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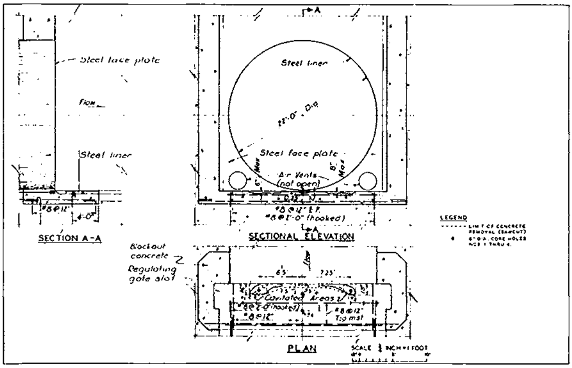

FIG. 8-1 DOWNSTREAM END OF TUNNEL NO. 10; LOCATION OF CORE HOLES AND CAVITATED AREAS

repair was selected because it would provide a tightly bonded, smooth filling for the core holes and the cavitated areas at nominal cost. This paper will discuss the steps taken to refill four core holes, repair two cavitated areas, and provide an armor coating over the repaired areas and the adjacent original portland-cement concrete surface immediately downstream from the tunnel. It will also discuss the effectiveness of the repair as evaluated from visual observations made after the area had been under water for 5 years.

LABORATORY TESTS

Laboratory testing was conducted to develop proper proportioning, mixing, and placing procedures. The tests and the end results obtained are as follows:

(1) Several epoxy-resin mortar and epoxy-resin concrete mixtures were made and cast into simulated core holes in

portland-cement concrete blocks. The most suitable gradings and batch quantities of materials were determined by visual observation of the working characteristics of the mixtures, and the exact yield was determined for each mixture.

(2) Half of the epoxy-resin mortar and epoxy-resin concrete mixtures were placed in simulated core holes in portland-cement concrete blocks with dry bonding surfaces. The remainder was placed in simulated core holes in moist concrete blocks with surface-dry walls, in order to evaluate the effect of moisture upon the bonding characteristics of the epoxy-resin binder which was to be used. This testing was considered necessary in anticipation of the moisture problem in the repair area, since it would be very difficult to get the concrete thoroughly dry in the cavitated areas and core holes. The epoxy-patched specimens were allowed to set in laboratory air for 7 days and were then tested in compression. The specimens were tested on edge in such a manner that the long 6-in. side of the portland-cement-concrete samples and the circumference of the epoxy-resin-concrete core were each in shear. It was observed that the shear strength of the blocks prepared in the wet condition was approximately 35 percent less than the strength of the blocks prepared in the dry condition. The blocks prepared wet failed in bond by shearing, for the most part, along the planes of contact between the epoxy concrete or mortar core and the portland-cement concrete. The blocks prepared in the dry condition showed failure by crushing of the portland-cement concrete with perfect bond on all planes of contact between epoxy and portland-cement concrete. These results indicated that it would be very desirable to get the concrete in the repair area as dry as possible before any epoxy resin was applied.

FIELD INSTRUCTIONS

When the laboratory testing had been completed, detailed instructions were furnished for the field office to follow, and the repair was accomplished in early June 1960. Following are descriptions of materials and equipment used.

Materials

(1) Epoxy-Resin Binder. Eleven gal. of epoxy-resin binder and packaged aggregates were furnished. The binder conformed to the requirements of the Office of the Chief of the Corps of Engineers Purchase Description, 10 April 1959, "Binder (Adhesive), Epoxy Resin Base, Flexible," Type II.

(2) Fine Aggregate for Epoxy Concrete. The fine aggregate for epoxy concrete was dry, natural river sand furnished in packages and processed to meet the following gradation.

Sieve Designation U.S. Std sq mesh	Percent Passing, By Weight
3/8 in.	100
No. 4	95-100
No. 8	80-100
No. 16	50-85
No. 30	25-60
No. 50	10-30
No. 100	2-10
No. 200	0-5

(3) Fine Aggregate for Epoxy-Resin Mortar. This was dry, natural river sand conforming to the following gradation.

Sieve Designation U.S. Std sq mesh	Percent Passing, By Weight
No. 4	100
No. 8	95-100
No. 16	60-100
No. 30	35-70
No. 50	15-35
No. 100	2-15
No. 200	0-5

(4) Coarse Aggregate. This was dry, crushed Sioux quartzite, processed to meet the following gradation and furnished in packages.

Sieve Designation U.S. Std sq mesh	Percent Passing, By Weight
3/4 in.	100
1/2 in.	90-100
3/8 in.	40-70
No. 4	0-15
No. 8	0-5

(5) Toluene Solvent. Approximately 5 gal. of toluene was furnished for cleaning equipment and tools, for other cleanup, and for preparing the epoxy primer.

(6) Protective Creams. These were available for skin protection for workmen engaged in blending, mixing, and placing operations.

Equipment

(1) Electric (sparkproof) mixer with propeller-type blade for mixing the two components of the epoxy binder

(2) Hemispherical-bottomed polyethylene container for mixing epoxy binder

(3) Large metal pans for mixing epoxy concrete and mortar

(4) Hoes, shovels, and wooden paddles used to hand-mix epoxy concrete and mortar

(5) Hand tampers to consolidate epoxy concrete and mortar

(6) Batteries of infrared heat lamps, 250-watt, for preconditioning concrete when concrete temperatures were less than 50 F and for drying the concrete surface

(7) Tarpaulins were not used but were on hand to build heated enclosures and for use in protection of epoxy concrete against rainfall.

(8) Stiff bristle brushes used in applying prime coat and armor coat

(9) Goggles, protective coveralls, and neoprene-coated gloves used in all blending, mixing, and placing operations

(10) A concrete saw with a diamond blade

EPOXY MIXTURE DATA

The following batch quantities pertain only to the coarse and fine aggregate and epoxy-resin binder used for this repair work. Specific gravity values of 1.275 for the polysulfide component and 1.169 for the epoxy-resin component were used. An assumed specific gravity of 0.864 (based on 7 lb 3 oz per gal.) for toluene was used in the conversion of volume batches to weight batches. Weight batching was considered to be more convenient for the work since the volumes of materials to be mixed at one time were usually smaller than the 1:2 volume (half-gal. and gal.) containers in which epoxy materials are usually supplied. The batch weights which follow were based upon the use of one lb of polysulfide component, in order to provide easy projection of batch weights in the field.

(1) Epoxy Primer

Polysulfide component	1.00 lb
Epoxy component	1.83 lb
Toluene	0.87 lb

These amounts yielded somewhat over one qt of epoxy primer. It was found that one qt of epoxy primer would normally cover approximately 100 sq ft.

(2) Epoxy Binder for Armor Coating

Polysulfide component	1.00 lb
Epoxy component	1.83 lb

These amounts yielded slightly over one qt of epoxy binder. It was found that epoxy binder coverage ranged between 35 and 45 sq ft per qt. Since the pot life of epoxy binder was about 30 min, no more binder was prepared in one batch than the applicators could apply within this time period.

(3) Epoxy Concrete

Polysulfide component	1.00 lb
Epoxy component	1.83 lb
Fine aggregate (natural sand)	7.92 lb
Coarse aggregates (Sioux quartzite)	11.89 lb

These weights of materials yielded approximately 290 cu in. of epoxy concrete.

(4) Epoxy Mortar

Polysulfide component	1.00 lb
Epoxy component	1.83 lb
Fine aggregate (natural sand)	11.32 lb

These weights of materials yielded approximately 220 cu in. of epoxy mortar.

(5) Batching Accuracy. A Fairbanks-Morse 70-lb scale having a single beam with 0.01-lb graduations was found to be ideal.

PREPARATION FOR PLACING

Refilling the core holes, repairing cavitated areas, and armor coating, utilizing epoxy resin binder, were accomplished when the atmospheric and concrete temperatures were above 50 F. All fines, dust, and other loose material on the walls and bottom of the core holes was removed by scrubbing with a stiff bristle brush, and then washing and dewatering. Cavitated areas were prepared by making a saw-cut at least one in. outside the cavitated area to a minimum depth of 2 in. The concrete between the saw-cut and the edge of the cavitated area and the concrete throughout the cavitated area was then chipped out to solid concrete. The cavity thus formed was thoroughly cleaned with compressed air and sandblasted to remove all loose material (Fig. 8-2). Then the contact surfaces were completely dried and kept dry, throughout the entire period of repair, using compressed air and heat lamps. A prime coat of epoxy-resin binder cutback (3 parts of toluene to 7 parts of epoxy-resin binder by volume) was applied on the dry, cleaned surfaces of the concrete. The prime coat was applied in a thin coat and briskly scrubbed into the dry concrete surface with a stiff bristle brush. Placement of the epoxy-resin concrete was delayed until the prime coat became stringy, in order to permit the solvent (toluene) to escape from the primer. Care was taken that the primer did not pool in depressions.

FIG. 8-2 PREPARED CAVITATED AREA ON WEST SIDE OF TUNNEL CENTER LINE. CORE HOLE AT LEFT CENTER

MIXING AND PLACING

Epoxy Concrete

Epoxy concrete was used for refilling the core holes and for refilling all but the top 1/2 in. of the cavitated areas. Prior to mixing, the two components of the epoxy-resin binder and the coarse and fine aggregates were conditioned to 70 F to 85 F. The polysulfide-curing-agent component was added gradually to the epoxy-resin component with constant stirring which was continued until a uniform mixture was obtained. The rate of stirring was controlled so that entrained air was held to a minimum. An electric, sparkproof mixer with propeller-type blade was used for mixing the two components of the epoxy-resin binder in a hemispherical-bottomed polyethylene container. The epoxy-resin-concrete proportions by weight were seven parts of aggregate to one part of epoxy-resin binder. The maximum individual batch size for epoxy-resin concrete was kept under 100 lb. Epoxy-resin concrete was mixed in large metal pans using appropriate hand tools; the fine aggregate was then added to the epoxy-resin binder and the material was mixed until a rich mortar consistency was reached. Then the coarse aggregate was added and the epoxy concrete thoroughly mixed. The epoxy-resin concrete was placed in layers not over 3 in. thick. The thickness of courses and time interval between courses were controlled so as to ensure that the temperature of the epoxy concrete at no time during hardening exceeded 140 F. Hand tampers were used to consolidate the epoxy concrete. Any excess epoxy concrete which was spilled on the adjacent surfaces of the hardened concrete was removed immediately before it hardened. Considerable difficulty was experienced in finishing the surface of the epoxy concrete in core holes due partly to the relatively small space involved and partly to the harshness of the epoxy concrete caused by the coarse aggregate. Approximately 2,480 cu in. of epoxy concrete was used to fill the four core holes. The core fillings appeared to be well compacted, well bonded, and smooth, but the surfaces of the fillings in the undamaged area were noted to be slightly below the level of the floor surface after curing; it is believed that this difference was caused by a slight shrinkage of the epoxy concrete.

The cavitated areas were filled with epoxy-resin concrete to approximately 1/2 in. below the surface of the floor, and the remaining space was filled with epoxy-resin mortar immediately after placement of the epoxy concrete (Fig. 8-3). The cavitated area on one side of the tunnel centerline was found to have a maximum depth of 8 in. and on the other side 6 in. The epoxy concrete was mixed in batches which yielded approximately 680 cu in. Approximately 4,750 cu in. of epoxy concrete was required for filling the cavitated areas.

Epoxy Mortar

The top 1/2 in. of the cavitated areas was filled with epoxy-resin mortar (Fig. 8-4). Prior to mixing, the two components of the epoxy-resin binder and the fine aggregates were conditioned to 70 F to 85 F. The epoxy resin and the polysulfide-curing-agent components were thoroughly mixed as described previously for preparing epoxy-resin concrete. The mixed epoxy-resin binder was then transferred to a metal pan and the fine aggregate was gradually added to the binder and hand mixing was continued until all particles were coated. The epoxy-resin mortar was immediately troweled onto the surface of the epoxy concrete until the surface was flush with the adjoining original portland-cement-concrete surface. Approximately 1,610 cu in. of epoxy mortar was required to fill the top 1/2 in. of the cavitated areas, which had a surface area of approximately 18 sq ft.

Epoxy Binder Armor Coating

The floor area immediately down stream from the end of the steel liner in Tunnel 10, approximately 21 ft wide and 7 ft long

FIG. 8-3 PLACING EPOXY MORTAR OVER EPOXY CONCRETE IN WEST CAVITATED AREA

FIG. 8-4 FINISHING SURFACE OF EPOXY MORTAR IN WEST CAVITATED AREA

in the direction of flow, was armor-coated (Fig. 8-5). The area was thoroughly cleaned by sandblasting and compressed air to remove all loose material. Surfaces to receive the epoxy-resin armor coating were clean and dry and were kept in that condition prior to application, during application, and throughout a 48-hr curing period for the epoxy-resin armor coat. The armor coat was applied in two heavy applications, each approximately 1/64 in. in thickness. Epoxy-resin binder was mixed as described for epoxy concrete above and was used without thinning. The epoxy-resin binder was scrubbed into the surface with a stiff bristle brush. The second application was made as soon as the first coat was dry enough for access to the area. The coverage per coat ranged from 140 to 170 sq ft per gal. depending on the tackiness of the underlying coating.

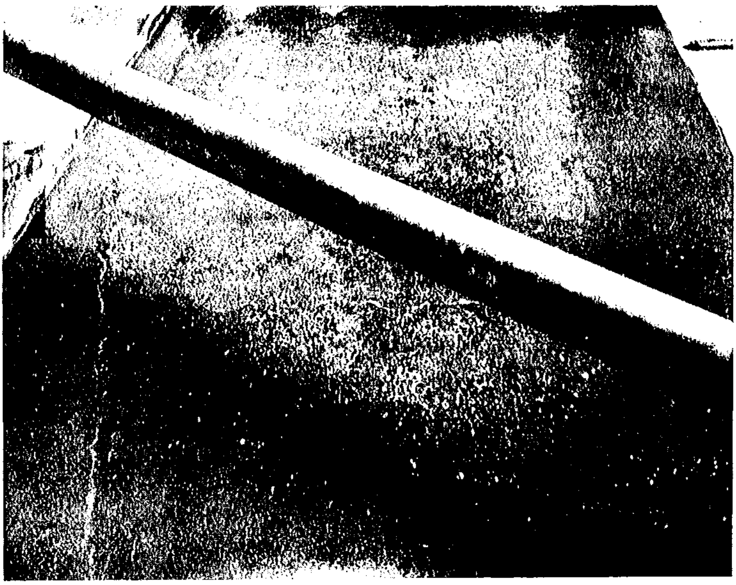

FIG. 8-5 EPOXY BINDER ARMOR COATING. NOTE OUTLINE OF REPAIR OF CAVITATED AREA AT LEFT AND FILLED CORE HOLES IN PORTLAND-CEMENT CONCRETE AT TOP CENTER

Health and Safety Precautions

(1) Full face shields or goggles were used for all mixing and blending operations and for placing operations as required.

(2) Protective coveralls and neoprene-coated gloves were used by all workmen engaged in the operations.

(3) Protective creams were available to keep epoxy resins from direct contact with skin.

(4) Portable eye-washing facilities were maintained at mixing, batching, and placing operations.

(5) Adequate fire protection was maintained at all mixing and placing operations.

(6) Smoking or the use of spark or flame-producing devices was prohibited within 50 ft of mixing and placing operations.

(7) The mixing, placing, or storage of epoxy-resin binder or solvent was prohibited within 50 ft of any vehicle, equipment, or machinery which could be damaged by fire or could ignite vapors from the material.

(8) Any contaminated clothing which could not be decontaminated was burned at the end of each work day.

(9) The solvent (toluene) which was used in preparation of the prime coat and for cleaning equipment presented problems of toxicity, fires, and possible explosion (toluene has a low flash point). This danger made fire protection measures mandatory.

PERFORMANCE

Almost exactly 5 years after the work was done, an inspection was made by the author while the repaired area was unwatered for inspection and repair. The following are comments based on the inspection:

(1) The repaired area had not been subjected to high-velocity water flow but it had been under water (10 ft or more) for the 5-year period.

(2) Visual inspection indicated that the epoxy concrete in the core holes was in excellent condition. The epoxy mortar on the surface of the cavitation areas was also found to be in excellent condition.

(3) There were two small spots where the epoxy-binder armor coating had come off the concrete surface. The epoxy armor coating adjacent to these spots could be peeled from the portland-cement-concrete surface of the floor with a pocket knife, indicating poor bond.

CONCLUSIONS AND RECOMMENDATIONS

1. Advance preparation of simplified mix data and aggregates prepackaged in the laboratory simplified the operation in the field and made it possible to make rapid progress and obtain a very good job.

2. The mixes selected provided dense, well bonded epoxy concrete and mortar. Hand-mixing of fine and coarse aggregates in the epoxy concrete proved to be adequate for the relatively small quantity of material but required vigorous physical exertion. The