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16. ABSTRACT

This report summarizes the work accomplished under PRESS Project No. DR-381, Applications Development of Concrete Polymer Materials, from FY75 through FY83. Individual program studies are identified in the section entitled "Program Summary" under the fiscal year the work was undertaken. Many of the studies continued for a number of years. Several were performed at a single site. Each project is discussed in greater detail in the section entitled "Project Summaries."

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APPLICATIONS DEVELOPMENT OF CONCRETE POLYMER MATERIALS-A SUMMARY REPORT

by

Carl E. Selander

Prepared under Contract No. 3-PT-81-29540

February 1985

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

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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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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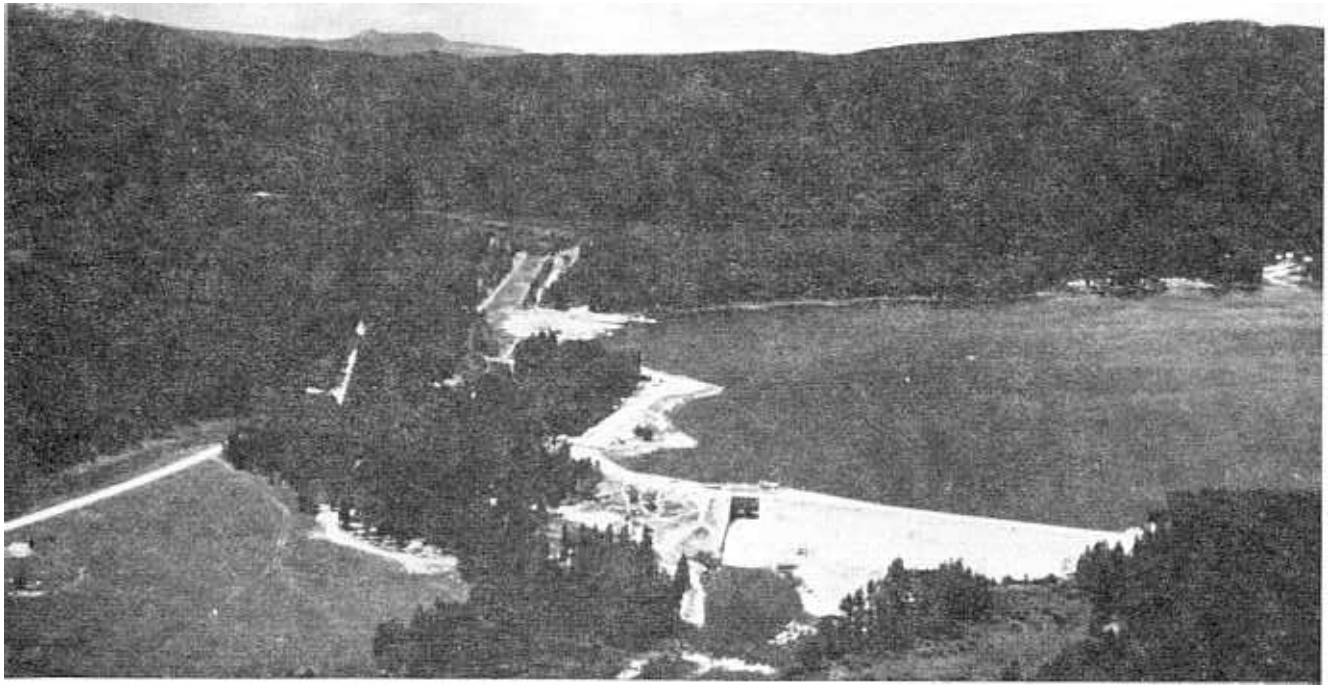

Frontispiece. Shadow Mountain Dam and Lake, Colorado – Big Thompson Project, Colorado.

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INTRODUCTION

This report summarizes the work accomplished under PRESS (Program Related Engineering and Scientific Studies) Project No. DR-381, entitled "Applications Development of Concrete Polymer Materials." The period of performance was from July 1974 through September 1983.

This study was established when it became apparent that large-scale field testing of concrete polymer materials[1] was essential for their development for use in civil engineering structures. Before FY75, particularly from 1970-1974, field applications were made under other projects [1][2].

Throughout the entire research and development period, DR-381 was supported by other existing projects. During the period covered by this report, FY75 through FY83, the principal cooperating projects were DR-256, Concrete Materials Systems Research (laboratory studies of concrete polymer materials); DR-380, Improved Repair Systems for Concrete (laboratory and field studies of materials other than concrete polymer materials); and DR-85, OCCS (Open and Closed Conduit Systems). The OCCS project provided support not only to E&R Center (Engineering and Research Center) personnel, but also to regional projects and offices for the performance of a variety of field studies.

When first established in July 1974, the purpose of Project No. DR-381 was defined as follows:

> "To develop practical applications of concrete polymer materials in a variety of civil engineering structures. This will demonstrate the capabilities, advantages, etc., of these composites. The program will maintain continuity in the development of these materials by moving from just laboratory studies to field application." [2]

Throughout the program the purpose was refined, and in the latest document describing this study [3], the purpose was restated as follows:

> "The purpose of this program is to develop, apply, and optimize concrete polymer materials in Bureau structures. This includes transfer and adaptation of the technology from the laboratory to the field, development of methods for field applications, and evaluation of methods and materials under field conditions. This program is directed specifically to meeting Bureau needs that cannot be met by other repair and maintenance materials."

In a paper by De Puy and Selander [4], presented at the Second International Congress on Polymers in Concrete, problems in scaling up from laboratory procedures to field applications were briefly described. As stated in that paper, field conditions are always different than laboratory conditions, and these differences can provide unexpected and sometimes unpleasant surprises. In addition, actual durability and performance are difficult to predict from the results of standard laboratory tests. Although the relative performance of concrete polymer materials compared with other materials can be fairly well established in the laboratory, even this comparison can be different under different field conditions. In each case reported, the best materials and/or procedures from laboratory studies were selected for these application studies. The results are interesting.

Although this program was terminated at the end of FY83, the need to continue with field testing still exists. New problems are encountered in every instance although many of the materials and procedures are now operational. Efforts to improve the applications must be made.

At this writing, no new field tests are being planned; however, as project needs are identified consideration should be given for additional concrete polymer materials applications. Funding must now come from other related programs or project sources.

In this report the individual program studies are identified in the section entitled "Program Summary," under the fiscal year in which the work was undertaken. Many of these studies continued for a number of years. Several were performed at a single project site. Each project study is discussed in greater detail in the section entitled "Project Summaries."

CONCLUSIONS

1. Even under the best circumstances, field conditions are always different from laboratory conditions; therefore, field testing is essential to the development of new materials for engineering applications. Implementation studies under this program illustrate this well.

2. The ultimate physical properties and engineering properties of concrete polymer materials depend on the environmental conditions existing at the time of their fabrication and application. Therefore, modifications to laboratory-developed formulations and

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[1] Concrete polymer materials mentioned in this report include: PIC (polymer impregnated concrete), precast portland cement concrete fully impregnated after hardening by a monomer system that is subsequently polymerized in situ; PC (polymer concrete), a mixture of aggregates and monomer or resin that is subsequently polymerized in place; and surface-impregnated concrete, precast or cast-in-place concrete partially impregnated to a finite depth with a monomer that subsequently polymerized in situ.

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

procedures may be required under particular field conditions. Field tests conducted under this program have resulted in modifications and changes optimizing materials and procedures for some applications.

3. PIC (polymer-impregnated concrete) has demonstrated excellent performance in the situations tested under this program. However, the relatively high cost of producing PIC has deterred its widespread use. Nevertheless, PIC should be considered for applications where improved durability must be obtained, even at higher costs.

4. Surface impregnation improves the durability of exposed concrete subjected to severe freeze-thaw conditions or surface erosion. However, the processing technique may produce or aggravate cracking in the surface of the treated concrete. Cracking is not a serious problem when precast or unrestrained structures are treated. Surface impregnation is considered operational.

5. Serious problems have occurred in scaling up to field applications with PC (polymer concrete) materials. Discoloration, surface degradation, shrinkage, warping, and cracking have all occurred. The most serious problem has been the occurrence of cracking in PC materials machine-applied to large areas. Equally harmful, but not as prevalent, has been the occurrence of shearing failures in substrate materials. These problems are less prevalent in small hand-applied PC repairs, and these are considered operational.

6. Thin polymer overlays show promise as new construction materials for severe environments. These are new composites developed from a combination of polymer concrete and protective coating technologies.

7. As a result of these studies, USBR (Bureau of Reclamation) project personnel and several construction contractors have become experienced in handling and applying concrete polymer materials. Alternative, competitive materials are now available for several applications.

PROGRAM SUMMARY

FY 75 Program Summary

During FY75, the following work was scheduled and accomplished [5]:

- Designs and fabrication of two PIC CHO (constant head orifice) turnouts: one for installation in the Columbia Basin Project, Washington, the other to be used as backup and later as a display specimen if not needed.
- Fabrication of PIC and PIAC (polymer-impregnated asbestos cement) pipes and PC slabs for field testing in geothermal environments at the East Mesa Test Site in California. Installation has begun.
- Planning for initial field tests of concrete polymer materials and other materials in the spillway at Shadow Mountain Dam, Colorado-Big Thompson Project, Colorado.

FY75 Transition Quarter and FY76 Program Summary

From July 1, 1975, to September 30, 1976, the following was accomplished [6]:

- Installation of the PIC CHO on the Columbia Basin Project.
- Completion of the installation of the PIC, PIAC, and PC specimens at the East Mesa geothermal test site.
- Completion of the first field applications at Shadow Mountain Dam. Phase 1 included surface impregnation, a PC overlay, and three epoxy overlays. (Several coatings were also tested under another branch program.)
- Support was provided for a PC field test at Madera Canal, Central Valley Project, California.
- Support was provided for a PC shotcrete application at Azotea Tunnel, San Juan-Chama Project, New Mexico.

FY77 Program Summary

The major effort during this fiscal year was to complete an additional field test at Shadow Mountain Dam. A special shape study was also made. The work scheduled and accomplished was as follows [7]:

- Completion of phase 1 tests at Shadow Mountain Dam.
- Shadow Mountain Dam, phase 2 - removal of the test materials from the first field test locations and application of a machine-applied PC overlay.
- Laboratory testing of a variety of sizes and shapes of PC specimens and analysis of results.

FY78 Program Summary

During this fiscal year, a surface impregnation field test was accomplished. The FY78 program was as follows [8]:

- Shadow Mountain Dam, phase 3 - surface impregnation of a portion of the spillway; this work was performed by contract.

- (Unscheduled) The return of failed test pipes from the geothermal test site to the E&R Center for testing and analysis.

FY79 Program Summary

The FY79 program was as follows [9]:

- Inspection of the PC test materials at Madera Canal.

- Inspection of the PC shotcrete at Azotea Tunnel, and inspection of damage at Blanco Tunnel, San Juan-Chama Project, New Mexico, for potential PC materials trials.

- Trial applications of PC materials at Grand Coulee Dam, Columbia Basin Project, Washington, to prepare for a major field repair at that structure.

- Partial support of PC repairs at Arthur R. Bowman Dam near Prineville, Oregon.

- Field trials of machine-applied PC overlays at the DFC.

FY80 Program Summary

The planned program was as follows [10]:

- Shadow Moutain Dam, phase 4 - removal of the PC overlay applied in FY77 and machine application of an improved PC. The actual application was deferred to FY81 because of extended runoff in the spillway.

- Partial support for gate seal repairs at Blanco Tunnel.

- Application of a polymer shotcrete on a drop structure on the Madera Canal. This work was not accomplished because developmental work on the shotcrete was delayed by inclement weather in Denver.The canal was available only from November 1 to January 31, a period of only 3 months. Additional field trials were conducted in the spring at the DFC (Denver Federal Center), but a satisfactory polymer shotcrete was not developed for service in the Madera Canal. Alternative plans were made for a hand-applied PC overlay.

FY81 Program Summary

Substantial fieldwork was planned for this fiscal year, not only to complete the delayed tests at Shadow Mountain Dam and Madera Canal, but also to address new problems that were identified. The planned FY81 program included the following [11]:

- Completion of phase 4 at Shadow Mountain Dam.

- Application of a commercial acrylic PC overlay to a drop structure on the Madera Canal.

- Application of a thin polymer overlay at Spring Creek Debris Dam, Central Valley Project, California.

- Application of a commercial PC repair material on a gate sill at Dille Diversion Dam, Colorado-Big Thompson Project, Colorado.

FY82 Program Summary

Much of the work scheduled for FY82 was to review performance at a number of field test sites. In addition, two new and different field needs were identified and test materials installed. Participation in a bridge repair program in Oklahoma was also scheduled. The program accomplished in FY82 was as follows:

- Field inspections at Shadow Mountain Dam, Dille Diversion Dam, and Madera Canal.

- A PC repair in a sluiceway at Milburn Diversion Dam, PSMBP (Pick-Sloan Missouri Basin Project), Nebraska.

- A followup inspection at Milburn Diversion Dam.

- Observation of a machine-applied PC overlay to a bridge in Oklahoma. This program was sponsored by FHWA (Federal Highway Administration).

- PC repair of damaged concrete in Carter Lake Dam outlet, Colorado-Big Thompson Project, Colorado.

- (Unscheduled) Field trials of fiber-reinforced PC overlays at DFC.

Several other work items and inspections were planned, but were not accomplished because of unavailability of suitable test sites or test materials on structures that could not be taken out of service for inspection.

FY83 Program Summary

The FY83 PRESS programs were developed to include phases so that progress could be reported separately. Project No. DR-381 was scheduled to be

terminated as a separate title, at the end of the fiscal year. The program for FY83 included the following:

- Phase 1 - planning for and accomplishing repairs to the test PC overlay at Shadow Mountain Dam (phase 5 of the Shadow Mountain program).
- Phase 2 - new field tests: thin polymer overlay at Grand Coulee Dam Visitor Center; and joint repairs in the spillway at Green Mountain Dam, Colorado-Big Thompson Project, Colorado.
- Phase 3 - inspections of previous applications: including the drop structure at Madera Canal, the Oklahoma Bridge, a roundrobin inspection of bridges in the Northwest treated under an FHWA program, Grand Coulee Dam roadway, Dille Diversion Dam, Carter Lake Dam outlet, and the surface-impregnated area in the spillway at Shadow Mountain Dam.
- Preparation of a program summary report.

PROJECT SUMMARIES

Each of the project studies mentioned in the previous section "Program Summary" is discussed in greater detail in this section under a specific project title. In the few instances where several different studies are included under one project title, each is discussed separately.

CHO Turnouts, FY75-FY83

Early in 1974, negotiations were completed for the installation of a PIC turnout in the Wahluke Branch Canal Laterals, Block 253, Columbia Basin Project. The PIC CHO would replace a type 2 CHO turnout at station 175+35.0 of the WB44E lateral being constructed under Specifications No. DC-7068. The contractor, Ball, Ball, and Brosamer, Inc., agreed to install the substitute PIC CHO as an extra work item under their contract, No. 14-06-D-7576. Design data are shown in table 1.
The CHO was designed to be cast in sections and bolted together after impregnation. This type of fabrication was necessary because the available impregnation facilities were not large enough to handle a full-size CHO in one piece.

Design drawings were provided, and two identical structures were precast. One was impregnated with a 60-40 styrene TMPTMA (trimethylolpropane trimethacrylate) system, the other with MMA (methyl methacrylate). Two systems were used because neither was available in sufficient quantity to process more than the components for one structure. The design drawings, the details of the polymer impregnations, and strength data are contained in appendix A.

Table 1. – Allowable stresses and material properties for PIC CHO used in the Wahluke Branch Canal Laterals.

Precast concrete - ultimate compressive strength	34.4 MPa
PIC properties	
Modulus of elasticity	41.37 GPa
Ultimate compressive strength	103.42 MPa
Allowable modulus of rupture	8.97 MPa
Allowable shear stress	6.89 Mpa

A back and side view of an assembled PIC CHO is shown on figure 1. A pipe stub was bonded into the circular hole in the headwall during installation.

A canal-side view is shown on figure 2. Note the thin sections of the structural components of the turnout. The high strength of PIC allowed these thin sections to be used, resulting in a relatively light structure. The components were assembled using a self-adhering, cold-applied, plastic sealing compound in preformed tape form (Federal Specification SS-S-0210) and with stainless steel nuts and bolts, or bolts in embedded anchors [19]. When the fasteners were tightened so that the sealing compound squeezed out slightly, a completely watertight structure was obtained.

The styrene-TMPTMA impregnated CHO turnout was crated and shipped to the project. The MMA-impregnated turnout was held as a standby in the event of damage during shipment and is now on display in the test-machine area of building 56 at the E&R Center.

Installation of the CHO structure (fig. 3) was made on July 8, 1975, observed by an engineer from the Division of Research. Because of the light weight of the PIC unit, only a backhoe and slings were needed to set the structure in place.

Detailed documentation of the installation is no longer available in E&R Center files. However, there is a discussion of it in a memorandum report by H. C. Riffle, dated June 24, 1976 (see appendix B). The project forces and the contractor's crew were pleased with the ease of installation. The CHO has been in service since shortly after installation and has been reported as trouble free. No visible distress or deterioration was found when it was examined in late 1983.

Geothermal Well Test Facility Field Tests, FY75-FY76

In 1974, extensive discussions were held with Lower Colorado Region and Washington, D.C. personnel regarding the possibility of including test sections of PIC and PIAC pipes and PC ditch lining in the East

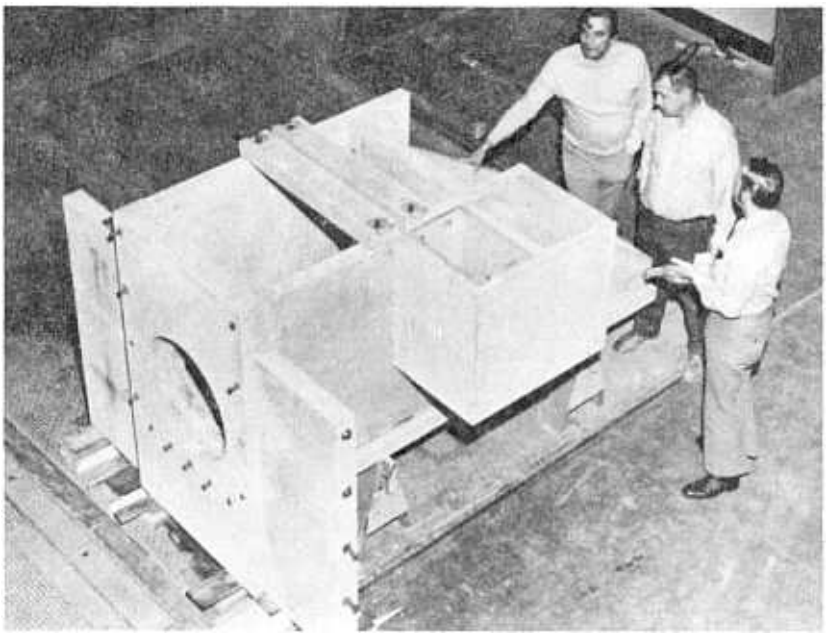

Figure 1. – Back and side view of assembled PIC CHO. Photo 801-D-80845

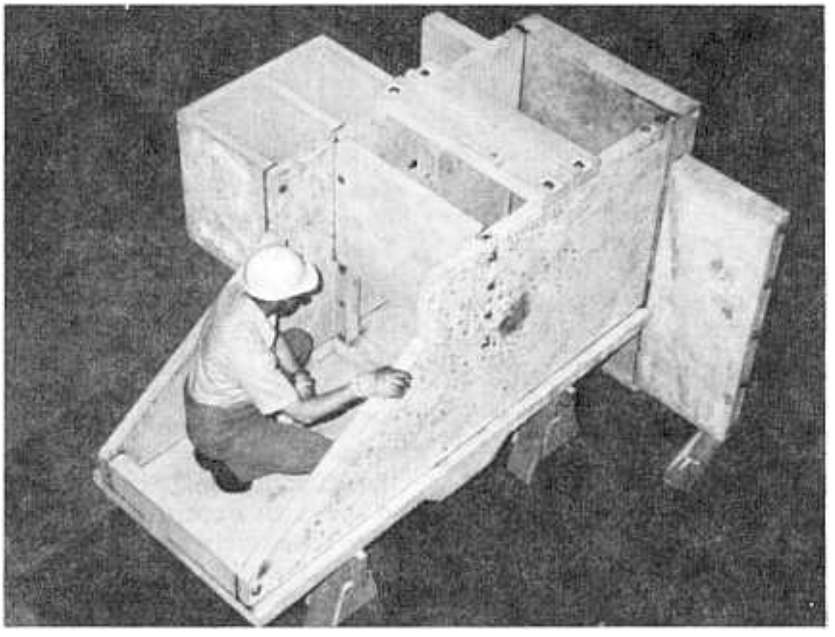

Figure 2. – Front (canal-side) view of assembled PIC CHO. Photo 801-D-80846

Figure 3. – Installation of the PIC CHO in the Wahluke Branch Canal Lateral at station 175+35.0 of the WB44E lateral. Photo 801-D-80847

Mesa Test Site, Geothermal Well Test Facility, Holtville, California. The general plan was to install the test pipe sections as bypasses in existing 100- and 200-mm-diameter steel pipelines. The test sections would be removable for periodic inspections and tests. Replacement pipes would be provided. The PC ditch lining would be constructed at slabs installed in the discharge ditch to the holding pond.

In FY75, commercially produced concrete and AC pipes (asbestos-cement) were procured for impregnation. The concrete pipes were 300-mm in diameter, class 12A50, and 1.92-m long. The AC pipes were 200-mm in diameter, class AC45, and 0.99-m long with 200-mm rubber-gasketed couplings. The pipe sections were impregnated at the E&R Center with a 60-40 styrene-TMPTMA system. Previous work with this system in high-temperature desalting tests showed a compressive strength of about 75.8 MPa at 177 °C. Complete details of the pipe impregnations are presented in appendix C.

The PC slabs were also fabricated with a 60-40 styrene-TMPTMA monomer system. These slabs were 0.57 m by 1.18 m by 63.5 mm thick and contained 19-mm-maximum-size aggregate. The monomer system accounted for 8 percent of their mass. The slabs were reinforced with 150- by 150-mm 10 gauge steel welded wire fabric. Mix design data are shown in table 2.

In all, 26 PIC pipes with gaskets, 11 PIAC pipes with 10 couplings and gaskets, and 13 PC slabs were shipped to the test site in June 1975.

Table 2. – PC mix design data for test slabs at the Geothermal Well Test Facility.

Aggregate		Monomer (8% by mass)	
Size	Percent	Component	Percent
Pan	17.0	Styrene	60
No. 100	5.7	TMPTMA	40
No. 50	8.7	Benzoyl peroxide	1.5
No. 30	9.0	Dimethyl analine	1.0
No. 16	5.4	Silane	0.5
No. 8	5.4		
No. 4-9.5 mm	19.5		
9.5 mm-19 mm	29.3		

The design and specifications for the installation were completed and issued by the Lower Colorado Regional Office in March 1976 [12]. A contract was issued to Jetco Petro Company, Logan, Utah, in May 1976. The design scheme required three bypasses: No. 1 with four sections of PIC pipe to carry steam, No. 2 with four sections of PIC pipe to carry waste brine from the desalting plant, and No. 3 with four sections of PIC pipe and four sections of PIAC pipe to carry brine from the steam separator. In addition, the PC slabs were to be installed by project personnel in the ditch from the silencer to the holding pond. The installation of the pipes began in early June 1976. Installation of bypass No. 3 is shown on figure 4.

Bypass No. 1 showed thermal cracking shortly after being put into service, but no water or steam escaped through the cracks (see on fig. 5). Bypasses

Figure 4. – Bypass No. 3 with PIC and PIAC test sections under construction. Photo 801-D-80846

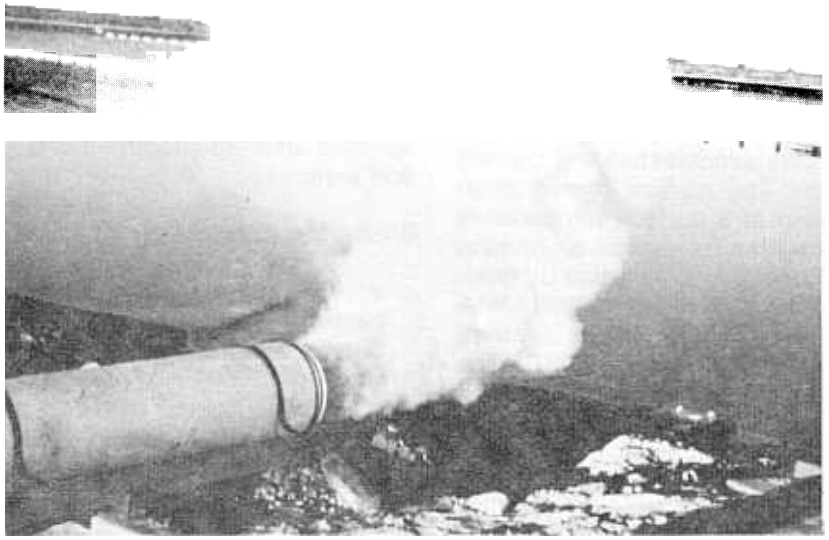

Figure 5. – End of bypass No. 1 pipe discharging waste steam. Cracking caused by thermal stresses occurred shortly after the pipe was put into service. Photo 801-D-80849

No. 2 and 3 were pressure tested to 0.483 MPa upon completion. The PIC in No. 3 had a few pinhole leaks, but these later sealed. The PIAC did not leak. It was concluded that PIC and PIAC pipes must be brought to service temperatures gradually to avoid thermal shock or distress that could cause damage, as occurred in bypass No. 1.

Unfortunately, further service data are not available. The USBR terminated geothermal testing in December 1976, and this field test was discontinued. Some

further exposure was achieved when the facility was operated for a while by ERDA (Energy Research and Development Administration), but no observations were made nor data taken. The PIC pipes from bypass No. 1 were returned to Denver in FY78, but nothing was done with them. Salt encrustations were evident in the cracking pattern so leakage must have occurred. The replacement pipes were given to BNL (Brookhaven National Laboratory) for testing under their geothermal program with DOE (Department of Energy).

Shadow Mountain Dam Field Tests, FY74-FY83

During the latter half of FY74, Division of Research personnel, LM (Lower Missouri) Region personnel, and Colorado-Big Thompson Project personnel engaged in discussions to develop a field test program in the spillway of Shadow Mountain Dam (see frontispiece). The concrete in the spillway was showing some degradation, and repairs were anticipated. The structure presented an ideal test site to evaluate the field performance of experimental repair materials.

In July of 1975, a multifaceted test program was developed, which included surface impregnation, a PC overlay, three epoxy overlays, and a series of coatings to be applied by the Applied Sciences Branch. The proposed experimental repair program was submitted to the LM Region in a letter dated August 4, 1975, and approval was given by a response dated August 11, 1975. The work was performed from August 13-22, 1975.

A 3.0- by 9.8-m area was sandblasted and treated by surface impregnation. The surface-impregnation treatment included drying at a surface temperature of 121 °C for 60 hours with a forced hot-air heating system, cooling for 60 hours, impregnation by gravity soaking for 9 hours with a 95-mass percent MMA and 5-mass percent TMPTMA monomer system, and thermal catalytic polmerization at 77 °C. The monomer application rate was approximately 7.3 kg/m^2.

The PC overlay was placed on an area 2.1 by 6.1 m. About half of the area had been treated by surface impregnation. The PC was prepared by mixing a VE (vinyl ester) resin with a graded aggregate in the ratio of 8 parts aggregate to 1 part resin by mass. A VE resin bond coat was applied to the concrete surface just before the overlay application. The PC was mixed in a small mixer and applied by hand, using conventional concrete finishing trowels. The PC overlay averaged about 13 mm in thickness. The edges of the overlay were featheredged.

Epoxy mortar overlay No. 1 was a two-component, 100 percent solids, polyamide epoxy resin, which the manufacturer claimed could be applied to damp concrete at temperatures as low as 4 °C. The epoxy resin was mixed with a graded sand in a 1:6 epoxy-to-sand ratio. Epoxy mortar overlay No. 2 was prepared using another two-component, 100-percent solids, polyamide epoxy resin with manufacturer's claims similar to the epoxy resin used in overlay No. 1, but supplied by a different manufacturer. The No. 2 mortar was prepared using a 1:6 epoxy-to-sand ratio. Epoxy mortar overlay No. 3 was prepared with a two-component, 100-percent solids, polysulfide epoxy resin meeting all requirements of Federal Specification MMM-B-350B for type II flexible epoxy resin adhesive binder. This resin was also mixed with a graded sand in a 1:6 epoxy resin-to-sand ratio. All of the epoxy overlays were applied by hand, as were the PC overlays.

A schematic layout of the experimental repairs on the floor of the spillway is shown on figure 6. Full details of the applications are documented in an interim report entitled "Experimental Repair of Shadow Mountain Dam Spillway" (appendix D). Included in this report are evaluations of performance after 1 month and after 9 months of service.

The enclosure used for drying and for polymerization of impregnated monomer in the surface impregnation process during the drying cycle is shown on figure 7. Application of the VE PC (vinyl ester polymer concrete) overlay is shown on figure 8.

In addition to the 1-month and 9-month inspections and evaluations, the experimental repairs were inspected after 13 months and 21 months of service and exposure.

Briefly, the results after 21 months were as follows:

a. The exposed surface-impregnated area appeared to be in good condition; further surface deterioration did not occur.

b. An area coated with only the VE resin showed no further deterioration from the slight erosion found after 1 year.

c. The VE PC appeared to be in good condition with some minor cracking and slight surface erosion evident.

d. The Federal specification type epoxy mortar, epoxy overlay No. 3, showed some random cracking, some softening that resulted in surface rippling, and some disbonding.

e. The two commercial epoxy mortar overlays showed surface deterioration, severe cracking, some softening in No. 2, and drumminess.

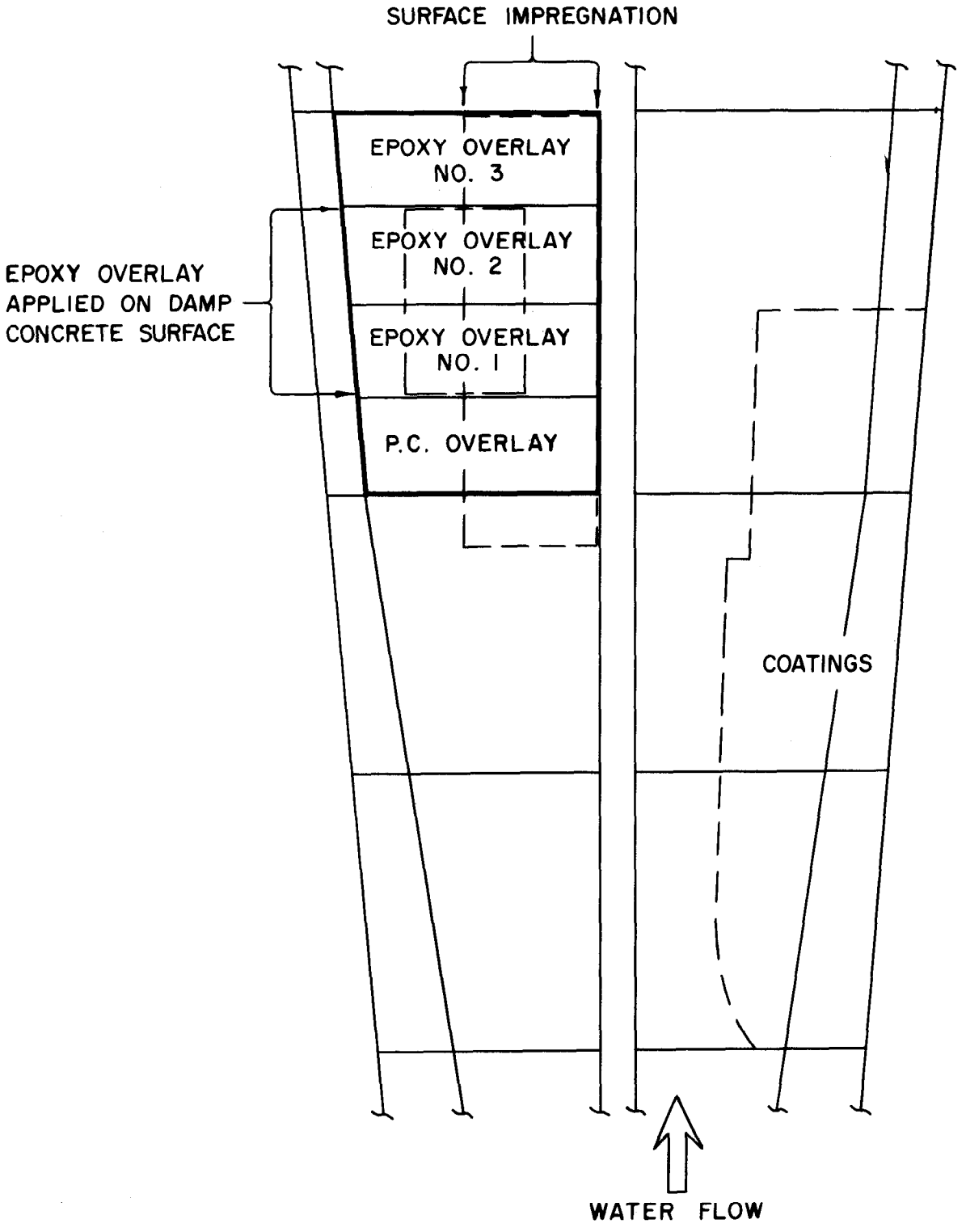

Figure 6. – Schematic layout for experimental repairs on the floor of the Shadow Mountain Dam spillway.

Figure 7. – Enclosure used for drying and for polymerization of impregnated monomer in the surface impregnation process during the drying cycle. Photo 801-D-80850

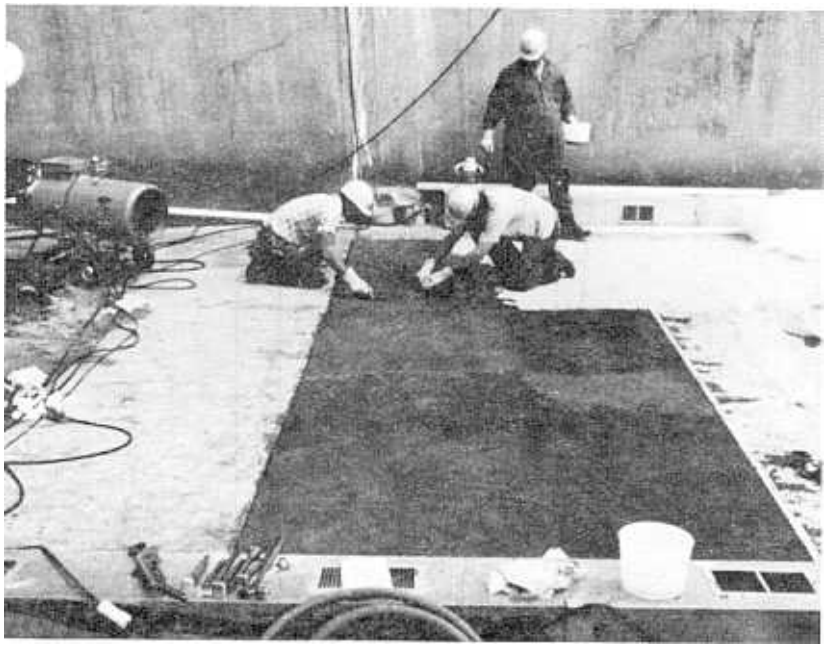

Figure 8. – Application of the vinyl ester PC overlay on the concrete surface. The overlay was applied by hand and trowled on. Photo 801-D-80851

As a result of the 21-month inspection, it was felt that the field test sections had served their purpose, and little would be gained from continuing. Thus, phase 1, as it is now called, was completed near the end of FY77.

Following completion of phase 1 and in further discussions with regional and project personnel, tentative agreement was reached to continue the experimental field applications at Shadow Mountain Dam. In a letter to the Regional Director dated July 7,

1977, continued field testing was proposed. Phase 2 would include removal of the test materials from phase 1, and placement of a machine-applied PC overlay over most of the left side of the spillway. Phase 3 would be to surface impregnate the right half of the spillway floor by contract. Possible development of a polymer surface treatment for the spillway walls would be undertaken under the DR-256 program.

Laboratory preparations for the phase 2 program were completed under the DR-256 program, except for a trial application of the PC on a sidewalk at the DFC. Field preparations were made by project personnel.

For phase 2, a Bidwell Model OF400 concrete paving machine was rented from the manufacturer. The USBR was committed to a field demonstration of a machine-applied overlay at one of its projects as part of its contribution to a cooperative program with FHWA for development of a VE PC overlay for bridge surfacing.

The phase 2 work at Shadow Mountain Dam was accomplished from July 18-22, 1977. During the removal of the four overlay test sections from phase 1, it was noted that in all cases the overlays were bonded better to the concrete treated by surface impregnation than to the sections overlayed on the nontreated concrete.

The machine-applied VE PC overlay was placed with the Bidwell concrete paver, which had been designed for placing a dense low-slump concrete (see fig. 9). The objective of this phase of the program was to demonstrate the feasibility of using a concrete paving machine to apply a PC overlay and to observe its performance under field exposure conditions. The concrete paver required no modifications to apply the PC overlay. The overlay was placed on an area of about 8 by 20 m, with a nominal thickness of 25 mm.

The VE PC was prepared by mixing 7.5 to 7.75 percent (by mass) VE resin with a dried graded concrete aggregate in 0.25-m^3-capacity drum-type concrete mixers. The mix was moved from the mixers to the test area in wheelbarrows, ahead of the paving machine. The machine spread and leveled the PC mixture and compacted and vibrated it in the finishing operations.

The day after placing, a system of fine cracks forming roughly circular patterns about 300 mm in diameter was observed in the PC overlay, (see fig. 10). In some areas, horizontal cracking occurred in the concrete just below the contact plane with the PC overlay, producing several delaminated areas. In other areas the PC overlay was intact and tightly bonded to the concrete. Both types of cracking were attributed to the shrinkage of the polymer during polymerization.

The field test demonstrated the feasibility of using a concrete paving machine to apply the PC overlay, but also pointed out the need to control the shrinkage that occurs during the polymerization of the PC mix.

In 1978, the overlay was examined cursorily during the surface impregnation work and in more detail in September 1979. Further cracking had not developed, but the inspections revealed progressive continuation of delamination. Two areas of the overlay had been washed out. After these inspections tentative plans were made to remove the PC overlay and apply a new overlay when an improved PC was developed. This was expected before the summer of 1981.

Phase 3 of the experimental work at Shadow Mountain Dam was scheduled for FY78. This phase was to demonstrate the surface impregnation process on a portion of the right side of the spillway floor; the work was to be performed by contract. The surface impregnation technique was developed by the USBR under a cooperative program with FHWA, which was interested in improving the durability of highway bridges. The USBR's interest was in improving the durability of other pavements, particularly waterways on grade.

Contract Specifications 70-C0038 were issued on January 25, 1978 [13]. Contract No. 8-07-70-C0038 was awarded for $34,506 to Concrete Specialties, Inc., of Fargo, North Dakota on April 21, 1978. On July 6, 1978, the notice to proceed was issued by the authorized representative of the Contracting Officer to start work on July 25, 1978—the date the operation of the spillway would be terminated for the 1978 season. Between award of the contract and notice to proceed, the contractor's proposed procedures and specifications were reviewed and modified or approved, and the work was started as soon as the spillway was available, on July 25.

The contractor's plan was to divide the total area into five sections of equal length and to work on one or two sections at a time using two enclosures for the processing.

Cleaning was started with a small commercial metal-shot blaster, (see fig. 11), in lieu of sandblasting. However, this process was extremely slow and required numerous passes to satisfactorily clean the surface. In addition, the contractor experienced frequent equipment breakdowns. Eventually, the original blaster was replaced with a new, larger machine that was more effective. The contractor's principal reason for using the new machine was that it almost

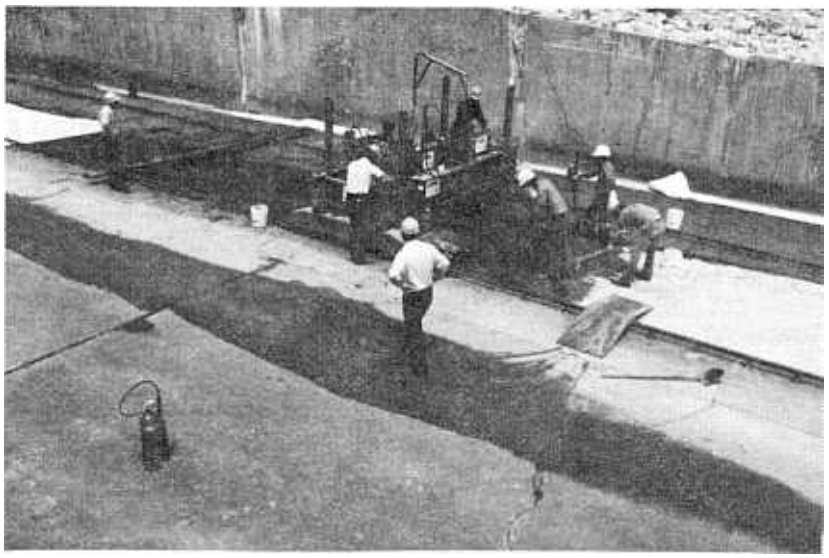

Figure 9. – Bidwell Model OF400 concrete paving machine finishing the VE PC overlay during the first field trial. Photo 801-D-80852

Figure 10. – Pattern cracking the the VE PC overlay examined by research and field personnel. Photo 801-D-80853

eliminated cleanup of sandblasting residue because it recycled the shot and vacuumed the dust. Only minor cleanup of residual shot was required.

The enclosures were prefabricated to span one-fifth of the total length to be treated. The sidewalls were of frame and insulation construction, with steel trusses to support the insulation roof. The heaters for drying and polymerization were gas-fired infrared radiant tube heaters suspended about 1 m above the surface. The system delivered approximately 11.4 MJ per m^2 of surface, raising the concrete temperature to 121 °C in about 4 hours. That temperature had to be held for 8 hours. One set of heaters was used, alternating between the two enclosures.

The first enclosure is shown during the cooling cycle on figure 12. In this photograph the roof is partially removed, and the infrared heaters are in place.

The cooling cycle was the most time-consuming part of the process. The specifications required cooling until the surface temperature reached 38 °C. Frequent light showers complicated this matter, and the cooling took as long as 41 hours.

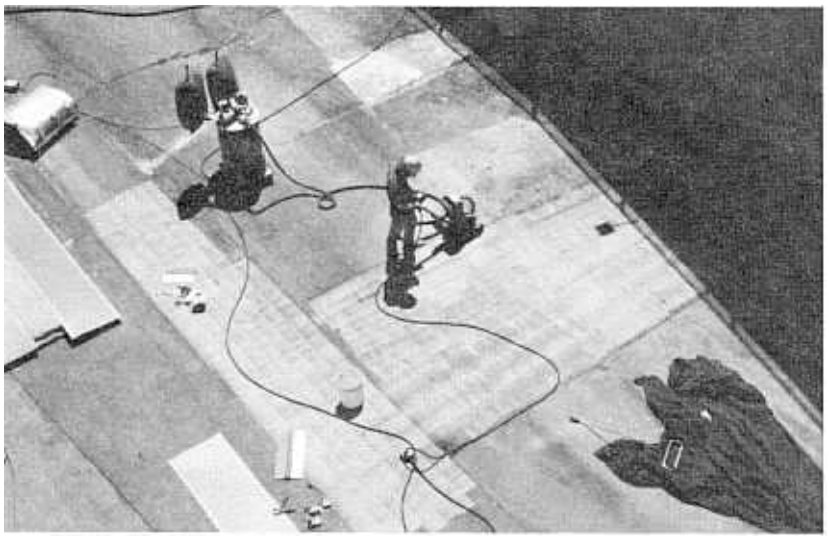

Figure 11. – Cleaning the concrete surface with commercial shot blast equipment. The result of the first pass is shown. As many as six passes were needed to get acceptable cleaning. Photo 801-D-80854

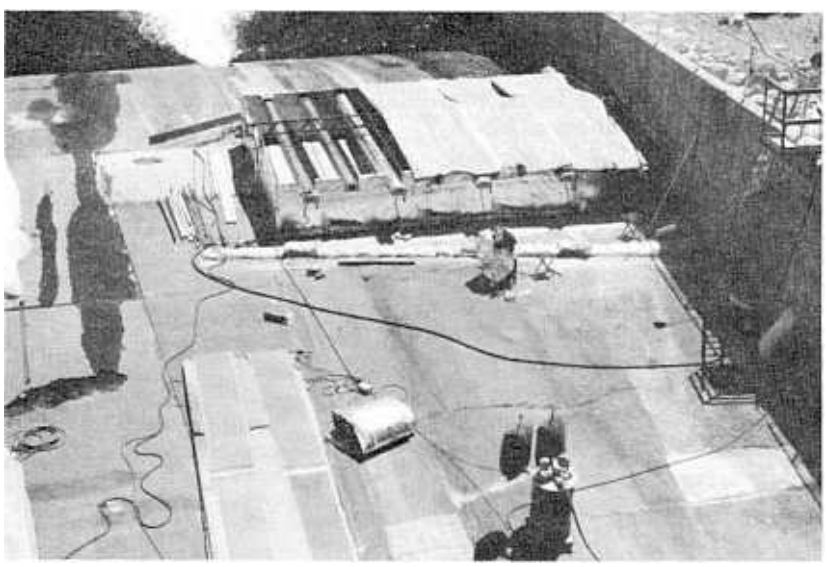

Figure 12. – The first enclosure, during the cooling cycle of the surface impregnation process. Photo 801-D-80855

In an effort to maintain dryness, aluminum covers for the insulation roof were fabricated, and during the nonheating cycles these were covered with polyethylene. The aluminum covers on the second enclosure are shown on figure 13. The enclosures were partially disassembled during the cooling cycle to speed cooling.

The work proceeded through August 20, 1978, when the last of the five areas was completed. All sections had bonded sand on the surface from the polymerization cycles. Removal of this bonded sand and cleanup of the area were completed on August 25, 1978. In all, the job took about twice the time originally estimated by the contractor, but substantially less than allowed by the contract.

The USBR's technical advisor was present on the jobsite from July 25 to August 8, 1978, to train the two project inspectors, to ensure compliance with specifications, and to modify the requirements if necessary. Thereafter the technical advisor made spot visits during the critical phases of the processing. Because this was the first contract for surface impregnation, numerous other persons interested in the

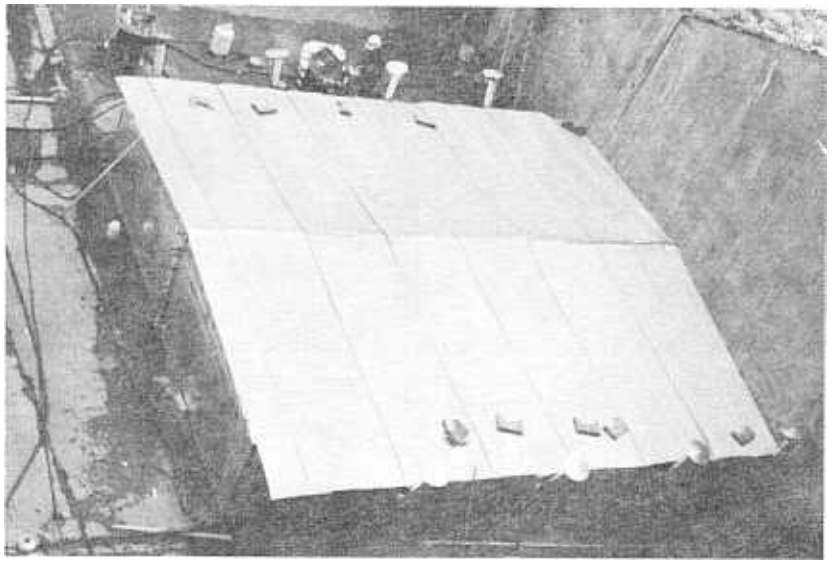

Figure 13. – The second enclosure, with aluminum covers on the roofing. Photo 801-D-80856

process visited the jobsite throughout the period of performance. One significant trip was made by the Division of Research Safety Engineer. He found that personnel exposure did not exceed 24 p/m of MMA, well below the 100 p/m TLV (threshold limit volume).

Cores were taken from the five treated areas to check on the effectiveness of the impregnations. Area No. 5, the first area treated, was cored before the other four areas were impregnated. Polymer penetrations ranged from 12.7 to 15.9 mm. The results of the coring from the other areas are presented in table 3. The cores were taken from the upper, middle, and lower sections of each area and were broken lengthwise to show the polymer penetration. Area 5 was the first treated, area 2 the second, area 4 the third, area 1 the fourth, and area 3 the fifth, and last area treated.

All cores showed unusually dark polymer penetrations, indicating high polymer concentrations in the treated zones. The relatively shallow depths of penetration were expected, as previously experienced with slabs on grade. The specifications requirement for a maximum 38 °C surface temperature at monomer application, rather than 38 °C at a depth of 25 mm (the usual point of temperature measurement for bridge decks), may have affected the penetration and denseness of color in the treated zone.

The impregnated portion of the spillway was inspected after exposure of 1 year and was found to be sound and unchanged in appearance. No hollowness, delamination, or weak areas were detected. Surface raveling from freeze-thaw action had been deterred. Annual inspections since have shown essentially no changes. Phase 3 at Shadow Mountain Dam is considered fully successful.

Table 3. – Core tests of polymer penetrations into the spillway floor at Shadow Mountain Dam.

Area	Location	Polymer depths mm	Comments
	Upper	9.5-12.7	
	Middle	7.9- 9.5	
	Lower	9.5-12.7	
2	Upper	15.9-19.0	
	Middle	12.7	dark band 1.6 mm thick below 1.6-mm leached surface
	Lower	6.4- 9.5	
3	Upper	7.9	
	Middle	9.5-12.7	
	Lower	4.8- 6.4	1.6-mm surface leaching, light zone to 22.2 m
4	Upper	6.4-12.7	
	Middle	9.5-12.7	
	Lower	6.4- 7.9	

Plans for phase 4 were discussed early in FY79, but because of the reduced DR-381 budget for that year, no work at Shadow Mountain Dam was scheduled. The phase 4 program was developed in FY80, but was dependent on the development of an improved VE PC in the DR-256 studies. Phase 4 would include removal of the PC overlay from the left side of the

spillway, which was applied in FY77 and was showing substantial distress, followed by machine application of the improved VE PC overlay. At that time, the USBR had a Bidwell Model OF400 paving machine with 3.7-m screeds, which was procured under a research-development program with FHWA and was to be used to apply the overlay.

During FY80, three VE PC trial mixes were made using different additives to reduce polymerization shrinkage. Although shrinkage was reduced, none of the mixes were satisfactory, as reported in the *DR-256 Annual Progress Report for FY80* [14]. However, this did not seriously affect the phase 4 program because extensive runoff and spillway operations kept the spillway unavailable during FY80. The work was rescheduled for FY81 when normal operations would make the spillway available from about late July to early October.

During FY81 under the DR-256 program, 33 additional VE PC mixes were tested for reduced shrinkage, as reported in the *FY81 Annual Progress Report* [15]. A low-shrinkage mix (PC 263), which contained 7-1/4 percent low-viscosity VE resin, fly ash, and a polymer powder, was selected for the application at Shadow Mountain Dam. However, when it was time to batch for the job, the fly ash and fine aggregate were not available in sufficient quantities. The mix was modified; F-95 Ottawa sand was substituted for fly ash. This modified mix (PC 285) had 0.15 percent shrinkage (compared with 0.14 percent for the original mix), about half the shrinkage of the PC applied in FY77. Mix design data are presented in table 4. Full details can be obtained from [15].

Arrangements were made in mid-1981 with the Project Manager for the work to be undertaken during the fall. Before the arrival of a crew from the E&R Center, project personnel removed the old overlay with an airpowered jackhammer. Underlying deteriorated concrete was removed with a scabbler and final cleaning was done by sandblasting. All equipment, materials, and supplies were delivered before September 1, 1981.

Table 4. – Mix PC 285 - 7-1/4 percent VE Mix with F-95 Ottawa sand, silica, and polymer powder.

Aggregated system		Resin system (7-1/4 percent of total mass)	
Size (mm) or materials	Percent	Material	Percent
9.5	34.3	65 cps shell VE	97.2
2.36	15.5	CHP	1.5
1.18	12.0	CoN	0.3
0.60	8.7	Silane	1.0
0.30	6.8		100.0
F95 Ottawa Sand	14.2		
Silica flour	5.5	Pigment	
Polymer powder	3.0		
	100.0	TiO_2	0.12 percent of aggregate mass
		Carbon black	0.014 g/kg aggregate

The actual application was made from September 1 to 16, 1981. The removal and cleaning operations produced a number of areas cut about 75-mm into the surface. These were repaired by filling with the VE PC and compacting and rough finishing with a gasoline engine-powered vibrating screed (see fig. 14). Approximately 35 percent of the surface was treated in this way. The patched areas were cured 4 to 5 days and lightly sandblasted just prior to the overlay application. The patches were sound, well bonded to the concrete substrate, and contained only a few small hairline cracks.

The VE PC overlay was applied in two passes with the Bidwell paver over a period of several days, (see fig. 15). Several problems were encountered including rain on the first day, difficulties in placing and finishing the PC, and premature polymerization of the bond coat and the PC. The overlay was sawcut after the material polymerized to form grooves on about 1-m centers in an attempt to control cracking.

Because of the premature polymerization of the PC, a poorly finished and rough surface was produced. About a week after the machine application, a hand-troweled polymer mortar was applied to smooth the rough areas in the surface and at the ends of the overlay.

Approximately 2 weeks after completion of the machine application, the overlay was closely inspected. The PC applied during the first pass, before the rain, was in the best condition. This area had been applied over a rubber modified VE primer coat and contained essentially no patched areas. The remainder of the first pass, applied over numerous patched areas, contained frequent cracks and drummy areas. The second pass, with the resin-rich PC mix, contained more cracks and drummy areas than the first. Because these cracks were late in forming, it was thought that the coefficient of thermal expansion was the principal contributing factor. In only one instance did a crack follow a sawcut, otherwise they formed in a random pattern.

Cores were drilled through the PC overlay from areas that indicated disbonding or shearing by hammer tapping. The overlay was found firmly bonded to the concrete and indicated no failure or distress. The only horizontal cracks found in the cores were located 12 to 50 mm below the PC-concrete interface. Three of the five cores did not contain cracks. From such a small sampling, it was not possible to determine if

Figure 14. – Deep holes in the surface were filled with VE PC and finished with a vibrating screed prior to the overlay application. Photo 801-D-80857

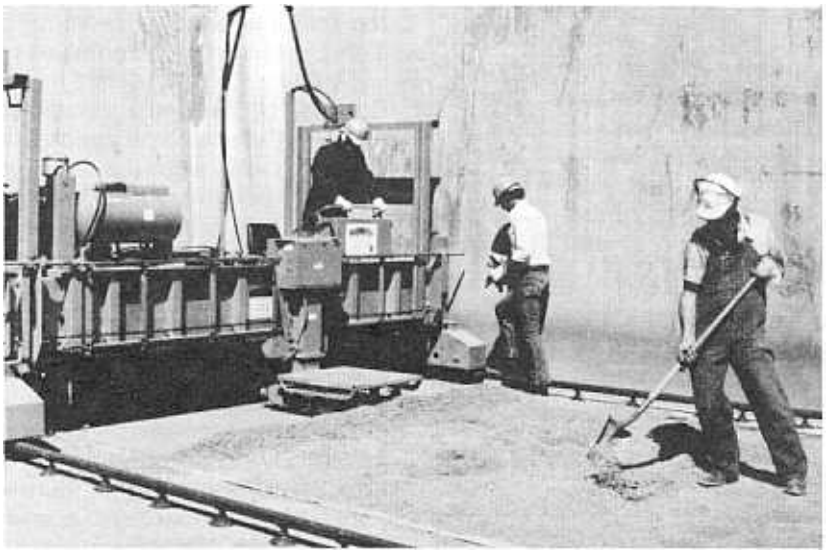

Figure 15. – The paving machine applying the VE PC overlay on the first pass. At this point all was going well. Photo 801-D-80858

the cracks existed prior to PC application or if the PC application caused the cracking. Previously, cracks of this nature had formed in the concrete immediately below the PC-concrete interface.

The mechanism for crack formation so deep in the concrete has not been defined. It is also not understood why hollow-sounding areas, as determined by hammer tapping, did not contain horizontal cracks as expected.

This particular field test well illustrated the difficulties in moving experimental materials from the laboratory to the field. At this time, a satisfactory VE PC is not available for machine-applied overlays, and further developmental work is not planned.

Although the overlay is cracked and drummy, it has presented no problems in the operation of the spillway during 1982 or 1983. The most notable change is that the cracking is more visible. The overlay was last inspected on May 25, 1983. During that inspection, plans were developed to remove a portion of the VE PC overlay and replace it with a commercially available acrylic PC that was being field tested at other sites. This would be phase 5 at Shadow Mountain Dm, the final work at that site scheduled under the DR-381 program.

In September 1983, the phase 5 work was accomplished (see fig. 16). As in previous phases of work at Shadow Mountain Dam, project personnel had removed the old overlay and prepared the surface. A three-man crew from the Polymer Concrete and Structural Section assisted the project people in the application.

The area was approximately 3 m by 5.6 m, and the applied overlay was about 75 mm thick. The acrylic PC overlay has not been inspected since it was applied; therefore, no evaluation data are available.

Shape Study, FY77

In the early 1970's, test specimens of various shapes and sizes were studied to develop relative strength data for polymer concretes. This study was performed to develop the correction factors necessary for comparing strength data from one size or shape concrete test specimen with similar data from a different size or shape specimen. During FY74, data were developed for portland cement concrete and shotcretes under *DR-326, Shotcrete for Tunnel Supports* [16].

Polymer shotcretes had been developed, and a major field test planned for FY77. However, because comparative data for polymer concretes had not been developed, and information was not available in the literature, a preliminary test program was scheduled under DR-381. Three or more specimens of 10 different sizes and/or shapes were tested for compressive strength, and the data was documented by H. C. Riffle in a memorandum report [17]. The relationships resulting from this preliminary study are presented in table 5. Specimen sizes have been converted to metric for this table.

Although these data are not statistically significant because of the small sampling, they are useful in comparing strength data. They have been particularly useful in comparing polymer shotcrete strengths data with cylinder test data. They have also been useful in comparing Soviet test data with U.S. data. The Soviets use prisms for many strength tests, the U.S., cubes or cylinders. As can be seen from table 5, the ratios vary from 0.80 to 1.26, a substantial range.

San Juan-Chama Project Field Tests, FY75 Transition Quarter FY80

Most of the field testing at the San Juan-Chama Project was funded by the OCCS Program, DR-85. However, because some funding was provided by DR-381, these tests are included in this report. Under this program, two principal field tests were supported: the first, a polymer shotcrete application on

Figure 16. – The Acrylic PC was mixed in a conventional concrete mixer and placed, screeded, and finished by hand trowelling. Photo 801-D-80859

Table 5. – Ratios (Y/X) of average compression strengths of various shapes and sizes of polymer concrete specimens.

Y \ X	150 x 300 mm cylinder	75 x 150 mm cylinder	50 x 100 mm core	100 x 100 mm cube	75 x 75 mm cube	50 x 50 mm cube	50 x 50 x 100 mm prism	25 x 50 x 50 mm prism	25 x 25 x 50 mm prism	25 x 37.5 x 50 mm prism
150 x 300 mm cylinder		0.96	1.03 *1.11	0.95 *0.92	0.91 *1.02	0.88 *0.96	0.99	1.00	1.11	0.95
75 x 150 mm cylinder	1.04		1.07	0.99	0.95	0.92	1.03	1.03	1.16	0.99
50 x 100 mm core	0.97 *0.92	0.93		0.92 *0.83	0.88 *0.92	0.86 *0.86	0.96	0.96	1.08	0.92
100 x 100 mm cube	1.05 *1.07	1.01	1.08 *1.22		0.96 *1.12	0.92 *1.05	1.04	1.04	1.17	1.00
75 x 75 mm cube	1.09 *1.01	1.06	.1.14 *1.10	1.05 *0.91		0.97 *0.95	1.09	1.09	1.22	1.05
50 x 50 mm cube	1.13 *1.08	1.09	1.17 *1.18	1.08 *0.98	1.03 *1.08		1.12	1.12	1.26	1.08
50 x 50 x 100 mm prism	1.01	0.97	1.04	0.96	0.92	0.89		1.00	1.12	0.96
25 x 50 x 100 mm prism	1.00	0.97	1.04	0.96	0.91	0.89	1.00		1.12	0.96
25 x 25 x 50 mm prism	0.90	0.86	0.93	0.86	0.82	0.80	0.89	0.90		0.86
25 x 37.5 x 50 mm prism	1.05	1.01	1.08	1.00	0.95	0.93	1.04	1.04	1.16	

*From SM 74 Concrete Series by USBR Concrete Section (code D-1511)

baffle blocks at the outlet of Azotea Tunnel in northern New Mexico, and the second, a VE PC repair around a seal plate of a radial gate at the intake works of Blanco Tunnel in southern Colorado. Both structures are exposed to severe abrasion during operations and provided ideal test sites to field test abrasion resistant composites.

At Azotea Tunnel, the technical feasibility of polymer shotcrete was demonstrated. The application was made by laboratory personnel with assistance by field personnel, from September 13-16, 1976. The nearly vertical upstream surfaces of the concrete baffle blocks were resurfaced with the VE shotcrete (see fig. 17). These surfaces were badly eroded from exposure to sediment-laden waters moving through the system.

The details of the development of the polymer shotcrete material, equipment modifications, laboratory trials, and the field application were well documented by F. E. Causey in a laboratory report published in May 1977 [18]. This information was condensed as part of a paper prepared for the Second International Congress on Polymers in Concrete held in October 1978 [4].

After 1 year, adhesion to the concrete was excellent, and there was little erosion damage. However, during the second year of exposure, the VE polymer shotcrete on the baffle blocks sustained severe erosion damage – severe enough to consider the test a failure. The second year of the test was an extremely high water year with large volumes of water passing through the system, often carrying many large cobbles and unusual amounts of gravel and sediment. The VE composite used did not have the durability needed for that severe erosion environment, although it looked good after laboratory erosion tests. This field test illustrates the need for field trials of new materials and the difficulty in predicting long-term durability from laboratory tests.

The second application was an installation of a VE PC material around a seal plate on a radial gate in Blanco Tunnel intake (see fig. 18). The purpose was to demonstrate the feasibility of using PC in lieu of epoxy compounds for small, quick repairs. The PC composition is shown in table 6. The repair was made in October 1979. It has not been examined since, because of the high cost of dewatering the tunnel; however, it is presumed to be satisfactory because operating problems with the gate have not recurred.

Madera Canal, Central Valley Project, FY76-FY83

The Madera Canal is an earth-lined canal 57.8-km long extending from Friant Dam to the Chowchilla River in California; it is part of the Friant Division. Completed in 1945, it operates at capacity for 9 months of each year. Historically, the concrete structures on the canal have experienced severe erosion and have presented difficult and unusual maintenance problems. A number of conventional repair techniques have been tried without much success.

Figure 17. – Field application of VE polymer shotcrete to baffle blocks at the outlet of Azotea Tunnel. Photo 801-D-80860

Figure 18. – Hand placing and finishing the VE PC at Blanco Tunnel. Photo 801-D-80861

Table 6. – Composition of the polymer concrete used at Blanco Tunnel. The polymer concrete contains 6 percent resin by mass.

Aggregate system		Monomer system*	
Sieve size	Percent	Materials	Percent
19.0-38.0 mm	20.0	VE411C resin	100
9.50-19.0 mm	27.9	CHP	1.5
No. 4-9.5 mm	10.0	CON	0.3
No. 8	3.3	Silane	1.0
No. 16	3.3		
No. 30	5.5		
No. 50	5.3		
No. 100	3.6		
Pan	6.6		
Fly ash	6.6		
Polymer powder composite	7.9		

* VE411C is vinyl ester resin that contains 50 percent styrene
CHP is Cumene Hydroperoxide
CON is Cobalt Naphthenate
Silane is a coupling agent

In 1975, with the development of VE PC, a program was initiated to develop a more abrasion-resistant PC for a field trial at one of the two drop structures at the discharge end of the canal. This particular study was of special interest because it would be the first field application of VE PC.

After agreements were reached with the Mid-Pacific Regional Office and the Central Valley Project, the experimental VE PC patches were applied to the lower drop structure in February 1976. Project personnel prepared the surfaces to be repaired and applied the VE PC with technical assistance from research personnel (see fig. 19).

The developmental program for the abrasion-resistant PC, the results of the abrasion tests, and details of the field application were documented by F. E. Causey in a report published in July 1977 [19]. Mix design data for the VE PC extracted from that report are presented in table 7.

This particular VE PC was stiff and somewhat difficult to apply to the steep slope of the drop. However, it cured overnight to a very hard overlay.

The patches were inspected after each water year by project personnel, with occasional participation by research personnel. Some cracking and only slight wear were apparent after 1 year. After 3 years of operation it was noticed that the aggregate appeared to be wearing at the same rate as the polymer matrix. About this time, the VE shotcrete process had been developed, and tentative plans were made to continue this field testing at Madera Canal with a shotcrete application. The VE PC patches were last inspected in November 1982. Continued wear in the PC was reported, but it was not as severe as in the concrete. Some undercutting was occurring in an upper patch, but little change could be detected in the

Figure 19. – The first field application of VE PC, made on the steep slope of a drop structure on the Madera Canal. Photo 801-D-80862

Table 7. – Mix design data for experimental VE PC for Madera Canal drop structure.

Aggregate system				Resin system (8 percent of total mass)	
Aggregate size		Percent retained, by mass	Accumulated percent, by mass		
mm	sieve			Materials	Parts
9.5	3/8	0	0	Vinyl ester	100
4.75	No. 4	25.7	25.7	Methyl ethyl ketone peroxide	1.5
2.36	No. 8	18.6	44.3		
1.18	No. 16	14.2	58.5	Cobalt naphthenate	0.75
0.6	No. 30	8.8	67.3	Silane	0.5
0.3	No. 50	6.2	73.5		
0.15	No. 100	3.5	77.0		
Pan	Pan	11.5	88.5		
Cement	Cement	11.5	100.0		

slope patch. Cracking that had been previously reported was seen, but additional cracking was not detected. The VE PC patches were still hard and well bonded. These patches have given some of the best service of any materials field tested under this program.

In FY80, the application of a full floor of polymer shotcrete in the second, or upper, drop structure on the canal was planned. The technical feasibility of the application had been proven on the baffles at Azotea Tunnel, but the performance of the PC there was not satisfactory. Several modified mixes showed improved abrasion resistance in laboratory tests, and trial applications at the DFC were scheduled. A low-viscosity resin was selected for the next outdoor trial. These tests were conducted on a vertical wall at the DFC. This particular low-viscosity resin did not mix well with the aggregate during the application. There was a high loss of fines causing a poor, nonuniform application (see fig. 20). The mixture also had a long polymerization time, which caused the applied mixture to slough off the wall.

Figure 20. – Trial application of low-viscosity VE polymer shotcrete. The high loss of fines caused a poor, nonuniform application. Photo 801-D-80863

Several modifications were made to the mixture: the fines were reduced, the coarse aggregate was increased, and the catalyst was changed to shorten the polymerization time. This resulted in a better application and quicker polymerization; however, it was apparent that further developmental work was needed before the system would be operational. This work was delayed because inclement weather suddenly postponed outdoor trials. The outdoor trials at the DFC could not be completed in time to accomplish the field test at Madera Canal during FY80; therefore, the Madera field test was rescheduled for FY81.

In the interim, additional laboratory work was undertaken to improve the VE composite so that outdoor trials could resume in the spring of 1980. As it turned out, none of the more abrasion-resistant PC mixtures could be applied satisfactorily with the shotcrete equipment. Further developmental work has not been undertaken, although the need still exists.

In 1979 and 1980, a number of commercial polymer concretes were developed and introduced into the construction market. Most of these products were tested by the USBR under the DR-256 program. The technology for these products was based on early work with MMA polymer concretes by the USBR and others. They generally are classed by the generic terms "acrylic" or "methacrylic" polymer concretes. Most of these systems are quite fluid and easy to handle, and some display performance comparable to the VE. With approval from the Central Valley Project, a field test of a particular commercial acrylic PC was scheduled for FY81. The commercial acrylic PC was modified by the addition of fine aggregate so that the mixture could be hand-applied to the steep 34° slope without excessive slumping. This particular system could be applied by project personnel without shotcrete equipment.

A technique to apply the material was developed, in which the composite would be placed by hand in small areas, in checkerboard fashion, starting at the bottom and working up. This technique was demonstrated at the DFC on a large test slab inclined at the same slope as that of the actual structure.

The field application was accomplished from December 15-19, 1980, by project personnel, with technical assistance from an engineer from the Division of Research.

After the floor surfaces were cleaned by sandblasting, longitudinal and lateral wood strips were fastened to the concrete to block out the checkerboard pattern and to provide some support for the fresh PC. The acrylic PC was troweled on alternate sections of the surface by workmen supported by ropes (see fig. 21). The floor of the drop was overlaid with the acrylic PC to a nominal depth of 50 mm. Alternate

Figure 21. – Application of an acrylic PC on a drop structure of the Madera Canal. The checkerboard pattern provided working space and minimized slumping during application. Photo 801-D-80864

sections were overlaid after the first sections cured, and the wooden strips were removed. The completed checkerboard overlay (see fig. 22) was later smoothed with a thin top coat of acrylic polymer mortar. The baffle blocks at the bottom of the drop were also repaired with the acrylic PC.

Because this was the first field test of a commercial PC, annual inspections were scheduled. The first inspection was made in November 1981 after 1 water year of service. The PC appeared to be in good condition and showed little signs of wear. The overlay was sound, but displayed two cracks that were judged to be reflection cracks from joints in the base concrete. There was one small area near the bottom where the polymer mortar top coat had disbonded from the overlay.

This overlay was also examined in November 1982, along with the VE PC. During the 1982 water year, 269 million cubic meters of water passed through the canal. This was considered a high water year. The acrylic overlay was still in good shape, but there was some surface erosion through the center section of the floor. The surface was rough because of the loss of the sand filler at the surface. Addiitonal cracking was also found in the application pattern; there was also some pattern cracking. Performance was judged satisfactory for that extremely erosive environment. An inspection by project personnel after the third year of service is planned, but has not yet been made.

The Madera Canal tests have been useful in comparing and evaluating the performance of PC materials. The VE PC test patches in the lower drop structure are showing less wear than the concrete after 6 years of exposure,and it appears that the VE PC is more resistant to erosion than the acrylic PC in the upper drop structure.

Grand Coulee Dam, Columbia Basin Project, FY79-FY83

In November 1977, a Concrete Polymer Materials Seminar was conducted by the Polymer Concrete and Structural Section staff at the E&R Center. Among the 87 participants were 4 from Grand Coulee Dam. Their interest was to learn if these new materials might be useful in solving a problem that existed at the dam. After some 40 years of service, the concrete roadway over the dam at Grand Coulee was showing the effects of exposure. Surface raveling, similar to that in the spillway at Shadow Mountain Dam, was progressing slowly, and there was loose and spalling concrete at many joints. The problem was complicated by the fact that the gantry crane rails were embedded in the roadway with only 12-to 25-mm clearance between the roadway and the crane. This precluded the use of conventional overlays.

In a series of discussions with dam, project, and regional personnel, the potential of concrete polymer repair materials was outlined. Based on previous field tests, surface impregnation could correct the surface raveling, and PC was a likely repair material for the spalled concrete. However, before developing a repair program, a detailed inspection was scheduled.

A research engineer, accompanied by a FHWA representative, performed that inspection in June 1979 as part of a roundrobin inspection of bridges previously treated with surface impregnation. During that inspection, a tentative program was developed to field test a number of polymer concretes during 1978, and to begin writing specifications to accomplish full repairs to the dam in 1979. However, because of scheduling problems, the field testing was delayed until 1979, and the surface impregnation rescheduled for 1980.

In October 1979, three PC trial patches were placed by Grand Coulee personnel, under the direction of

Figure 22. – The fully resurfaced sloping floor of the Madera Canal drop structure, before application of a smoothing top coat. Photo 801-D-80865

the responsible research engineer. The intent was to evaluate these PC materials under traffic until specifications were needed, then to select the best material for the permanent repairs. During this trip detailed plans were made to accomplish the permanent repairs, and a tentative time schedule was established. However, the schedule slipped to 1982 because of funding delays.

Specific details of these field trials were documented in a memorandum report by W. Glenn Smoak, dated January 21, 1980. The application of one of the trial acrylic polymer concretes is shown on figure 23.

The details reported on site preparation, equipment, materials, and application techniques later served as a base for preparing the specifications. This constituted the total effort in this particular program funded by DR-381.

The work did not end at this point, however. With project funding and technical assistance from the Polymer Concrete and Structural Section, specifications for the repair of the roadway were prepared and issued as Solicitation No. 10-C0183 [20]. A contract was awarded by the project, under competitive bidding procedures, to Butler Sealants, Inc., of Seattle, Washington. The repair program extended from May to December 1982. The details of the repair program and the work accomplished were documented by W. Glenn Smoak in a paper prepared for and presented at the 1983 Fall Convention of the American Concrete Institute, Kansas City, Missouri, September 25-30, 1983 [21]. Further discussion is not included in this report, except to say that at this writing, some distress is present in the PC repairs, and remedial measures are being considered.

A second program was undertaken at Grand Coulee Dam in the fall of 1983. Three concrete roofs of the restroom buildings of the new visitors' center facility had some surface faults. In addition, their appearance was poor when viewed from other parts of the center. A thin polymer overlay had been developed in 1980 for application at Spring Creek Debris Dam, and this particular problem at Grand Coulee presented an ideal site to further demonstrate the system.

In September 1983, research personnel assisted project personnel in the application of the thin polymer overlay. Although service data are not available yet, the tinted overlay produced an excellent uniform appearance. The mix design data from the referenced travel report for the three-layer overlay are presented in table 8.

The amounts listed in table 8 are sufficient to overlay approximately 9.75 m^2 with a total thickness of 0.76 mm. The thin polymer overlay handles much like a 100-percent solids coating and can be applied by conventional coatings application techniques (see fig. 24).

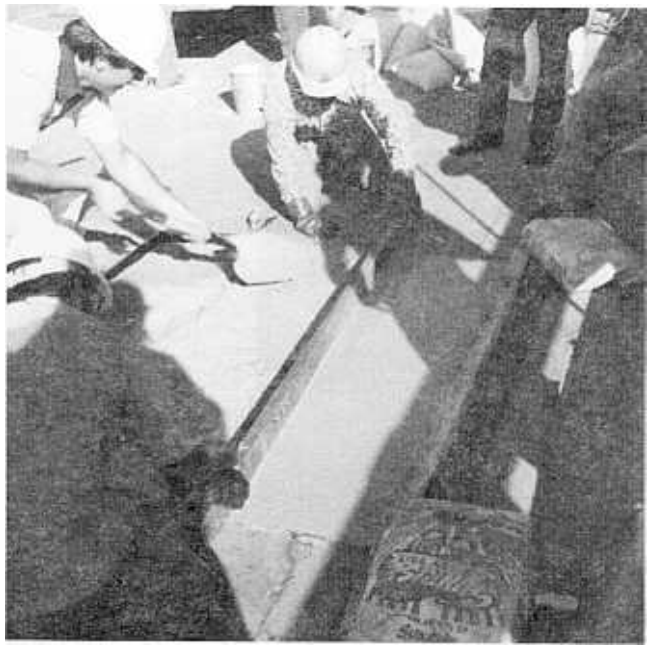

Figure 23. – Screeding one of the trial PC materials placed at Grand Coulee Dam. Photo 801-D-80866

Table 8. – Mix design data for the thin polymer overlay used at Grand Coulee Dam.

Prime layer			Intermediate and topping layers		
Vinyl ester resin	8.0	kg	Vinyl ester resin	6.8	kg
Cumene hydroperoxide	119	g	Silica flour	6.1	kg
Cobalt naphthenate	23.8	g	TiO_2 (titanium dioxide)	0.7	kg
			Cumene hydroperoxide	204.2	g
			Cobalt naphthenate	40.8	g
			Carbon black	3.8	g

Demonstrations at Various Projects, FY79-FY83

Beginning in late 1979, a series of field applications was made to demonstrate the performance of commercially available polymer concretes in actual repairs. The demonstrations provided real opportunities for small concrete repairs and afforded training opportunities for project personnel in the use of PC materials. In most cases, the DR-381 program funded the procurement of the materials and assistance at the jobsite by technical experts from the laboratory. The actual applications were generally made by project or district personnel. Performance of the materials were monitored by project and/or regional personnel. Further use of the materials was left at the option of these personnel.

The first of these demonstrations was made at Arthur R. Bowman Dam (formerly Prineville Dam), Crooked River Project, Oregon, in December 1979. A commercial acrylic PC was used to repair a damaged section of the spillway floor near the center dentate of the flip bucket. An area of approximately 8.2 m^2 was patched with an approximately 50-mm thickness of the PC. Because the flip bucket has not been dewatered since this repair, performance has not been evaluated.

The second demonstration was a repair of a gate sill at Dille Diversion Dam, Colorado-Big Thompson Project, Colorado. In its sluiceway, flood conditions had caused abrasion of the concrete under and along the radial gate sill and wall plates. The damage, which extended to depths as great as 150 mm, was deeper than other damage repaired with PC. Three hundred pounds of commercial acrylic PC were used, with three mixes developed for the different depths of repair. The more shallow areas of repair, those upstream and those behind the base of the wallplates, were repaired with a mix extended with No. 8 sand (2.36 mm). The sill plate and deeper downstream repairs, up to 150 mm, were made with a mix extended with a blended aggregate sized from 2.36 to 19.0 mm. The unaltered mix was used to bring the repair to grade and to featheredge to floor level. The repairs only on the downstream side were inspected in May 1983, and were found to be in good condition. There was no abrasion damage or disbonding to these repairs although adjacent concrete showed continuing abrasion damage. Further repairs with the PC were planned by the project.

The next demonstration was at Milburn Diversion Dam, Middle Loup Division, Pick-Sloan Missouri Basin Program, Nebraska. For about 15 years, its sluiceway had experienced severe erosion damage in the chute and on the baffle blocks and chute blocks. The irrigation district planned conventional concrete repairs as a normal maintenance activity for the fall of 1981. They also planned to field test two protective coatings and a PC overlay, all applied to the newly repaired concrete. This provided an opportunity to demonstrate the PC overlay on relatively new concrete.

In October 1981, the selected commercial PC was applied by district personnel to the sloping portion of the sluiceway floor on the left chute, on one chute block, and on the face of one baffle block. The right side of the sluiceway floor, which was the area of greatest wear, and the face of the baffle blocks had been repaired first with concrete. These surfaces and the original concrete on the left side of the floor and on the chute block were overlayed with the PC. The repair nearing completion is shown on figure 25. The coatings work was done by Applied Sciences Branch personnel under another program.

The repairs were examined about a week after application. The PC was tight, well bonded, hard, and free of cracks. The overall appearance was excellent.

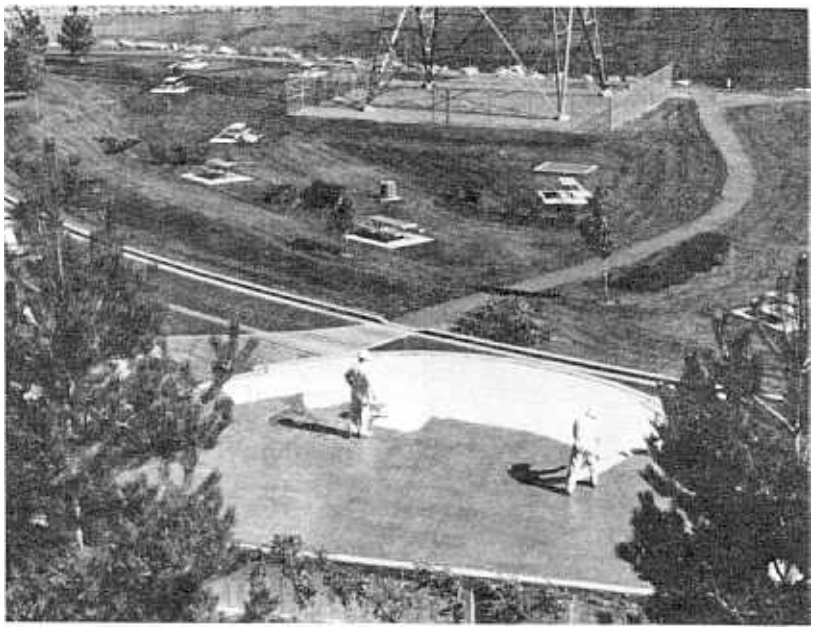

Figure 24. – Roller application of the intermediate layer of the thin polymer overlay to the primed roof of a restroom building at Grand Coulee Dam. Photo 801-D-80867

Figure 25. – Placing an acrylic PC in the sluiceway at Milburn Diversion Dam. Photo 801-D-80867

A second inspection was made in June 1982 after one season of sluicing. The PC overlay was found to be sound, but abrading at a faster rate than expected. Maximum wear was measured at about 4.75 mm. Based on these results, several years of service were predicted.

In February 1982, two repair systems were applied to cavitation-damaged concrete in the outlet of Carter Lake Dam, Colorado-Big Thompson Project, Colorado. One system was a commercial acrylic PC, the other was a commercial low-modulus epoxy system, which the project was interested in testing.

Both systems were applied by project personnel with assistance by laboratory personnel: the PC on the floor downstream of the right gate, and the epoxy on the floor and the wall downstream of the left gate. These repairs were inspected in May 1983 after 1 year of operation. Both the PC and the epoxy were in good condition, and it was not possible to judge if one had performed better than the other. Annual inspections are scheduled.

In August 1980, responsibility for concrete repair research under PRESS Project DR-380 was transferred from the Concrete Section to the Polymer Concrete and Structural Section. Testing and evaluation of epoxy compounds for the repair of concrete falls under this program. In June 1983, the South Platte River Projects Office, Colorado-Big Thompson Project, Loveland, Colorado, requested assistance in repairing two transverse cracks in the spillway floor at Green Mountain Dam, Colorado. The cracks, which were not at construction joints, had been repaired with an epoxy material more than 10 years before. The repair material was disbonded and loose and could have caused severe damage if removed during a spill. High spillway flows expected to last for a long period of time were predicted for 1983. This provided an opportunity to demonstrate and compare new epoxy compounds with PC. Two commercial epoxy concretes and an acrylic PC were selected for a comparison with conventional epoxy-bonded concrete. This was the final field demonstration scheduled under the DR-381 program.

Figure 26. – Application of epoxy concrete on the steep slope of the spillway at Creek Mountain Dam. Photo 801-D-80868

The patches were placed during two periods in June 1983, by project personnel assisted by a three-man crew from the laboratory. The acrylic PC and the epoxy-bonded concrete repairs were easily prepared and placed in the upper crack area. Some difficulties were experienced with the mixing of the epoxy concretes because of their high viscosities and the low ambient temperature in the spillway. Their placement was also difficult because of the steeper slope at the lower crack area (see fig. 26). Temporary forms were required to hold the epoxy concretes in place until they cured. These were plastic-covered plywood sheets held in place by sandbags and buckets. As a result, the surface finishes were somewhat poor.

The repairs at Green Mountain Dam have not yet been examined. As expected, the 1983 spill was far greater than normal; so the repairs were timely. An inspection will be scheduled in the spring of 1984. At that time the effects of the severe winter on the materials will be evaluated.

Spring Creek Debris Dam, Trinity River Division, Central Valley Project, FY80-FY81

The work under DR-381 for Spring Creek Debris Dam, California, was unusual in that a special polymer material was developed to solve a unique problem. Specifications were issued by the Upper Missouri Region to accomplish the program, but it is still uncompleted.

Spring Creek Debris Dam is on Spring Creek, a tributary of the Trinity River, in California. It is a small embankment structure with an ungated chute spillway and a concrete outlet works and stilling basin. The dam retains debris that would otherwise pass to Spring Creek Powerplant. During the spring runoffs, low pH waters are produced from old mine tailings on the creek, and these produce extremely corrosive environments in the channels, particularly in the stilling basins, where these acidic waters remain in pools for long periods of time.

In response to a regional request for a sealant, a thin polymer overlay was developed using an adherent, chemically resistant VE resin, extended with inert fillers and pigments. Mix design data, sources of supply, cost estimates, and specifications guide paragraphs were sent to the Regional Director by a memorandum dated May 12, 1980. The original mix design was similar to that shown in table 8, except that about 10 percent more filler was used in the intermediate and topping layers.

Specifications No. 20-C0103(SF) were issued by the Regional Director on August 8, 1980 [22]. A contract was awarded to Woolhethers Concrete company, a local firm. Work began in Novmeber 1980, and technical assistance was provided by an engineer from

the laboratory. The contractor had considerable difficulty in dewatering and cleaning the concrete, and some delays were experienced. After a portion of the sloped section of the basin was cleaned, application of the prime layer began,(see fig. 27).

Before the priming could be completed and before any of the intermediate and topping layers could be applied, seasonal rains stopped the work. At this writing, this work has not been rescheduled. Thus, the effectiveness of a thin polymer overlay in corrosive environments is still unknown. However, corrosion-resistance tests are being conducted in the laboratory and at Grand Coulee Dam, but are not yet complete.

DFC Sidewalk Overlay Tests, FY77, FY79-FY82

Before each of the field trials of machine-applied PC overlays, trial applications were made on portions of parking lot sidewalks and concrete slabs at the DFC using the Bidwell paver. Arrangements to use the sidewalks were made with the Buildings Manager, Public Buildings Service, General Services Administration, DFC.

The first of these trials was made in 1977 before phase 2 at Shadow Mountain Dam. Ironically, cracking did not appear in these trial overlays until after the first pass was applied at the dam. Ultimately, the cracking patterns in both of the overlays were similar.

Additional trials were made in 1979, 1980, and 1981, as new mixes were developed to reduce the shrinkage cracking, preparatory to phase 4 at Shadow Mountain Dam. The application of one of the trial mixes is shown on figure 28. Grooves were troweled over joints in the sidewalk in an attempt to control the cracking that might occur. However, slight pattern cracking eventually occurred in all of these trials. The last two systems applied to the upper sidewalk, the 8084+BA and the 411C-50 systems, have not pattern cracked.

As mentioned previously, these overlay studies were part of a joint study with FHWA to develop a machine-applied VE PC for bridge decks and other pavements. Because the phase 4 overlay at Shadow Mountain Dam was judged unsatisfactory, a VE PC material was not available, and further mix design studies were scheduled.

In FY81 and FY82, these mix design studies were undertaken under DR-256. Modifications that were studied with two commercial VE resins included the use of a commercial gap graded Clear Creek aggregate (laboratory standard aggregate), addition of a surfactant, and addition of fibrillar polypropylene fibers. Eight of these systems with various combinations of resin, aggregate, fibers, and surfactants were hand applied to small sidewalk areas. These mixes were then adjusted for machine application, usually by increasing the total resin content. In the spring of 1982, these eight systems were machine applied to a sidewalk at the DFC.

Figure 27. – Brush application of the prime layer of thin polymer overlay to the stilling basin at Spring Creek Debris Dam. Photo 801-D-80869

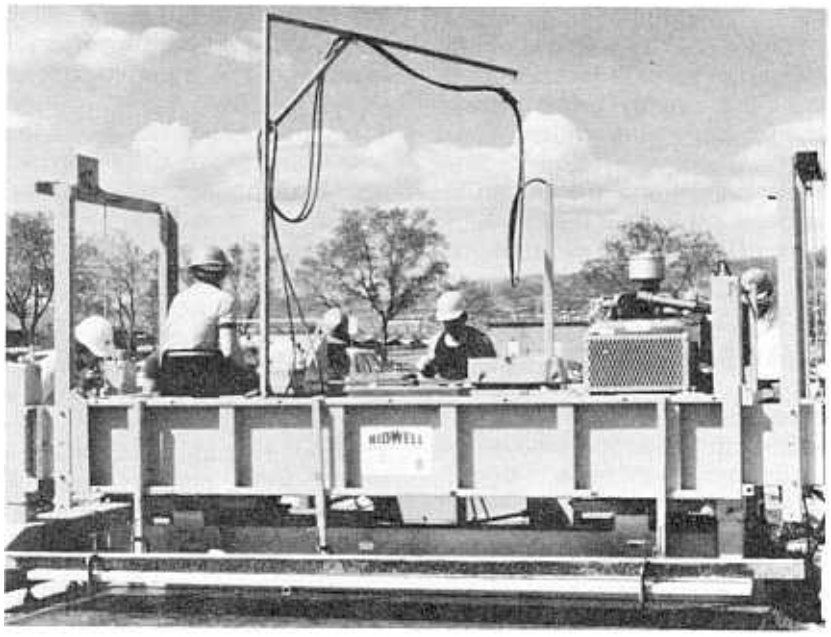

Figure 28. – A trial PC overlay being machine applied to a sidewalk at the DFC. Note the excellent appearance of the finished surface just behind the machine. Photo 801-D-80870

Occasional examinations were made, but a detailed evaluation was not made at the conclusion of the DR-381 program. When last examined, all systems appeared to be sound. Reflective cracks at sidewalk joints were evident, but only a few random small cracks could be found elsewhere. The surface roughness present immediately after the applications of those systems with fibers had worn off, and appearances have improved. Since these tests were conducted, the FHWA program has expired; by mutual consent, the planned bridge overlay with VE PC will not be done. Further overlay tests on USBR structures are not planned either. Thus, the improved VE polymer concretes may not be field tested.

Oklahoma Bridge Overlay, FY82-FY83

In October 1981, the Oklahoma Department of Transportation was scheduled to machine apply a polyester resin PC overlay on a bridge on Oklahoma Highway No. 51 near Stillwater, Oklahoma, as part of a cooperative FHWA program. Arrangements had been made previously with FHWA for the USBR to provide the Bidwell OF400 paver for this job and to furnish an experienced operator to run the machine, this work to be funded by FHWA. As part of the plan, a Concrete Mobile continuous mixer was to be used to feed the paver. Because of this, the USBR sent an observer to the job to evaluate the total operation.

As it turned out, the polyester PC mix would not cure under the field conditions, so a VE PC was substituted at the last minute. This VE PC mix had not been tested, but was similar to that used in phase 4 at Shadow Mountain Dam. During the application a second VE had to be used when the first one ran out.

The work proceeded for 3 days with the usual difficulties, including prolonged rain showers that delayed the work. However, upon completion of the work, it was concluded that the Concrete Mobile mixer was effective in mixing the PC for the paver. It was reported that the monomer preparation and metering equipment was troublesome to keep in calibration and that there was some variation in the composition of the PC delivered to the paver. Automation of the equipment used for PC mixing would have improved the operation.

The bridge overlay was examined in April 1982, by the observer who was present at the application. Its appearance was nonuniform; however, the entire overlay was almost crack free and bonded to the substrate concrete. It was again examined in May 1983, when some repairs to a broken-out area were to be made. Except for the damaged area, approximately 0.6 mm in diameter, the surface appearance was still unchanged and the surface still free of cracks. However, chain dragging and hammer tapping revealed many large disbonded areas not yet

broken out. As these were being removed additional disbonding occurred. The PC overlay was not tightly bonded and was easily removed with jackhammers and chipping hammers. The overlay broke cleanly from the surface. Some moisture was evident along the interface. This field trial was judged a total failure. Because this was a new bridge and the PC broke away cleanly from the deck, no further repairs were planned by the Oklahoma Department of Transportation.

Roundrobin Inspection of Bridges, FY83

During the performance of Project DR-381, the Polymer Concrete and Structural Section worked on several cooperative programs with other Government agencies. These were studies closely related to the DR-381 work, particularly those in cooperation with FHWA. From 1971-1974, laboratory studies were funded by FHWA, Office of Research, Materials Division, McLean, Virginia, for the USBR to develop the surface impregnation and polymerization processes for concrete bridge decks (Contract No. 2-1-1214, dated December 7, 1971). With development of the process, a second study was undertaken to implement the impregnation process by treating actual highway bridges (Contract No. 6-3-0001, dated July 8, 1975). This contract extended to September 30, 1982, and all work was completed in May 1983, when the draft of the final report by W. Glenn Smoak was submitted to FHWA [23]. Throughout the implementation program, numerous bridges throughout the United States were treated through contracts with FHWA, with technical assistance by USBR research personnel.

In September 1983, three of these bridges were inspected under the DR-381 program. This roundrobin inspection was scheduled in conjunction with the application of the thin polymer overlay at Grand Coulee Dam.

The first bridge was a small structure on State Highway No. 200 near Sand Point, Idaho, which had been impregnated in 1975. Its appearance had changed little; the typical pattern cracking was still visible and small quantities of polymer-bonded sand were still evident on the surface. Wheel wear paths were somewhat visible in the polymer-depleted zone at the surfce. Performance was judged to be satisfactory.

The second bridge was a precast, prestressed bulb-tee structure over the Santa Rosa Canal at Yakima, Washington, which was constructed in 1977. The roadway surfaces of its seven precast members were polymer impregnated at the precasting yard in Clackamas, Oregon, before shipment to the construction site. The bridge was found to be in excellent condition, almost unchanged since impregnation. No cracks were found in the riding surface or from the underside. Freedom from cracks is the usual result in polymer-impregnated precast structures.

The third bridge was a two-lane concrete structure over Rattlesnake Creek on State Highway No. 36 near Redding, California. It was a newly constructed bridge when impregnated in late 1975. Unfortunately, a Caltrans contractor erringly installed a chip seal coat to the highway and bridge shortly before the inspection was made. The inspection was to be made before the seal coat was applied. Although the deck surface could not be examined, Caltrans personnel reported that it was in excellent condition.

To fully evaluate the surface impregnation of the bridge decks, plans are being formulated to inspect and examine the other bridges treated under the impregnation program.

BIBLIOGRAPHY

[1] Selander, C. E., *Development of Concrete Polymer Materials by the Bureau of Reclamation - A Summary Report,* Bureau of Reclamation Report No. GR-1-75, Denver, Colo., June 1975.

[2] *Program Review, WRPER (Water Resources Planning and Engineering Research), FY74 Accomplishment, FY75 Program,* Bureau of Reclamation, Division of General Research, Denver, Colo. Research Project Statement, Project No. DR-381, p. 138, December 1974.

[3] *Program Review, PRESS (Program Related Engineering and Scientific Studies), FY82 Accomplishments, FY83 Program,* Bureau of Reclamation, Engineering and Research Center, Division of Research, Denver, Colo., Summary Project Statement, Project No. DR-381, pp. 97-98, February 1983.

[4] De Puy, G. W., and Selander, C. E., "POLYMER CONCRETE - Trials and Tribulations," Proceedings of the Second International Congress on Polymers in Concrete, College of Engineering, The University of Texas at Austin, Austin, Tex., pp. 461-482, October 25-27, 1978.

[5] *Program Review, WRPER, FY75 Accomplishments, FY76 Program,* Bureau of Reclamation, Division of General Research, Denver, Colo., Research Project Statement, Project No. DR-381, p. 146, December 1975.

[6] *Program Review, WRPER, FY76 Accomplishments, FY77 Program,* Bureau of Reclamation,

Division of General Research, Denver, Colo., Research Project Statement, Project No. DR-381, p. 142, December 1976.

[7] *Program Review, WRPER, FY77 Accomplishments, FY78 Program,* Bureau of Reclamation, Division of General Research, Denver, Colo., Research Project Statement, Project No. DR-381, p. 138, March 1978.

[8] *Program Review, WRPER, FY78 Accomplishments, FY79 Program,* Bureau of Reclamation, Division of Research, Denver, Colo., Research Project Statement, Project No. DR-381, p. 126, December 1979.

[9] *Program Review, WRPER, FY79 Accomplishments, FY80 Program,* Water and Power Resources Service, Division of Research, Denver, Colo., Research Project Statement, Project No. DR-381, p. 130, February 1980.

[10] *Program Review, WRPER, FY80 Accomplishments, FY81 Program,* Bureau of Reclamation, Division of Research, Denver, Colo., Research Project Statement, Project No. DR-381, p. 75, August 1981.

[11] *Program Review, WRPER, FY81 Accomplishments, FY82 Program,* Bureau of Reclamation, Division of Research, Denver, Colorado; Research Project Statement, Project No. DR-381, page 67.

[12] Specifications No. 300C-392, Installing Polymer-Impregnated Pipe, East Mesa Test Site.

[13] Specificatiions No. 70-C0038, Surfce Impregnation of Spillway Floor, Shadow Mountain Dam, Colorado-Big Thompson Project.

[14] Causey, Fred E., Memorandum to Chief, Concrete and Structural Branch; Subject: Concrete Polymer Materials Systems Research, DR-256 - Annual Progress Report FY80, October 31, 1980.

[15] Causey, Fred E., Principal Investigator Memorandum to Chief, Concrete and Structural Branch; Subject: Engineering Materials Systems Research, DR-256 - Annual Progress Report FY81, October 28, 1981.

[16] Rutenbeck, Todd, unpublished data on GS-75 and SM-74 series strength tests, FY74.

[17] Riffle, H. C., Memorandum to Files; Subject: Study of Relationships of Size and Shape of Specimen to PC (Polymer Concrete) Strength (Part of DR-381 Polymer Applications Studies), January 28, 1977.

[18] Causey, F. E., *Laboratory Investigation and Experimental Field Application of Vinyl Ester Polymer Shotcrete;* Bureau of Reclamation, Report No. GR-6-77, Denver, Colo., May 1977.

[19] Causey, F. E., *Vinyl Ester Polymer Concrete and Experimental Repair of Madera Canal Drop Structure,* Bureau of Reclamation Report No. GR-7-77, Denver, Colo., July 1977.

[20] Solicitation No. 10-C0183, Polymer Impregnation of Roadway Surfaces, Grand Coulee Dam, Grand Coulee Project Office, Columbia Basin Project, Wash., 1982.

[21] Smoak, W. Glenn, "Polymer Impregnation and Polymer Concrete Repairs at Grand Coulee Dam," a paper presented at the 1983 Fall Convention, American Concrete Institute, Kansas City, Mo., September 25-30, 1983.

[22] Specifications No. 20-C0103(SF), Stilling Basin Rehabilitation, Spring Creek Debris Dam, Central Valley Project, Calif. August 8, 1980.

[23] Smoak, W. G., *Implementation of Polymer Impregnation as a Bridge Deck Sealant,* Bureau of Reclamation Report No. REC-ERC-84-11, Denver, Colo., 1984.

APPENDIX A

POLYMER IMPREGNATION OF CONSTANT HEAD ORIFICE TURNOUTS FOR GRAND COULEE DAM, COLUMBIA BASIN PROJECT

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Memorandum

TO : Head, Polymer Concrete and Structural Section

Denver, Colorado
DATE: June 12, 1975

FROM : Fred E. Causey, Chemical Engineer

SUBJECT: Polymer Impregnation of Constant Head Orifice Turnouts for Grand Coulee, Columbia Basin Project

Introduction

Two precast reinforced concrete constant head orifice turnout structures were designed for the Columbia Basin, Grand Coulee Irrigation System. Figures 1 through 8 show the design and assembled turnout. The structures were cast in the laboratory and impregnated in the Bureau's facility. Two monomer systems were used to impregnate these two turnouts. These monomer systems were 60-40 styrene-TMPTMA (trimethylolpropane trimethacrylate) and MMA (methyl methacrylate). The monomer systems were selected on the basis of availability of sufficient quantities for impregnation.

Impregnation

Two canal turnout structures consisting of 11 sections each and six 6-inch by 12-inch cylinders were impregnated with 60-40 styrene-TMPTMA and MMA in five treatments. The large sections were loaded into the large drying oven with a 4,000-pound capacity forklift. The smaller sections were dried in the 2-foot by 2-foot by 6-foot capacity oven. All sections and 6x12's were dried at 350° F and cooled to room temperature. The temperature was raised slowly as not to exceed 40° F per hour in the heat cycle and thus oven control was so regulated that it took 8 hours to reach 350° F. Specimens were cooled overnight.

The turnout sections are shown in table 1. After the specimens were weighed they were taken out to the impregnator on the forklift where they were loaded into the carrier with a crane. The one-piece stilling basin was impregnated in the vertical impregnator while the other sections were impregnated in the horizontal impregnator.

The vacuum pump was switched on and 23 inches of Hg (Denver mean 24.7 inches) were drawn. While the vacuum cycle was in progress, previous weighed drums of styrene and TMPTMA for turnout No. 1 and MMA for turnout No. 2 catalyzed with one-half percent DA-79 (α-t-butylazo isobutyronitrile) were mixed by bubbling air through the monomer system. The weight mix ratio for the styrene-TMPTMA system was 60 percent styrene and 40 percent TMPTMA.

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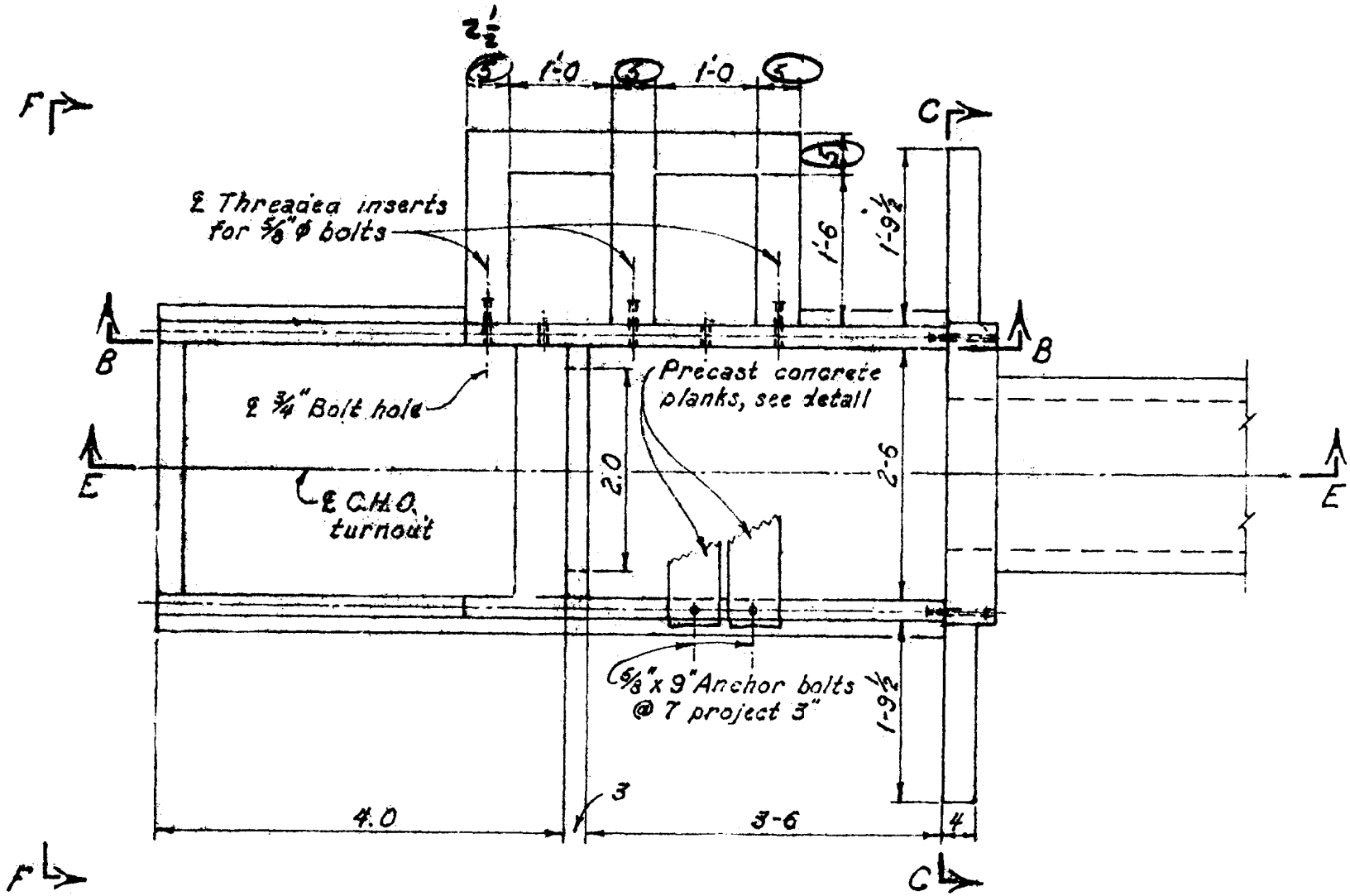


Figure 1. – Constant-head orifice canal turnout.

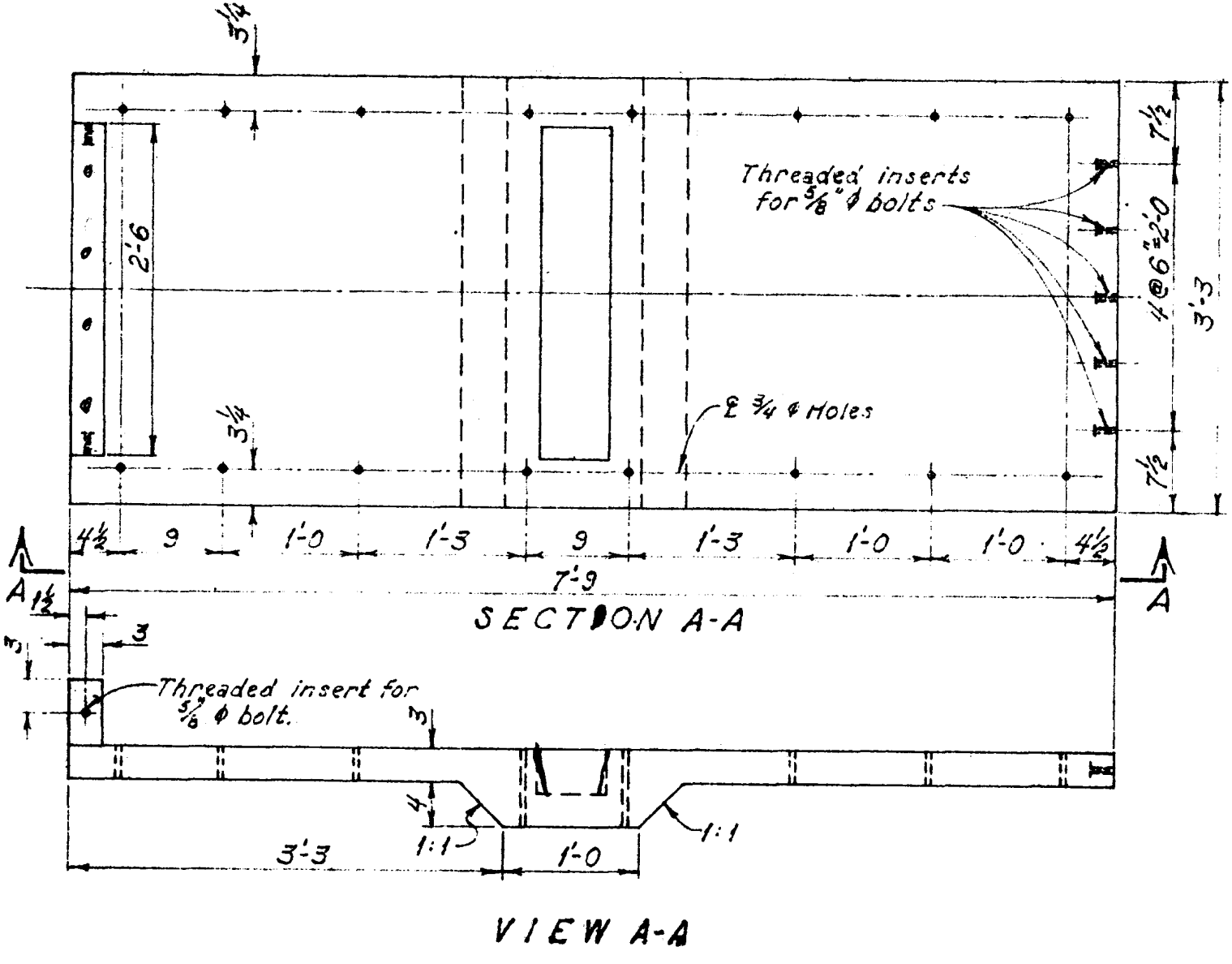


Figure 2. – Detail drawing of section A-A.

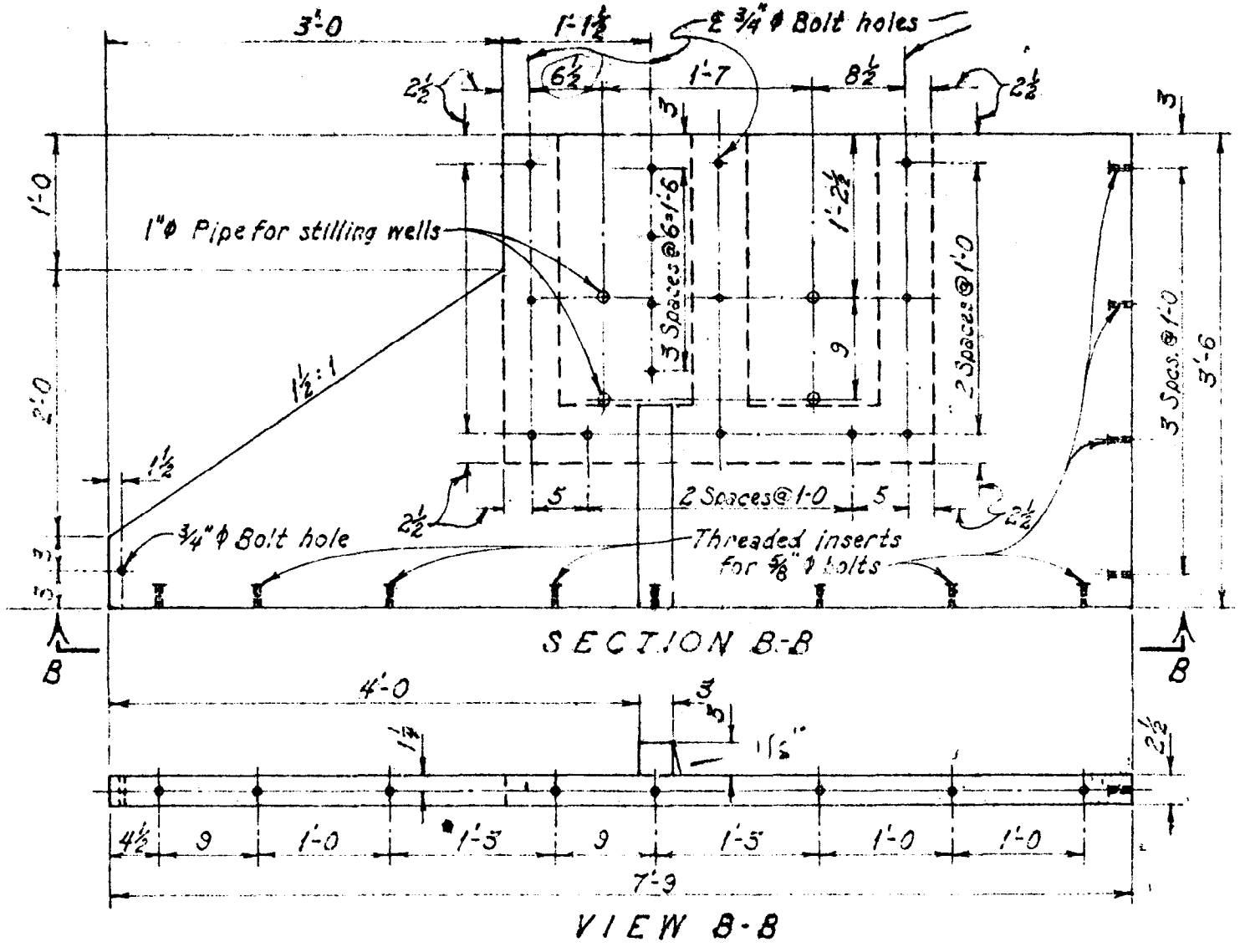


Figure 3. – Detail drawing of section B-B.

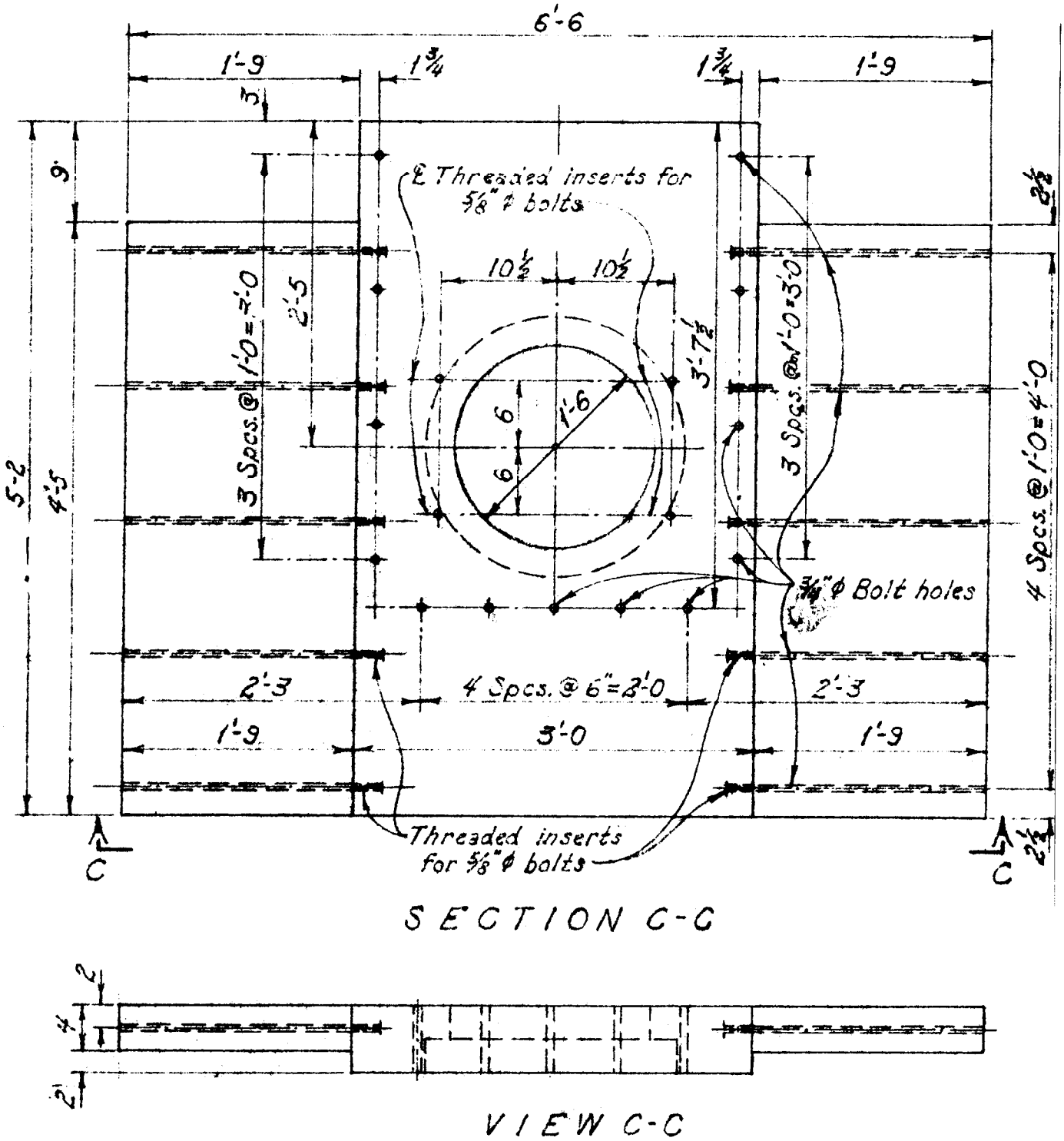
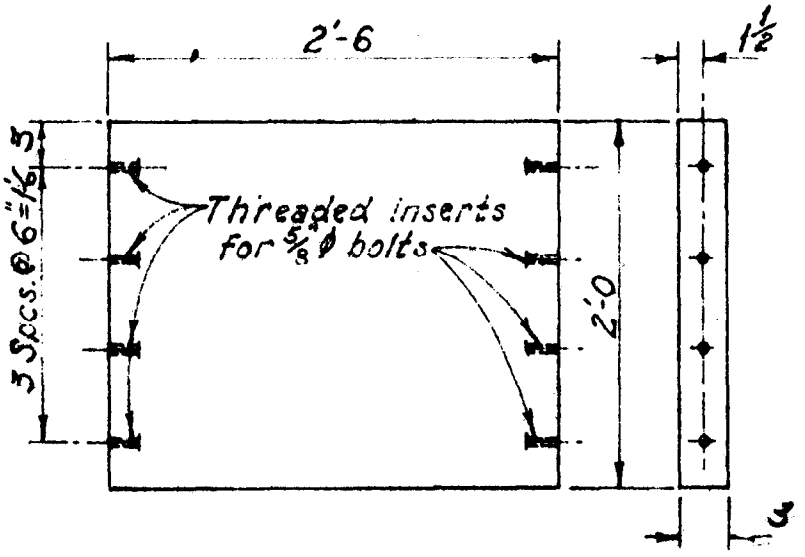
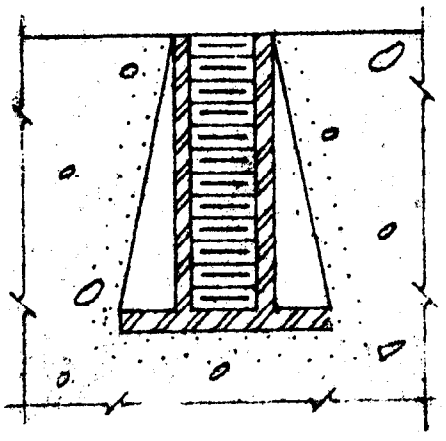


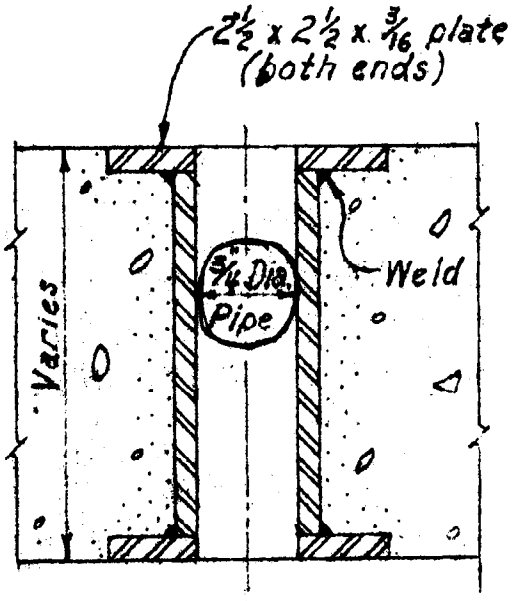
Figure 4. – Detail drawing of section C-C.



SECTION D-D



DETAIL FOR THREADED INSERT FOR ⅝" ϕ BOLT (NOT TO SCALE)



DETAIL FOR HOLES THROUGH PANELS (NOT TO SCALE)

Figure 5. – Detail drawings of section D-D, and for bolt inserts and holes.

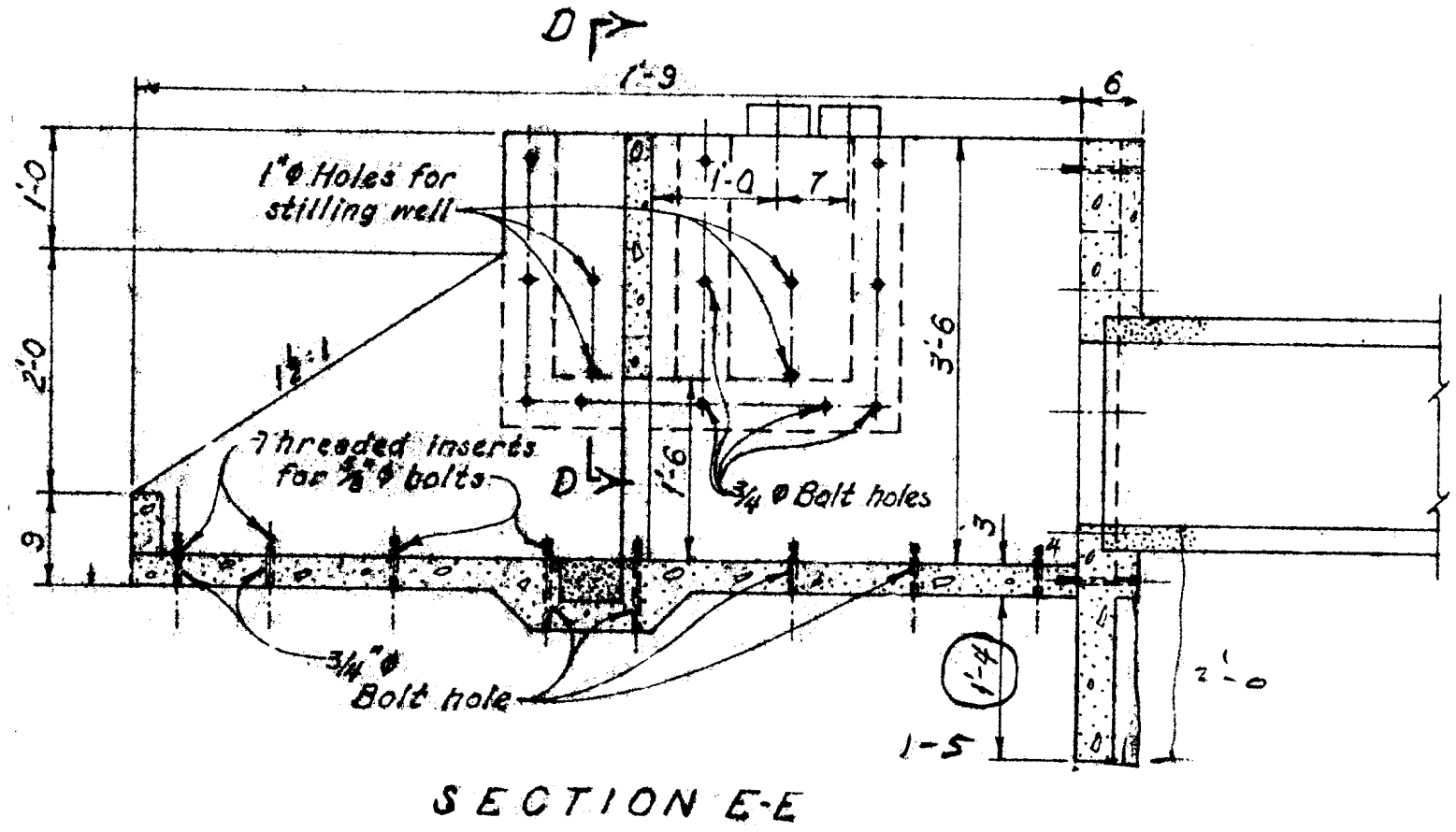


Figure 6. – Detail drawing of section E-E.

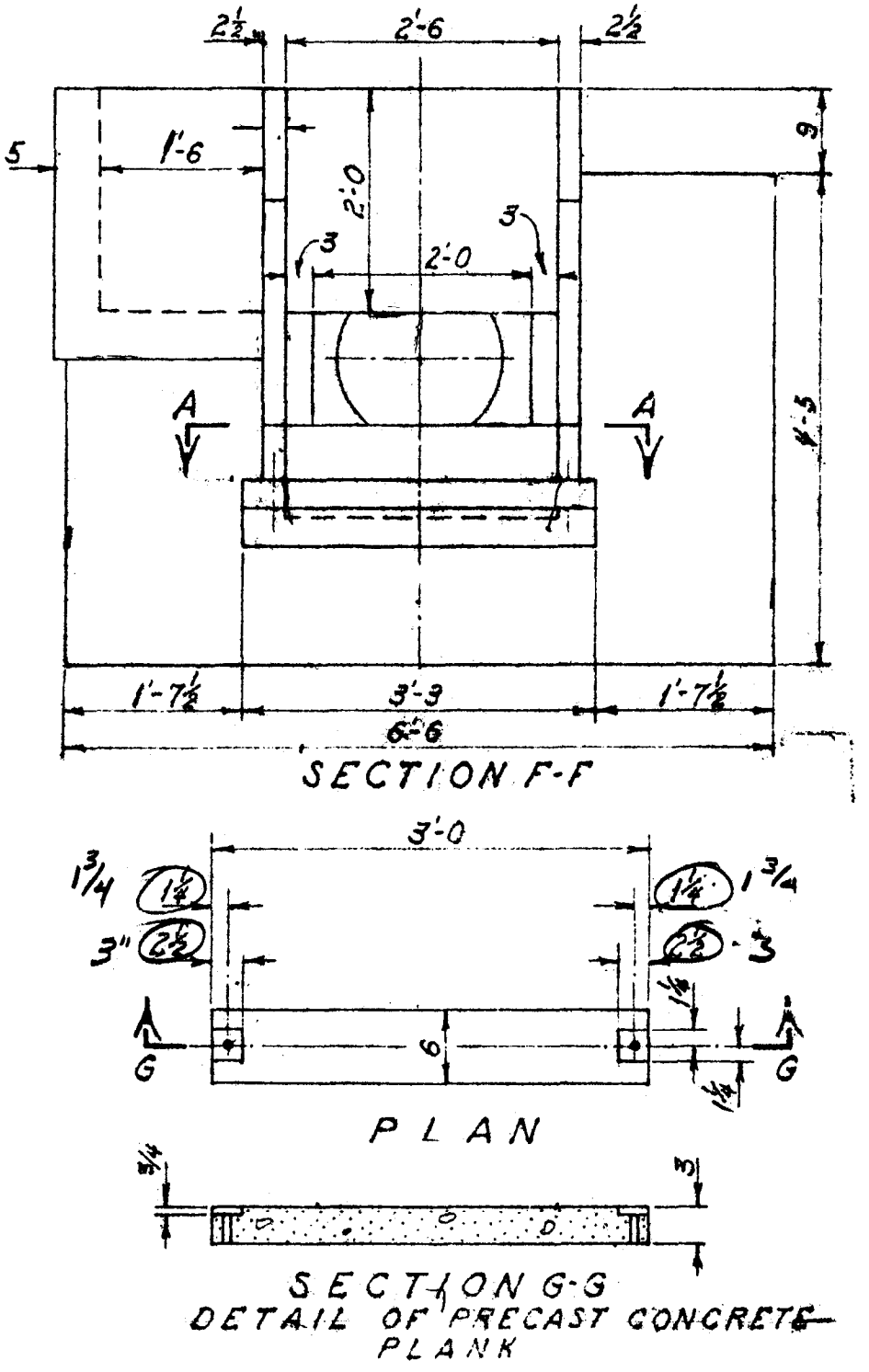


Figure 7. – Detail drawings of sections F-F and G-G.

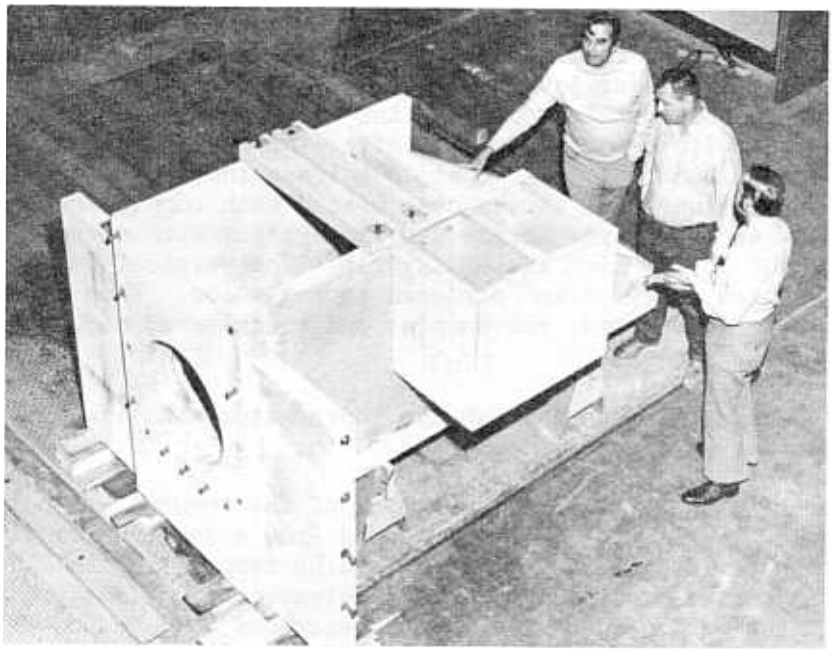


Figure 8. – The assembled constant-head orifice canal turnout.

After the vacuum cycle was completed, the catalyzed monomer was drawn into the impregnator from the transfer tank by the 23 inches of vacuum. When the proper monomer level was reached, the valve to the impregnator was closed and monomer left in the line was transferred back into the transfer tank with compressed air. After the monomer transfer was completed, the vent valve was open to release the remaining vacuum. The impregnator was then slowly pressurized with compressed air to a pressure of 40 lb/in^2 for horizontal impregnator with styrene-TMPTMA system and 50 lb/in^2 with the MMA system. The vertical impregnator was pressurized to 40 lb/in^2 for each impregnation. When pressure soak cycle was completed, the monomer was transferred back into the transfer tank.

Compressed air was blown through the impregnator and line to remove excess monomer before polymerization.

The monomer in the impregnated sections of the turnout was polymerized under water. Warm water was transferred from a large water heater into the impregnator-polymerization vessel using compressed air. Temperature of the water brought in for each polymerization is given in table 1. The water around the turnout sections impregnated with 60-40 styrene-TMPTMA was raised to about 185° F. Steam was used to heat this water and was shut off after this temperature was reached. The polymerization goes to completion in a couple hours. Turnout sections impregnated with MMA were done in similar manner with water temperature brought to 160° F. The water was drained the next morning, and compressed air was blown through to cool the specimens and to remove the last of the water. The turnout sections removed and weighed. Polymer loadings were calculated from the dried and impregnated weights. These data are shown in table 1.

Results

Polymer loading for the canal turnout sections ranged from 6 to 7 percent as was expected. The loading with styrene system was higher than the MMA system with styrene around 7 percent and MMA around 6 percent. Two 6x12's impregnated with the styrene system were broken in compression using celotex rather than grinding. The average compressive strength was 8,325 lb/in^2. Similar impregnated 6x12's with the styrene system and specimens which were ground gave an average of 17,590 lb/in^2. Two 6x12's impregnated with MMA were also tested using celotex and yielded an average compressive strength of 15,500 lb/in^2. The ground specimens showed an average compressive strength of 19,800 lb/in^2. Complete compressive strength data are shown in table 2.

Fred E Carey

Table 1

WEIGHTS AND IMPREGNATION CYCLES

Test 1

Nine assorted pieces of a canal turnout section and two 6x12's were dried 24 hours at 350° F and cooled overnight, 8 hours were used to reach 350° F.

Impregnated with 60-40 styrene-TMPTMA 1/ and one-half percent DA-79,2/ monomer temperature was about 40° F.

Cycle: 2 hours vacuum at 23 in Hg
3 hour pressure at 40 lb/in^2

Polymerized under water overnight at 185° F and 0 lb/in^2

Spec. No.3/ 6 x 12's	Dry wt	Imp wt	Poly wt	% loading
1	11.59 kg	12.45 kg	.86 kg	7.42
2	11.51	12.41	.90	7.82
Turnout Large piece	470.37	500.76	30.39	o.46
3	19.54	20.95	1.41	7.22
4	23.16	24.80	1.64	7.08
5	23.04	27.70	1.66	7.20
6	160.01	173.30	10.29	6.43
7	160.09	171.75	11.66	7.28

Test 2

One stilling basin for turnout section was dried at 350° F for 24 hours and cooled overnight, 8 hours was used to reach 350° F.

Impregnated with 60-40 styrene-TMPTMA and one-half percent DA-79, monomer temperature was about 39° F

Cycle: 2 hours vacuum at 23 in Hg
3 hours pressure at 40 lb/in^2

Polymerized under water overnight at 175° F.

Spec. No.	Dry wt	Imp wt	Poly wt	% loading
S.B-1	248.75 kg	266.83 kg	18.08 kg	7.27

Test 3

One slab for turnout structure dried 24 hours at 350° F and cooled 3 hours, 8 hours used to reach 350° F.

Impregnated with 60-40 styrene-TMPTMA and one-half percent DA-79, monomer temperature was 45° F.

Cycle: 1 hour vacuum at 23 in Hg
2 hours pressure at 40 lb/in^2

Polymerized under water overnight at 190° F.

Specimen was not weighed.

Test 4

Ten assorted pieces of a canal turnout section and four 6x12's were dried 24 hours at 350° F and cooled overnight, 8 hours were used to reach 350° F.

Impregnated with MMA 4/ plus one-half percent DA-79, monomer temperature was 50° F.

Cycle: 2 hours vacuum at 23 in Hg
4 hours pressure at 50 lb/in^2

Polymerized under water at 160° F overnight.

Spec. No.	Dry wt	Imp wt	Poly wt	% loading
CHO-2-1	469.24 kg			
CHO-2-2	318.50 kg	337.10 kg	18.60 kg	5.84
CHO-2-3	121.50	129.00	7.50	6.17
CHO-2-4	120.75	128.15	7.40	6.13
CHO-2-5	79.09	84.27	5.18	6.55
CHO-2-6	19.82	21.06	1.24	6.26
CHO-2-7	20.08	21.28	1.20	5.98
CHO-2-8	16.62	17.68	1.06	6.38
CHO-2-9	290.75	308.70	17.95	6.17
CHO-2-10	287.35	306.49	19.14	6.66

6 x 12's				
CHO-1	11.76 kg	12.52 kg	.76 kg	6.46
CHO-2	11.74	12.50	.76	6.47
CHO-3	11.72	12.48	.76	6.48
CHO-4	11.75	12.51	.76	6.47

Test 5

One stilling basin dried at 350° F 24 hours and cooled overnight 8 hours were used to reach 350° F.

Impregnated with MMA plus one-half percent DA-79, monomer temperature was 50° F.

Cycle: 1 hour vacuum at 23 in Hg
2 hours pressure at 40 lb/in^2

Polymerized under water at 160° F overnight.

Spec. No.	Dry wt	Imp wt	Poly wt	% loading
CHO-2-11	253.2 kg	268.9 kg	15.7 kg	6.20

1/ TMPTMA - Trimethylolpropane trimethacrylate
2/ DA-79 - α - t - butylazo isobutyronitrile
3/ Spec. No. - Specimen Number, Dry wt - Dry weight, Imp wt - Impregnated weight, Poly wt - Polymer weight
4/ MMA - Methyl Methacrylate

Table 2

COMPRESSIVE STRENGTHS

60-40 Styrene-TMPTMA System

Spec. No.	Strength (lb/in^2)
ST-1	8,280
ST-2	8,320

MMA System

Ground Spec. No.	Strength (lb/in^2)
CHO-1	20,340
CHO-2	19,210
S-4	19,810

Un-ground Celotex Spec. No.	Strength (lb/in^2)
CHO-3	15,280
CHO-4	16,770
S-2	15,350
S-3	14,820

APPENDIX B

PROGRESS REPORT FOR FY75-76, POLYMER APPLICATIONS, DR-381

Form DFC-11
(12-61)
Bureau of Reclamation

INFORMATIONAL ROUTING

[20] 1572

Memorandum
Chief, Concrete and Structural Branch

Denver, Colorado
June 29, 1976

Head, Polymer Concrete and Structural Section

H. C. Riffle

Progress Report for FY75-76, Polymer Applications, DR 381

This program was started in 1974 (FY75) to develop and demonstrate the use of polymer composites in field applications. To date, three applications have been made as follows:

1. Installation of polymer-impregnated concrete (PIC) and asbestos-cement (PIAC) pipe and polymer concrete (PC) ditch lining at the Geothermal Test Facility, East Mesa Test Site, near Holtville, California

2. Installation of a prefabricated polymer-impregnated concrete turnout - WB44E lateral - Wahluke Branch Canal Laterals, Block 253 - Specifications No. DC-7068 - Columbia Basin Project, Washington

3. Shadow Mountain Dam Spillway repairs - Grand Lake, Colorado

The status of each of the foregoing applications is described separately hereinafter.

Riffle 6/29
Spencer 6/29
DeRy 6-30
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Installation of Pipe and Ditch Lining at the Geothermal Test Facility, Holtville, California

The Geothermal Test Facility was selected as a test site for polymer composites because there they could be exposed to steam or brines of various concentrations from 0 to 100,000 parts per million total dissolved solids at temperatures of 60° to 160°C (140° to 320°F). Exposure conditions and locations for the pipe and ditch lining materials are shown in table 1.

Three varieties of composite materials will be installed at the Geothermal Test Facility, as follows:

1. Polymer-impregnated concrete (PIC) pipe
2. Polymer-impregnated asbestos-cement (PIAC) pipe
3. Polymer-concrete (PC) ditch lining slabs

Commercially manufactured Class 12A50 concrete pipe was purchased because this is the smallest (0.3048-metre = 12-inch) inside diameter reinforced concrete pressure pipe available with the required rubber gasket joint (type R-4). These pipe sections were the shortest available standard laying length of 6 feet so that they would fit inside the existing impregnation tank. The 0.2-metre (8-inch) i.d. asbestos-cement pipe is a commercially produced Class AC45 with a 0.99-metre (3-ft 3-in.) laying length. The pipe sections were impregnated with 60-40 styrene-TMPTMA (trimethylolpropane trimethacrylate) monomer system and thermal catalytically polymerized at building 77 of the E&R Center. The PC ditch lining slabs are 0.565 by 1.181 metres (22-1/4 by 46-1/2 inches) with 63.5-millimetre (2-1/2-inch) thickness. These slabs are reinforced with 0.15- by 0.15-metre (6- by 6-inch) No. 10 gage steel welded wire fabric. The slabs contain 19.05-mm (3/4-inch) maximum-size aggregate and 8 percent 60-90 styrene-TMPTMA monomer by weight. This monomer was used because of its stability at higher temperatures.

The objective of this application is to investigate the capability and advantages, if any, of these materials as compared to conventional materials such as steel pipe. It is now planned to determine their serviceability by periodic inspection and tests after about 2 and 5 years' exposure to the aforementioned conditions. Concrete and asbestos-cement pipe were tested before impregnation for 3-edge bearing strength and water absorption in accordance with ASTM Designations: C 497 and C 500. These tests were also conducted on the impregnated and polymerized pipe. Results of these tests are shown in tables 2A, 2B, and 3. These tests are scheduled for sections of each kind of pipe removed from service in the geothermal well piping system after 2 and 5 years' exposure. A comparison of these periodic test results should provide information on serviceability of these materials. Serviceability of the PC ditch lining slabs is to be determined by visual examination at the same time intervals. The pipe sections and ditch slabs were shipped to the Geothermal Test Facility by June 1975. Design and specifications for the installation of the pipe (Specifications No. 300C-392, Installing Polymer Impregnated Pipe, East Mesa Test Site) were completed by the Lower Colorado Regional Director's Office, at Boulder City, Nevada, in March 1976. Bids for this work were opened April 27, 1976, and the low bid of $7,679 was received from Jetco Petro Company of Logan, Utah. The contract was awarded about May 26, 1976, and the work was completed June 15, 1976.

Installation of PIC Turnout, Columbia Basin Project, Washington

Block 253 - Waluke Branch Canal Laterals - Columbia Basin Project - was selected for this proposed demonstration installation of a precast PIC constant head orifice (CHO) turnout structure. Block 253 was about to get underway and it was believed that a small PIC precast structure could be installed by the contractor with little or no disruption of the proposed construction procedures and would provide a timely installation of demonstration of the PIC material.

To facilitate construction, a CHO turnout with a 0.6096-metre (24-inch) orifice gate as shown on Specifications No. DC-7068, drawing No. 222-D-23582, was established as the structure type to be designed and fabricated.

Station 53+44.67 (175+35.0) of the WB44E lateral was proposed by the Columbia Basin Project Office as the installation location. The structure was to be installed by the contractor (Ball, Ball and Brosamer). The Chief, Construction Division, Columbia Basin Project Office, Ephrata, Washington, negotiated with the contractor for the deletion of the conventional structure and for installation of the Government-furnished PIC structure.

Figure 1 shows the completed CHO structure, which was designed by the Water Conveyance Branch, Division of Design, E&R Center, Denver, Colorado. Design was based on the following allowable stresses and material properties:

Modulus of elasticity = 41.37 GPa (6,000,000 lb/in^2)
Ultimate compressive strength = 103.42 MPa (15,000 lb/in^2)
Modulus of rupture = 8.97 MPa (1,300 lb/in^2)
Shear stress = 6.89 MPa (1,000 lb/in^2)

The CHO was designed to be cast in sections and bolted together after impregnation. This method of construction was necessary because the E&R Center impregnation facility is not large enough to impregnate the CHO structure in one piece.

Specifications for the concrete mix used for both structures were:

Cement - 7.85 bags per m^3 (6 bags per cubic yard)
Maximum size aggregate - 9.52 mm (3/8 in.)
Sand content - 42 percent
(Water cement ratio - 0.45)
Slump - 0.08 metre (3.2 inches)
Entrained air - 5.0 percent
Unit Weight - 2290.64 kg/m^3 (143 lb/ft^3)

Estimated compressive strength of 23.44 MPa (3,400 lb/in^2) was based on four 0.15 by 0.30 m (6 by 12 inch) tested at 28 days' age. The test specimens were water cured with the CHO structure for 14 days and then allowed to dry until test age.

The precast concrete sections were reinforced with No. 10 gage square welded wire fabric with 0.15- by 0.15-metre (6- by 6-inch) spacing to insure the strength required for handling prior to polymer impregnation.

Two CHO turnout structures were fabricated at the E&R Center where polymer impregnation facilities were available. The first structure

was designated for installation and was transported at Government expense to the jobsite on May 12, 1975. The second structure was a standby in case the first structure was damaged in shipment and is on display in building 56 of the E&R Center. The cost of fabrication and transportation was covered by research funds.

The first CHO structure was impregnated using a 50-40 styrene-TMPTMA (trimethylolpropane trimethacrylate) system and the second CHO structure was impregnated with MMA (methylmethacrylate). The monomer systems were selected on the basis of availability of sufficient quantities for impregnation. Five treatments were required to impregnate the 11 sections and the companion 0.15- by 0.30-m (6- by 12-inch) cylinders for each structure. The sections were oven dried and cooled to room temperature. The oven temperature was raised at a rate not to exceed 22.1°C (40°F) per hour to 177°C (350°F) thus the heat cycle required 8 hours. Then the sections were cooled overnight.

After the sections were weighed they were loaded into the impregnator. The stilling basin was impregnated in the small vertical impregnator while the other sections were impregnated using the horizontal impregnator. After loading the impregnator tank with the section, the tank was sealed and a vacuum of 0.58 m (23 inches) of Hg applied. While the vacuum cycle was in progress, previously weighed drums of styrene and TMPTMA for turnout No. 1 and drums of MMA catalyzed with one-half percent DA-79 (α-t-butylazo isobutyronitrile) for turnout No. 2 were mixed by bubbling air through the monomer system. The mix ratio, by weight, for styrene-TMPTMA system was 60 percent styrene and 40 percent TMPTMA.

After the vacuum cycle was completed,the catalyzed monomer was drawn into the impregnator by the vacuum. When the proper monomer level was reached the impregnator was slowly pressurized, forcing monomer into the concrete voids. At the end of the pressure cycle the monomer was transferred back into the transfer tank and the impregnator tank was filled with warm water. The water for the sections impregnated with styrene-TMPTMA was raised to 85°C (185°F) using steam to heat the water. The polymerization is completed in 2 hours. Sections impregnated with MMA were done in a similar manner with the water temperature brought to 71°C (160°F). The water was then drained and the sections cooled before they were removed from the tank and weighed. The polymer loading with styrene was about 7 percent and around 6 percent for the MMA.

Two 0.15- by 0.30-metre (6- by 12-inch) cylinders impregnated with the styrene system indicated a compressive strength of 57.23 MPa (8,300 lb/in^2). Two 0.15- by 0.30-metre (6- by 12-inch) cylinders impregnated with MMA showed an average compressive strength of 106.85 MPa (15,500 lb/in^2).

The precast structure was assembled using a self-adhering, cold-applied, plastic sealing compound. This joint sealant was preformed in tape form and complied with Federal Specification SS-S-00210 (GSA-FSS). The cap screw fasteners were tightened sufficiently to produce a slight squeeze out of the plastic gasket thus producing a completely watertight seal.

The installation of this structure by the contractor on July 8, 1975, was observed by R. W. Spencer, Concrete and Structural Branch, Division of General Research, E&R Center, Denver, Colorado; project office personnel; and representatives of the water district. Project office personnel included representatives of Construction, Inspection, and General Engineering.

The precast PIC structure installed was similar to a type I No. 205 monolithic CHO turnout (drawing No. 222-D-23582). This CHO was not well proportioned with respect to the hydraulic requirements. If the structure had been similar to a No. 205C, it would have been more suitable for the installation location.

The formed surface of the precast PIC walk planks was used for the walking side. A rough troweled surface would have been better to reduce the possibility of the operator slipping when the structure is wet.

Precast PIC walk planks appear to be very suitable for use on small canal structures both precast and monolithic. Precast PIC has high strength which allows a thin section without using reinforcement. The thin section has a better appearance as well as a reduction in weight.

The CHO structure was installed level and at the proper invert elevation on carefully trimmed, undisturbed, silty sand foundation without using mortar bedding. The lightweight PIC stilling well made it easy to install this structure. Usually when installing a precast CHO turnout structure, the thick concrete used to cast the stilling well makes the structure hard to balance in the slings when lowering it into position. Monolithic stilling wells are hard to form, and form removal is difficult. The use of these precast PIC structures should be considered for future use on Bureau projects.

A conduit stub not over 0.61 metre (24 inches) long should be cast in the structure headwall rather than making a field installation. The structure was placed in position in 45 minutes but 4 hours were required to epoxy the stub into the headwall. The epoxy procedure was time consuming and material costs were excessive.

On this installation the precast concrete pipe was in position and the CHO turnout structure was placed onto the conduit rather than laying the pipe to the structure after it was installed. The latter method may be the better approach.

Shadow Mountain Dam Spillway Repairs - Grand Lake, Colorado

Experimental repairs were made on Shadow Mountain Spillway in August 1975. A laboratory report covering this work is now in the process of publication. The repairs included newly developed concrete polymer materials and techniques. These were surface-impregnation, vinyl ester polymer concrete overlay, and a painted-on vinyl ester resin. Other materials under study on the spillway are a specifications-type epoxy mortar overlay, two types of wet curing epoxy mortars, and a number of protective coatings. After one winter's exposure, the vinyl ester polymer concrete overlay appeared to be in better condition than the other overlays. The surface-impregnation appears to be beneficial in providing a sound bond between the overlay and the concrete. Surface-impregnation without an overlay may also be of benefit, but a much longer exposure is required for evaluation of field performance. Further work is planned in developing polymer concrete overlays for Bureau structures.

H. C. Riffle

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Table 1

SUMMARY OF POLYMER COMPOSITE TEST SECTION
LOCATIONS AND EXPOSURE CONDITIONS

Location	Bypass No.	Test section b/	Size c/ M	Size c/ ft	No. of sections	Medium transported	Temperature °C	Temperature °F	TDS parts per million a/
Steam line to holding pond	1	PIC pipe	0.305 x 1.829	1 x 6	4	steam	160	320	0.0
Waste fluid line from desalting plant	2	PIC pipe	0.305 x 1.829	1 x 6	4	brine	60-121	140-250	28,000-100,000
Brine line from steam separator	3	PIC pipe	0.305 x 1.829	1 x 6	4	brine	160	320	26,000
		PIAC pipe	0.203 x 0.991	0.67 x 3.25	4	brine	160	320	26,000
Discharge ditch to holding pond	-	PC ditch lining slabs	0.61 x 1.22 x 0.064	0.21 x 2 x 4	12	brine	104	220	28,000

a/ Total dissolved solids concentration
b/ PIC - Polymer-impregnated concrete
PIAC - Polymer-impregnated asbestos-cement
PC - Polymer concrete
c/ Inside diameter by laying length of pipe

Table 2A

THREE-EDGE BEARING TEST RESULTS
(Metric Units)

Specimen No.	Polymer loading (% by wt)	Three-edge bearing load (kg per linear metre) 0.254-mm crack	Ultimate	Average 0.254-mm crack load	Improvement factor c/	Average ultimate load	Improvement factor c/
Class 12A50 Concrete Pipe (ASTM Designation: C 497)							
0-0-1	0.0	6 086	11 771	6 518	-	11 920	-
0-0-2	0.0	6 965	12 069				
0-0-10	5.61	15 388	15 789	15 894	2.4	16 370	1.4
0-0-11	5.79	16 385	16 950				
Class 8AC45 Asbestos-cement Pipe (ASTM Designation: C 500)							
0-0-1A a/	0.0	-	8 869	-	-	9 122	-
0-0-2A a/	0.0	-	9 375				
0-0-10A a/	3.60	-	11 489	-	-	10 878	1.2
0-0-11A a/	2.92	-	10 268				
0-0-3A b/	0.0	-	8 959	-	-	9 286	-
0-0-4A b/	0.0	-	9 614				
0-0-12A b/	8.21	-	11 995	-	-	11 518	1.2
0-0-13A b/	6.56	-	11 042				

a/ Pipe section machined overall
b/ Pipe section machined each end
c/ Improvement in strength resulting from impregnation

Table 2B

THREE-EDGE BEARING TEST RESULTS
(English Units)

Specimen No.	Polymer loading (% by wt)	Three-edge bearing load (lb per linear foot) 0.01-inch crack	ultimate	Average 0.01-inch crack load	Improvement factor c/	Average ultimate load	Improvement factor c/
Class 12A50 Concrete Pipe (ASTM Designation: C 497)							
0-0-1	0.0	4,090	7,910	4,380		8,010	
0-0-2	0.0	4,680	8,110				
0-0-10	5.61	10,340	10,610	10,680	2.4	11,000	1.4
0-0-11	5.79	11,010	11,390				
Class 8AC45 Asbestos-cement Pipe (ASTM Designation: C 500)							
0-0-1A a/	0.0	-	5,960	-		6,130	
0-0-2A a/	0.0	-	6,300	-			
0-0-10A a/	3.60	-	7,720	-	-	7,310	1.2
0-0-11A a/	2.92	-	6,900	-	-		
0-0-3A b/	0.0	-	6,020	-	-	6,240	-
0-0-4A b/	0.0	-	6,460	-	-		
0-0-12A b/	8.21	-	8,060	-	-	7,740	1.2
0-0-13A b/	6.56	-	7,420	-	-		

a/ Pipe section machined overall
b/ Pipe section machined each end
c/ Improvement in strength resulting from impregnation

Table 3

WATER ABSORPTION TEST
(ASTM Designation: C 497, 5-hour boiling method)

Specimen No.	Polymer loading (% by wt)	Absorption (% by wt)	Decrease in absorption (percent) a/
		Class 12A50 Concrete Pipe	
0-0-1	0.0	6.06	-
0-0-2	0.0	6.22	-
0-0-10	5.61	0.55	91
0-0-11	5.79	0.44	93
		Class 8AC45 Asbestos-cement Pipe	
0-0-1A b/	0.0	14.27	-
0-0-2A b/	0.0	14.25	-
0-0-10A b/	3.60	9.23	35
0-0-11A b/	2.92	10.02	30
0-0-3A c/	0.0	16.95	-
0-0-4A c/	0.0	16.99	-
0-0-12A c/	8.21	6.88	59
0-0-13A c/	6.56	7.00	59

a/ Percent decrease in absorption resulting from impregnation
b/ Pipe section machined overall
c/ Pipe section machined each end

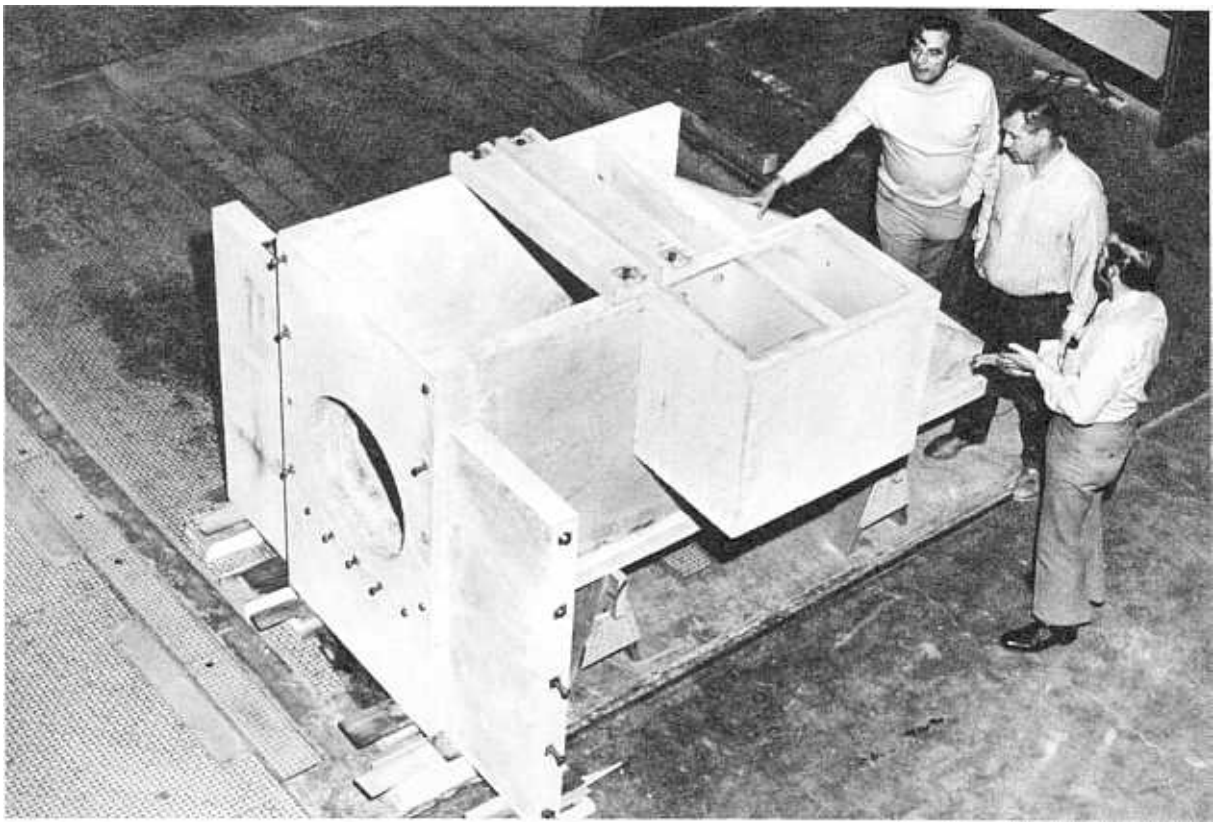

Figure 1. The assembled constant-head orifice canal turnout.

APPENDIX C

IMPREGNATION OF PIPE FOR GEOTHERMAL WELLS

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Memorandum

TO : Head, Polymer Concrete and Structural Section

Denver, Colorado
DATE: May 19, 1975

FROM : Fred E. Causey, Chemical Engineer

SUBJECT: Impregnation of Pipe for Geothermal Wells

Introduction

Test sections of polymer-impregnated concrete and asbestos-cement pipe were proposed for installation at the Geothermal Facility near Holtville, California. Since the hot brine will be about 320° F (160° C), it was decided that a 60-40 styrene-TMPTMA (trimethylolpropane trimethacrylate) monomer system would be used to impregnate the pipe. Previous work showed this system had a compressive strength of about 11,000 lb/in^2 (774 kg/cm^2) at 350° F (177° C). Thus, the pipe sections were impregnated with the styrene-TMPTMA monomer system. Also some 6-inch by 12-inch (15.2-cm by 30.5-cm) cylinders were impregnated to check compressive strength.

Impregnation

Twenty-eight 12-inch-inside-diameter by 6-foot 3-5/8-inch (30.5- by 192.1-cm) concrete pipe sections and fifteen 8-inch-inside-diameter by 3-foot 3-inch (20.3- by 99-cm) asbestos-cement pipe sections and twelve 8-inch (20.3-cm) asbestos-cement pipe couplings were treated in seven impregnations. Several 6-inch by 12-inch (15.2-cm by 30.5-cm) cylinders were also impregnated to check compressive strength for each impregnation.

The concrete pipe sections were loaded into a large drying oven with a 4,000-pound (1,800-kg) capacity fork lift. Only one specimen was hauled from the yard to the oven at a time. Four pipe sections were stacked into the oven for each impregnation. Figures 1 and 2 show loading and unloading of the oven and how the specimens were stacked in the oven. The asbestos-cement pipe sections and couplings were brought in from the yard in groups of four at a time on the fork lift. These specimens were loaded and unloaded into a second oven shown in figure 3. These specimens were hand loaded. All sections and couplings were dried at 350° F (177° C) and cooled to room temperature as indicated in the table. The temperature was raised slowly as not to exceed 40° F (22° C) per hour in the heat cycle and thus was so regulated that it took 8 hours to reach 350° F (177° C). All specimens were cooled overnight.

The concrete pipe sections were weighed on a 375-kg-capacity scale, the asbestos-cement pipe sections were weighed on a 90-kg scale and

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Figure – Loading and unloading of pipe in oven.

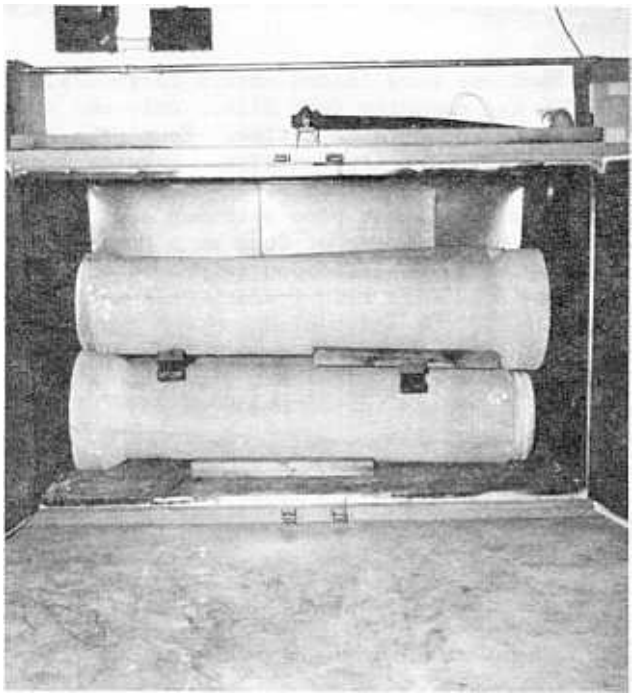


Figure 2. – Specimens stacked in oven.

couplings were weighed 5,000-g plus 1,000-g-tare capacity scale. The concrete sections were placed on the scale as shown in figure 4, while other specimens were placed on scales by hand. All dried weights and impregnated weights are shown in table 1.

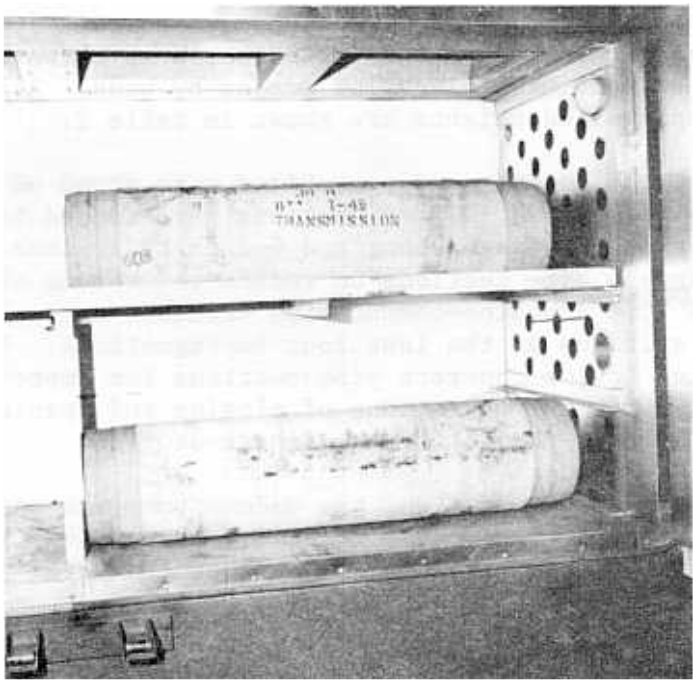
After weighing, the concrete pipe sections were stood on end by a lifting device (figure 5). Three sections were loaded bell down and one bell up for each impregnation, and 6-inch by 12-inch cylinders were placed between pipe sections to reduce the volume of monomer (figures 6 and 7). Asbestos-cement pipe sections were placed inside concrete pipe sections in the last four impregnations. Pipe couplings also were placed inside concrete pipe sections for impregnation. Figures 8 and 9 show the operations of closing and opening, and bolting and unbolting the top of the impregnator.

After the lid had been bolted on, the vacuum pump was switched on and 23 inches (584 mm) Hg [Denver mean 24.7 inches (627 mm) Hg] were drawn. While the vacuum cycle was in process the water jacket was filled with tap water (about 10° C). The water was then heated by steam for thermal-catalytic polymerization.

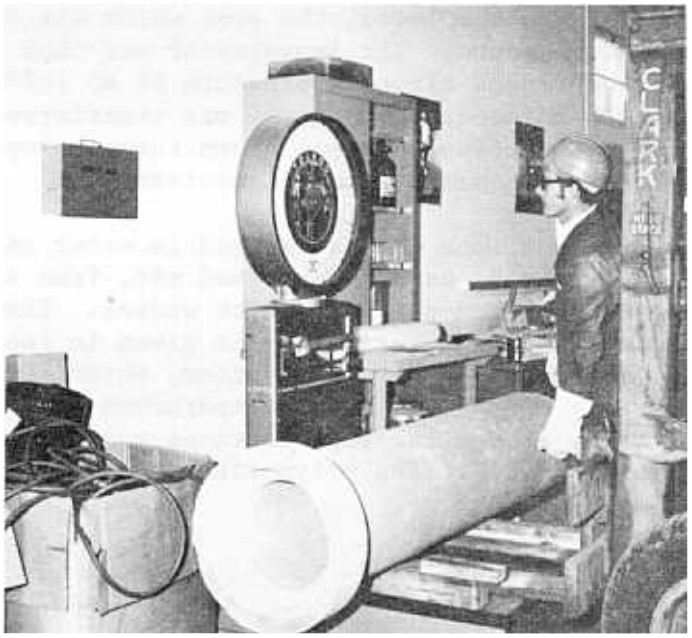
While the vacuum cycle was in progress, by styrene and trimethylol-propane trimethacrylate (TMPTMA), monomers catalyzed with one-half percent D-A79 (α-t-butylazo isobutzronitrile) were mixed by bubbling air through the transfer tank. The weight mix ratio of the monomer system was 60 percent styrene to 40 percent TMPTMA by weight.

After the vacuum cycle was completed, the catalyzed monomer was drawn into the impregnator from the transfer tank by the 23 inches of vacuum. When the proper monomer level was reached, the valve to the impregnator was closed and monomer left in the line was transferred back into the transfer tank with compressed air. After the monomer transfer was completed, the vent valve was opened to release the remaining vacuum. The impregnator was then slowly pressurized with compressed air to a pressure of 40 lb/in^2. When pressure cycle was completed, the monomer was transferred back into the transfer tank. Compressed air was blown through impregnator and line to remove excess monomer before polymerization.

The impregnated pipe sections were submerged in water and polymerized. Warm water was transferred, using compressed air, from a large water heater into the impregnation-polymerization vessel. Temperature of the water brought in for each polymerization is given in table 1. The water in the water jacket was heated by steam, which heats the water in the vessel. The jacket water temperature was raised to 200° F (93° C) and the water around the pipe sections raised to 190° F (88° C). The steam was then shut off. The polymerization goes to completion



Asbestos–cement pipe stack



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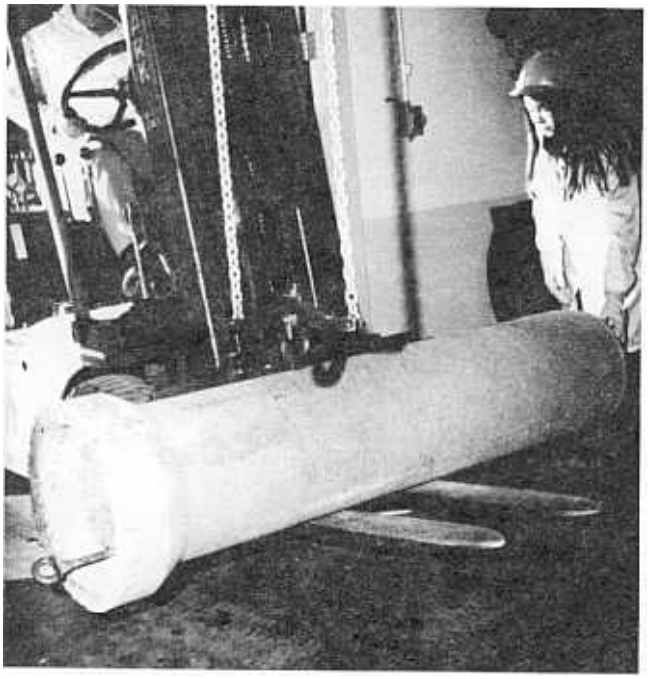


Figure 5. – Preparing to lift pipe to load into impregnator.

Figure 6. – Loading pipe into impregnator.

Figure 7. – Pipe loaded in impregnator.

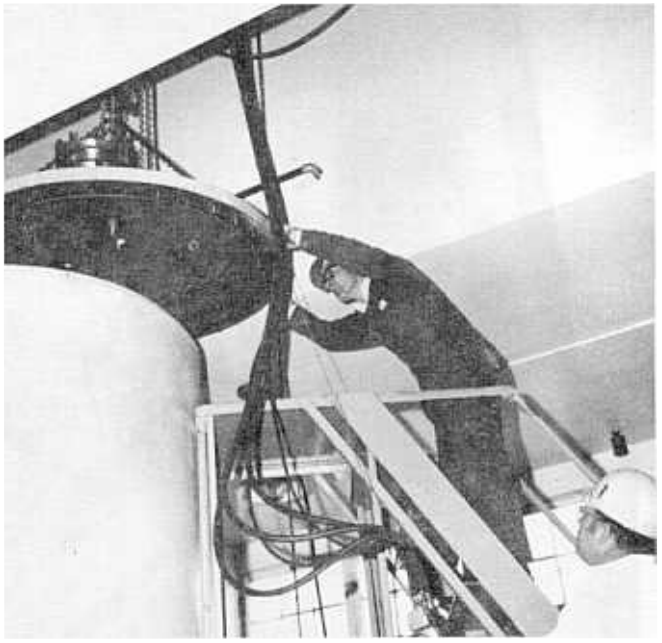


Figure 8. – Hoisting lid onto impregnator.

Figure 9. – Bolting lid on impregnator.

in a couple of hours. The water was drained the next morning, and compressed air was blown through to cool the specimens and remove the last of the water. The pipe sections were removed. Polymer loadings were calculated from the dried and impregnated weights. These data are shown in table 1.

Results

Polymer loadings for concrete pipe sections ranged from 5 to 6 percent, as was expected. The polymer loadings for the asbestos-cement pipe sections and couplings were somewhat variable and generally lower than expected, ranging from 3 to 9 percent. Three sections having the very low loadings were of a different pipe finish. The asbestos-cement specimens may not be fully impregnated, possibly because of fine porosity which restricts the impregnation by a large diameter monomer molecule. Thus, a water absorption test should be conducted to see if water absorption has been reduced to justify use of this pipe in geothermal wells. The 6-inch by 12-inch (15.2-cm by 30.5-cm) cylinders were broken in compression. The average compressive strength at room temperature (220° C) was 17,590 lb/in^2 (1,237 kg/cm^2). Table 1 shows polymer loadings and table 2 shows compressive strengths. ?

Fred E Causey

Table 1. - Weights and Impregnation Cycles

Test 1

Four 12-inch-inside-diameter by 6-foot 3-5/8-inch section of concrete pipe dried 24 hours and cooled about 24 hours; 8 hours were used to reach 350° F. Impregnated with 60-40 styrene-TMPTMA[1] and one-half percent D-A79[2] monomer temperature was about 62° F.

Cycle: 1-hour vacuum at 23.5 inches Hg.
3-hour pressure at 40 lb/in^2.

Polymerized under water overnight at 190° F and 0 lb/in^2. Water came in at 120° F and dropped to 110° to 115° F.

Spec No.[3]	Dry wt	Imp wt	Poly wt	% loading
HR-1	271.6 kg	286.45	14.85	5.47
HR-2	273.7	287.55	13.85	5.06
HR-3	272.3	286.85	14.55	5.34
HR-4	275.0	289.30	14.30	5.20

1. TMPTMA = trimethlolpropane trimethacrylate.
2. D-A79 = α-t-butylazo isobutyronitrile.
3. Spec No. = specimen number; Dry wt = dry weight; Imp wt = impregnated weight; Poly wt = polymer weight; kg = kilogram; and g = gram.

Test 2

Four 12-inch-inside-diameter by 6-foot 3-5/8-inch section of concrete pipe dried 24 hours and cooled about 24 hours; 8 hours were used to reach 350° F. Impregnated with 60-40 styrene-TMPTMA plus one-half percent D-A79 monomer temperature was about 65° F.

Cycle: 1-hour vacuum at 23.5 inches Hg.
3-hour pressure at 40 lb/in^2.

Polymerized under water overnight at 190° F and 5 lb/in^2; water came in at 155° F and dropped to 145° F.

Spec No.	Dry wt	Imp wt	Poly wt	% loading
HR-5	269.80 kg	285.60	15.80	5.86
HR-6	273.15	287.40	14.25	5.22
HR-7	271.20	286.30	15.10	5.57
HR-8	273.25	287.60	14.35	5.26
6-inch by 12-inch cylinders				
DT-27	12.65 kg	13.23	0.58	4.58
DT-14	12.85	13.49	0.64	4.98

Test 3

Four 12-inch-inside-diameter by 6-foot 3-5/8-inch sections of concrete pipe dried 24 hours and cooled about 24 hours; 8 hours were used to reach 350° F. Impregnated with 60-40 styrene-TMPTMA plus one-half percent D-A79 monomer temperature was about 65° F.

Cycle: 1-hour vacuum at 23 inches Hg.
3-hour pressure at 40 lb/in^2.

Polymerized under water overnight at 190° F and 15 lb/in^2; water came in at 180° F and dropped to 170° F.

Spec No.	Dry wt	Imp wt	Poly wt	% loading
HR-9	271.45 kg	286.60	15.15	5.58
HR-10	271.00	286.20	15.20	5.61
HR-11	270.10	286.10	16.00	5.92
HR-12	269.80	286.00	16.20	6.00
6-inch by 12-inch cylinders				
DT-43	12.57 kg	13.22	0.65	5.17
DT-39	12.67	13.30	0.63	4.97

Test 4

Four 12-inch-inside-diameter by 6-foot 3-5/8-inch sections of concrete pipe, 4-inch to 8-inch-inside-diameter by 3-foot 3-inch sections of asbestos-cement pipe, and 4-inch to 8-inch asbestos-cement pipe couplings dried 24 hours and cooled over the weekend; 8 hours were used to reach 350° F. Impregnated with 60-40 styrene-TMPTMA plus one-half percent D-A79 monomer temperature was about 38° F.

Cycle: 1-hour vacuum at 23 inches Hg.
3-hour pressure at 40 lb/in^2.

Polymerized under water overnight at 190° F and 5 lb/in^2; water came in at 115° F and dropped to 105° F.

Spec No.	Dry wt	Imp wt	Poly wt	% loading
HR-13	274.15 kg	288.00	13.85	5.05
HR-14	269.70	285.30	15.60	5.78
HR-15	273.75	287.15	13.40	4.89
HR-16	270.25	285.65	15.40	5.70
Asbestos				
AHR-1	18.82 kg	19.35	0.55	2.92
2	18.08	19.40	1.32	7.30
3	16.88	18.52	1.64	9.72
4	18.53	19.08	0.55	2.96
Couplings				
ACHR-1	4,977.2 g	5,238.5	261.3	5.25
2	4,767.6	5,096.0	328.4	6.89
3	4,999.2	5,402.3	403.1	8.06
4	4,997.9	5,321.5	323.6	6.47
6-inch by 12-inch cylinders				
DT-34	12.68 kg	13.32	0.64	5.05
DT-60	12.62	13.29	0.67	5.31

Test 5

Four 12-inch-inside-diameter by 6-foot 3-5/8-inch sections of concrete pipe, 4-inch to 8-inch-inside-diameter by 3-foot 3-inch sections of asbestos-cement pipe and 4-inch to 8-inch asbestos-cement pipe coupling dried over the weekend at 350° F and cooled about 24 hours; 8 hours were used to reach 350° F. Impregnated with 60-40 styrene-TMPTMA plus one-half percent D-A79 monomer temperature 33° F.

Cycle: 1-hour vacuum at 22.8 inches Hg.
3-hour pressure at 40 lb/in^2.

Polymerized under water overnight at 190° F and 5 lb/in^2; water came in at 150° F and dropped to 135° F.

Spec No.	Dry wt	Imp wt	Poly wt	% loading
HR-17	276.90 kg	290.75	13.85	5.00
HR-18	273.30	288.60	15.30	5.60
HR-19	270.80	286.15	15.35	5.67
HR-20	274.20	288.10	13.90	5.07
Asbestos				
AHR-5	17.90 kg	19.14	1.24	6.93
6	18.32	18.98	0.66	3.60
7	18.24	18.87	0.63	3.45
8	17.87	19.17	1.30	7.27
Couplings				
ACHR-9	4,779.4 g	5,077.2	297.8	6.23
10	4,733.3	5,061.0	327.7	6.92
11	4,912.9	5,171.2	258.3	5.26
12	4,999.1	5,268.0	268.9	5.38
6-inch by 12-inch cylinders				
DT-42	12.55 kg	13.20	0.65	5.18
DT-4	12.60	13.26	0.66	5.24

Test 6

Four 12-inch-inside-diameter by 6-foot 3-5/8-inch sections of concrete pipe, and 4-inch to 8-inch-inside-diameter by 3-foot 3-inch sections of asbestos-cement pipe dried 24 hours and cooled about 24 hours; 8 hours were used to reach 350° F. Impregnated with 60-40 styrene-TMPTMA plus one-half percent D-A79 monomer temperature about 33° F.

Cycle: 1-hour 15-minute vacuum at 22.8 inches Hg.
3-hour pressure at 40 lb/in^2.

Polymerized under water overnight at 190° F and 9 lb/in^2 water came in at 155° F and dropped to 135° F.

Spec No.	Dry wt	Imp wt	Poly wt	% loading
HR-21	272.15 kg	287.00	14.85	5.46
HR-22	270.60	286.55	15.95	5.89
HR-23	271.30	287.00	15.70	5.79
HR-24	272.80	287.70	14.90	5.46
Asbestos				
AHR-9	18.22 kg	19.40	1.18	6.48
10	18.08	19.58	1.50	8.30
11	17.41	18.83	1.42	8.16
12	17.77	19.06	1.29	7.26
6-inch by 12-inch cylinders				
DT-57	12.68 kg	13.36	0.68	5.36
DT-45	12.75	13.41	0.66	5.18

Test 7

Four 12-inch-inside-diameter by 6-foot 3-5/8-inch sections of concrete pipe, 3-inch to 8-inch-inside-diameter by 3-foot 3-inch sections of asbestos-cement pipe, and 4-inch to 8-inch asbestos-cement pipe couplings dried 24 hours at 350° F and cooled about 24 hours; 8 hours were used to reach 350° F. Impregnated with 60-40 styrene-TMPTMA plus one-half percent D-A79 monomer temperature was about 26° F.

Cycle: 1-hour 15-minute vacuum at 22.8 inches Hg.
3-hour pressure at 40 lb/in^2.

Polymerized under water overnight at 190° F and 10 lb/in^2; water came in at 135° F and dropped to 120° F.

Spec No.	Dry wt	Imp wt	Poly wt	% loading
HR-25	271.25 kg	286.65	15.40	5.68
HR-26	271.65	290.75	19.10	7.03
HR-27	269.75	285.10	15.35	5.69
HR-28	269.45	285.40	15.95	5.92
Asbestos				
AHR-13	17.92 kg	19.27	1.35	7.53
14	17.90	19.37	1.47	8.21
15	18.15	19.34	1.19	6.56
Couplings				
ACHR-5	4,999.4 g	5,333.3	333.9	6.68
6	4,900.9	5,222.1	321.2	6.55
7	4,940.0	5,257.5	317.5	6.43
8	4,813.0	5,104.8	291.6	6.06
6-inch by 12-inch cylinders				
TP-5	13.49 kg	14.08	0.59	4.37
6	13.38	13.98	0.60	4.48
9	13.52	14.10	0.58	4.29

Table 2. - Compressive Strength of 6-inch by 12-inch (15.24-cm by 30.48-cm) Cylinders

Spec No.[1]	Load		Compressive Strength	
	lb.	kg	lb/in^2	kg/cm^2
DT-14	460,000	208,650	16,270	1,144
27	482,000	218,630	17,050	1,199
39	513,000	232,690	18,150	1,276
43	501,000	227,450	17,720	1,247
34	539,000	227,450	19,070	1,340
60	501,000	227,450	17,720	1,247
4	492,000	223,170	17,400	1,224
42	517,000	234,510	18,290	1,286
45	529,000	239,950	18,710	1,316
57	523,000	237,230	18,500	1,301
TP- 5	477,000	216,360	17,040	1,198
6	468,000	212,280	16,710	1,175
9	449,000	203,660	16,040	1,127

1. DT specimens have a surface area of 28.27 in^2 (182.38 cm^2) for compressive strength; TP specimens have a surface area of 28.0 in^2 (180.64 cm^2).

APPENDIX D

EXPERIMENTAL REPAIR OF SHADOW MOUNTAIN DAM SPILLWAY

Form DFC-11
(12-61)
Bureau of Reclamation

INFORMATIONAL ROUTING

[28]

Memorandum
Chief, Concrete and Structural Branch

Denver, Colorado
January 14, 1977

ACTING Head, Polymer Concrete and Structural Section
Head, Concrete Section

Experimental Repair of Shadow Mountain Spillway

Attached is an interim report of the subject repair program. It is expected that the evaluation of the repair areas and materials performance will be completed in FY78. A final report of this project will be prepared at that time.

Most of the measurements were made in British units which were converted to SI units in compliance with the policy for showing both units at the time the report was drafted. Portions of the report have since been revised, but for consistency both units have been retained throughout the report.

S. A. Nelson
Edward M. Harboe

Attachment

Copy to: 1511
1512
(with attachment to each)

Carl E. Schmidt
MAR 3 1977

EXPERIMENTAL REPAIR OF SHADOW MOUNTAIN DAM SPILLWAY

Interim Report

by

W. G. Smoak
F. E. Causey
G. W. DePuy
T. E. Rutenbeck
O. R. Werner

INTRODUCTION

Shadow Mountain Dam is located on the Colorado River near Grand Lake, Colorado. The crest of the spillway is at elevation 2544 m (8,348 ft) above sea level and is subjected to the typical climatic exposure conditions of the Rocky Mountains, ranging from subzero temperatures and heavy snows in the winter to warm and sunny days in the summer with occasional mountain rain showers. Construction of the dam and spillway was completed in 1946.

On June 13, 1975, Messrs. Smoak, Causey, Rutenbeck, and DePuy accompanied by Charles Calhoun and Lowell Crow of the Lower Missouri Region Office, met with Bob Murray, Western Slope Manager, and Zenas Blevins and Paul Roosa from the Loveland Project Office at Shadow Mountain Dam and inspected the spillway as a possible site for experimental spillway repairs. The spillway floor showed some surface deterioration from freezing and thawing and possibly some minor damage from rocks thrown over the side by tourists. The deterioration is unsightly, but does not present an immediate threat to the structural integrity of the spillway. As there was no immediate need for a permanent repair of the spillway, this was an excellent opportunity to test experimental repair and protective systems and obtain several years' exposure to evaluate their field performance. It was anticipated that a permanent repair would be made at a later time using one of the systems proven acceptable in these tests.

EXPERIMENTAL REPAIR PROGRAM

During the inspection of the damaged portions of the spillway, it was determined that freeze-thaw damage was also occurring beneath epoxy mortar patches that had previously been placed. This damage caused disbonding of the patches and failure of the patch as a repair technique.

In laboratory durability tests, polymer impregnated concrete has shown greatly improved freeze-thaw resistance over conventional concrete

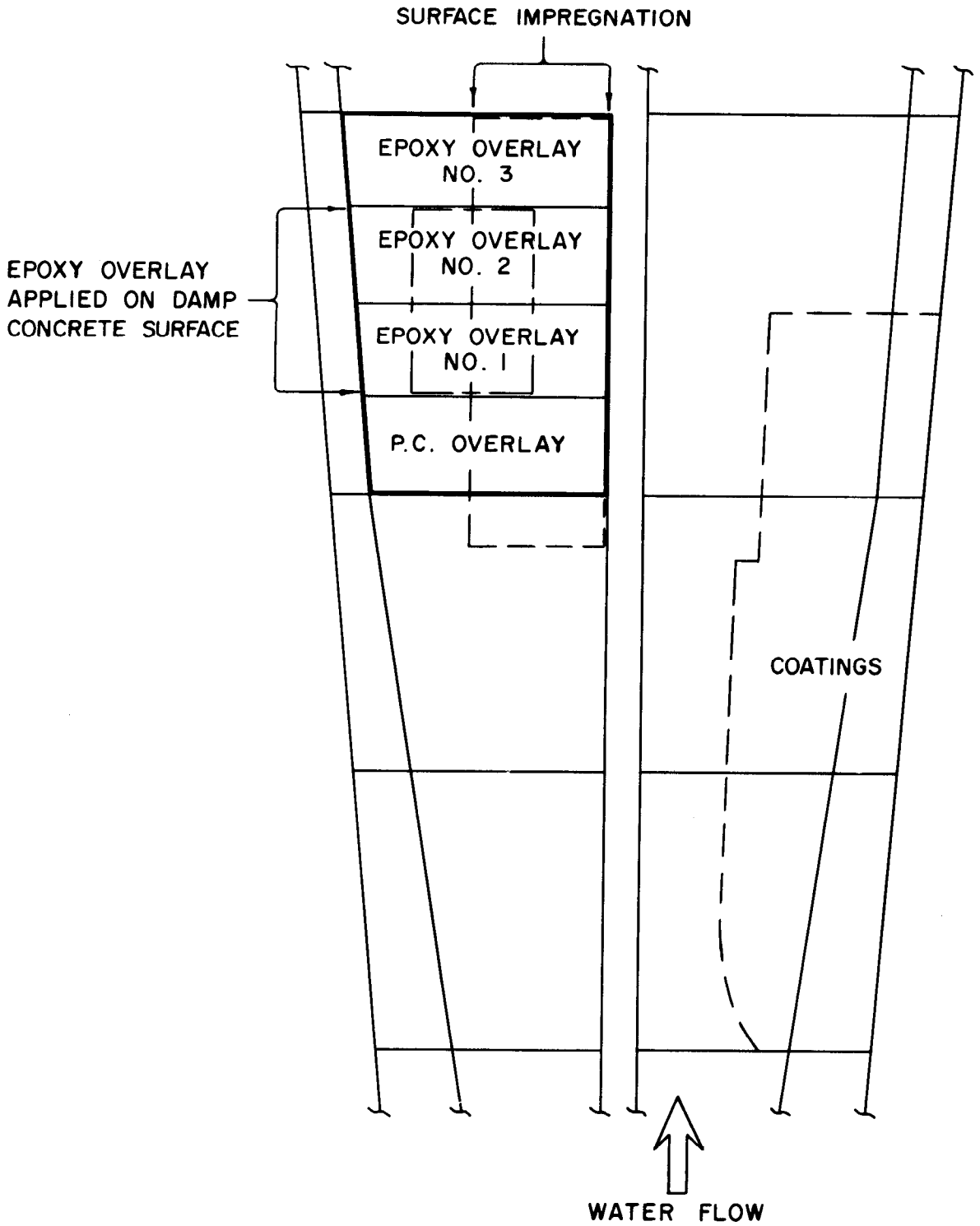


Figure 1. - Sketch shows schematic layout for the experimental repairs on the floor of the Shadow Mountain Spillway.

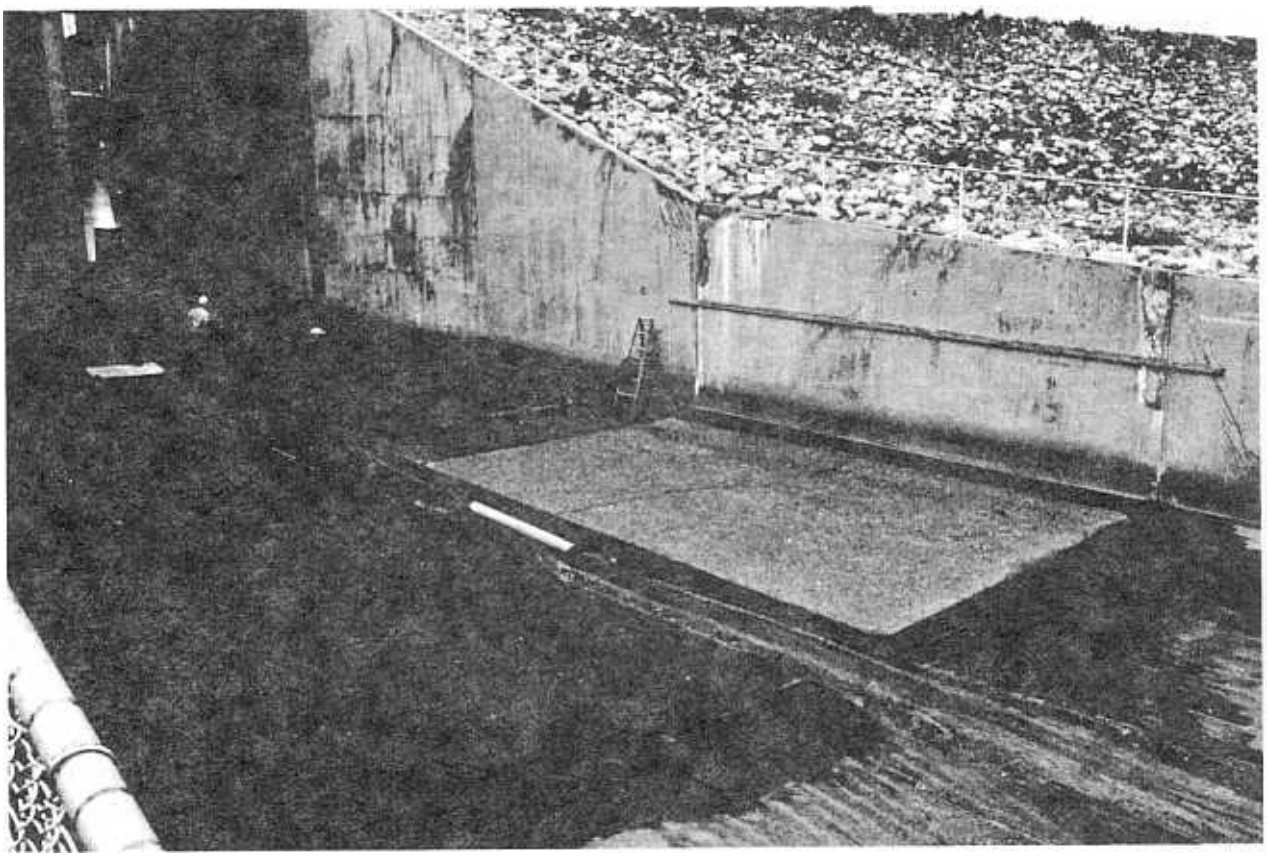


Figure 2. - Spillway area selected for experimental repairs. Area has been sandblasted in preparation for overlays.

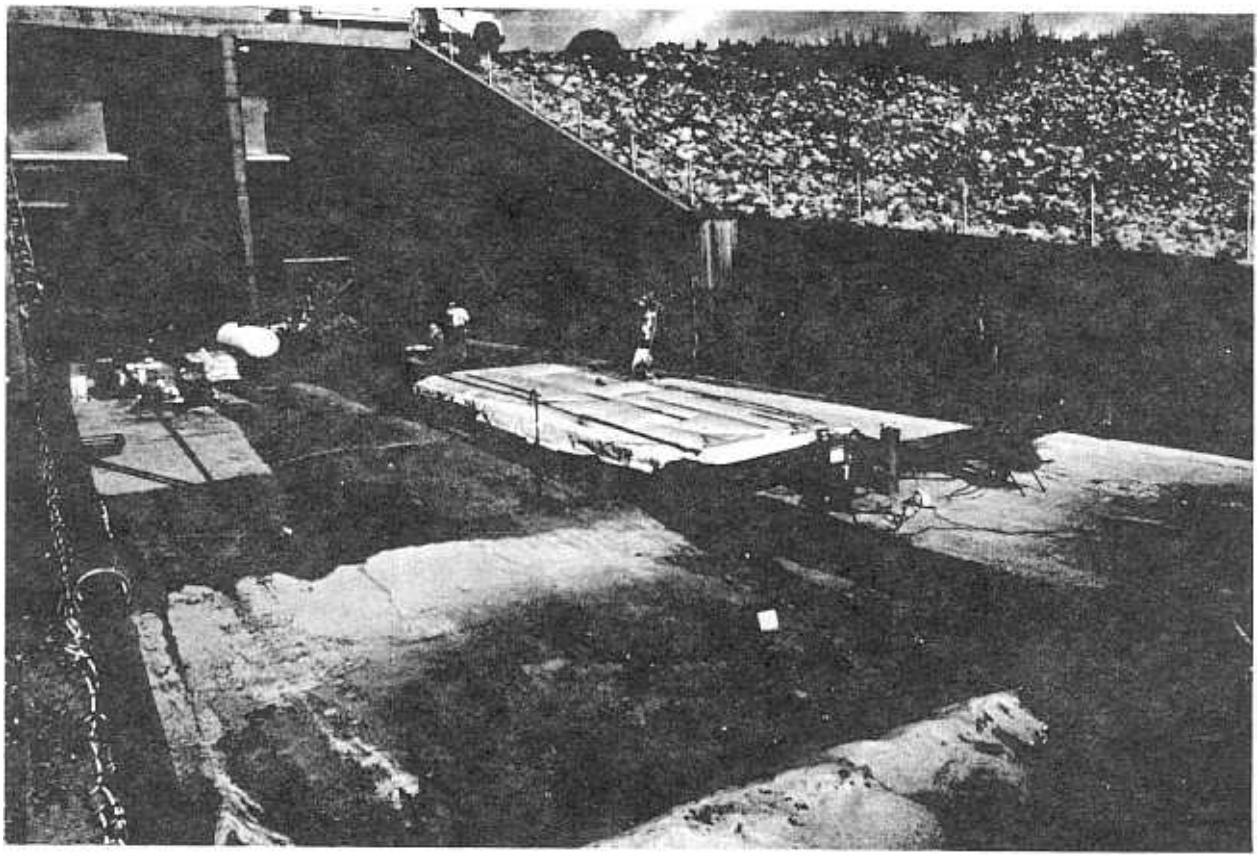


Figure 4. - The drying enclosure has been completely installed and is shown in operation during the drying of the spillway floor.

(TMPTMA). In the mixing operation, the proper weights of the respective monomers were added to a container and mixed by bubbling low-pressure compressed air into the container. The mixed monomer was then placed in standard drums and transported to the jobsite. At the spillway and just prior to use, the polymerization catalyst, 2,2 azobis (2,4 dimethylvaleronitrile), was added to the monomer system. Mixing was accomplished with low-pressure compressed air (fig. 6).

Due to the monomer system's sensitivity to solar radiation, monomer application to the spillway was done at night. Previous experience with this monomer system has shown that an application rate of approximately 7.3 kg/m^2 (1.5 lb/ft^2) applied in two applications, 4 to 5 hours apart, yields the desired polymer penetration. For the first application, the polymerization catalyst was added to the monomer at the concentration of 0.5 wt percent. After mixing, the monomer system was applied to the sand with sprinkling cans (fig. 7). The initial application was made at the rate of approximately 4.9 kg/m^2 (1.0 lb/ft^2) which was sufficient to fully saturate the sand. The wet surface was then covered with polyethylene plastic to reduce monomer evaporation and left to soak for 4 hours. A second application of monomer was then made at the rate of 2.4 kg/m^2 (0.5 lb/ft^2), again fully saturating the sand.

The treated area was then recovered with polyethylene plastic and the enclosure with its related heating and control equipment reinstalled on the spillway (fig. 8). Soaking was allowed to continue for an additional 5 hours before the heaters were turned on to begin the polymerization cycle.

Prior to turning on the heater burners, the heater fans were turned on to clear the enclosure of flammable monomer vapors. When the enclosure was safely ventilated, the heater burners were turned on and the concrete surface temperature slowly increased to 77°C (170°F) over a period of about 10 hours. This temperature, ±10°C (20°F), was then maintained for an additional 14 hours.

At the completion of the polymerization cycle, the heat was turned off and the enclosure removed from the treatment area. Most of the sand used as a monomer reservoir during impregnation and polymerization could be swept from the surface. In one area (fig. 9) the sand was tightly bonded to the concrete and was removed by sandblasting and chipping (fig. 10).

Five 50-mm (2-in.) diameter core specimens were subsequently drilled from the impregnated area and broken in tensile splitting to determine the polymer penetration. These specimens showed visible polymer penetrations of 13 to 38 mm (1/2 to 1-1/2 in.).

Figure 7. - Monomer is applied to concrete surface at night to avoid premature polymerization initiated by sunlight. Sprinkler cans were a convenient means for applying monomer to the relatively small treatment area.

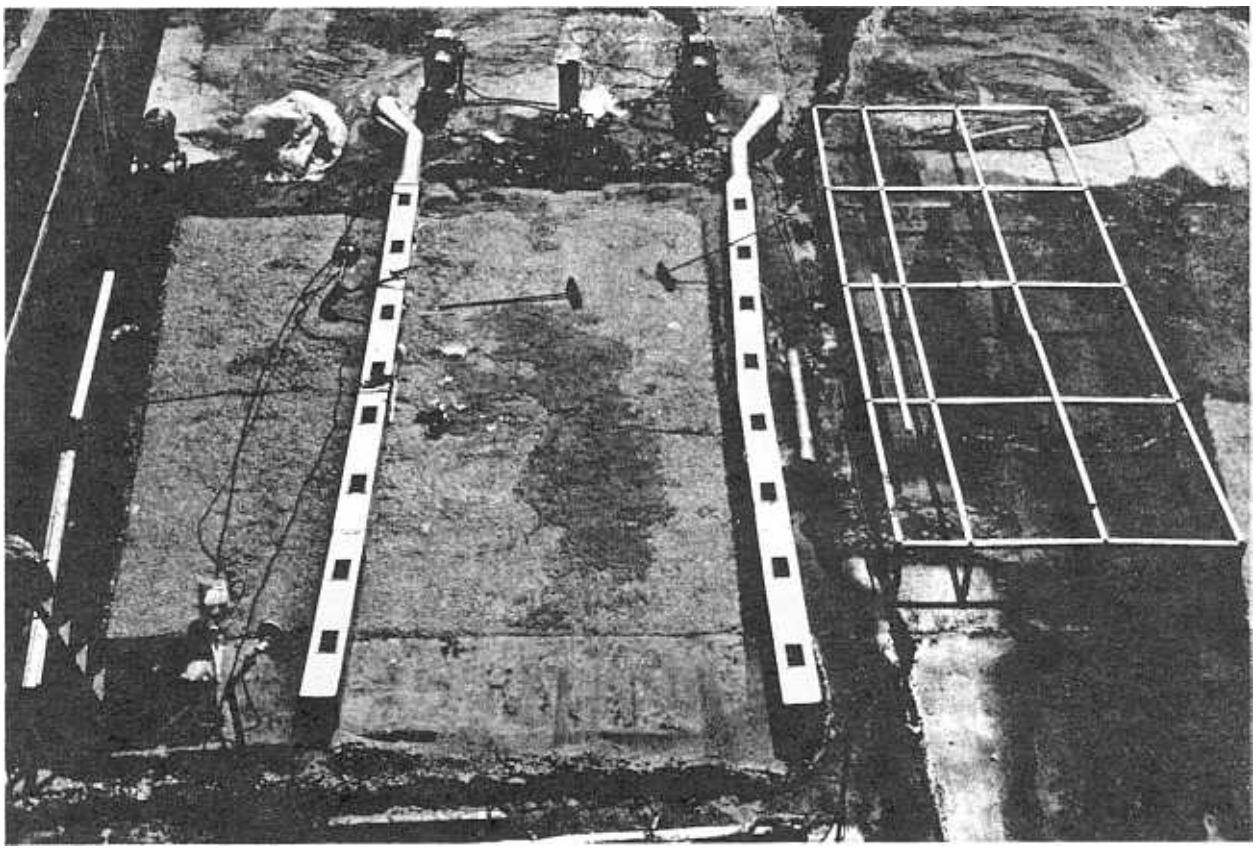


Figure 9. - The surface-impregnated area is shown after completion of the polymerization cycle. The irregular-shaped patch was formed by sand bonded to the concrete by excess polymer.

The surface impregnation equipment was then removed from the test slab in preparation for placement of the PC and epoxy mortar experimental repair overlays.

PC Overlay

A PC overlay was placed on an area 2.1 by 6.1 m (7 by 20 ft) as shown in figure 1. Approximately one-half of the area overlaid, 2.1 by 3.0 m (7 by 10 ft), had received the surface impregnation treatment. Rain had fallen during the night prior to overlay application and the moisture was dried from the surface using two 530-MJ (500,000-Btu) space heaters as shown in figure 11. Water which leaked by the seals of the spillway gates during the overlay application was diverted by dikes made from a fast-setting cement.

PC Materials

A vinyl ester resin manufactured by Dow Chemical Company with a trade name of Derakane 470 was mixed with a graded aggregate to form PC for the overlay.

The vinyl ester resin was preweighed in Denver. Two promoters, cobalt naphthenate and dimethyl aniline, were added to the resin during this operation. Methylethyl ketone peroxide, the catalyst, was preweighed into small bottles for mixing when needed at the jobsite. The monomer system formula on a mass basis was:

PC Monomer System

Derakane 470 - vinyl ester resin	100	parts
cobalt naphthenate - promoter	0.2	parts
dimethyl aniline - promoter	0.05	parts
methylethyl ketone peroxide - catalyst	0.5	parts

The monomer system was mixed with the aggregate in a ratio of about eight parts graded aggregate to one part monomer system by mass.

Graded sand for making the PC was preblended in Denver. The sand was batched in large cans holding 20 kg (45 lb) each with the aggregate graded as shown in the following chart:

No. 16 maximum[1]			No. 30 maximum[2]		
Sand* size No.	Individual percent retained	Cumulative percent retained	Sand size No.	Individual percent retained	Cumulative percent retained
16	31	31			
30	22	53	30	31	31
50	16	69	50	23	54
100	10	79	100	16	70
Pan	21	100	Pan	30	100

[1] This mix was used for the deeper overlays.
[2] This mix was used for the featheredge areas.
* Sands were from Clear Creek.

Application of Overlay

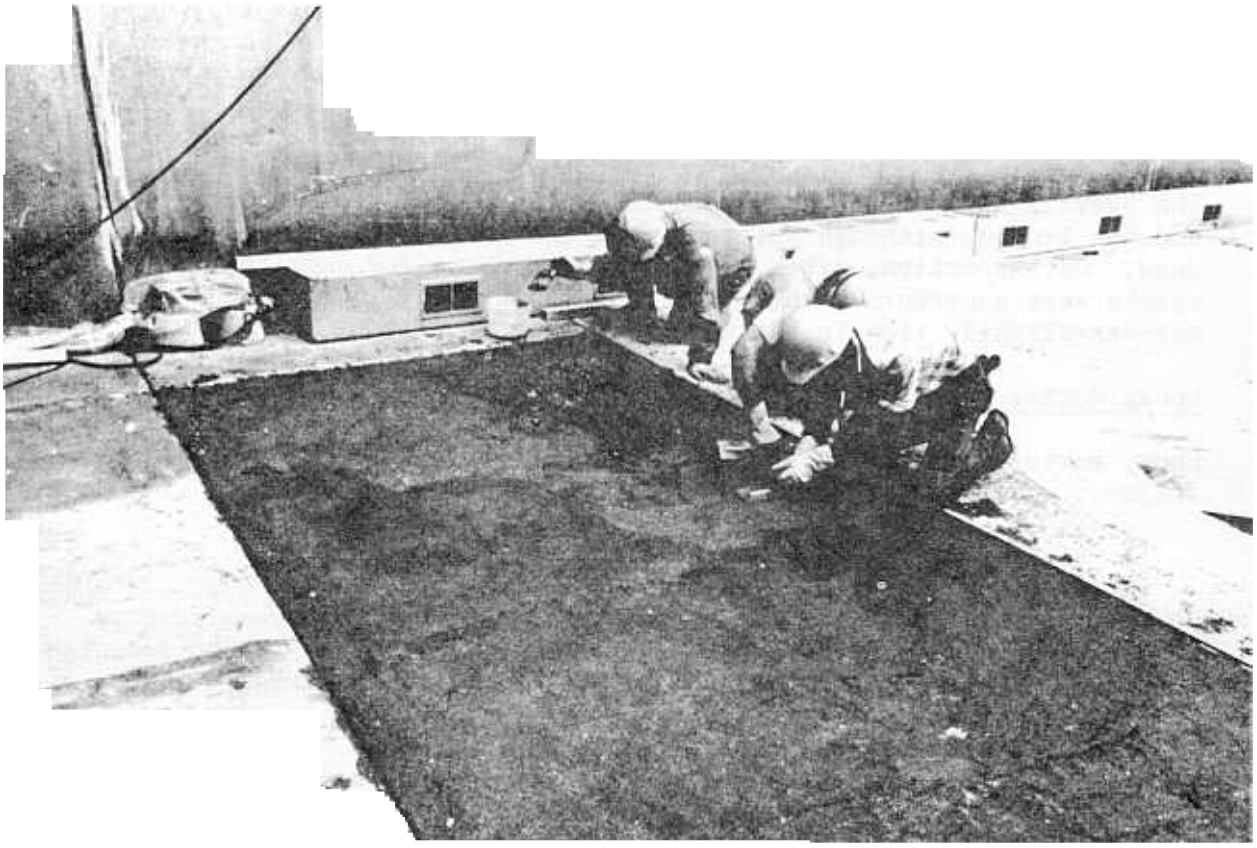
The PC overlay was applied over a promoted and catalyzed monomer system bond coat.

1. Bond coat. - The weighed vinyl ester resin containing the promoters was poured into a 5.3-ℓ (5-qt) pail and the catalyst was added. These components were then mixed with a spatula until uniform without streaks.

After the materials were thoroughly mixed, a large paint brush [90 mm (3-1/2 in.)] was used to apply the bond coat to the area expected to be overlaid with a batch of PC. The bond coat was scrubbed into voids of the concrete with the brush to assure good bond between the concrete and the overlay. Pot life for the mix was about 25 minutes. The overlay was placed before the bond coat cured.

2. Polymer concrete overlay. - The same monomer system components were mixed as for the bond coat. The system was then mixed with graded sand to form PC. A Hobart mixer was used to mix the graded aggregate and monomer system in batches of 15 kg (33 lb) (fig. 12). The sand was placed in the mixer bowl and the mixer started. The monomer system was then slowly added to the graded sand and mixed until a uniform blend was achieved.

After the PC was thoroughly mixed, it was placed onto the area primed by the bond coat. Regular concrete finishing trowels were used to spread and level the PC to form the overlay (fig. 13). Most of the overlay was 13-mm (1/2-in.) thick with areas up to



19-mm (3/4-in.) thick where more extensive freeze-thaw spalling had occurred. After several square feet of overlay were completed, a sheet of polyethylene was laid over the overlay and a water-filled lawn roller was used for final compaction and leveling (fig. 14). The overlay cured hard to the touch in 1/2 to 1 hour after being placed.

Vinyl Ester Polymer Coating

An area about 1.5 by 1.2 m (5 by 4 ft) was coated with the vinyl ester monomer system to determine whether it would provide protection to the spillway concrete against future freeze-thaw deterioration. Part of the area, about 0.6 by 1.2 m (2 by 4 ft) was sandblasted and dried. The remaining area, about 0.9 by 1.2 m (3 by 4 ft), was broom cleaned and dried. A 90-mm (3-1/2-in.) paint brush was used to scrub the monomer system into the surface of the concrete.

PC Curing

The overlay was hard to the touch in 1/2 to 1 hour after being placed and the finish, although splotchy from the individual batches, appeared good. On inspection, after an overnight cure, a few hairline shrinkage cracks were apparent in the surface of the overlay in areas where the mix was slightly rich in the monomer system.

Epoxy Mortar Overlays

Epoxy mortar overlays were prepared with three epoxy resins as follows:

1. Sikadur Lo-Mod is a two-component, 100 percent solids, polyamide epoxy resin manufactured by Sika Chemical Corporation. Because this resin is a polyamide epoxy, it does not meet the requirements of Federal Specification MMM-B-350B for Flexible Epoxy Resin Adhesive Binder. Sikadur Lo-Mod was chosen because the manufacturer claims that it can be applied in cool weather [4°C (40°F)] to damp concrete without appreciable loss of ultimate bond strength. Sikadur Lo-Mod epoxy resin was mixed as recommended by the manufacturer, combined with sand meeting Bureau specifications requirements, and applied to both damp and dry concrete. The temperature of the repair area during and after application of the epoxy mortar varied greatly with the radiation of the sun during the day and the cool weather at night.

2. Sinmast Rapid Cure Mortar Mix Resin, another two-component, 100 percent solids, polyamide epoxy resin, is marketed by Sinmast of America and also does not meet requirements of the Federal

Table A

MIX DESIGN DATA FOR EPOXY MORTARS

Epoxy resin	Physical property*	5-1/2:1 ratio (sand to resin)	6:1 ratio (sand to resin)	6-1/2:1 ratio (sand to resin)
Probond ET150H	Workability	Sticky	Fair	Fair
	Vacuum-saturated absorption (percent by dry mass, 24-hour soak)	0.2	0.2	0.0
	Porosity (percent by total volume)	7.5	7.2	8.1
	Compressive strength,** MPa (lb/in^2) at 5 days age, cured at 24°C (75°F) temp.	94.5 (13,700)	88.7 (12,860)	84.3 (12,230)
Sikadur Lo-Mod	Workability	Sticky	Good	Good
	Vacuum-saturated absorption (percent by dry mass, 24-hour soak)	0.5	0.2	0.2
	Porosity (percent by total volume)	12.2	11.3	8.3
	Compressive strength,** MPa (lb/in^2) at 5 days age, cured at 24°C (75°F) temp.	54.3 (7,880)	51.8 (7,520)	57.9 (8,400)
Sinmast mortar mix	Workability	Good	Good	Good
	Vacuum-saturated absorption (percent by dry mass, 24-hour soak)	0.2	0.6	0.7
	Porosity (percent by total volume)	6.9	7.8	8.1
	Compressive strength,** MPa (lb/in^2) at 5 days age, cured at 24°C (75°F) temp.	97.4 (14,120)	78.5 (11,390)	81.9 (11,880)

* Each value is an average of tests on two specimens.
** Compressive strengths represent 50-mm-diameter by 100-mm (2-in. by 4-in.) cast cylindrical specimens.

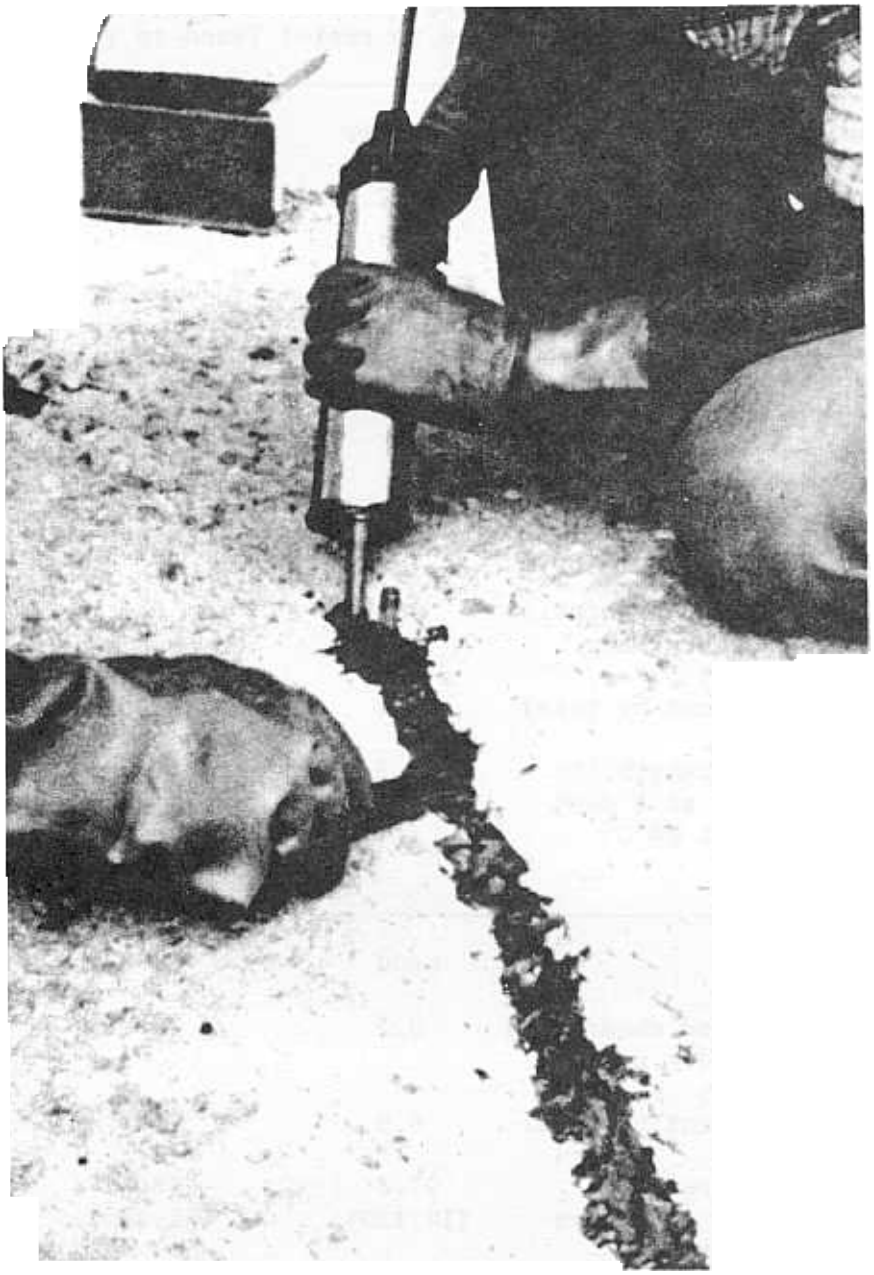


Figure 15. - Crack in concrete on spillway floor is being sealed with epoxy paste in preparation for epoxy resin injection. Note the injection nipples through which epoxy is later to be injected.

2. After placement of the mortar overlay was complete, no effort was made to cure the epoxy at an elevated temperature. However, the mortar lay exposed to direct sunlight and to very cool nights. The exposure of the dark mortar surface to the afternoon sun immediately after placing gave the overlay a brief, high temperature cure [exceeding 45°C (113°F)] which was then followed by exposure to nighttime temperatures below 0°C (32°F).

Figures 16 through 20 are a sequence of photographs taken throughout the application of the mortar overlays.

The Sinmast and Sika epoxy bond coats were applied at a coverage of approximately 1.60 m^2/ℓ (65 ft^2/gal). The Probond was more viscous, so its bond coat was thicker, about 1.35 m^2/ℓ (55 ft^2/gal). When the Sika and Sinmast bond coats were applied to damp surfaces, the resin became milky in appearance. However, the liquid resin still adhered well to the surface, and it seemed to mix well with the water.

All three epoxy mortars were applied at an average thickness of 10 mm (0.4 in.). The first few batches of each epoxy mortar overlay were mixed at proportions chosen during preliminary investigations. However, the mortar appeared to have excessive epoxy resin during finishing of the mortar surface. This excess may have been caused in part by bleeding of the bond coats through the thin mortar layers. Thereafter, the mortar mix proportions were adjusted for better workability. The major portions of the epoxy mortar overlays contained sand to epoxy ratios, by weight, of 6.9:1, 6.2:1, and 6.5:1 for the Probond, Sika, and Sinmast mortars, respectively.

Probond epoxy-bonded mortar was fairly difficult to finish compared to the other two epoxies used. From the time the Probond resin was first mixed, mortar could be worked effectively with a trowel for only 15 to 25 minutes. The short pot life may be due in part to use of a cold weather epoxy intended for use at temperatures below 20°C (68°F) on a concrete surface that was warmer than expected. The Probond epoxy mortar also had a tendency to stick to the trowels, thus making troweling difficult.

Sika and Sinmast mortars, on the other hand, were very workable compared to the Probond product. These two mortars were easily screeded, could be effectively troweled using a typical sweeping motion with the trowel, and had a "pot life" of about 1 hour after mixing. However, bulges appeared on the surface of both Sika and Sinmast epoxy mortar overlays, while the mortar was still plastic. These bulges grew slowly after troweling to a maximum visible diameter of approximately 40 mm (1-1/2 in.) and to a height of up to 5 mm (3/16 in.). These blisters occurred over the entire surface of the overlays and, therefore, do not appear to be caused by the water in the damp-surface overlay section or prevented by the polymer impregnated overlay section.

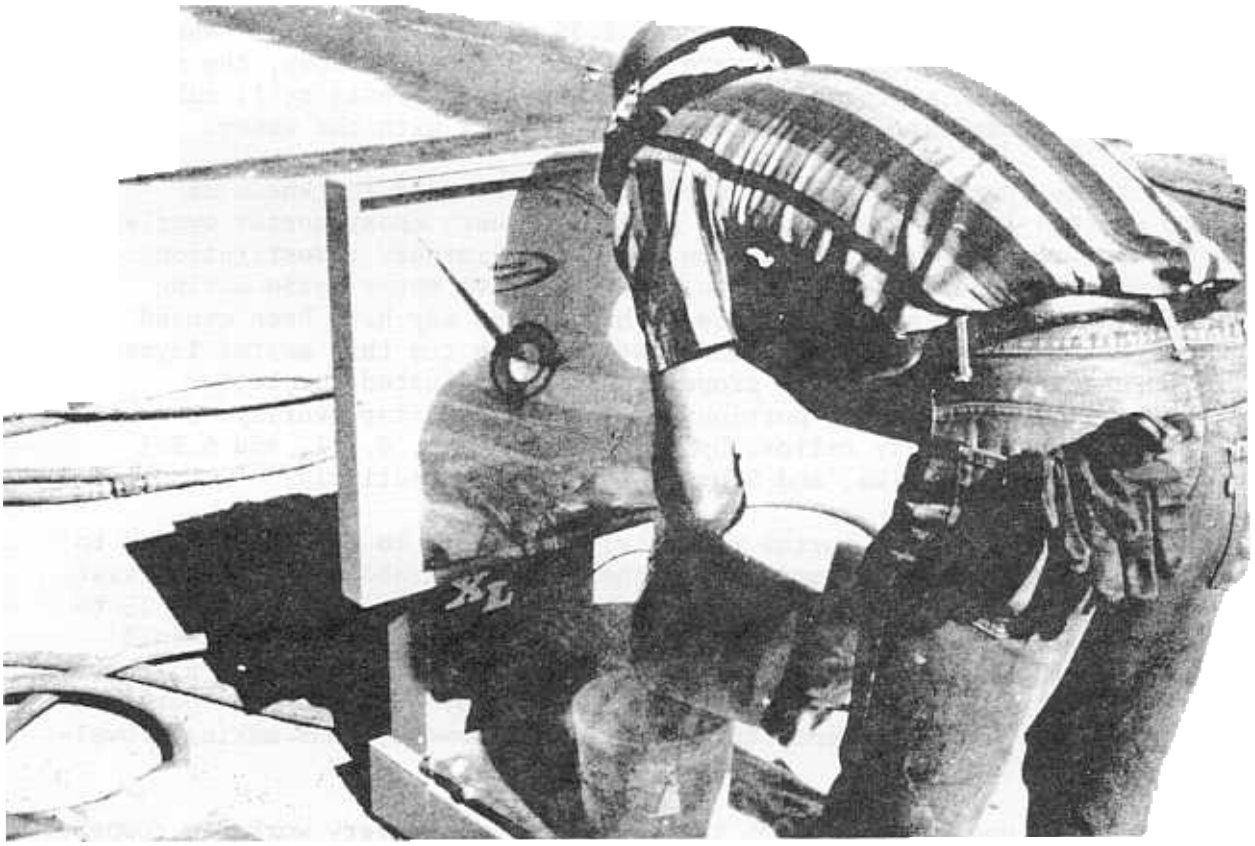


Figure 17. - Sand was most easily measured by mass rather than by volume.

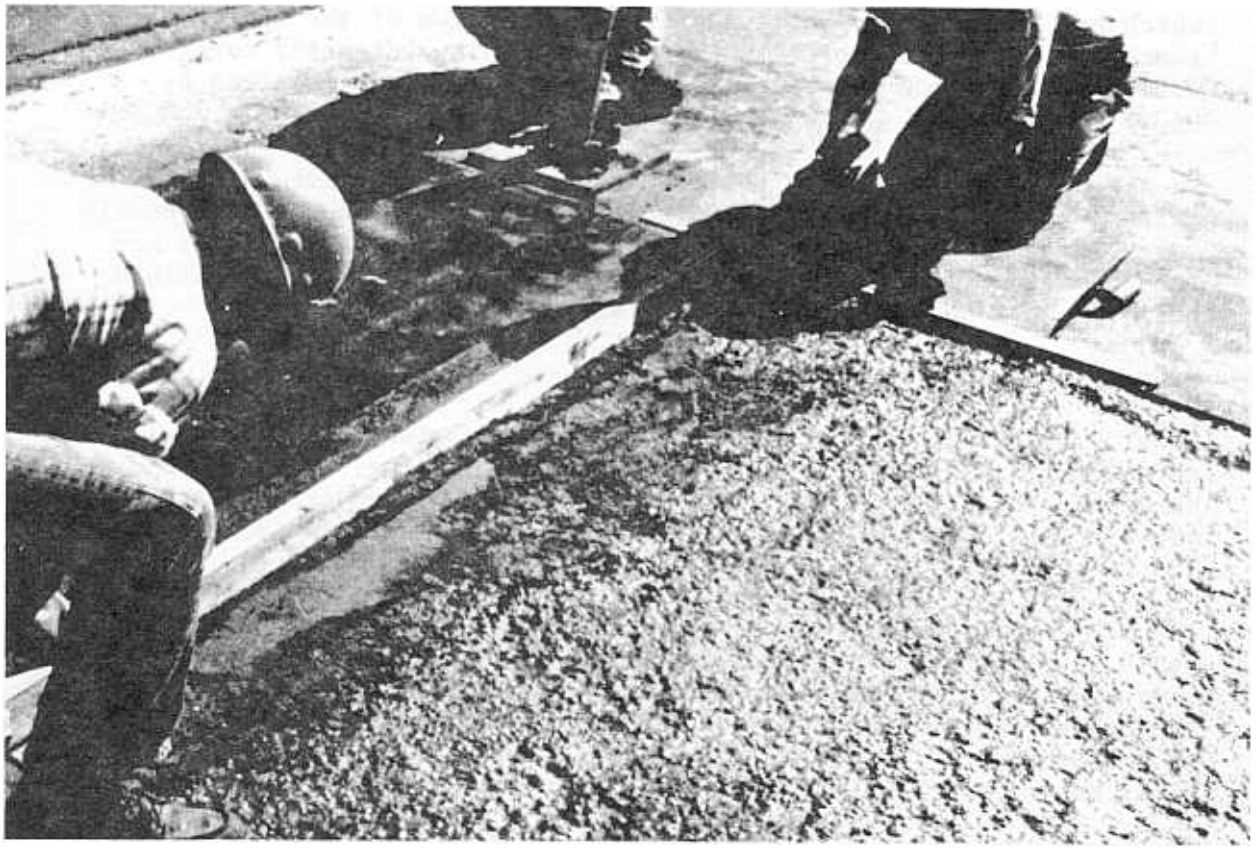


Figure 19. - Epoxy mortar is being screeded over the freshly placed epoxy bond coat on the concrete surface. Note the milky appearance of the epoxy resin bond coat, which is caused by the presence of water on the concrete surface.

One-month Inspection

About 1 month after the repairs had been completed, they were inspected. The appearance of the PC had not changed. The Sinmast mortar was pattern cracked over the entire surface as shown in figure 21. The Probond and Sika mortars appeared to be free from significant surface cracking. Cores were extracted during the 1-month inspection to evaluate the epoxy mortar and PC overlays, epoxy injection repair, and to determine the depth of monomer impregnation. NX-size cores were extracted from all three epoxy overlays and from the PC overlay.

Several of the NX cores were drilled through the surface bubbles which had appeared as previously described in two of the epoxy overlays immediately after troweling. Also, 75-mm (3-in.) diameter cores were extracted from the concrete containing the crack repaired by epoxy injection.

In all but one core, which was extracted from badly cracked epoxy mortar, the overlays were bonded well enough to the concrete to enable core extraction without disbonding at the concrete-overlay interface. The "bubbles" found in two of the epoxy mortars had a poorly defined hollow center apparently created by expanding gas.

Nine-month Inspection

About 9 months after the repairs had been completed, the PC and all three epoxy mortar overlays were checked for bonding, cracking, and hardness. During that 9 months, the repairs had been exposed to the winter cycle, and water had been flowing about 1 week in the spillway due to the onset of spring runoff.

The vinyl ester PC overlay appeared to be in good condition. Some small hairline pattern cracks were observed on the overlay. These were similar to those observed when the overlay was first installed. The cracks are more prominent along the southern and northern portions of the overlay. The cracks do not present a serious problem at this time, but should be closely observed over the next few years.

The overlay was tapped with a hammer to locate hollow-sounding, loose, or poorly bonded areas. Two small poorly bonded areas were detected: one area was 250 mm (10 in.) in from the downstream edge of the overlay and 3.3 m (10 ft 10 in.) from the south edge; the other was 230 mm (9 in.) in from the upstream edge and 4.0 m (13 ft 3 in.) from the south edge. The loose areas appeared to be roughly 250 mm (10 in.) in diameter. The loose area on the upper edge was chipped

out. The cause for the loose areas is possibly deteriorated concrete immediately below the overlay, but may be related to a very thin overlay thickness less than 6 mm (1/4 in.) and unsatisfactory mixing equipment used to prepare the PC. A crack located 300 mm (12 in.) north of the chipped out area was left intact for continued observation.

The loose areas were in the part of the spillway not surface impregnated. The remainder of the PC overlay over the area not surface impregnated and the entire PC overlay over the surface impregnated area appeared sound and well-bonded to the concrete. Therefore, it appeared that there may be a definite benefit from surface impregnation in providing good bond and perhaps in strengthening weak areas of the concrete.

An area treated by surface-impregnation only and an area treated by application of vinyl ester monomer system only appeared to be in good condition. These areas were wet, and cracking could not be observed.

The three epoxy mortar overlays were checked for bonding, cracking, and hardness.

Bonding

A geologist's hammer was used to locate drummy sounding areas. Both the mortar made with Probond epoxy and the mortar made with Sika epoxy were sound (not drummy) over about 98 percent of the area. Each contained isolated drummy spots of very small area [less than 0.1 m^2 (1 ft^2)]. On the downstream edge of the Probond overlay, 2.4 m (92 in.) from the edge of the overlay nearest the wall, a small drummy area was probed with a geologist's hammer. Mortar in this area had been applied in two layers, the second layer being placed soon after the first. As the first layer was assumed to be still plastic when the second layer was placed, a bond coat was not used between the first and the second layer of mortar, but these two layers had disbonded. Removal of the lower layer of mortar revealed failure in the concrete rather than disbonding at the bond coat.

The Sinmast epoxy mortar overlay was drummy over much of its area. While drummy areas appeared to be randomly located on the other two overlays, drummy areas found on the Sinmast mortar overlay were more prevalent over the nonimpregnated concrete. Sinmast mortar that had been applied over dry, impregnated concrete was sound, while Sinmast mortar applied over wet, impregnated concrete was drummy in several small areas. Over the moist, nonimpregnated concrete, about 70 percent of the Sinmast mortar was drummy, while about 25 percent was drummy where applied over the dry nonimpregnated concrete. A small piece

Discussion of Experimental Repair Failures

1. Epoxy injection. - The epoxy injection resin failed to fill the finest portion of the crack in the spillway floor. Cracks of this width [about 0.2 mm (0.008 in.)] have been successfully injected in the past. Injection pressure used at Shadow Mountain [350 kPa (50 lb/in^2)] should have been sufficient to inject a crack of this width. Cores taken after injection, however, revealed that the crack was not filled with epoxy. It is likely that during the drilling of holes for installation of injection nipples, dust from the drilling operation sealed the crack at the injection points.

2. Blistering of epoxy mortars. - Bubbles which formed after troweling the two slower-setting epoxy mortars were apparently the result of the expansion of entrapped air. As the Bureau has experienced similar blisters caused by high temperature curing prior to sufficient set of mortar, it is likely that the temperature rise brought about by the sun's radiation on freshly repaired surface caused the swelling of entrapped air in concrete just below the epoxy-concrete interface of air entrapped in the epoxy mortar mix. The temperature of one of the overlays within several hours after placement was found to be rather high at about 48°C (118°F). As troweling had effectively sealed the surface of the mortar, there would have been no means of escape for expanding gas.

CONCLUSIONS

The described method of installing nipples for injecting epoxy resin was inadequate for the narrow portion of the crack on the spillway floor. Future procedure for injection into narrow cracks should provide a means of preparation which does not inadvertently plug the crack and which exposes a sufficient length of crack to allow for a reasonably rapid injection rate.

The PC overlay appeared to have performed adequately for the 9-month period. Poor control of the mixing procedure is believed responsible for the surface cracks.

The epoxy overlays which were applied to damp concrete seemed to be as well bonded as those applied to dry concrete. Small pieces of mortar removed during the 9-month inspection indicate that areas where the mortar was drummy were caused by failure in the underlying concrete, not in the epoxy bond coat.

Sunshades and other methods should be used as needed to control blistering of fresh epoxy mortar.

GPO 847-064

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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.

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