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ELECTRICALLY CONDUCTIVE POLYMER CONCRETE OVERLAY INSTALLED IN PULASKI, VIRGINIA

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Electrically Conductive Polymer Concrete Overlay Installed In Pulaski, Virginia

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Synopsis: We report the development of a premixed electrically conductive polymer concrete overlay for use on bridge decks and other concrete members, in conjunction with cathodic protection systems. The development of a conductive overlay culminated in the installation of such an overlay on a full-bridge deck in Pulaski, Virginia; the active cathodic protection system has operated for eight months and is being monitored on a monthly basis. The monitoring shall continue for about 18 months.

The conductive overlay was placed by a local contractor with technical assistance from Brookhaven National Laboratory (BNL) personnel. The cathodic protection system was designed by a corrosion engineering firm and installed by BNL personnel. The installation of the conductive overlay and cathodic protection system cost less than $18.00 a square foot.

Keywords: polymer concrete; resin; corrosion; bridge decks; reinforcing steel; cathodic protection; conductive overlay; shot-blasting; electrically conductive polymer concrete; anode; mortar mixers; vinyl ester; aniline promoter.

INTRODUCTION

The deterioration of concrete bridge decks and other structures has become a major maintenance problem throughout the United States. Deterioration of concrete bridge decks is generally caused by chloride induced corrosion of reinforcing steel which results in cracking and spalling of the concrete because of the volumetric increase of the corroded steel.

Due to its open cell structure, concrete allows critical quantities of chlorides to permeate its structure to the level of the reinforcing steel. The chloride ions in the presence of moisture and oxygen initiate the corrosion of the reinforcing steel. As the corrosion products are formed, there is an increase in the volume of the steel, thereby exerting tensile forces on the sorrounding concrete. As these forces become larger than the tensile strength of the concrete, the concrete cracks thus allowing additional paths for the intrusion of water and chlorides. Eventually the concrete spalls and/or delaminates, and the concrete structure can become completely deteriorated.

It has become common practice to repair concrete spalls and delaminations with various patching materials and then overlaying the bridge deck with a non-permeable overlay such as polymer concrete. However, unless all of the chloride-contaminated concrete around the reinforcing steel is removed and replaced, the corrosion process will continue. Although it is technically feasible to remove all of the salt-contaminated concrete, in many instances it is economically unfeasible. The one method that has shown itself to be economically and technically feasible to prevent and stop the corrosion process is the use of impressed current cathodic protection (CP).

The use of impressed current cathodic protection in salt-contaminated concrete bridge decks has been well decumented in the literature (1-8). In the early CP systems developed for bridge deck applications, an electrically conductive asphaltic-concrete overlay was used which performed well but required significant changes in elevation and increases in the structure "dead load"(5). Recently two other systems have been used with some success; the "Slotted Anode System" and the "Strip or Mound Anode System." Both of these systems have one common fault. Neither of them entirely cover the concrete surface, therefore, the current distribution is non-uniform and both require high current levels to successfully distribute the current through the salt-contaminated concrete to the corroded reinforcing steel.

The development of an electrically conductive polymer concrete overlay that can also be used as the riding surface of the bridge deck now makes it possible to successfully distribute very low levels of CP current uniformly across the concrete bridge deck surface. By using very low current levels, it will be possible to operate these systems for relatively long periods of time without effecting the polymer composition. In addition, the conductive overlays are relatively thin, 3/8 to 1/2 in. in thickness, thus the dead load is only increased by less than 5 lb/ft^2 which is relatively insignificant. By adjusting the ramp elevations, the transition from roadway to bridge deck is smooth and scuppers and curblines are essentially uneffected.

EXPERIMENTAL RESULTS

A study was initiated to find a resin system that had a relatively high tensile elongation and strength with a curing shrinkage that was relatively low. Since polymer concretes have substantially higher coefficient of expansions than do portland cement concretes, it is important to allow the polymer concrete to be able to move without fracturing. Most of the successful polymer concrete overlay placements in the U.S. have used resin binders that have tensile elongations of 20 to 50% or more. Thus, although there is a significant difference in the thermal coefficients of the PC overlay to the portland cement concrete, the high elongations of the resin binder allow it to move internally without disbonding from the substrate. Simultaneously, the resin in conjunction with an electrically conductive aggregate, such as calcined coke breeze, must be able to produce a polymer concrete that has a very low electrical resistivity (<5 ohm-cm) and strong enough to maintain vehicular traffic without wearing down too quickly.

Several formulations were developed and tested in the laboratory. Two of these formulations were optimized and fully characterized and used in a full scale field installation. The following formulations were selected and the reasons for their selection are described in detail.

System 1.
Resin System
    19.2 wt% Derakane 8084, vinyl ester
    57.7 wt% A457, low modulus polyester
    23.1 wt% Shrinkage reducing agent
Aggregate System
    50 wt% DW, calcined coke breeze
    50 wt% Crushed basalt

Past experience had shown that Derakane 8084 was very effective in electrically conductive polymer concrete. This resin has a very high tensile strength (>4,000 psi) and has exceptional bonding capabilities to portland cement concrete. When it is used in thin conductive coatings (9, 10, 11), it has performed exceptionally well. However, it has a very low tensile elongation, and in order to increase its elongation it was necessary to copolymerize it with a very low modulus resin. It was found that a 3/1 ratio of A457 to Derakane 8084 increased the tensile elongation from 2.7% to 29.4% without effecting the tensile strength. Unfortunately, this combination produced a polymer concrete that had a high curing shrinkage (>0.30%). In order to reduce the curing shrinkage, it was necessary to add a shrinkage reducing agent to the mixture. This reduced the curing shrinkage from 0.30% to 0.03%. There was some sacrifice in the tensile strength and the tensile elongation was also reduced to 18.6%.

The aggregate system consists of DWI calcined coke breeze and crushed basalt. Previous studies have indicated that calcined coke breeze aggregate is very weak, and if used by itself, would not withstand vehicular traffic. The crushed basalt was added to strengthen the conductive polymer concrete and increase its wear resistance. A laboratory machine was built at BNL to test the wear resistance of the conductive overlay under the load of a full scale tire running at approximately 30 mph (Figure 1). The studies indicated that up to 2 x 10^6 tire passes did not have any effect on the overlay surface.

System 2

Resin System

100% Hetron Q6305, modified vinyl ester

Aggregate System

50 wt% DW1, calcined coke breeze

50 wt% Silica sand

After investigating several resin formulations from Ashland Chemical Co., it was decided to use a resin system that has a tensile elongation of over 50% even though we knew that its linear curing shrinkage in polymer concrete was 0.22%. Within the time restrictions that Ashland Chemical Co. Inc., they could not design a vinyl ester resin with both a high tensile elongation and a low curing shrinkage. The advantages of having a one component resin system is that the material can be used exactly as it is shipped by the manufacturer and does not have to be modified by a resin formulator.

The aggregate system consists of DWI calcined coke breeze and silica sand. The silica was substituted for the crushed basalt simply to lower the cost of the composite. The wear tests of the conductive polymer concrete made with silica sand instead of crushed basalt did not indicate any difference in the length of time that they were run.

The physical and electrical properties of the systems are given in Table 1.

Table 1
Some Physical Properties of Electrically Conductive Polymer Concrete Overlays.

	System 1	System 2
Tensile bond strength, psi	243	298
Linear curing shrinkage, %	0.03	0.22
Electrical resistivity, ohm-cm	<2.2	<2.5
Compression strength, psi @ 48 hr	5442	6035
Wear resistance, zero wear at hrs test	90	100
Tensile elongation of resin only, %	18.6	56.7

Field Application

In order to determine the effectiveness of the electrically conductive polymer concrete overlay, a field installation of the overlay was made on a bridge deck that was known to have corroded embedded reinforcing steel. The overlay was used to uniformly distribute the cathodic protection (CP) current to arrest the active corrosion of the reinforcing steel. The performance of the conductive overlay and the CP system would be monitored for a period of at least 1 1/2 years.

The bridge deck that was selected for the installation was a two lane bridge on Route 99 over Peak Creek in Pulaski, Virginia (Figure 2). The bridge deck has a surface area of 4400 ft^2. The deck has a total of six spans, three in each lane. Electrical half-cell potential readings were taken on a 4-ft grid in both lanes. The mean for 168 readings in the north bound lane was 0.41 V with a standard deviation of 0.12 V. The mean for 168 readings in the south bound lane was 0.35 V with a standard deviation of 0.12 V. Generally, half-cell potentials above 0.30 V indicate active corrosion of the embedded reinforcing steel.

About 2000 ft^2 of the concrete bridge deck surface was so highly deteriorated that it had to be removed and replaced before the conductive overlay could be installed. Repairs were made by a local contractor (Lanford Bros. of Roanoke, Virginia) as per Virginia Department of Transportation (VDOT) specifications for Type B repairs except that the epoxy bonding compound was not used. The deteriorated concrete was removed to a depth of 1 in. below the reinforcing steel and replaced with portland cement concrete having a minimum compression strength of 4000 psi. The repair work was completed in the first two weeks of August 1987.

The corrosion engineering firm of Kenneth C. Clear, Inc. of Sterling, Virginia, was hired to design a cathodic protection system for the bridge deck which would utilize the conductive overlay as the system anode to uniformly distribute the CP current across the bridge deck surface. The system was designed so that each individual span could be monitored separately. Each span had its own corrosion probe and reference cell as well as a reinforcing bar ground. The conductive overlay on each span was isolated electrically from each other so in effect there are six individual CP zones all being controlled from the same rectifier. The system was designed this way so that if there were isolated failures of the conductive overlay, the overall integrity of the entire system would not be affected. The design was as simple as possible to demonstrate that CP does not have to be highly sophisticated electronic marvel to work effectively.

The corrosion probes and reinforcing steel grounds were installed by BNL personnel during the week of October 5, 1987. All of the probes were installed in the old concrete. Holes were cut in the concrete bridge deck to accept the concrete cylinders containing the corrosion probe and reference cell. The concrete cylinders were installed parallel to the top embedded reinforcing steel at approximately the same elevation (Figure 3). Wires leading from the corrosion probes and reference cells were placed in slots cut in the bridge deck with dry cutting silicon carbide fiberglass reinforced masonary blades in an electric powered saw or a diamond chip edged steel blade in a gasoline motor powered saw (Figure 4). The diamond edged blade was more efficient than the silicon carbide masonary blade. The slots carrying the lead wires went from the corrosion probes to access holes through the deck so that they could be wired in the appropriate junction boxes and then all the junction boxes would be tied together with one run of conduit going back to the rectifier.

The wiring of the junction boxes and the rectifier was all done from the underside of the bridge deck. A scaffold was set up next to one of the piers and scaffold plans were placed on the flanges of the bridge I beams (Figure 5). These planks were moved across the beams as the conduit was attached to the underside of the bridge deck (Figure 6). The rectifier was mounted on the abutment at the Northwest end of the bridge (Figure 7). The AC power comes into the rectifier through a meter and rain tight disconnect box mounted on a service pole about six feet away from the abutment.

The conductive overlay was placed by Lanford Bros. Construction Company of Roanoke, Virginia, (who had also done the concrete repairs on the bridge) under contract to Brookhaven National Laboratory (BNL). BNL had premixed the aggregate and resin systems at the Laboratory and shipped them to the job site.

One lane of the bridge was overlaid while the other lane remained opened to vehicular traffic at all times. Traffic control was maintained with temporary traffic lights allowing alternating traffic across the open lane of the bridge. Traffic cones were used down the centerline of the bridge to denote the work zone.

The bridge deck surface was cleaned by steel shotblast (Figure 8). When the shotblast operation was completed by the contractor, the deck was blown off with compressed air to remove any residual dust. BNL personnel then installed the primary anode on each slab (Figure 9). The primary anode (platinum-nobium covered copper wire) was laid out about 3 ft inside the circumference of the entire slab in a loop. The ends of the anode wire were passed through the same access holes used for the corrosion probe leads (Figure 10). The wire was held down by drilling 1/4-in. diam holes in the deck and then driving plastic studs with large heads into the holes. The anode wire was strung tight under the heads of the studs. This method holds the anode wire close to the concrete surface and eliminates the need to cut slots in the deck to install the anode. The conductive polymer concrete bonds very well to the wire and allows for a good transfer of current from the anode to the conductive polymer concrete.

Once the anode wires were installed, the contractor set up the rails for the screed guide. One rail was on the curb and the other was at the centerline of the bridge. The screed was adjusted to allow placement of a 1/2-in. thick overlay. The conductive polymer concrete was mixed in mortar mixers (Figure 11). Two martar mixes were set up at the Southeast end of the bridge. The aggregate blend was prepacked in 65 lb bags at BNL. The resin used for the first overlay was the Ashland Q6305 vinyl ester. The resin contained 0.5% Dimethyl aniline promoter and the benzoyl peroxide initiator (BZP C50) was in the prepackaged aggregate. Before the overlay was to be placed, test batches of the conductive polymer concrete indicated that additional initiator would have to be added to obtain a gel time of 45 to 60 minutes. Later shelf-life studies indicated that the effectiveness of the benzoyl peroxide initiator is markedly reduced when it is in intimate contact with coke breeze. Therefore, in order to insure that the conductive polymer concrete would cured properly, it was necessary to add an additional 0.5 wt% of BZP-C50 (based on the resin) to each batch mixed for the overlay.

Once the composite was mixed in the mortar mixers, it was placed in wheelbarrows and dumped on the deck in front of the vibrating screed (Figure 12). The material was spread across the deck with shovels and the screed, which was pulled with a winch, uniformly leveled out the mix to a 1/2-in. thickness (Figure 13). The first 10 to 15 linear feed gelled within 10 minutes and, therefore, were not grooved, however, adjustments were made to the initiator concentrations to extend the gel time. It took about 25 linear feed before the mix design was such that it could be properly screeded and grooved within 30 minutes without gelling. The resin content was between 16 and 18 wt% of the total mix. In any batch-mix field application, it is always difficult to get exact resin percentages particularly when the resin is drained from a drum.

Toward the end of the last span, the resin supply was running out, and since the last drum was inaccessible, it was necessary to change to System 1, the BNL blended resin system. The resin was stirred within the drum for at least 15 minutes before it was used and seemed to be well mixed. Unfortunately, the cold temperatures earlier in the week had caused the shrinkage reducing agent to coagulate and fall out of the solution. The separation of the material was not noticed until the last 10 gal were drawn from the drum at which time the coagulated shrinkage reducing agent came out of the drum all at once. The conductive polymer concrete made with this resin system never fully cured and had to be replaced at a later date.

Since the resin system that was selected had separated it could not be used for the field application. The only viable alternative at the time was a polyester resin from Reichold Chemical Co., 32-044, which was locally available. This resin had been used extensively in Virginia for broom and seed polymer concrete overlays. The resin had a history of success for more than five years in field applications and is still specified for PC overlays. In a previous project at BNL, this resin had been evaluated for electrically conductive polymer concrete overlays and was found to be acceptable. Although it was not originally chosen for this project, it was available and would allow the overlay placement to proceed without further delays.

The overlay placement on the second lane proceeded on schedule. The contractor cleaned the deck by steel shot-blasting early in the morning. It took 3 hours to clean 2200 ft^2 of surface area. The anode wire was installed as previously described. This operation took 1 1/2 hours. The contractor began setting up the screed rails while the PT anode wire was being installed. The actual mixing and placement of the conductive overlay started in the afternoon. The resin (32-044) was prepromoted with cobalt naphthenate so methyl ethyl ketone peroxide was used as the initiator. The catalyst concentration used was between 1.0 and 1.5 wt%.

The contractor used two mortar mixers (as on the previous day) to mix the PC. After mixing for 2 to 3 minutes, the PC was dumped into wheelbarrows, rolled to the area of the deck being overlaid and dumped directly on the surface. Several workers spread it out in front of the vibrating screed which then leveled and compacted it. The finished surface was then grooved transversely (Figure 14) using a teflon roller grooving tool. It took approximately 2 hours to place 2200 ft^2 of overlay. All of the expansion joints were cut within several hours after the overlay was placed.

Traffic was not allowed on the freshly overlaid deck until the next morning to allow the conductive PC to properly cure. Compression strength versus cure time studies indicated that the PC does not achieve sufficient strength (approximately 2500 psi) for almost 24 hours. The ultimate strength achieved was approximately 6000 psi after 7 days.

The overlay was placed on October 15 and 16, 1987. After a week or so, several delaminations were reported particularly in the first lane that was overlaid. During the week of November 4, 1987, 4 BNL personnel returned to the job site and removed and repaired approximately 650 ft^2 of the overlay. The entire bridge deck was chain dragged to identify the delaminated areas (Figures 15, 16, and 17). All of the delaminations were found in the first lane that was overlaid including some areas in which the overlay did not fully cure.

The perimeter of the areas to be repaired were cut with a silicon carbide fiberglass reinforced masonary blades down to the concrete surface. The overlay was then removed with electric chipping hammers. Extreme care had to be exercised to insure that the PT wire was not cut or damaged in any way. The bridge deck areas to be repaired were sandblasted to clean them before replacing the overlay. The conductive PC was mixed in a small barrel-type concrete mixer and dumped directly in the area to be repaired. The mix was spread out and leveled with an electric vibrator mounted on a magnesium box beam (Figure 18). The last 150 ft^2 of repairs were delayed for several hours until a snow shower passed by. The repair areas were covered with polyethylene sheets to keep the deck dry. Once the snow ended, the repairs were completed. Vehicular traffic was kept off the repaired areas until the next morning.

On December 23, 1987, the cathodic protection system was activated. A current distribution of 1 ma/ft^2 of surface area was applied. The current distribution appears to be uniform throughout the individual spans. The rectifier output voltage was approximately 2.5 V TRMS. All indications are that polarization levels are significant, and effective cathodic protection is being achieved on the rebar embedded in the deck. The CP system is very efficient as indicated by the relatively uniform polarization across the structure and the low voltage required to provide the PC current. Monitoring of the overlay and the CP system will continue for approximately 18 months.

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Figure 1. Surface Wear Resistance Machine at Brookhaven National Laboratory.

Figure 2. Bridge Over Peak Creek on Route 99 in Pulaski, Virginia.

Figure 3. Installation of Corrosion Cells to Monitor Cathodic Protection System.

Figure 4. Cutting Slots in Bridge Deck to Install Lead Wires for Corrosion Cells.

Figure 5. Scaffolding Used to Install Electric Conduits on Underside of Bridge.

Figure 6. Installing Electric Conduit to Underside of Bridge Deck.

Figure 7. Rectifier Installation for Cathodic Protection System.

Figure 8. Steel Shot-Blasting Concrete Bridge Deck.

Figure 9. Installation of Primary Anode Wire.

Figure 10. Primary Anode Fully Installed.

Figure 11. Mortar Mixers Used for Mixing Electrically Conductive Polymer Concrete.

Figure 12. Conductive Polymer Concrete Placed in Front of Screed.

Figure 13. Vibrating Screed Used to Level Out Conductive Polymer Concrete.

Figure 14. Transverse Groove for Skid Resistance.

Figure 15. Areas Repaired in Conductive Overlay, Span A.

Figure 16. Areas Repaired in Conductive Overlay, Span B.

Figure 17. Areas Repaired in Conductive Overlay, Span C.

Figure 18. Repairing Conductive Polymer Concrete Overlay.

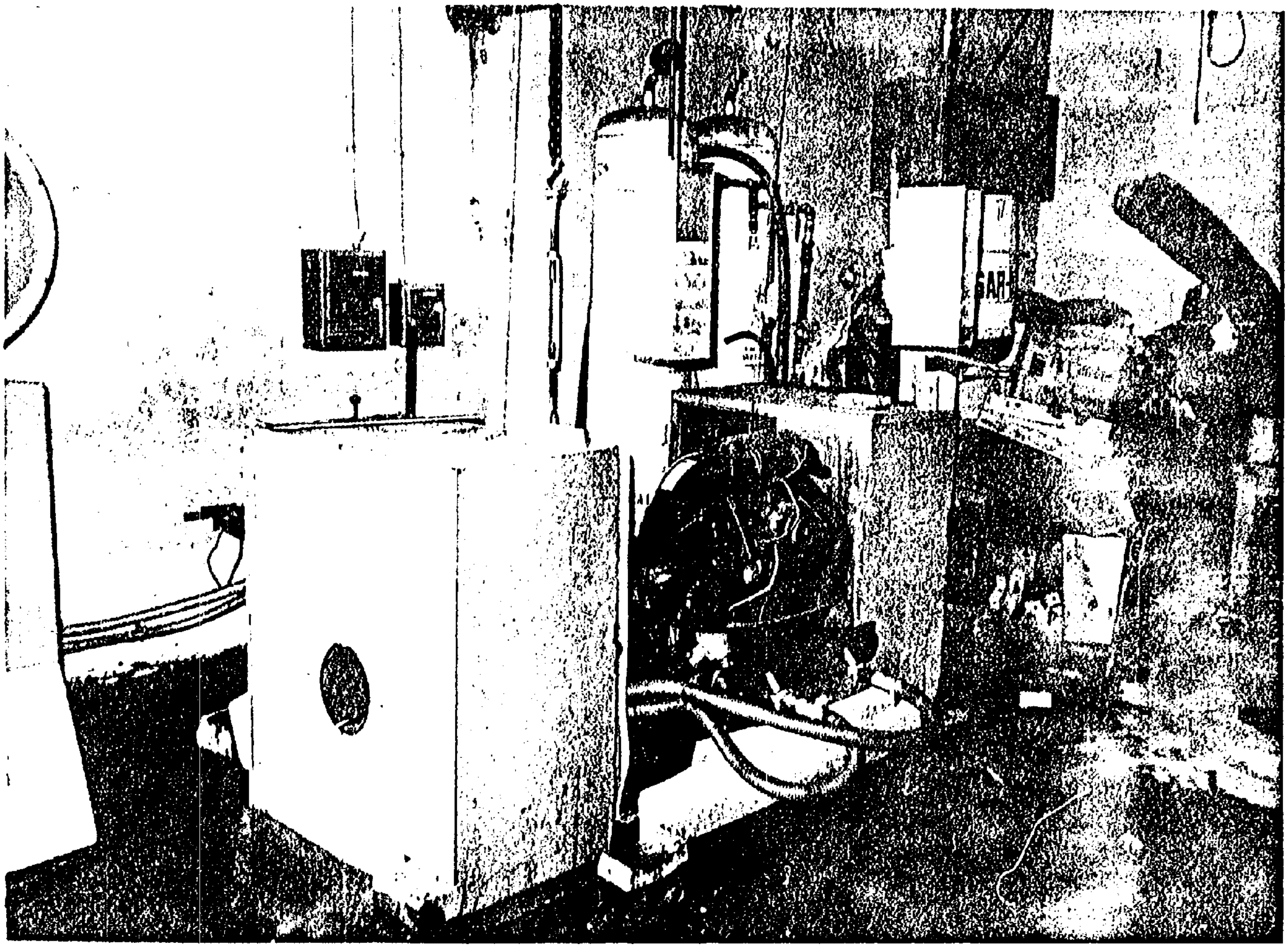


Figure 1.

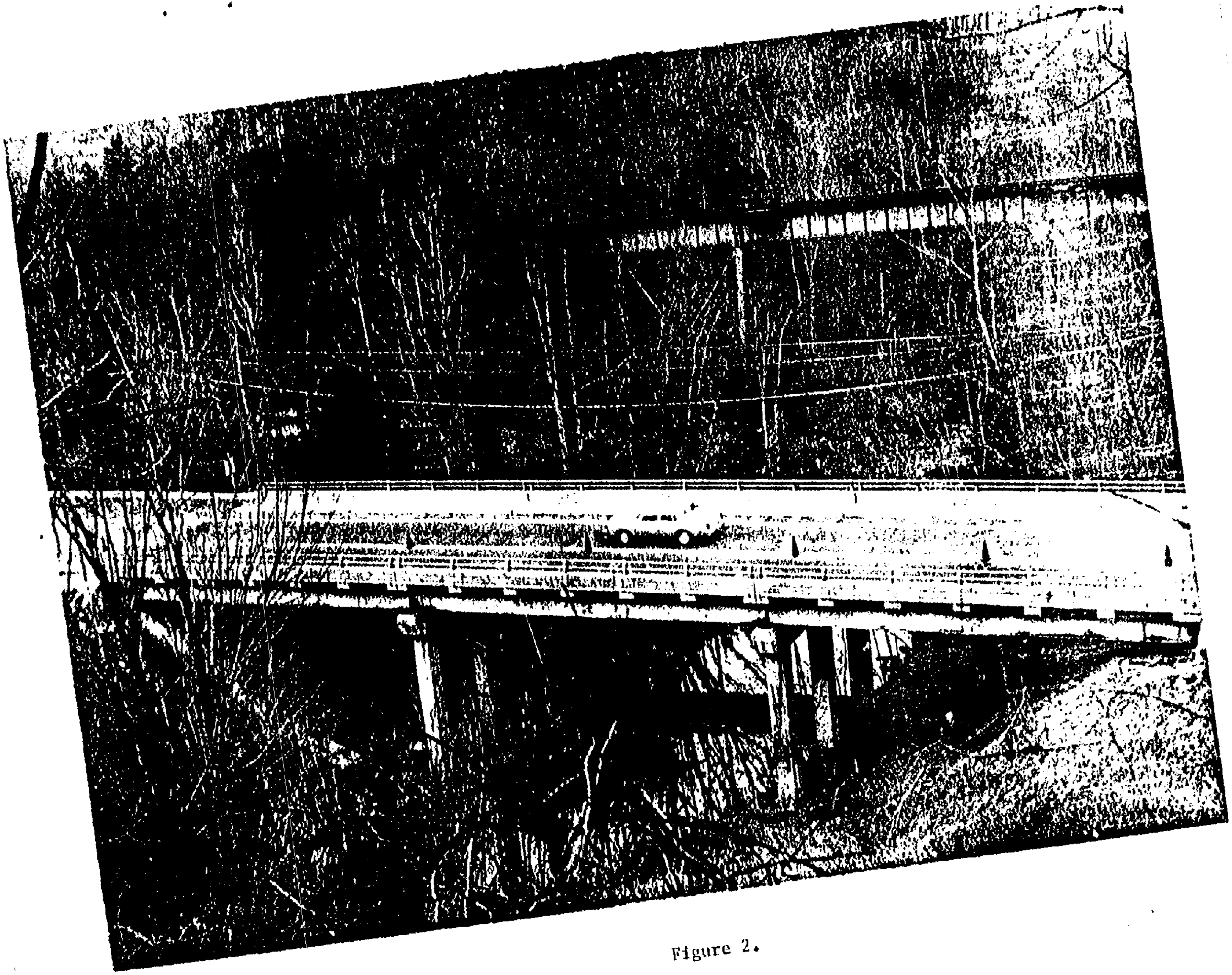
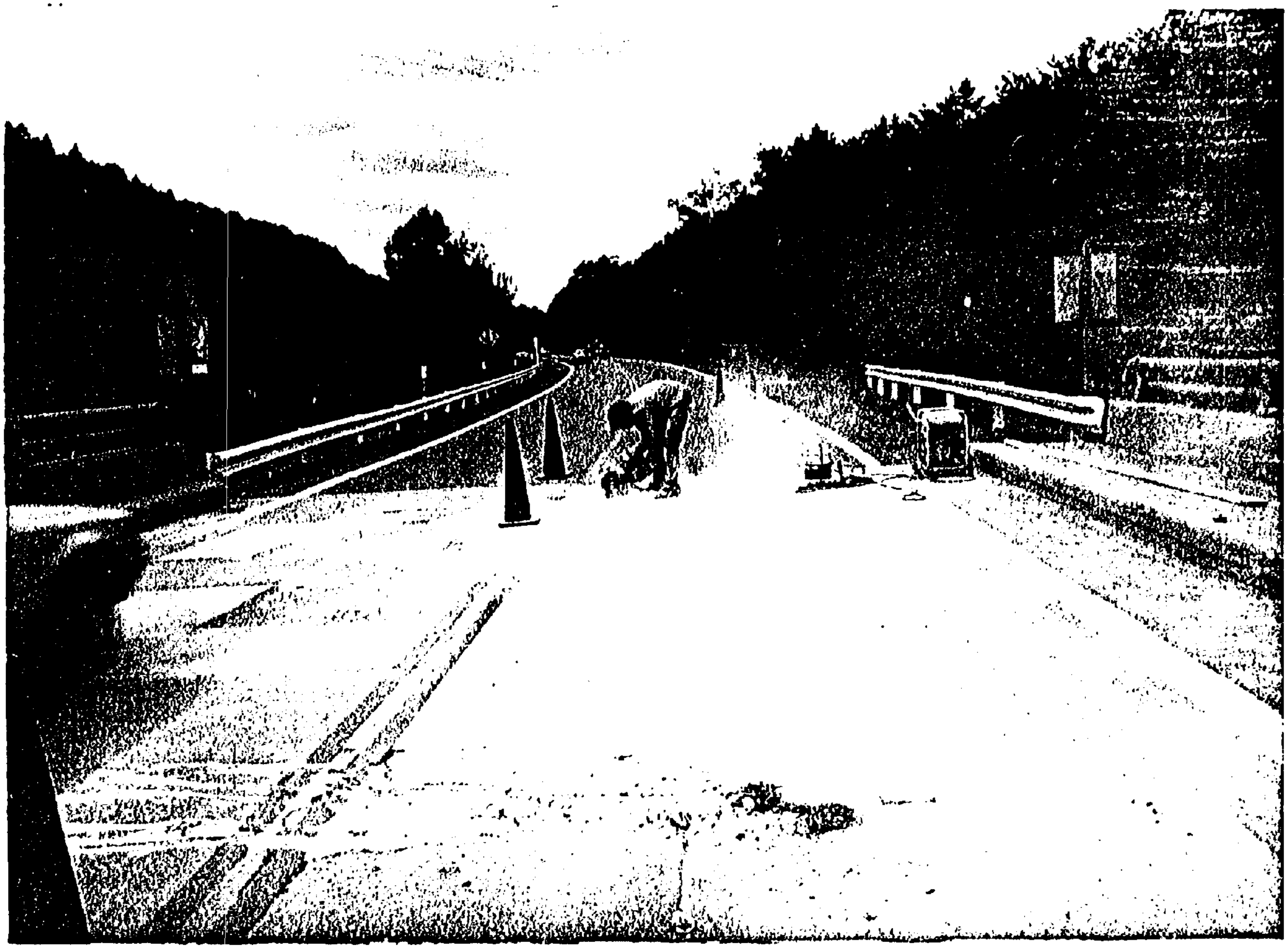


Figure 2.

Figure 3.



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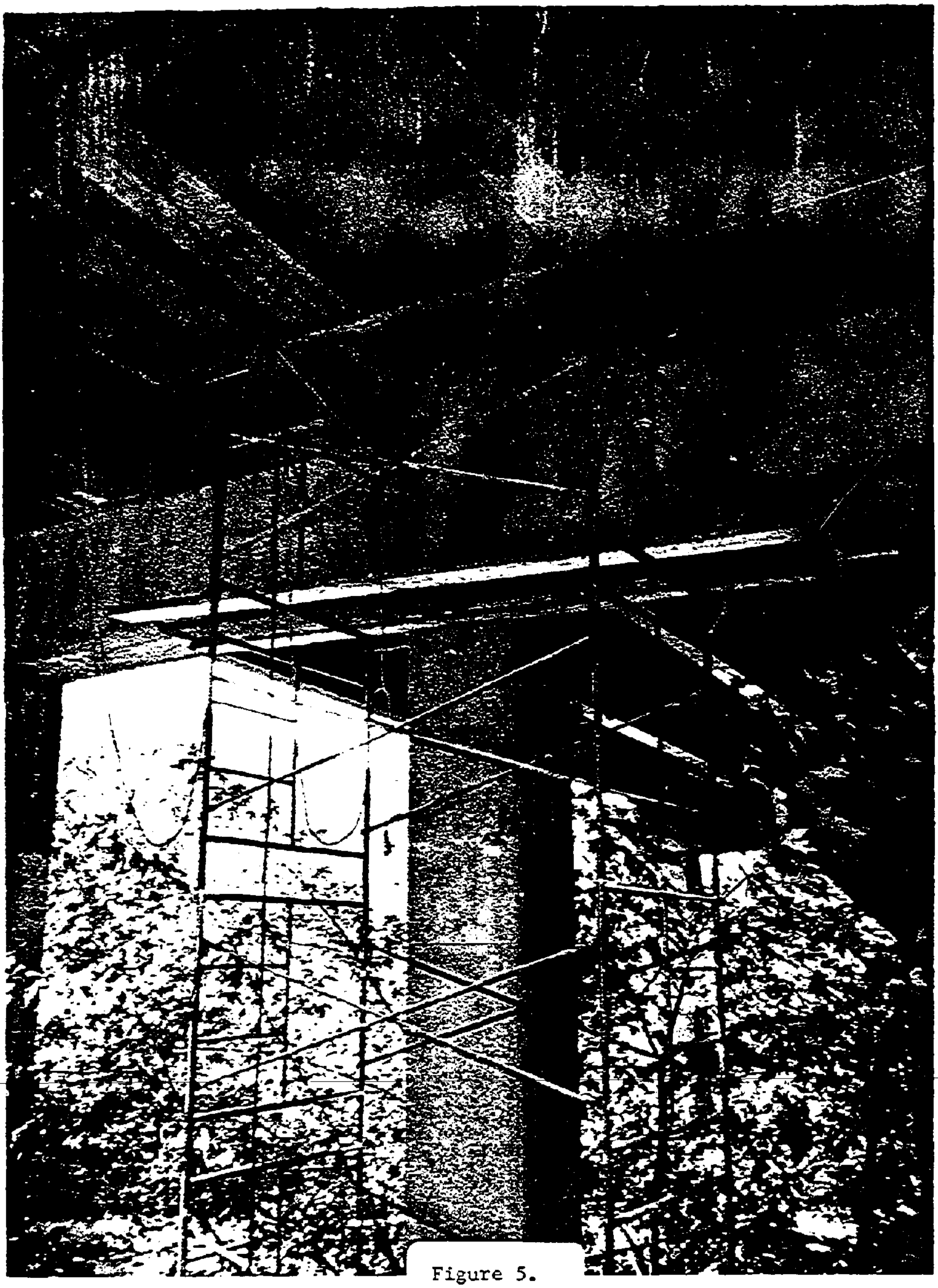

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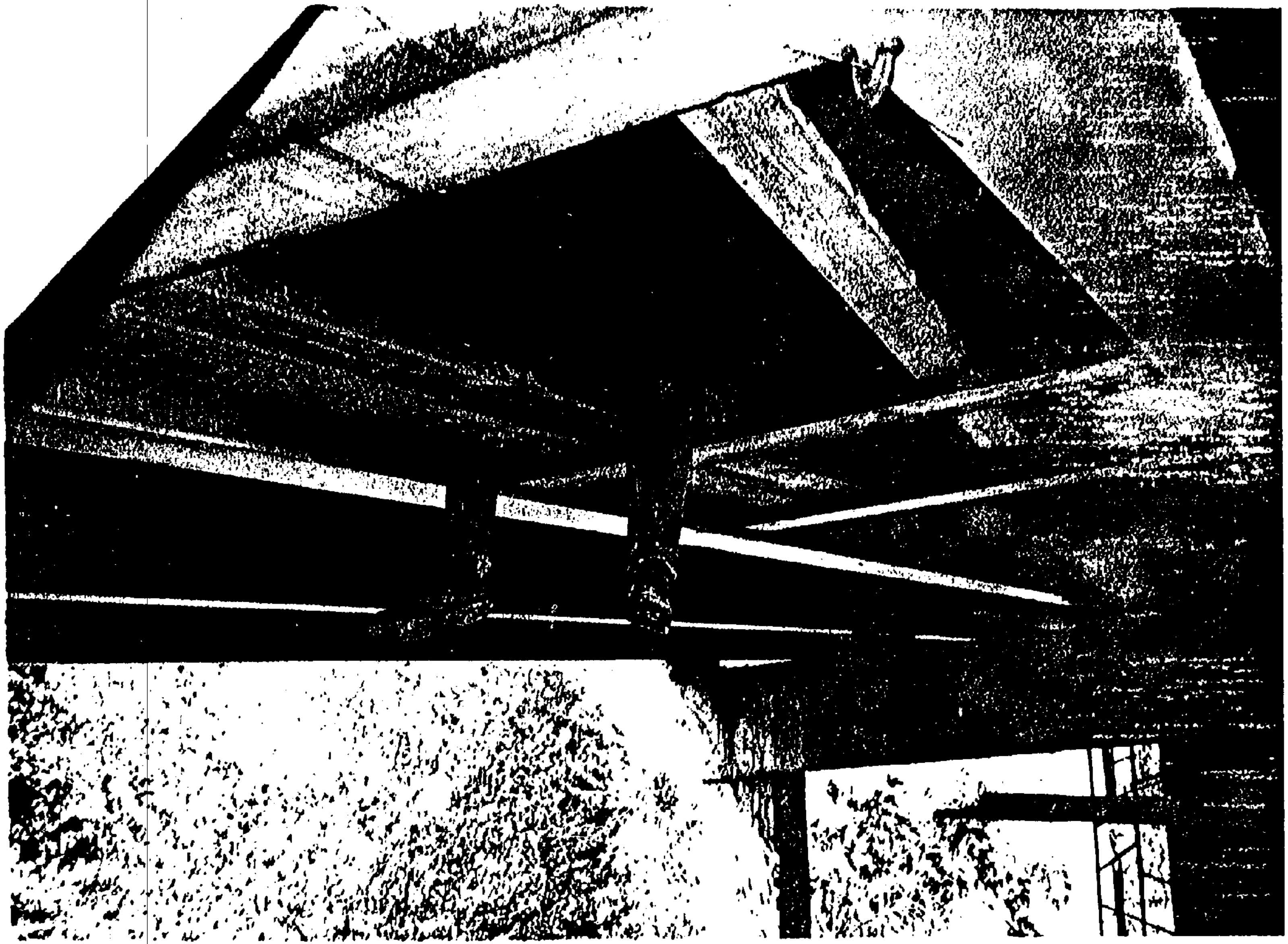
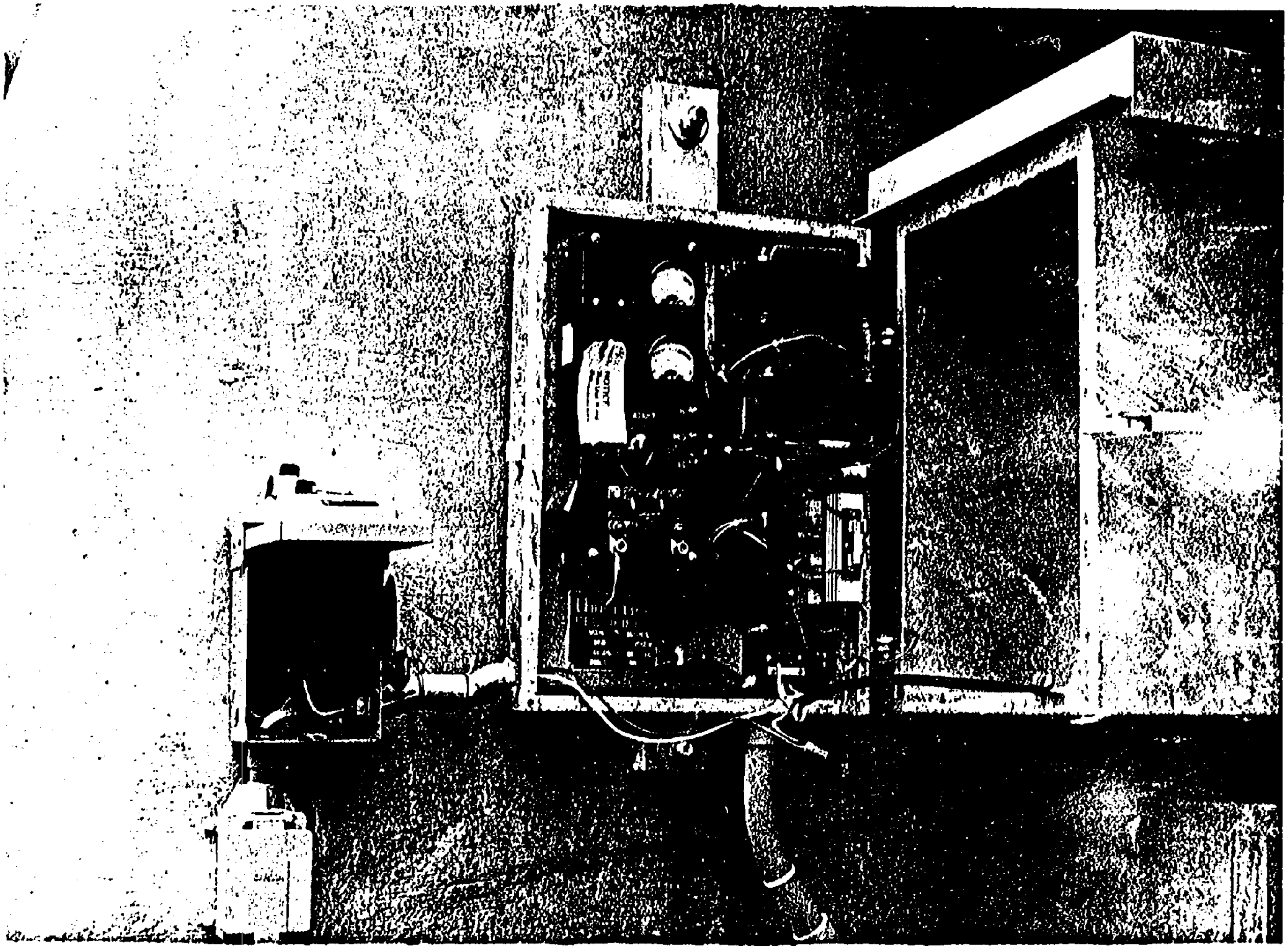


Figure 6.



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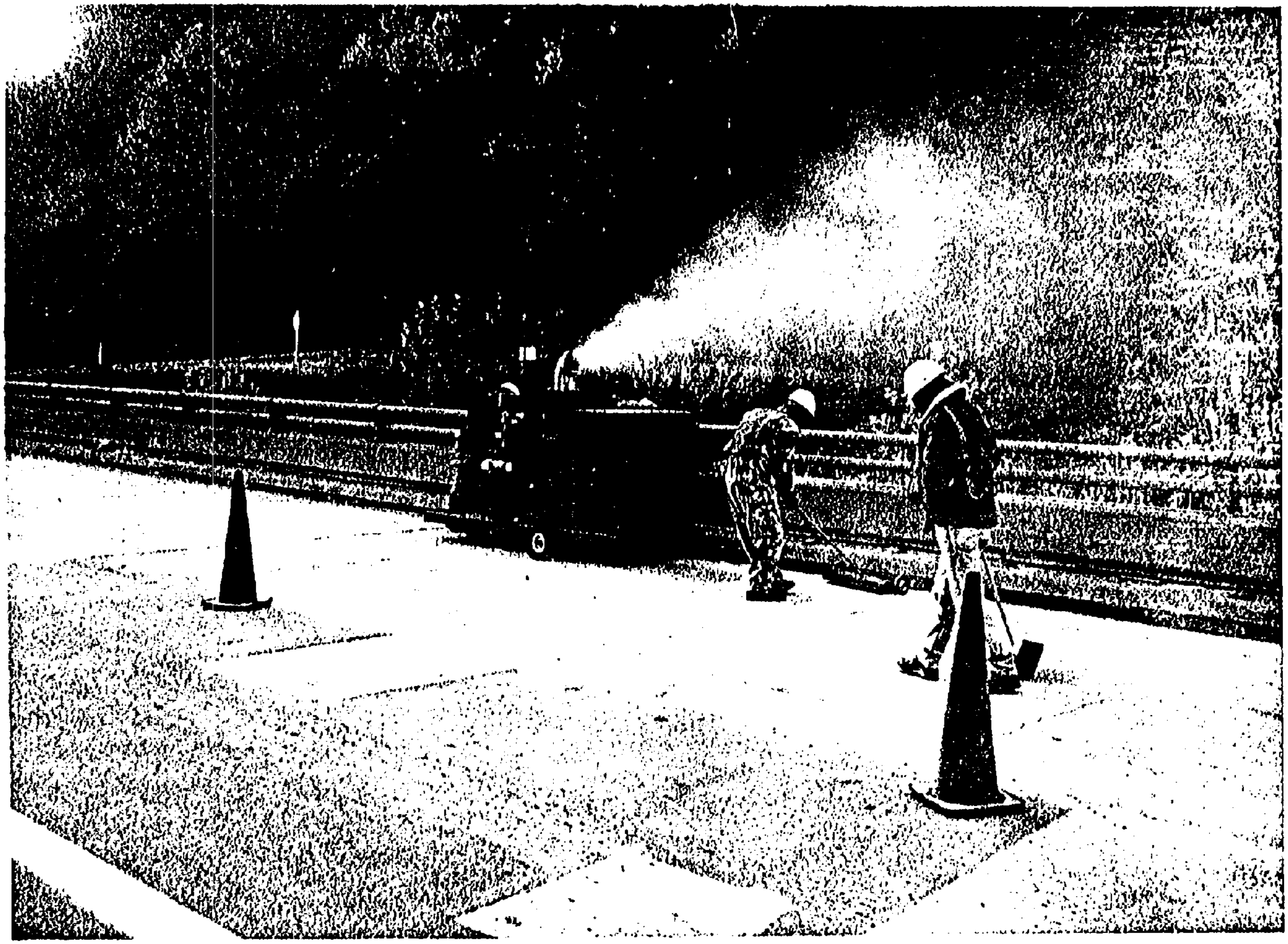

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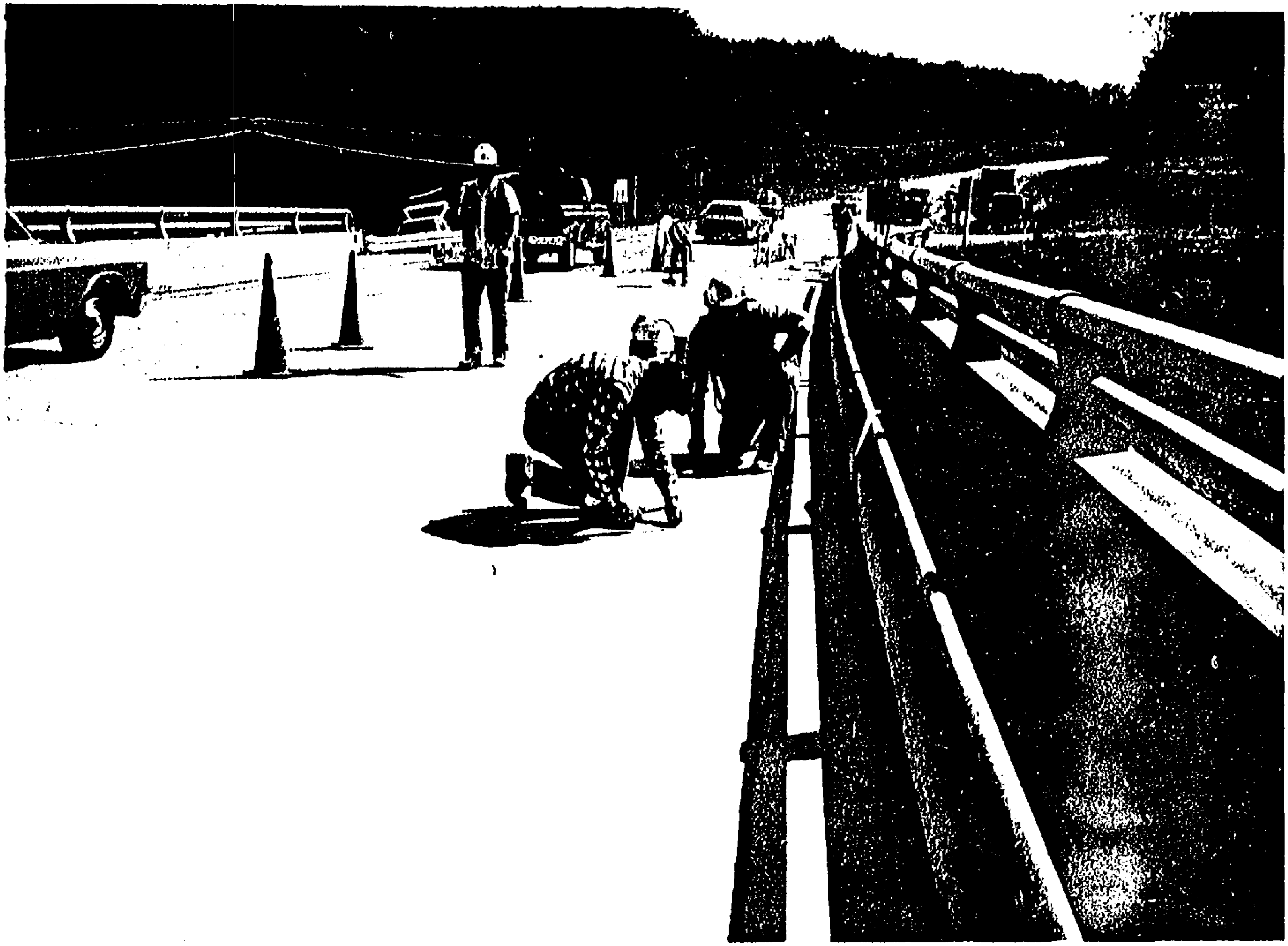

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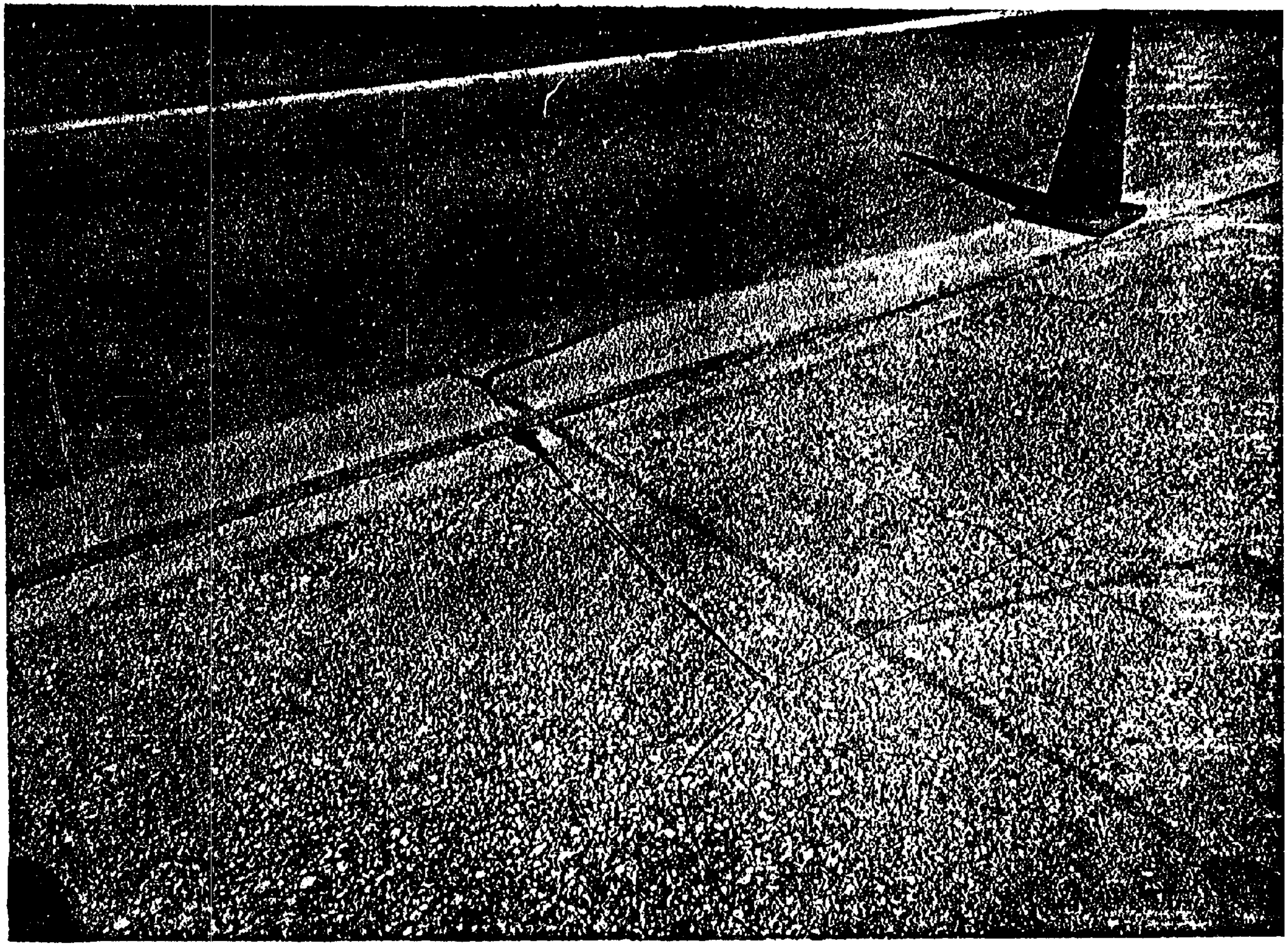
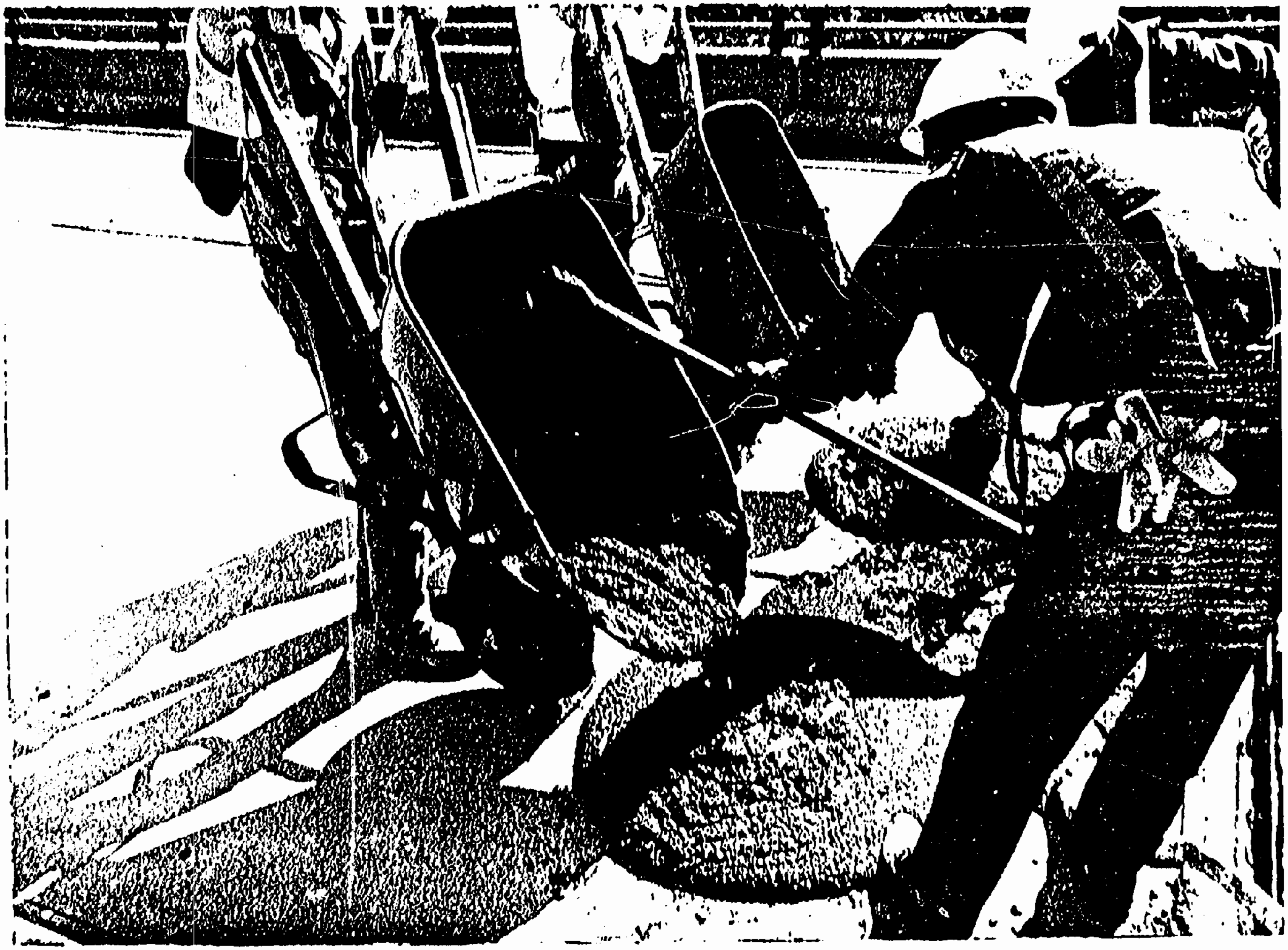


Figure 10.

Figure 11.



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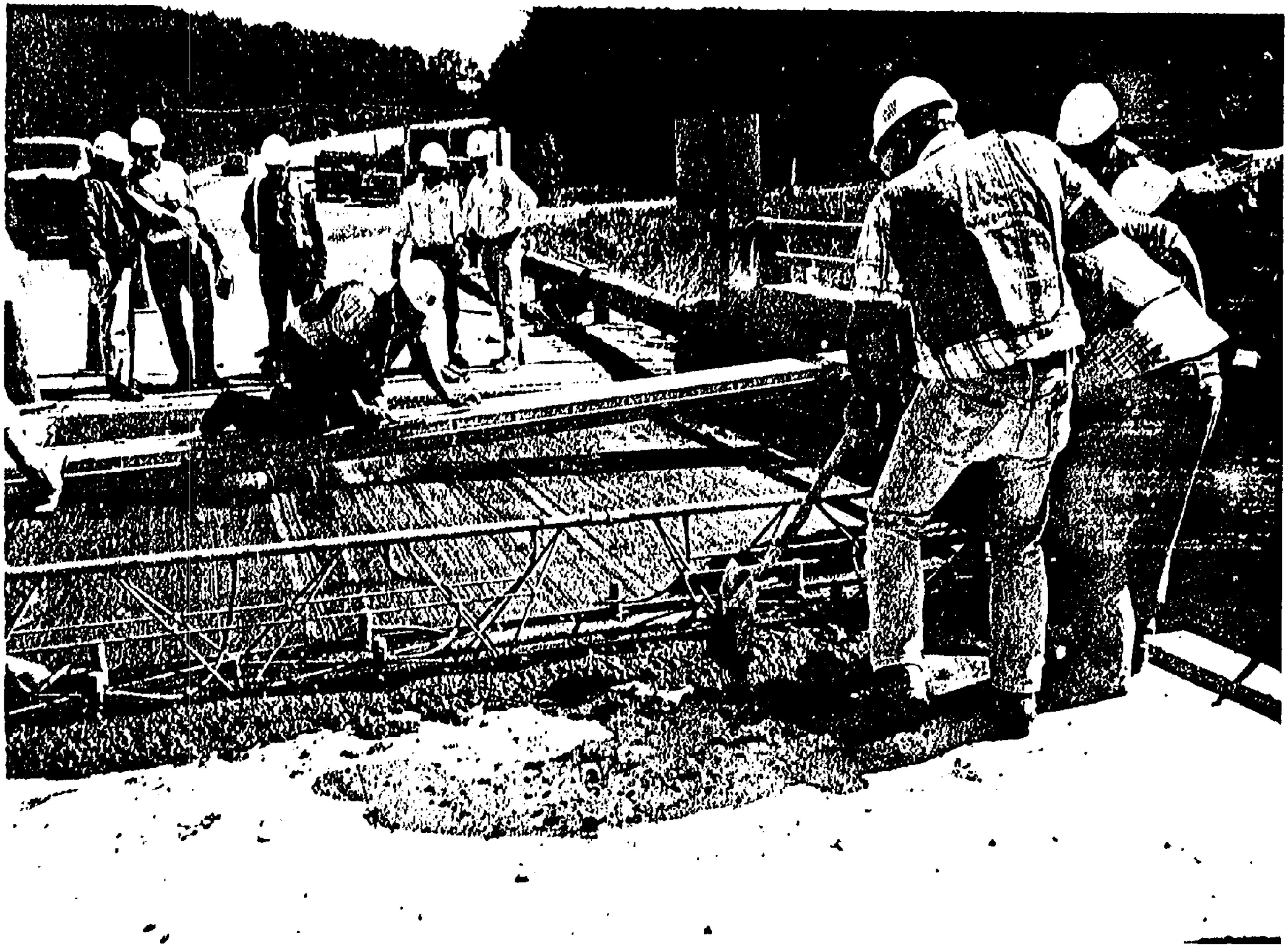

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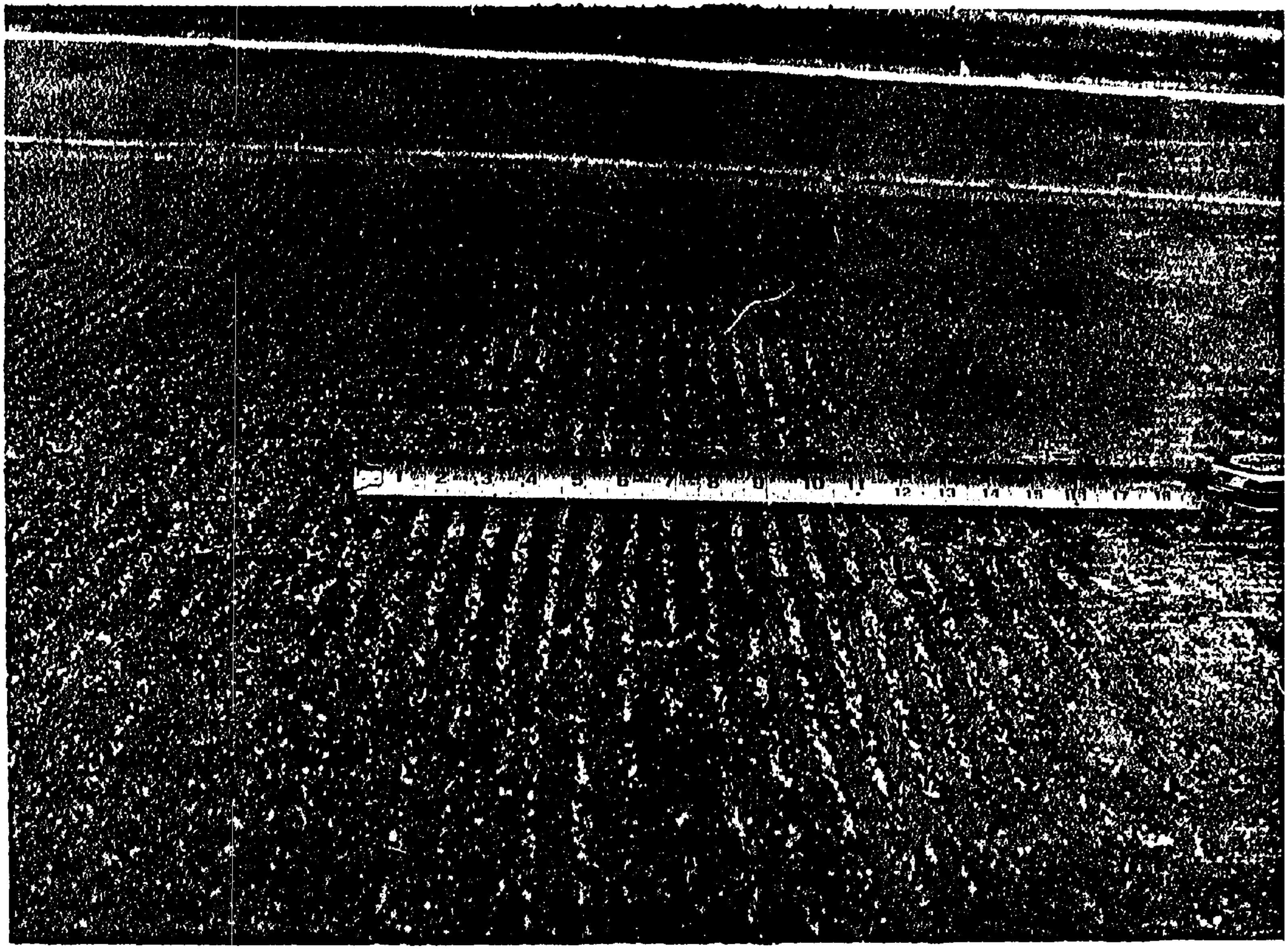

Figure 14.

Bridge over Peak Creek on Rt. 99, Pulaski, VA
Span A

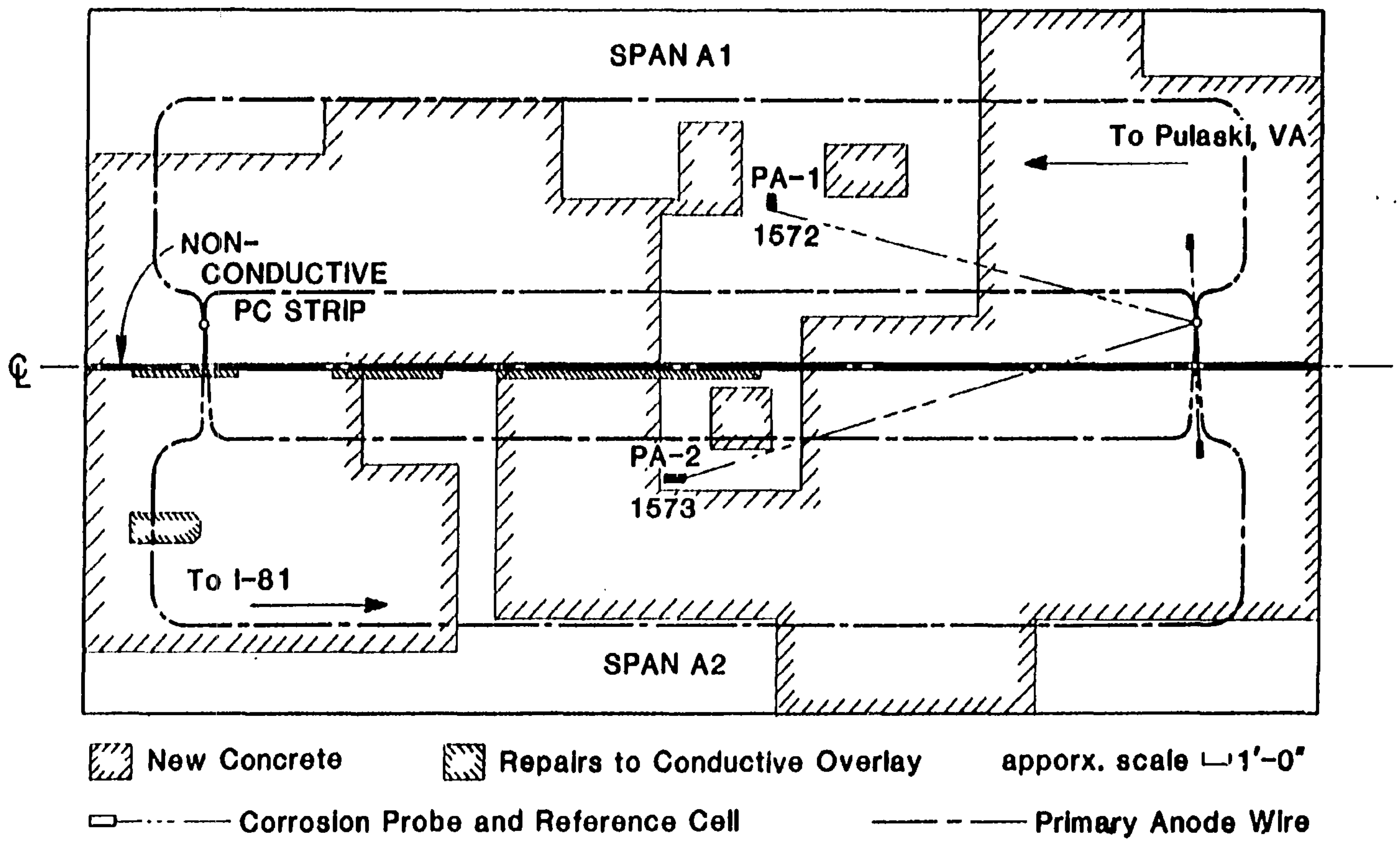

Figure 15.

Bridge over Peak Creek on Rt. 99, Pulaski, VA
Span B

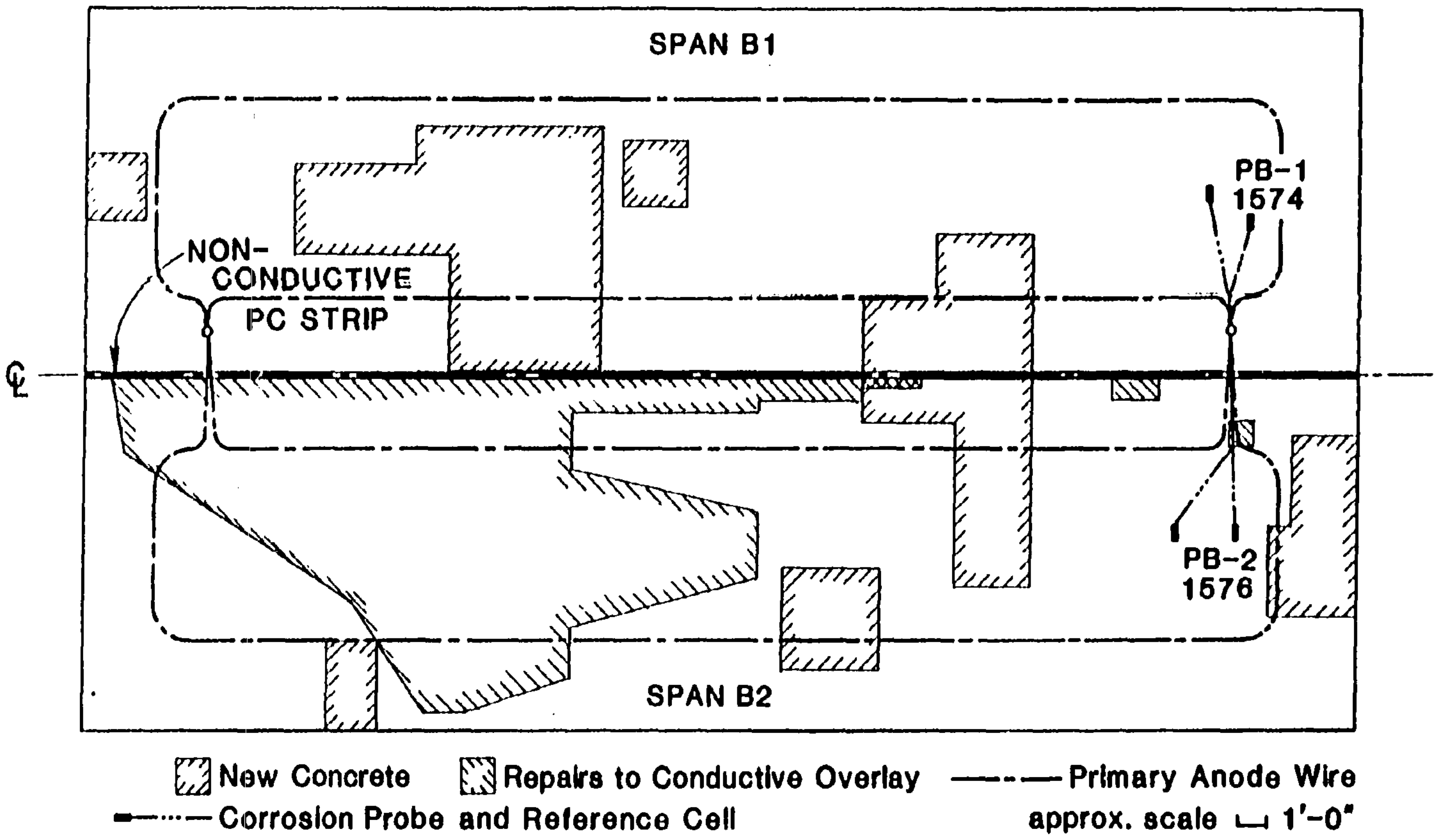

Figure 16.

Bridge over Peak Creek on Rt. 99, Pulaski, VA
SPAN C

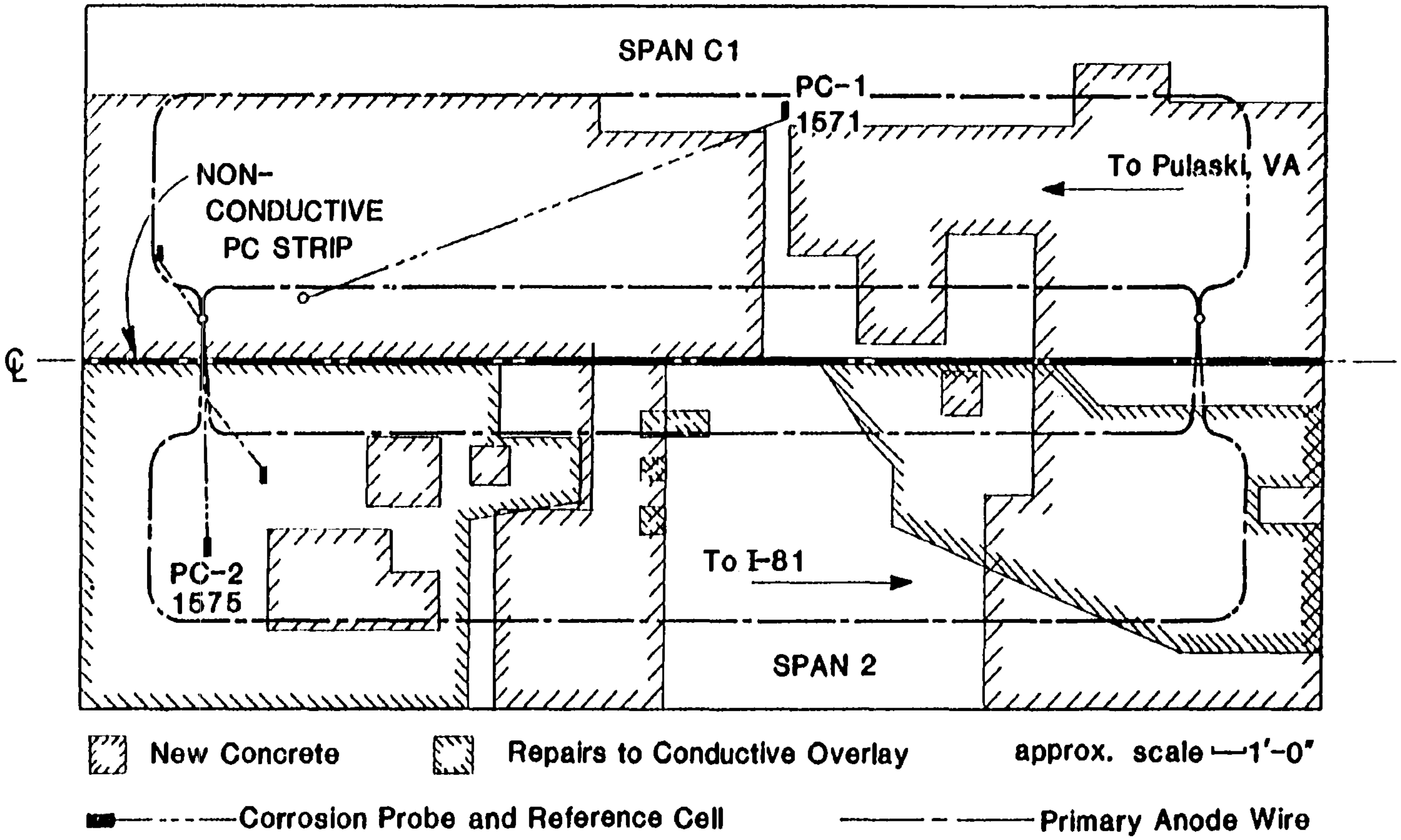

Figure 17.

Figure 18.