REC-ERC-84-25

PERFORMANCE OF SOIL-CEMENT DAM FACINGS — 20-Year Report

September 1984

Engineering and Research Center

U. S. Department of the Interior

Bureau of Reclamation

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. REC-ERC-84-25

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE

PERFORMANCE OF SOIL-CEMENT DAM FACINGS–20-Year Report

5. REPORT DATE

September 1984

6. PERFORMING ORGANIZATION CODE

D-1540

7. AUTHOR(S)

T. J. Casias and A. K. Howard

8. PERFORMING ORGANIZATION REPORT NO.

REC-ERC-84-25

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Bureau of Reclamation
Engineering and Research Center
Denver CO 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

Same

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE

DIBR

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at E&R Center, Denver, Colorado.

Editor: RDM

16. ABSTRACT

The soil-cement slope protection on three Bureau of Reclamation embankment dams has been damaged enough to require repair. They were the first three Bureau embankments to use soil-cement in place of riprap, and have been in service 18 to 20 years. The soil-cement facings on later Bureau dams are still in excellent condition. The lack of bond between the soil-cement lifts, in combination with severe weather and wave action, appear to be the main factors contributing to the damage. Laboratory tests and field test sections indicate that cement applied between the soil-cement lifts may be a practical solution to prevent damage to the facing when severe weather and wave conditions exist. Another soil-cement test section is planned for a future Bureau dam. The test section will be incorporated into the soil-cement facing where both dry cement and a cement slurry will be used for the surface treatment between soil-cement lifts.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- Soil-cement/ slope protection/ soils/ portland cements/ earth dams/ embankments/ dam facings/ soil-cement compaction/ freeze-thaw tests/ wet-dry tests/ compressive strength tests/ mixing/ construction equipment/ compaction equipment/ construction/ construction materials/ construction control/ durability/ wave action/ freeze-thaw action/ bond/ construction joints/ shrinkage cracks/ slurry

b. IDENTIFIERS-- Bonny Dam, CO/ Merritt Dam, NE/ Cheney Dam, KS/ Lubbock Regulating Reservoir, TX/ Starvation Dam, UT/ Palmetto Bend Dam, TX/ Calamus Dam, NE

c. COSATI Field/Group 13B *COWRR:* 1303 *SRIM:*

18. DISTRIBUTION STATEMENT

Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161.

(Microfiche and/or hard copy available from NTIS)

19. SECURITY CLASS (THIS REPORT) *UNCLASSIFIED*

20. SECURITY CLASS (THIS PAGE) *UNCLASSIFIED*

21. NO. OF PAGES 8

22. PRICE

REC-ERC-84-25

PERFORMANCE OF SOIL-CEMENT DAM FACINGS –20-Year Report

by
T. J. Casias
A. K. Howard

September 1984

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

SI METRIC

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.

The research covered by this report was funded under the Bureau of Reclamation Program Related Engineering and Scientific Studies allocation No. DR-400, Soil-Cement Research.

CONTENTS

FIGURES

INTRODUCTION

Since 1963, the Bureau of Reclamation has used compacted soil-cement as an upstream slope protection for 10 embankments. Another dam utilizing soil-cement is under construction, and two more are planned for the near future. The first two dams to use soil-cement slope protection have been in service for about 20 years. Merritt Dam, built in 1963, is currently undergoing repair of its soil-cement facing. Cheney Dam, built in 1964, has had the soil-cement facing repaired three times. Lubbock Regulating Reservoir was built in 1966, and the soil-cement facing is presently in need of repair. Another four embankments have been in service for about 15 years, and the soil-cement facings are in excellent condition. The damage that has occurred is apparently due to two factors: (1) lack of bonding between the soil-cement lifts, and (2) the severity of the weather and wave action on the facing. All of the facings have poor bond between the lifts; however, the weather conditions at Merritt and Cheney Dams are more severe than at the other locations.

HISTORY OF SOIL-CEMENT SLOPE PROTECTION ON BUREAU PROJECTS

Soil-cement slope protection was first tried by the Bureau in 1951 on an experimental test section at Bonny Dam in eastern Colorado. A special embankment with a soil-cement facing was constructed at a site expected to get maximum destructive exposure. The test section was separate from the dam, and the soil-cement was constructed using mixed-in-place techniques. The facing was inspected frequently and, after 10 years of evaluation, soil-cement was added to Bureau specifications as an alternate to riprap as a method of upstream slope protection, as discussed by Holtz and Walker [1].[1]

Completed in 1963, Merritt Dam was the first dam to have soil-cement slope protection, followed closely by Cheney Dam in 1964. From 1966 to 1969, five other embankments were constructed with soil-cement facings. Two of these were dikes with minimum wave action on them. The embankment at Lubbock Regulating Reservoir completely encloses the reservoir, and soil-cement was used on the interior slopes and on the bottom. The remaining two embankments, Glen Elder Dam and Starvation Dam, are major earth dams.

A small dam with a very sheltered reservoir was faced with soil-cement in 1972. To date, even the rubble left from construction has not been washed away at the water surface.

Palmetto Bend Dam, constructed in Texas in the late 1970's, used soil-cement as slope protection for an embankment for a railroad relocation through a portion of the reservoir as well as for the upstream slope protection of the dam. Another dam in Texas, Choke Canyon, that used soil-cement slope protection, was constructed in 1980-81, and has only recently had water against the facing. Calamus Dam in Nebraska is currently under construction, and soil-cement will be used as slope protection and also as a cover for a portion of the upstream blanket. Two additional dams to be built in the near future will probably use soil-cement slope protection.

All the soil-cement facings completed to date were constructed using a central batch plant, and compacted with sheepsfoot rollers followed by pneumatic rubber-tired rollers. The lifts were compacted to 6 inches for all of the features except three which used 8- to 9-inch compacted lifts.

All of the soil-cement was specified to have either 12 or 14 percent cement (by dry weight of the soil). The percent cement was based on minimum compressive strength requirements of 600 lb/in^2 at 7 days and 875 lb/in^2 at 28 days, or durability losses of 6 percent maximum for wet-dry tests and 8 percent maximum for freeze-thaw tests.

For all of the features, the compressive strengths of specimens prepared during construction and of record cores from the facings exceeded the design values. The percent compaction averaged 98 percent or more of the maximum laboratory dry density, as determined by the Bureau compaction test. Details for some of these projects have been reported by DeGroot [2] and by Davis, et al. [3].

MERRITT DAM

Merritt Dam is an earth dam located on the Snake River about 25 miles southwest of Valentine, Nebraska. The dam has a crest length of 3,222 feet and a maximum height of 126 feet above the valley floor. Construction of the dam started in 1961, and water storage began in 1964. Merritt Dam supplies water to the Ainsworth Canal, which transports the water to the Ainsworth Irrigation District.

Merritt Dam was the first Bureau dam where the contractor selected soil-cement as an alternative to riprap for upstream slope protection. Approximately

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

51,000 yd^3 of soil-cement were placed on the 4:1 slope, upstream face of the dam embankment in the fall of 1963. An asphalt-emulsion penetration treatment was also used for upstream slope protection on the 10:1 slope, right abutment of the dam. By November 1965, the asphalt slope protection had deteriorated significantly and, in 1968, was replaced with soil-cement.

The soil-cement for the 4:1 slope was mixed in a continuous mixing stationary plant using a twin-screw pugmill. The soil-cement was hauled to the placement site in trucks, spread in a loose 8- to 9-inch-thick layer, and then compacted with six passes from a sheepsfoot roller and four passes from a pneumatic, rubber-tired roller. The exposed portion of the compacted soil-cement slope was coated with an RS-1 asphalt emulsion. The specifications required that the soil-cement be compacted to a lift thickness of about 6 inches and a horizontal lift width of 8 feet. Each lift was offset 2 feet toward the dam centerline so that a minimum compacted thickness of 2 feet normal to the slope was obtained. A silty, fine sand and an average cement content of 14 percent was used for the mixture. The resulting densities of the soil-cement averaged 102.3 percent compaction with a standard deviation of 2.0 percent, and the average moisture was 0.3 percentage point dry of optimum with a standard deviation of 0.7 percent.

In October 1968, the asphalt mat on the 10:1 slope of the right abutment was replaced with soil-cement. The soil-cement was mixed in a stationary mixing plant, and the mixture was then hauled to the placement site. The soil-cement was placed in two 6-inch lifts parallel to the slope of the dam embankment starting at the bottom of the embankment and adjacent to the existing 4:1 soil-cement slope protection. This resulted in a smooth pattern instead of the stair-step pattern previously used. The soil-cement was spread in a strip and compacted to about 1.5 feet from the edge of the strip. The next strip was spread and the uncompacted portion was then compacted with the adjacent strip. Thus, the compaction operation resulted in joints only at the end of a strip and at the end of the day's run. The soil-cement was compacted by eight passes with a pneumatic rubber-tired roller. Placement moisture contents were maintained at 1 to 2 percentage points dry of optimum to prevent excessive rutting of the soil-cement. The first lift was cleaned with a power broom before placement of the overlying lift. The soil-cement was then covered with a moist soil cover to aid in curing.

First 10 Years After Placement

An inspection of the soil-cement slope protection 3 years after construction indicated that the slope protection was in excellent condition with only minor wearing and breakage. At that time, the most severe conditions at the damsite were 60- to 70-mi/h winds from the northwest, which resulted in 4- to 5-foot waves. According to the caretaker of the dam, it is not unusual to have waves of this size breaking onto the dam facing.

The first notable damage to the slope protection was observed during an inspection in September 1973. A 6- by 10-foot section of soil-cement had been significantly damaged. At that time, a program was initiated to monitor the erosion of the soil-cement annually.

1979 Assessment of Damage

By 1979, the soil-cement slope protection over the entire length of the 4:1 slope had deteriorated; however, the most significant damage occurred on the left side. About 300 feet from the left abutment, sections of the soil-cement lifts 30 to 40 feet long and 3 feet wide had been washed away. This extensive damage was attributed to ice forming between unbonded soil-cement lifts, and severe wave action. The ice formation between the lifts caused the soil-cement to crack, and the broken pieces were then removed by wave action.

The soil-cement on the 10:1 slope remained in good condition; however, there was cracking occurring at the construction joints at about 300-foot intervals. At some of these joints, there was an overlapping displacement which may have been caused by freeze-thaw action and temperature stresses, rather than wave action.

In October 1980, Bureau personnel initiated a sampling and testing program to determine the thickness of the soil-cement slope protection on the 10:1 and 4:1 slopes, and to determine the cause of the uplift of the soil-cement on the 10:1 slope at the vertical construction joints. Compressive strength, wet-dry durability, and freeze-thaw durability tests were performed.

Results of the coring indicated that the thickness of the remaining slope protection on the 10:1 slope ranged from 13.0 to 16.5 inches. The specifications called for a thickness of 12 inches. The slope protection on the 4:1 slope varied in thickness from 8.5 to 26.8 inches. The specifications called for a minimum thickness of 24 inches. Repair was necessary in the severely damaged areas.

The average compressive strength of the 16 cored specimens tested was 3,623 lb/in^2. The record cores during construction had an average compressive strength of 930 lb/in^2. The percent loss after wet-dry durability testing was less than 1 percent for all cored test specimens. The percent loss following freeze-thaw durability testing was 1 percent for all cored test specimens. Laboratory testing indicated that the soil-cement on both slopes was of good quality. The severe damage on the 4:1 slope appeared to be due to the lack of bonding between lifts and temperature stresses caused by extreme weather conditions.

The cause of the uplift of the 10:1 soil-cement slope was sand filling the construction joints. The sand-filled vertical construction joints caused the slope protection to uplift when the soil-cement expanded during the summer.

Repair of Damage

In the fall of 1980, repair of the soil-cement on the 4:1 slope began. The repair consisted of placing an overlay of a 4-sack mix of lean concrete over the soil-cement surface from El. 2948, down the slope about 20 feet. The lean concrete was tied into the existing facing with reinforcement bars. This type of repair is planned for almost the entire length of the soil-cement facing and covers the elevation range of the water level fluctuation. The repair will cover the severely damaged area and will protect the facing from future damage. Ice forming between the unbonded lifts of soil-cement is a major problem. Since the lean concrete will cover the soil-cement, ice will be unable to form between the lifts, thus preventing future damage. In the fall of 1980, about 150 yd³ of lean concrete was placed at a cost of $10,000. Another 123 yd³ of lean concrete was placed in 1983 at a cost of $8,000. The remaining repairs were performed in 1984.

The vertical displacement of the soil-cement on the 10:1 slope is a minor problem and should not impair the slope protection. There are no plans for repairs in this area at this time.

CHENEY DAM

Cheney Dam is an earth dam about 25 miles west of Wichita, Kansas. The dam has a crest length of 24,500 feet and a height of 86 feet above river bottom. The dam, completed in 1964, was built to provide a municipal water supply for Wichita.

The 180,000 yd³ of soil-cement for the upstream slope protection was constructed between April and October of 1964. The construction operation was identical to that used at Merritt Dam with one exception. The specifications required an 8-foot horizontal width for the compacted lift, and a 1:8 slope of the lifts toward the reservoir was used to provide a 10-foot width for ease in placement. The resulting densities of the soil-cement averaged 98.7 percent compaction with a standard deviation of 1.8 percent; the average moisture content was 0.3 percentage point dry of optimum with a standard deviation of 0.7 percent.

1966 Damage

The first recorded damage occurred during a storm period of March 3-5, 1966. The water elevation was 1415 and the soil-cement was damaged from about El. 1413 to 1415. The wind direction was primarily from the northwest, the average wind velocity ranged from 10.5 to 17.5 mi/h over the 3 days, and the fastest mile (observed over 1 minute) was 31 to 62 mi/h. The riprap placed around the spillway structure was completely removed by the storm as well as 18 inches of the clay embankment beneath the riprap. In several areas between stations 50 and 125, the soil-cement lifts had broken back about 2 to 3 feet from the edge of the lift. At eight locations, the breakage was considered extensive enough to be measured and photographed for future observation. The worst area was at station 85+75, where portions of three lifts had broken off and washed away so that the lift at the bottom of the breakout was exposed for a width of 5 feet over a length of 35 feet.

A survey showed that the soil-cement had originally been overbuilt enough that, in the damaged areas, the required normal thickness of soil-cement remained. The riprap removed around the spillway structure was replaced using larger pieces than were originally used.

1970 Repairs

By 1970, four areas had broken back enough that the city of Wichita patched them by grouting reinforcing bars into the existing soil-cement and filling in the space around them with transit-mix concrete. These areas were not the same areas noted in observations after the 1966 storm. The damage was between elevations 1419 and 1422; normal water surface had been about elevation 1422.

1971 Damage and Repairs

On March 18, 1971, a severe windstorm occurred in the Wichita area. The wind direction was from the northwest, the fastest mile was 57 mi/h, and the maximum gust (instantaneous speed) was 82 mi/h. Waves on the dam were reported by the dam tender to be 15 feet high; however, calculations showed that the waves should have been about 7 to 8 feet high. Where the earth ramps had been left in place, there were no remains of the ramps below 8 feet above the water surface at the time of the storm. Spray from the waves caused windshields to ice up on automobiles that were on a road a few hundred feet downstream of the dam.

The water surface at the time of the storm was at elevation 1421.4. The damage occurred between elevations 1415 and 1420. Damage was severe between stations 60 and 110. A total of about 300 linear feet of the clay embankment was exposed at three different locations between stations 95 and 105. A total of about 600 linear feet in three locations between stations 80 and 95 had only two lifts of soil-cement remaining. Figures 1, 2, and 3 illustrate some of this damage.

The patches placed in 1970 remained intact. The riprap replaced around the spillway structure was not disturbed.

Repairs required about 1,100 yd³ of lean concrete at a cost of about $34,500. The repair procedure was similar to the 1970 repairs using reinforcing bars grouted into place and transit-mix concrete to fill the space around them.

1981 Repairs

In 1981, about 800 yd³ of concrete was used to patch several locations where the soil-cement had broken away since 1971. The cost was about $56,000. No unusually severe storms had occurred; the damage appeared to be from normal wear.

A survey and drilling program was conducted in 1980 to evaluate the thickness of soil-cement remaining in some of the broken away areas. At eight sites, the soil-cement was thicker than 18 inches (limit of drill). At three sites, the thickness remaining was determined to be 13, 17, and 7 inches.

LUBBOCK REGULATING RESERVIOR

Lubbock Regulation Reservoir is near Lubbock, Texas, and is part of the Canadian River Project which delivers water from Sanford Dam to several cities in the Texas Panhandle. The reservoir was formed with compacted earth embankment up to 20 feet high that completely surrounds the reservoir area of about 40 acres. The soil-cement facing on the interior 3:1 slope of the embankment was 2.5 feet thick normal to the slope, and there was a single 6-inch layer of soil-cement placed on the bottom of the reservoir. Construction was similar to Merritt and Cheney Dams and was finished in 1966.

The soil-cement had 12 percent cement by dry weight. The dry density averaged 100 percent compaction, and the moisture content averaged 0.3 percentage point dry of optimum.

Although the magnitude of the waves in the reservoir is not as severe as at Merritt or Cheney, enough damage has occurred that repairs are considered necessary. The southeast corner has the most damage, but all four sides with soil-cement facing will require some repair.

EVALUATION OF PERFORMANCE

The cost of repairs to date for Cheney and Merritt Dams is far less than the cost savings realized by using soil-cement (compared to the bids for riprap for each dam). In addition, the repair cost may be less than if riprap had been used. Many dams in the Midwest have required extensive repair of the original riprap. However, an economical solution to preventing extensive repairs should be considered. In the case of major damage, such as at Cheney Dam, adequate protection for the embankment behind the soil-cement facing must be a design consideration for embankments that may be susceptible to erosion. The Bureau is continuing to evaluate the performance of Merritt and Cheney Dams and is considering possible improvements in construction techniques used in soil-cement slope protection. In areas where severe wave action can occur, bonding of the soil-cement lifts is being evaluated and considered. One test section of bonded lifts has been incorporated into one Bureau dam soil-cement facing (discussed later in this report) and another test section is being planned.

Bonding of Lifts

The bond between soil-cement layers is generally weak. As a result, when stresses created from severe wave action are considered, the soil-cement facing may be thought of as a series of offset horizontal slabs stacked on the slope of the embankment as shown in figure 4. If the exposed portion of the slab acts as a cantilevered beam during strong wave action, the low tensile strength of the soil-cement would result in a vertical crack. Combined with vertical shrinkage cracks, smaller slabs are created that can be washed away. As each exposed portion is cracked and washed away, the layer below has an additional exposed portion. This process can continue until the soil-cement has been completely removed, as has happened at a few locations at Cheney Dam.

The shrinkage cracks cannot be prevented, but bonding the layers together would create more massive

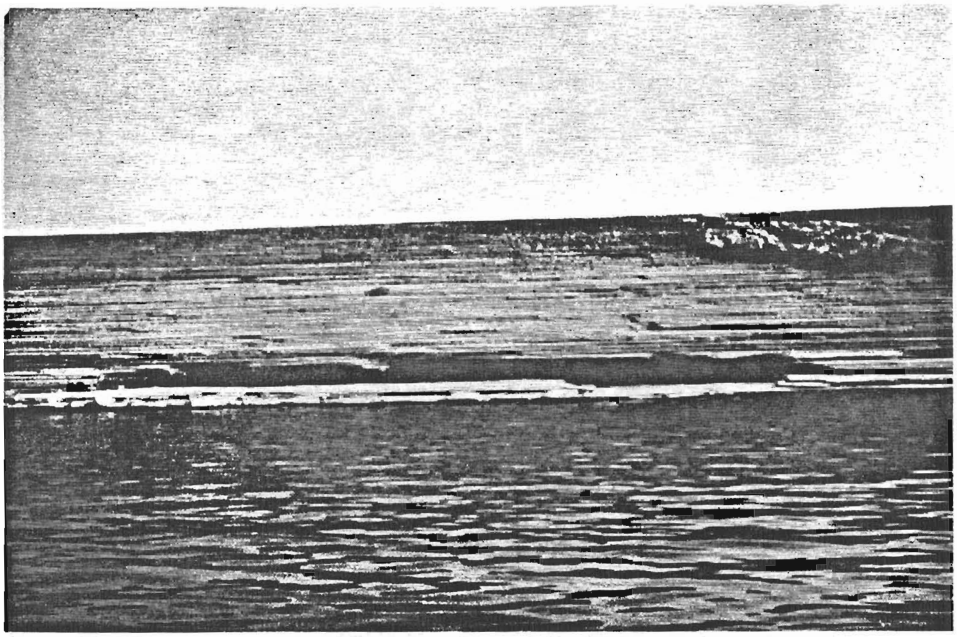

Figure 1. – Damage to soil-cement at Cheney Dam. Photo P801-D-80916

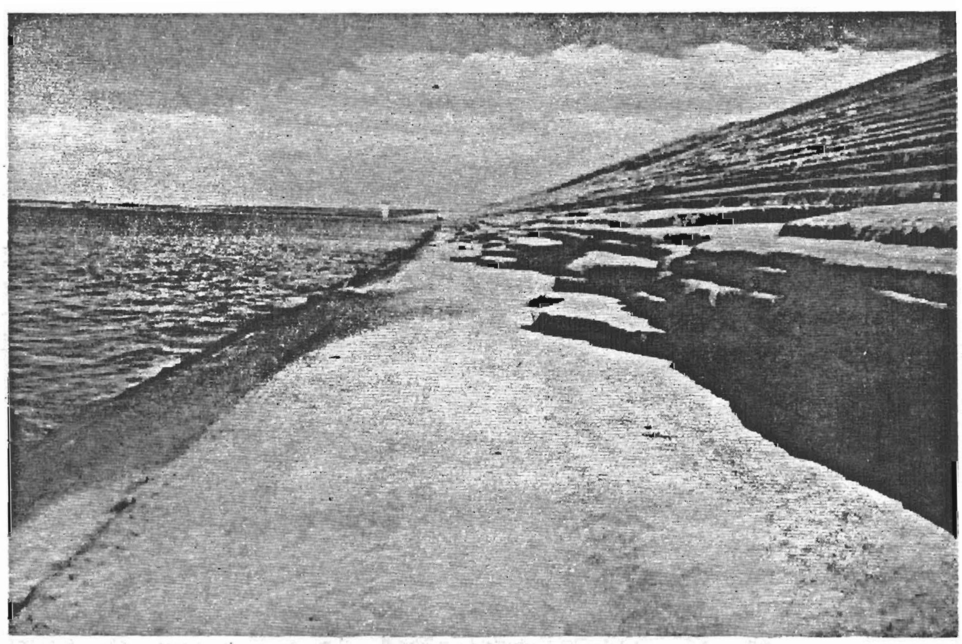

Figure 2. – View of most severely damaged soil-cement at Cheney Dam. Photo P801-D-80917

sections of soil-cement that would not wash away and would protect the underlying layers.

Data on the bonding between the soil-cement lifts have been collected from some of the record coring and followup inspections of the soil-cement after construction. The percent of the recovered lifts that have been bonded has ranged from 0 to about 50 percent. There is probably some degree of bonding between all the lifts but not enough to survive the coring operation. The results of direct shear tests have shown that the strength of some of the recovered bonds can be almost as high as that of the intact soil-cement. However, some of the recovered

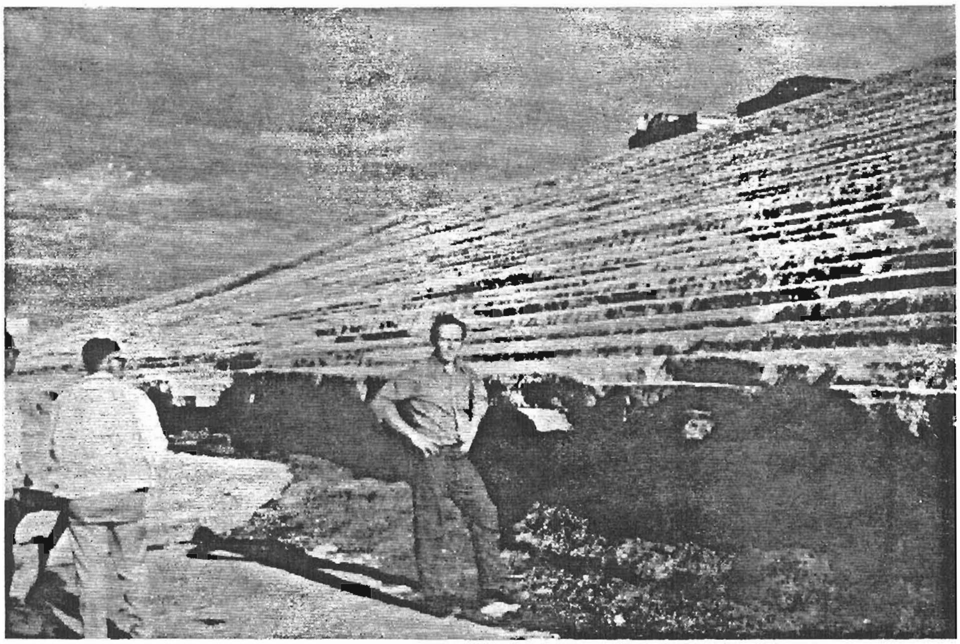

Figure 3. – Exposed embankment behind soil-cement at Cheney Dam. Photo P801-D-80918

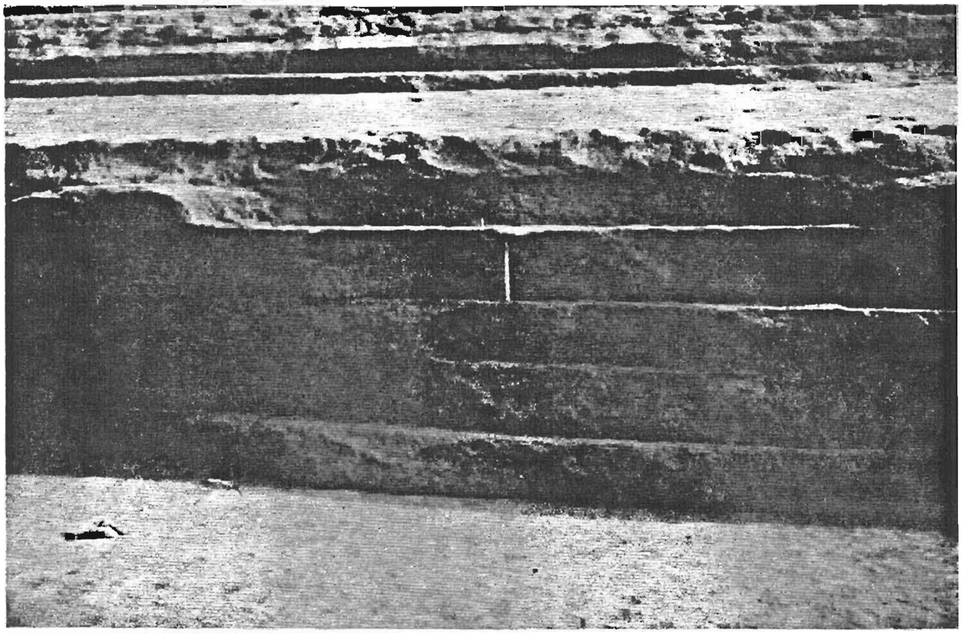

Figure 4. – Lifts of soil-cement shown at the back of break-out. Photo P801-D-80919

bonded lifts separated during handling or transit. The percent of bonded lifts recovered depends on two factors: (1) the original bond strength that was created between the lifts, and (2) the variations in the coring operations.

As reported by DeGroot [4], laboratory tests have shown that the original bond created between the lifts depends on the time delay between lift placement, the frequency of moisture being added to the lift surface, the available moisture during curing, and the surface texture. The time delay has a much greater effect on the bond strength than the other variables. In field coring operations, it has been observed that in specific areas known to have less than 2 to 3 hours delay between lift placements, the recovery of bonded lifts has been almost 100 percent. However, for most of the field coring data, the time delay between specific lift placement is not known. The age of the soil-cement also affects the percent of bonded lifts recovered. In the same way that the compressive strength of soil-cement has been shown to increase with time, the strength of the bond should also increase.

The percent of bonded lifts recovered also depends on the coring operation. The type and condition of the drilling equipment and the amount of care taken during drilling can create varying amounts of shear stress on the bonded lift. The size of the core has also been shown to be a significant factor. For one coring investigation, two different core barrel diameters were used for companion holes at various locations on the facing. For a 3-inch core, 29 percent of the recovered lifts were bonded together; and for a 4-inch core, 47 percent were recovered as bonded. The ratio of recovery between the two sizes is about the same as the ratio of the cross-sectional areas of the cores.

Bonding of the lifts appears to be the most critical factor in ensuring adequate performance of soil-cement slope protection. High-quality soil-cement does not necessarily ensure long-term durability. High compressive strength and low durability loss do not seem to be related to the ability of the soil-cement to withstand the uplift forces caused by severe wave action and ice buildup on the unbonded layers.

SOIL-CEMENT BONDING STUDIES

Bureau specifications for upstream soil-cement slope protection require that prior to placement of the overlying lift, the soil-cement be kept moist and the surface cleaned with a power broom to increase the roughness of the surface. These requirements help to provide a mechanical bond between lifts. Direct shear tests indicate that a stronger bond can be formed by application of cement between the layers of soil-cement.

In 1980, in an experiment to improve the method of bonding lifts together, a test section was constructed as part of the overall slope protection at Palmetto Bend Dam in Texas. The purpose of the test section was to evaluate the effectiveness of applying a bonding agent (cement slurry) between layers of soil-cement. The test section was 600 feet long, and located between stations 182+00 and 188+00 and elevations 41 and 47 feet. For this 600-foot test section, 500 feet was a broomed surface with cement slurry applied between lifts, and 100 feet was only broomed.

The water/cement ratio of the slurry ranged from 0.71 to 0.80 (average of 0.72) with application rates (pounds of dry cement per square yard of soil-cement) varying between 0.73 and 1.13 (average of 0.89). The slurry was mixed in 55-gallon drums and sprayed onto the soil-cement with a gardenhose-type nozzle immediately prior to placement of the next lift.

Initial results of the test section have been very encouraging. Results of coring operations showed that many of the lifts in the slurry-treated portion of the test section were bonded together. No bonded lifts were recovered in cores taken outside of the slurry-treated portion of the test section.

Another soil-cement test section is planned for a future Bureau dam. This test section will be incorporated into the soil-cement slope protection, and will be used on a dam that will experience more severe wave action than the facing at Palmetto Bend Dam. In addition, the soil-cement will undergo freeze-thaw cycles.

The material to be used for the surface treatment will be portland cement applied both dry and in slurry form. The water/cement ratio of the slurry will be 0.70. The application rates for both the cement slurry and dry cement will be 1 pound of dry cement per square yard of soil-cement.

The test section will provide information on: (1) the additional costs of bonding lifts together, (2) the techniques contractors might use to apply dry cement and slurry, (3) the evaluation of construction control techniques, and (4) the performance of dry cement and slurry bonded soil-cement under severe environmental conditions. The test section will be evaluated by periodic inspections and an extensive coring and laboratory testing program. Laboratory testing will consist of direct shear, unconfined compression, and water loss tests to evaluate the effect of curing time on shear strength and the permeability of the bonded joints. A comparison will be made of the number of bonded lifts in the test section to the number of bonded lifts in the untreated soil-cement.

SUMMARY AND CONCLUSIONS

The soil-cement upstream slope protection on three Bureau embankments built in the 1960's has been damaged enough to require repair. Although repair cost is less than the cost savings realized during construction and probably less than if riprap had been used, the Bureau is studying methods of preventing such damage. Laboratory and field test sections indicate that bonding the soil-cement lifts together may prevent major damage due to severe wave action on the facing. An extensive test section using lift bonding is planned for a future Bureau dam.

BIBLIOGRAPHY

[1] Holtz, W. G. and F. C. Walker, "Soil-Cement as Slope Protection for Earth Dams," *Journal of the Soil Mechanics and Foundations Division*, ASCE, vol. 88, No. SM6, pp. 107-134, 1962.

[2] DeGroot, G. *Soil-Cement Protection on Bureau of Reclamation Features*, Bureau of Reclamation Report No. REC-ERC-71-20, Denver, CO, 1971.

[3] Davis, F. J., E. W. Gray, Jr., and C. W. Jones, "The Use of Soil-Cement for Slope Protection," *Eleventh Congress on Large Dams*, Madrid, pp. 237-255, 1973.

[4] DeGroot, G., *Bonding Study on Layered Soil-Cement*, Bureau of Reclamation Report No. REC-ERC-76-16, Denver, CO, 1976.

GPO 848-234

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.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-822A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.