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CEMENT-MODIFIED SOIL IN CANAL LINING

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16. ABSTRACT

In 1958, test sections of silty loessial soil lining treated with portland cement were installed on one side of the Driftwood Canal to resist erosion from water action. This canal, located near McCook, Nebr., has a capacity of 6.3 m^3/s. The cement, in amounts of 4.5 percent by volume for one section and 2.5 percent for another, was mixed with the soil in 600-mm-wide horizontal strips in the lining, which was otherwise constructed as a normal thick-compacted soil lining. In 1981, the cement-treated soil was sampled and laboratory compressive strength and durability tests were performed. Although the soil with 4.5 percent cement was cracked and had a blocky structure, it has resisted erosion reasonably well, even on a curve. The test reach with 2.5 percent cement resisted erosion slightly better on a straight section than the opposite untreated side. However, this section did not contain sufficient cement to adequately resist erosion on a curve.

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Geotechnical Branch
Division of Research
Engineering and Research Center
Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

This investigation was funded from allocations for the Lower Cost Canal Lining and Open and Closed Conduit Systems research programs. The field installation was made under the direction of Construction Engineer W. J. Quinn and Materials Engineer H. E. Hines. K. F. Von Fay, L. J. Flores, and D. H. Novotny of the Geotechnical Branch obtained the samples, and D. H. Novotny, T. J. Spritzer, and J. A. Conrad performed the laboratory tests. R. R. Richmond of the Geotechnical Branch reviewed the report.

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INTRODUCTION

Fine-grained soils of low plasticity (plasticity index less than 10 to 12), including a large proportion of the loessial areas of Kansas and Nebraska, are sufficiently low in permeability for a compacted soil lining. However, these soils are subject to erosion from flowing water and wind-wave action and may need protection, such as a granular cover, to resist erosion. In some areas, good cover materials are not locally available and would have to be imported at considerable expense.

In 1958, after some preliminary laboratory tests were made, experimental test sections of compacted soil lining, with small amounts of Type I portland cement added for stabilization, were placed on the Driftwood Canal, which is located in Nebraska on the Frenchman-Cambridge Division of the Pick-Sloan Missouri Basin Program (fig. 1). Samples of the cement-treated lining were obtained in 1981, and the lining was evaluated by observations of the test reaches and from laboratory tests.

CONCLUSIONS

For a canal in silty loessial soil of the type on the Driftwood Canal test reaches and with the design characteristics of this canal, the following conclusions are drawn:

1. The 4.5-percent portland cement by volume would be enough to adequately stabilize the inside slopes and prevent major erosion from water action. Soil with this amount of cement developed cracks and resulted in a blocky soil structure.

2. The 2.5-percent cement is not sufficient to stabilize the soil on a 20° curve.

3. The sawing of weakly cemented soil into cubic or octagonal laboratory test specimens is feasible and preferable to the coring of cylinders.

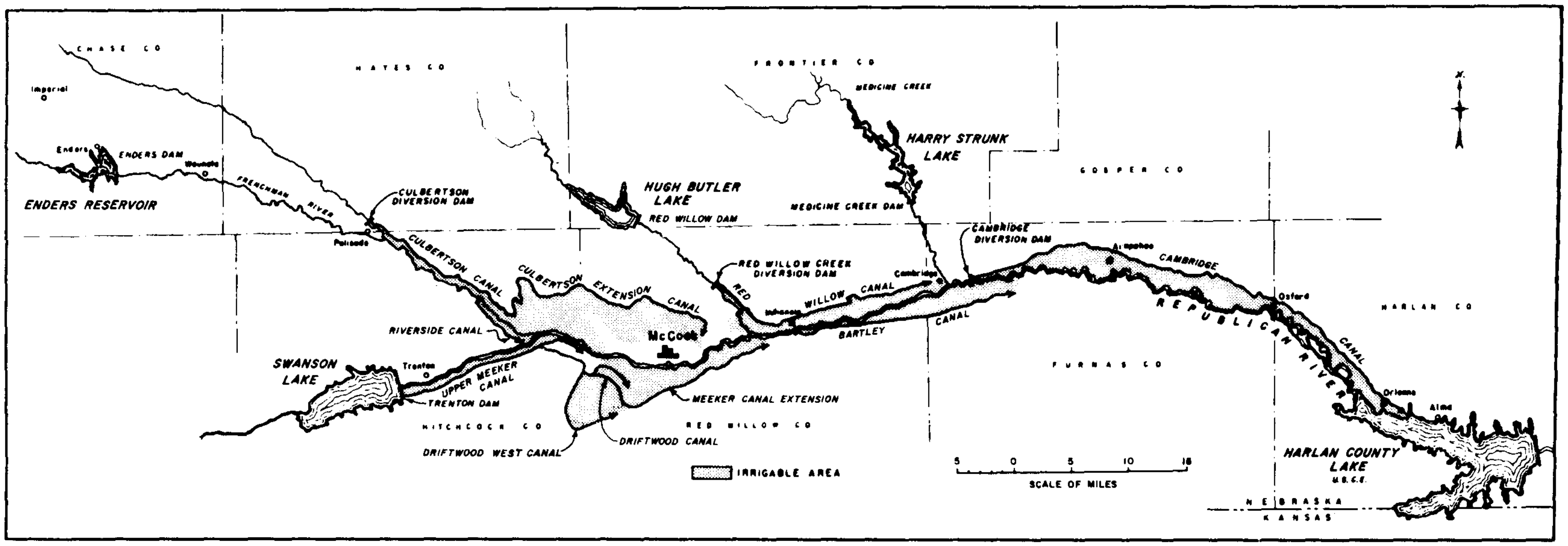


Figure 1. — Frenchman-Cambridge Division, Pick-Sloan Missouri Basin Program.

APPLICATIONS

The investigation described in this report indicates that portland cement can be used to modify the properties of a silty loessial soil in a canal to resist erosion from water action. Such soil treatment should be considered as an alternative method along with gravel cover or other agents where stabilization is needed. The method selected depends on the availability of erosion protection materials and the economics involved.

PRELIMINARY LABORATORY TESTS

In 1957, laboratory tests were performed on silty loessial soils treated with portland cement for proposed usage in canal lining [1][1]. For these tests, soils having similar characteristics to those from the Driftwood and Upper Meeker Canals were mixed and treated with 2, 4, and 6 percent portland cement by volume of soil. Soils treated with such small percentages of cement are usually called cement-modified soils. The untreated soil had a maximum Proctor dry density of 1750 kg/m^3 and an optimum water content of 15.3 percent. The soil had an average liquid limit of 28 and a plasticity index of 7. Also, 94 percent of the soil was finer than the 75-μ m (No. 200) sieve and 14 percent was finer than 0.005 mm.

Specimens of the cement-modified soil were tested for compressive strength, freeze-thaw, and erosion resistance. The specimens for the compressive strength and freeze-thaw tests were 117 mm in diameter and 100 mm long. All specimens were compacted to 96 percent of the laboratory maximum Proctor density and cured for 28 days in a 100-percent humidity room before testing. The compressive strengths of the specimens with 0, 2, 4, and 6 percent cement were 0.076, 1.52, and 4.17 MPa, respectively. For the freeze-thaw tests, specimens were subjected to the standard 12 cycles of freezing and thawing in accordance with the procedure described in ASTM Designation: D 560-57 [2], except that the specimens were brushed only after the 12th cycle. The specimens with untreated soil

[1]Numbers in brackets refer to literature cited in the Bibliography.

failed after the seventh cycle. The losses from brushing after 12 cycles for the 2-, 4-, and 6-percent cement were 27, 15, and 6 percent, respectively.

For the erosion tests [3], specimens 200 mm in diameter by 75 mm long were compacted in plastic permeability molds. After saturation, specimens in the molds were tested in an erosion apparatus (fig. 2). The tank was filled with water to a level above the impeller blades. During an erosion test, the speed of the impeller blades was gradually increased until erosion by water flowing over the surface of the specimen occurred. The equipment was calibrated to determine erosion in terms of tractive forces. When subjected to this erosion test, the specimens containing no cement showed a loss of 32.2 percent by dry mass. The specimens containing 2, 4, and 6 percent cement showed no loss of mass at the capacity of the erosion machine, which was equivalent to a tractive force of 37 N/m^2.

About 3 years after placement of the field test sections on the Driftwood Canal, laboratory erosion and outdoor weathering tests were performed on soil from the field test area treated with portland cement [4]. At that time, there was no appreciable difference in appearance between the untreated and treated soil lining (fig. 3). The soil was loess, classified as a borderline lean clay-silt (CL-ML), which had a maximum Proctor dry density of 1665 kg/m^3 and an optimum water content of 17.8 percent (fig. 4). The liquid limit was 26 and the plasticity index was 7. The soil specimens were compacted in 200-mm-diameter by 125-mm-high plastic cylinders at 95 percent of the laboratory Proctor density. One specimen had 2.5 percent by volume of Type I portland cement and the other 4.5 percent. The specimens were submerged in water for a 5-day curing period. They were then subjected to five cycles in which they were alternately soaked for 48 hours and dried with the surface exposed to an air temperature of 38 °C for 48 hours. The specimens were then tested in the erosion apparatus. After the erosion tests, the specimens were removed from the plastic cylinders and placed in an exposed area on the roof of the laboratory and allowed to weather for 6 months. Photographs (fig. 5) show some surface cracking of the 4.5-percent cement specimen but none in the 2.5 percent cement specimen. However, there was a small amount of vertical cracking in both specimens.

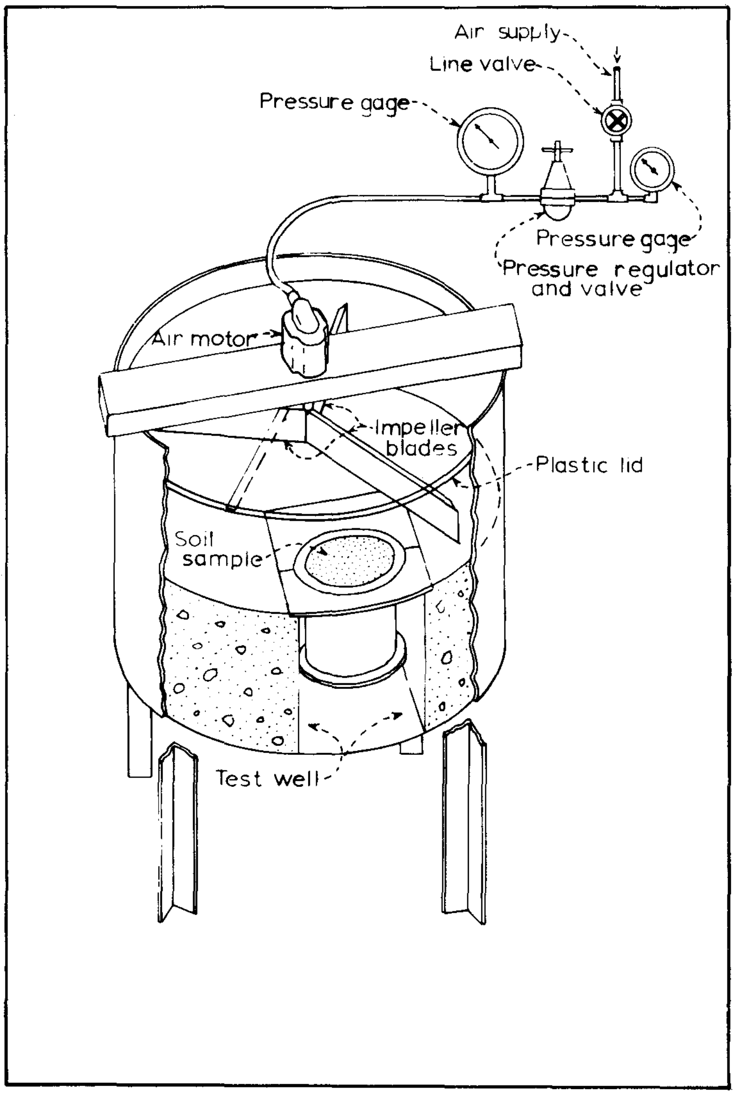
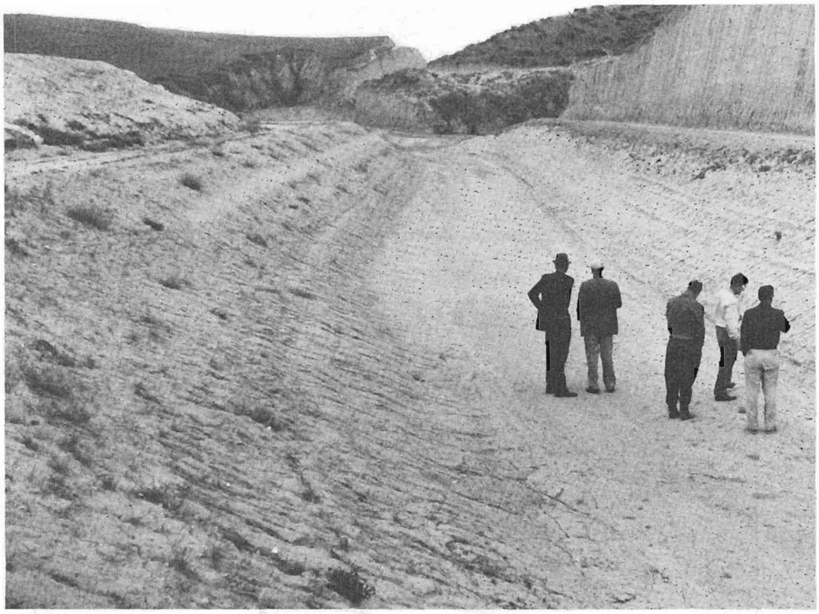
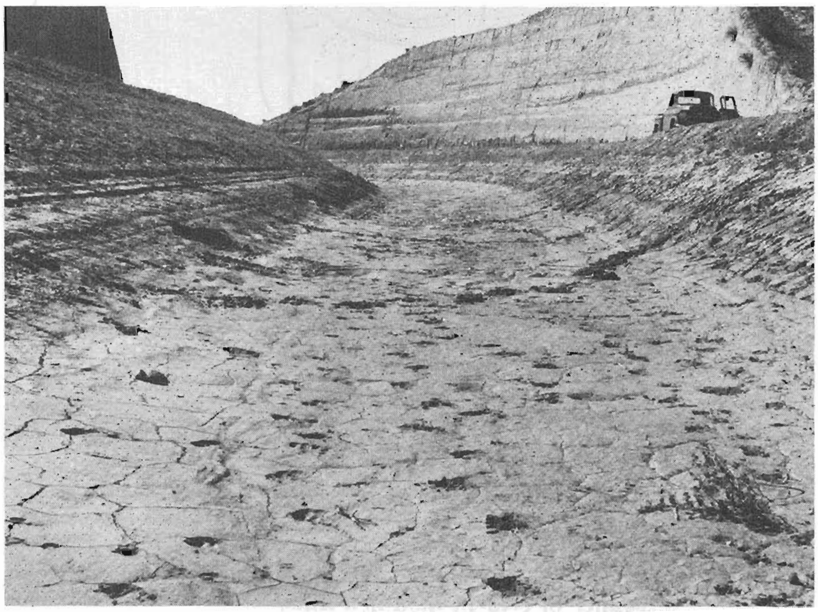


Figure 2. — Apparatus for determining erosion resistance of cement-modified soils.



(a) Station 301+14 with 4.5 percent cement. P328-D-21359.



(b) Station 313+94 with 2.5 percent cement. P328-D-21396.

Figure 3. — Upstream views of cement-modified soil lining on right slope of Driftwood Canal. May 1960.

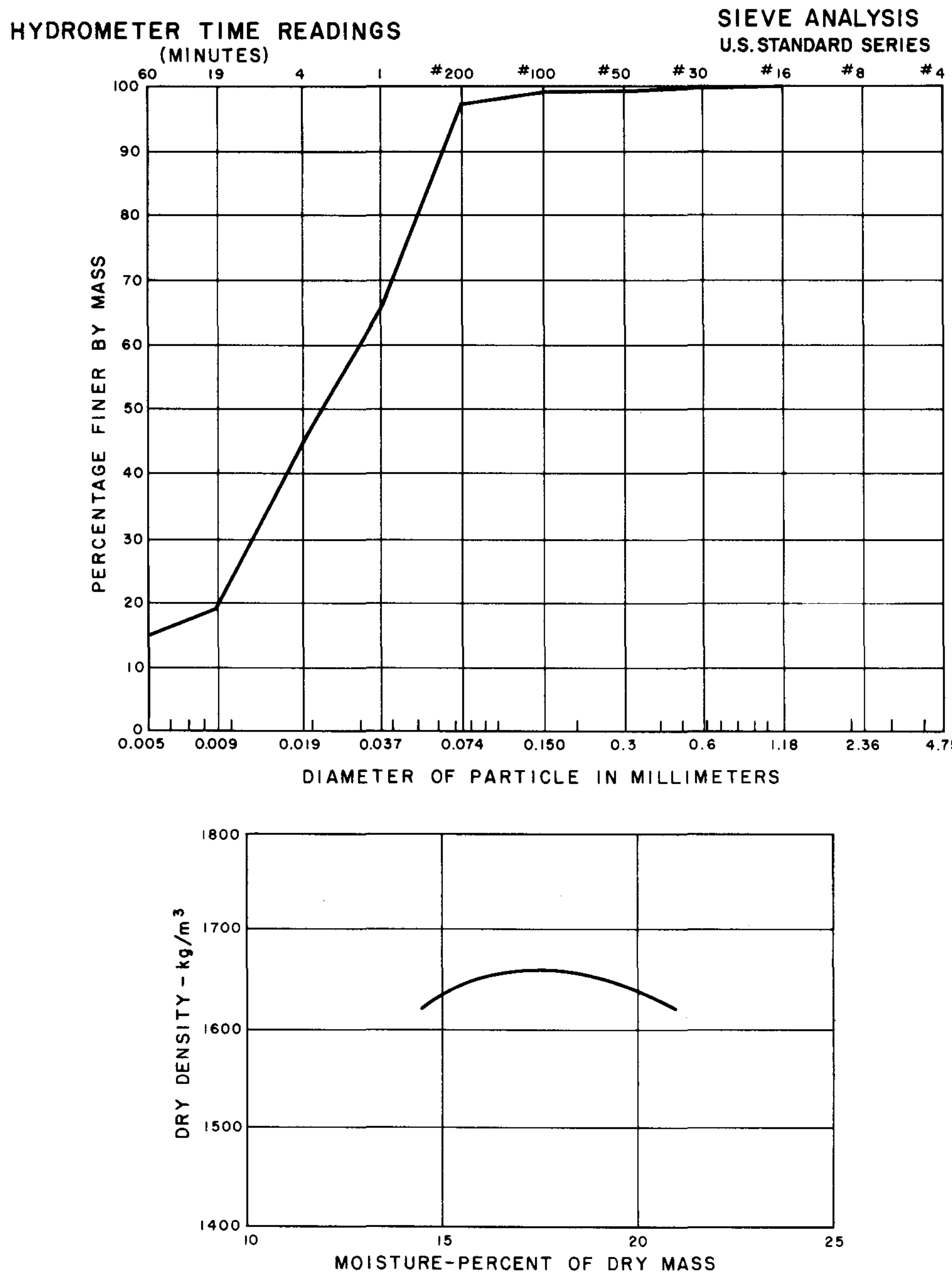


Figure 4. — Gradation analysis and Proctor compaction curve for Driftwood Canal soil.

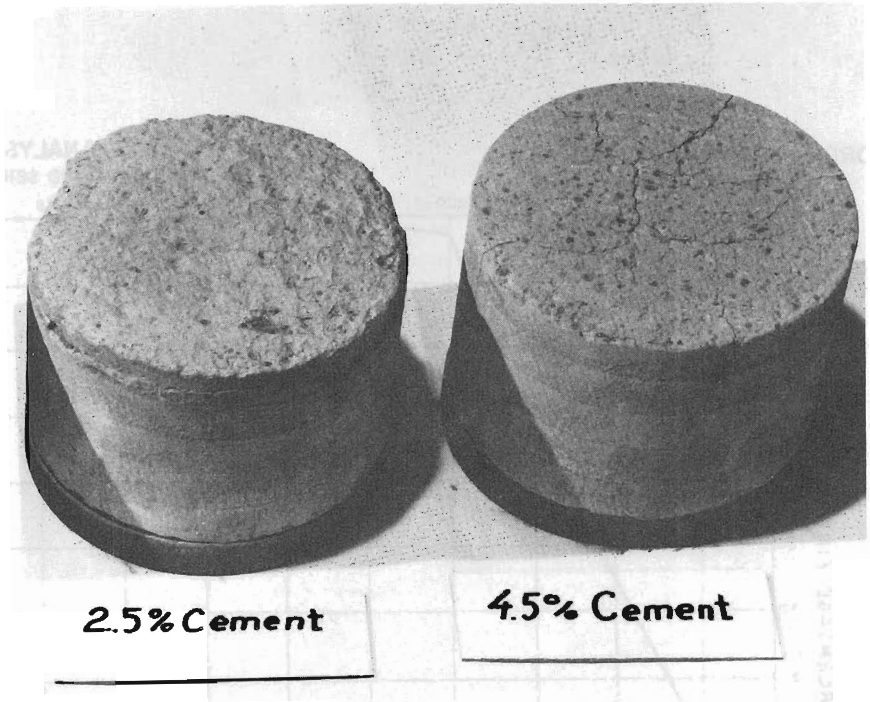


Figure 5. — Cement-modified Driftwood Canal soil specimens after 6 months of outdoor weathering. P801-D-80027.

The procedures for tests mentioned in this section are in accordance with the Bureau's Earth Manual [13] unless otherwise noted.

FIELD TEST SECTION

The Driftwood Canal, where the cement-treated test sections were located, has a designed base width of 4.9 m, a water depth of 1.4 m, side slopes of 2:1, and a water velocity of 0.59 m/s. The longitudinal slope of the canal as designed is 0.00018. The tractive force T on the canal bottom is 2.5 N/m^2, as calculated by the formula $T = wds$. In this formula, w is the unit mass of water, d is the canal water depth, and s is the canal slope [5].

Two cement-treated test reaches of lining were placed on one side of the canal only; one extended from station 298+61 to 301+61 with a specified cement content of 4.5 percent by volume, and the other extended from station 312+32 to 315+07 and contained 2.5 percent cement. The specifications for the lining are given in appendix A.

The cement-modified soil lining was constructed like an ordinary thick-compacted soil lining except that cement was added to a 600-mm-wide horizontal section in the center of the 1800-mm-wide lining. Later, the inside 600 mm of soil was excavated to expose the cement-stabilized soil directly to water in the canal. Each soil layer of the lining was transported and spread by scrapers in the usual manner for compacted soil lining. The layer was then spread to a uniform thickness by two passes of a grader.

The cement was spread by a shop-made, five-bag capacity, cement spreader mounted behind a small tractor (fig. 6). This spreader was constructed similar to a fertilizer spreader with a rotating agitator at the bottom of the hopper. The bottom of the hopper was surrounded by canvas to reduce loss of cement from wind. The spreader was mounted to the tractor with a hinged connection and there was a hydraulic lift so the spreader could be raised off the ground at the end of a run. Also, there was a gate with a lever which was used for opening and closing the bottom of the hopper. For the 4.5-percent cement placement, a second pass was required to apply the specified amount of cement.

Mixing the cement with the soil was accomplished with a rotary tiller (fig. 7) that was pulled by a tractor. Power for the rotating blades of the tiller was supplied by the tractor. The mixer was 1500 mm in width, and mixing action extended into untreated soil on each side of the strip of cement. From visual observations, there did not appear to be appreciable lateral dispersion of the cement outside the application strip. Since the soil being used for the lining was on the dry side of optimum water content, it was necessary to add moisture during mixing (fig. 7). Two passes of the tiller were made before the addition of water. Then, two, occasionally four, more passes of the tiller were required to properly mix the cement and water with the soil. The lining was compacted with a sheepsfoot roller in the normal manner for lining.

The E&R Center Chemical Engineering Laboratory Section of the Applied Sciences Branch determined the cement content of samples of the hardened, cement-treated soil

Figure 6. — Tractor-mounted, shop-made spreader for placing the 600-mm-wide strip of cement. July 1958. P801-D-80028.

Figure 7. — Watering and mixing the soil and cement with a Seaman rotary tiller. July 1958. P801-D-80029.

obtained during the field installation. The test procedure used was essentially that of ASTM Designation: D 806-74 [2] for hardened soil-cement mixtures. Table 1 shows the results of the tests made on the section where 4.5 percent cement by volume was specified. The values shown in table are in terms of cement content by dry mass of soil. The average was 3.5 percent by mass which is equivalent to 3.7 percent by volume for a soil-cement dry density of 1670 kg/m^3. Thus, the cement content by testing was somewhat less than was intended; however, this difference may have been partly due to the laboratory test procedure. Tests on other soil-cement mixtures made at about the same time with known quantities of cement produced results up to 1 percent lower by mass than the actual cement content. The test results show the relative differences in cement content at different locations in the layers.

Table 1. — *Results of cement content tests in 4.5 percent test reach*

Layer No.	Station	Sample location	Cement content, percent by mass
1	300+91	Top half of layer	3.3
		Bottom half of layer	3.1
8	299+92	Top half of layer	3.2
		Bottom half of layer	4.1
		*Inside 100 mm of 600-mm strip	3.4
		Outside 100 mm of 600-mm strip	3.3
10	300+23	Top half of layer	3.8
		Bottom half of layer	4.9
		Inside 100 mm of 600-mm strip	2.7
		Middle of 600-mm strip	4.9
13	299+62	Top half of layer	3.1
		Bottom half of layer	2.0
Average			3.5

*Side to be exposed to canal water.

SAMPLING OF CEMENT-TREATED LINING

In October 1981, samples of the cement-treated soil lining on Driftwood Canal were obtained for laboratory testing. Figures 8 and 9 are views at the sampling location near station 299+82 where a waxed block sample of the stabilized soil was cut with a chain saw. Another sample was obtained near station 300+82 (fig. 10), but this sample came out in small pieces. The cement-treated soil in the 2.5-percent section near station 314+25 (fig. 11) was too fragile to obtain a block sample. Figure 12 shows cross sections of the canal at the sampling locations and the specified canal design section for comparison.

LABORATORY TESTING OF FIELD SAMPLES

Laboratory tests were performed on specimens from the block sample taken from the 4.5-percent cement-treated reach. As shown on figure 13, the block was badly cracked even though extra care was taken in removing and coating it with wax reinforced with cheesecloth.

Density

The average dry density of small irregular waxed chunks found by weighing in air and water was 1670 kg/m^3 (table 2); this is about 100 percent of the average Proctor maximum density.

Compressive Strength

Compressive strengths of the 4.5-percent cement-modified specimens averaged 1.91 MPa (table 3). This test was made on 50-mm cubes sawed from the block sample. Previous experience had shown the difficulty in obtaining good specimens for testing by

Figure 8. — Sampling location in 4.5 percent cement-modified reach on inside curve at station 299+82. Gravel has been added on the opposite, untreated bank to reduce erosion. P801-D-80030.

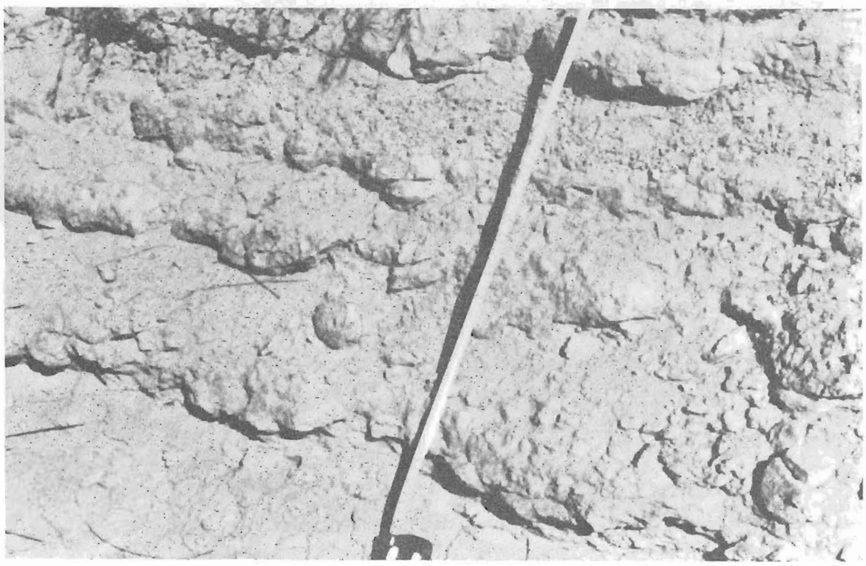


Figure 9. — View of 4.5 percent cement-modified soil near station 299+82. P801-D-80031.

Figure 10. — Sampling location in 4.5 percent cement-modified reach on outside curve at station 300+82. P801-D-80032.

Figure 11. — Looking upstream at sampling location for 2.5 percent cement-modified soil lining at station 314+25. Treated bank on right and untreated bank on left. P801-D-80033.

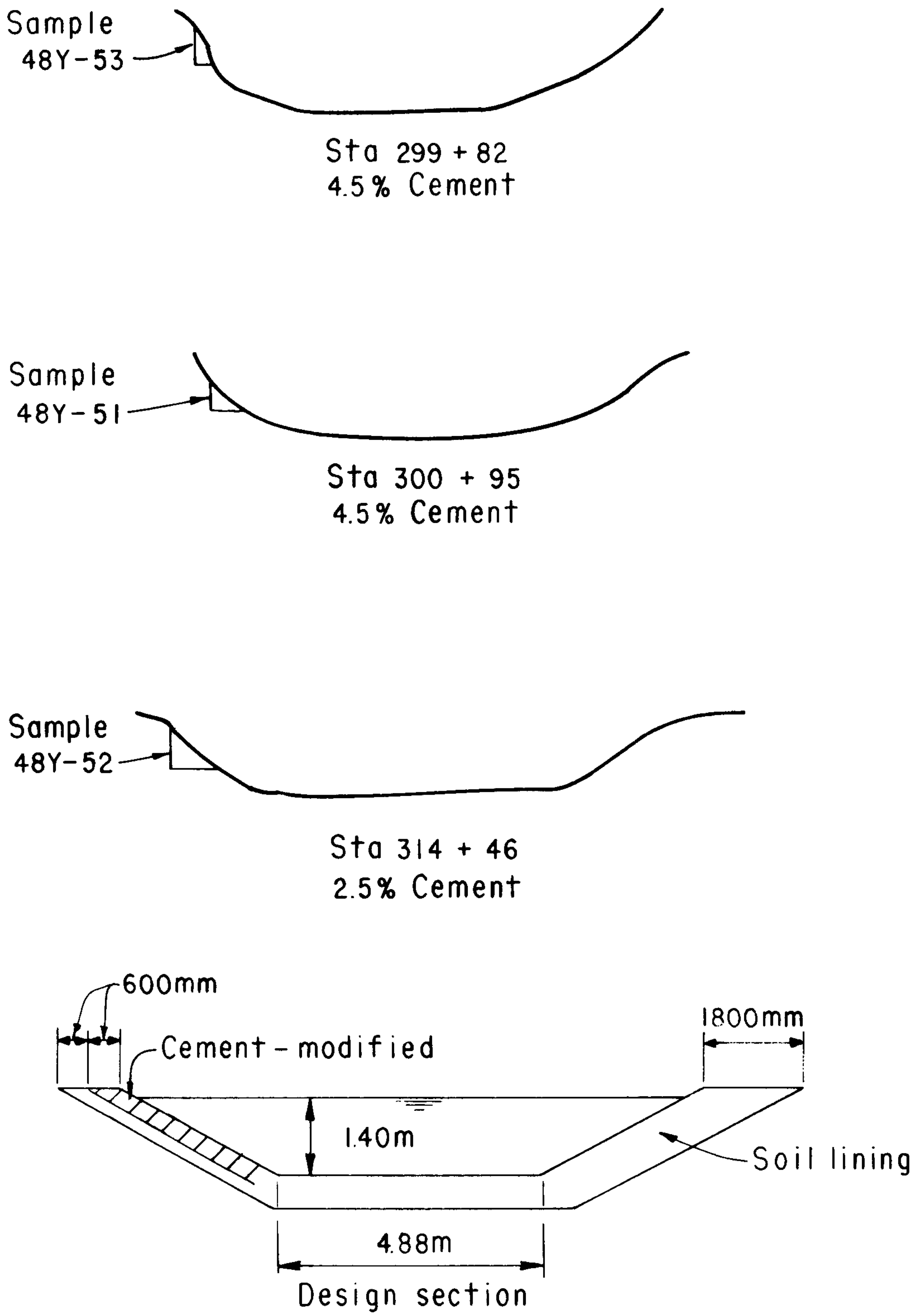


Figure 12. — Cross sections of cement-modified test sections on Driftwood Canal.

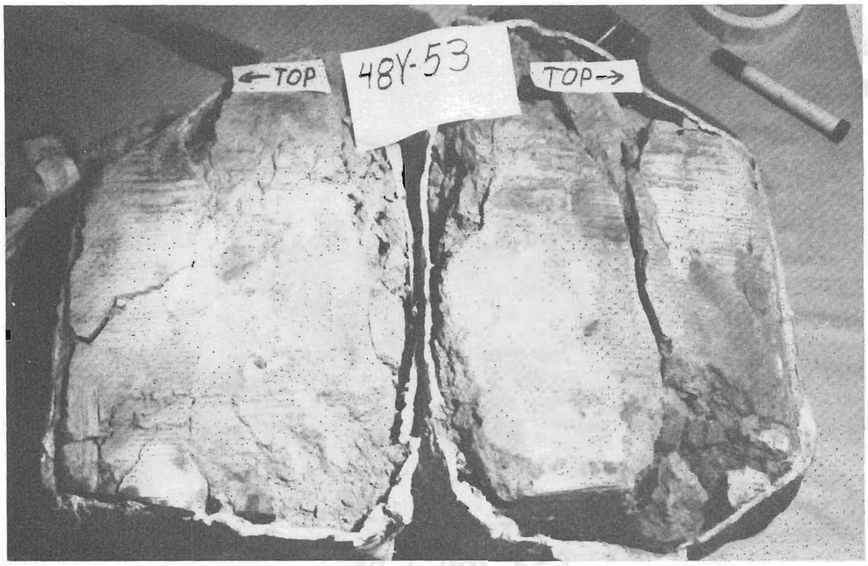


Figure 13. — Halves of block sample from 4.5 percent cement-modified soil lining. P801-D-80034.

Table 2. — *Density of 4.5 percent cement-modified soil*

Specimen No. (Sample 48Y-53)	Dry density, kg/m^3	Percent of Proctor max. density	Water content, percent
1	1670	100	13.1
2	1560	94	15.5
3	1580	95	16.0
4	1640	98	15.1
5	1750	105	13.4
6	1540	92	16.9
7	1770	107	15.4
8	1760	106	16.1
9	1780	107	14.8
Average	1670	100	13.4

coring fragile materials and therefore, a method of sawing cubic specimens was developed; this is described in appendix B. Table 3 also shows the density of the specimens as determined by measurements; however, there were some broken edges on the cubes and the densities were about 4 percent lower than those from the waxed chunks. The average moisture content increased from 15.1 to 26.1 percent during the soaking period prior to the compressive strength test.

Table 3. — *Compressive strength, density, and moisture content of 50-mm cube specimens of 4.5 percent cement-modified soil*

Specimen No.	Compressive strength, MPa	Density, kg/m^3	Moisture content	
			*	**
T-2	1.64	1490	13.0	28.4
B-1	1.21	-	-	25.9
B-2	-	1630	16.8	-
B-3	-	1670	14.9	-
B-4	1.78	1600	15.0	25.2
B-5	3.00	-	15.8	24.7
Average	1.91	1600	15.1	26.1

*Indicates before soaking for compressive strength test.

**Indicates after soaking for 6 hours partly submerged followed by 42 hours fully submerged.

Durability

Freeze-thaw and wet-dry tests were made on specimens sawed from the block sample of 4.5 percent cement-modified soil. For each type of test, four 25-mm cubic specimens and four cubic 25-mm cubic specimens with the corners cut to form octagonal specimens were used (fig. 14).

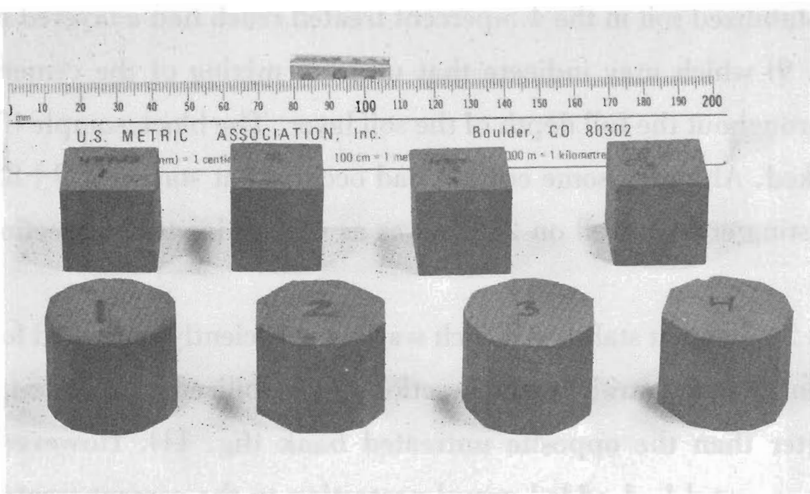
The freeze-thaw tests were made with the specimens placed on a wet felt pad in an open 177-mL can. The specimens were placed in a freeze cabinet set at −23 °C for 24 hours and thawed at room temperature (about 21 °C) for 24 hours. The test was continued for 12 cycles with observations made after each cycle. At the end of 12 cycles, the specimens were in poor to good condition (fig. 14b). The average mass loss was 14 percent. Although there was some softening of the specimens, the edges remained generally sharp. Some of the specimens had developed fine cracks, and one broke apart.

The wet-dry specimens were placed in the open cans without a pad. For each of 12 cycles, the specimens were placed in a 50 °C oven for 24 hours and cooled at room temperature (about 21 °C) for 24 hours. These specimens remained relatively intact throughout the test, although edges and corners became rounded and some fine cracks developed (fig. 14c). The average mass loss during the 12 cycles was about 11 percent.

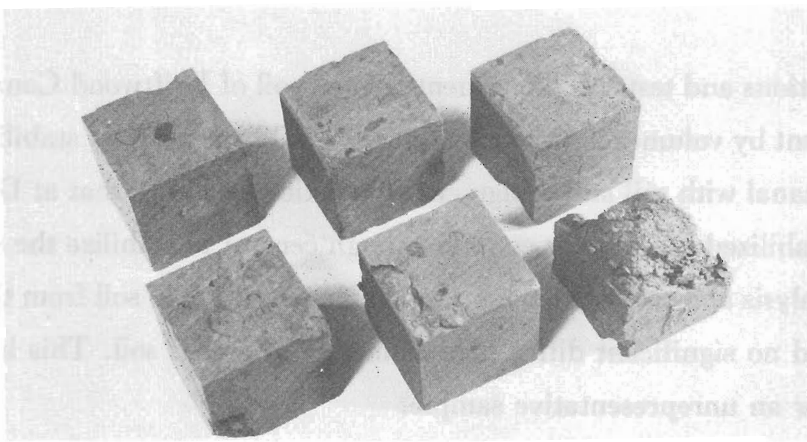
DISCUSSION

The addition of a small percentage of portland cement to soil to form a cement-modified material has been used to improve the bearing capacity of subbases for highways. This mixture would not be expected to produce a very hard material, which can be accomplished with larger amounts of cement to form soil-cement. However, for some soils, it will improve soil properties sufficiently to warrant its usage.

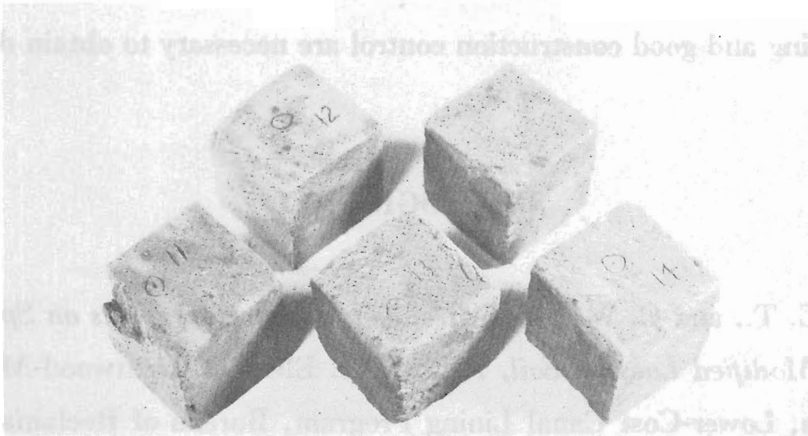
For the Driftwood Canal experiment, the cement was added to increase the stability of the low plasticity soil and to resist erosion from flowing water and wind-wave action, particularly on curves. On straight sections, erosion of the untreated soil is not a significant problem.



(a) Cubic and octagonal specimens before testing. P801-D-80035.



(b) Cubic specimens after freeze-thaw test. P801-D-80036.



(c) Cubic specimens after wet-dry tests. P801-D-80037.

Figure 14. — Sawed specimens of 4.5 percent cement-modified soil lining.

The exposed stabilized soil in the 4.5-percent treated reach had a layered and blocky appearance (fig. 9) which may indicate that uniform mixing of the cement was not accomplished throughout the full depth of the soil layer. The block sample (fig. 13) was extensively cracked. Although some erosion had occurred at station 299+82 (fig. 12), the bank was resisting erosion well on 28° curves as well as in straight sections.

The soil in the 2.5-percent stabilized reach was not sufficiently cemented for a block sample to be obtained. In the straight canal section, the stabilized bank maintained its shape somewhat better than the opposite untreated bank (fig. 11). However, on a curve, maintenance personnel had added gravel protection to the cement-treated bank where erosion had apparently occurred.

From observations and tests on the cement-treated soil of Driftwood Canal, 4.5 percent portland cement by volume, if properly applied, would successfully stabilize soil against erosion for a canal with soil and design characteristics similar to that at Driftwood. The 2.5-percent stabilized soil did not contain enough cement to stabilize the soil on curves. Gradation analysis and consistency limit tests on one sample of soil from the 2.5-percent section showed no significant differences from the untreated soil. This indicates either poor mixing or an unrepresentative sample.

For any treatment of soils with admixtures, particularly where small amounts are added, thorough mixing and good construction control are necessary to obtain desired results.

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APPENDIX A

SPECIFICATIONS FOR

EXPERIMENTAL SECTIONS OF CEMENT-MODIFIED SOIL LINING

ON DRIFTWOOD CANAL

General

The work outlined herein provides for a modification of compacted earth canal lining paragraphs of specifications No. DC-4934 to include experimental test sections of portland cement-stabilized earth lining to increase the resistance of the soil to deterioration and erosion.

The test sections for soil stabilization shall consist of two approximate 300-m reaches, each with the stabilization continuous on one side slope only. It is intended that the placement of soil layers, application of water, and compaction of soil in the lining will proceed insofar as possible as in normal lining operations with a minimum of modification necessary to ensure a good quality of soil stabilization.

The following test sections will be constructed:

a. 4.5 percent cement by volume of the soil
b. 2.5 percent cement by volume of the soil

Location of Test Sections

The two test sections may be placed in any order on one of the side slopes at the following locations:

	Stationing		Length,
	From	To	m
Station	298+61	301+66	305
Station	312+33	315+07	274

Materials

Cement. — Either Type I or Type II portland cement may be used where cement is required for stabilization purposes. The required quantities of cement will be furnished by the contractor.

Constructing Cement-Stabilized Test Sections

a. General. — This portion of the specifications shall apply to the reach stabilized with 4.5 percent cement by volume and to the reach stabilized with 2.5 percent cement by volume. The lining shall be constructed in accordance with paragraphs 43 and 51 of specifications No. DC-4934 with the following exceptions: The middle section of the lining, as shown on figure A-1, for a horizontal width of 600 mm shall be stabilized with cement, and the inside 600-mm horizontal width removed to expose the stabilized soil and bring the lining surface to designated line and grade.

All operations specified in subparagraphs (c) to (f), inclusive, shall be continuous and, when started on any lining material, shall be completed the same day.

b. Pulverizing. — When necessary, the soil to be processed shall be scarified and pulverized prior to the application of cement. Pulverizing shall continue, during mixing operations if necessary, until 100 percent of the soil by dry mass passes a 19-mm sieve, and a minimum of 80 percent of the soil passes a 4.75-mm (No. 4) sieve, exclusive of any gravel retained on these sieves.

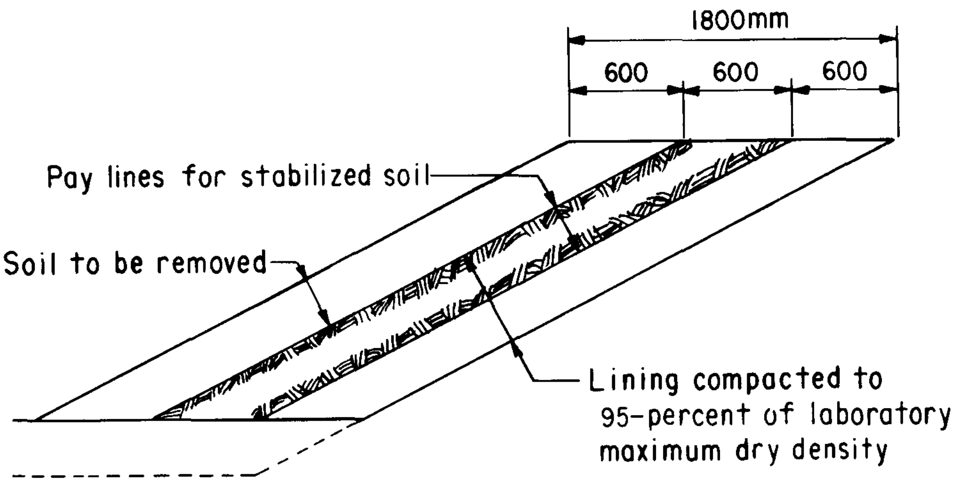

Figure A-1. — Cross section of cement-modified soil lining on Driftwood Canal.

c. Application of cement. — The quantity of cement specified by the contracting officer shall be applied uniformly on the soil, in the 600-mm horizontal width to be processed, in an approved manner. At the time of cement application, the percentage of moisture in the soil shall not exceed the quantity which will permit a uniform and intimate mixture of soil and cement during mixing operations. During seasons of probable freezing temperatures, cement shall not be applied when the air temperature is below 7 °C: *Provided*, that if the temperature is 4 °C or above, cement may be applied if the temperature is rising. Cement shall not be applied if the soil to be processed is frozen or, if in the judgment of the contracting officer, weather conditions are such that the material being processed cannot be completely compacted and protected before the advent of freezing temperature.

d. Mixing. — Immediately after the cement has been distributed over the soil, it shall be uniformly mixed with the soil for the full depth of the layer being processed. Any soil-cement mixture that has not had final compaction shall not remain undisturbed for more than 1 hour. Mixing shall be accomplished in the 600-mm horizontal processing width by a rotary speed mixer of the Seaman pulvi-mixer type. The mixer shall be capable of producing a homogeneous soil-cement mixture to the extreme depth of loose layer thickness applied and to a 25-mm depth in the compacted soil below. Initial mixing of soil and cement shall continue until the cement has been sufficiently blended with the soil to prevent the formation of cement balls if additional water is applied. The mixing shall be done with as little lateral dispersion of cement as possible outside the 600-mm horizontal width of lining being processed.

e. Application of water. — Immediately after the initial mixing, the moisture content of the soil-cement mixture will be determined by the contracting officer and, if required, water shall be uniformly applied in such quantities and at such a rate as directed by the contracting officer. Each application or increment of water shall be incorporated in such a manner as to avoid concentration of water near the surface. After the last increment of water has been added, mixing shall be continued until a thorough, uniform, and intimate mixture of soil-cement and water is obtained throughout the full depth and width of processing. When water application and mixing is completed, the percentage of moisture in the mixture and in unpulverized soil lumps, based on oven-dry weights, shall be between optimum moisture content and 120 percent of optimum moisture content for standard maximum density as prescribed in subparagraph 51(b)(1) of specifications No. DC-4934: *Provided*, that the moisture content of the mixture, when placed, shall be less than that moisture content which will cause the lining to become unstable during compaction. This specified optimum moisture shall be that prevailing in the moist soil-cement at the time of compaction and shall be determined in the field by the compaction test described in subparagraph 51(b)(1) on representative samples of soil-cement mixture obtained from the layer being processed at the conclusion of moist mixing operations.

f. Compaction. — Compaction of the soil-cement mixture shall be accomplished simultaneously with the surrounding untreated soil by tamping rollers. The dry density of the mixture and the soil lining behind it (for a horizontal distance of 600 mm) shall be compacted to a dry density of not less than 95 percent of the laboratory maximum soil dry density as described in subparagraph 51(b)(1). The compaction tests for maximum density and optimum moisture content will be made by the Government on representative samples of soil-cement mixture from the lining being processed at the time of compaction.

g. Protection and cover. — After completion of compaction of the soil-cement mixture, it shall be protected against drying and freezing for 7 days. Between the time of finishing one compacted layer and placement of the next, the cement-stabilized soil surface shall be kept continuously moist. After completion of the test section, the 7-day curing can be accomplished by leaving the cement-stabilized material covered with a minimum of 150 mm of continuously moist soil.

APPENDIX B
SPECIMENS CUT BY SAWING

For some weakly-cemented, friable materials, it is difficult and time consuming to shape suitable specimens from undisturbed field samples by coring or hand trimming for laboratory testing. Test specimens are needed for the evaluation of field installations of stabilized soils such as soil-fly ash or cement-modified soils. For canal lining, unconfined compressive strength, freeze-thaw, wet-dry, and permeability tests are required.

From the 4.5-percent cement-treated block sample from Driftwood Canal, test specimens were formed by sawing. The specimens had a cubic, octagonal, or multisided shape approaching that of a cylinder with the average diameter about the same as the height. It is easier to saw these shapes without breakage than for specimens with length to diameter (l/d) ratios greater or less than 1.

There is some experience in testing cubes of concrete and rock and cores with an l/d ratio less than 2, which is commonly used for soil and concrete testing. The Bureau's Concrete and Structural Branch has performed compressive strength tests on cubes of concrete and shotcrete where it was not convenient to obtain cores. Also, this same branch has developed some unpublished relationships among 50-, 75-, and 100-mm cubes; 75- by 75-mm, 100- by 100-mm, 50- by 100-mm, 75- by 150-mm, 100- by 200-mm cores, and 150- by 300-mm concrete cylinders. Relationships have also been established between cores with l/d ratios of 0.5 to 4.0 [6], 0.5 to 2.0 [7], 1.00 to 1.75 [8], and 1 to 2 [9]. In England [10] and New Zealand [12], the cube has been used for determining the compressive strength of concrete. Where it has been more convenient to obtain cores for the evaluation of concrete structures, an attempt has been made to relate the strength of cores to cubes, which is considered to be the British standard for "actual concrete strength."

In attempts to obtain correction factors relating the compressive strength of concrete cylinders with l/d ratios different from 2 to the strength of cylinders with an l/d equal to

2, it has been found that the correction factors vary with the type and strength of concrete. For example, there are different correction factors for lightweight concrete than for the standard type concrete. Therefore, if it were necessary to establish correction factors for soil to correct strength to a standard l/d ratio such as 2, then it would be necessary to determine such factors on a particular soil by actual strength tests on specimens with different l/d ratios. Although, for general soils and concrete purposes where strength is the main concern, compressive strength specimens with l/d ratios of 2 would be best because of the opportunity to develop characteristic shear planes; this may not be necessary in connection with canal linings. For properly supported canal linings, performance depends not so much on strength properties as on durability against climatic changes and resistance to water erosion. Relationships between lining performance and the required properties for durability have not been thoroughly investigated for canal linings, although research on stabilized soil is now being directed toward that end. For Bureau purposes, cubic specimens or cylinders with l/d ratios of about 1 should be valid for the comparison of different stabilized materials and the correlation between laboratory test results and field performance.

Some of the specimens used for the freeze-thaw and wet-dry evaluation of the cement-modified soil were 25-mm cubes. One of the important factors in determining the size of specimens is the maximum particle size. For concrete, estimates of concrete strength have been made on the basis of testing cores with diameters of less than 100 mm [9], although larger specimens are normally recommended. Generally, the recommended diameter for concrete cores, or formed cylinders of concrete, is three to four times that of the maximum aggregate size. Based on this criteria, the 25-mm cubes would allow for a maximum particle size of 4.75 mm. For permeability tests of soil compacted in cylinders, this ratio of particle size to diameter could not be tolerated because of the possibility for the formation of voids of significant size between the soil specimen and the cylinder wall; however, in the case of an undisturbed specimen sealed in a cylinder with modeling clay, voids would be filled by the clay. Therefore, the permeability testing of soils with maximum particle sizes of about 2 to 3 mm in a container with a 25-mm or larger diameter would seem to be justified when clay for sealing is used. The use of small specimens conserves material. Also, the testing of several small specimens instead of a single large one would possibly provide a more representative average test result.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.