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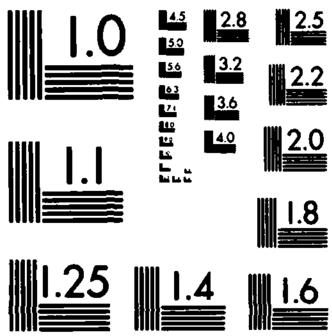


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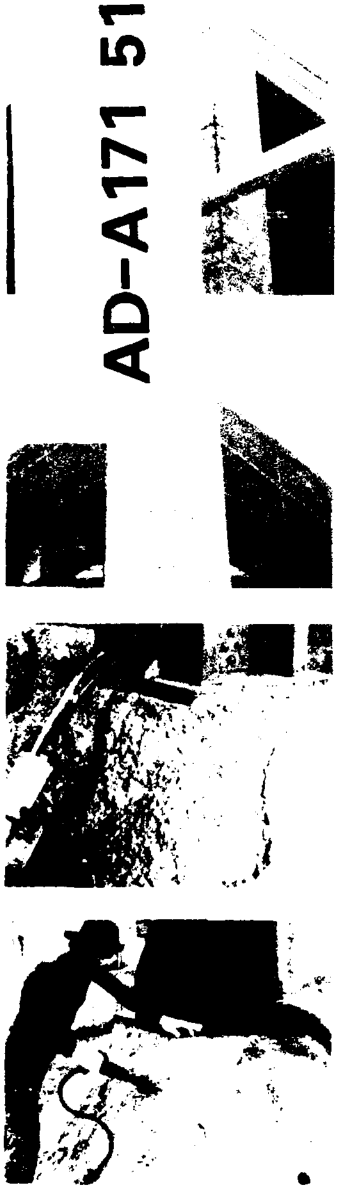

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# FACILITIES TECHNOLOGY APPLICATION TESTS; CONCRETE REPAIR

by


Tony B. Husbands

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631


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April 1986

Final Report

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The Office, Chief of Engineers, through the Facilities Technology Application Tests Program, requested that the US Army Engineer Waterways Experiment Station demonstrate some of the latest technology in the use of polymeric systems for repairing concrete. Two US Army facilities were selected for the demonstrations, Fort Bragg, N.C., and Fort Ord, Calif.

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20. ABSTRACT (Continued).

Two sites at Fort Bragg were chosen for repair, a water tower and a multistory building. The six concrete footings around the base of the water tower contained numerous cracks, with some spalling and delaminated areas. One of the footings was severely scaled. The concrete balconies and support columns of the building contained numerous spalls and cracks. The cracks and delaminated areas in the footings were repaired by pressure injection of epoxy resin. The severely scaled footing was repaired by overlaying with freshly hardened concrete. The spalls were repaired with a latex-modified concrete. The spalls located on the balconies and columns of the multistory building were repaired using an epoxy-resin paste and a latex-modified concrete. The cracks were sealed with a one-component polyurethane.

The concrete roof decks of two water storage tanks at Fort Ord were repaired. Both roof decks had exhibited the same problem; the concrete around the steel reinforcement had started to spall due to corrosion of the reinforcing steel, and some cracking of the roof deck was apparent. The roof decks were repaired by removing all of the unsound concrete and patching these areas with a polyester concrete. The entire roof was then cleaned and sealed with a polyester sealer followed by overlaying with a thin (3/8-in.) coating of the polyester concrete. The old joint sealant material was removed and replaced with a new joint sealant and new air vents were installed.

# PREFACE

The work described in this report was part of the Facilities Technology Application Tests Program sponsored by the Office, Chief of Engineers (OCE), US Army, Mr. Chester Kirk (DAEN-MPO-B) was the OCE Technical Monitor when this report was prepared. The work was authorized in September 1983.

The work was performed at the US Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. Bryant Mather, Chief, Structures Laboratory (SL), and John M. Scanlon, Jr., Chief, Concrete Technology Division, (CTD). Mr. Charles White, CTD, assisted in the Fort Bragg demonstrations. Videotapes of the demonstrations were made by Mr. Alan Middleton and Mr. Jon Warwick, Photography Branch, Publications and Graphic Arts Division. The report was prepared by Mr. Tony B. Husbands, CTD, SL.

The author greatly appreciates the assistance and cooperation of the maintenance personnel who performed the in-house work at Fort Bragg under the direction of Mr. Bruce Anderson, Chief, Maintenance Division. The assistance and cooperation of Mr. Bob Patterson, Structural Engineer, and Mr. Doug Yontz, Fort Ord, are also greatly appreciated.

COL Allen F. Grum, USA, was Director of WES during the preparation and publication of this report. Dr. Robert W. Whalin was Technical Director.

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# CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| centipoises | 0.001 | pascal-seconds |
| cubic yards | 0.7645549 | cubic metres |
| Fahrenheit degrees | 5/9 | Celsius degrees or Kelvins* |
| feet | 0.3048 | metres |
| gallons | 3.785412 | litres |
| inches | 2.54 | centimetres |
| mils | 0.0254 | millimetres |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (mass) | 0.4535924 | kilograms |
| square feet | 0.09290304 | square metres |

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

# Facilities Technology Application Tests; Concrete Repair

## Part I

## INTRODUCTION

1. Concrete structures can be damaged by a number of causes including: impact, chemical attack, foundation movements, freezing and thawing, corrosion of steel within the concrete, and sulfate attack. Damaged concrete can be restored to serviceable conditions using proper repair materials and techniques. Replacing damaged concrete structures or elements of a structure is expensive and if the damage is not extensive enough to warrant replacement, repair of the concrete is the proper solution.

2. Repair of concrete involves a variety of techniques and materials. Standards and guides for many of these newer techniques and materials are not available. Written information regarding these techniques and materials and their costs is limited. For these reasons, facility engineers experience difficulty in choosing procedures and materials when preparing specifications for concrete repair or when instructing in-house labor.

3. The success of concrete repair depends on four factors:

- Evaluation of the cause and extent of the deterioration and damage.
- Selection of an appropriate repair material and method.
- Preparation of concrete for repair.
- Placement of repair material.

Once the cause and extent of damage have been determined, then and only then can a rational selection be made among alternative maintenance and repair strategies. The selection of the repair materials will depend on the cause of failure and the shape, size, and location of repairs. The physical properties, compressive and flexural strengths, and modulus of elasticity and other properties such as shrinkage on drying, coefficient of thermal expansion, and resistance to freezing and thawing should be considered in choosing a repair material. Other properties such as chemical resistance, permeability, water vapor transmission, and abrasion resistance may be of equal importance for certain types of repairs. Before any repair can be successful, the proper preparation of the concrete and placement of the repair material are essential.

4. Concrete is the material most often used to repair concrete both because of compatibility and because of cost and appearance of the finished repair. Occasionally, the repairs may warrant a material that has properties different from conventional concrete. Polymers can be

used to repair concrete, and this report discusses some polymeric systems that are used for such repairs. Polymers used to repair concrete are used neat (no fillers or aggregates added) and as a binder for concrete composites. Polymer concrete (PC) is a composite material formed by polymerizing a monomer that has been mixed with aggregate. The polymerized monomer acts as a binder for the aggregate. Polymer-portland cement concrete is a premixed material in which either a monomer or polymer is added during mixing of a concrete mixture. When latex (an emulsion of polymer and water) is added to a fresh concrete mixture, the product is most often referred to as a latex-modified concrete (LMC).

5. Many different types of polymers are being used in the repair of concrete. The most widely used is the epoxy resin. This is due both to its ready availability and to its good adhesion to concrete and durability. Other polymers which are often used for concrete repair and are available commercially include: acrylics, polyesters, vinylesters, polyurethanes, styrene-butadiene, and polyvinyl acetate. There are additional commercial products available which contain other polymers not mentioned above.

# Part II

# DEMONSTRATION SITES

## Site Selection

6. A survey was made by communicating with various US Army facilities as to their needs for concrete repair and their willingness to cooperate in the demonstrations. Two facilities were selected for the concrete repair demonstration projects: Fort Bragg, N. C., and Fort Ord, Calif. Both facilities were inspected by US Army Engineer Waterways Experiment Station (WES) personnel to determine the extent of the concrete damage and to choose which concrete structures would be repaired. Two sites at Fort Bragg were chosen for repair: (a) concrete footings around the old division elevated water tower, and (b) a multistory barracks building. Two water storage tanks at Fort Ord, designated as reservoir D and the sand trap, were chosen for repairs.

## Coordination of Repairs

7. The repairs of the concrete footings around the water tower at Fort Bragg were contracted, and the repairs of the multistory barracks building were done with in-house personnel and overseen by WES. Materials for the building repairs were obtained by WES and stored at Fort Bragg. Personnel and equipment for performing the repairs of the building were furnished by Fort Bragg. Personnel responsible for the coordination of repairs are listed in the Preface.

8. The concrete repairs of the water storage tanks at Fort Ord were contracted. Again, the personnel responsible for the coordination of these repairs are listed in the Preface.

## Logistics

9. Materials for the building repairs at Fort Bragg were ordered by WES and shipped to Fort Bragg by the distributor of the materials. Representatives of WES were present at both demonstrations and a WES photographer prepared videotapes of the demonstrations. Notices were sent out to inform facilities engineering personnel of the location, date, and time of each demonstration. Handouts and orientation talks were prepared for the observers.

## Condition Surveys

10. Demonstration sites at both Fort Bragg and Fort Ord were inspected by WES and facilities engineering personnel to evaluate the cause and extent of damage to the concrete. Based on the inspection and laboratory tests, repair materials and methods of repair were selected.

## Fort Bragg

11. The six concrete footings around the base of the water tower contained numerous cracks, with some spalling and delaminated areas. One of the footings, designated as footing 3, was severely scaled. This scaling was most likely due to freezing and thawing of the concrete which was wetted frequently because of a water overflow pipe. A typical footing at Fort Bragg and footing 3 are shown in Figures 1 and 2. The footings were inspected by WES personnel in June 1983. They were sounded during the inspection with a metal rod and many hollow sounds were obtained indicating delaminated areas in the concrete surfaces of all the footings. Eight cores were taken in January 1984 to determine the extent of the surface damage and the soundness of the concrete below the apparent surface damage. Laboratory testing of the cores indicated that the concrete was sound below the upper portion of the footings, having an average compressive strength of 4,070 psi* with a compressive strength range from 3,450 to 4,490 psi. The cracks appeared to penetrate the concrete only 2 to 6 in.; however, it was difficult to estimate the depth of all the cracks from observing only eight cores. Some of the cracks observed were open, with widths of the cracks ranging from a few thousandths of an inch to approximately 0.06 in. Most of the cracks were not open and appeared to be filled with secondary deposits.

12. Six multistory buildings in the same vicinity were inspected. All of the buildings inspected had concrete balconies which were supported by concrete columns. The balconies contained some small concrete spalls 2 to 6 in. wide and 4 to 18 in. long located on the bottom side. All of these

**Figure 1. Typical condition of concrete footings, Fort Bragg**

**Figure 2. Concrete footing 3, Fort Bragg**

concrete spalls were located on cracks which penetrated the slab. These spalls were most likely caused by water entering the cracks from the top side of balconies that were open, causing the reinforcing steel to corrode. A typical spall on a balcony is shown in Figure 3. The support columns also contained numerous small and some large spalls. These spalls were due to corrosion of the reinforcing steel. These buildings were constructed around 1929 and the corrosion of the reinforcement steel in the columns was probably due to weathering of the concrete. The concrete cover over the reinforcing steel appeared to vary from 1/2 to 1 in. Numerous spalls

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Figure 3. Overhead spall on balcony, Fort Bragg

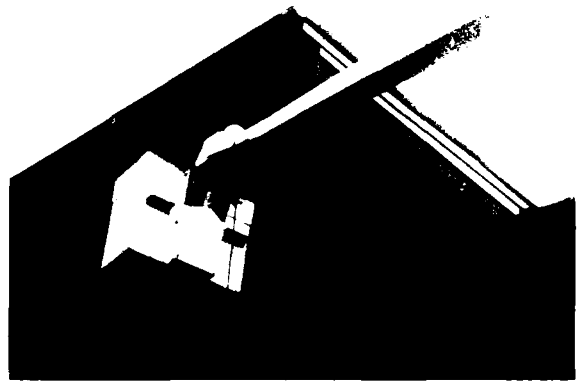

Figure 4. Spalling of concrete columns, Fort Bragg

on the balconies and columns had previously been repaired by in-house personnel using a cementitious repair material, and a large number of these repairs had started to fail due to loss of bond and cracking. Spalling of the concrete columns is shown in Figure 4.

**Fort Ord**

13. Both of the water storage tanks inspected had the same problem. The concrete roof decks of each water storage tank had started to spall. Numerous spalls were present on the roof decks. Approximately twice as many spall areas were observed on the roof deck of reservoir D as compared with the spall areas on the sand trap. These spalls were located along the reinforcing steel and varied in width from 1 to 6 in. and varied in length from a few inches to 4 ft. The spalls were due to the corrosion of the reinforcing steel which caused steel expansion in the concrete and ultimate failure of the concrete. The pattern of the reinforcement steel was visible over large areas of the roof deck. Some hairline cracks in the concrete above the reinforcing steel were visible. Some of the spalled areas located on the roof deck of reservoir D are shown in Figure 5. The roof deck had started to bulge above some of the support columns, resulting in local cracking around the columns. There were areas, especially on the roof deck of reservoir D, that were sagging between support columns. One of the bulges and localized cracking are shown in Figure 6. The concrete coverage over the reinforcing steel was originally designed to be 3/4 in. thick. Concrete removed from the spalled areas indicated that the concrete coverage was as thin as 1/2 in. in many areas.

14. The inside of the sand trap water storage tank was inspected by personnel from WES and Fort Ord. (The inside of reservoir D could not be inspected because the tank could not be drained.) The inside appeared to be in good condition. No spalls

Figure 5. Spalls on roof deck of water storage tank, Fort Ord

**Figure 6. Cracks and bulge of roof deck around support columns**

were visible and none of the cracks had penetrated through the concrete roof deck. Samples of the spalled concrete were taken back to WES and analyzed for chloride content since these water storage tanks were located close to the ocean. None of the samples analyzed were found to contain any chlorides, which indicates that the corrosion of the reinforcing steel was not due to salts, but to the thin coverage, cracks, and weathering over the 27 years since construction.

# Part III

# REPAIR METHODS AND MATERIALS

## Fort Bragg

15. The following methods and materials were chosen to repair the concrete footings around the old division elevated water tower and the multistory building at Fort Bragg. Cracks and delaminated areas of the footings were repaired by pressure injection of an epoxy resin into the cracks. Footing 3, which was severely scaled, was repaired by removing all unsound concrete and restoring the footing to its original shape using portland cement concrete (PCC). An epoxy resin was used to bond the freshly mixed concrete to the hardened concrete. The cracks located on the balconies of the multistory building were routed out and sealed with an elastomeric sealant. The overhead spalls were repaired using an epoxy-resin paste and a latex-modified mortar (LMM). All vertical spalls located on the columns of the building were also repaired with an LMM.

### Repair of water tower footings

16. Epoxy-resin injection, which was chosen because of economics, is a proven method for repairs of cracks and delaminated areas by reinstating satisfactory structural strength to damaged concrete. Epoxy resins obtain excellent bond strength to hardened concrete, and the strength of the material exceeds that of concrete in compression, flexure, and tension. Epoxy resins can be formulated to have low viscosities to provide deep penetration into fine cracks in concrete. Epoxies exhibit low shrinkage during curing and are chemically resistant to the alkali in concrete.

17. When repairing narrow cracks and delaminated areas in concrete, such as those found in the footings, the correct type of equipment should be used. The equipment specified for these repairs was a two-component proportioning pump of a positive piston displacement type which would have the capability of discharging the mixed epoxy resin at pressures up to 200 psi and maintaining that pressure. It was also required of the equipment that the mixing of the two components occur in-line using a mixer head having the capability to thoroughly mix the two components to obtain prescribed properties of the cured epoxy resin. A ratio accuracy of the two components of ±3 percent by volume at any discharge pressure up to 200 psi was required. Caulking guns and pressure pots can also be used to inject epoxy resin into cracks.

18. A field test to determine the ratio tolerance and mixing efficiency of the equipment was specified. Depth of penetration of the epoxy resin into the cracks can be determined by coring and with the

use of ultrasonic equipment. Coring was not done, but all delaminated areas were checked the day after the footings had been injected with the epoxy to determine if any hollow spaces existed.

19. Cracks that are at least 0.003 in. in width and open can be injected with epoxy resins using the correct equipment and a low-viscosity resin. Portholes (at least 3/4 in. deep) are drilled into the center of the crack. Entry ports may also be bonded to the concrete over the crack. The spacing of the portholes will depend on the depth of the crack being injected. Portholes should not be spaced apart at a distance greater than the depth of penetration desired. Intermediate portholes should be placed into narrow cracks to monitor the flow of the epoxy resin. The spacing of the portholes in the cracks of the footings was specified to be no more than 6 in. This small spacing was specified because of the shallow cracks. Delaminated areas like those on the footings should be outlined by sounding. At least four portholes should be drilled into these areas, two near the bottom and two near the top, spread apart. This is done to prevent entrapment of water that may be present. All portholes should be cleaned of debris left by the drilling, using water or vacuum methods. Entry port tubes made of copper or plastic are inserted into the cored holes. Entry ports can be obtained commercially from a number of suppliers. The crack surface is completely sealed with a thixotropic epoxy-resin system. The epoxy-resin sealant should be allowed to cure until it is sufficiently hardened to withstand the pressure from the injection equipment (generally overnight). When pressure-injecting epoxy resins into vertical cracks, the epoxy is first injected into the lowest entry port. On cracks in horizontal structures, epoxy-resin injection should be started at one end of the crack and continued until the epoxy resin flows from the adjacent port. The first entry port is then sealed and injection commences at the next sequential port until the crack is filled. There are many references available which describe both equipment and techniques for the injection of epoxy resins (US Army Construction Engineering Research Laboratory 1971, Furr 1984, Mizulo 1980, and Department of the Army 1979).

**Footing 3**

20. Footing 3 was severely scaled and approximately 75 percent of the surface concrete was unsound. Because of this poor condition, epoxy-resin injection was not specified. All unsound concrete from the surface of the footing was removed with an air hammer. The surface of the footing was then restored to its original shape using PCC. An epoxy resin was specified for bonding the freshly mixed PCC to the prepared hardened PCC surface. When using an epoxy resin to bond freshly mixed PCC to hardened PCC, the mixed epoxy resin should be brushed or sprayed onto the surface of the hardened PCC to obtain a film approximately 20 mils thick. The concrete should be dry; however, if the surface cannot be dried, there are types of epoxy resins that will bond to damp concrete free of standing water if thoroughly scrubbed into the surface of the concrete using a stiff bristle brush. The epoxy-resin bond coat should be tacky when the freshly mixed concrete is placed. Information on bonding freshly mixed concrete to hardened concrete and other usage of epoxy resins can be found in American Concrete Institute (1983).

21. The concrete used for the overlay was specified to have a compressive strength of 4,000 $\pm$ 500 psi, a slump of 2-1/2 $\pm$ 1/2 in., an air content of 6 $\pm$ 1 percent, nominal maximum coarse aggregate size of 1/2 in., and to contain 470 lb (five bags) of portland cement. Proper consolidation of concrete is necessary to obtain good-quality concrete. Vibrators were specified to consolidate the concrete during placement. Curing of the freshly placed concrete is also essential to obtain good-quality concrete. A number of

methods for curing concrete are satisfactory: wet curing, plastic films, and curing compounds. Curing compounds were not used since they would have to be removed. Since the footing was going to be coated, wet curing was selected. Two layers of burlap were placed around the footing and wetted with water. Plastic films were then wrapped around the burlap to prevent evaporation of the water.

22. Epoxy resins specified were to conform to requirements given by the American Society for Testing and Materials (ASTM) (1983). The epoxy resin used for injection was designated as a Type I, Grade 1, Class C, except for the viscosity requirement. The viscosity of the mixed epoxy resin was specified to be less than 800 centipoises. The ASTM specification requires that the viscosity of a Grade 1 epoxy resin be less than 2,000 centipoises. The epoxy resin used for bonding the freshly mixed concrete was designated as Type II, Grade 2, Class C, under the ASTM specification. The epoxy resin used for overhead patching was designated as Type III, Grade 3, Class C.

**Repair of multistory building**

23. The method chosen for the spall repairs on the multistory building consisted of removing all unsound concrete within and around the spall area and patching the area with an LMM. An epoxy-resin paste was also used to patch some of the overhead spalls. The cracks on the balcony were routed out and sealed with a polyurethane sealant.

24. It is essential to remove all unsound concrete when repairing a spalled area. When reinforcing steel is exposed, the concrete around the steel should be removed to expose the total circumference of the steel bar. All corrosion products should be removed from the reinforcing steel before repairs are made. The amount of corrosion of the reinforcing steel should be noted; excessive corrosion might justify replacement of the reinforcing steel.

25. The exposed reinforcing steel was coated with an epoxy resin after the corrosion products had been removed in order to prevent any further corrosion of the steel in that area. The epoxy resin used was one recommended for bonding freshly mixed concrete to hardened concrete since the LMM was placed shortly after coating the steel.

26. The LMM used for repairing the vertical and overhead spalls was a commercial LMM supplied as a two-component kit: one component, the latex and the other component, the powder (portland cement, fine aggregate, and other admixtures). There are numerous products of this type commercially available. WES has tested a number of these LMM's, and tests indicate that these materials are satisfactory as patching materials for concrete. The acrylic LMM's are recommended for repair of buildings because these materials do not yellow or chalk with time as do some of the other types of latexes. Desirable properties of LMM include good bond strength to concrete, low shrinkage, high flexural and tensile strengths compared with conventional mortar, low permeability, and good resistance to freezing and thawing.

27. LMM's do not need to be moist-cured for long periods of time. The latex forms a film which maintains high levels of internal moisture in the mortar. When placed in a hot or windy environment, it is recommended that LMM be covered with wet burlap followed by covering with a polyethylene film to prevent shrinkage cracking. The moist curing is continued for 24 hr. LMM is mixed, placed, and finished using conventional methods applicable to portland cement repair materials. LMM should not be applied when the temperature is below 45° F or above 90° F. The latex will not form a tough, durable film at temperatures below 45° F and the working time is too short at temperatures above 90° F.

28. Acrylic-latex admixtures for port-

land cement mortars and concrete can be obtained from numerous suppliers. These latexes can be mixed with fresh portland-cement mortars or concretes rather than purchasing prepackaged kits, which would significantly lower the cost of the repair material. These latexes can be obtained in 1-, 5-, and 55-gal containers. The polymer solids content may vary from 12 to 50 percent, depending on the supplier and brand, and the polymer may or may not contain antifoaming materials. Information on polymer solids and antifoaming materials should be obtained from the supplier before using the latex admixture for preparing LMM. Acrylic latexes that do not contain antifoaming materials will cause excessive air to be entrapped in the mortar and concrete. Antifoaming materials can be obtained and added to the latex before mixing or during the mixing of the mortars and concretes. A polymer-cement ratio range of 10 to 15 percent is most often used, but greater and smaller polymer-cement ratios can be used depending on the desired properties.

29. The epoxy resin used for repairing some of the overhead spalls was chosen because of color (gray when mixed), flexibility, and its ability to resist sagging when placed overhead in lifts up to 1 in. thick. There was some concern that the cracks in the concrete balconies might be working cracks, and flexible epoxy resin used would have more resistance to debonding or cracking than the LMM. Gages were installed to monitor the crack movement but malfunctioned before enough readings could be obtained for verification.

30. The polyurethane joint sealant used to seal the cracks in the concrete balcony met the requirements of Federal Specification TT-S-00230C, Type 1, Class B. This single-component joint sealant material was chosen because of its ease of application, self-leveling ability, good bond strength, and flexibility.

## Fort Ord

31. The method chosen for repairing the roof decks of the two water storage tanks at Fort Ord consisted of the following steps:

*a.* Remove unsound concrete and expose reinforcing steel in spalled areas.

*b.* Clean entire roof deck and exposed reinforcing steel by sandblasting.

*c.* Patch all spalled areas.

*d.* Coat roof deck with a thin, impermeable coating.

*e.* Remove and replace joint sealant material.

32. A thin coating was required to prevent any excessive weight being placed on the roof deck. There was some degree of sagging of the roof decks between some of the support columns and additional weight would enhance this problem. The coating would also have to be impermeable to prevent water from coming in contact with the reinforcing steel which was corroding due to the fine cracks and carbonation of the concrete.

33. A number of coatings were considered: LMM, latex-modified shotcrete, epoxy resin, methyl methacrylate, and polyester resin. The LMM and latex-modified shotcrete materials would have been the least expensive materials and were considered as the repair materials for the roof decks. There was some concern that the wider cracks around the support columns would reflect through thin overlays (1/2 in. thick) with these materials. There was also some concern that plastic shrinkage cracking might occur if the repair materials were applied on a hot and windy day. The methyl methacrylate and epoxy-resin systems considered were too expensive. Below are estimated material costs for 1 sq ft at a thickness of 1/4 in.

| *Material* | *Cost per sq ft* |
|---|---|
| Methyl methacrylate PC | $1.04 |
| Epoxy-resin PC | 1.35 |
| Polyester-resin PC | 0.44 |
| LMM | 0.20 |

The polyester-resin system has been evaluated at WES and found to have high bond strength to hardened concrete, thermal compatibility with concrete, low shrinkage, high flexural and tensile strengths, rapid curing, and impermeability to water. This material has also been tested by a number of departments of transportation and has been used to overlay a section of pavement in one state. The material has also been used to overlay bridge decks. Consequently, the polyester resin was chosen for the repairs.

34. The polyester-resin system chosen for the roof deck repairs consisted of two different types of polyester resins, one used as a primer, and the other as a binder for PC. The polyester-resin primer bonds well to concrete and is chemically resistant to alkalies. The polyester-resin binder is less costly ($0.90 per lb) and satisfactory PC can be prepared from this polyester resin. Both polyester resins were required to contain 0.5 percent of a silane coupling agent which improves the bond to concrete and aggregates.

35. When repairing and coating concrete, it is essential that all unsound concrete be removed and that the surface be free of any contaminants that would affect the bond of the coating to concrete. In this case, it was required that all unsound concrete be removed around the spalled areas using air hammers. Feather edging was allowed since no heavy loads would be applied to the coating. If loads such as automobiles, trucks, or tow motors are going to be in contact with repairs, the edges of patch areas should be saw cut or undercut with a chipping hammer to eliminate feather edges. The depth of the cut around the edges of the patch will depend on the patching material. For PC patching materials, 1/2 in. is satisfactory, while 2 in. is normally recommended for PCC. The contractor was given an option of cleaning the surface by sandblasting or using mechanical means, such as a scabbler or planer, to expose the aggregate and obtain a sound, clean surface. Sandblasting was the method chosen for preparing the surface. After cleaning and removal of unsound concrete, a second inspection was made to detect any remaining unsound concrete and surface contaminants. When steel had been exposed and cleaned, it was inspected to see whether corrosion had caused significant loss of cross-sectional area.

36. The joint around the edge of the water storage tanks was protected during repairs to prevent any of the repair materials from falling into the joint opening or bridging the joint. A flexible strip of wood was used to protect the joint opening. The joint faces were sandblasted after overlaying the roof deck to expose the aggregate in the PC in order to obtain a good bond between the joint sealant material and the PC. A clean dry substrate is essential for obtaining good bond of a joint sealant material to concrete.

37. The contractor was given the option of using a single-component or multicomponent joint sealant material meeting the requirements of Federal Specification TT-S-00230C or TT-S-00227e. The contractor chose the single-component material. A backing rod was required to limit the depth of the joint sealant material to 1/2 to 5/8 in. Very little published information is available for selection and application of backing materials for joints. The contractor elected to use a polyethylene backing rod which was approved.

## Part IV

# DEMONSTRATION AT FORT BRAGG

38. The Fort Bragg demonstration was conducted during the period 20-28 August 1984. The repair of the concrete footings around the old division elevated water tower was performed by contractor. The repairs of the multistory building were performed with in-house personnel under the supervision of WES personnel.

### Repair of Concrete Footings, Water Tower

39. The soil around the footings was removed to a depth of 18 in. to expose the concrete below the surface which was to be repaired. The cracks and delaminations were repaired by epoxy-resin injection. Entry portholes were drilled along cracks that were open and at least 0.003 in. wide. Entry portholes were also drilled into the delaminated areas. Entry portholes were drilled to a depth of 9 in., which was greater than the depth specified. WES approved the entry hole depth recommended by the contractor because deeper penetration of the epoxy resin into the concrete could be obtained and this would be beneficial, especially for repair of the delaminated areas. High-pressure water was used to clean the entry portholes. Drilling and cleaning of the portholes are shown in Figure 7. The entry ports were placed into each of the entry portholes. The entry ports were made from a hollow, threaded steel tube 2-1/4 in. long with an outside diameter of approximately 1/4 in. and an inside diameter of 1/8 in. A rubber sleeve was placed over the middle of the steel tube with washers and nuts at each end (Figure 8). The entry ports were placed into the holes and tightened by turning the nut on the end, which expanded the rubber sleeve. An Alemite fitting was placed on the end of each entry port. Water was injected into each entry port using an airless sprayer equipped with a pressure gage and a nozzle that fit the Alemite fitting. This was done to determine where leaks existed and where to seal the surface. The surface areas where

**Figure 7. Drilling and cleaning of entry portholes for epoxy-resin injection**

Figure 8. Entry port

Figure 9. Sealing of cracks and leaks with epoxy resin

leaks were observed were sealed by troweling on an epoxy-resin gel. Application of the epoxy-resin gel sealant is shown in Figure 9. The gel was allowed to harden overnight before the footings were injected with the epoxy resin.

40. The equipment used for the epoxy-resin injection was a two-component proportioning pump of a positive piston displacement type. The mixing of the two epoxy-resin components is accomplished in-line using a mixer head. The pump had the capability of discharging the mixed epoxy resin at pressures exceeding 1,000 psi. The epoxy resin was injected into each entry port using pressures up to 500 psi. The contractor would determine when the voids between the delaminated areas were filled by observing an increase in the pressure. Injection of the epoxy resin into the entry ports is shown in Figure 10.

41. A ratio-tolerance test was made before the injection of the epoxy resin. The volumes of each component were measured simultaneously, discharging the components into separate calibrated containers. Mixing tests were made shortly after the injection process was started and again after 2 hr. These tests were done by injecting approximately 150 ml of the mixed epoxy into a calibrated plastic container and determining the gel time.

Figure 10. Injection of epoxy resin into concrete footings

42. All entry ports were removed the following day after the epoxy-resin injection had been completed. The holes left after removal of the entry ports were filled with the LMM. This material was recommended by WES over an epoxy-resin mortar proposed by the contractor because it would be less expensive and compatible with the coating to be used. All footings were sounded to determine if any delaminations were evident after injection and if unsound concrete was present. Six areas in three of the footings were found to be unsound, and these areas were removed with an air hammer and repaired with the LMM (Figure 11). The footings were then cleaned

**Figure 11. Repair of spalls on concrete footings with latex-modified mortar**

**Figure 12. Removal of unsound concrete for footing 3**

by sandblasting to remove the old paint and epoxy-resin sealant.

43. Footing 3 was repaired by removing all of the unsound concrete and overlaying with freshly mixed concrete. The unsound concrete was removed with an air hammer (Figure 12). A wood form was placed around the footing to contain the freshly mixed concrete. The form was approximately 2 in. below the top of the footing, which was not satisfactory. Since the concrete had been ordered and construction of a new form would delay the repairs, the contractor was given the option to overlay this 2 in. with an epoxy-resin mortar or LMC once the new concrete had cured for 7 days. An epoxy resin was used to bond the freshly mixed concrete to the hardened concrete. The epoxy resin was brushed on the concrete using a stiff bristle brush attached to a hoe handle (Figure 13). The freshly mixed concrete was placed into the form and consolidated by the use of a vibrator. The wood form was wetted shortly after placement of freshly mixed concrete and twice more during the working day. The following day the forms were removed and honeycomb areas were filled with the LMM. Two layers of burlap were wrapped around the footing and wetted. Polyethylene sheets (6 mils thick) were then wrapped around the footings. Wet curing of the new concrete was continued for 7 days.

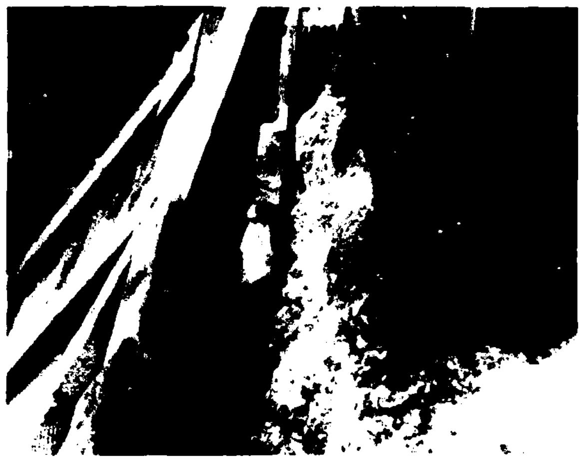

**Figure 13. Application of epoxy-resin bond coat**

44. After all repairs of the concrete footings were completed, the footings were coated with a cementitious-base acrylic latex coating. Two coats were applied at a rate of 150 sq ft/gal per coat, waiting 2 hr between coats.

## Repair of the Multistory Building

45. All cracks on the top side of the balconies were sealed to prevent water from entering into the cracks. The cracks

were routed to a depth of 3/8 in. using a lightweight electric air hammer. The groove formed by the chipping hammer was then brushed with a wire brush followed by removing the fines with a commercial vacuum cleaner. A single-component polyurethane joint sealant material meeting the requirements of Federal Specification TT-S-00230C, Type II, was used to seal the groove (Figure 14).

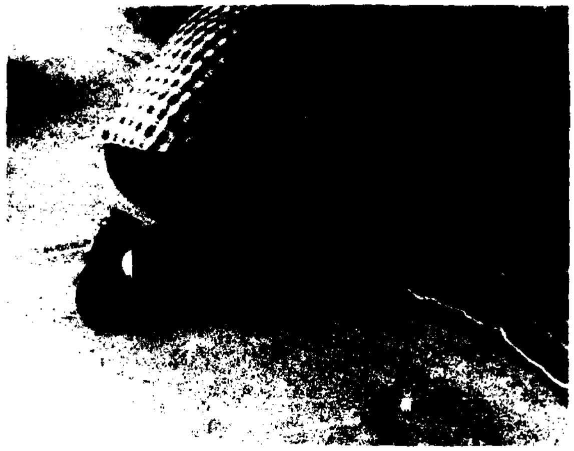

**Figure 14. Sealing of cracks in the balconies**

46. All overhead spalls located on the bottom of the balconies were repaired with three materials, a thixotropic epoxy-resin paste and two LMM's. All unsound concrete around and within the spall areas was removed with a chipping hammer. The concrete around the reinforcing steel was chipped back to expose as much of the circumference of the reinforcing steel as possible. It was difficult to completely remove all of the concrete around the reinforcing steel because the work was done from a ladder and the concrete was extremely hard. The reinforcing steel exposed within the spalled area was cleaned with a wire brush to remove the corrosion products. Sandblasting of the reinforcing steel would have been the preferred method of cleaning the reinforcing steel; however, sandblasting equipment was not available.

**Figure 15. Coating of reinforcing steel with epoxy resin**

47. When repairing the overhead spalls with the LMM (Figure 15), the reinforcing steel was coated with an epoxy resin, using a small brush. The epoxy resin chosen was designated for bonding freshly mixed concrete to hardened concrete. A slurry coat of the LMM was prepared by mixing two parts of the powdered component with one part of the latex by volume. The slurry coat was brushed on the prepared surface area. The LMM was mixed in a mechanical mixer and applied and finished with a trowel. A damp sponge was then used to float the surface of the repair material. This improved the appearance of the repair material to more closely match the appearance of the existing concrete.

48. Approximately one-third of the overhead spalls were repaired with the epoxy-resin paste. The epoxy resin was mixed by adding one part of the A component to one part of the B component by volume. Small quantities of the epoxy were measured using a plastic measuring cup and the two components were mixed by hand using a spatula. One component was black in color and the other white, and complete mixing could be observed when a gray color formed without streaks. The mixed epoxy was placed into the prepared area and consolidated and finished with a trowel.

49. All vertical spalls on the columns were repaired with an LMM. The spalled areas were prepared using the same method described in paragraphs 46 and 47. It was less difficult to remove the concrete around the reinforcing steel, and the reinforcing steel was completely exposed for most vertical spall repairs. A few of the columns had been repaired using a fast-setting cementitious patching material. Some of these repairs had started to fail because of excessive cracking and loss of bond. Four of these areas were repaired by removing the previous repair material and repairing again using the LMC. Preparation of these areas and the finished repairs are shown in Figures 16 and 17, respectively. Some of the vertical repairs were exposed to direct sunlight and wind. A few of these were protected by covering the freshly placed material with a damp cloth to protect the material from the heat and wind which could cause shrinkage cracking. Most of the repairs were not protected and the heat did not appear to cause any cracking. The largest spalled area repaired was located on a column near the top of the building. A lift was used to raise personnel performing the repairs to the desired heights. The repair materials were prepared on the ground and transferred to the lift bucket by means of a rope and pulley. Removal of the unsound concrete and the finished repairs are shown in Figures 18 and 19, respectively.

**Figure 16. Preparation for vertical spall repair on columns**

**Figure 17. Finished spall repairs on column**

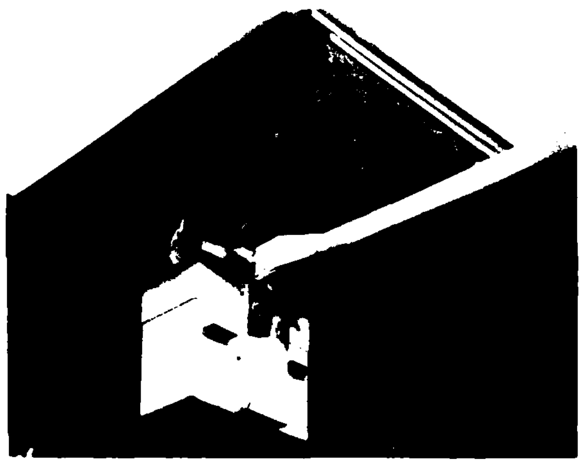

**Figure 18. Removal of unsound concrete for column repairs**

**Figure 19. Finished repair of column**

## Part V

# DEMONSTRATION AT FORT ORD

50. The Fort Ord demonstration was conducted during the period of 3-15 December 1984. The repairs of the roof deck on reservoir D, which were performed by a contractor, were not completed until 4 January 1985.

51. The roof decks of two concrete water storage tanks at Fort Ord were repaired, the sand trap tank and reservoir D. Reservoir D is 132 ft in diameter and has a water storage capacity of 2 million gallons. The sand trap is 116-1/2 ft in diameter and has a water storage capacity of 1 million gallons.

52. The concrete roof decks were sounded with metal rods to determine any delaminated and unsound concrete areas. All of these areas were marked with spray paint to outline the areas for concrete removal. The concrete within these areas was removed with air hammers. Concrete around reinforcing steel was removed to expose the complete circumference of the steel bars. Approximately 1,500 sq ft of the surface of the sand trap roof deck and approximately 3,000 sq ft of the surface of reservoir D were removed for patching. The depth of the concrete removed in these areas varied from 1/2 to 2 in.

53. The entire roof decks were cleaned to remove all substances detrimental to the bond of the polyester sealer such as laitance, dirt, previous coatings, and the epoxy resin used to seal the cracks. Cleaning was accomplished by sandblasting. The subcontractor in charge of the cleaning operation used a large rotary sandblaster which obtains a constant air pressure of up to 1,800 psi. An air pressure of 1,000 psi was used for the sandblasting of the roof decks. All excess fines left by the sandblasting were removed using a mechanical sweeper. The remaining fines were blown off using compressed air. The preparation of the roof deck before repairs is shown in Figures 20 and 21.

54. The old joint sealant material in the joint between the walls and roof deck was

**Figure 20. Removal of unsound concrete, Fort Ord**

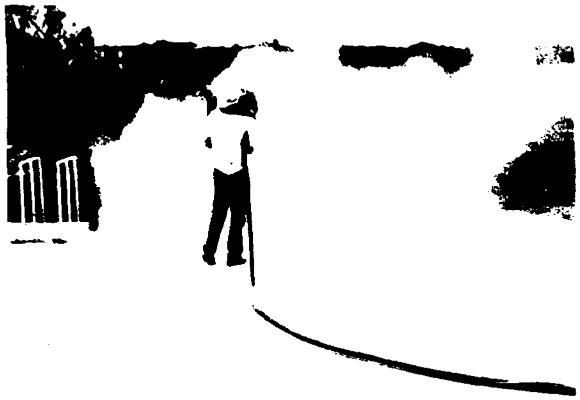

**Figure 21. Cleaning of roof surface by sandblasting, Fort Ord**

**Figure 22. Priming spall areas with polyester primer, Fort Ord**

removed. A machine used to cut roofing materials was used to cut the joint sealant material loose from the concrete surfaces. The sealant material was then pulled from the joint. Joint sealant material which remained adhered to the concrete inside and outside of the joint was removed with a small chipping hammer. Final cleanup of the joint was accomplished by sandblasting.

55. All exposed reinforcing steel was sandblasted just before repairing the spall areas to remove any rust that had formed since the initial cleaning. The reinforcing steel and the concrete surfaces within the spall areas were coated with the polyester-resin primer using a paintbrush (Figure 22). The polyester-resin primer was allowed to cure until the coating was no longer tacky. The coating should not be cured over 24 hr before placing the polyester-resin mortar or concrete. A polyester-resin mortar was prepared for patching the spalled areas. It contained 15 percent polyester resin and 85 percent of the fine aggregate by weight. Each batch consisted of 30 lb of the polyester resin and 200 lb of the fine aggregate. The polyester-resin mortar was mixed in a 1/2-cu-yd mortar mixer. The polyester resin was first added to the mixer. The catalyst (1-1/2 percent by weight of polyester resin) was added during mixing, and mixed for 1 min. The fine aggregate was then added and mixed for 2 min. The mixed polyester-resin mortar was placed into the prepared spalled areas and compacted and finished using a trowel (Figure 23).

56. Two methods were used for coating the roof decks at Fort Ord with the polyester resins. The roof deck of the sand trap water storage tank was coated by screeding 3/8-in.-thick polyester-resin concrete over the roof deck after application of the polyester-resin primer. The roof deck of the reservoir D water storage tank was coated by applying two slurry coats of polyester-resin mortar over the roof deck

**Figure 23. Patching of spalls with polyester mortar, Fort Ord**

after application of the polyester-resin primer. The reason for using two different coating methods was the difference in the levelness of the two roof decks. The roof deck of reservoir D contained a greater degree of sagging between support columns and it would have been difficult to obtain a coating less than 1/2 in. thick for large areas of the roof deck if it had been screeded.

## Repair of Sand Trap Water Storage Tank

57. The roof deck of the sand trap water storage tank was coated first with 3/8-in. polyester-resin concrete. Screed rails (redwood strips 3/8 in. thick) were fastened to the concrete using nails. The screed rails were placed 7 ft apart in circles (Figure 24). The joint was preserved by placing the redwood strips upright into the joint to the correct height. Small wooden dowels were cut and placed behind the redwood strip in the joint to support the redwood strips. Each day, the area to be coated was first covered with a thin layer of the polyester-resin primer. The primer was mixed in a 5-gal plastic pail, then poured onto the concrete and spread with squeegees (Figure 25). The application rate for the primer was 100 sq ft/gal. The coating was allowed to cure until it was no longer tacky.

58. The polyester-resin concrete was mixed in a mortar mixer. Each batch consisted of the following proportions:

90 lb polyester resin
600 ml cumene hydroperoxide (catalyst)
400 lb fine aggregate
200 lb coarse aggregate

The polyester resin was first added to the mortar mixer, the catalyst was added during mixing, and mixed for 1 min. The coarse aggregate was then added, followed by adding the fine aggregate. The polyester-resin concrete was mixed for 2 min after the addition of the fine aggregate.

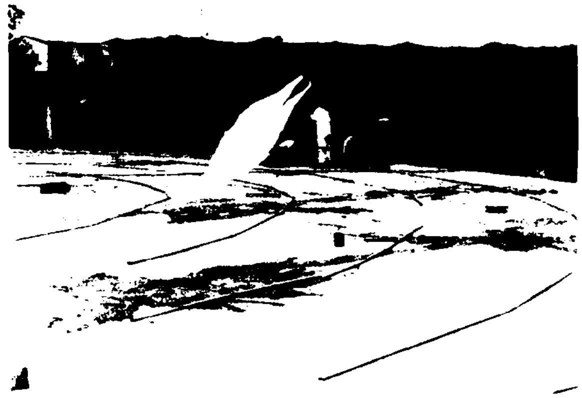

**Figure 24. Placement of screed rails**

**Figure 25. Application of polyester-resin primer**

The concrete was transferred into a wheelbarrow and unloaded at the area to be coated.

59. An 8-ft vibrating screed was used to consolidate and spread the coating. A magnesium float was used to finish the surface of the coating (Figure 26). Every other circular area formed inside the screed rails was coated, and the following day the remaining areas were coated. This alternating procedure was used to provide a hard surface to support men and equipment while placing the freshly mixed polyester-resin concrete. New air ventilators were installed. The air ventilator base was placed over the air ducts and the coating was placed approximately 2 in. over the flange of the air ventilator base to hold the air ventilator in place (Figure 27).

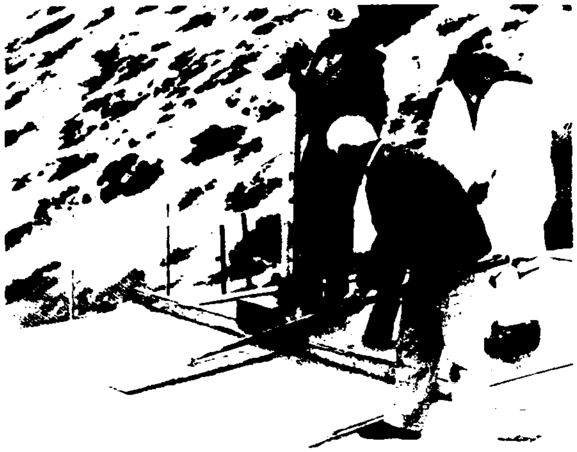

Figure 26. Application of polymer-concrete coating

Figure 28. Finished coating on sand trap water storage tank

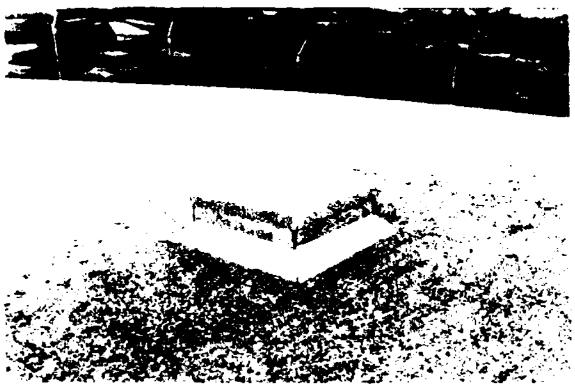

Figure 27. New air ventilator installed

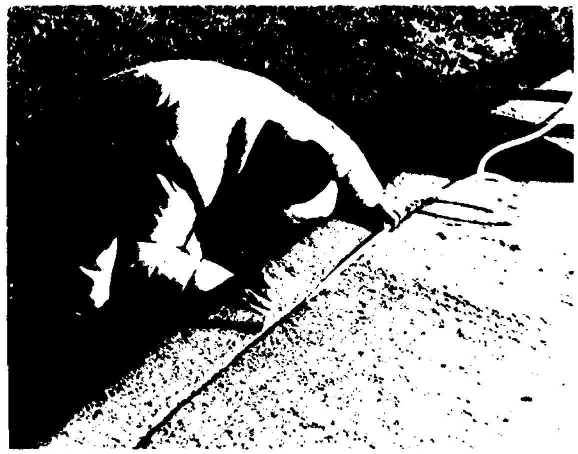

Figure 29. Installation of backing rod in joint

The finished coating of the sand trap water storage tank is shown in Figure 28. The light-colored areas are areas coated that day. The coating was trowelled on the top side of the wall section.

60. A single-component polyurethane was used to seal the joint. The inside surfaces of the joint were sandblasted to expose the aggregate in the polyester-resin concrete coating so that a better bond of the sealant to the coating could be obtained. A polyethylene backing rod was placed into the joint to limit the depth of the joint sealant material to 1/2 in. (Figure 29). The joint sealant material was placed into the joint using a caulking gun.

## Repair of Reservoir D Water Storage Tank

61. The roof deck of the reservoir D water storage tank was coated with two slurry coats of polyester-resin mortar. The roof deck of this tank was cleaned and repaired using the same procedure that was used for the sand trap water storage tank. Two low areas (Figure 30) were brought to grade using the polyester-resin concrete before the polyester-resin mortar coatings were applied.

62. The polyester-resin primer was first applied by squeegees to the area to be coated. The primer was allowed to cure

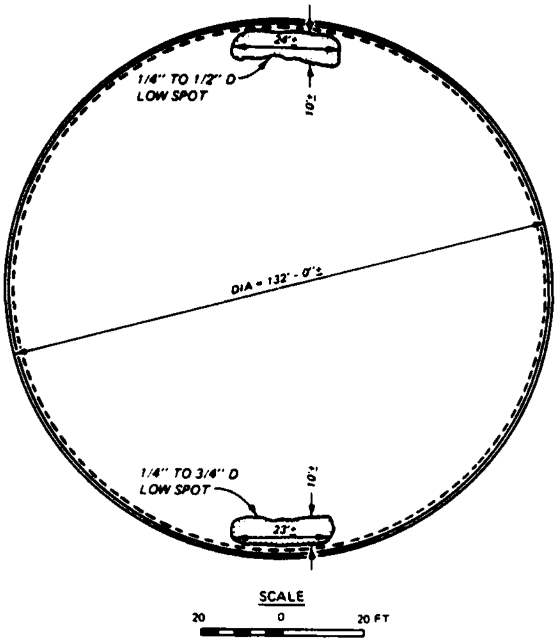


**Figure 30. Low areas on reservoir D**

**Figure 31. Application of polyester-resin primer for reservoir D**

**Figure 32. Finishing of slurry coat, reservoir D**

until it was no longer tacky. The polyester-resin mortar was spread over the primed surface using squeegees followed by finishing with a magnesium float. The mortar coating was allowed to cure overnight and a second application of the coating was applied.

63. The polyester-resin mortar was mixed in a mortar mixer and was composed of 25 percent polyester resin and 75 percent fine aggregate by weight. The two applications of the polyester-resin mortar produced a coating approximately 1/8 in. thick. Application of the coating is shown in Figures 31 and 32.

# Part VI

# SUMMARY

64. The Office, Chief of Engineers, through the Facilities Technology Application Tests Program, requested that WES demonstrate some of the latest technology in the use of polymeric systems for repairing concrete. Two US Army facilities were selected for the demonstrations: Fort Bragg, N. C., and Fort Ord, Calif.

65. Site inspections were made by WES and facility personnel before preparation of the specifications for repair to determine the cause of the concrete failures and the extent of damage to the concrete structures. Concrete cores and samples were taken from some of the structures for laboratory examination.

## Fort Bragg

66. Two sites at Fort Bragg were chosen for repair, a water tower and a multistory building. The six concrete footings around the base of the water tower contained numerous cracks, with some spalling and delaminated areas. One of the footings was severely scaled. The concrete balconies and support columns of the building contained numerous spalls and cracks. Concrete cores taken from the footings were examined and tested. The tests indicated that the concrete was sound below the upper portion of the footings and that the cracks only penetrated the concrete 2 to 6 in. The spalls located on the bottom side of the balconies were all located on cracks. These spalls were probably caused by water entering the cracks from the top causing the reinforcing steel to corrode and spall the concrete over the steel. The spalls on the concrete columns were also caused by corrosion of the reinforcing steel.

67. The Fort Bragg demonstration was conducted during the period 20-28 August 1984. The cracks and delaminated areas in the footings were repaired by pressure injection of epoxy resin. One day after injecting the cracks and delaminated areas with epoxy resin, the footings were sounded to determine if delaminated areas had been bonded together and if any unsound concrete remained. A few areas were found to be unsound and the concrete was removed from these areas and patched with an LMM. The severely scaled footing was repaired by removing all the unsound concrete with a chipping hammer and restoring the footing to its original shape with freshly mixed PCC. An epoxy resin formulated to bond freshly mixed PCC to the hardened PCC was used as the bond coat for bonding the freshly mixed PCC to the hardened PCC. The cracks in the balconies of the multistory building were routed out and sealed with a polyurethane sealant. The spalls located on the balconies and columns were repaired by removing

the unsound concrete with a chipping hammer and patching the spall with an LMM.

## Fort Ord

68. The concrete roof decks of two water storage tanks at Fort Ord were chosen for repairs. Both roof decks had exhibited the same problem; the concrete around the steel reinforcement had started to spall due to corrosion of the reinforcing steel and some cracking of the roof deck was apparent. The cracks did not penetrate the roof slab and most of the cracks were hairline cracks that appeared to be surface cracks. The roof deck had started to bulge above a few of the support columns, resulting in local cracking around columns. There were some areas on the roof deck of the larger water storage tank that were sagging between support columns. The corrosion of the reinforcing steel was due to the thin coverage of concrete, to cracks, and to weathering over 27 years.

69. The Fort Ord demonstration was conducted during the period of 3-15 December 1984. The roof decks were repaired with two polyester resins, a polyester-resin primer and a polyester-resin binder for making polymer concrete. The polyester-resin primer bonds well to concrete and is resistant to alkalies. The polyester-resin binder is less expensive and is used for making the polymer concrete. The polyester-resin primer is first placed on the concrete before applying the polymer concrete for patching and coating. All unsound concrete in the spalled areas was removed, exposing the complete circumference of the reinforcing steel. The areas were patched with the polyester-resin mortar. The entire roof deck was cleaned by sandblasting and coated with the polyester-resin concrete and mortar. The roof deck of the smaller water storage tank was coated with a 3/8-in.-thick polyester-resin concrete using a vibrating screed to consolidate and finish the coating. The roof deck of the larger water storage tank was coated with two coats of a polyester-resin mortar slurry to obtain a coating thickness of 1/8 in. using squeegees. The old joint sealant material was removed and replaced with a polyurethane joint sealant material.

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