since it would be carrying all the hoisting force of the drum, and then the other two ropes on the gate would likely slip since they would be carrying twice their normal load. It also should be mentioned that the two dead wraps of each rope on the drums did not produce enough friction to prevent the pullout failure.

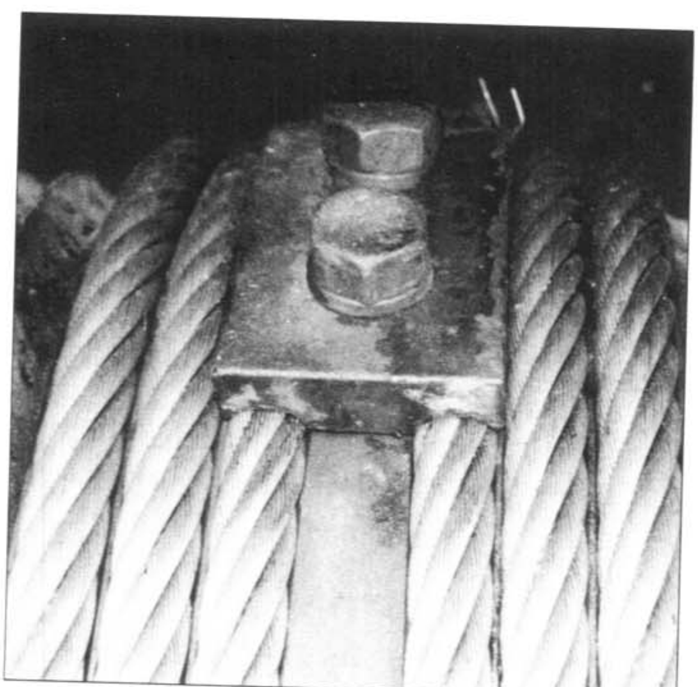

Figure 2.—Wire rope clamp bolted to hoist drum.

Other factors were considered as well but were not suspected as the primary cause of the failure. Binding of the gates had not been a problem in the past, so it is not thought that this could cause the problem, although it is possible that the gate did bind after one pair of ropes had come loose. There also had been vibration noticed at the gates when the reservoir was at a level sufficient to leak through a splice in one of the side seals. However, the vibration stopped once the reservoir dropped.

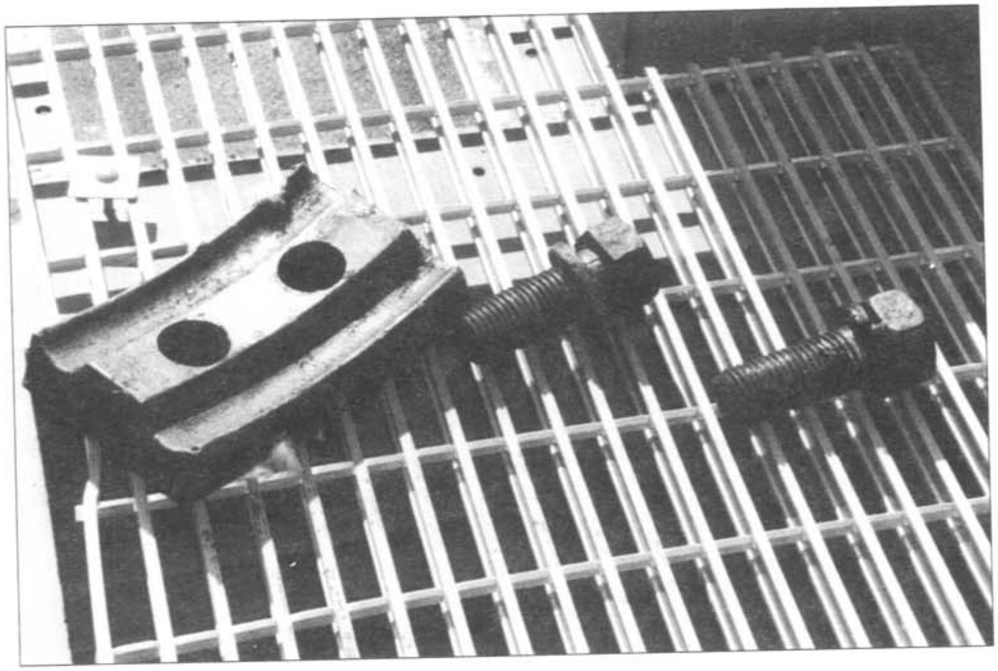

Figure 3.—Underside of wire rope clamp showing grooves that accommodate the wire rope.

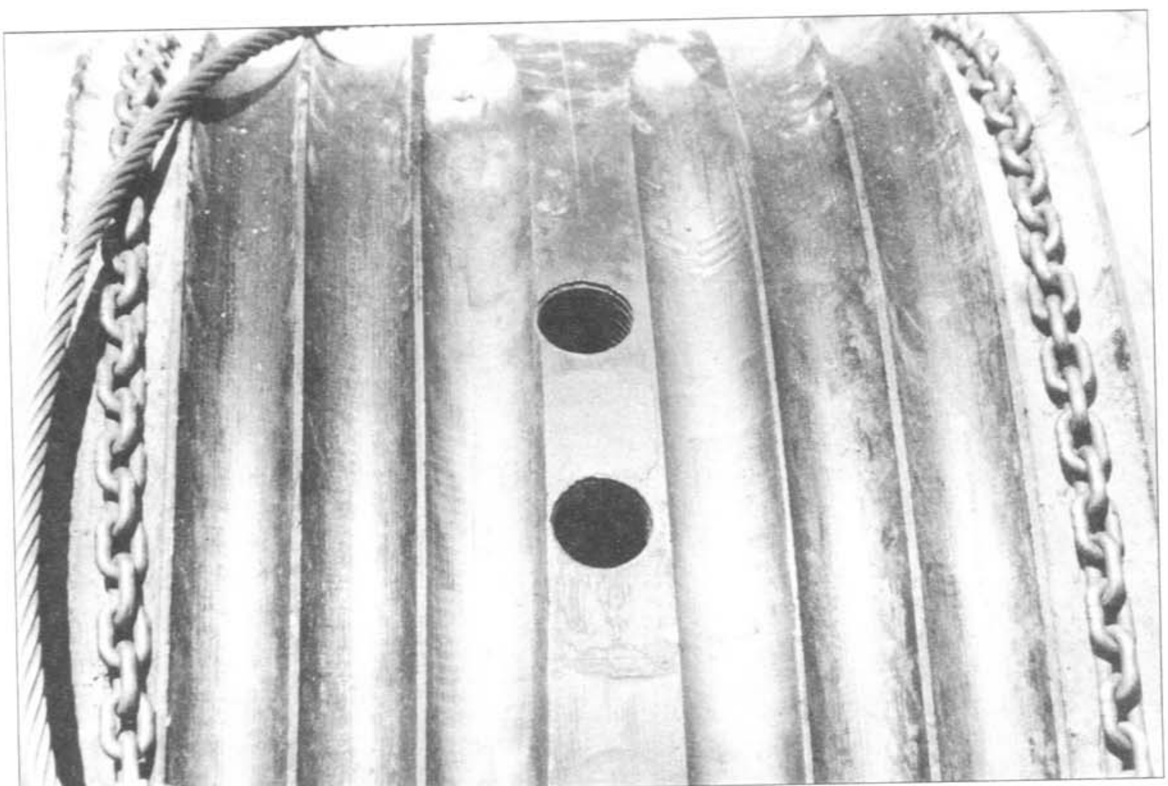

Figure 4.—End tapers of machined grooves near center of right hoist drum, gate No. 2 (center top of photo). Note that the groove on the right tapers to an end sooner than the groove on the left.

In order to continue making spillway releases, which require equal gate openings, the frayed ends were cut from the wire ropes of gate No. 2, the ropes were reattached to the drums and clamps, the limit switch was reset, and the ropes were marked to provide a visual aid to detect any further slippage. After further analysis of the problem, several actions were taken to increase the factor of safety and help prevent problems in the future:

1. The bolts at all clamps were replaced with Superbolt® tensioners from Superbolt, Inc. (see figure 5). The Superbolt® tensioners have several jack bolts around the perimeter of the bolt *head*. These jack bolts are torqued in order to tension the main *bolt* shaft. The jack bolts are designed to give a reliable relationship between torque on the jack bolts and tension in the main shaft; thus, the clamping force can be estimated more accurately. Also, a regular torque wrench can be used on the smaller jack bolts rather than the hydraulic wrench used for large conventional hex head bolts.

2. All the clamps, which were a 2-bolt design, were cut in half, in effect converting them to twice as many 1-bolt clamps (figure 6). The smaller 1-bolt clamps will provide a more uniform clamping force because they will be less likely to "ride high" where unsymmetrical groove depths might occur.

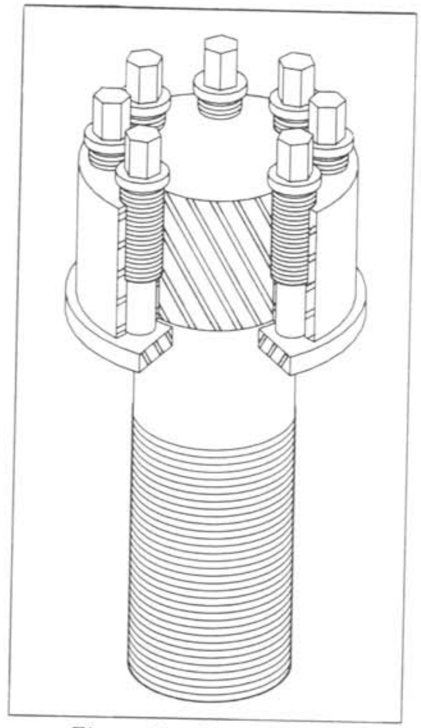

Figure 5.—Cutaway view of a Superbolt®.

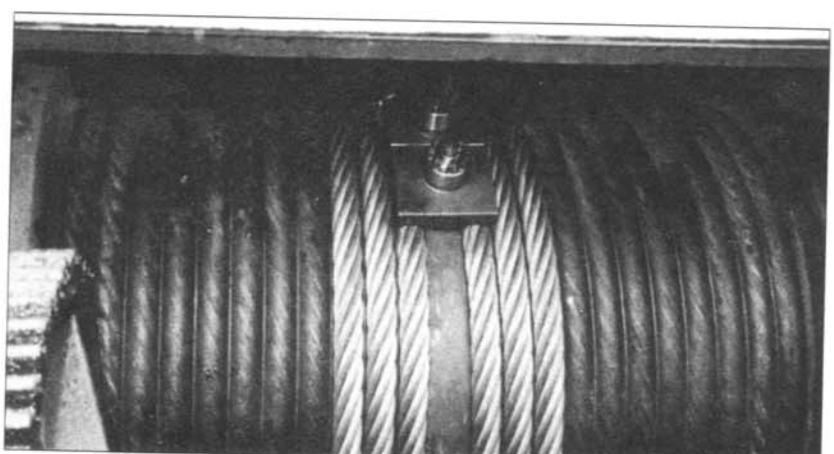

Figure 6.—Superbolts® holding wire rope clamp against wire ropes on hoist drum. Note that clamp has been cut in two.

3. On all the wire ropes, the lubricant at the clamping point was removed with a solvent to increase the coefficient of friction between the ropes and the clamps/hoist drum (the hoist drums are protected from the elements).

4. The shallower groove on the right hoist drum of gate No. 2 was ground somewhat deeper where it tapers to an end. This will help even the clamping force on the ropes.

Incidents of wire rope problems on radial gates are relatively common. It is hoped that the experiences at Yellowtail Dam will help other operation and maintenance personnel avoid similar problems.

REMEDIATION OF EXISTING CANAL LININGS

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Abstract

The Bureau of Reclamation (Reclamation) has installed over 4,000,000 m^2 of geomembrane canal liner since 1968. Reclamation continues to evaluate the performance of new materials in new applications for canal lining. Recent installations in South Dakota, Washington, Nebraska and Oklahoma contain relatively new materials installed as either exposed or covered canal liners. Although the majority of geomembranes used as canal liners have been soil covered, since July of 1987, several geosynthetic systems have been covered with concrete or left exposed. Results from monitoring a soil covered polypropylene (PP) geomembrane in South Dakota, an exposed high density polyethylene (HDPE) geomembrane in Kansas, and an exposed very low density polyethylene (VLDPE) geomembrane in Nebraska are reported in this paper. Geomembranes used as canal liners appear to reduce seepage in the canals when they are constructed in highly permeable or collapsible types of soils.

Introduction

Reclamation began investigating the use of plastic films as canal liners in the 1950s (Hickey, 1969). Originally these materials were used only for rehabilitation of old canals and then later used in new canal construction efforts (Morrison & Starbuck, 1984). As the canal distribution system in the Western United States ages, Reclamation is using geomembranes in new ways to repair and rehabilitate unlined, earth lined and concrete lined canals.

Approximately 85% of Reclamation canals are concrete or compacted earth lined (Haider, 1992). Geomembranes have provided especially effective canal seepage control in areas where there are limited construction access, exposure to freeze/thaw cycling, remote construction locations, and cold weather construction. This paper will discuss several recent canal remediation techniques using buried, exposed, and concrete covered geomembranes.

Buried Geomembranes

Historically, buried polyvinyl chloride (PVC) has been the most widely used geomembrane for canal lining applications for several reasons. PVC is flexible over a wide temperature

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range, available in large panels, easily field seamed, and has good puncture and abrasion resistance. Reclamation began specifying 0.25mm (10 mil) thick PVC for canal rehabilitation on the Helena Valley Project in Montana in 1968 (Morrison & Starbuck, 1984). In the early 1980s, the specified thickness was increased to 0.50mm (20 mil) to increase service life and reduce construction related damage to the PVC. In total, Reclamation has installed over 4 million m^2 of PVC canal lining since 1968.

As new geomembranes are developed which do not rely on plasticizers to impart flexibility, Reclamation has conducted field studies to evaluate their effectiveness as canal seepage barriers. A study site near Belle Fourche, South Dakota, contains three relatively new types of buried geomembranes installed over normal subgrades. These materials include: very low density polyethylene (VLDPE), a composite (geotextile/low density polyethylene (LDPE/ geotextile), and unreinforced polypropylene (PP). The installation and monitoring results of the VLDPE and composite LDPE section are reported in Comer (1994).

In April of 1992, a 150 m long, 0.75 mm thick PP test section was installed on the South Canal, Belle Fourche, South Dakota. Polypropylene installation time was reduced because the PP was factory assembled into panels 20 m wide by 75 m long using wedge welded seams. The panels were then folded, rolled, and shipped to the job site. Panels were joined in the field using hot air welding. Eleven sets of test coupons were installed. Two of these coupons have been retrieved to date. Polypropylene physical properties test results for the first two coupons over 3 years of service are shown in Table 1. After 3 years of service, the PP geomembrane has adequate seam peel and shear strength and still exhibits good tear, tensile, and elongation properties.

Table 1
Physical Properties Test Results for Polypropylene Geomembrane After 3 Years of Service on South Canal, Belle Fourche Project, South Dakota

			1.5 years exposure		3 years exposure	
Physical property	Test method	Original	AWL	BWL	AWL	BWL
Thickness, mm (mils)	ASTM D751 (as modified in NSF 54)[1]	0.77 (30.8)	0.71 (28.3)	0.73 (29.3)	0.71 (28.3)	0.71 (28.4)
Seam shear strength, kN (lbf)	ASTM D4437 (as modified in NSF 54)	N/A	0.219 (49.2) Factory 0.136 (30.5) Field	0.214 (48.0) Factory 0.129 (29.1) Field	0.216 (48.6) Factory 0.181 (40.7) Field	0.211 (47.5) Factory 0.171 (38.5) Field
Seam peel strength, kN (lbf)	ASTM D4437 (as modified in NSF 54)	N/A	0.156 (35.1) Factory 0.055 (12.3) Field	0.157 (35.3) Factory 0.085 (19.1) Field	0.149 (33.4) Factory 0.077 (17.4) Field	0.152 (34.1) Factory 0.066 (14.8) Field
Graves tear resistance, N (lbf)	ASTM D1004	64 (14.4) L 57 (12.9) T	63 (14.2) (L) 65 (14.6) (T)	67 (15.1) (L) 69 (15.5) (T)	64 (14.4) (L) 65 (14.7) (T)	66 (14.8) (L) 64 (14.4) (T)
Tensile strength at break, N/mm (lbf/in)	ASTM D638 (as modified in NSF 54)	16.6 (95.1) L 14.4 (82.5) T	14.8 (84.3) (L) 15.3 (87.5) (T)	14.7 (83.8) (L) 16.3 (93.4) (T)	15.1 (86.3) (L) 15.0 (85.7) (T)	15.4 (88.2) (L) 16.5 (94.3) (T)
Elongation at break, %	ASTM D638 (as modified in Annex A)	1157 L 1146 T	1173 (L) 1173 (T)	1206 (L) 1167 (T)	1253 (L) 1063 (T)	1315 (L) 1197 (T)

[1] National Sanitation Foundation, AWL = above the waterline, BWL = below the waterline.

All of the Belle Fourche test sections are installed over traditionally acceptable subgrades with a firm, reasonably even and smooth surface with no offsets larger than 20 mm, no roots, sticks, or objectionable foreign matter. All of the test sections are visually demonstrating good seepage control, however no water measurements have been taken. The disadvantage of the VLDPE, composite LDPE and PP sections is that these materials require thermal seaming techniques which require specialized heat seaming equipment. These specialized needs could add to the labor cost of installation.

Exposed Geomembranes

The majority of the expense of a geosynthetic canal lining results from overexcavating for and burying the geomembrane. In addition, cover stability problems can result when canal side slopes are steepened to reduce rights-of-way. Because of these concerns, exposed geomembranes have been used in several locations.

Whiterock Extension Canal

An experimental test section of 0.75 mm (30 mil) HDPE was installed by irrigation forces in the Whiterock Extension Canal, Bostwick Division, Kansas, in May 1983. The bottom invert was covered with 30 cm of cover material, providing for a 1.0 m bottom width and water depth of 0.6 m. The HDPE lining was left exposed on the 1.5 (vertical): 1 (horizontal) side slopes of the canal.

This test section was inspected in October 1995. The overall condition of this 12 year old lining is satisfactory and continues to offer seepage control for the canal system. Two test coupons were retrieved below the normal water surface level approximately 60 m from the beginning of the 270 m long geomembrane lined section. Sample no. 1 was obtained from the north facing slope and no. 2 was obtained from the south facing slope. Physical properties test results are provided in Table 2. All of the properties are higher than the specified minimum values except the tensile strength at break for both sides of the canal. It is believed that the ultimate breaking strength of the field samples may have been lowered by scratches on the geomembrane caused during installation and coupon removal.

The depth of the existing cover material was not measured during the October 1995 inspection. However, the condition of the cover material and anchor trench was acceptable. The irrigation district reported no major problems with the geomembrane section. The district has done repair work on a number of small punctures and holes believed to be caused by deer. Most of the holes can be described as punctures or puncture/slits. Because of the tautness of the membrane and undulations in the existing subgrade surface, it appears the membrane in some areas has 'bridged' across any depressions or voids in the subgrade.

Table 2
Physical Properties Test Results for Exposed High Density Polyethylene on the White Rock Extension Canal, Bostwick Division, Kansas

Physical property	Test method	Original†	South facing slope after 12.5 years of service	North facing slope after 12.5 years of service
Thickness, mm (mills)	ASTM D751	nominal 0.75 (30) minimum 0.69 (27)	0.79 (32)	0.79 (32)
Graves tear, N (lbf)	ASTM D1004	89 (20)	99.2 (22.3) L 111.0 (24.9) T	100.0 (22.5) L 118.0 (26.6) T
Tensile strength at yield, N/mm (lbf/in)	ASTM D638	11 (63)	13.4 (76.6) L 14.4 (82.5) T	14.7 (84.1) L 15.5 (88.3) T
Tensile strength at break, N/mm (lbf/in)	ASTM D638	20 (114)	20.7 (118.3) L 16.2 (92.9) T	17.9 (102.3) L 19.1 (109.3) T
Elongation at yield, %	ASTM D638	12	21 L 15 T	21 L 17 T
Elongation at break, %	ASTM D638	560	1004 L 844 T	787 L 909 T

† Original values taken as National Sanitation Foundation 54 minimum values for HDPE non-textured sheet.
L = longitudinal or machine direction, T = transverse or cross-machine direction.

Several folds and creases were examined and no deterioration of the geomembrane was noted. The geomembrane continues to appear to be in good condition with no major changes (Morrison & Comer, 1995).

The district continues to perform repairs on the geomembrane by patching the deer holes using bituthene elastomeric mastic and bituthene liquid membrane.

In May 1992, approximately 200 holes were repaired with bituthene material. This was the first major repair done on the canal since the installation in 1983. In October 1995, it was observed that there are at least 40 additional small holes that require repair. The holes continue to be a puncture or occasional puncture/slit made by deer hoofs. Most of the holes were 25-50 mm^2 in area with the slits generally 50-75 mm in length.

Most of the repairs made in 1992 using the bituthene performed satisfactorily. However, there are a number of areas that now require a repatch because the bituthene material has exhibited some signs of deterioration, i.e. cracking. It is realized that the bituthene materials provide only a short term fix and that a thermally welded patch will be required in the future.

Because of the high cost of ownership of the welding equipment, the district has elected to provide the 'temporary' repairs until there is a large enough number of repairs to justify a thermal repair method.

Courtland Canal, Phase I

Exposed VLDPE was specified for geomembrane lining of the Courtland Feeder Canal in southern Nebraska. The Phase I specifications called for 1.0 mm (40 mil) VLDPE in the canal invert, welded to 1.5 mm (60 mil) VLDPE on the side slopes. Phase II specified 1.5 mm (60 mil) HDPE. The Phase I lining was installed between September and November of 1992. For convenience during installation, in some areas the contractor chose to use all 1.5 mm VLDPE. Gravel cover material was placed in the invert to weight down the geomembrane and provide a driving surface for maintenance purposes.

The geomembrane was placed in the existing canal prism that had 1.5:1 side slopes, a water depth of 2.1 m and a bottom width of 7.0 m. Exposed geomembrane was selected because it was determined that it would be cost prohibitive to flatten the side slopes to accommodate the traditional covered membrane alternative.

Four coupon samples were retrieved from the canal slopes in October, 1995. Two coupons were retrieved from the north facing slope and two from the south facing side slope. One coupon from each side slope contained an extrusion thermal weld. Physical properties test results for coupons retrieved from the Courtland (Phase I) VLDPE lining exposed for 3 years are reported in Table 3. All of the physical properties are above the specified values, except the tensile strength at break.

The overall condition and appearance of the geomembrane is satisfactory. There is no noticeable indication of any deterioration or damage to the material. The operating district has reported that there are a few locations with puncture holes on the side slopes created by deer hoofs. Although it does not appear to be a serious problem, there are certain areas along the canal where deer have a tendency to concentrate their crossing frequencies, causing more holes in the geomembrane. Animal escapes (flattened gravel covered exit ramps) were constructed, but it is unknown how effective the ramps are for deer attempting to leave the canal.

An inspection of the structure attachments was also made for some of the structures. Stainless steel batten strips with concrete wedge anchor bolts were specified. The attachments that were examined appeared to be in satisfactory condition. One bridge pier location did have a small geomembrane tear below the batten strip, most likely caused by trash and ice flowing in the canal. The batten strip continues to be adequately attached to the concrete structure and is in a satisfactory condition.

Table 3
Physical Properties Test Results for Very Low Density Polyethylene on the Courtland Feeder Canal, Phase I, Nebraska

Physical property	Test method	Original†	South facing slope after 3 years of service	North facing slope after 3 years of service
Thickness, mm (mills)	ASTM D751	nominal 1.5 (60) minimum 1.35 (54)	1.47 (58.9)	1.49 (59.8)
Seam, N/mm (lbf/in) Peel	ASTM D4437 (NSF 54 modified)	not specified	9.10 (51.9)	11.1 (63.5)
Shear			11.9 (68.1)	12.0 (68.4)
Graves tear, N (lbf)	ASTM D1004	107 (24)	(27.5) L (27.7) T	(26.8) L (28.7) T
Tensile strength at break, N/mm (lbf/in)	ASTM D638	37 (210)	26.8 (153) L 25.9 (148) T	33.1 (189) L 31.5 (180) T
Elongation at break, %	ASTM D638	780	1078 L 1054 T	1269 L 1210 T

† Original values taken as specified quantities. NSF = National Sanitation Foundation, L = longitudinal or machine direction, T = transverse or cross-machine direction.

Unusual operating conditions in 1994 left water in the canal during the first part of the winter season. An ice cap formed on the canal with an estimated depth of approximately 0.3 m. The ice did not cause any damage to the geomembrane. However, the canal safety ladders attached to the side slopes were extensively damaged.

Bituminous Liner

An exposed polymer modified bituminous liner was installed by the Kennewick Irrigation District in the state of Washington in 1992 and the Lugert-Altus Irrigation District in Oklahoma in 1994 (Provine, 1994). The resin combines styrene-butadiene-styrene polymer and high-quality asphalt with puncture resistant polyester reinforcement. As shown in Fig. 1, this material can be easily unrolled and placed in the canal. Although the liner itself is more expensive than polyethylene, the water district personnel can install it themselves with no need for specialized thermal welding equipment. An acetylene torch is used to join the seams and bond any patches needed for repairs.

The Kennewick Washington bituminous liner was installed over three sections totaling about 400 m in length. One of these sections was placed over a deteriorated concrete section of canal. The concrete surface was patched to provide a smooth surface and the liner installed

Fig. 1. Bituminous geomembranes being installed near Altus, Oklahoma, May 1994.

by district forces. No firm data are available on seepage rates; however, the water district reports that they are pleased with the performance of the liner to date and have not noted any signs of deterioration. Following canal lining in Oklahoma, arable land adjacent to the test section was utilized for the first time in over a decade.

Concrete Covered Geomembranes

Reclamation has over 8000 km (5000 miles) of concrete lined canals and laterals in operation. The condition of these conveyance systems varies depending on climatic conditions, age and operating and maintenance history. Recent repair projects indicate that geomembranes can be used for the expedient repair of deteriorated concrete linings. A concrete covering then restores the situation completely. Repair of two concrete-lined canals, the Mirdan Canal and Putah South Canal, are briefly described in this paper, but are detailed in Morrison and Comer (1995). The most recent concrete repair using a geomembrane at the Tucson Aqueduct, Reach 3, is discussed in detail.

In July 1987, a geosynthetic lining was used to repair a damaged section of the concrete lined Mirdan canal in Nebraska. The repair used a geomembrane with a gravel cover in the invert and a geotextile form concrete protective revetment on the 1.5:1 side slopes for protection. About 550 m (1800 ft) of the canal were reconstructed in four sections. Geomembranes used included 1.0 mm (40 mil) HDPE and 0.75 mm (30 mil) PVC.

In the fall of 1989, a less expensive repair technique was used to rehabilitate about 1500 m (5000 ft) of the Putah South Canal in California. In this project, 1.0 mm HDPE was covered with a 50 mm thick layer of shotcrete having varying amounts of fibermesh reinforcement. After 5 years, the Solano Irrigation District reports good seepage control from this section.

Approximately 2.4 km (1.5 miles) of the Tucson Aqueduct, Reach 3, concrete lining were found to be cracked, broken, and buckled due to settlement of saturated foundation materials (see Fig. 2). To eliminate water leakage, a repair contract was awarded. To minimize repair time and cost, a geomembrane was selected rather than overexcavating and replacing the subgrade and concrete canal lining.

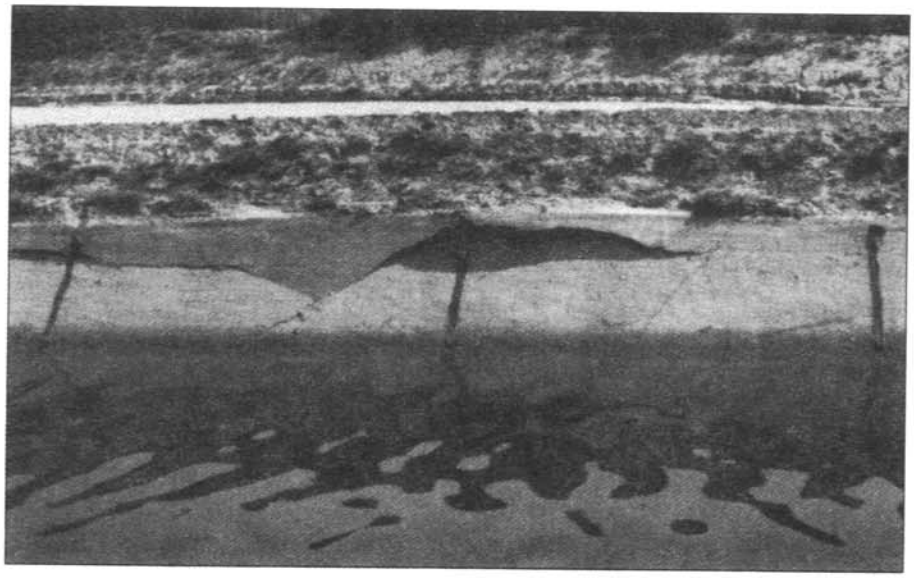

Fig. 2. Cracked concrete lining on the Tucson Aqueduct Reach 3.

Recent laboratory testing results (Comer & Dewey, 1995) suggested that textured VLDPE would be the preferred lining material due to its excellent bi-axial elongation properties. In addition, VLDPE exhibits some elastomeric properties which enhance the resistance to puncture. This additional 'toughness' which is reflected in higher tear strengths than PVC, was seen as an advantage during construction of this project. To reduce the effects of thermal expansion which cause wrinkling of the geomembrane, a white-surfaced material was selected. Texturing increases resistance to sliding of the geomembrane itself and its shotcrete (spray-applied concrete) cover on the canal side slopes, which are 1.5:1.

In the Fall of 1994, repairs to the damaged sections were made using a 1.5 mm textured white-on-black VLDPE geomembrane. Figure 3 shows placement of the geomembrane following patching of the concrete. The specifications required removal of large concrete chunks or smoothing of the existing surface with shotcrete to provide no offsets greater than 20 mm (3/4 in). Following placement of the geomembrane, a 75 mm (3 in) layer of shotcrete was applied to the geomembrane surface, as shown in Fig. 4. The shotcrete prevents flotation of the geomembrane and protects it from damage due to solar ultraviolet radiation, animals, vandals, and the equipment used during canal cleaning operations. This repair will be monitored to determine the long term effectiveness.

Other concrete covered geomembranes have been used to line leaking earth lined canals as well as repair concrete lined canals. For example, a PVC geomembrane with a concrete cover was used on the Coachella underwater lining test section in 1991. Here the concrete provided

Fig. 3. Placement of a 1.5 mm textured VLDPE geomembrane to repair a section of the Tucson Aqueduct Reach 3.

Fig. 4. Shotcrete protective cover being placed on the geomembrane at the Tucson Aqueduct Reach 3.

the weight necessary to submerge a 0.75 mm thick PVC geomembrane (Morrison, 1990). The technique for placing a concrete/geomembrane lining system if used in the dry may avoid the need for overexcavation in expansive shales or clays, gypsiferous, loessial, and high-sulfate soils.

A 0.5 mm PVC with a drainage composite and concrete cover was used to line a portion of the Towaoc Canal, Dolores Project, Colorado. In this project, the drainage composite collects seepage water that passes through the concrete liner and provides relief from hydrostatic back pressure on the concrete lining during canal drawdown. This elaborate system was designed to provide an extremely watertight lining to prevent any embankment failures (Morrison & Comer, 1995).

Conclusions

Buried, exposed, and concrete covered geomembranes are effectively providing seepage control in the aging water conveyance system of the Western United States. As the population in the West increases, the need to transport water more efficiently also increases. Water conservation by canal lining continues to become more sophisticated.

Acknowledgements

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A Cloudy Issue

How Prepared Are You for Chlorine Leaks?

by Clyde W. Young

It has been said that the job of operator, no matter what the process, is one of long periods of routine, sometimes boring work, interrupted occasionally by intense, stressful situations that require snap decisions and quick action. Some operators dread these situations. Others look forward to the excitement. One of the most intense situations that can develop in a water treatment facility is a chlorine leak. A well-developed emergency response plan is the best protection for employees, the public, and the environment. In the day-to-day operations of your plant, the emergency plan may be an area that has not been updated for quite some time.

While most chlorine leaks could be considered nuisance leaks, it doesn't take much chlorine escaping to the atmosphere to escalate the situation from nuisance to emergency. The National Institute for Occupational Safety and Health provides operators with guidance for chlorine exposure. A release of 30 ppm is considered immediately dangerous to life and health (IDLH). Compare this to the IDLH level for hydrogen cyanide, which is 50 ppm.

Many chlorine leak detectors only register an alarm at 10 ppm. How do you know if you are approaching the IDLH? If the chlorine alarm goes off, the operator must assume that the atmosphere will eventually reach the IDLH level and that a nuisance leak has escalated into an emergency.

In the HAZWOPER compliance directive, CPL 2-2.59, the Occupational Health and Safety Administration has stated that "a release of chlorine gas above the IDLH ... moving through a facility is an emergency situation. Employees who would respond to this hypothetical situation, whether they work in the immediate area or come from outside, would need to act in accordance with 29 CFR 1910.120(q)."

29 CFR 1910.120(q) details the requirements for establishing an emergency response plan. It also establishes the training requirements for operators expected to stop the leak. OSHA's process safety management (PSM) standard requires facilities to develop an emergency response plan. The US Environmental Protection Agency's recently published risk management plan (RMP), which covers those water treatment facilities OSHA does not cover, also requires emergency response planning.

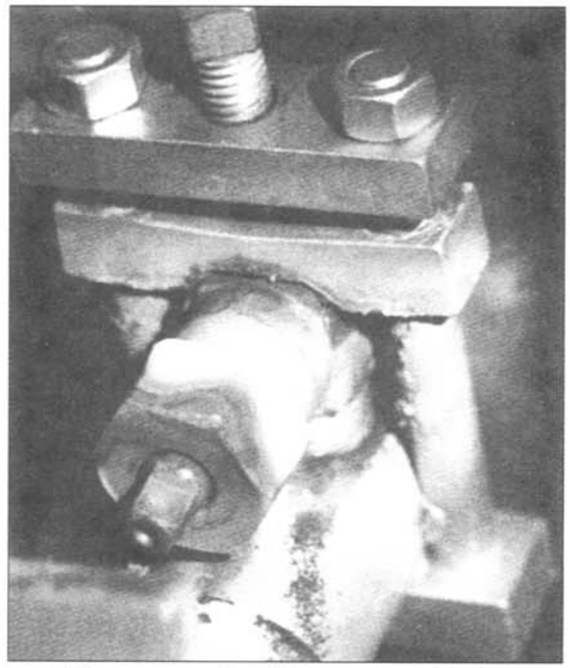
What's Your Plan?

If your chlorine alarm sounds, what is the established procedure for responding? Does your facility's emergency plan call for operators to respond to the leak? What is the response supposed to be?

If operators at your facility have not received training at the hazardous materials technician level [see 29 CFR 1910.120(q)(6)(iii)], the proper response to a chlorine leak would be to evacuate the area and call for help. This may be contrary to past practices in which the operator enters the area and closes a cylinder valve.

Finding the leak will require someone with the proper level of training and the appropriate personal protective equipment to enter the area and examine every fitting that could leak. Using chlorine leak-detecting paint can make the examination quicker and safer.

If your facility's emergency plan calls for evacuating the area and summoning help, what should be done in the meantime? Ventilation systems in chlorine processes are designed to evacuate the room to the atmosphere. Some are designed to automatically start when the chlorine alarm sounds. Is this the best procedure under the circumstances? It may take a considerable amount of time for emergency response personnel to appear. During this period, chlorine will be leaking and the ventilation system will be moving the chlorine outside.



When exposed to chlorine, special paint turns bright red (shown above as a dark stain on the fitting).

Containment of the chlorine may be the best practice. This is an area in which discussions with the local emergency planning committee should be held. Is it safer to contain the chlorine and enter the area with appropriate personal protective equipment to shut down the source? What are the consequences of releasing the chlorine to the atmosphere through the ventilation system? Are you creating a more serious problem?

Analysis May Be Required

Other requirements of OSHA's PSM standard and USEPA's RMP call for hazard analysis or assessment and compliance auditing. Any of these analyses should include a thorough evaluation of the facility's emergency plan. USEPA's risk management plan requires an analysis of a worst-case release scenario. This is an excellent method of determining how large the vapor cloud would be from a release and where the cloud would go.

As communities have grown, once-remote plants are now bordered by residential and commercial buildings. Preparing for a release should now include plans for alerting, evacuating, and assisting the public.

When evaluating where a chlorine vapor cloud might travel, consider the effect of buildings, hills, trees, and other features on the cloud. One water treatment plant released smoke bombs to study the route a vapor cloud might take and discovered the main door to the plant would be exposed to the cloud of chlorine. This required plant personnel to reevaluate the escape routes they had planned.

Complacency a Threat

Operators working around chlorine can become complacent about working with this toxic chemical, especially because most leaks are minor. Because it takes so little chlorine to be considered dangerous, it is important to plan and practice emergency procedures before they are needed. Determine what will happen if a leak does occur. Decide how to respond. Practice the emergency procedures by conducting drills.

Be creative when conducting drills. Throw a few curve balls to see how operators will react. You may find that no matter how many times you conduct a drill successfully, your plan will not work as designed during a real emergency. Something will throw you off. Evaluate every drill or emergency and modify the plan to account for mistakes, then train everybody on the modifications.

Keeping the chlorine contained is the best practice, and the industry has a pretty good record at this. If chlorine ever does get loose, having a well-thought-out emergency plan may prevent catastrophe.

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3 Simple Steps to Effective Maintenance

by Jim Flynn

A critical component of a utility's success is the performance of its maintenance program. The program's main responsibility is to ensure the efficient and reliable delivery of a high-quality product at the lowest cost. The rising costs of equipment, supplies, materials, and spare parts, in addition to the high-tech nature of modern water treatment and distribution equipment and processes, have caused more attention to be paid to the organization and effectiveness of maintenance programs. This is more apparent in today's economy, where downsizing prevails.

Avoiding the high costs of service associated with breakdowns can be a significant factor in the utility's ability to meet its mission and budget. Maintenance is sometimes looked at as a necessary evil, rather than an important component of the utility's overall operation. A philosophy of "If it ain't broke, don't fix it" will result in equipment breakdowns and the associated high costs of overtime, replacement, and loss of service.

By following the three simple steps of effective maintenance, any utility, regardless of size, can reduce costs and downtime, maximize equipment reliability, and provide the highest level of customer service.

Organize

To be effective, a maintenance program must be managed in an organized manner. One primary utility responsibility is the organization and administration of a maintenance program. Today's maintenance manager's knowledge, skill, and ability must be administrative, financial, and supervisory, as well as technical; he or she must be a skilled manager who is multitalented. Most important, the person who is responsible for the maintenance program must be given the necessary time, support, and assistance needed to perform at the level of maintenance required.

Organize the work activities toward preventive and predictive maintenance tasks, as opposed to repair work. In general, preventive maintenance activities will lengthen equipment life span and reduce breakdowns and overtime repair costs. The utility should focus on activities that increase equipment reliability, which in turn will reduce breakdown maintenance costs and increase profit. Successful maintenance programs develop in organizations where more time is spent on preventing problems before they occur.

Plan

Some simple planning will help to organize a preventive maintenance program (PM) and ensure its success. Whether the program is computerized or manual, the following components should be included:

Equipment Database

Develop a master listing of the equipment to be maintained. The equipment database should include as much information as possible, such as, but not limited to, nameplate data, recommended maintenance, fixed-asset financial information, spare parts, and the name of the manufacturer's authorized service representative.

Types of major equipment that should be included in the maintenance program are pumps, motors, control valves, generators, electrical systems, electronics, chemical feed systems, HVAC systems, and buildings and grounds.

Tasks, Instructions, and Schedules

Identify the recommended PM tasks for each piece of equipment in the database. Detailed instructions should be developed, including parts, materials, and special tools needed; these can be incorporated in a work order. The various tasks can then be scheduled based on the recommended frequency, manpower availability, and maintenance budget.

In order to better organize PM activities and manage available manpower, similar tasks on similar pieces of equipment should be performed together, based on a planned schedule.

Inventory Control

To effectively schedule PM tasks, the correct parts and materials need to be on hand when needed. First determine the parts required for each PM task, as well as the basic spare parts or components needed to get a piece of equipment back on line quickly in an emergency. One person should be responsible for controlling the parts inventory, and each worker needs to be accountable for materials used on a specific job.

Maintaining stock on every recommended spare part is difficult and costly; there are a few methods of reducing inventory while ensuring that parts are available for routine and emergency maintenance: Keep uniformity in equipment; you can stock fewer replacement parts. Have easy access to local vendors to allow quick access to parts and materials. Plan ahead for scheduled PM work and order the parts to arrive "just in time." Maintain a basic stock level of parts, and place orders routinely, based on the basic stock level.

Train

Well-trained personnel are the main force behind an effective maintenance program; they are its most valuable asset. Training not only assures adequate skill and ability but also improves morale

Table 1 Maintenance Task Schedule

Equipment	Task	Frequency
Pump maintenance	Inspection, oil change and lube, disassemble and rebuild, vibration analysis	Weekly inspection, semiannual lube, annual teardown
Motor maintenance	Inspection weekly, oil change and lube, test and rebuild, vibration analysis	Weekly inspection, semiannual lube, 5-year rebuild cycle
Chemical feed pumps	Inspect, change oils, rebuild heads, PRVs, and back psi valves	Daily inspection, semiannual oil change and rebuilds
Control valves, PRVs, altitude valves	Inspection, strainer and filters, pilot rebuilds, valve rebuilds	Inspect monthly, clean strainers monthly, pilots quarterly, rebuild annually
Electrical maintenance	Inspection, clean, adjust all high- and low-voltage switchgear	Inspect quarterly, annual preventive maintenance by OEM service rep
Standby engines and generator sets	Inspect and test run, PM as per OEM manuals	Test run and inspect weekly, annual PM by OEM service rep
Chlorinators, booster pumps, and controls	Inspect, rotate out of service, and rebuild	Daily inspection, semiannual rebuild
Flow, level, and pressure transmitters	Inspect, test, and calibrate	Inspect quarterly, test and calibrate annually
HVAC equipment	Inspect and preventive maintenance as per manufacturer manuals	Inspect monthly, spring and fall preventive maintenance
Storage tanks	Inspection, vent screens, flappers, ladders, and coatings	Semiannually

and motivation. The training component of a good maintenance program should include basic skills, theory of operation, troubleshooting techniques, documentation, safety, and personal development. Training can be in-house or "on-the-job" or formal through a manufacturer.

Consolidate workers' skills through cross training to allow more flexibility and productivity; develop attitudes of teamwork so that everyone works toward the common goal of proactive maintenance. There will always be a need to employ outside service personnel; however, these instances can prove to be valuable training opportunities for in-house personnel.

To remain cost-efficient, utilities can realign their strategy of maintenance. An organized, well-planned approach, using the three simple steps above, will reduce costly equipment repairs and maximize life span and reliability. Focusing on preventive maintenance with a well-rounded workforce will play an important role in the ability of a utility to provide the highest quality product at a reasonable cost.

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Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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