SOIL-ASPHALT MIXTURE FOR CANAL SEEPAGE CONTROL: LABORATORY STUDY

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A material for lining irrigation canals composed of soil, anionic asphalt emulsion, Wyoming bentonite, an enzymatic wetting agent, and water was developed in the laboratory. Discs of the material were tested for seepage control, and resistance to erosion, weathering, freezing, and thawing. A ditch model was subjected to a continuous stream of water (70 liters/min with an average velocity of 114 cm/sec) for 30 days. The material was satisfactory under laboratory conditions. It had some flexibility and, when wet, was soft and spongy, similar to gum rubber. This flexibility would be advantageous for canals where shifting of the base or frost-heaving is a problem. But, because of its softness, damage from livestock and similar traffic may be a problem.

INTRODUCTION

Seepage from canals is a major problem in the irrigation districts of Canada. Canal seepage has been identified as the principal cause of salinization (Sadler 1966) of an estimated 15% (van Schaik 1973) of the 0.26 million hectares of irrigated land in Alberta, and the affected area is increasing. Seepage can generally be controlled by lining the canals with one of several materials. The cost of lining often exceeds the direct economic benefit, however, and the performance of the various materials depends upon climate, soil, and drainage conditions.

An ideal lining should be inexpensive to install and maintain, and have a long, effective life. In a study of four lining materials used in Canada, Pohjakas and Rapp (1967) reported that concrete linings were the most costly to install, followed by asphalt, buried black polyethylene, and compacted earth. The durability of each lining exceeded 15 yr, except compacted earth, which deteriorated in 5-10 yr. Frost heaving caused most damage to concrete. Since their report, costs of labor and materials have changed drastically, and the relative cost ratings by Pohjakas and Rapp (1967) are no longer valid. Further, it is generally known that the maintenance cost of buried plastic lining greatly exceeds that of concrete, so that the total cost of concrete may be lower than that of the initially cheaper plastic lining (R.L. Francis, Alberta Agriculture, Lethbridge, personal communication). Concrete has a low coefficient of roughness and is resistant to erosion but, under Canadian conditions, it is subject to fracturing and displacement due to frost heaving.

Elsewhere, other materials have also been investigated for seepage control. For instance, butyl rubber will effectively control seepage (Lauritzen 1967) but, because of cost and availability, its use in Alberta is not attractive. Buried asphalt-impregnated jute is installed in essentially the same manner as buried polyethylene (Geier and Morrison 1968), but its performance is inferior to buried polyethylene and its cost is greater. Lime has been used succcessfully for a highway base stabilizer (National Lime Association 1965), but its potential as a canal lining, where it would be exposed to running water, is questionable.

Chemicals, such as sodium carbonate, have been used successfully to seal ponds (Reginato et al. 1968). This technique for seepage control is attractive because of simplicity of technique, low cost, and availability of material.

Previously, it was not economically feasible, in many cases, for agriculture to bear the costs of lining canals for seepage control. However, demands for greater agricultural production, accompanied by limitations of available land and irrigation water, have necessitated action to prevent further damage of productive lands from seepage, to reclaim those lands already damaged, and to conserve water. Consequently, the objective of this study was to develop a durable, effective lining suitable for Canadian conditions that was less costly than concrete and without some of the disadvantages discussed above.

MATERIALS AND METHODS

Preliminary Investigations

Three types of materials were investigated in the laboratory: chemical, latex, and asphalt emulsions. Cylinders of sodium carbonate-impregnated soil were subjected to heads of flowing water to determine the effectiveness of sodium carbonate as a sealing agent in a dynamic system. Also, mixtures of soil with latex, anionic asphalt emulsions, or cationic asphalt emulsions were subjected to heads of water to determine their effectiveness for seepage control. Because asphalt emulsions are readily available and considerably cheaper than latex, four (supplied by Pounder Emulsions, Edmonton, Alberta; mention of a supplier or product does not constitute an endorsement of the supplier or product) were tested. The emulsions tested were a cationic emulsion and three anionic high float emulsions, having approximage penetration numbers of 133, 400, and 600 with 58, 62, and 66% asphalt content, respectively. These were screened by their miscibility with the soil, plasticity of the mixture, and effectiveness in controlling seepage. The effect of Wyoming bentonite and wetting agents were also evaluated in the soil-asphalt mixtures as additives to enhance seepage control and miscibility of the ingredients.

The results of this preliminary study were used as guidelines in designing the primary investigations.

Primary Investigations

Disc study

In a three-replicate experiment, 200 g of air-dried Cavendish fine sandy loam (Bowser et al. 1963) containing 3 g moisture was thoroughly mixed with 40 ml of anionic asphalt emulsion, 15 ml of water, Terazyme (an enzymatic wetting agent supplied by United Industrial Industries Ltd., Calgary, Alberta) (0 or 0.8 g), and bentonite (0, 2, 4, or 6 g). The asphalt rate and moisture level (soil field capacity, 0.3 bar) had been established in the preliminary investigations.

The homogenous mixtures, having a consistency of thick paste, were transferred to specially made cylinders for seepage testing (Fig. 1). (The cylinders consisted of two sections of plexiglass tubing 5 cm long, 10 cm inside diam, and wall thickness of 0.56 cm. One end of each section was rabbetted to form a watertight shiplap joint when a rubber "O" ring was placed at the internal angle of the joint and the two sections were firmly clamped together.) Before transferring the mixtures to the cylinders, the basal sections, which had porous bottoms glued to the plexiglass section, were half filled with air-dried soil of known moisture content on which a 10-cm diam filter paper was placed. The asphalt mixture was applied to the filter paper, uniformly spread, and lightly compressed to form a disc about 2 cm thick (the upper wall of the base section had been previously heavily coated with petroleum jelly to make a watertight seal between the cylinder and the mixture). Another filter paper was placed on the disc and dry soil was added to keep the filter in place. After the mixture had cured for 2 h, a head of water was applied to the reservoir above the disc and left for 1 wk in a seepage test. Plastic bags were attached to the base of the cylinders to collect any seepage water.

After the seepage test, the discs were removed from the cylinders, wiped dry and free of petroleum jelly, weighed, air-dried (48 h at 22 C), and reweighed to determine moisture loss. The air-dried discs, with a small channel cut across the upper surface, were placed on a rack at a 25% slope, with the channels oriented along the steepest gradient, and a small stream of water was directed down the channels for 48 h (Fig. 2). The effects of the water on the disc were determined visually and by weighing the disc before and after the water was applied.

The discs were then subjected to 10 cycles of freezing and thawing (-29 and 21 C) to observe visible disintegration. Also, measurements to 0.005 cm between two fixed points were taken on the frozen and thawed discs to determine the amount of expansion. Finally, the discs were set on racks out-of-doors (Fig. 3), exposed to the elements to determine their resistance to weathering. This phase of the study has continued for 4 yr to date; the air temperature has varied from -30 to 37 C.

Ditch model

Erosion and seepage were studied in a ditch model (Fig. 4) to evaluate the mixture that appeared superior in the disc study. The mixture consisted of 100 parts (by weight) soil, 20 parts (by weight) anionic asphalt emulsion, 9 parts (by weight) water, 0.1 part (by weight) Terazyme, and 2 parts (by weight) bentonite.

To form the lining in situ, the plexiglass chamber, 125 cm long, was filled with air-dry soil and a ditch channel was shaped (10 cm deep with 2.5 cm bottom and 1.5:1 side slope). Asphalt emulsion, bentonite, and water were each uniformly applied over the surface of the ditch channel (in sufficient quantity for a lining 2 cm thick) and thoroughly mixed with the surface 2 cm of soil. The mixture was trowelled smooth along the course of the ditch, lightly rolled, and left to cure overnight before the water was introduced. (Before spreading the mixture, the ends of the plexiglass chamber were heavily coated with petroleum jelly to form a watertight joint betwen the ends of the lining and the chamber.) The chamber was elevated on one end to give a 10% gradient to the ditch and a continuous stream of water was applied (70 liters/min with a mean velocity of 114 cm/sec and 1.1 cm hydraulic radius) for 30 days. By knowing the mean velocity, slope, and hydraulic radius of the stream, it was possible to calculate Manning's *n*-coefficient of roughness (Linsley and Franzini 1972). The system was observed, visually, throughout the test period for evidence of erosion and seepage: erosion being evident from removal of materials from

Figure 1. Soil-asphalt discs being subjected to seepage control testing. The discs are located at the label level in the cylinders and the plastic bags are to catch any effluent should there be seepage.

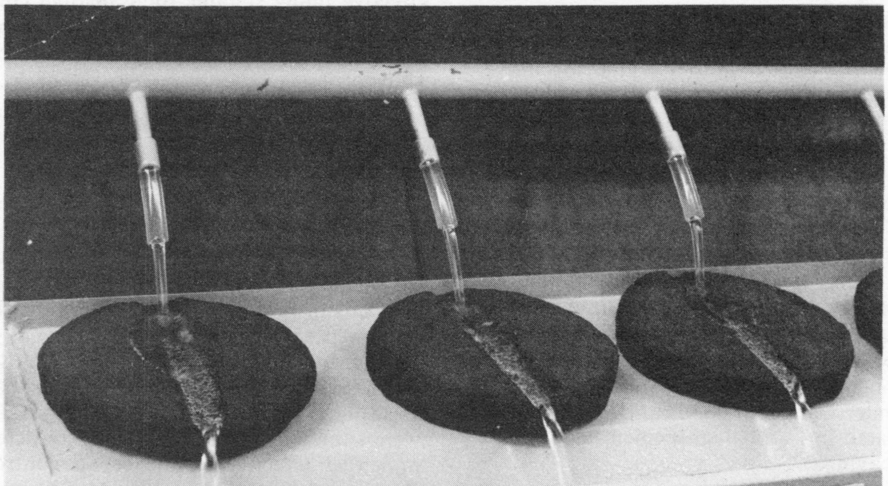

Figure 2. Small stream of water flowing over soil-asphalt discs (on a 25% slope).

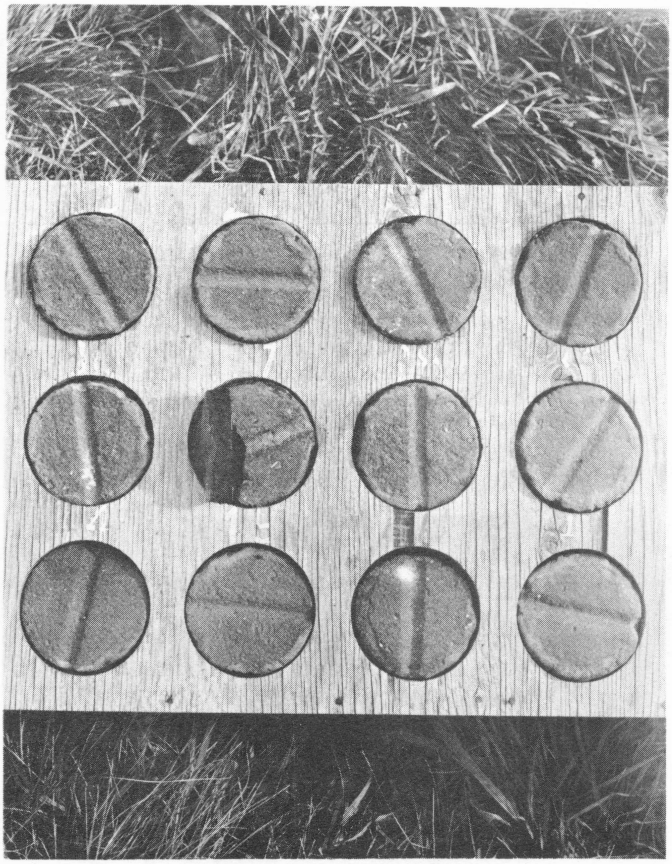

Figure 3. Discs after 4 yr of exposure to weather. Note the dark, unweathered interior of the fractured

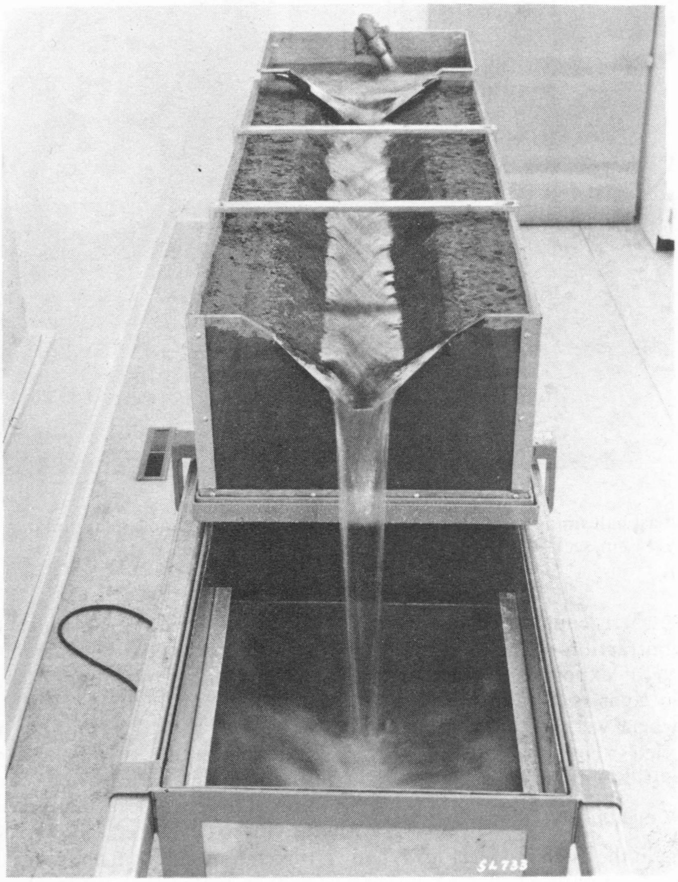

Figure 4. Turbulent water flow in ditch-model lined with soil-asphalt lining. The ditch is on a 10% slope.

channel area and accumulation of sediment in the stilling reservoir, and seepage being evident by signs of wetting of the air-dried soil beneath the lining.

RESULTS AND DISCUSSION

Preliminary Investigations

Sodium carbonate, though satisfactory for lining ponds, failed within 7 days to control seepage in a dynamic system.

Anionic asphalt emulsions, which retained the mixture in a dispersed condition, and latex were effective in seepage control. Cationic asphalt emulsions were ineffective because the mixtures tended to aggregate and seepage resulted. One anionic emulsion (Pounder No. AE658 — slow setting, low viscosity, 66% asphalt content, and a penetration no. of 600) was superior to the others in ease of mixing and seepage control and was the asphalt emulsion used in the mixtures reported here.

Wyoming bentonite and Terazyme seemed to enhance seepage control and miscibility of the soil-asphalt material. Other wetting agents (two claiming to be wetting agents and a household detergent) did not exhibit the same properties as Terazyme. Because of the apparent value of the bentonite and Terazyme in the mixture, they were included as variables to be studied in the primary investigations.

Primary Investigations

Disc evaluation

The intended purpose for bentonite in the mixture was to absorb moisture, swell, and seal any voids left by the asphalt. Based on the moisture content of the soil beneath the discs (Table I), the best mixtures contained 2 parts bentonite to 100 parts of soil by weight. However, after the seepage study, the moisture content of discs containing 3 parts of bentonite with 100 parts of soil was similar to that of those containing 2 parts bentonite (Table I). Of the 24 cylinders, water drained

TABLE I **MOISTURE CONTENT OF THE SOIL BENEATH THE SOIL-ASPHALT DISCS AND OF THE SOIL-ASPHALT DISCS AFTER THE SEEPAGE TEST, AS AFFECTED BY BENTONITE AND ENZYMATIC WETTING AGENT**

	% of dry-wt basis	
Treatment†	H_2O in soil	H_2O in discs
Bentonite		
0	26.3	10.5
1	14.6	10.6
2	9.8	11.7
3	14.6	12.2
Wetting agent		
0	16.9	11.3
0.1	15.7	11.2
	SD = 10.4	SD = 1.0

†Grams per 100 g of soil.

TABLE II WEIGHT LOSS OF THE SOIL-ASPHALT DISCS AFTER 48 H OF WATER RUNNING DOWN CHANNELS (WT OF DISC ABOUT 200 G)

Treatment†	Wt loss (g)
Bentonite	
0	0.09
1	0.19
2	0.14
3	0.59
Wetting agent	
0	0.22
0.1	0.23

†Grams per 100 g of soil.

into the plastic bags in seven and of these, no bentonite had been added in four and only 1 part of bentonite had been added per 100 parts of soil in three. This strongly suggests that the absence of bentonite allowed greater percolation of water. Apparently, the bentonite functioned by adsorbing moisture, swelling, and further sealing-off the discs.

Based on the water content of the soil beneath the discs, the wetting agent tended to restrict seepage, although the reduction was not significant (Table I). Also, the wetting agent had no effect on the amount of moisture retained by the discs (Table I). Furthermore, of the seven instances where leakage was recorded, three were from cylinders where wetting agent was added and four from where there was none. Hence, it appears that the wetting agent alone did not increase the effectiveness of the mixture for seepage control. However, the miscibility and workability of the mixture were greatly enhanced by the inclusion of the wetting agent.

After a 48-h exposure to small streams of water (Fig. 2), the changes in weights of the discs were small (Table II) and no breakdown was visible. The changes in weight were attributed to evaporation of water from the discs. Although the erosive energy in the stream was small, the mixture itself appeared to be resistant to erosion because of its cohesive and hydrophobic characteristics. The angle of contact between the water and the disc surface exceeded 90°, as with mercury and most surfaces. The weak adsorptivity of the surface for water should inhibit moisture movement into the mixture.

TABLE III LINEAR EXPANSION (CM/CM/DEGREE C X 10^{-4}) OF SOIL-ASPHALT MIXTURE OVER A 50C TEMPERATURE INTERVAL (FROM -29 TO 21C)

Soil-asphalt mixture plus†		Replication		
Bentonite	Wetting agent	1	2	3
0	0	2.53	0.00	-0.27
	0.1	0.00	0.00	0.00
1	0	-1.19	0.00	-0.70
	0.1	-0.45	-0.39	-0.14
2	0	0.00	-0.39	-0.28
	0.1	0.14	0.39	-0.13
3	0	0.00	0.16	-0.13
	0.1	0.00	0.80	-0.66

†Grams per 100 g of soil.

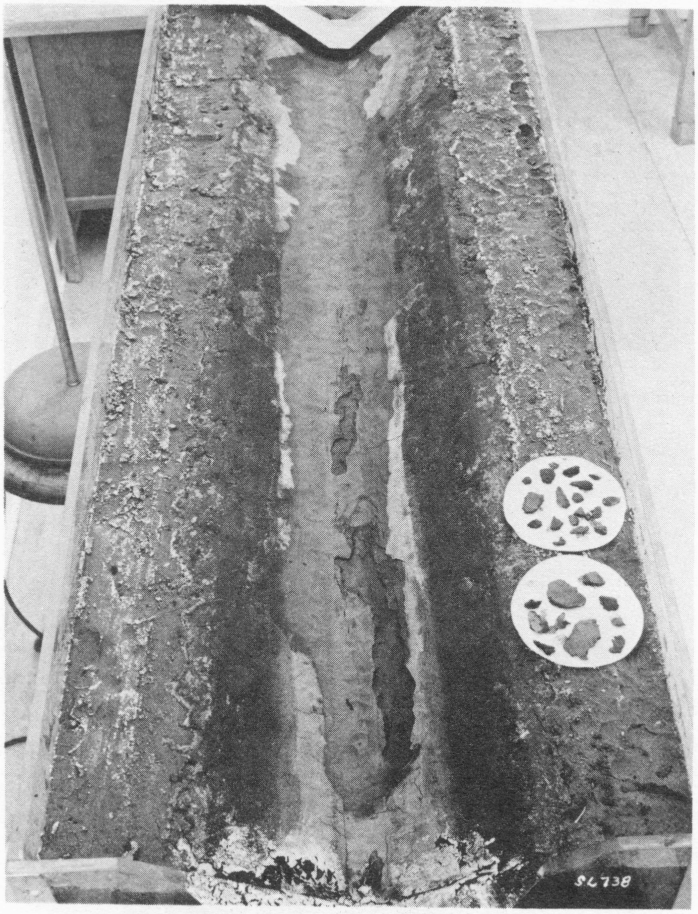

Figure 5. Soil-asphalt lining in ditch model after 30 days of continuous operation (q = 70 liters min; $\overline{v}$ = 114 cm/sec).

Freezing and thawing had no visible effect on the discs and neither disintegration nor fracturing was evident. Expansion results were variable (Table III). Negative values were obtained in 11 instances and zero in 8. There were undoubtedly compensating expansion-contraction reactions among the ingredients, such as contraction of the melted free water, and of density changes of the adsorbed water by the clay (Low 1961), which could affect the overall expansion-contraction of the mixture.

After 4 yr of exposure to weather, the discs had no signs of breakdown (Fig. 3). However, when wet, as in a rainstorm, surface particles could be dislodged by rubbing the discs with a finger.

Ditch model evaluation

The lining in the ditch model (Fig. 4) had a coefficient of roughness (n for Manning's equation) of 0.014. It performed satisfactorily for 30 days, at which time leakage occurred between the wall of the chamber and the end of the lining. Also, it was noted that chips of the lining had lifted from the bottom of the ditch (on filter paper, Fig. 5) probably as a result of taking depth measurements at various times for determination of the cross-sectional area of the stream. Cavities developed under the film and through mechanical action of the water, the surface materials over the cavities chipped off.

In both the disc and model studies, the cured mixtures, when under water, were spongy, similar to gum rubber, and this characteristic was evident to a lesser degree in the fresh, air-dried mixtures. However, after more than 4 yr of weathering, the discs were somewhat rigid, like soft sandstone. This flexibility of the mixture should allow the lining to flex and shift without fracture, as under conditions of frost heaving. However, because of its softness and flexibility, the linng would be damaged easily by traffic such as livestock in the field.

Based on the results of this study, the soil-asphalt mixture as used in the model was effective in controlling seepage and has a favorable potential as a lining for seepage control. It performed satisfactorily under the various laboratory tests, and the materials cost less than concrete. However, the cost advantage lessens as the cost of oil rises. For instance, in 1972, the cost of materials for a soil-asphalt lining was 54% that of concrete of equal thickness, but in 1976 it was 65%. Field studies are in progress to further evaluate the mixture as a lining to control seepage from canals. If these studies substantiate the laboratory results, this soil-asphalt lining should provide a satisfactory substitute for concrete at considerably less cost and with many of the advantages of concrete, plus the advantage of flexibility.

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