GR-84-6

TREATMENT OF EXPANSIVE CLAY CANAL LINING

March 1984
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16. ABSTRACT

The Friant-Kern Canal, part of the Central Valley Project in California, extends from Friant Dam, on the San Joaquin River east of Fresno, south to the Kern River near Bakersfield. The canal was constructed during 1945-51. The canal is 152 mi (245 km) long and has a normal operating capacity of 4000 ft^3/s (113 m^3/s), decreasing to 2000 ft^3/s (57 m^3/s) at the terminus. About one-third of the length of the canal, from mile 34 to mile 88 (km 55 to km 142), transverses an area of expansive clay (Porterville formation). About half of this 54-mile (87-km) length is earth lined; the remainder is concrete lined.

The canal began experiencing cracking, sliding, and sloughing of the side slopes in both the concrete- and earth-lined sections in the area of expansive clay after 3 years of operation. In the early 1970's, the Bureau decided to remove portions of the canal lining, flatten the canal slopes, and reline the canal using a compacted soil-lime mixture in an attempt to stabilize the slopes.

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by
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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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INTRODUCTION

The Friant-Kern Canal is a feature of the Central Valley Project in California. The canal diverts water southerly from Friant Dam, on the Sam Joaquin River east of Fresno, to the upper San Joaquin Valley, terminating at the Kern River near Bakersfield. The canal is 152 mi (245 km) long, and delivers water to more than 1 million acres (405 000 ha) of irrigated farmland in southern California. The canal is designed for a normal operating capacity of 4000 ft^3/s (113 m^3/s) for the first 71 mi (114 km), gradually decreasing to 2000 ft^3/s (57 m^3/s) at the terminus, and operates under velocities up to 4.5 ft/s (1.4 m/s). The canal was constructed during 1945-51. The information, test results, and conclusions presented in this report are a summary of previously published and unpublished information concerning the canal.

About one-third of the canal length, 54 mi (87 km), from mile 34 to mile 88 (km 55 to km 142), traverses an area of the Porterville Formation. Of this 54 mi, 23 mi (37 km) are earth lined, and 31 mi (50 km) are concrete lined. The soils of the Porterville Formation contain expansive clays, which exhibit significant volume change, shrink-age, and expansion with changes in moisture content. Volume change can be a serious problem for canal linings in that lower densities and strengths occur below the waterline due to absorption of water by the soil. Above the waterline, shrinkage occurs with cracks forming several feet deep, resulting in a loss of shear strength. As a result, the canal slopes become unstable and slides occur. The photograph on figure 1 shows the condition of the canal prior to stabilization, note the slope failures along the canal.

After the first 3 years of operation, the canal developed several lining failures. The concrete lining of the canal cracked and buckled from the earth pressures of the expansive clay. The earth-lined canal slopes sloughed and failed excessively. The failures were a continual maintenance problem. Several methods of stabilizing the slopes were tried without success including electrochemical treatment, flattening the slopes, and the dumping of riprap on the canal slope. The maintenance of the canal slope became an expensive problem and, in the early 1970's, the Bureau decided to remove several sections of the canal lining, flatten the canal slopes, and reline the canal using a compacted soil-lime mixture in an attempt to stabilize the slopes.

Figure 1. — Friant-Kern Canal prior to lime stabilization. Note slope failure along linings, P801-D-80750

Two reaches of the canal were initially selected for lime treatment: (1) an earth-lined reach at about mile 60 (km 97) extending for 8900 ft (2713 m), and (2) a concrete-lined reach at about mile 80 (km 129) extending 1820 ft (555 m). After the initial lime-stabilized lining was evaluated, a third reach was selected for lime stablization. This earth-lined reach was 700 ft (213 m) long, extending from station 2045+00 to 2115+00 ft (623+31.6 to 644+65.2 m). Typical rehabilitation cross sections of the earth- and concrete-lined canal reaches are shown on figure 2, [1][1].

The Bureau's E&R Center Denver Laboratory conducted tests to determine the soil type and the amount of lime to be added to the soil for the three reaches. The addition of lime was intended to reduce the plasticity index and increase the shrinkage limit of the soil, thereby controlling the volume change characteristics [2].

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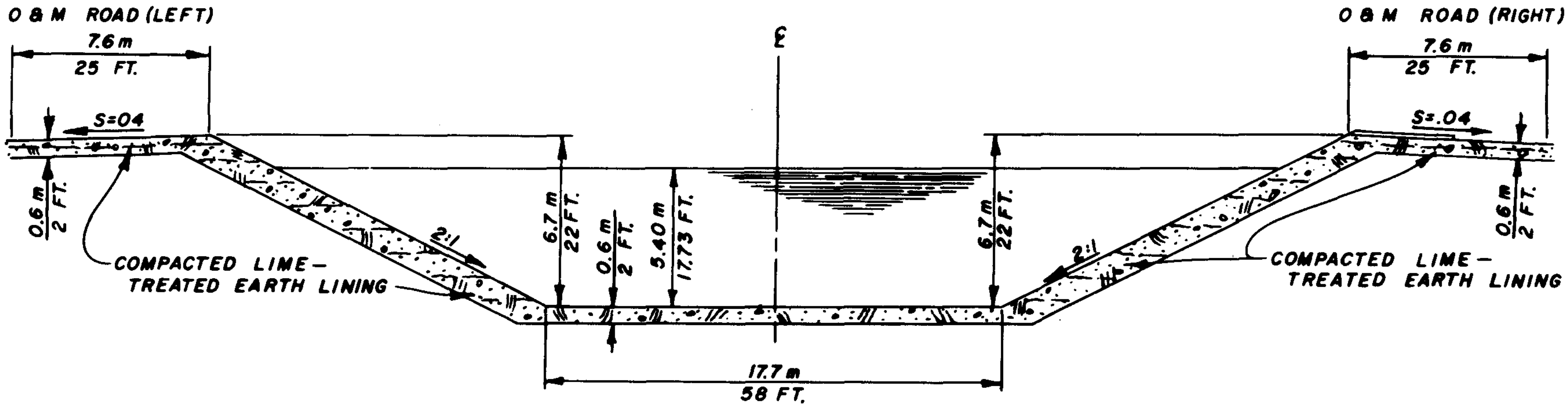
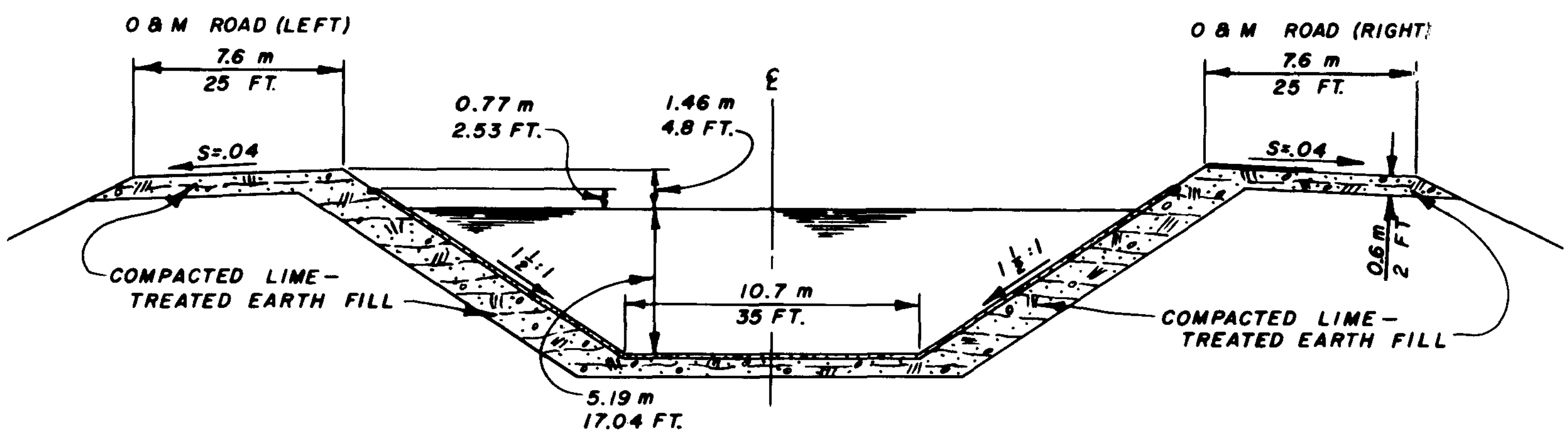
[1] Numbers in brackets refer to entries in the Bibliography.



TYPICAL EARTH-LINED REHABILITATION SECTION



TYPICAL CONCRETE-LINED REHABILITATION SECTION

Figure 2. — Typical rehabilitation cross sections of earth- and concrete-lined reaches for Friant-Kern Canal.

The construction procedure required several operational steps. The basic operation consisted of removing the rock and scarifying the existing material. Several problems were encountered during construction and will be discussed later.

The evaluation of the soil-lime lining in the expansive clay of the Porterville Formation has consisted of several types of testing. The test programs included unconfined compression tests, chemical analysis, erosion measurements, and extensive visual examinations.

SUMMARY

Canal lining failures along Friant-Kern Canal, traversing the expansive clay of the Porterville Formation, presented a continual, expensive maintenance problem. To stabilize the canal lining, 4 percent quicklime by dry weight was added to the clay, mixed, and recompacted. The lime modified the clay by reducing the plasticity index, increasing the shrinkage limit, and improving the workability of the material. The amount of lime to be added to the material was determined by pH, consistency limits, and unconfined compression tests. The performance of the lime-stabilized canal lining was evaluated by laboratory testing, erosion measurements, and visual observations.

CONCLUSIONS

1. Since the rehabilitation, the Friant-Kern Canal lining has not experienced any failures in the areas where compacted soil-lime lining was used.

2. The addition of lime to the expansive clay modified the volume change characteristics of the clay. The pasticity index was reduced and the shrinkage limit increased.

3. The unconfined compressive strength of the soil-lime material is dependent on the unit weight (density), and as much as five times the strength can be realized with dry unit weight differences of 15 lbf/ft^3 (2.4 kN/m^3). The increase in unconfined compressive strength indicates a significant increase in the shear resistance of the canal lining.

4. The soil-lime lining is extremely erosion resistant. The erosion was, in general, restricted to less than 0.1 ft (0.03 m) after 6 years of operation. There were some locations where the original compaction tracks are still clearly visible after 6 years of canal operation.

SOIL INVESTIGATIONS

Soil that is to be compacted and used as canal lining must comply with established criteria for permeability, erosion, stability, and volume change. In general, canal earth linings are constructed of soils with plasticity indexes from 10 to 25. Permeability and shear tests are performed to evaluate the seepage potential and soil strength. Usually, if the plasticity index is 20 or less, the soil workability is satisfactory and volume change is not a problem. The soil consistency tests performed on the Porterville clay material, along the alinement of the Friant-Kern Canal, indicated the material had a liquid limit ranging from 57 to 70, a plasticity index ranging from 37 to 46, and a shrinkage limit of about 8. The soil test results indicated the clay was highly expansive. Expansive soil volume change characteristics are affected by the density, moisture, and structure of the soil, and the expansive potential of clay may be increased when it is used as a recompacted construction material.

The addition of lime to the clay was intended to modify the soil by reducing or eliminating the volume change characteristics. It was believed that controlling the volume change would stabilize the canal slopes. The selection of the percentage of hydrated lime additive was based on pH, consistency limits, and unconfined compressive strength tests.

The natural lime, calcium oxide (CaO), content of the soil ranged from 3 to 4 percent. The pH tests were performed to determine the minimum amount of lime required to react with the soil. The addition of 2 percent lime was determined to be sufficient based on the pH values. The results of these tests are shown on figure 3.

The consistency limits used for determining the hydrated lime percentage were the plasticity index and the shrinkage limit. Although 2 percent hydrated lime reduced the plasticity index, 4 percent lime increased the shrinkage limit to near the optimum moisture (placement moisture) content of the material. These test results are shown on figure 4. Because of these

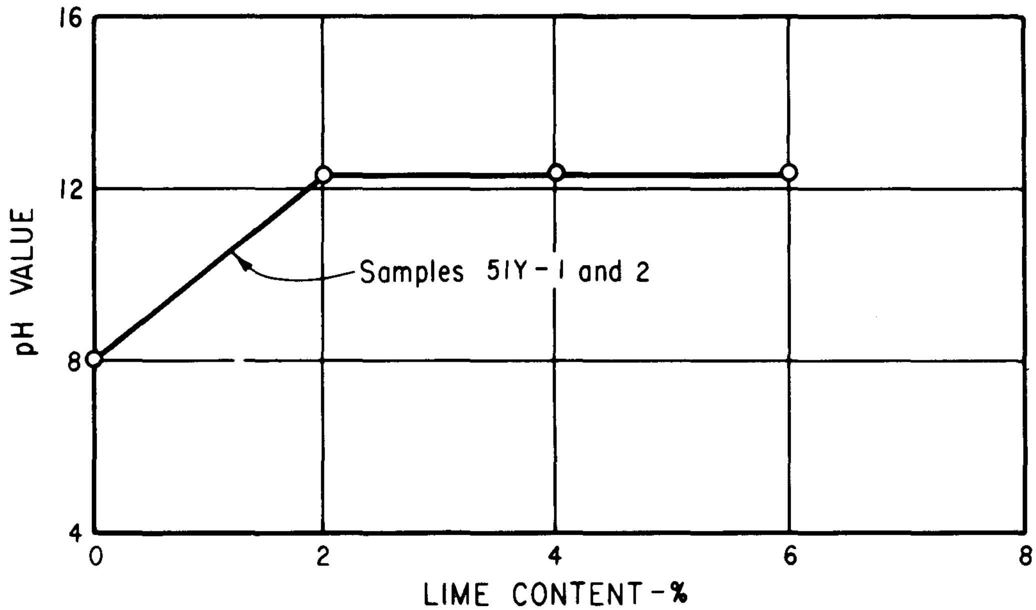


Figure 3. — Results of pH soil tests.

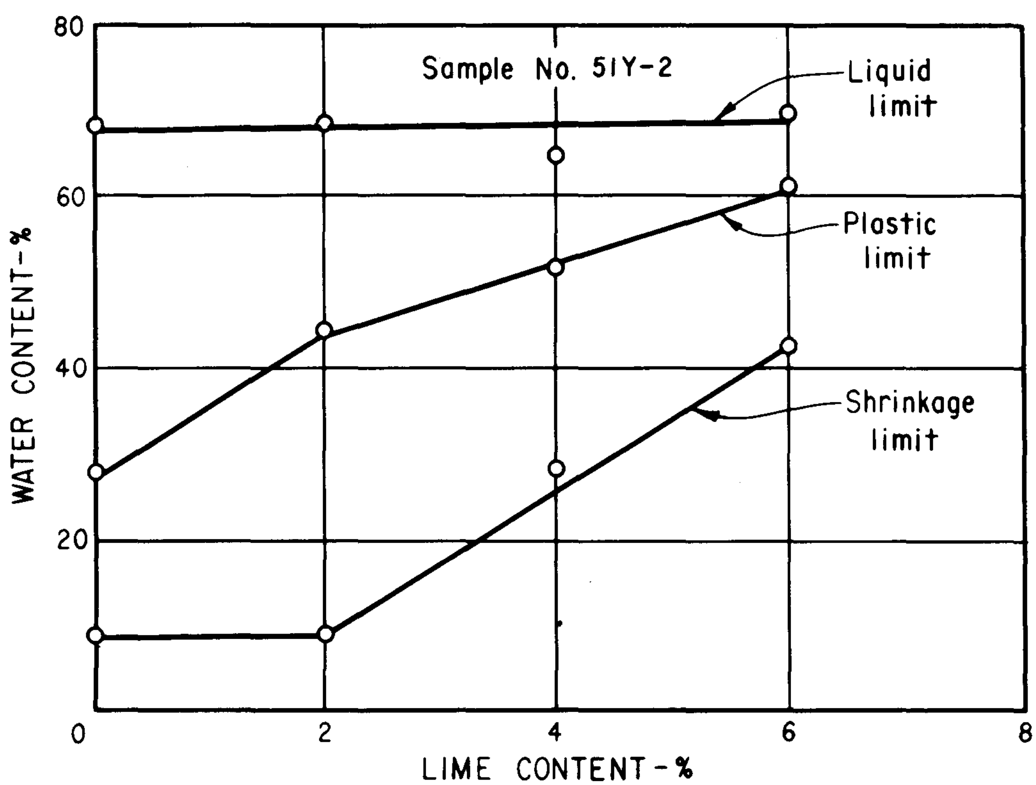


Figure 4. — Results of tests to determine consistency limits.

results and the variation in the control of the percentage of lime added during construction, 4 percent hydrated lime was recommended.

During the initial investigation, unconfined compression tests were performed on several treated and untreated soil samples. The unconfined soil strength of undisturbed samples of natural clay ranged from 2 to 23 lb/in^2 (14 to 159 kPa). The addition of 4 percent hydrated lime increased this strength range to 126 to 516 lb/in^2 (869 to 3558 kPa).

The contract specifications allowed the use of either hydrated lime or quicklime; the contractor elected to use quicklime. Because quicklime contains about 20 percent more available lime (CaO) than hydrated lime, 3.2 percent quicklime was allowed in place of 4 percent hydrated lime. However, to assure that adequate lime was available for a complete soil-lime reaction, 4 percent quicklime was used, with additional lime added when determined necessary by Bureau inspectors.

CONSTRUCTION

The canal is dewatered for only 2 months of the year, December and January. Therefore, the construction season is very limited. The first contract for construction of the soil-lime lining took two construction seasons to complete, 1972-73 and 1973-74. The second contract was completed in one season, 1975-76.

The construction of the initial contract proceeded in three phases: (1) berm road reconstruction, (2) canal invert reconstruction, and (3) canal side slope reconstruction. The first stage of the soil-lime reconstruction program was to rebuild the berm roads along the canal banks to provide a stable roadway of soil-lime so that seasonal rains would not halt construction operations. The road was to be 2 ft (0.6 m) thick. First, the top half of the roadway material was excavated and stockpiled; the bottom half was then ripped, quicklime and water added, mixed, allowed to mellow, and then recompacted. A large quanity of rock was present, which was removed with a rock rake mounted on a dozer during the mixing operation. However, it was necessary to add lime to the highly plastic clay soil before the rock could be removed. Without the addition of lime, the clay stuck to the rock and prevented the rakes from picking up the rocks. The contractor first tried rotary mixers for pulverizing the clay and mixing the lime; however, the amount of rock present broke the mixer blades and the soil-lime had to be mixed using bulldozers and road graders. The compaction of the lower 1-ft (0.3-m) lift was done with a vibratory sheepsfoot roller. The material for the top lift was then spread, 4 percent quicklime added, watered, mixed, allowed to mellow, and recompacted with a vibratory sheepsfoot roller. During the second stage, the invert of the canal was stablized to a thickness of 2 ft (0.6 m). The invert of the canal was constructed similar to the roadway.

Prior to the third phase of reconstructing the canal side slopes, the rock riprap that had been dumped into slide areas for slope stabilization had to be removed. The material that was to be stablized with lime and recompacted was then removed by a benching operation. A series of long, sloping benches or ramps were cut from the top of the bank down to the canal bottom with the cut extending far enough into the slope to remove the entire depth of material required for rehabilitation. The 2 percent quicklime was spread over the bench surface, 1 ft (0.3 m) of material from the bench was mixed with the quicklime, and the lime-clay mixture was pushed into the canal bottom where the remaining riprap material had been removed. The long ramp cuts overlapped for a considerable distance, which created problems of construction control. If this method had continued, some areas of canal lining would have been removed twice and some areas not mixed at all. To alleviate the situation, a similar method of slope stripping was performed. The side slopes were worked from top to bottom along 800-ft (244-m) long benches sloped into the side slope to provide the 3.6-ft (1.1-m) thick lining required. The material was spread on the canal bottom and 2 percent additional lime added. Water was added to at least 2 percent over optimum moisture, and then about 1-ft (0.3-m) depth of material was mixed with dozers and graders with the rock being continually removed. When about 6.6 ft (2 m) of the material had been mixed and cured for 24 hours, bulldozers started spreading the material on the slopes, which were then compacted with a self-cleaning sheepsfoot roller moving up and down the slope. A cable winch on a crane "yo-yoed" the roller up and down the slope. The side slopes were constructed in three 1.2-ft (0.4-m) compacted lifts normal to the slope to give the specified 3.6-ft (1.1-m) compacted depth. Photographs of the construction sequences are shown on figures 5 through 8.

The 1975-76 construction proceeded somewhat differently. The material was compacted in nearly horizontal layers. A 6-inch (152-mm) overbuild inside the canal prism was necessary; the

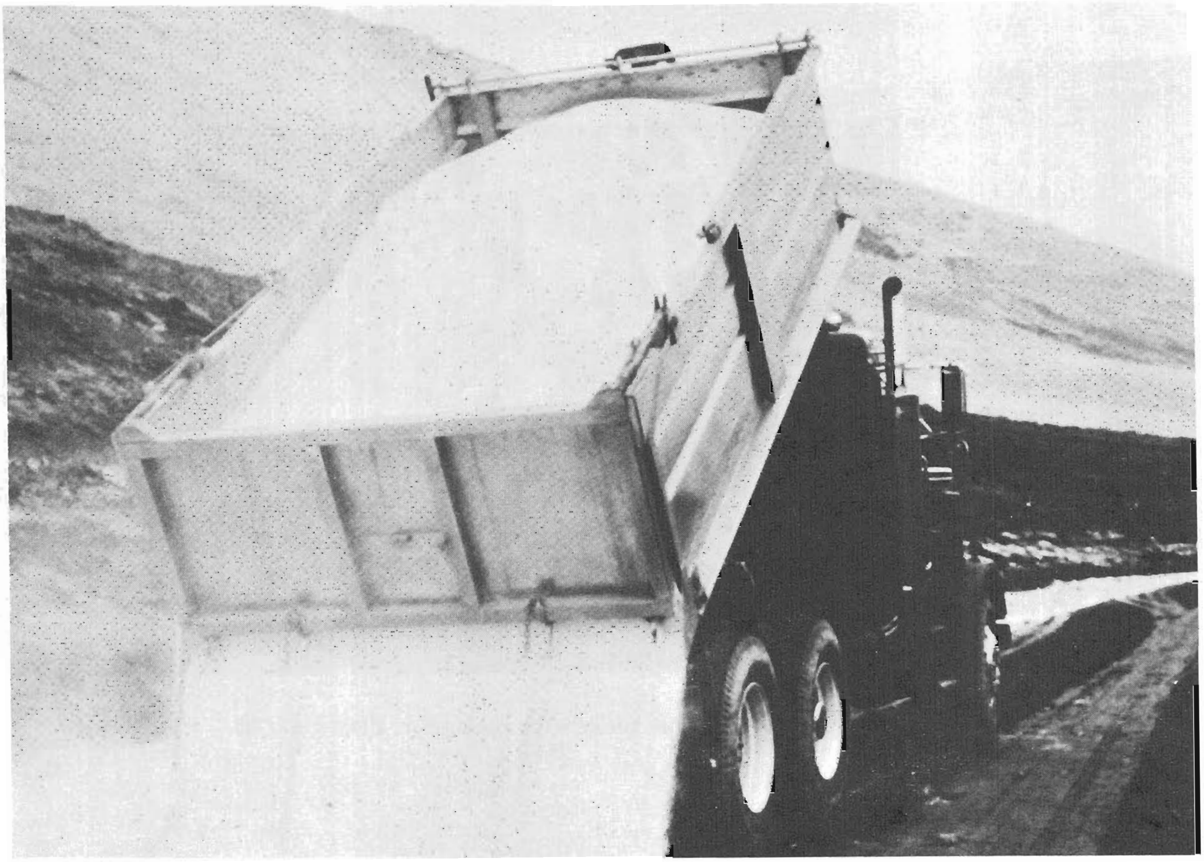


Figure 5. — Spreading quicklime on canal invert. P801-D-80751

Figure 6. — Mixing quicklime with expansive clay. P801-D-80752

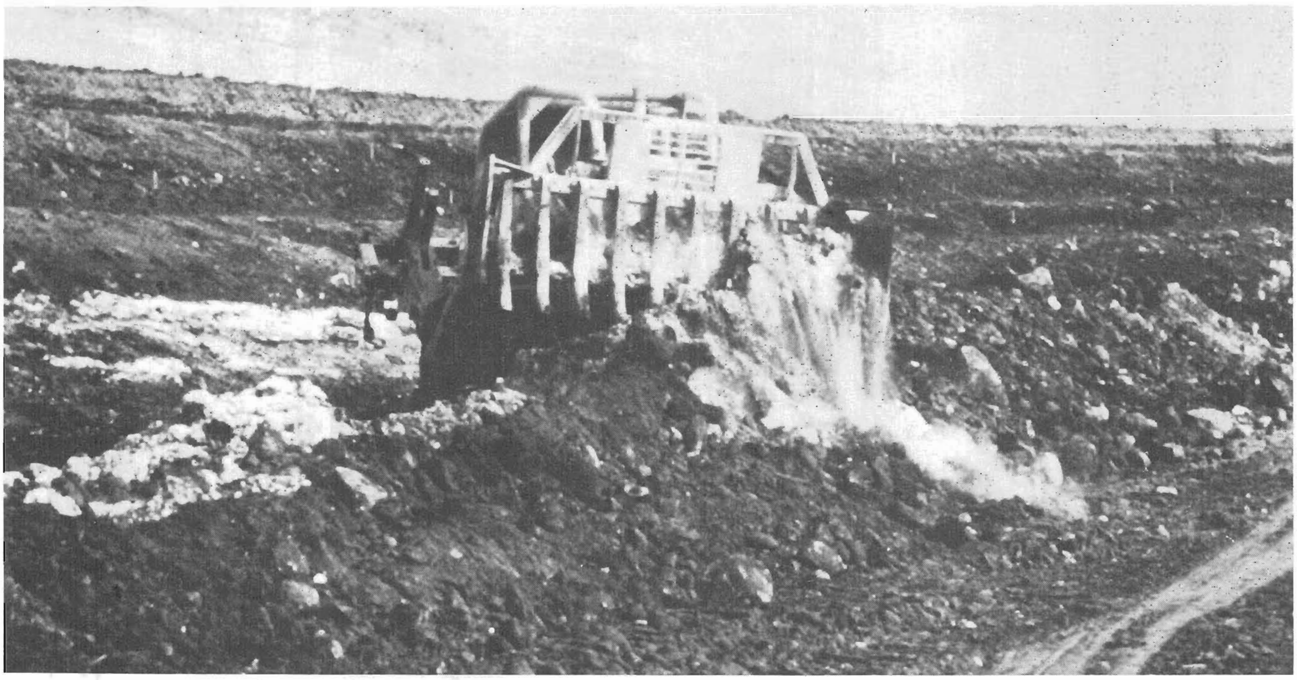


Figure 7. — Removing large rocks with rock rake. P801-D-80753

Figure 8. — Compaction of soil-lime canal lining. P801-D-80754

overbuild was then trimmed from the canal slopes. Both construction processes required the addition of 5 to 7 percent additional water at the time of mixing the lime with the soil. The soil-lime material was allowed to mellow for about 9 hours prior to compaction operations.

The quality control of the soil-lime lining construction was based on two test procedures. The percent lime added to the soil was controlled by the spread rate. A pan of known dimensions was placed in the lime spread path and the weight of the lime within the pan after the spread pass was considered to be the lime mixed into the soil to a depth of 2 ft (0.6 m). The percent lime was calculated by the weight of the dry soil.

The unit weight (density) and moisture control procedure was adapted from the *Rapid Method of Earthwork Construction Control* developed by the Bureau [3]. The procedure was modified by performing the compaction tests on material just prior to field compaction, and the field sand cone density test was performed after field compaction. This was necessary since the soil-lime material could not be completely degraded after field compaction. The specifications required a minimum unit weight (density) of 95 percent standard Proctor maximum laboratory unit weight.

EVALUATION

The soil-lime canal lining performance was evaluated by performance laboratory tests, visual observations, and field erosion measurements. The laboratory evaluation consisted of determining the unconfined compressive strength, moisture, density, and lime content (CaO) of the block and core samples of the compacted soil-lime lining.

Sampling the soil-lime lining involved obtaining undisturbed block and core samples from several locations periodically from 1975 through 1979. A summary of this sampling is given in the following tabulation:

Undisturbed samples

Year	Type	Construction season	Total No. of samples
1973	Block	1973	4
1974	Block	1973	2
1974	Block	1974	1
1976	3-in (76-mm) core	1973	6
1976	3-in core	1974	4
1976	3-in core	1976	2
1979	3-in core	1973	6
1979	3-in core	1974	2
1979	3-in core	1976	3

Lime Content

The lime content was determined as calcium oxide (CaO). The percent of effective lime (the percent lime added during construction) was determined by subtracting the natrual lime content from the test result. The effective lime contents are accurate to ±0.5 percent due to the range of natural lime content; therefore, the effective lime content varied within the samples. The block samples had effective lime contents ranging from 0 to 3.5 percent with individual block samples having variations up to 1 percent. The core samples had effective lime contents ranging from 0 to 7.5 percent. The soil-lime samples with low effective lime contents (1 percent or less) still had strengths up to eight times the strength of the untreated clay.

There has been no significant decrease in effective lime content from year to year. The variations of effective lime content are due to the construction method. Figures 9, 10, and 11 show the effective lime content versus time for the data available.

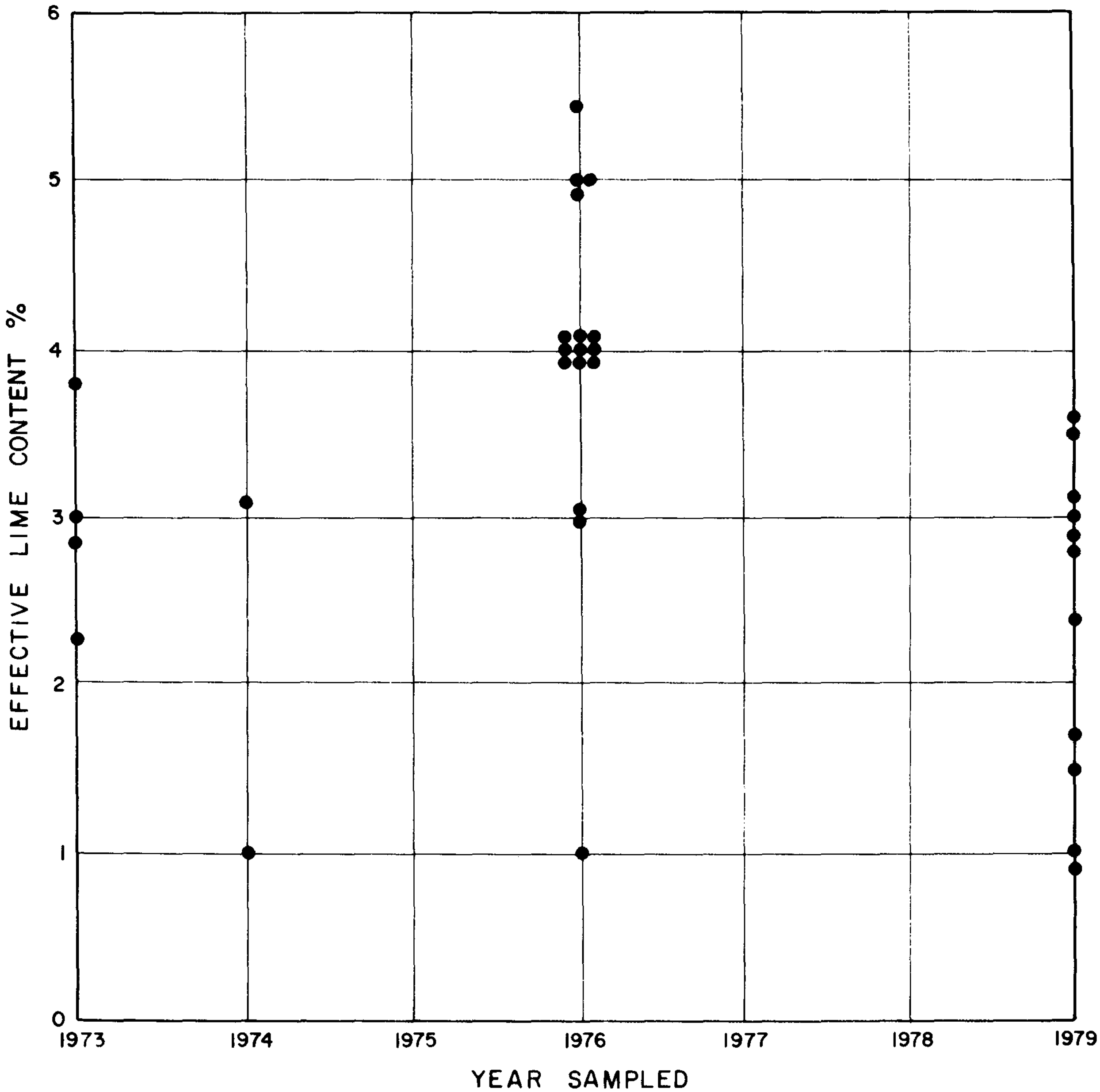


Figure 9. — Effective lime content for soil-lime lining installed in 1972-73.

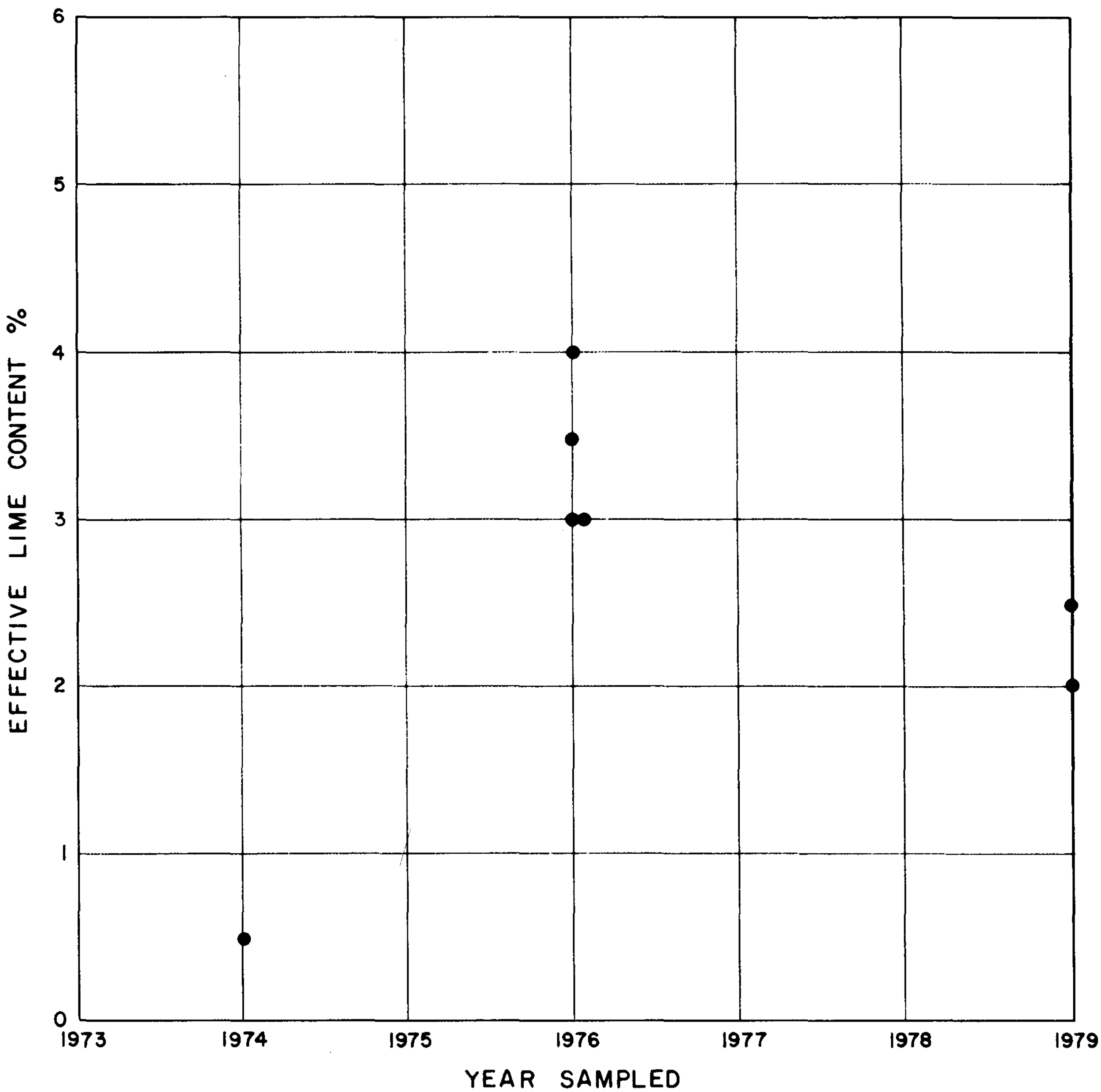


Figure 10. — Effective lime content for soil-lime lining installed in 1973-74.

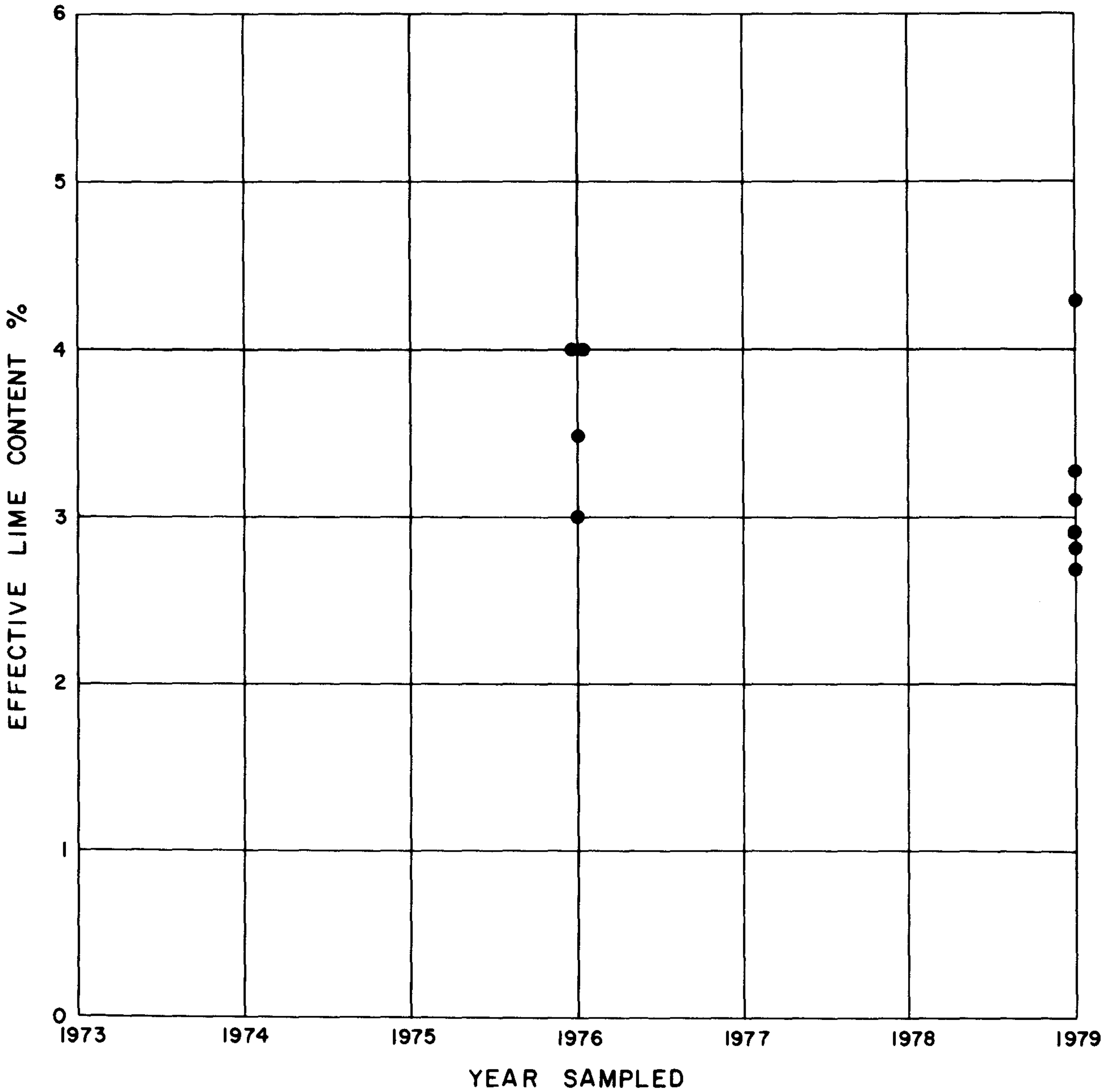


Figure 11. — Effective lime content for soil-lime lining installed in 1975-76.

Density (Unit Weight)

The dry unit weight was determined by direct measurement of the size and weight of the samples obtained. The dry unit weight ranged from 73 to 102 lbf/ft^3 (11.5 to 16.0 kN/m^3), with variations within the samples up to 18 lbf/ft^3 (2.8 kN/m^3). The dry unit weights calculated from each construction season have remained constant over several years.

Unconfined Compressive Strength

The unconfined compressive strength test was performed on lime treated soil specimens with a constant rate of strain. The strengths ranged from 127 to 1146 lb/in^2 (875 to 7900 kPa). The strength is dependent on the density of the material. Even the low-density lime-treated material showed a significant increase in strength over the natural clay. Figure 12 shows the significant increase in strength due to increase in density.

Erosion Evaluation

A total of 12 cross sections were selected along the soil-lime lined sections of the canal to monitor erosion of the compacted lining. The measuring system consisted of 18-in (460-mm) metal bars driven about 12 inches (300 mm) into the canal lining. A hole in the top of each bar allowed a string to be pulled tight to provide a baseline. Measurements from the string to the canal slope were used to determine the erosion. The elevation of each bar was established from bench marks. The bar elevations were checked annually from 1975 through 1978, and showed no significant change in elevation. The erosion measurements were taken at 1-ft (0.3-m) intervals along the string. The maximum erosion measured after 6 years was about 0.3 ft (0.1 m), and occurred at only one location. The erosion was generally about 0.1 ft (0.03 m). These values indicate total erosion from 1975, or placement, to December 1978. The sections selected for erosion measurements appear to be representative of the canal cross section.

In many places, the marks of the sheepsfoot roller used for compacting the lining are currently (1984) clearly visible on both the canal sides and the invert. A photograph of the canal lining showing its present condition is shown on figure 13.

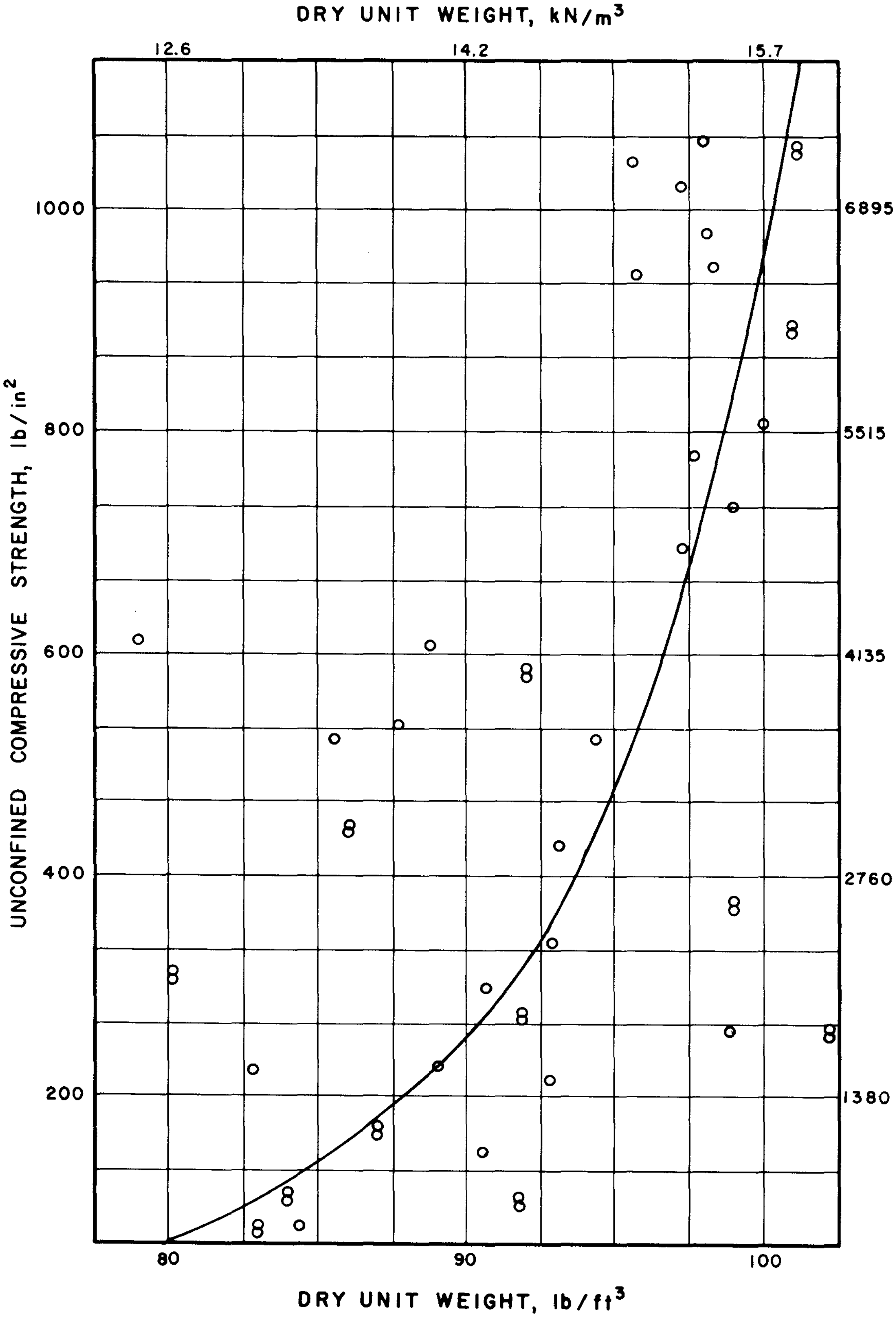


Figure 12. — Results of unconfined compressive strength tests on core specimens of lime-treated soils.

Figure 13. — Soil-lime lining on Friant-Kern Canal after 5 years of operation. P801-D-80755

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[3] *Rapid Method of Earthwork Construction Control*, Geotechnical Branch Training Manual No. 3, Bureau of Reclamation, Denver, Colo., 1979.

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