INTRODUCTION

Approximately 7.5 percent of the irrigable land in southern Alberta, or 50,000 acres, has been salinized because of seepage from canals and ditches. This seepage can be effectively controlled by lining the canals and ditches with relatively impermeable materials. Polyethylene and compacted clay have been the most popular lining materials in southern Alberta. Except for a few isolated cases, concrete has not been used, probably because of its high initial cost and a lack of knowledge of its performance under the widely fluctuating temperatures of the chinook climate in the area.

In 1914 a half-mile of concrete lining was manually placed in a canal near Strathmore, Alberta, by the Canadian Pacific Railway (5). In 1966 the lining appeared to be still in good condition but no quantitative information on its effectiveness in seepage control is available.

In 1950 a 964-foot section of canal near Swift Current, Saskatchewan, was lined with shotcrete (pneumatically applied mortar) as part of a study undertaken by the Prairie Farm Rehabilitation Administration (PFRA) over canal and dugout linings. In 1953, both precast concrete slabs and ‘cast-in-place’ concrete linings were installed in a 450-foot section of canal near Outlook, Saskatchewan, under the PFRA program. Periodic reports (1, 2, 3, 4) indicate that shotcrete lining controlled seepage and was particularly effective when reinforced with wire mesh. The unreinforced sections were beginning to deteriorate, and the use of steel reinforcement was strongly recommended for concrete lining in canals and ditches. Shotcrete, precast concrete slabs, and ‘cast-in-place’ concrete, although effective in lining canals and ditches, all had high initial costs.

Since 1946 the United States Bureau of Reclamation has conducted a research program aimed at reducing the cost of seepage control (7). The resulting relaxation of specification standards and elimination of reinforcing steel to permit greater mechanization of placing equipment have made it economically feasible to line small canals and ditches in the United States.

In the opinion of the authors the 50-foot expansion joint intervals in the shotcrete lining of the Swift Current canal were responsible for much of the uncontrolled cracking between joints. With the use of shorter intervals and the elimination of reinforcing steel an improved concrete lining could be constructed at reduced cost. Consequently a study was undertaken in 1963 to determine the performance, under the climatic extremes of southern Alberta, of unreinforced concrete ditch lining placed with a subgrade-guided slip-form.

MATERIALS AND METHODS

A farm ditch in a recently developed irrigated pasture near Hays, Alberta, was selected. The loam soil is representative of much of the irrigated area in southern Alberta. In October 1963, 1550 feet of unreinforced concrete lining were placed directly on this soil without gravel underlay, using a subgrade-guided slip-form. The design specifications for the completed ditch were: bottom width 18 inches, side slopes 1.14 to 1, depth 18 inches, slope 0.001, capacity 6 cfs, and lining thickness 3.6 inches.

Before the concrete was placed the ditch was shaped to the desired cross section with a specially constructed bucket on a truck-mounted hydraulic excavator. The slip-form used in placing the concrete lining was towed by a crawler tractor (figure 1). Concrete was hauled to the slip-form by transit mix trucks from a mixing plant temporarily set up at the site (figures 2 and 3). Expansion joints were made at 10-foot intervals using a template and a grooving tool (figure 4). After placement the concrete was moist-cured under a polyethylene film. The expansion joints were later filled with a sealing compound.

The coarse aggregate used in the concrete mix was well graded but on the fine side of the limits for a 1½-inch
in the mix. The unit water requirement was 245 pounds per cubic yard and so, with a water to cement ratio of 0.47, the cement factor was 6 sacks per cubic yard.

Tests for slump and air content were made as the concrete was produced. Compressive strength and freeze-thaw tests were carried out on cylinders and beams which were molded during mixing.

Inspections and ponding tests were carried out annually or oftener to determine the performance of the concrete lining in controlling seepage. At each inspection the location and orientation of new cracks between the expansion joints were recorded. In each ponding test, seepage losses were determined from the drop in the level of water ponded between checks in the ditch. Seepage losses (corrected for evaporation during tests) were compared with those measured in a ponding test prior to lining. For comparison the ditch was divided into seven approximately equal sections.

RESULTS AND DISCUSSION

Slump tests during the mixing operation gave slump values from 1 1/4 to 3 1/2 inches. This moderate variability in slump was attributed to non-uniformity of the moisture content of the fine aggregate and to difficulties in accurately measuring the water. Good control of air content was obtained; measured values were between 4.5 and 5.0 percent for all tests.

The 28-day compressive strength of six out of seven test cylinders exceeded 4800 psi. In the seventh cylinder failure occurred at 3440 psi and was probably related to the unusually high 3 1/2-inch slump of that batch. However, all seven values are considered adequate for concrete ditch lining.

Tests on three beams indicated that the concrete would perform very well under freeze-thaw conditions. According to a system used by PFRA (6) for evaluating freeze-thaw resistance, this concrete was classified as fair to good on the basis of weight loss during the test and excellent on the basis of durability factor.

The results of inspections and ponding tests are presented in tables I and II. Only data on cracks appearing between the expansion joints are included in table I. The November 1963 inspection was conducted about six weeks after construction. The cracks observed then were probably the result of shrinkage. The total length of cracks between expansion joints increased each year. A spectacular increase in cracking in the

| TABLE I. CUMULATIVE LINEAL FOOTAGE OF CRACKS IN CONCRETE (EXCLUDING CRACKS IN EXPANSION JOINT GROOVES) |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|
| Date of inspection | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1-7 |
| Nov. 27, 1963 | 24 | 6 | - | - | - | - | 30 |
| Apr. 27, 1964 | 39 | 6 | 6 | 2 | 2 | - | 5 | 60 |
| Sept. 28, 1964 | 44 | 12 | 12 | 9 | 2 | - | 9 | 88 |
| Apr. 28, 1965 | 83 | 14 | 16 | 9 | 3 | - | 12 | 137 |
| May 4, 1966 | 132 | 65 | 70 | 9 | 4 | - | 12 | 292 |

| TABLE II. SEEPAGE LOSSES IN CUBIC FEET PER SQUARE FOOT OF WETTED PERIMETER PER DAY |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|
| Date of ponding test | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1-7 |
| Sept. 17-19, 1963 | 0.25 | 0.30 | 0.34 | 0.52 | 0.23 | 0.34 | 0.40 | 0.34 |
| Sept. 15-21, 1964 | 0.07 | 0.07 | 0.07 | 0.04 | 0.02 | 0.02 | 0.10 | 0.06 |
| Oct. 8-13, 1964 | 0.04 | 0.04 | 0.05 | 0.01 | 0.00 | 0.00 | 0.04 | 0.03 |
| Oct. 26-29, 1965 | 0.12 | 0.08 | 0.12 | 0.04 | 0.04 | 0.01 | 0.15 | 0.08 |
| Oct. 4-7, 1966 | 0.15 | 0.10 | 0.22 | 0.02 | 0.07 | 0.02 | 0.13 | 0.10 |

1 Prior to lining October 16-18, 1963.
2 Prior to joint sealing September 30, 1964.
first three sections was noted in the May 1966 inspection. This increase was due primarily to the formation of longitudinal cracks, which were not present in the remaining four sections.

The water table at this site has been rising each year as a result of seepage from an adjacent unlined canal and deep percolation during the irrigation season. The average depth of the water table during the winter preceding the May 1966 inspection was 8 feet. The water table had risen more rapidly under the first three sections because of the proximity of the unlined canal. Probably the rising water table has increased frost heave and accelerated crack formation.

The expansion joint grooves in the first three sections were smaller than is usually considered adequate. The grooves in these sections were about ¼ inch wide and ⅞ inch deep; in the remaining four sections they were about ½ inch wide and ¾ inch deep. Presumably the smallness of the grooves in the first three sections was partly responsible for the formation of cracks between expansion joints, particularly in the presence of a high water table.

The seepage loss from this ditch was reduced by more than 80 percent from the pre-lining value of 0.34 cubic foot per square foot of wetted perimeter per day (table II). There was a further 10 percent reduction after the expansion joint grooves had been filled with a sealing compound. During the two years after the joints were sealed there was a slight increase in seepage loss. However, the seepage loss reduction was still greater than 70 percent.

After three years of service most of the seepage loss was occurring from the first three and the last sections. The reason for the high loss from the last section is not apparent. However, the relatively high losses from the first three sections were probably due to the greater amount of interjoint cracking in these sections. In general, crack formation between joints was reflected by greater seepage loss. Evidently the restriction of cracking to the expansion joints is a significant factor in seepage control. The relatively low losses from sections four, five, and six indicate that cracking between joints can be controlled by proper groove construction.

Experience gained during the construction of this concrete-lined ditch indicated that its cost on a commercial basis would be about $1.50 to $2.00 per lineal foot.

**SUMMARY**

Seepage loss from an irrigation ditch was reduced by more than 90 percent by installing an unreinforced concrete lining with a subgrade-guided slip-form. After three years of service the seepage reduction was still greater than 70 percent. Most of the increase in seepage is attributed to crack formation between expansion joints. The importance of providing adequate expansion joints is emphasized.

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**REFERENCES**

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**...DEEP TILE DRAINS**

**continued from page 70**

expressed as ECe/SAR ratios over the range of ECe from 1 to 20 mmhos/cm. Ratios obtained throughout this study were combined and grouped according to the ECe values (table II). Although the standard deviation was fairly large for the lower ECe ratios did not change very much. No differences in relation to the ECe during the reclamation period were observed for the various drainage practices. Thus the concentration of Na+ relative to Ca++ and Mg++ decreased continuously with decreasing ECe, indicating that water movement through these soils was probably not restricted. The gypsum present probably had a beneficial effect.

**CONCLUSIONS**

The study showed that reclamation of salt-affected glacial soils can be attained on sloping land with deep tile drains. However, it is questionable if deep tile drains are more useful than shallow tile drains for salt removal at depths from 3 to 6 feet. Care should be taken that the water table is not within 3 feet of the surface for long periods during the growing season.

Although the areas with a combination of shallow and deep tile drains received more water than the area with deep tile drains only, no significant difference was found in the effectiveness of reclamation of both treatments. The initial salt content of the soil with deep drains only was higher than that of the other treatment but at the end of the study ECe values were nearly the same for both treatments.

The ECe of soil leached without artificial drainage did not drop below 7.5 mmhos/cm, indicating that fall leaching of soils in seepage areas is not effective in reclaiming land.