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CONCRETE REPAIR MATERIALS— A PROGRESS REPORT

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16. ABSTRACT

The Bureau of Reclamation's investigations of concrete repair materials were divided into four tasks or phases: (I) epoxy injection study, (II) screening of repair materials for concrete repair, (III) comprehensive laboratory testing and development of testing methods, and (IV) field testing. Three epoxy resins were injected into cracked or sawed concrete specimens to study the resin's effectiveness at various temperatures and moisture conditions. Repair materials were screened for concrete repair, and promising materials were then selected for further testing. Both the epoxy concretes and polymer concretes had higher strengths than portland cement concrete, but may develop problems when used as concrete repair materials due to thermal incompatibility when there are large temperature gradients. The acrylic and latex emulsions had strengths in the range of portland cement concrete, but their freezing and thawing resistance was less than that of good air-entrained portland cement concrete.

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

SI METRIC

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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

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INTRODUCTION

The Bureau of Reclamation has many concrete structures which are subject to deterioration from abrasion, erosion, freezing and thawing, chemical attack, or a combination of these agents. Materials which will resist these types of deterioration are needed to repair such structures. There are many new materials that can be applied satisfactorily under dry, warm conditions, but few can be applied satisfactorily under the cold, wet conditions often present on Bureau water-conveyance systems needing such repairs.

The research program, DR-380, Concrete Repair Materials, was divided into four phases:

Phase I – Study of epoxy injection materials
Phase II – Initial laboratory screening of repair materials
Phase III – Comprehensive laboratory testing of promising materials and development of test methods
Phase IV – Field trial application of repair materials that perform well in laboratory tests

This report describes the progress made, from January 1979 to June 1983, in evaluating commercial products for repairing concrete.

The repair systems currently used by the Bureau are generally satisfactory, but they require expert workmanship, extensive surface preparations, and can be very expensive. The proven performance of adequate repair systems that are less expensive and require less preparation and expertise will be a great benefit to the Bureau and the construction industry. Moreover, test methods developed to evaluate materials in this program can be used to evaluate new materials proposed for use on future Bureau projects. There are many repair materials which the manufacturers claim are adequate for concrete repair in wet and cold environments. Also, there are many repair products that require less-skilled workers and less preparation than those presently endorsed by the Bureau.

Three epoxy resins were injected into cracked or sawed concrete specimens to study the resin's effectiveness under warm and cold and dry and wet conditions. Repair materials were screened for their effectiveness in concrete repair, and then promising materials were selected for further tests. The products tested were grouped into the following categories:

(1) Epoxy injection materials to repair cracked structural concrete
(2) Latex or epoxy modifiers for portland cement concrete and mortar for patching
(3) Latex and epoxy systems for bonding new concrete or mortar to old concrete

(4) Latex, epoxy, and polymer-based concretes and mortars that are prepackaged for patching concrete
(5) Inorganic emulsions for modifying concrete and mortar

The Corps of Engineers' WES (Waterways Experiment Station) abrasion-erosion procedure [1,2],[1] and ASTM C 779-82, procedure A, Abrasion Resistance of Horizontal Concrete Surfaces, were used to measure the abrasion-erosion resistance of repair materials. The repair materials were evaluated also for bond strength to assure that a repair would not disbond. A hydraulic jack pullout test device was adapted for use as a method to evaluate the bond of a repair material and/or the soundness of the old concrete [3]. The results of these tests were compared with shear bond test results to verify the usefulness of this method.

CONCLUSIONS

Epoxy Injection Materials

Three injectable epoxy resins were tested at various application temperatures and moisture conditions. Two of the epoxies were labeled for use on cold, moist concrete and the other epoxy was a general purpose epoxy adhesive. Each of these epoxies bonded poorly when injected into cracked concrete in a cold environment (−12 °C). However, in a cool environment (4 °C), the epoxies bonded as well as they did in a warm environment (21 °C), provided the curing time was extended. These epoxies appear suitable for use on Bureau construction under dry and warm to cool conditions using the extended curing times.

All three resins lost bond strength when applied to wet surfaces. The resins lost about 30 percent of their bond strength; the general purpose epoxy lost slightly more than the two other resin systems. These epoxies do not appear to be as good as the Bureau would like for construction.

Repair Materials

Thirty concrete repair materials were exposed to continual wetting and outdoor exposures. These materials included acrylic and latex emulsions, epoxy and polymer concretes, and special additives or concretes. Eighteen of these materials showed satisfactory performances, therefore, compre-

[1] Numbers in brackets refer to the bibliography.

hensive tests were performed on them. These tests included: (1) compressive tests, (2) tensile tests, (3) bond tests, (4) abrasion-erosion tests, and (5) thermal tests.

Compressive tests showed relatively high strengths for most epoxy and polymer concretes (45 to 74 MPa). Acrylic and latex emulsions showed good compressive strengths (22 to 46 MPa). All tensile strengths and bond tests indicated similar strengths for the materials tested. Pullout tests reflected the strengths of the portland cement concrete slabs to which the overlay was bonded.

Three epoxy concretes showed better abrasion resistance than the portland cement concrete control. An epoxy system, which is furnished with sand, showed poor abrasion resistance. The acrylic and latex emulsions showed slightly better abrasion resistance than the portland cement control.

Coefficients of thermal expansion for the epoxy and polymer concretes ranged from 15×10^{-6} (m/m)/°C to 33×10^{-6} (m/m)/°C, contrasted with 7×10^{-6} (m/m)/°C[2] for portland cement concrete. Epoxy and polymer concretes are not thermally compatible in repairing large surface area sections of concrete that are exposed to a wide range of temperatures. On the other hand, acrylic and latex concretes showed better thermal compatibility with coefficients ranging from about 7 to 9 $\times 10^{-6}$ (m/m)/°C.

Freezing and thawing tests had mixed results for epoxy and polymer concretes. All materials except for one epoxy showed a loss in compressive strength after 2000 cycles of freezing and thawing. The one epoxy had a loss of about 2 percent as contrasted with 28 to 70 percent for the other epoxy and polymer concretes.

Two of the acrylic and latex emulsions, that had not deteriorated too much to test after 2000 cycles of freezing and thawing, had a significant compressive strength loss.

DISCUSSION OF RESULTS

PHASE I – Epoxy Injection Study

Three epoxy resins were tested as injectable adhesives for repairing cracked structural concrete. The resins were injected into cracked concrete specimens at various application temperatures

[2] Average coefficient of thermal expansion for portland cement concrete calculated from [4, 5, 6, 7, and 8].

(−12 °C, 4 °C, 22 °C, and 38 °C) under both wet and dry conditions. The specimens were tested after the epoxy had sufficient time to cure.

The Sinmast and Sika epoxies are labeled for use on moist, cold concrete. The third epoxy, Hunt HB-151, is a general purpose epoxy adhesive binder. At this time, the Bureau requires that concrete repairs with epoxy injection be dry and warm (above 16 °C). The program consisted of flexural tests on 150- by 150- by 510-mm beams that had been cracked in flexural load or sawed through the center and subsequently injected with epoxy resin. The results are shown on figures 1, 2, and 3, and in table 1.

A summary of results from this phase follows:

(1) All of the epoxies exhibited significant loss of bond strength when applied and cured at −12 °C. The least viscous material (Sinmast injection resin) gave the most consistent results, probably because it wet the concrete surfaces and filled voids (displaced air bubbles) better than the other two epoxies.

(2) All of the epoxies exhibited loss of bond strength when applied to wet concrete surfaces. This loss of strength was the same (about 30 percent) for all three products on wet, cracked surfaces, but was quite variable for wet, sawed surfaces, probably because the sawed surfaces were smoother. The Sika epoxy attained as much strength on the wet, sawed surfaces as it did on the wet, cracked surfaces.

(3) Although the curing time must be increased when an epoxy is applied in a cooler environment, the final strength of an epoxy and its bond apparently did not show a decrease when applied at 4 °C. This observation directly contradicts present Bureau policy for concrete repair. (This conclusion may not be valid for concrete with higher strength than that used in this study.)

(4) The general purpose epoxy adhesive binder (Hunt HB-151) performed almost as well as the two epoxies labeled for use in cold environments.

(5) The general purpose epoxy adhesive binder was inferior for use in moist environments.

Phase II – Initial Laboratory Screening of Repair Materials

The initial laboratory screening test consisted of placing repair materials as overlays on concrete base slabs, and then observing the performance of the overlays over a period of time. Each repair material was placed as an overlay of a uniform, nominal 40-mm thickness, and as an overlay tapering from 40-mm thick on one side to a featheredge on the opposite side. The overlays were placed on concrete slabs that were approximately 0.9- by 1.2- by 0.15-m thick, which were subsequently cut into 0.9- by 0.3-m sized specimens for testing.

One specimen of each repair material was placed in outdoor exposure and a comparison specimen was placed in a continual fog room exposure at 23 °C. The specimens were inspected for bond and soundness and then placed in the outdoor and continual wetting exposures, where periodic inspections were made. Table 2 gives the mix designs for the repair materials and table 3 summarizes the performance of these materials. Questions arose on the performance and the identification of certain materials, and eight were selected for reevaluation. Table 4 summarizes the results of the second series of screening tests, which included the performance of the materials selected for reevaluation and several new materials.

Phase III – Comprehensive Laboratory Testing and Development of Testing Methods

The repair materials selected from the screening tests are shown in table 5, and a summary of their performance is shown in table 6. The following tests were selected for use in evaluating these materials:

- *Compressive tests*
  - Compressive strength
  - Modulus of elasticity
  - Poisson's ratio
- *Tensile tests*
  - Direct tensile tests
    - Direct tensile strength
    - Modulus of elasticity
    - Poisson's ratio
  - Tensile splitting strength
- *Bond tests*
  - Shear bond strength
  - Tension test
- *Double shear test*
- *Abrasion-erosion tests*
- *Thermal tests*
  - Coefficient of thermal expansion
- *Freezing and thawing tests*

Cylinders, overlay slabs, and slab specimens were cast in accordance with ASTM and manufacturer's recommendations for the various tests. Mix designs for the various materials are shown in table 7.

Compressive tests. – Compressive strength testing was performed on 150- by 300-mm cylinders in accordance with ASTM C 39-81, and modulus of elasticity was determined in accordance with ASTM C 469-65, using a frame and dial gauge. General epoxy concretes showed the highest compressive strength, followed by polymer concretes, then acrylic and latex emulsions. A complete summary of the compressive strength data is shown in table 8. It should be noted that the compressive strength and modulus of elasticity values obtained are somewhat dependent on mix proportions.

The epoxy concretes showed compressive strengths approximately twice that of previously tested portland cement concrete (55 versus 27 MPa).[3] Three epoxy concretes, Probond, Flexocrete, and Flexocrete III had moduli of elasticity about half that of portland cement mortar (11.70, 11.80, and 13.93 GPa, respectively, versus 26.8 GPa). Hultscrete, which had a relatively low compressive strength (32.7 MPa), also had a very low modulus of elasticity (3.93 GPa).

The polymer concretes were divided into two groups: (1) prepackaged MMA (methyl methacrylate) based, and (2) MMA-based monomer systems. The three prepackaged MMA-based polymer concretes (Concresive, Crylcon, and Silikal) had similar compressive strengths (44.9, 58.8 and 54.2 MPa) respectively; these were higher than that of previously tested portland cement concrete (27 MPa)[3]. Their moduli of elasticity (18.40, 24.40, and 21.80 GPa) were near that of the portland cement concrete (26.8 GPa). The two MMA-based monomer system polymer concretes (Degadur 330 and Degadur 410) varied widely in compressive properties. Degadur 410 had a high strength (45.1 MPa) and modulus of elasticity (9.31 GPa), while Degadur 330 had a low strength (18.8 MPa) and modulus of elasticity (1.31 GPa).

The acrylic and latex emulsions had compressive properties similar to those of the portland cement concrete. The compressive strengths ranged from 21.6 MPa for Barnacle Milk (an acrylic emulsion) to 46.0 MPa for Set Acryl Set. The Barnacle Milk showed low compressive properties, whereas a portland cement mortar mix with the same cement content showed a higher compressive strength (35.3 MPa).

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[3]Average compressive strength of portland cement concrete calculated from [5, 6, and 7].

Tensile tests. – Tensile testing was performed on 75- by 150-mm cylinders. Two types of tensile tests were made: (1) direct tensile, USBR Procedure 4914 "Direct Tensile Strength, Static Modulus of Elasticity, and Poisson's Ratio of Cylindrical Concrete Specimens in Tension," and (2) tensile splitting, ASTM C 496-71. A summary of these data is shown in table 9. The trends shown in the tensile tests were generally the same as those shown in the compressive tests. The epoxy concretes had the highest tensile strengths, followed by polymer concretes, then the acrylic and latex emulsions. The direct tensile strengths were generally higher than the tensile splitting strengths. The direct tensile strengths of eight of the nine epoxy and polymer concretes tested ranged from 6.32 to 11.32 MPa, about two to three times higher than that of previously tested portland cement concrete (2.8 and 3.5 MPa)[4]. The acrylic and latex emulsions had strengths (3.89 to 5.29 MPa) that were slightly higher than that of the portland cement concrete, with the exception of Barnacle Milk, which had a strength of 2.26 MPa. Special additive concretes showed a wide range of results with direct tensile strengths of 0.30, 0.67, and 4.19 MPa and splitting tensile strengths of 2.92, 2.65, and 4.19 MPa.

Bond tests. – Bond strength tests were made by the shear bond method and by a tension test method. These tests were made on 51-mm cylinders or cores to indicate whether the repair material would fail in bond or delamination. A summary of the bond tests is shown in table 10.

The shear bond strength of the emulsions ranged from 3.36 MPa for Rhoplex to 5.35 MPa for Synthemul. The shear bond strength of the epoxy concretes ranged from 3.23 MPa for Flexocrete III to 5.20 MPa for Flexocrete. The three prepackaged polymer concretes had shear bond strengths of 5.0, 5.03, and 5.6 MPa, while the two MMA-based monomer system polymer concretes had 2.99 MPa (Degadur 330) and 4.76 MPa (Degadur 410).

Most of the repair materials had about the same tension test bond strengths. Most of the failures occurred in the concrete base slab and were not adhesion or material failures. Details of the tension test for bond strength and equipment are described in GR-83-14 [3]. The average tension test bond strength for the base slab was 3.96 MPa. The Barnacle Milk specimen was the only one to fail in the repair material and the only emulsion to fail in any way. Two epoxy concretes, Flexocrete III (3.47 MPa) and Hultscrete (2.91 MPa), had adhesion failures. Two polymer concretes, Concresive (2.94 MPa) and Silikal (3.51 MPa) also failed in adhesion. The lowest break in the concrete was 3.64 MPa for MMA-based monomer system polymer concrete, Degadur 330. Specialty-type materials, Set 45 and Ali/Cite, showed adhesion failure with tension test bond strengths of 2.61

[4]Average tensile strengths for portland cement concrete calculated from [5, 6, and 7].

and 2.39 MPa, respectively. A Nicklepoxy, the other special-additive concrete, had a strength of 4.19 MPa.

Double shear tests. – A double shear test was performed also on the materials. The double shear test is performed by supporting two ends of a specimen and shearing through the middle of the specimens. This test has the advantage of eliminating a possible bending movement that can be induced by the conventional single-shear test method (table 11).

Abrasion-erosion tests. – The methods used for testing abrasion and abrasion-erosion were ASTM C 779-82, procedure A, and the Corps of Engineers abrasion-test. For the ASTM C 779 tests, 300- by 300- by 50-mm slabs of the repair material were cast and cured in accordance with manufacturer's recommendations. Slabs for the Corp of Engineers' abrasion-erosion tests were 300-mm diameter by 100 mm thick.

Three epoxy concretes had good abrasion resistance. With wear depths of 0.13, 0.18, and 0.25 mm in 1 hour of testing, they showed about one-third the wear of the portland cement control (0.86 mm). The polymer concretes had between 0.24 and 0.48 mm abrasion. The acrylic and latex emulsions also had better abrasion resistance than the control, with abrasion depths varying from 0.48 to 0.69 mm.

Only a few materials were tested using the Corps of Engineers, WES abrasion-erosion test. (For complete details on the WES abrasion-erosion test, see Report GR-84-1 [1].) Two epoxy concretes – Probond and Flexocrete III – were tested and showed less than 0.01 percent mass loss in 72 hours. The three polymer concretes that were tested had the following mass losses in 72 hours: (1) Concresive, 0.84 percent; (2) Crylcon, 1.34 percent; and (3) Silikal, 1.24 percent. Two portland cement concretes had much larger mass losses of 7.00, and 9.07, percent, in only 48 hours. The WES tests showed that the epoxy and polymer concretes had much better abrasion-erosion resistance than the portland cement concrete. A summary of abrasion-erosion data is given in table 12.

Thermal tests. – Thermal tests were determination of the coefficient of thermal expansion. A summary of the data is shown in table 13.

The epoxy and polymer concretes showed high coefficients of thermal expansion ranging from 15.25×10^{-6}(m/m)/°C to 32.98×10^{-6}(m/m)°C, in contrast with that of the conventional portland cement concrete which is only 7.24×10^{-6}(m/m)°C. The acrylic and latex emulsions had values from 7.27×10^{-6}(m/m)/°C to 9.43×10^{-6}(m/m)/°C, slightly higher than that of the conventional concrete. Special concrete additives were in the same range as the emulsions. The coefficient of thermal expansion indicates that epoxy concretes are not compatible for the repair of concrete where a large temperature gradient is experienced. The polymer concretes also are not thermally compatible over large temperature gradients. However, the emulsions and special additives had good thermal compatibility.

Freeze-thaw tests. – The freezing and thawing test consists of immersing a 75- by 150-mm cylindrical specimen in water and subjecting the specimen to approximately 50 cycles of freezing and thawing per week. The specimens are evaluated on a mass loss basis.

Generally, specimens are considered to have failed the test with a mass loss of 25 percent or more at 500 cycles.

Many materials failed after 2000 plus cycles of freezing and thawing (table 13). The acrylic and latex emulsions usually lasted 2000 cycles; however, many were too deteriorated to be tested in compression to check strength loss. The Rhoplex and Dylex Latex had 6 and 8 percent mass losses respectively after 2000 plus cycles. Each had a high compressive strength loss – Rhoplex with 37 percent and Dylex latex with 32 percent. The epoxy and polymer concretes also had high compressive strength losses with the exception of Probond. Probond had a compressive strength loss of only 2 percent. The other epoxy and polymer concretes had from 24 to 70 percent compressive strength losses even though none showed a mass loss. A conventional non-air-entrained concrete had a 25-percent mass loss in 740 cycles. A 351-kg/m^3 FHWA (Federal Highway Administration) portland cement air-entrained mix had less than 2-percent mass loss in over 2000 cycles. Thus, repairs with air-entrained concrete may prove more resistant to freezing and thawing than most available concrete repair materials.

Phase IV – Field Tests

Five concrete repair materials have been used in trial repairs on four projects. These materials and projects are: (1) Concresive 2020 (polymer concrete) on Dille Diversion Dam; (2) Crylcon 7000 series (polymer concrete) on Milburn Dam spillway and Carter Lake Dam tunnel; and (3) Concresive 2020 (polymer concrete), Probond ET150G (epoxy concrete), Flexocrete III (epoxy concrete), and Probond 821B (epoxy-bonded concrete) on Green Mountain Dam spillway. These materials for the Green Mountain Dam field tests were selected to give a comparison of the performance of a commercial acrylic PC and two types of epoxy concretes with a conventional epoxy bonded concrete repair. The Probond ET150G epoxy meets Bureau specifications for a flexible polysulfide epoxy concrete. The Flexocrete III is another type of flexible epoxy. The Probond 821B is a general purpose epoxy which meets ASTM C 881 specifications for a type II, grade I, epoxy adhesive for bonding fresh concrete to hardened concrete.

Reports describing the selection and use of those repair materials are included in appendix A.

Table 1. – Flexural tests of bond strength at various temperatures and moisture conditions for repairs with injected epoxy.

Material	Cracked beams — Strengths, MPa					
	Temperature – dry				Temperature – wet	
	−12 °C	4 °C	22 °C	38 °C	4 °C	22 °C
Hunt HB-151	1.2	6.1	5.2	4.8	4.0	2.8
Sika HI-MOD LV	1.3	6.1	4.4	4.5	4.5	3.6
Sinmast	2.4	6.3	4.8	5.2	4.1	3.8

Material	Sawcut beams — Strengths, MPa					
	Temperature – dry				Temperature – wet	
	−12 °C	4 °C	22 °C	38 °C	4 °C	22 °C
Hunt HB-151	1.0	6.6	5.9	5.9	3.8	0.4
Sika HI-MOD LV	0.7	6.3	5.5	5.4	4.0	3.5
Sinmast	0.7	6.4	4.7	6.2	5.2	1.8

Table 2. – Mix design of repair materials.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	Ali/Cite	
9.5 to 19.0	Clear Creek aggregate	21.9
4.75 to 9.5	Clear Creek aggregate	21.9
2.36 to 4.75	Clear Creek sand	4.7
1.18 to 2.36	Clear Creek sand	4.8
0.60 to 1.18	Clear Creek sand	7.9
0.30 to 0.60	Clear Creek sand	7.9
0.15 to 0.30	Clear Creek sand	4.9
Pan	Clear Creek sand	1.6
	Ali/cite	*
	Water	8.1
	Portland cement	16.3

* Liquid added in the amount of 67.6 cc per 50 kg batch.

	Bondurment*	
Bondurment		80.0
Water		20.0

* Preblended mortar mix used for patching.

	Concresive 2020	
4.75 to 9.5	Clear Creek aggregate	28.5
2.36 to 4.75	Clear Creek sand	9.5
	Polymer powder	56.0
	Liquid polymer	6.0
	Cretamite A and Cretamite B*	
9.5 to 19.0	Clear Creek aggregate	20.9
4.75 to 9.5	Clear Creek aggregate	20.9
2.36 to 4.75	Clear Creek sand	5.0
1.18 to 2.36	Clear Creek sand	5.0
0.60 to 1.18	Clear Creek sand	8.3
0.30 to 0.60	Clear Creek sand	8.3
0.15 to 0.30	Clear Creek sand	5.0
Pan	Clear Creek sand	1.7
	AP-303 admixture	3.9
	Water	3.9
	Portland cement, type III	17.2

* Cretamite B was a shotcrete application.

Table 2. – Mix design of repair materials. – Continued

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	Dow Saran	
9.5 to 19.0	Clear Creek aggregate	19.1
4.75 to 9.5	Clear Creek aggregate	23.4
2.36 to 4.75	Clear Creek sand	5.0
1.18 to 2.36	Clear Creek sand	5.0
0.60 to 1.18	Clear Creek sand	8.4
0.30 to 0.60	Clear Creek sand	8.4
0.15 to 0.30	Clear Creek sand	5.0
Pan	Clear Creek sand	1.7
	Portland cement, type I	16.9
	Dow Saran	3.4
	Water	3.6
	Antifoam agent	0.05
	Dow 460	
9.5 to 19.0	Clear Creek aggregate	18.5
4.75 to 9.5	Clear Creek aggregate	15.1
2.36 to 4.75	Clear Creek sand	6.3
1.18 to 2.36	Clear Creek sand	6.3
0.60 to 1.18	Clear Creek sand	10.5
0.30 to 0.60	Clear Creek sand	10.5
0.15 to 0.30	Clear Creek sand	6.3
Pan	Clear Creek sand	2.1
	Water	2.2
	Dow 460	5.3
	Portland cement, type I	16.8
	Antifoam B	0.05
	Duracal*	
4.75 to 9.5	Clear Creek aggregate	30.3
2.36 to 4.75	Clear Creek aggregate	4.6
1.18 to 2.36	Clear Creek sand	4.6
0.60 to 1.18	Clear Creek sand	7.6
0.30 to 0.60	Clear Creek sand	7.6
0.15 to 0.30	Clear Creek sand	4.6
Pan	Clear Creek sand	1.5
	Water	8.9
	Duracal	30.3

* Temporary-type repair; expands while curing.

Table 2. – Mix design of repair materials – Continued.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	Dylex Latex	
9.5 to 19.0	Clear Creek aggregate	16.6
4.75 to 9.5	Clear Creek aggregate	16.7
2.36 to 4.75	Clear Creek sand	6.2
1.18 to 2.36	Clear Creek sand	6.2
0.60 to 1.18	Clear Creek sand	10.4
0.30 to 0.60	Clear Creek sand	10.4
0.15 to 0.30	Clear Creek sand	6.2
Pan	Clear Creek sand	2.1
	Water	3.8
	Portland cement, type I	16.8
	Latex emulsion	4.6
	Gemite	
0.60 to 1.18	Clear Creek sand	16.3
0.30 to 0.60	Clear Creek sand	16.3
0.15 to 0.30	Clear Creek sand	9.7
Pan	Clear Creek sand	1.8
	Gemite GT-11	12.5
	Portland cement, type I	31.2
	Water	12.2
	Hydroepoxy	
0.60 to 1.18	Clear Creek sand	24.1
0.30 to 0.60	Clear Creek sand	18.8
0.15 to 0.30	Clear Creek sand	14.1
Pan	Clear Creek sand	11.6
	Portland cement, type 1	8.4
	Epoxy, part A	11.5
	Epoxy, part B	11.5
	Probond ET150G (ebem)*	
0.60 to 1.18	Clear Creek sand	26.4
0.30 to 0.60	Clear Creek sand	19.6
0.15 to 0.30	Clear Creek sand	13.5
Pan	Clear Creek sand	25.5
	Probond, part A	10.0
	Probond, part B	5.0

* Epoxy-bonded epoxy mortar

Table 2. – Mix design of repair materials – Continued.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	Rhoplex E-330	
0.60 to 1.18	Clear Creek sand	27.1
0.30 to 0.60	Clear Creek sand	27.1
0.15 to 0.30	Clear Creek sand	5.7
Pan	Clear Creek sand	2.9
	Portland cement	24.6
	Water	5.2
	Acrylic emulsion	7.3
	Defoaming agent	0.04
	Set Acryl Set	
4.75 to 9.5	Clear Creek aggregate	33.7
2.36 to 4.75	Clear Creek sand	5.1
1.18 to 2.36	Clear Creek sand	5.1
0.60 to 1.18	Clear Creek sand	8.4
0.30 to 0.60	Clear Creek sand	8.4
0.15 to 0.30	Clear Creek sand	5.1
Pan	Clear Creek sand	1.7
	Water	3.3
	Portland cement	22.6
	Acrylic emulsion	6.6
	Set 45	
4.75 to 9.5	Clear Creek aggregate	31.5
	Water	5.2
	Magnesium phosphate and fine aggregate	63.3
	Sikatop 122	
Manufacturer batched system: cement, sand, aggregates		89.3
Liquid resin		10.7
	Silikal K17/K7	
4.75 to 9.5	Clear Creek aggregate	28.5
2.36 to 4.75	Clear Creek sand	9.5
	Polymer powder	56.0
	Liquid polymer	6.0

The following products are resins used only as bonding agents:
Brutem
Probond ET150G (ebc)*
Weldcrete

* Epoxy-bonded concrete

Table 3. – Summary of first series of screening tests.

Product name	Estimated percent of surface disbonding		Months in exposure	Performance rating
	Continual wetting	Outdoor exposure		
Ali/Cite	0	– –	24	OK
Bondurment	100	100	24	Failed
Brutem	0	0	24	OK
Concresive 2020	0	– –	9	OK
Cretamite A	0	0	24	OK
Cretamite B	100	35	24	Failed
Dow Saran	17	0	24	Fair
Dow 460	20	15	24	Poor
Duracal	100	75	24	Failed
Dylex Latex	5	5	24	OK
Gemite	20	40	24	Poor
Hydroepoxy	80	100	24	Failed
Probond (ebc)	0	10	24	OK
Probond (ebem)	5	30	24	Poor
Rhoplex E-330	0	15	24	Fair
Set Acryl Set	0	– –	24	OK
Set 45	5	0	24	OK
Sikatop 122	30	– –	24	Poor
Silikal K17/K7	– –	0	9	OK
Weldcrete	0	0	24	OK

Table 4. – Summary of second series of screening tests.

Product name	Estimated percent of surface disbonding: Continual wetting	Estimated percent of surface disbonding: Outdoor exposure	Months in exposure	Remarks or performance
Acrylic and Latex Emulsions				
Barnacle Milk	*	*		
Dylex Latex 1186**	0	0	23	OK
Rhoplex E-330**	10	20	23	Fair
Set Acryl Set**	0	5	23	Outdoor test shows disbonding on form edge
Synthemul	0	0	13	Outdoor test shows surface cracking
Tylac	0	0	13	OK
Epoxy Concretes				
Flexocrete	0	10	23	Outdoor test shows thermal delamination
Flexocrete III	0	0	13	OK
Hultscrete	0	0	13	Outdoor test shows thermal delamination
Probond ET150G (ebem)**	0	0	23	OK
Polymer Concretes				
Concresive 2020**	0	0	23	OK
Crylcon 7000	0	5	23	Possible edge disbonding
Degadur 330	0	0	13	OK
Degadur 410	0	25	13	Outdoor test shows thermal delamination
Silikal K17/K7**	0	0	23	Outdoor test shows pattern cracking
Special Materials				
Ali/cite**	0	0	23	Outdoor test shows weathering
Nicklepoxy	0	0	7	OK
Set 45**	0	0	23	Outdoor test shows weathering

* Specimen not in these tests
** Second evaluation

Table 5. – Repair materials selected for comprehensive tests.

Product name	Manufacturer	Type
Ali/Cite	Dry Pack It Company	Aluminum & copper sulphates
Barnacle Milk	North Coast Chemical Co., Inc.	Acrylic emulsion
Concresive 2020	Adhesive Engineering	MMA-based polymer concrete*
Crylcon 7000	DuPont, Inc.	MMA-based polymer concrete
Degadur 330	Degussa Corporation	PMA-based polymer concrete**
Degadur 410	Degussa Corporation	PMA-based polymer concrete
Dylex Latex 1186	Tex-Crete, Inc.	Polymer latex
Flexocrete	Dural International, Inc.	Flexible amino epoxy
Flexocrete III	Dural International, Inc.	Flexible amino epoxy
Hultscrete	The Hultscrete Co., Inc.	Amino epoxy
Nicklepoxy	Rocky Mountain Chemical Company	Epoxy emulsion
Probond ET150G	Protex Industries	Polysulfide epoxy
Rhoplex E-330	Rohm & Haas, Inc.	Acrylic emulsion
Set Acryl Set	Set Products, Inc.	Acrylic emulsion
Set 45	Set Products, Inc.	Magnesium phosphate concrete
Silikal K17/K7	Silikal Corporation	MMA-based polymer concrete
Synthemul	Reichhold Chemicals, Inc.	Acrylic emulsion
Tylac	Reichhold Chemicals, Inc.	Acrylic emulsion

* MMA – methyl methacrylate.
** PMA – polymethyl methacrylate.

Table 6. – Summary of repair material relative performance

Repair material	Compressive strength	Direct tensile strength	Splitting tensile strength	Pull-out strength	Shear bond strength	Double shear strength	Abrasion resistance	Coefficient of thermal expansion	Freeze-thaw durability	Continuous wetting exposure	Outdoor exposure
Acrylic and Latex Emulsions											
Barnacle Milk	P	P	P	Failed	G	P	[1]	E	Failed	[2]	[2]
Dylex Latex 1186	G	G	G	G	G	G	F[3]	E	F	G	G
Rhoplex E-330	G	G	G	G	G	G	F[3]	E	Failed	G	G
Set Acryl Set	G	G	G	G	G	G	F[3]	E	Failed	G	G
Synthemul	G	G	G	G	G	G	F[3]	E	Failed	G	F
Tylac	G	G	G	G	G	G	F[3]	E	Failed	G	G
Epoxy Concretes											
Flexocrete	E	E	E	G	E	E	E	F[4]	G[5]	E	P
Flexocrete III	E	E	E	F	E	E	E	F[4]	G[5]	E	E
Hultscrete	G	E	G	F	F	F	P	F[4]	F[5]	E	P
Probond ET150G	E	E	G	G	E	E	E	F[4]	E	E	E
Polymer Concretes											
Concresive 2020	E	E	E	F	G	G	E	F	G[5]	E	F
Crylcon 7000	E	E	E	G	G	G	E	F[4]	G[5]	E	F
Degadur 330	F	F	G	G	G	G	E	F[4]	F[5]	E	G
Degadur 410	E	E	E	G	G	G	E	F[4]	F[5]	E	P
Silikal K7/K17	E	E	G	G	G	G	E	F[4]	G[5]	E	F
Special Materials											
Ali/cite	G	P	G	F	G	G	F	E	Failed	G	G
Nicklepoxy	E	G	E	G	G	G	F[3]	G	Failed	[1]	[1]
Set 45	E	P	F	F	P	F	P	E	Failed	G	F

E is excellent, G is good, F is fair, and P is poor.
[1] Test not completed.
[2] Test not run.
[3] These materials were tested only with by ASTM C 779-82, procedure A.
[4] The coefficient is much higher than that of concrete, and will not be compatible for large repairs with large temperature fluctuations.
[5] Repair material showed a large compressive strength loss after 2000 plus cycles of freezing and thawing.

Table 7. – Mix design of concrete repair materials, comprehensive testing.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	ACRYLIC AND LATEX EMULSION	
	Barnacle Milk	
0.60 to 1.18	Clear Creek sand	27.1
0.30 to 0.60	Clear Creek sand	27.1
0.15 to 0.30	Clear Creek sand	5.7
Pan	Clear Creek sand	2.9
	Portland cement, type I	24.6
	Water	7.2
	Barnacle milk	5.4
	Dylex Latex 1186	
9.5 to 19.0	Clear Creek aggregate	16.6
4.75 to 9.5	Clear Creek aggregate	16.7
2.36 to 4.75	Clear Creek sand	6.2
1.18 to 2.36	Clear Creek sand	6.2
0.60 to 1.18	Clear Creek sand	10.4
0.30 to 0.60	Clear Creek sand	10.4
0.15 to 0.30	Clear Creek sand	6.2
Pan	Clear Creek sand	2.1
	Water	3.8
	Portland cement	16.8
	Latex emulsion	4.6
	Rhoplex E-330	
0.60 to 1.18	Clear Creek sand	27.1
0.30 to 0.60	Clear Creek sand	27.1
0.15 to 0.30	Clear Creek sand	5.7
Pan	Clear Creek sand	2.9
	Portland cement	24.6
	Water	5.2
	Acrylic emulsion	7.3
	Defoaming agent	0.04
	Set Acryl Set	
4.75 to 9.5	Clear Creek aggregate	33.7
2.36 to 4.75	Clear Creek sand	5.1
1.18 to 2.36	Clear Creek sand	5.1
0.60 to 1.18	Clear Creek sand	8.4
0.30 to 0.60	Clear Creek sand	8.4
0.15 to 0.30	Clear Creek sand	5.1
Pan	Clear Creek sand	1.7
	Water	3.3
	Portland cement	22.6
	Acrylic emulsion	6.6

Table 7. – Mix design of concrete repair materials, comprehensive testing – Continued.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	Synthemul	
4.75 to 9.5	Clear Creek aggregate	27.0
2.36 to 4.75	Clear Creek sand	5.8
1.18 to 2.36	Clear Creek sand	5.9
0.60 to 1.18	Clear Creek sand	9.7
0.30 to 0.60	Clear Creek sand	9.7
0.15 to 0.30	Clear Creek sand	6.0
Pan	Clear Creek sand	2.0
	Portland cement, type I	21.8
	Water	4.7
	Acrylic emulsion	7.2
	Antifoam agent	0.2
	Tylac	
4.75 to 9.5	Clear Creek aggregate	33.1
2.36 to 4.75	Clear Creek sand	6.0
1.18 to 2.36	Clear Creek sand	6.2
0.60 to 1.18	Clear Creek sand	10.3
0.30 to 0.60	Clear Creek sand	10.3
0.15 to 0.30	Clear Creek sand	6.4
Pan	Clear Creek sand	2.1
	Water	3.9
	Acrylic emulsion	5.2
	Portland cement, type I	16.5

Table 7. – Mix design of concrete repair materials, comprehensive testing – Continued.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	EPOXY CONCRETES	
	Flexocrete	
4.75 to 9.5	Clear Creek aggregate	24.9
2.36 to 4.75	Clear Creek sand	18.0
1.18 to 2.36	Clear Creek sand	13.7
0.60 to 1.18	Clear Creek sand	8.6
0.30 to 0.60	Clear Creek sand	6.0
0.15 to 0.30	Clear Creek sand	3.4
Pan	Clear Creek sand	11.1
	Resin system, part A	9.9
	Resin system, part B	4.4
	Flexocrete III	
4.75 to 9.5	Clear Creek aggregate	24.9
2.36 to 4.75	Clear Creek sand	18.0
1.18 to 2.36	Clear Creek sand	13.7
0.60 to 1.18	Clear Creek sand	8.6
0.30 to 0.60	Clear Creek sand	6.0
0.15 to 0.30	Clear Creek sand	3.4
Pan	Clear Creek sand	11.1
	Resin system, part A	9.9
	Resin system, part B	4.4
	Hultscrete	
Epoxy sands		82.1
Resin system, part A		12.8
Resin system, part B		5.1
	Probond ET150G (ebem)	
9.5 to 19.0	Clear Creek aggregate	23.3
4.75 to 9.5	Clear Creek aggregate	17.4
2.36 to 4.75	Clear Creek sand	12.6
1.18 to 2.36	Clear Creek sand	9.6
0.60 to 1.18	Clear Creek sand	6.0
0.30 to 0.60	Clear Creek sand	4.2
0.15 to 0.30	Clear Creek sand	2.4
Pan	Clear Creek sand	7.8
	Resin system, part A	11.0
	Resin system, part B	5.7

Table 7. – Mix design of concrete repair materials, comprehensive testing – Continued.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	POLYMER CONCRETES	
	Concresive 2020	
4.75 to 9.5	Clear Creek aggregate	28.5
2.36 to 4.75	Clear Creek sand	9.5
	Polymer powder	56.0
	Liquid polymer	6.0
	Crylcon 7000	
4.75 to 9.5	Clear Creek aggregate	28.3
2.36 to 4.75	Clear Creek sand	9.4
	Polymer powder	56.7
	Liquid polymer	5.6
	Degadur 330	
4.75 to 9.5	Clear Creek aggregate	30.9
2.36 to 4.75	Clear Creek sand	14.1
1.18 to 2.36	Clear Creek sand	10.8
0.60 to 1.18	Clear Creek sand	7.9
0.30 to 0.60	Clear Creek sand	6.2
	F-95 Ottawa sand	7.9
	Silica flour	10.3
	Liquid polymer	11.7
	Benzoyl peroxide	0.2
	Degadur 410	
4.75 to 9.5	Clear Creek aggregate	30.9
2.36 to 4.75	Clear Creek sand	14.1
1.18 to 2.36	Clear Creek sand	10.8
0.60 to 1.18	Clear Creek sand	7.9
0.30 to 0.60	Clear Creek sand	6.2
	F-95 Ottawa sand	7.9
	Silica flour	10.4
	Liquid polymer	11.6
	Benzoyl peroxide	0.2
	Silikal K17/K7	
4.75 to 9.5	Clear Creek aggregate	28.3
2.36 to 4.75	Clear Creek sand	9.4
	Polymer powder	56.7
	Liquid polymer	5.6

Table 7. – Mix design of concrete repair materials, comprehensive testing – Continued.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	SPECIAL MATERIALS	
	Ali/cite	
9.5 to 19.0	Clear Creek aggregate	21.9
4.75 to 9.5	Clear Creek aggregate	21.9
2.36 to 4.75	Clear Creek sand	4.7
1.18 to 2.36	Clear Creek sand	4.8
0.60 to 1.18	Clear Creek sand	7.9
0.30 to 0.60	Clear Creek sand	7.9
0.15 to 0.30	Clear Creek sand	4.9
Pan	Clear Creek sand	1.6
	Ali/cite*	–
	Water	8.1
	Portland cement	16.3

* Liquid added in amounts of 67.6 cc per 50-kg batch.

	Nicklepoxy	
4.75 to 9.5	Clear Creek aggregate	17.1
2.36 to 4.75	Clear Creek sand	7.7
1.18 to 2.36	Clear Creek sand	5.7
0.60 to 1.18	Clear Creek sand	12.3
0.30 to 0.60	Clear Creek sand	10.3
0.15 to 0.30	Clear Creek sand	10.3
Pan	Clear Creek sand	8.3
	Portland cement (type I)	19.4
	Water	5.1
	Epoxy, part A	3.3
	Epoxy, part B	0.5
	Set 45	
4.75 to 9.5	Clear Creek aggregate	31.5
	Water	5.2
	Magnesium phosphate and fine aggregate	63.3

Table 7. – Mix design of concrete repair materials, comprehensive testing – Continued.

Nominal size (U.S.A. standard series sieves) mm		Amount, percent
	PORTLAND CEMENT	
	Steam Cured Concrete	
9.5 to 19.0	Clear Creek aggregate	25.8
4.75 to 9.5	Clear Creek aggregate	17.2
2.36 to 4.75	Clear Creek sand	4.8
1.18 to 2.36	Clear Creek sand	4.8
0.60 to 1.18	Clear Creek sand	7.9
0.30 to 0.60	Clear Creek sand	7.6
0.15 to 0.30	Clear Creek sand	5.2
Pan	Clear Creek sand	1.4
	Portland cement	17.6
	Water	7.7
	Air entraining agent*	
	W/C = 0.44	

* 143 mL of air entraining agent for 132-kg mix.

	Mortar	
0.60 to 1.18	Clear Creek sand	27.3
0.30 to 0.60	Clear Creek sand	27.3
0.15 to 0.30	Clear Creek sand	5.8
Pan	Clear Creek sand	2.9
	Portland cement, type I	24.8
	Water	11.9
	Air entraining agent*	–

* 37 mL per 45-kg batch.

Table 8. – Compressive strength and elastic properties

Material	Compressive strength MPa	Modulus of elasticity GPa	Poisson's ratio
Acrylic and Latex Emulsion			
Barnacle Milk	21.6	12.62	0.20
Dylex Latex 1186	41.2	21.80	0.16
Rhoplex E-330	39.8	18.50	0.23
Set Acryl Set	46.0	24.80	0.26
Synthemul	37.7	21.20	0.21
Tylac	35.0	25.40	0.20
Epoxy Concretes			
Flexocrete	60.3	11.80	0.24
Flexocrete III	73.9	13.93	0.32
Hultscrete	32.7	3.93	0.35
Probond ET150G (ebem)	59.4	11.70	0.27
Polymer Concretes			
Concresive 2020	44.9	18.40	0.31
Crylcon 7000	58.8	24.40	0.19
Degadur 330	18.8	1.31	0.78
Degadur 410	45.1	9.31	0.37
Silikal K17/K7	54.2	21.80	0.27
Special Materials			
Ali/cite	40.1	24.50	0.15
Nicklepoxy	57.3	22.48	0.21
Set 45	59.9	39.50	0.16
Portland Cement Concrete			
Steam cured	25.0	26.2	0.23
Mortar	35.3	26.8	0.24

Table 9. – Tensile strength and elastic properties

Material	Direct tensile strength MPa	Tensile modulus of elasticity GPa	Poisson's ratio	Splitting tensile strength MPa
Acrylic and Latex Emulsions				
Barnacle Milk	2.26	12.6	0.21	1.70
Dylex Latex 1186	4.52	21.5	0.15	3.28
Rhoplex E-330	4.32	15.6	0.22	3.01
Set Acryl Set	5.29	29.0	0.20	3.45
Synthemul	3.89	23.6	0.21	3.13
Tylac	5.07	26.9	0.17	2.71
Epoxy Concretes				
Flexocrete	11.32	13.2	0.25	6.69
Flexocrete III	11.21	11.9	0.26	5.20
Hultscrete	7.17	7.6	0.32	4.87
Probond ET150G (ebem)	9.23	13.7	0.25	3.85
Polymer Concretes				
Concresive 2020	6.32	19.1	0.26	5.70
Crylcon 7000	8.31	24.6	0.26	5.37
Degadur 330	2.68	0.5	0.31	3.13
Degadur 410	6.64	10.1	0.34	5.39
Silikal K17/K7	7.08	10.3	0.19	3.85
Special Materials				
Ali/Cite	0.67	17.9	0.18	2.65
Nicklepoxy	4.19	26.2	0.22	4.19
Set 45	0.30	6.4	0.12	2.92

Table 10. – Bond tests.

Material	Shear bond strength MPa	Tension tests	
		Strength MPa	Failure location
Acrylic and Latex Emulsions			
Barnacle Milk	3.90	2.76	Material
Dylex Latex 1186	4.87	3.84	Concrete
Rhoplex E-330	3.36	4.04	Concrete
Set Acryl Set	4.69	4.16	Concrete
Synthemul	5.35	3.84	Concrete
Tylac	4.55	3.73	Concrete
Epoxy Concretes			
Flexocrete	5.20	3.80	Concrete
Flexocrete III	3.23	3.47	Adhesion
Hultscrete	3.73	2.91	Adhesion
Probond ET150G (ebem)	3.97	3.95	Concrete
Polymer Concretes			
Concresive 2020	5.03	2.94	Adhesion
Crylcon 7000	5.60	3.96	Concrete
Degadur 330	2.99	3.64	Concrete
Degadur 410	4.76	4.37	Concrete
Silikal K17/K7	5.00	3.51	Adhesion
Special Materials			
Ali/cite	4.80	2.39	Adhesion
Nicklepoxy	3.89	4.19	Concrete
Set 45	2.84	2.61	Adhesion

Table 11. – Double shear tests.

Material	Double shear bond strength MPa
Acrylic and Latex Emulsion	
Barnacle Milk	3.12
Dylex Latex 1186	7.89
Rhoplex E-330	7.83
Set Acryl Set	9.56
Synthemul	14.61
Tylac	13.85
Epoxy Concretes	
Flexocrete	16.89
Flexocrete III	25.16
Hultscrete	17.09
Probond ET150G (ebem)	16.00
Polymer Concretes	
Concresive 2020	12.02
Crylcon 7000	15.49
Degadur 330	11.16
Degadur 410	15.49
Silikal K17/K7	16.77
Special Materials	
Ali/cite	8.58
Nicklepoxy	10.83
Set 45	11.10

Table 12. – Abrasion-erosion tests.

Material	ASTM abrasion tests Depth of abrasion mm (in 1 hour)	WES abrasion-erosion tests Mass loss in percent (in 72 hours)
Acrylic and Latex Emulsions		
Barnacle Milk	*	*
Dylex Latex 1186	0.48	*
Rhoplex E-330	0.61	*
Set Acryl Set	0.69	*
Synthemul	0.53	*
Tylac	0.69	*
Epoxy Concretes		
Flexocrete	0.25	*
Flexocrete III	0.13	0
Hultscrete	1.02	*
Probond ET150G (ebem)	0.18	0
Polymer Concretes		
Concresive 2020	0.38	0.84
Crylcon 7000	0.43	1.34
Degadur 330	0.24	*
Degadur 410	0.48	*
Silikal K17/K7	0.24	1.24
Special Materials		
Ali/cite	0.79	*
Nicklepoxy	0.66	5.05
Set 45	0.48	*
Portland Cement Concrete		
Portland cement mix (Fog cure)	0.86	9.07**
Portland cement mix (Steam cure)	*	7.00**
Epoxy bonded Portland cement concrete***	*	11.33

* Test not run.
** Tests run only 48 hours.
*** WES abrasion-erosion mass loss at 48 hours was 6.94 percent.

Table 13. – Coefficient of thermal expansion, and freezing and thawing tests.

Material	Coefficient of thermal expansion 10^{-6}(m/m)/°C	Freeze-thaw cycles	Mass change in freeze-thaw %	Compressive strength loss after 2000 cycles, %
Acrylic and Latex Emulsions				
Barnacle Milk	7.27	In test 1500	−0.94	*
Dylex Latex 1186	7.63	2000 plus	−8.03	31.87
Rhoplex E-330	9.43	2000 plus	−6.46	36.86
Set Acryl Set	8.21	Failed in less than 800 cycles	– –	*
Synthemul	8.41	2000 plus	−20.80	*
Tylac	7.94	2000 plus	−17.66	*
Epoxy Concretes				
Flexocrete	24.35	2000 plus	+1.88	37.86
Flexocrete III	26.08	2000 plus	+1.11	70.37
Hultscrete	32.92	2000 plus	+3.12	44.04
Probond ET150G (ebem)	15.57	2000 plus	+1.50	1.91
Polymer Concretes				
Concresive 2020	16.47	2000 plus	+0.81	28.50
Crylcon 7000	15.25	2000 plus	+0.93	32.96
Degadur 330	32.98	2000 plus	+2.49	66.54
Degadur 410	31.36	2000 plus	+0.66	61.86
Silikal K17/K7	20.10	2000 plus	+0.66	24.25
Special Materials				
Ali/cite	6.89	Failed in less than 800 cycles	+25	*
Nicklepoxy	7.51	Failed in 1470 cycles	−11.43	*
Set 45	9.77	Failed in less than 800 cycles	+25	*
Control Concretes				
Conventional concrete	7.24	740	−25	*
Portland cement mix	*	2000 plus (still testing)	−1.74	**

* Specimen deteriorated too much to test in compression.
** Specimen still in freezing and thawing.

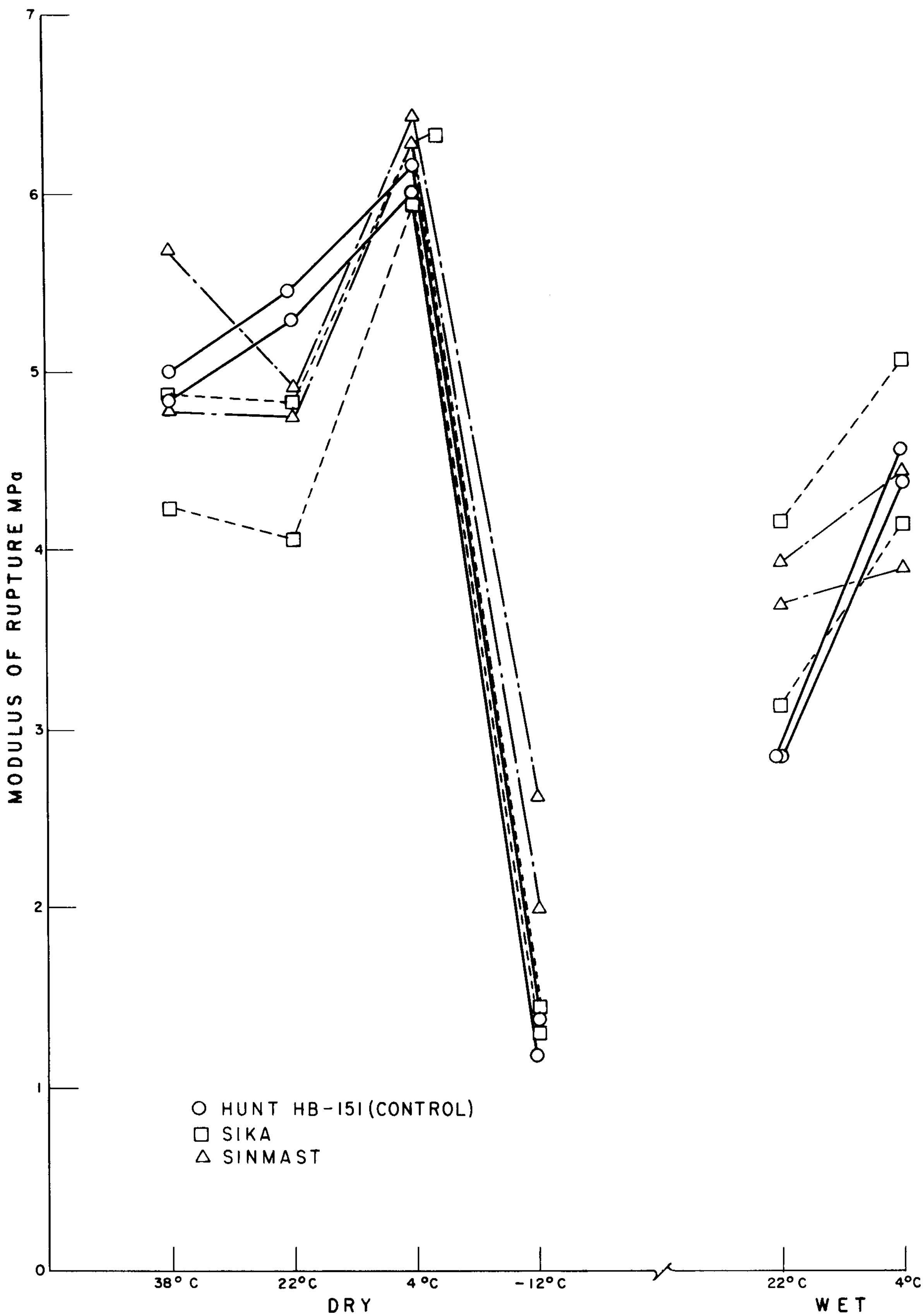

Figure 1. – Modulus of rupture of repaired beams (broken beams).

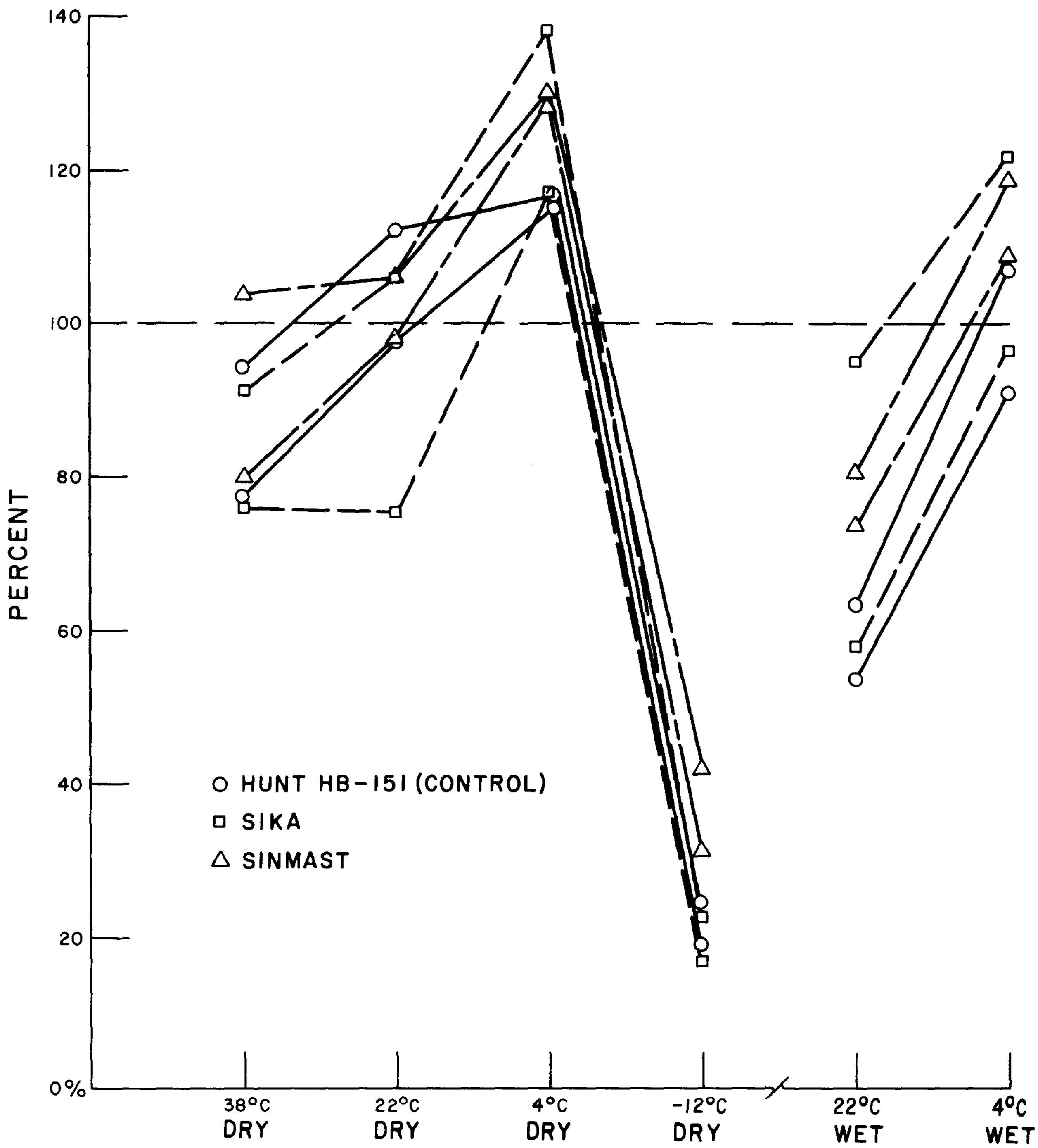

Figure 2. – Modulus of rupture of repaired beams as a percentage of the beam's original modulus of rupture.

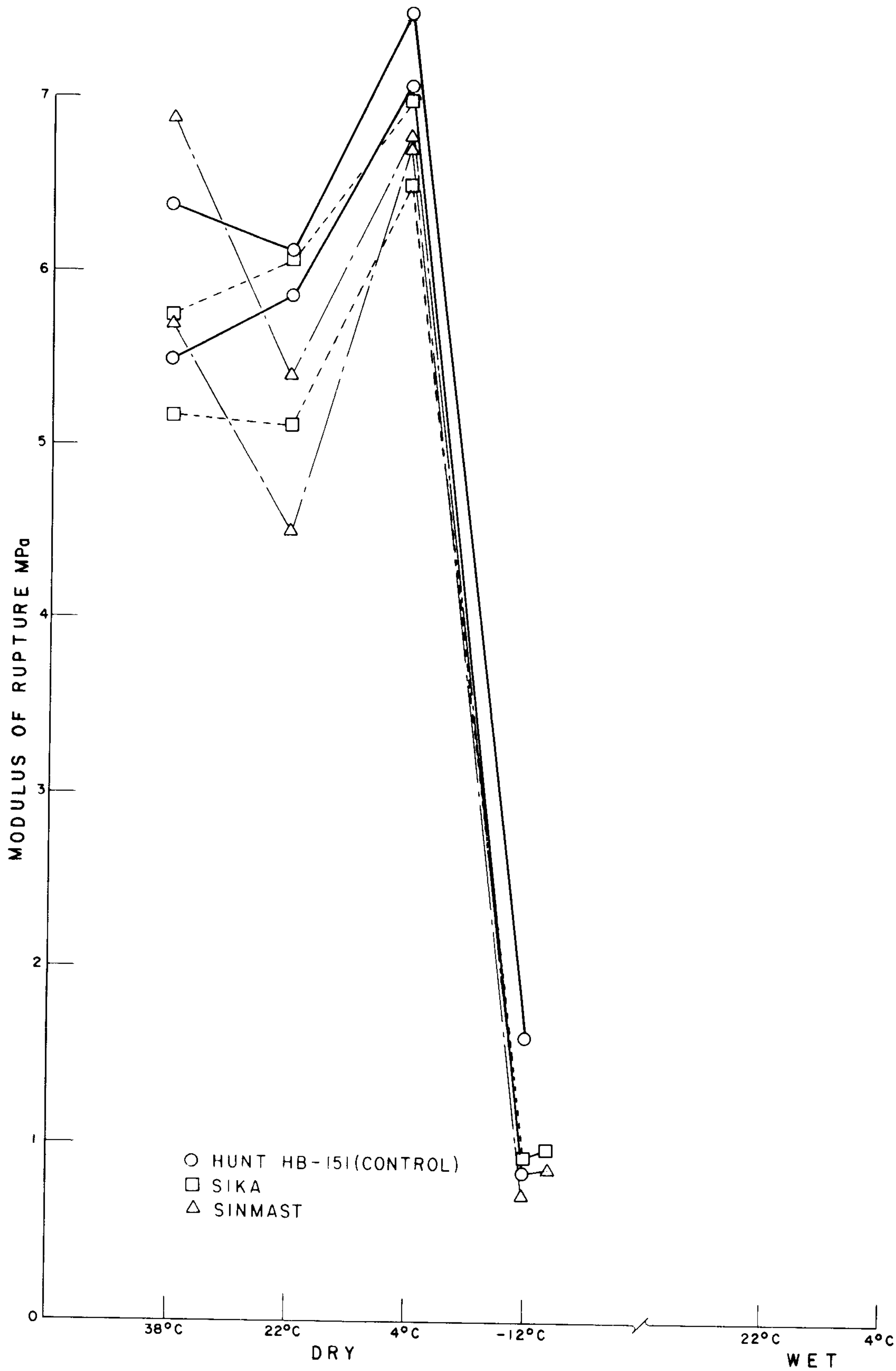

Figure 3. – Modulus of rupture of repaired beams (sawcut beams).

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APPENDIX A

REPORTS DESCRIBING THE SELECTION AND USE OF REPAIR MATERIALS

OPTIONAL FORM NO. 10 (O/P 4-65) 5010-107
MAY 1962 EDITION
GSA GEN. REG. NO. 27

UNITED STATES GOVERNMENT

Memorandum

Memorandum
Denver, Colorado

TO : Head, Polymer Concrete and Structural Section

DATE: January 21, 1981

THROUGH: Supervisor, Unit 2, Polymer Concrete and Structural Section 1-26-81

FROM : D. O. Arney

SUBJECT : Memorandum Report - Polymer Concrete Repair, Dille Diversion Dam, Colorado-Big Thompson Project

Loveland office O&M personnel and D. O. Arney, Co-principal Investigator for Concrete Repair research DR-380, inspected a deteriorated area of the Dille Diversion Dam, Colorado-Big Thompson Project, on November 14, 1980. Flood conditions had caused abrasion of the concrete under and along the radial gate sill and wall plates.

After this inspection, it was determined that a polymer concrete repair would be appropriate, I planned and conducted a trial test in the Polymer Laboratory to determine which commercially available repair material would be suitable. Concresive 2020 by Adhesive Engineering was chosen, and the repair was made on November 19, 1980.

Three hundred pounds of material was used for the repair, and three mixes were developed for the different depths of repair:

1. The more shallow areas of repair, upstream and behind the base of the wall plates, were repaired with a Concresive mix entended with No. 8 sand.

2. The sill plate and deeper downstream repairs (4 to 6 inches), were made with a mix extended with graded aggregate as follows:

Size	Percent
No. 8	18
No. 4-3/8	26
3/8 to 3/4 inch	56

This mix was firmly compacted into place, and the surface was trowel finished.

3. A regular Concresive 2020 mix, without extender sand, was used to bring the repair to existing grade and to featheredge to floor level.

In preparation for repair, unsound concrete was chipped away with a pneumatic hammer, and the surface was dried with hot forced air. The recommended concrete primer, Concresive 2042, was then scrubbed into the substrate and underneath the sill plate where necessary. Conditions for placing this repair were not ideal. Ice had to be chipped from the floor before the repair could begin, and the pump removing water from the leaking, temporary bulkhead continuously failed to operate.

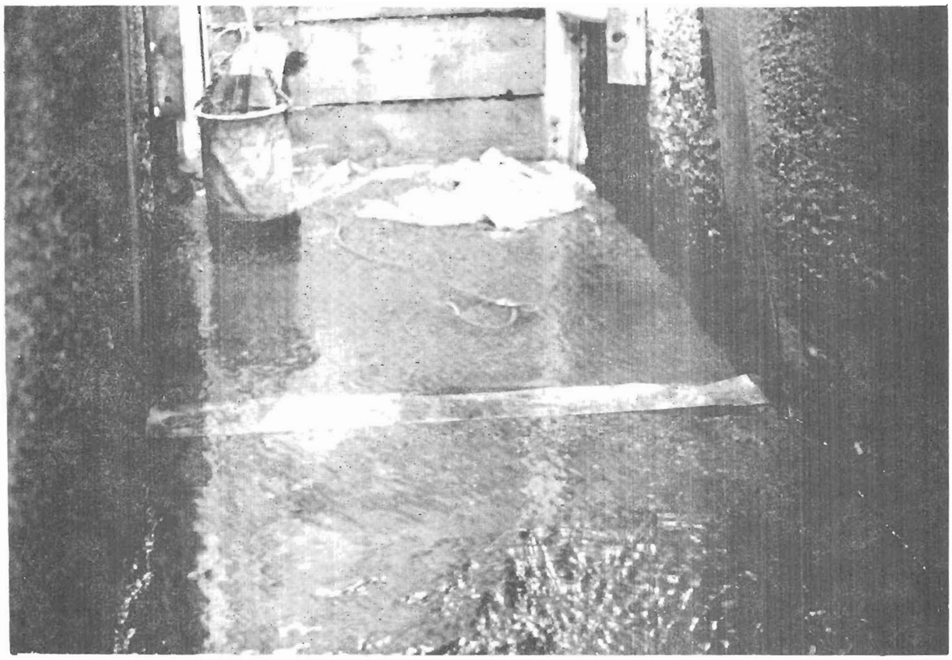
After the repair was finished, water seeped into a small area at one corner of the sill plate. The O&M foreman decided the following day to remove the small area that had gotten wet and to use conventional dry-pack concrete on that surface. The rest of the polymer concrete repair looked sound.

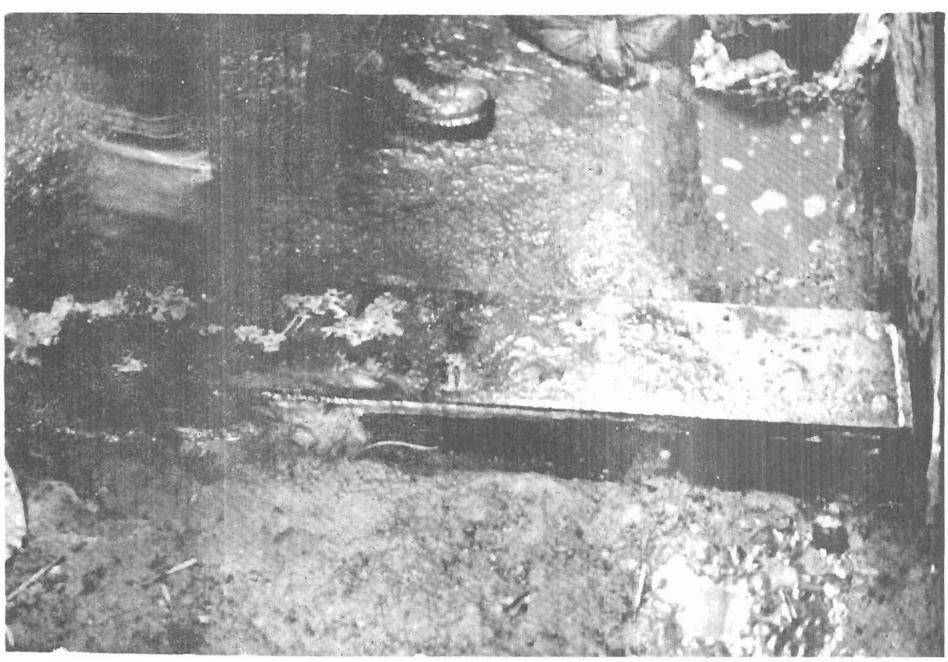
Other personnel involved in this repair were:

Zenas Blevins	Loveland O&M office
Bob Gibson and Crew	Loveland O&M office
Lowell Ploss	LM-430, Water O&M
Lowell Mellott	LM-210, General Engineering Branch

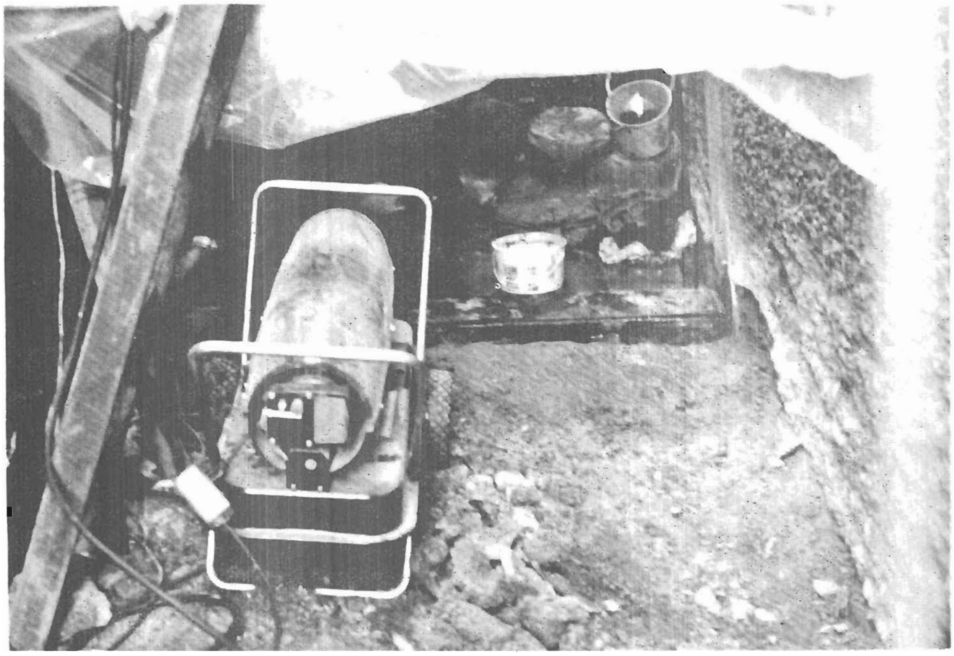
Dennis O. Armey

Copy to: Regional Director, Denver, Colorado, Attn: LM-210 and LM-430
Project Manager, Loveland, Colorado, Attn: S-400

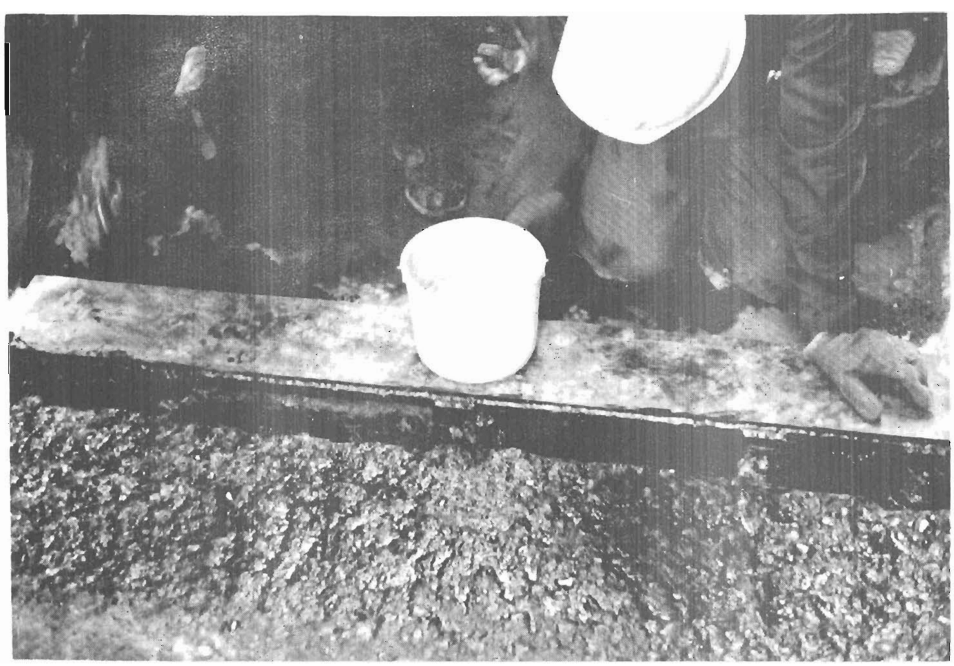




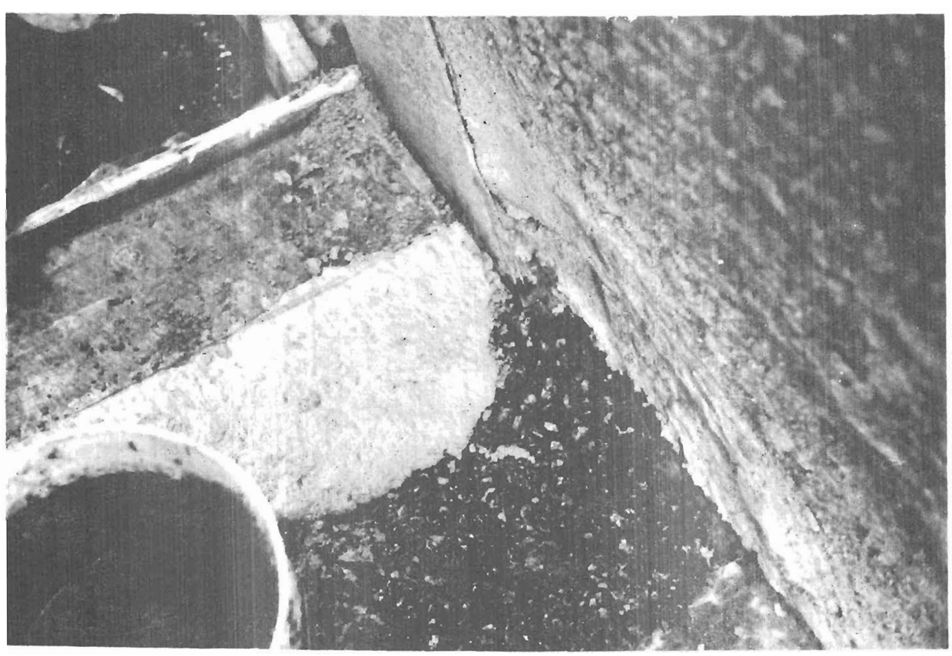
Condition of structure prior to repair.



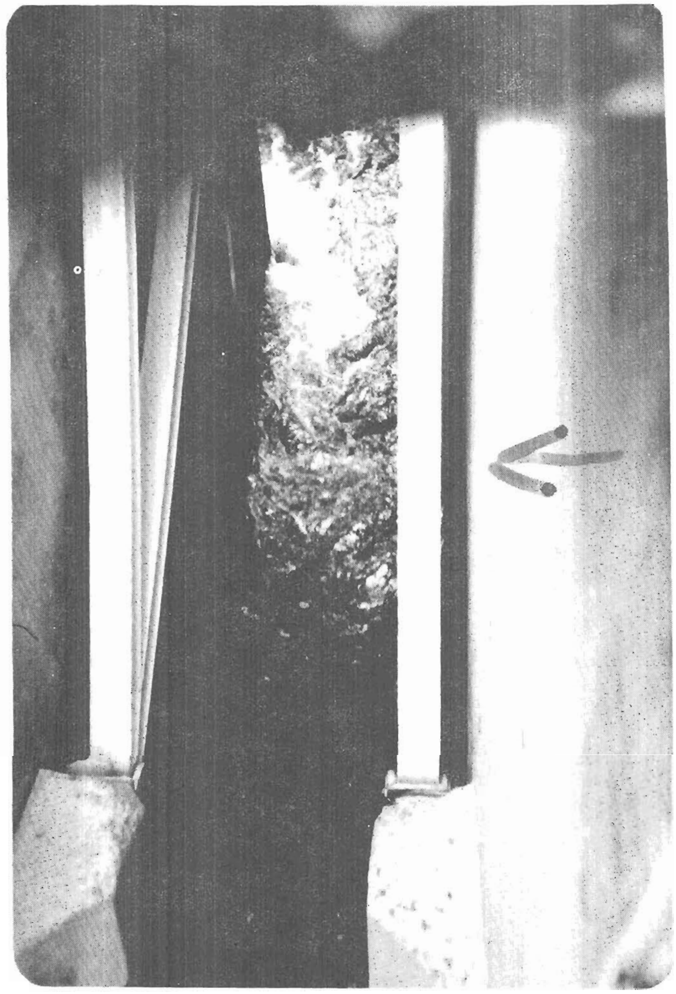
Forced air heater used for drying.

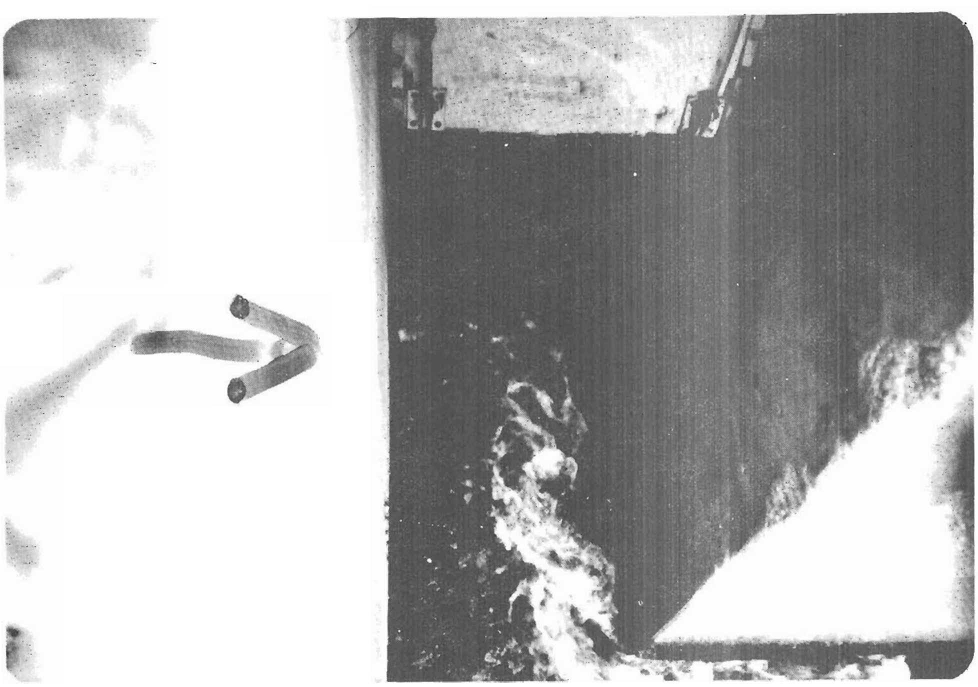


Bond coat being applied.



Polymer concrete mortar being applied downstream from sill plate.





Area of repair after structure
placed back in service January 2, 1981.

OPTIONAL FORM NO. 10 (O/P 4-65) 5010-107
MAY 1962 EDITION
GSA GEN. REG. NO. 27

UNITED STATES GOVERNMENT

Memorandum

Memorandum — Denver, Colorado

TO : Head, Polymer Concrete and Structural Section — DATE: March 10, 1982

THROUGH: Supervisor, Unit 2, Polymer Concrete and Structural Section

FROM : Dennis O. Arney and Fred E. Causey

SUBJECT : Repair of Carter Lake Outlet

Introduction

W. Frizell, L. Fink, G. W. DePuy, and T. J. Isbester of the Division of Research and Zenas Blevins of the Loveland Office inspected the Carter Lake outlet on January 8, 1982. See enclosed daily record for details of the inspection. The gates, downstream frames, and liners appeared to be in excellent condition considering the number of years the gates have been in operation. There was some cavitation damage just downstream from both liners. Some of the damaged areas were patched with epoxy materials about 10 years ago, and the damage had not progressed to a significant degree until this past irrigation season.

The right gate liner had a discontinuity in the alignment along the invert on the left side near the wall, and mild cavitation erosion had damaged the concrete downstream on the invert. This area had been previously patched with epoxy, and a glob of epoxy had been left in the lower corner just downstream of the frame. This glob provided a local offset in the flow and probably added to the damage to both the invert and sidewalls.

The left gate liner contained what appeared to be a warped section on the left wall which began about 2 inches above the floor and extended to about 15 inches above the floor. This warped portion extended inward toward the center of the flow passage and provided an offset at the junction of the liner and the concrete wall. The cavitation damage began at the end of the liner and extended downstream along the left wall about 8 feet.

Repair of Cavitated Areas

After some discussions between the Loveland Office personnel and Division of Research personnel, it was decided that the cavitated areas should be repaired. Two repair systems were selected for these repairs. A methyl methacrylate PC (polymer concrete) would be used down from the right gate; an epoxy mortar would be used down from the left gate.

Methyl Methacrylate PC Repairs

On February 17, 1982, Dennis Arney and Fred Causey traveled to Carter Lake to assist Loveland personnel with the repair of the right gate floor. The methyl methacrylate PC used in this repair was DuPont's Crylcon 7011-7020 system.

Loveland personnel had diverted the water and diked the right gate to dry the area for repair. All bad concrete had been chipped out, and the area to be repaired was sandblasted. Water was seeping through a joint in the area to be repaired. A space heater was used to dry the area just prior to repair. It was not used to cure the methyl methacrylate PC since there was a danger of igniting methyl methacrylate vapors. Crylcon 3049 primer for methyl methacrylate PC was used to prime the repair area just prior to patching. The repair systems used were as follows:

Deep Repair System

Aggregate System		Monomer	
Material	Amount	Material	Amount
No. 4 to 3/8-in Clear Creek	16.5 lb	Crylcon 7011	5 cups
Crylcon 7020 powder	16.5		
	33.0 lb		

Featheredge System

Aggregate System		Monomer	
Material	Amount	Material	Amount
Crylcon 7020 powder	16.5 lb	Crylcon 7011	4 cups

Four batches of the deep repair system were mixed and placed by the Loveland personnel. Upon completion of the deep repairs, a batch of the featheredge system was mixed and placed to complete repairs of the right gate invert.

Epoxy Repairs

On February 23, 1982, Causey assisted the Loveland personnel with repairs of left gate floor and wall. Sikadur Lo-Mod epoxy mortar system was used for these repairs. The epoxy resin was furnished by the Loveland office, and the graded sand was furnished by the Concrete Section of the Concrete and Structural Branch.

Loveland personnel had diverted the water to the right gate and diked up around the left gate to dry the area for repair. All bad concrete was chipped out, and the area to be repaired was sandblasted. Water seeped through a joint in a portion of the area to be repaired. A space heater was used to dry the repair area, but with water seeping in, some portions to be repaired were damp. The epoxy was mixed 2 parts of Sika component A (100 percent reactive epoxy resin) to 1 part of Sika component B (amine curing compound) by volume. About 2 quarts of the epoxy were mixed and brushed in for the bond coat for the epoxy mortar. The epoxy mortar consisted of 2-1/2 parts sand and 1 part epoxy by volume. About 2 gallons of mortar were mixed per batch. About 2 batches of mortar were used to repair the left gate floor and wall. A little over 2 gallons were used to repair the floor, and a little less than 2 gallons were used on the wall. A form covered with polyethylene was used to hold the epoxy mortar in place on the left wall.

A small area of the left wall which contained an eroded or cavitated area of less than 1-inch depth was repaired with M&T Chemical's Epibond 150. This is an epoxy putty which mixes in equal volumes of components A and B. The epoxy was troweled on with a wide blade (3-inch) putty knife. Curing of the epoxy mortar and epoxy occurred under damp, cool conditions. A small space heater added a little warmth to assist the curing.

Summary

All repairs went very smoothly as the Loveland personnel were knowledgeable in making preparations and making repairs. Thus, placement of methyl methacrylate PC and epoxy mortar only required a few hours of the day that each system was placed. Working space and damp conditions made repairing the cavitated areas difficult. Water seeping through joints in the repair areas and low temperature in the tunnel may cause portions of the methyl methacrylate PC and the epoxy mortar to be less durable than desired because of incomplete curing. All repairs appeared to be satisfactory.

Fred E Causey
Dennis O. Arney

Enclosure

Copy to: Regional Director, Denver, Colorado, Attention: LM-430
Projects Manager, South Platte River Projects Office, Loveland, Colorado, Attention: S-400

Blind to: D-1512 (Smoak)
D-1512 (DePuy)
D-1512 (Arney)
D-1533 (Isbester)

OPTIONAL FORM NO. 10
JULY 1973 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Denver, Colorado

DATE: January 18, 1982

TO : Chief, Division of Research

FROM : Chief, Hydraulics Branch

SUBJECT: Daily Record - Hydraulics Branch

January 8

Carter Lake Outlet Inspection (Isbester)

Frizell, Fink, DePuy, and Isbester were accompanied by Zenas Blevins of the Loveland Office on an inspection of the 3-ft by 3-ft outlets at Carter Lake. The gates and downstream frame and liner appeared to be in excellent shape considering the number of years the gates have been in operation. There is some cavitation damage to the concrete just downstream from both liners. Some of the damaged areas were patched with an epoxy material about 10 years ago, and the damage had not progressed to a significant degree until this past irrigation season.

The right gate liner had a discontinuity in the alignment along the invert on the left side near the wall. This discontinuity had produced mild cavitation erosion to the liner, with additional damage to the concrete downstream on the invert, and along the junction between the left wall and the invert. This area had been previously patched with epoxy, and a glob of epoxy had been left in the lower left corner just downstream of the frame. This glob provided a local offset into the flow and probably added to the damage to both the invert and sidewall downstream. The right concrete wall was offset away from the frame about 1/4 in near the bottom and faced to about 1/16 in near the top. The only cavitation damage on this wall was just downstream of the liner in two small areas and downstream of a small protruding stone about 16 in from the liner. This damage was very localized and essentially insignificant.

The left gate liner contained what appeared to be a warped section on the left wall which began about 2 in above the floor and extended to about 15 in above the floor. This warped portion extended inward toward the center of the flow passage and provided an offset at the junction of the liner and the concrete wall. The cavitation damage began at the end of the liner and extended downstream along the left wall about 8 ft. The invert of the left liner also contained a warped section along the middle 18 in of the flow passage, producing an offset away from the flow at the downstream end of the liner. The concrete damage on the invert extended downstream about 6 ft. On the right wall, the damage was confined to a small area about 6 to 8 in above the invert, about 4 to 6 in vertically and extended downstream about 12 in.

The downstream frames of both gates were in very good shape. There were areas just downstream of the gate slots where mild damage had occurred. The worst was on the right side of the left gate about 3 in above the invert. This damage extended vertically about 2 in, to a depth of 1/8 in and extended downstream about 1/4 in. This damage was just downstream of the bronze seat bar.

Both the liner and the downstream frame were shown to be gray iron in the specifications. The warped areas, however, had the appearance of expansion due to local heat from welding. The specifications drawings contain the statement, "These interior surfaces shall be smooth. Any sharp irregularities shall be ground or filled to form a straight surface with a maximum allowable deviation of 1/32 in from a true plane." The previously discussed surfaces are considerably in excess of this value. These warped surfaces will require grinding to eliminate the source of cavitation for the concrete downstream.

The general appearance of the concrete in the vicinity of the gates is quite rough. The fines have been eroded away leaving the rounded rock exposed. This roughness will require the application of an overlay to provide a smooth surface in the high velocity areas.

J. J. King

Copy to: D-1512 (DePuy)
D-1530
D-1531
D-1532
D-1533

BUREAU OF RECLAMATION
Engineering and Research Center
Denver, Colorado

Travel Report

Code : D-1512 Date: December 7, 1981

To : Chief, Division of Research

From : Dennis O. Arney

Subject: Application of Polymer Concrete Overlay at Milburn Dam

1. Travel period (dates): October 26 through 29, 1981.

2. Places or offices visited: Milburn Diversion Dam, Sargent Unit - Pick-Sloan Missouri Basin Program, Nebraska.

3. Purpose of trip (include reference to correspondence prompting travel): To supervise application of experimental polymer concrete repair materials at Milburn Dam. (Reference: Daily record dated August 21, 1981, from Chief, Concrete and Structural Branch, to Chief, Division of Research; and report of telephone call dated October 8, 1981, from Bill DePuy to Lowell Ploss.)

4. Synopsis of trip: Travel to Milburn Dam was made by Government automobile. Personnel contacted at the dam are listed in the appendix.

The PC (polymer concrete), duPont Crylcon 7020, was applied to the floor of the left sluiceway, on one chute block, and on one baffle block on the floor of the sluiceway immediately downstream of the chute block. The material was mixed at the site and placed by Loup Basin Reclamation District personnel on October 27 and 28. A representative from duPont, John Crisanti, was present during the application to provide technical assistance. Details regarding the mix design and the application are given in the appendix.

5. Conclusions: The placement of the polymer concrete materials proceeded smoothly and no difficulties were encountered. The application appeared to be satisfactory at the completion of the work.

Dennis O. Arney

Enclosure

Copy to: Regional Director, Denver, Colorado
Attention: LM-430
LM-210

Blind to: D-430
(Chairman, OCCS Committee)
D-1500
D-1510
D-1512
D-1512 (DePuy)
✓D-1512 (Smoak)
D-1512 (Causey)

DEC 18 1981
Noted
Howard J. Cohan
Chief, Division of Research

DOArney:bjs

Appendix

Application of Polymer Concrete Overlay at Milburn Dam

The PC (polymér concrete) overlay was placed on the sloping portion of the sluiceway floor of 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 block had been repaired by the conventional epoxy-bonded concrete repair method; the PC overlay was applied over the concrete repairs. The PC overlay also was applied over the original concrete on the left side of the sluiceway floor and on the chute block. The conventional concrete repairs had cured 28 days prior to the application of the PC overlay.

Surface preparation for the PC overlay consisted of sandblasting. The sandblaster was a field expedient device, which did not do quite as thorough a job as was desired; however, as the surface was clean and sound it was decided to go ahead with the PC application.

A meeting was held with all personnel prior to placement of the overlay. Safety instructions were outlined and mixing/placing procedures discussed.

All surfaces were primed prior to being overlayed. Primer components were mixed for an application at 50 °F. The overlay was placed on the prime coat while it was still tacky.

The steepness of the slope at the bottom of the sluiceway adjacent to the chute blocks caused some sliding problems.

Wood strip forms were placed every 10 inches to minimize sliding. Some surface tearing of the overlay did occur. DuPont's representative suggested placing a coating of primer liquid to seal all surface openings. This was done within 2 days.

Temperatures at the damsite for the two periods were: low, 31 °F; high, 73 °F.

Personnel Contacted at Milburn Dam

Loup Basin Reclamation District
- Ron Wolf, Supervisor
- Gerald Collier, Dam Tender
- Greg Zulkoski
- Jerald Amos
- Charlie Harris

DuPont Chemical Company - Technical Representative - John P. Crisanti, Chemical Engineer

Bureau of Reclamation, McCook Office
- Doug Mason

Mix Data

Bond Coat:	Percent of total batch
Liquid, Crylcon 3040	96.3
Initiator, Crylcon 3045	3.7
	100.0

Overlay Mix:	
Powder Component, Crylcon 7020	46.5
No. 4 to 3/8 inch aggregate (Clear Creek)	46.5
Liquid, Crylcon 7012	7.0
	100.0

Memorandum

Memorandum
TO : Chief, Division of Research

Denver, Colorado
DATE: June 23, 1983

THROUGH: Chief, Concrete and Structural Branch
Head, Polymer Concrete and Structural Section

FROM : W. Glenn Smoak

SUBJECT : Crack Repair at Green Mountain Dam Spillway

During the period June 8 through 10 and June 14 through 15, 1983, Dennis Arney, Fred Causey, and I traveled to Green Mountain Dam to assist West Slope Project Office personnel in a joint materials field evaluation/crack repair program. This work was performed as a result of a request by Zenis Blevins of the LM Region, Loveland Office.

The spillway floor contained two transverse cracks, not at construction joints, that had previously been repaired with what appeared to be some type of epoxy mortar. This repair had been accomplished in excess of 10 years ago. Inspection revealed that the repairs were very loose and potentially susceptible to erosion and removal during periods of spill expected this summer.

To accomplish the repair, we selected three of the most promising repair materials from our DR-380 and DR-381 research programs. A fourth material, epoxy bonded conventional concrete, was installed to serve as a control.

The three test repair materials used at Green Mountain Dam were as follows:

1. Adhesive Engineering's Concresive 2020 Polymer Concrete

2. Probond ET 150 G epoxy bonded epoxy concrete

3. Dural Flexocrete III epoxy bonded epoxy concrete

Mix data for each of the systems and the epoxy bonded conventional concrete are listed in table 1.

Substantial efforts were required to mix, place, and finish the epoxy concretes. The epoxy resins have high viscosity and are difficult to mix. This problem was compounded by the relatively low ambient temperature at the spillway. The Dural epoxy was much better in this respect than the Pro Bond epoxy which was difficult just to get out of the can.

Conclusions:

The PC and conventional concrete were easily prepared and placed. A potential for disbonding of these materials exists because of the old epoxy mortar left in the bottom of the repair. Another potential area of disbonding exists at the point the PC repair intersects the right retaining wall footing and keyed construction joint.

The right side of the lower crack repaired with Dural Flexocrete III does not contain problem areas except for poor surface finish. The left side of the lower crack repaired with Pro Bond ET 150 G may deteriorate due to delaminations in the downstream concrete and shallow reinforcing steel.

In the absence of long-term PC performance data, but based on economics, laboratory tests, observation of previous PC and epoxy mortar/concrete repairs, and the experience gained during this project, I would not recommend the use of epoxy concrete for this type or possibly any other type concrete repair. The PC is cheaper, easier to apply, and appears to have better thermal properties than epoxy concrete. If the long-term performance of PC proves acceptable, I believe that we should discontinue the listing of epoxy mortar/ concrete in the Standard Repair Specifications.

Mission of the Bureau of Reclamation

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

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

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

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