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Investigation of Cracks in Cylindrical Spun-Cast Concrete Piles in a Marine Environment

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16. Abstract

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The most extensive cracking was further investigated with help from a Federal Highway Administration demonstration boat. This boat was used to conduct underwater inspections on I-10 between Ramah and Whiskey Bay, on I-10 over the reserve relief canal, and on the Twin Spans between New Orleans and Slidell.
Underwater pictures and video were taken on the Ramah to Whiskey Bay span and on the Reserve Relief span. Half-cell corrosion potential measurements were also taken at the Reserve Relief location.
In general the damage uncovered during this investigation was found to be minor and only warrants monitoring. Therefore, in lieu of remediation guidelines, we have come up with revised inspection activities to be carried out during underwater inspections.
An extensive literature review, discussions with DOT's that possess marine environments, and discussions with a cylindrical pile did not definitively identify the cause of the cracks being investigated in this study. A number of theories abound, the most likely being that the significant cracks are due to overdriving the piles during installation.

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Implementation Statement

As a result of this study, the investigators recommend that DOTD not take any immediate actions to repair the existing cracks in the 54-inch cylindrical piles. The investigators recommend that the DOTD add the following to their five year underwater inspections:

1. Monitor and track existing hairline cracks and

2. Conduct half-cell potential tests on cracks with widths greater than 0.013 inches.

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INTRODUCTION

Louisiana uses 54-inch cylindrical piles post-tensioned in the southern part of the state on relatively long bridges above swamps and coastal waters. Typical examples include the US 90 Bridge over Wax Lake Outlet, I-10 on the east and west approaches to New Orleans, US 11 east of New Orleans, and I-55 north of New Orleans. DOTD bridge inspectors have reported that many of these piles exhibit vertical hairline cracks over the post-tensioning ducts.

Louisiana has thousands of these piles in service and typical remediation work for this problem has proven to be very costly (in the case of jacketing, the retrofit costs are on the order of thousands of dollars per pile). Therefore, before the problem of cracks in these piles reaches a critical repair state, it is imperative to set up a systematic monitoring procedure and determine accurately the level of damage in the inventory of these piles. As a follow-up, guidelines need to be set up for future underwater inspections.

OBJECTIVES

The objectives of this project are:

- Evaluate the extent of cracks in 54-inch cylindrical spun-cast concrete piles in Louisiana.
- Identify the piles exhibiting the worst cracking.
- Evaluate the in-site condition of the most severely cracked piles by non-destructive evaluation (NDE) methods.
- Identify possible causes of these cracks.
- Develop guidelines for future inspections of these piles.

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SCOPE

Impetus, Nature, and Scope of Problem

As mentioned previously, DOTD has a large inventory of 54-inch post-tensioned cylindrical piles in service in marine environments. These piles have performed very well for many years, with little maintenance. However, recent inspections of the Greater New Orleans Expressway Commission's Lake Pontchartrain Causeway have uncovered severe cracks in identical 54-inch post-tensioned cylindrical piles. Furthermore, discussions with DOTD district bridge maintenance personnel revealed that there was some cracking in DOTD's inventory of 54 inch piling. These two facts, the severe cracking on the Lake Pontchartrain Causeway and the existence of cracks in DOTD piles were the main impetus to this project.

At the start of this project, the nature and the scope of the problem was not completely known. It was known that cracks existed in DOTD's inventory of 54-inch post-tensioned cylindrical piles. However, the extent and severity of these cracks were not completely quantified. Thus, the major part of this project was to inspect and catalog the cracks in these piles.

This project was limited to 54-inch cylindrical piles in marine environments. The piles are confined to districts 2 (New Orleans), 3 (Lafayette), 61 (Baton Rouge), and 62 (Hammond).

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METHODOLOGY

Literature Survey

The information presented here is a result of a search of the TRIS and NTIS databases. A search on WWW databases was also performed and uncovered some references. The paper by Dilger, Ghali, and Rao is the most pertinent and is discussed first [*1*]. Most of remaining information available in the literature is either general in nature or peripheral to the problem of cracks in cylindrical piles.

Improving the durability and performance of spun-cast concrete poles

This paper by Dilger, Ghali, and Rao deals with the durability of spun-cast concrete poles [*1*]. These poles are tapered and much smaller than the concrete piles being investigated in this project (14" diameter and 2.5" thick at the base vs. 54" diameter piles with a 5" wall thickness), but they are spun-cast and are exhibiting the same type of vertical cracks. Thus, the findings of this paper may be applicable not only to spun-cast poles, but to spun-cast piles as well.

Dilger et. al. found that the most frequently observed type of damage was vertical cracking. The widths of these cracks ranged from 0.05 mm hairline cracks to 12 mm wide cracks. Through a series of experiments, they feel they have identified the cause of cracks. They propose that segregation during the spin-casting process, where the coarse aggregate migrates to the outer wall, is the cause of the cracks. They reason that the aggregate is restraining the shrinkage in the outer layers of the pole and not in the inner layers. This differential shrinkage strain causes an overall hoop stress that results in vertical cracks.

Dilger et. al. then describe a parametric study to develop a concrete mix that will improve the durability of spun-cast concrete poles. The desired properties of the new concrete mix are:

- High Strength
- Small Differential Shrinkage
- Durability Against Freeze-Thaw
- Resistance Against Chemical Attack

The high strength is an indicator of overall quality of the mix. High strengths are achieved by using silica fume and/or fly ash. The differential shrinkage is limited by limiting segregation of the mix during spin casting. Durability is improved by using air-entraining agents. Dilger et. al. carry out an extensive parameter study and have come up with a recommended mix to improve durability of spun-cast concrete poles.

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Cracks in concrete

There are numerous works on cracks in concrete. We will discuss the works concerned with cracking and corrosion in the next section. Studies of cracks in concrete that are not concerned with corrosion often deal with fracture in concrete (see, for example, [*1*]). The field of concrete fracture is currently in the developmental stages, and a detailed survey is beyond the scope of this work. Essentially, the principles of non-linear fracture mechanics are being applied to determine the strength and behavior of concrete members. No one has determined the effect of the cracks on the strength of the piles in question. However, since the pile design is governed by the soil conditions, the structural strength of the pile, even with cracks, may be completely adequate.

Even if the piles turn out to be structurally adequate, the cracks do allow ingress of salt water and the possible resulting corrosion and spalling is a major concern.

Corrosion of concrete

The corrosion of the steel reinforcing bars is an electrochemical process involving the chlorides in the concrete. This corrosion is also accelerated when the concrete cracks and allows moisture and salts to reach the bars. When the bars corrode, the rust expands in volume and creates high pressures against the confining concrete, eventually leading to spalling.

As mentioned earlier, most of the literature available is peripheral to cracks in piles. However, the GNOEC interim report on pile inspections of the Pontchartrain Bridge does address the extent of cracks in piles. While the authors do not report how prevalent the cracks are, their estimates for a pilot study project suggest the problem is affecting most of the piles supporting the bridge [*2*]. It is interesting to note however that a paper by JD Snow seems to indicate that the Raymond circular pile is extremely resistant to corrosion, thus implying that the cracks should not lead to corrosion problems [*3*].

Other than these reports and another report on a bridge in Virginia there are few works describing the extent of cracks and the resulting corrosion circular piles [*1*]. However, there are quite a few works addressing the more general problem of corrosion in concrete; many of these works focus on bridge decks. Corrosion of concrete bridge decks is now, and will continue to be, a major problem facing not only Louisiana, but also the entire United States. As early as 1985, Hull contended that 60 percent of the nation's bridge decks were susceptible to corrosion damage and estimated the eventual cost of replacing these bridge decks to be $112 billion [*4*].

Corrosion prevention/repair techniques

Epoxy injection. One technique to repair concrete cracks and inhibit further corrosion is to inject epoxy into the crack. This seals the crack and prevents deleterious materials from reaching the reinforcing bars. However, this method does not completely stop further corrosion as some of the corrosive solution may be trapped in the cracks.

Cathodic protection. Cathodic Protection halts the electrochemical corrosion process by inducing a current that will oppose the flow of chloride ions from the concrete to the steel. This is done by attaching an anode (+) to the concrete and causing the steel bar to act as a cathode (-). In 1982 the FHWA issued a memo saying that the only rehabilitation technique proven to stop corrosion in a salt environment is cathodic protection. While primarily used for bridge decks, there have been studies on using the system on vertical surfaces [*5*].
On the down side, the cathodic protection system must be installed as a permanent part of the structure and the anode attached to the concrete must be monitored for wear. Also, there is some concern that the CP process may embrittle the prestressing strands [*6*].

Electrochemical Chloride Extraction (ECE). ECE is a new process that Virginia is using on a test project [*7*]. The ECE method is similar to Cathodic Protection except much higher currents are used (up to 500x those used in CP). This causes the chloride ions, which cause corrosion to actually migrate to the surface of the concrete. After the treatment (about 6 to 10 weeks), the current inducing equipment is removed and the concrete is sealed to prevent further chloride penetration.

Accretion of seawater minerals. In 1993, the Virginia Transportation Research Council sponsored a feasibility study looking into repairing cracks in concrete by electrochemical accretion of minerals from seawater [*8*]. In this process the rebar acts as a cathode and an anode is placed outside the crack; this setup causes minerals to deposit on the rebars. Unfortunately, even at the lowest currents the accretion process occurred too rapidly causing an uneven deposit of minerals. It is likely that the level of current in a Cathodic Protection system would suffice to cause a uniform deposit of minerals. Thus one side benefit of a CP system would be the healing of cracks by mineral accretion.

Jacketing. In cases where the covering concrete is badly deteriorated, there are retrofit schemes where a jacket (either fiberglass or fabric) is put around the damaged pile and the annular space between the pile and the jacket is filled with grout (either Portland cement based or epoxy based). One such system, the Master Builder's APE system, is being tested on the Pontchartrain Bridge [*3*]. This system, which uses a clear fiberglass form and an epoxy-based grout injected from the bottom up, has performed well. The drawback to this type of system is that it is fairly expensive.

Nondestructive evaluation (NDE) of concrete

NDE methods are still being developed and may have only limited usefulness in determining the conditions of the piles in question. The information below is condensed from information provided by the Northwestern University Center for Advanced Cement-Based Materials and BIRL Industrial Research Laboratory and a 1994 Virginia Transportation Research Council report [*9*].

Pulse Velocity. In this method a pulse is introduced into a specimen and the velocity of the pulse is measured. The pulse wave travels faster through stiffer and denser material and thus the pulse velocity is correlated to the level of damage in the specimen. This method only gives qualitative results. For example, in the VTRC report on seawater mineral accretion, pulse velocity was used to make before and after comparisons.
For this project, it may be possible to get some sort of baseline reading on an intact portion of a pile and compare it to damaged sections.

Impact-Echo. In this method, stress waves are introduced on the surface by an impact and these waves reflect off of voids and/or cracks. The resulting resonances are analyzed to locate defects. This method is fairly effective for locating large voids or cracks in flat plates where the cracks are parallel to the surface. Since the cracks in the piles are perpendicular to the surface, this method probably would not work well.

Surface Waves. This method seems to be most applicable in determining the elastic properties of layered materials (such as pavement substrates) and therefore would have limited applicability to evaluating cracks in piles.

Acoustic Emission. In this method, the specimen is continuously monitored for sounds emanating from within the specimen. As the reinforcement corrodes and causes cracks, the resulting waves are an indication of the corrosion occurring in the specimen. Practical applications are limited since the acoustic emission is not very strong and concrete has a high attenuation rate.

Neutron Radiography. In this method, high-energy radiation is sent through the specimen and the amount of radiation making it through the specimen is measured. Since the radiation will travel easier through voids, it is possible to obtain images of cracks and voids. Unfortunately, this method only works for thin members and requires massive power to generate the necessary electron beams.

Other Agencies with Bridges Using Cylindrical Piles

One of the most valuable sources of information on the issue of cracks in cylindrical concrete piles has been discussion with transportation agencies from other coastal states. There are 19 coastal states and we have had in-depth discussions with engineers from Virginia, Maryland, Alabama, Florida, California, New York, and Texas. Georgia, Washington, and Massachusetts DOT say that they either do not use these types of piles or do not have problems with cracks in cylindrical concrete piles. We received no response from North Carolina and New Jersey. We did not contact Hawaii, South Carolina, Mississippi, Maine, New Hampshire, Rhode Island, Delaware, or Oregon.

Chesapeake Bay Bridge and Tunnel District (Virginia)

Prestressed cylindrical piles similar to the ones used by DOTD are used on the Chesapeake Bay Bridge and have exhibited cracks.

The piles used for this bridge are 54-inch diameter, five inch thick, cylindrical piles filled with sand or concrete, depending on the individual pile. In July 1988, the Chesapeake Bay Bridge and Tunnel District sponsored a study evaluating the condition of the Chesapeake Bay Bridge tunnel [*9*]. A visual inspection showed that the piles exhibited cracks that were vertical, of varying widths, lengths, and depths, both above and below the waterline. They carried out in-depth analysis of a small subset of ten piles to draw conclusions about the condition of all the piles. This in-depth analysis included measurement of corrosion potential and chloride content, which they correlated to crack width. Based on their results, they made the following recommendations:

- Minor and moderate cracks require no remedial action.
- Cracks should be monitored during future inspections.
- Cracks with widths between 1/16 inch and 1/4 inch should be epoxy injected.
- Piles with cracks wider than 1/4 inch should be jacketed.

In May 1989, the Chesapeake Bay Bridge and Tunnel District put a project out to bid for the repair of these piles. The piles were repaired by a combination of epoxy injection for fine cracks and epoxy packing for wider cracks. They did not attempt to repair any hairline cracks. In a discussion with Paul Burnette, Director of Maintenance, Mr. Burnette said that in hindsight he wished he had studied the problem more before proceeding with the repair project. Specifically, he wished he had taken more core samples to characterize the cracking.

They found after the project started that that many of the cracks necked down to zero width after a depth of one inch, which made the epoxy injection process difficult. If he had the opportunity to do the project over, he said he might consider routing the cracks and then packing them with epoxy and that he would look at some sort of bridging agent, possible an epoxy based coating material.

Maryland DOT

The Preston Lane Bridge in Annapolis is also supported by 54 inch prestressed cylindrical piles and is exhibiting cracks. In a conversation with Bill More, Director of Maintenance at the Preston Lane Bridge, Mr. More characterized the cracks as 30 to 40 feet long varying in thickness from hairline to 1/2 inch -- much more severe than the cracks in the Chesapeake bridges. Placing 1/4 inch thick by 4-inch wide stainless steel bands eight to ten inches on center along the width of the cracks repaired these cracks. They then epoxied all the cracks. This repair has been in place over 14 years and is still performing well.

Alabama DOT

Both the Mobile Bay Causeway Bridge and the I65 Delta Crossing use 54 inch spun cylindrical piles. Alabama DOT bridge inspectors have found vertical hairline cracks randomly distributed throughout the piles. They do not feel this is a problem because the piles have been in service since 1978 and the cracks have not grown during the last two inspection cycles. Their current plan is to continue to monitor the piles.

Florida DOT

Florida DOT's I-10 Escambia Bay Bridge (left and right) and US 98 Over Pensacola Bay both use 54 inch cylindrical piles. While DOT officials state that they have had no problems with cracking in these piles, according to bridge inspection reports on these bridges, "there are several class 1 and 2 vertical cracks" on the piling and "the piling have been sprayed with Penetrant Sealer to prevent moisture from entering."

New York DOT

The Chautauqua Lake Bridge uses the 54-inch cylindrical piles in question. According to Doug Daniels, with the New York DOT, they have not had any problems with these piles. In another discussion with Henry Daniels, project manager for the construction of this bridge, there were no problems with the piles when they were delivered or during driving in 1978. He characterized the piles as "of good quality," with compressive strengths in the 9,000-psi range. He mentioned that during test-driving they had problems with spalling but when forced to go with a smaller hammer and apply additional blows for environmental reasons, these problems disappeared. He also mentioned that during construction they took great care whenever they moved the piles and were also very careful to have the piles vertical for driving.

CALTRANS

CALTRANS uses 54-inch diameter cylindrical piles on various bridges. According to Mr. Joe Gallippi, a structure in Coronado did have cracks that appeared during construction and delivery in 1969. They modified their driving technique and subsequently have not had many problems. As for the damaged piles, they repaired these cracks with a corrugated sleeve and grout. They also have vertical cracks throughout the piles, are monitoring them, and have taken investigative cores. Mr. Gallippi also mentioned that their Los Angeles team is carrying out lateral load tests on damaged (cracked) 54 inch cylindrical piles and should have results fairly soon.

Greater New Orleans Expressway Commission

The investigators had a chance to peruse the Interim Report of Pile Inspection prepared for the GNOEC by Krebs, LaSalle, LeMieux Consultants, Inc. The piles discussed in the GNOEC interim report are identical to the piles in question in this study.

In this document, the consultant reports on their ongoing pile inspections and discusses various repair procedures. Of the 9,000 piles supporting the bridges, only two were found to be structurally damaged. They did find deterioration in a number of piles but gave no figures as to the number of piles and the extent of the deterioration. They took core samples and found that while there was no problem with chloride in the intact concrete, there was moderate to low levels of chloride in the vicinity of the cracks. A more severe source of salt-water entry was at butt joints where the grout had completely eroded away.

The consultant also made recommendations on repair and rehabilitation and seemed to favor a combination of jacketing schemes, proposing the fiberglass jacket for exterior piles and fabric jackets for interior piles.

New Jersey DOT

54-inch cylindrical piles support the Absecon Inlet Bridge.

Other Coastal States

Texas, Georgia, Washington, and Massachusetts DOTs do not have any projects using the 54-inch cylinder piles. Texas DOT is considering using them on a future project. Georgia DOT has had problems with cracks in octagonal prestressed piles due to improper driving.

Tasks and Activities

One of the first activities conducted was contacting all 19 coastal states regarding their experience with cylindrical spun-cast piles. Each state was asked the following three questions:

1. Are cylindrical spun-cast piles being used?
2. If so, have there been problems with cracks?
3. What has been done to address these problems?

The results of this phase are presented above.

The next task was visiting a manufacturer of these piles: Gulf Shore Prestress of Pass Christian, Mississippi. The objective of this task was to gather additional information to help determine the cause of the cracking.

Specifically, the manufacturing process, curing process, and mix design were evaluated. In particular, these factors were compared with the recent findings of Dilger, Ghali, and Rao [*10*].

Once this background information was obtained, the next task was to catalog the level of damage in DOTD Piles. This effort was started by reviewing DOTD maintenance databases, reviewing drawings, and interviewing appropriate DOTD personnel.

DOTD inspections reports did not identify any trends in the damage. There was no discernable correlation between pile cracking and age, pile manufacturer, or location. These reports and interviews with district personnel did however identify piles that seemed to have the most damage. These piles became the focus, a level I above water survey.

Several weeks were spent on a small boat conducting a drive-by inspection of all piles accessible via water. The cracking was sporadic and most cracks were only of hairline thickness, so there was no call for a rating scheme. Instead, records were kept of all piles with hairline cracks. The few piles with cracks wider than hairline were noted and identified for a more in-depth investigation.

The next task was a level III survey, including an underwater investigation of the piles with wider than hairline cracks. This phase of the work was conducted with the assistance of the Federal Highway Administration. The FHWA currently supports a demonstration project on inspection of underwater substructures. The centerpiece of this project is a boat equipped with underwater and non-destructive testing apparatus. This boat was available to this project for a one-week period.

With the assistance of the FHWA boat, underwater pictures and video were taken of the most severely damaged piles. In addition to this, half-cell potential tests were conducted on three of these piles.

The final task involved interviewing Dick Snow and representatives from Krebs, LaSalle, LeMieux Consultants, Inc. Dick Snow helped develop the original Raymond Cylindrical pile, and Krebs, LaSalle, and LeMieux are the consultants evaluating the Lake Pontchartrain Causeway for the Greater New Orleans Expressway Commission.

Discussion of Results

District Visits and Interviews

Every district was contacted and, if warranted, visited to determine if there were 54-inch cylindrical piles in use. The results of this survey are listed in table 1 below.

Table 1
District Surveys

District	Contact	Pile Inventory and Damage
2 New Orleans	Ken Orgeron	Piles on Twin Spans between New Orleans and Slidell and on I-10 over Bonney Carey Spillway Taken to Twin Spans – no cracks found (only seams)
3 Lafayette	Russel Shexnider	District personnel recall that the cracks are getting larger but could find no documentation. Piles on I-10.
4 Shreveport	Chuck Deramus	Don't have 54-inch cylindrical piles.
5 Monroe	Frank Nolan	Don't have 54-inch cylindrical piles.
7 Lake Charles	John Young	Visited district and found out they don't have 54 inch cylindrical piles.
8 Alexandria	Mike Dupuis	Don't have any Raymond piles.
58 Chase	Dennis Wollerson/Kirk Renfrow	Don't have 54-inch cylindrical piles.
61 Baton Rouge	Doug Allen	Visited district and found out that piles are used on I-10 between Baton Rouge and Lafayette. Worst ones are between Ramah and Whiskey Bay.
62 Hammond	Nace Garafola	Bridges, which use the 54-inch piling, are I-10 over Reserve Relief Canal and 55.

Pile Manufacturer Site Visit

A visit was made to a manufacturer of these piles: Gulf Shore Prestress of Pass Christian, Mississippi. The objective of this task was to gather additional information to help determine the cause of the cracking. The manufacturing process is illustrated in figures 1 to 11. Figures 1 to 3 show the processes involved in making the spiral cage for the pile segment. Figures 4 to 6 illustrate the centrifugal casting process. Figures 7 and 8 show the

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piles being cured horizontally initially and then vertically. Figure 9 shows the individual segments being prestressed together, and figure 10 shows a pile consisting of three segments prestressed together.

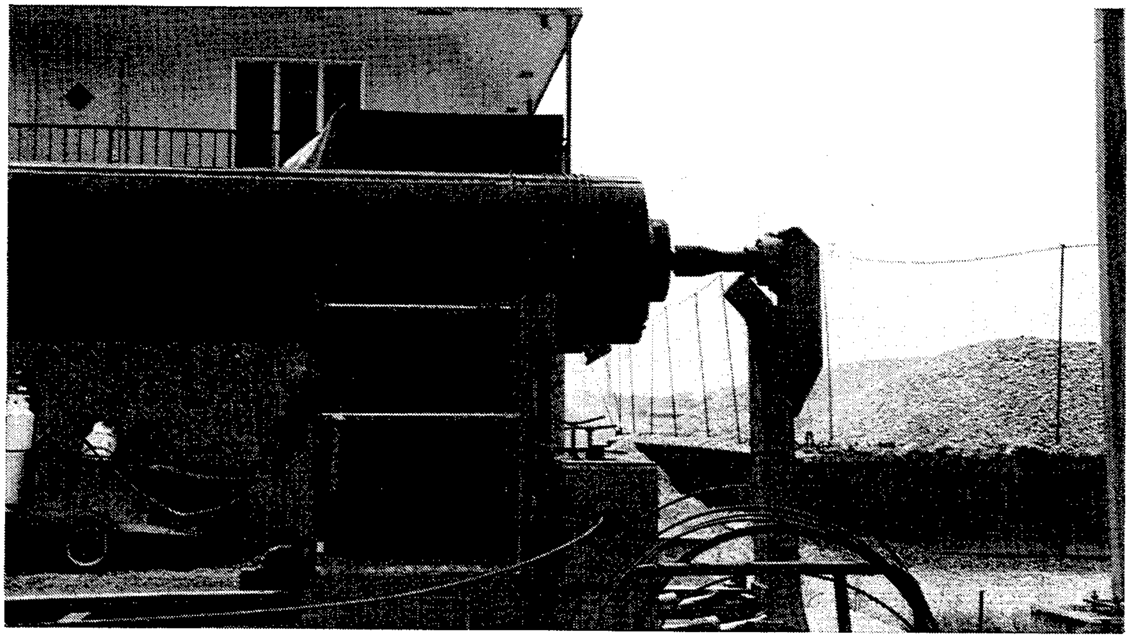

Figure 1
Machine for forming wire spiral

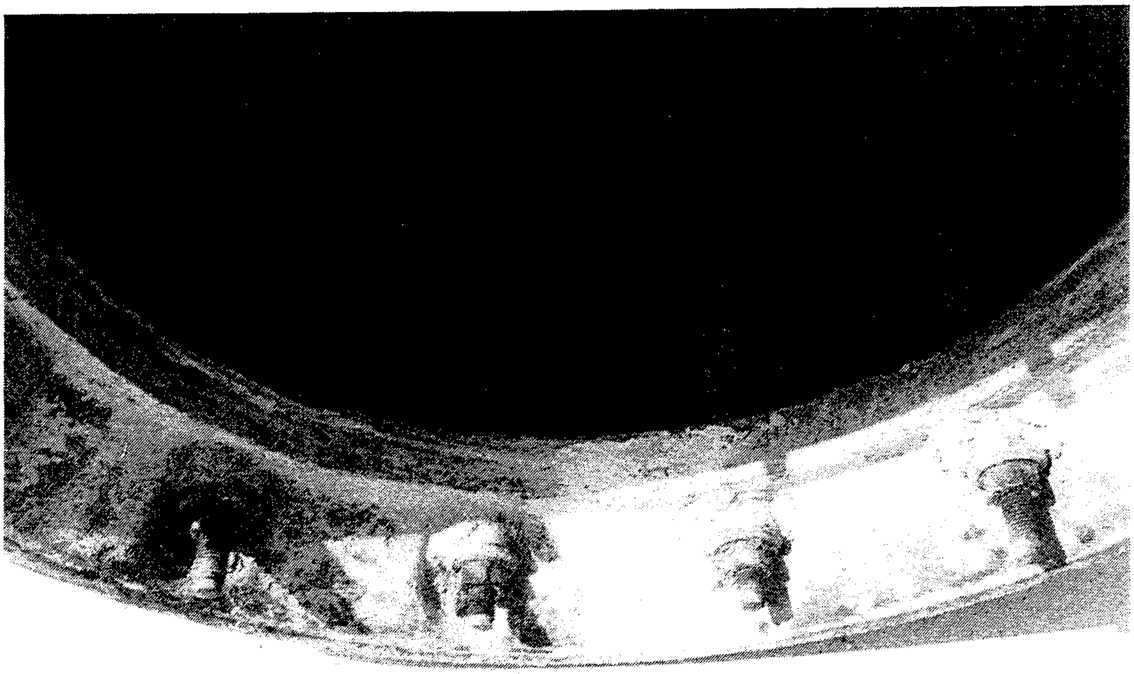

Figure 2
Close-up of spiral and duct formwork

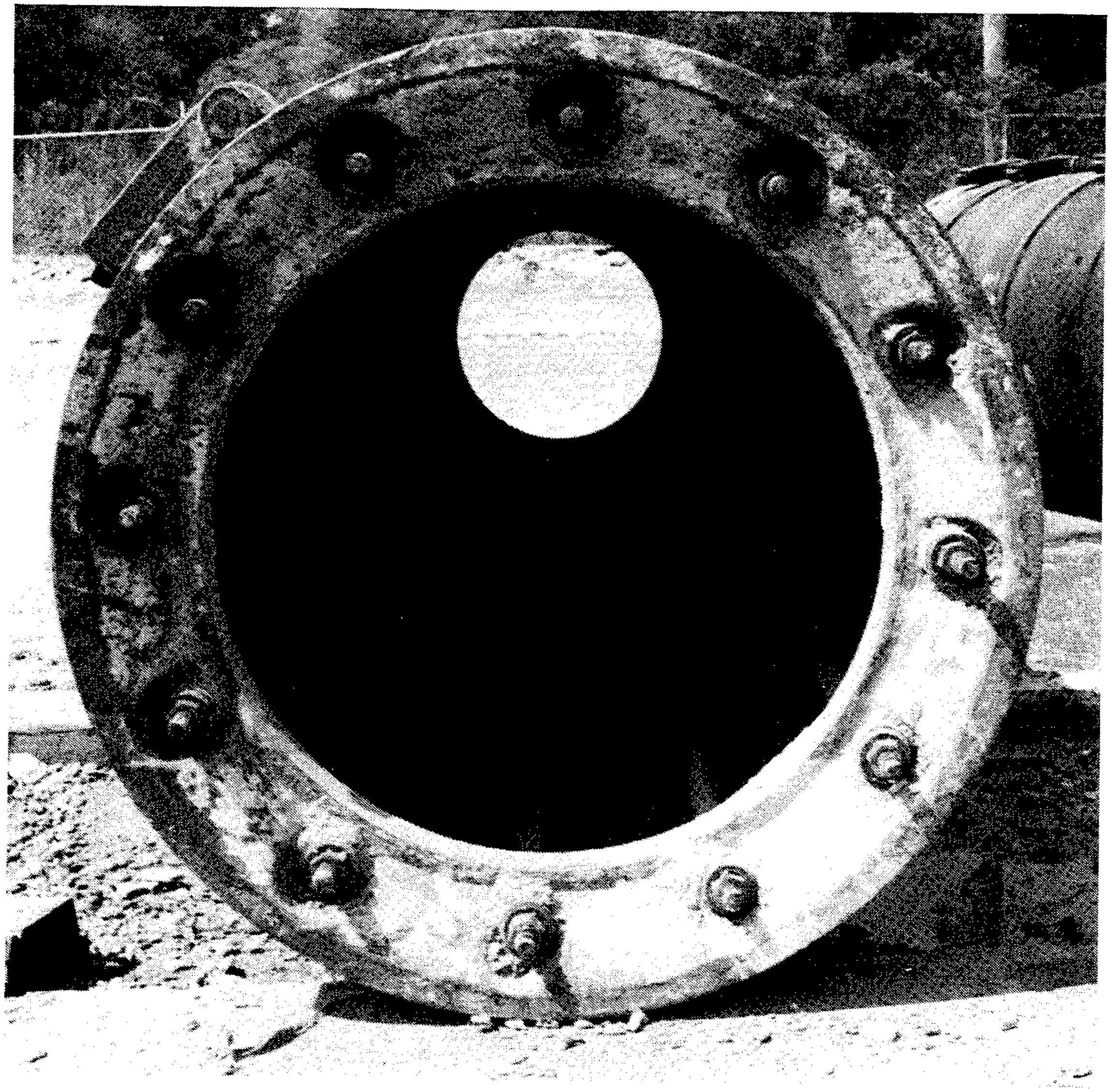

Figure 3
End view of form ready for casting and spinning

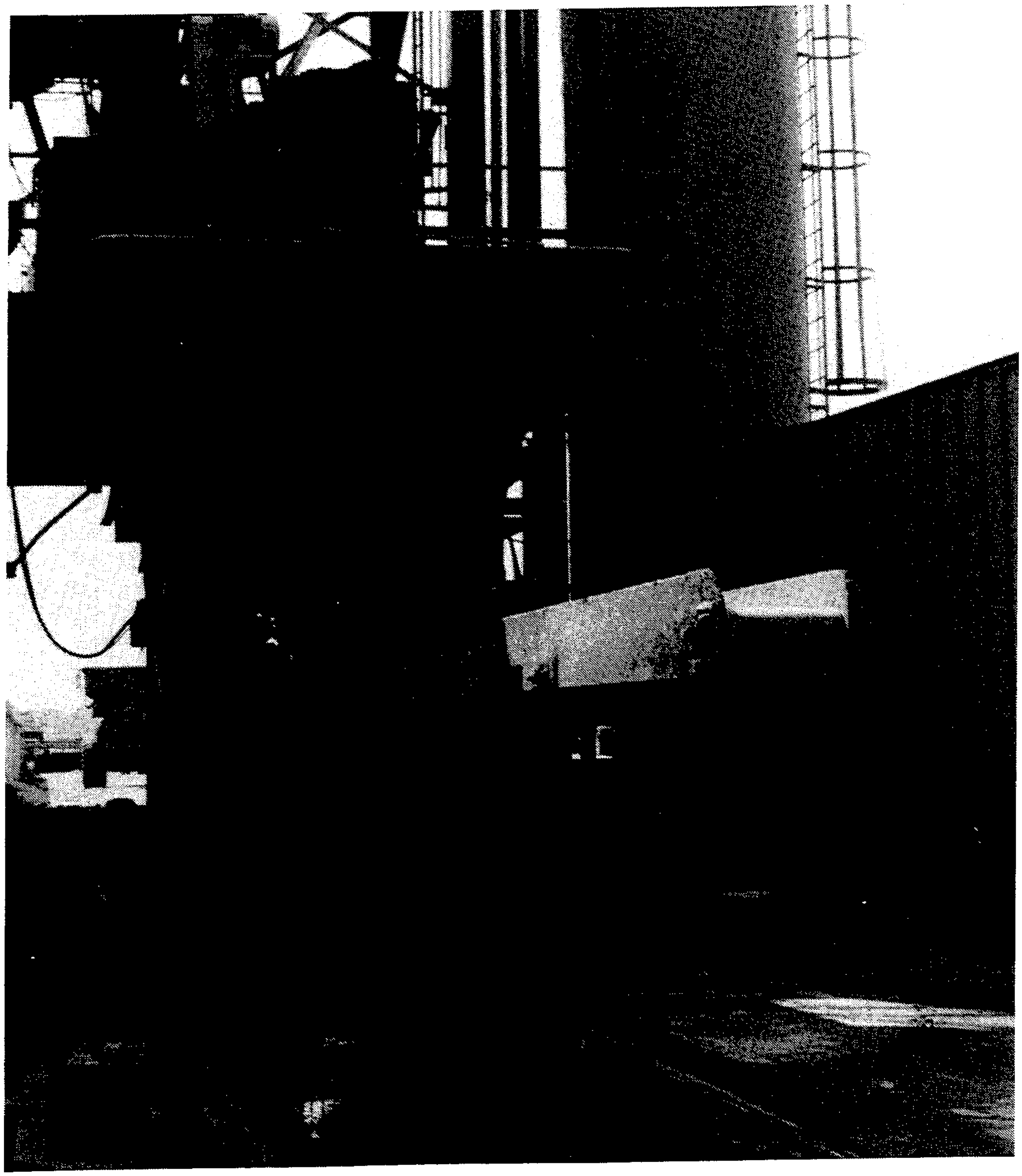

Figure 4
Conveyor mechanism for placing concrete

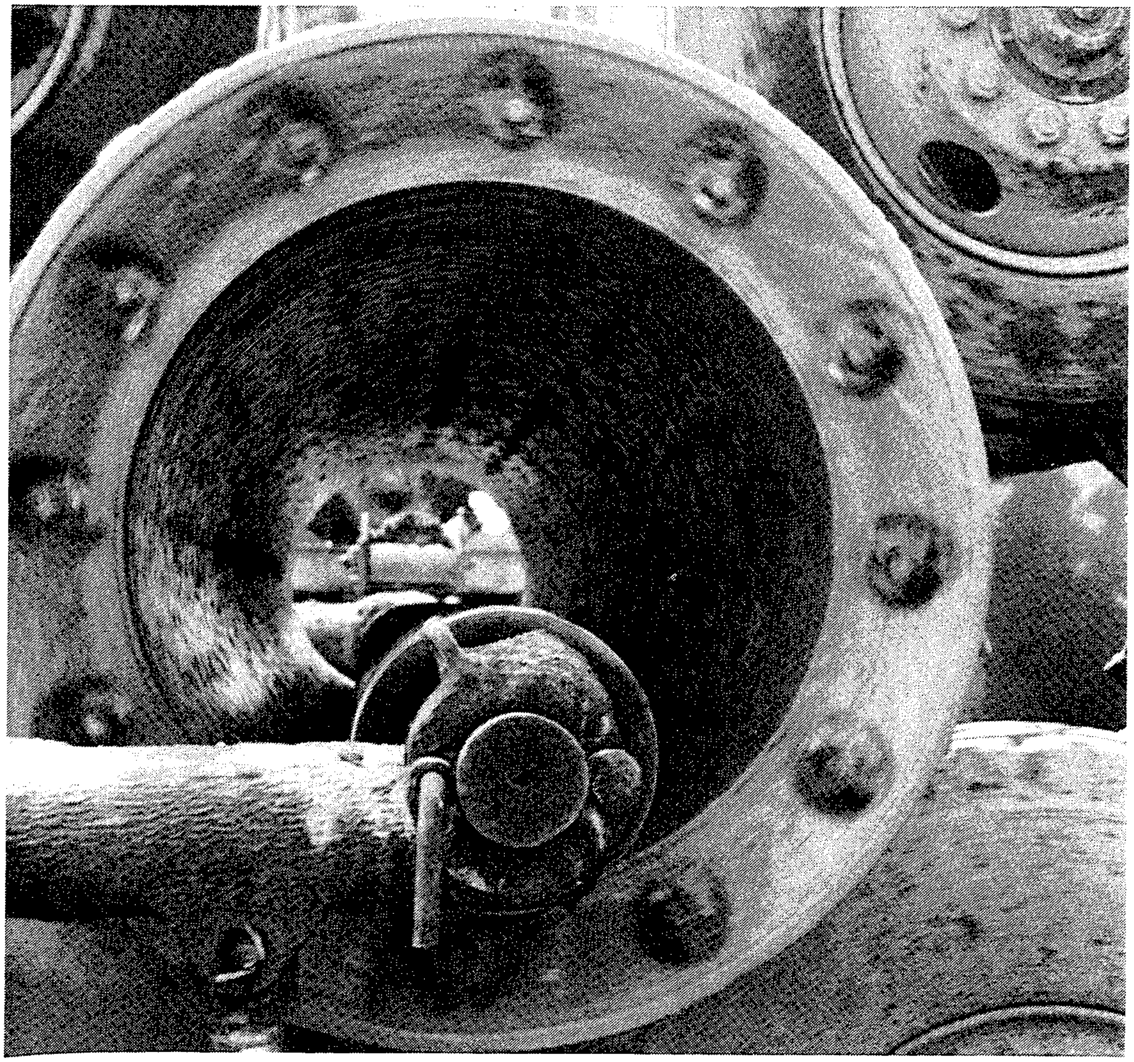

Figure 5
Concrete being placed and compacted

Figure 6
Concrete being spun-cast

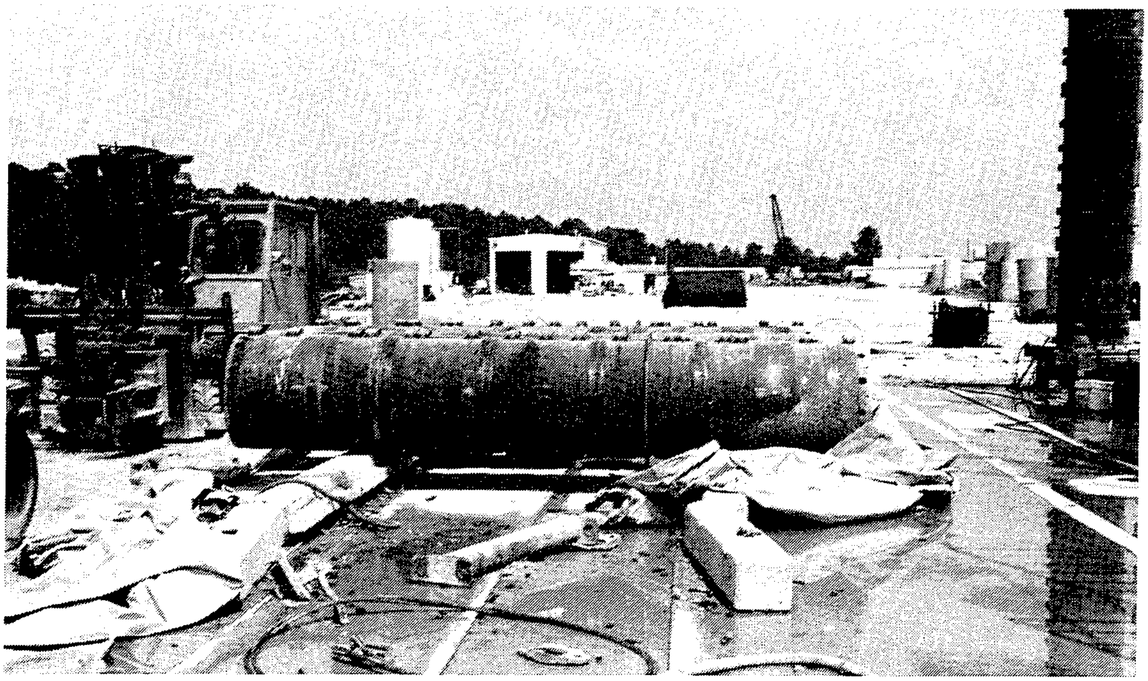

Figure 7
Pile segments being cured horizontally

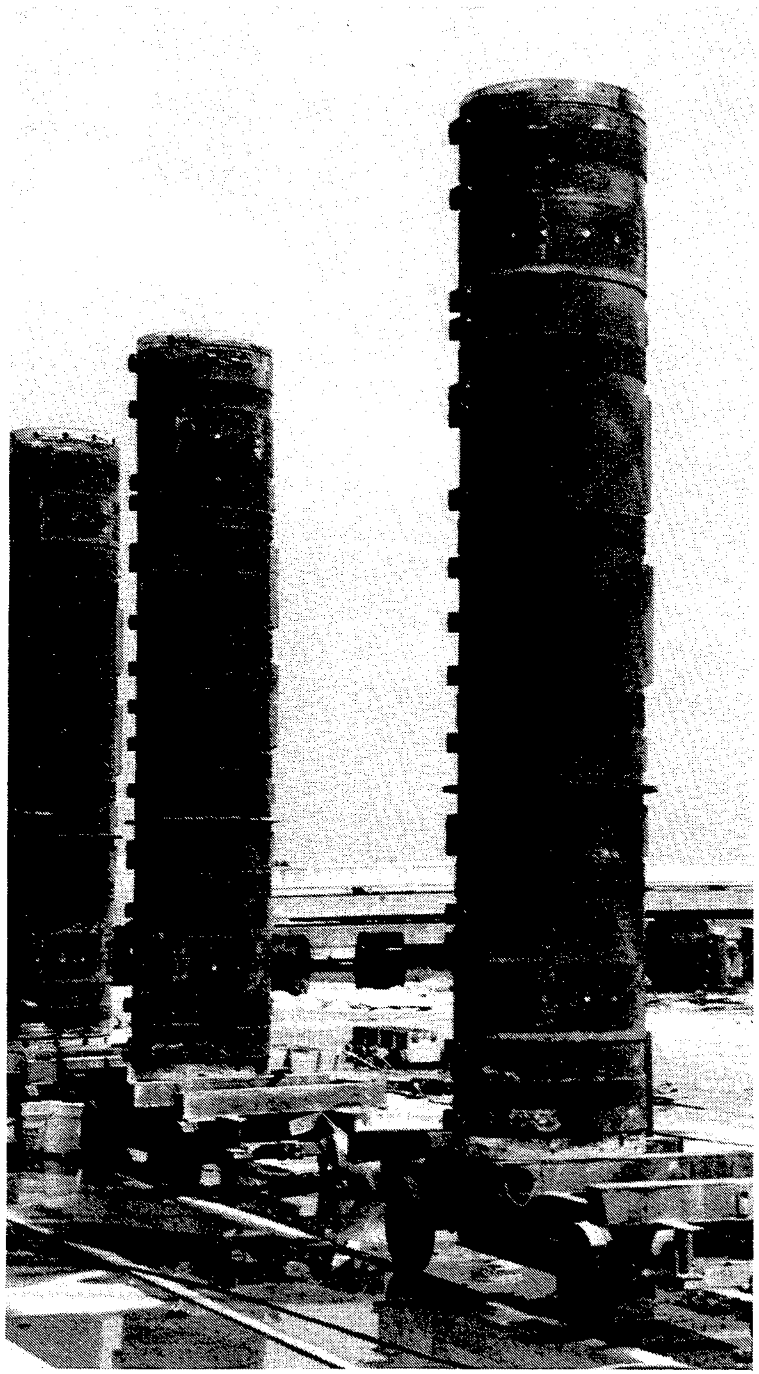

Figure 8
Pile segments being cured vertically

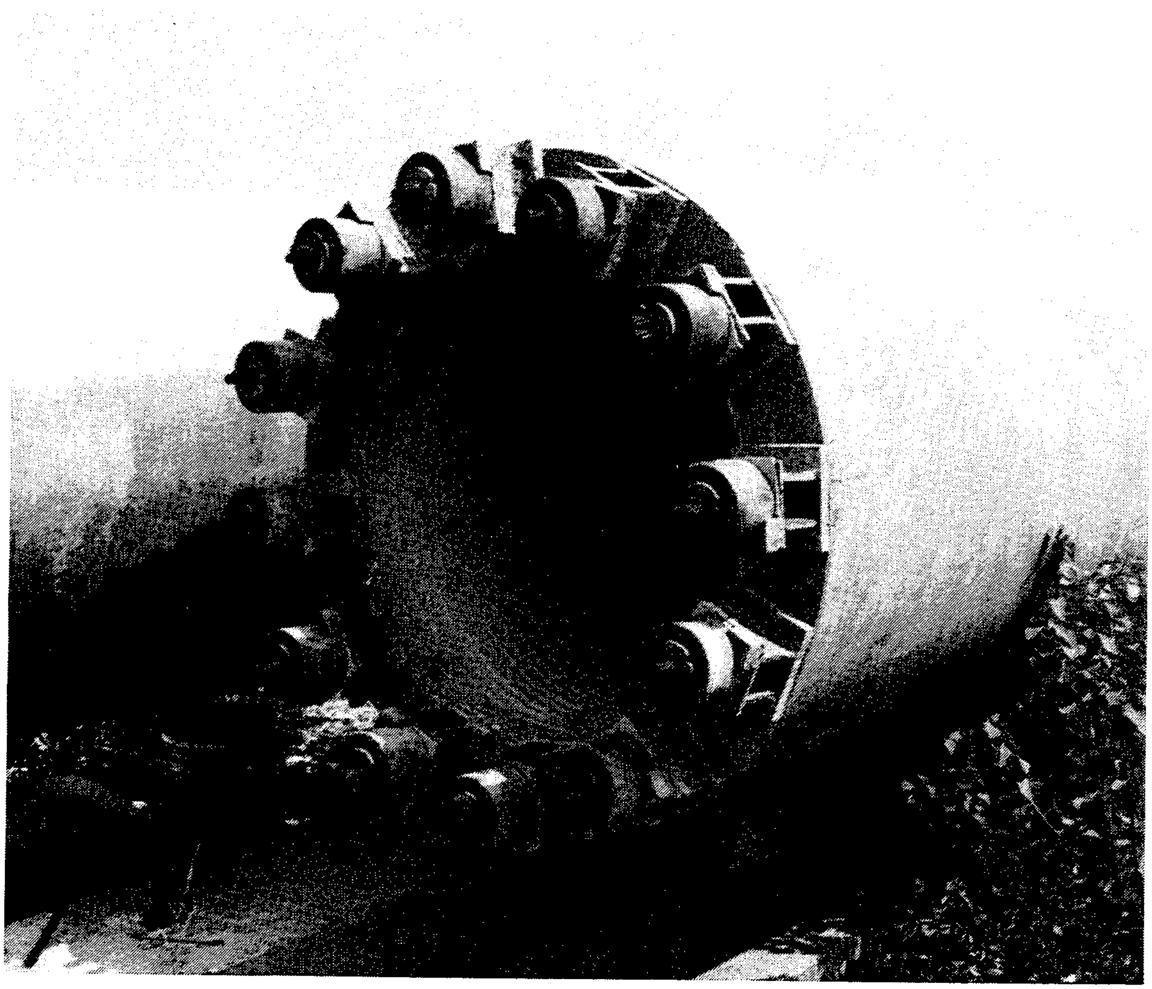

Figure 9
Prestressing anchors for connecting segments together

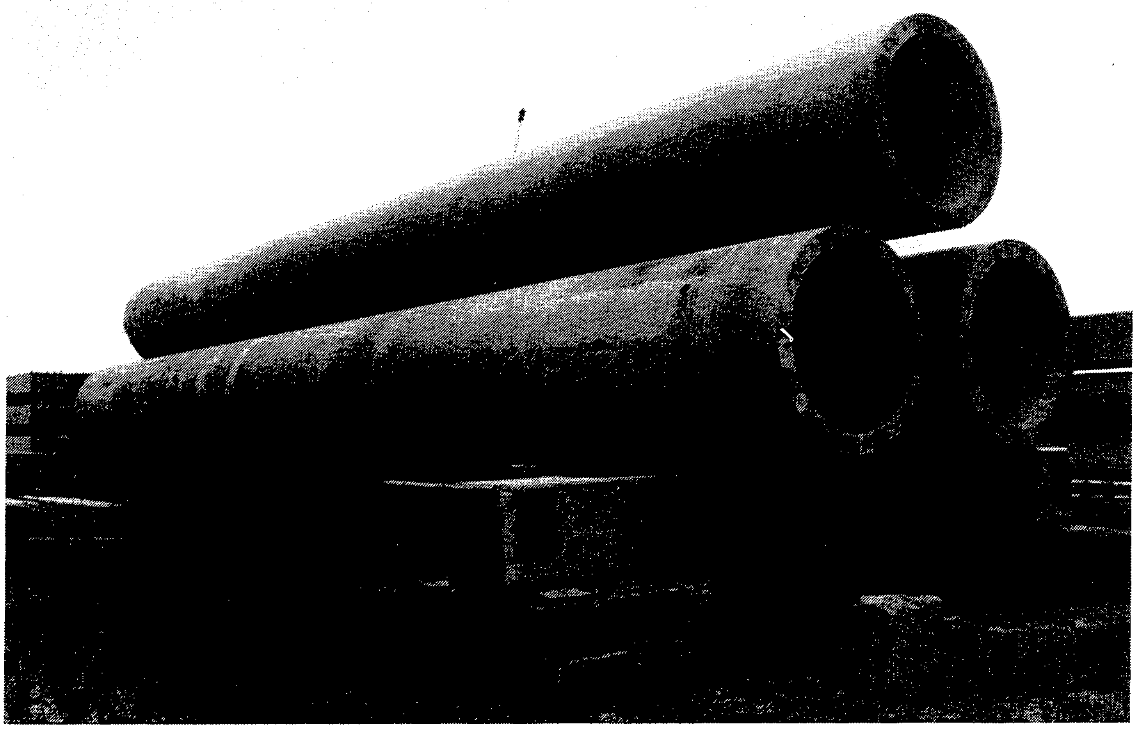

Figure 10

Three pile segments connected together to form 54-foot piles

Above Water Surveys

The level I above water inspections revealed that hairline cracking was confined to relatively few piles and in a few isolated instances to cracks approaching 1/8 inches at the surface that necked down to hairline cracks not far from the surface. These cracks were limited to I-10 over the Reserve Relief canal and I-10 between Ramah and Whiskey Bay. A database of piles with cracks was developed and a printout can be found in appendix A. Typical hairline cracks are shown in figures 11 to 14. These cracks are so small they do not show well in photographs except when highlighted by efflorescence. Cracks that appear at the junction with the pile cap girder are typically from piles supporting I-10 between Ramah and Whiskey Bay. Cracks found near the waterline are typically from I-10 over the Reserve Relief Canal.

Figure 11
Typical hairline crack near waterline

Figure 12
Typical hairline crack near waterline

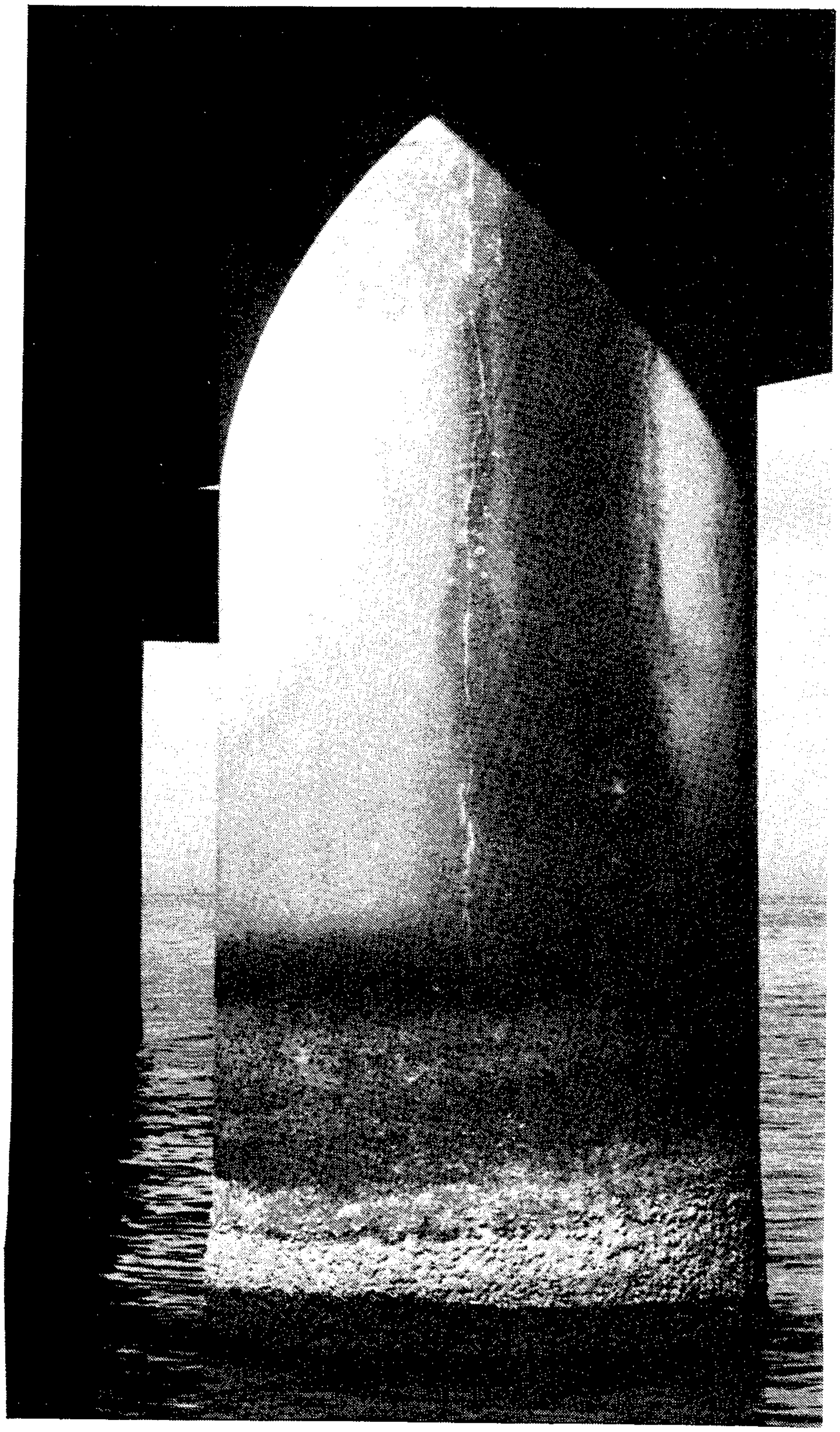

Figure 13
Typical hairline crack near pile cap

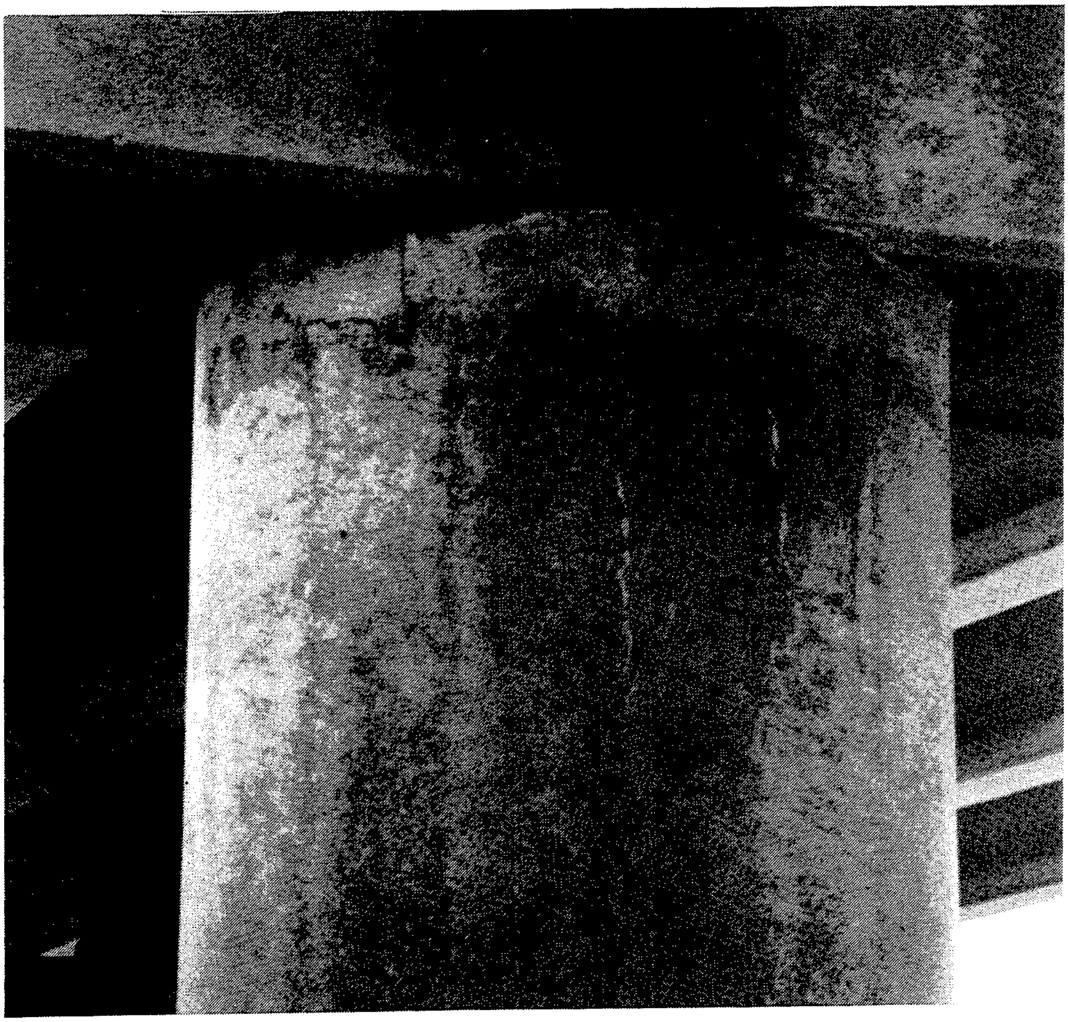

Figure 14
Typical hairline crack near pile cap

Pictures of the most severe cracks are shown in figures 15 to 19. These cracks were found on piles supporting I-10 over the Reserve Relief Canal near the waterline. These cracks were concentrated over a consecutive series of bents, centered on Bent 101. The complete information on this bent is:

Reserve Relief Canal
I-10 Copser
62484501305151
Bent 101

Figure 15
Crack near waterline on Reserve Relief Canal

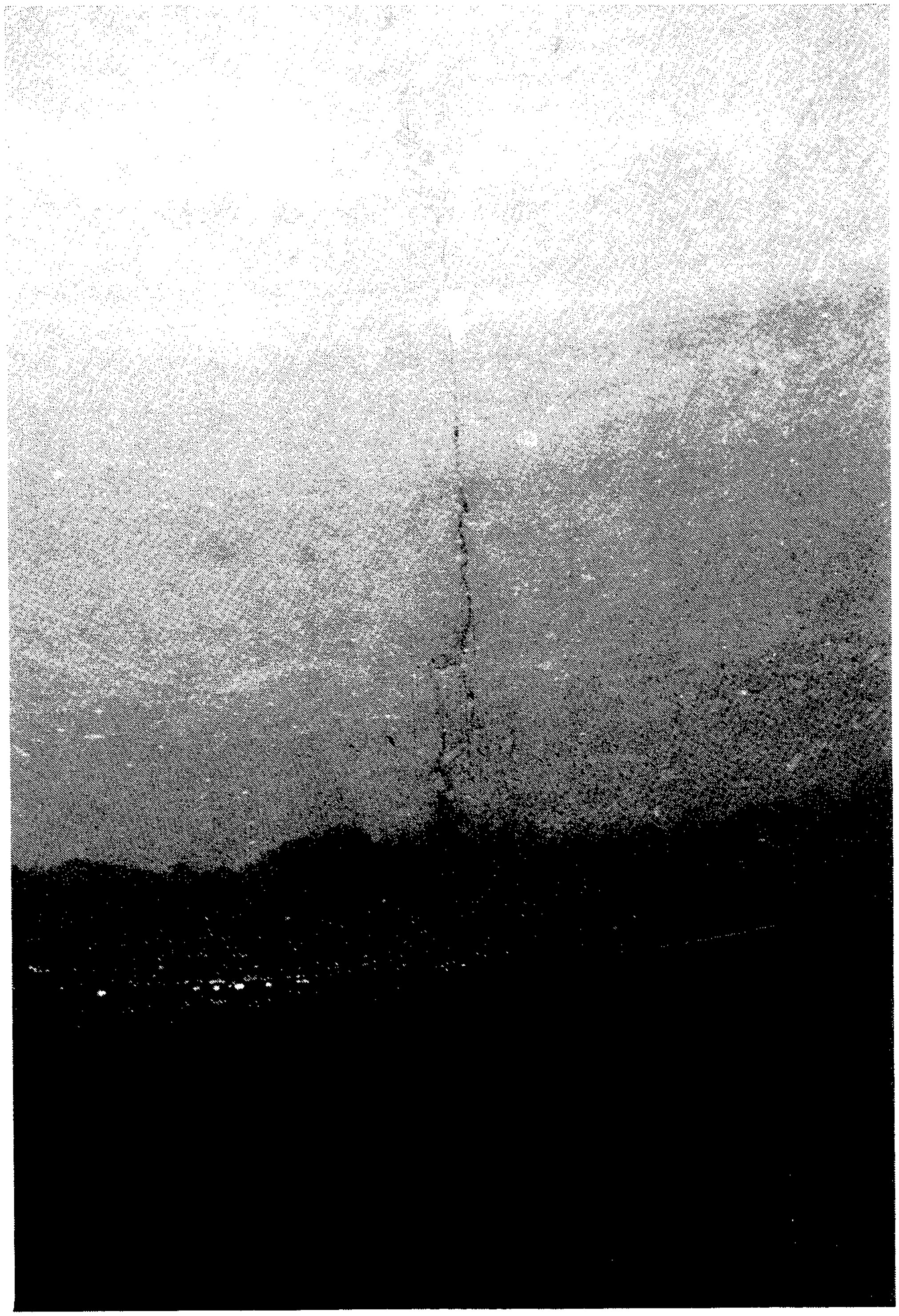

Figure 16
Crack near waterline on Reserve Relief Canal

Figure 17
Crack near waterline on Reserve Relief Canal

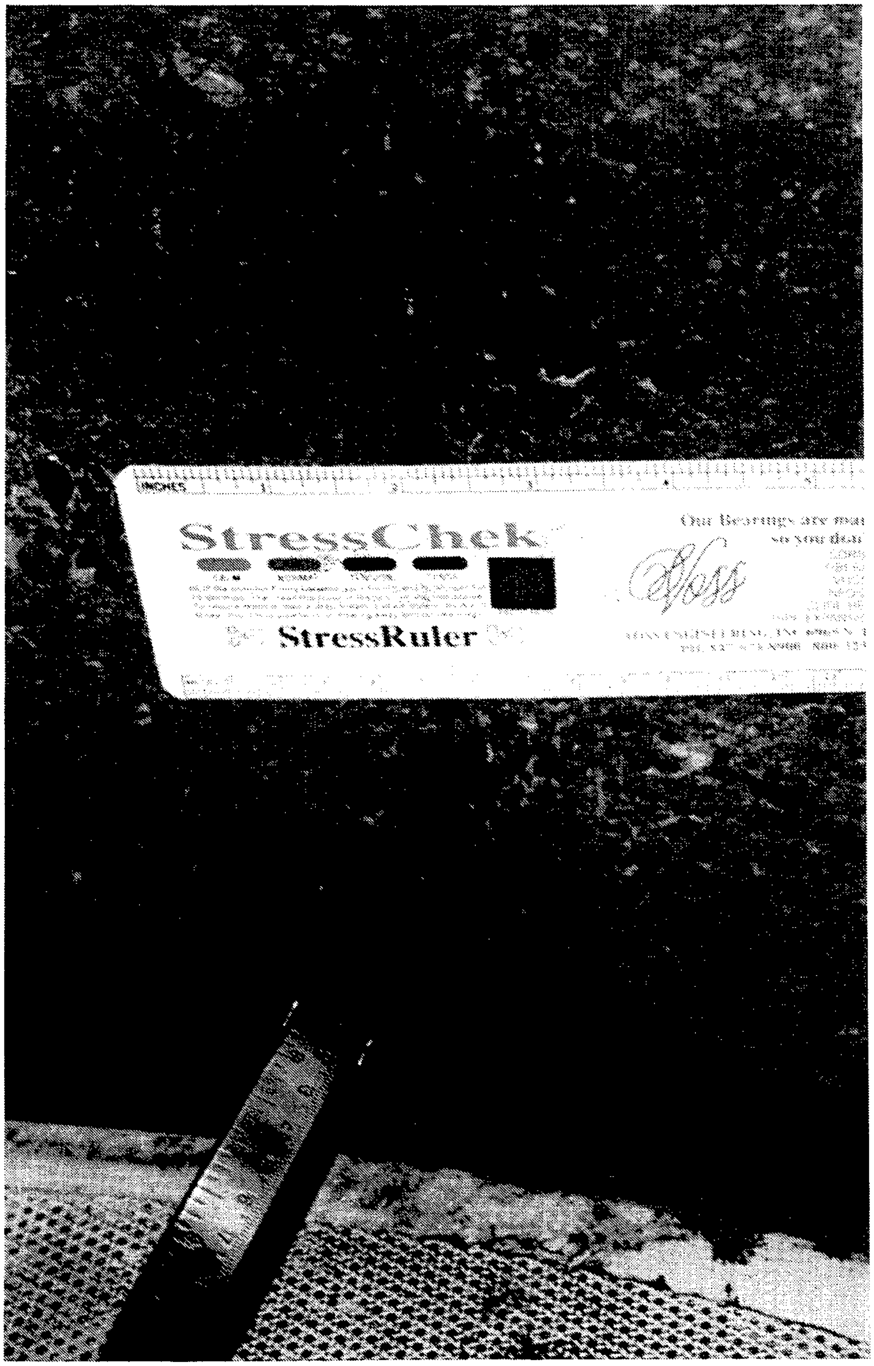

Figure 18
Crack near waterline on Reserve Relief Canal

Figure 19
Crack near waterline on Reserve Relief Canal

Apparent cracks on the Twin-Spans between New Orleans and Slidell turned out to be depressions made from the forms used in the rolling process. These seams, which did not penetrate into the concrete, are shown in figures 20 to 22.

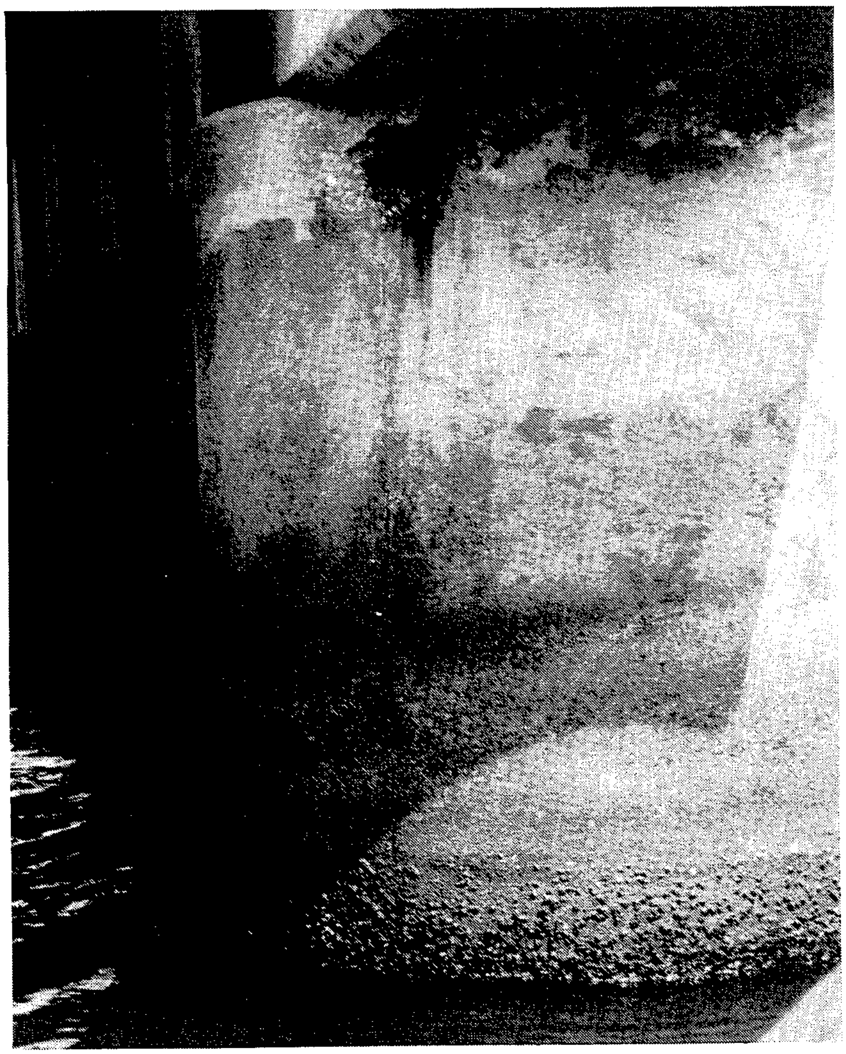

Figure 20
Seam in pile that looks like a crack

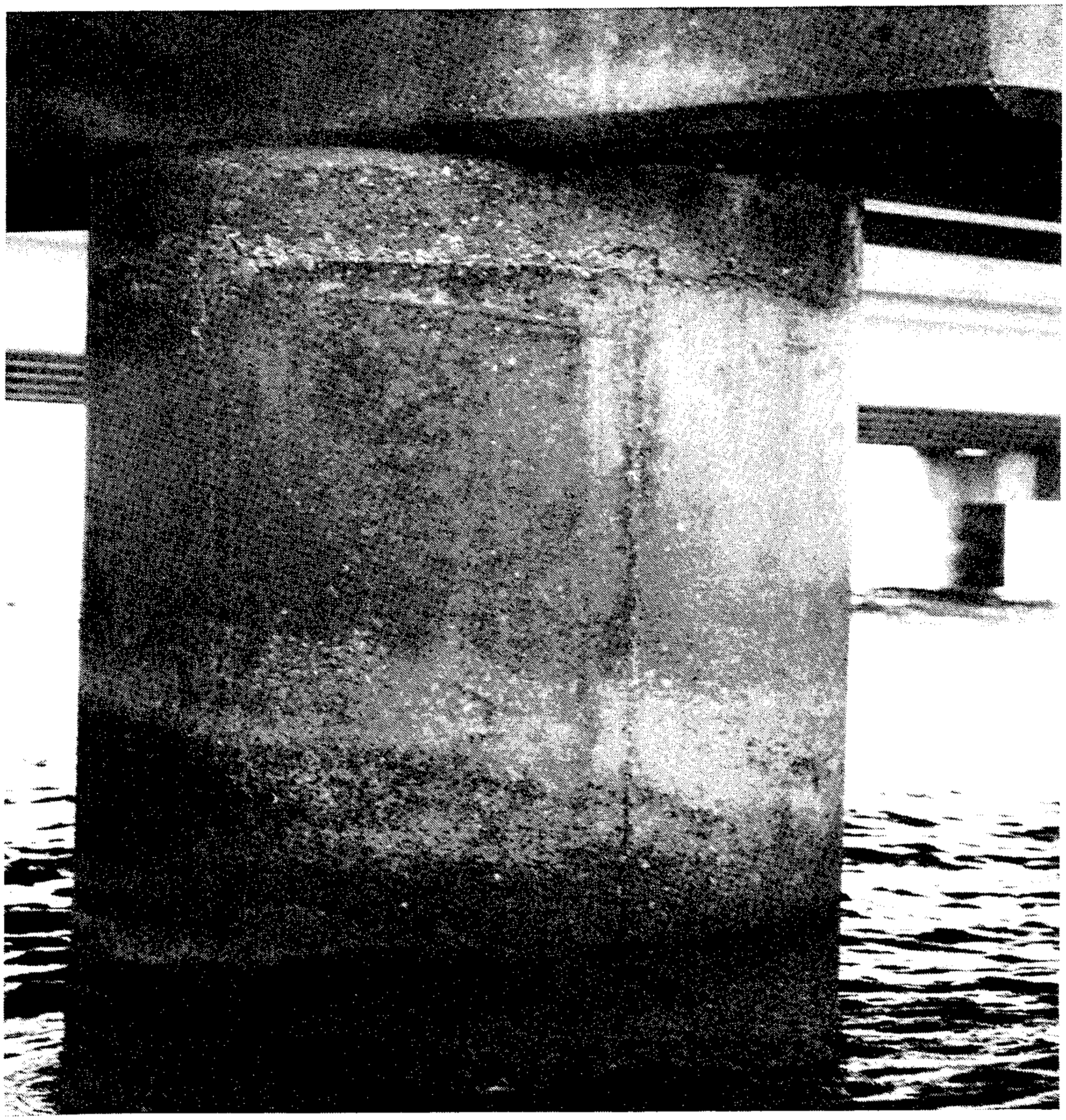

Figure 21
Seam in pile that looks like a crack

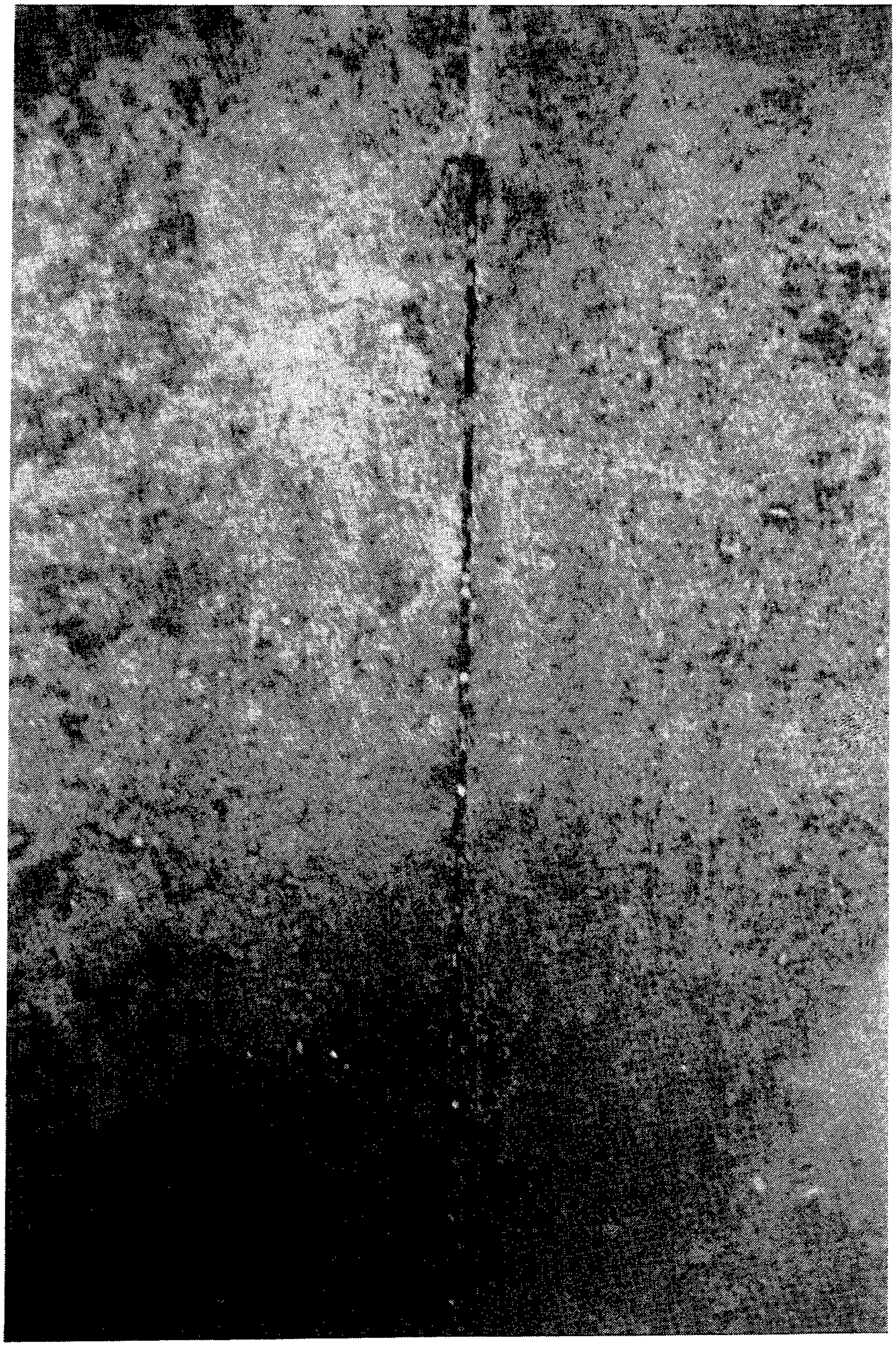

Figure 22
Close-up of seam in pile that looks like a crack

Underwater Surveys and Non-Destructive Testing

The most severe cracks on I-10 between Ramah and Whiskey Bay and over the Reserve Relief canal were the subject of an underwater inspection done with the FHWA demonstration boat. The boat and various equipments are shown in figures 23 to 25.

Figure 23
Federal Highway Administration showcase boat

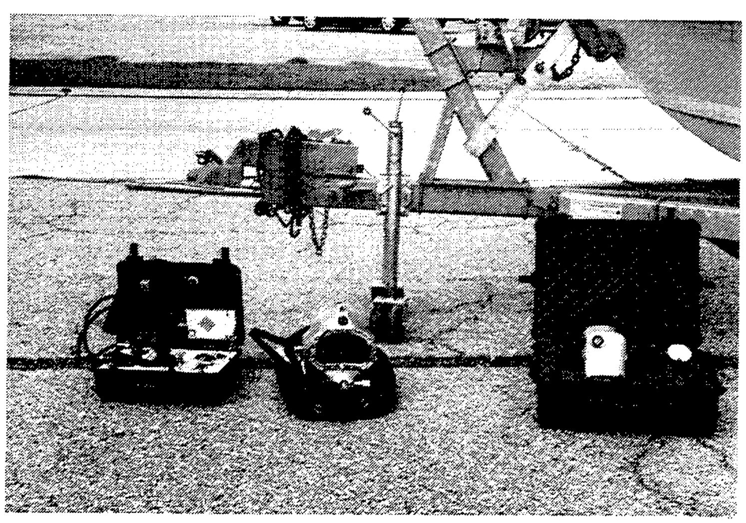

Figure 24
Underwater inspection equipment

Figure 25
Underwater Investigator ready to begin inspection

The underwater inspections revealed that even the most severe cracks did not widen much underwater. In one instance, a crack that was 1/32 inch wide at the waterline widened to between 1/4 inch and 1/2 inch at a depth of four feet and then narrowed to 1/16 inch at the mudline. It should be pointed out that the large crack width at the four-foot depth was mostly confined near the outer surface of the pile and quickly necked down with depth into the pile. In addition to conducting an underwater inspection, half-cell potential readings were taken at two locations. The process is illustrated in figures 26 to 28.

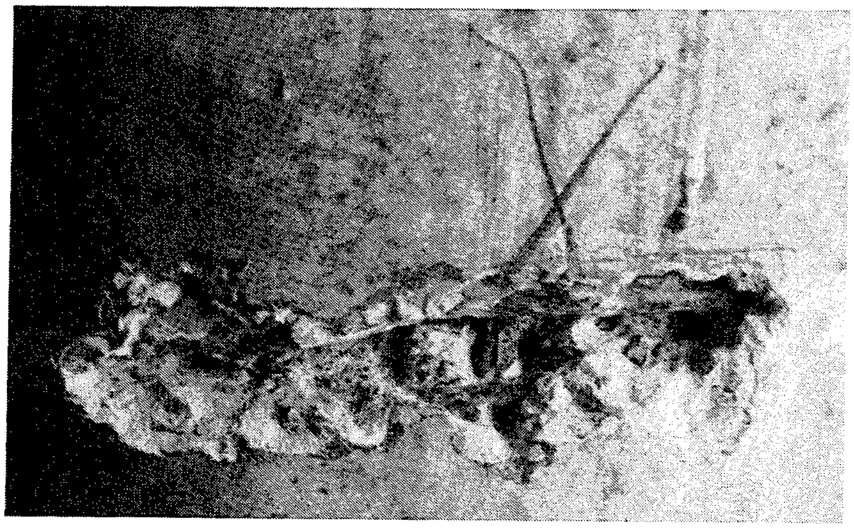

Figure 26
Concrete chipped away to attach half-cell potential probe

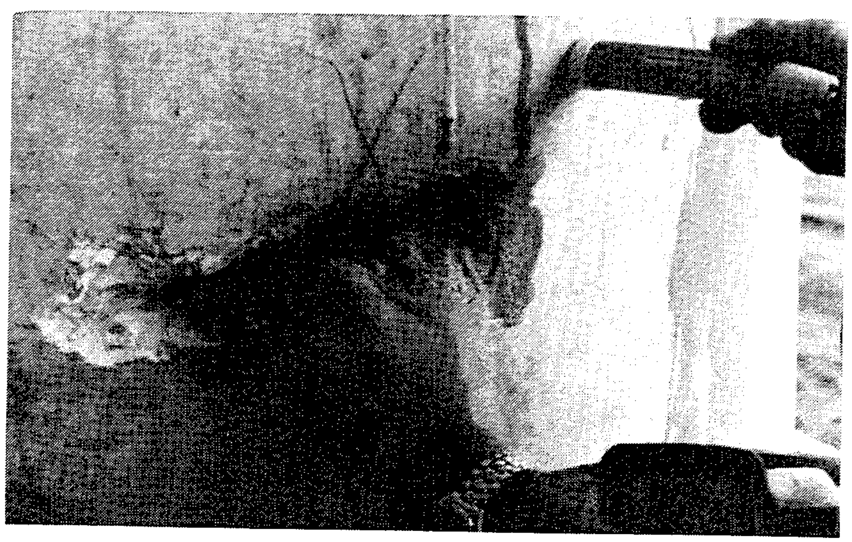

Figure 27
Half-cell potential test being conducted above water

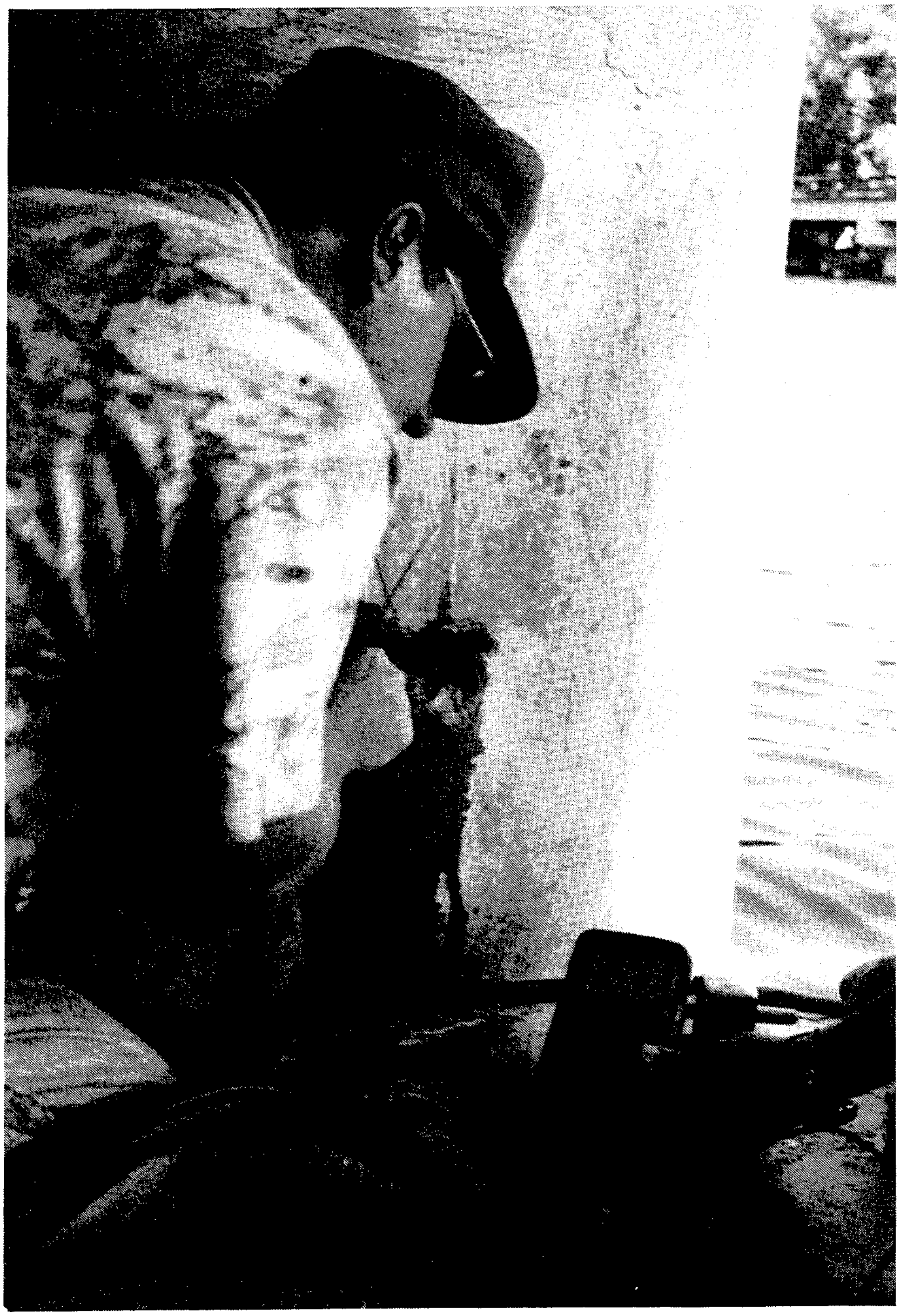

Figure 28
Half-cell potential test being conducted below the water

The results of the test shown in the figure were 3.2 above water and 5.5 under water. Both these results are on the borderline of corrosion beginning to occur.

Interview With Dick Snow

Mukai had an opportunity to discuss this project with Mr. Dick Snow, one of the designers of the original spun-cast pile, the Raymond pile. This discussion is summarized below:

1. Vertical hairline cracks appear in spun-cast piles.
2. These cracks tend to be over the prestressing strand ducts.
3. While many theories abound, there is no definitive cause for these cracks.
4. The cracks may have a negligible effect on the piles' structural performance.

Interview With Krebs, LaSalle, and LeMieux

The principal investigators also had an opportunity to discuss cracks in cylindrical piles with representatives from Krebs, LaSalle, and LeMieux, who are the consultants currently addressing similar problems on the Lake Pontchartrain Causeway. The main points of this discussion were:

1. The cracks on DOTD's piles are much less severe than the ones on the Lake Pontchartrain Causeway.

2. The most sever cracks on the Lake Pontchartrain Causeway were caused by overdriving the piles.

On the topic of overdriving the piles, it was pointed out that the older Causeway Bridge has much less severe cracking than the newer bridge. The construction procedure used on the first span was to drive the piles to the specified blow count and then cut off the tops of the piles at the correct elevation to place the superstructure. Since the cutting process was time-consuming and expensive, the construction procedure was altered for the construction of the newer bridge. On this bridge, the piles again were driven to the specified blow count. However, instead of cutting the tops of the piles to the proper elevation, pile driving continued until the tops of the piles were at the proper elevation. This over-driving of the piles is likely the cause of the severe cracks in the newer bridge. Lastly, there was one extremely large void in one of the piles (large enough for a diver to enter the pile); this was not due to over-driving but due to a collision with a falling piece of superstructure during an accident.

Discussion

The discussions with DOTD district personnel, the above water surveys, and the underwater surveys all indicate that the cracking in the piles is not severe. Most of the cracks are only of hairline width and the few that are wider quickly neck-down to hairline width. Moreover, these more severe cracks are confined to a limited number of bents, most notably those around bent 101 on I-10 over the reserve relief canal. Furthermore, the half-cell potential tests indicate that corrosion is not a problem.

These results seem at odds with the observations made by consultants investigating the Lake Pontchartrain Causeway. However, the discussions with these consultants indicate that the severe cracks on the Causeway were caused by improper driving procedures and are therefore not endemic to the piles used on DOTD bridges.

While the severe cracks on the Causeway seem to be isolated, the hairline cracks appear to be more prevalent. There are many proposed theories for these cracks. Some of these are:

1. Overdriving
2. Elastic rebound of prestress ducts
3. Differential shrinkage through thickness of pile
4. Freezing

There is no definitive answer to the question, "What is causing the hairline cracks?" However, it seems that the hairline cracks are not related to the severe cracks found in the causeway. Thus, the most prudent course of action would be to monitor the existing hairline cracks.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The vast majority of cracks found in 54-inch cylindrical spun-cast piles were only hairline width.
2. Even the most severe cracks were minor and do not warrant immediate repair.
3. These cracks are confined to a few bents.
4. The cracks in the DOTD piles are not caused by the same factors as the cracks in piles from the Lake Pontchartrain Causeway Bridge.

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RECOMMENDATIONS

The investigators recommend that:

No immediate repair actions be taken at this time.

The DOTD conducts underwater bridge inspections on five-year intervals. It is recommended that a special protocol be set up for future underwater inspections of the 54-inch spun-cast piles. The following is recommended:

1. A permanent numbering system should be established so that specific bents can be identified from inspection to inspection.
2. A series of crack width gauges should be installed on piles in the Rama to Whiskey Bay section and the Reserve Relief Canal section. The gauges should be placed over the larger cracks and distributed over the entire section. They should be attached in a manner that insures a degree of permanency so that readings can be taken on successive inspections.
3. The specifications for future underwater inspections should include taking gauge readings and comparing to previous readings.
4. Future contracts should also include half-cell potential measurements. It is recommended that ten be taken in each of the two sections.

5. If the half-cell potential measurements indicate corrosive activity, then consideration should be given to chloride sampling tests and rate of corrosion tests. It is possible that these tests may be done as part of FHWA Demonstration Project No. 84. The contact information for this project is:

   Mr. Donald Jackson, HTA-22
   Senior Project Manager
   Federal Highway Administration
   400 7th Street, SW
   Washington, DC 20590
   (202) 366-6770
   Donald.Jackson@FHWA.dot.gov

6. In future underwater inspections, it is recommended that a level III inspection be conducted on every 30th bent and that the same bents be inspected in subsequent inspections. The cracking patterns (including hairline) should be measured and mapped on these bents and compared to previous inspections.

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APPENDIX

Piles with Moderate Damage

District Baton Rouge 61
Bridge ID 4500700652
Roadway I-10
Direction West Bound

Number of Bents West from Ramah Launch	Damage
-1	midway to water
3	
30	
43	bad at water/top
84	at water
90	
95	
162	plaster at top
169	white cracks
171	midway
239	at water
240	at water
387	at water
392	at water
399	at water/top
432	in bad condition
457	seam at water
462	at water crack filled with white substance
469	midway
470	midway
501	also has white substance
524	white substance
533	white substance

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Piles with Moderate Damage

District Baton Rouge 61
Bridge ID 4500700651
Roadway I-10
Direction East Bound

Number of Bents East from Whiskey Bay Launch	Damage
136	filled with white substance
228	filled with white substance
295	filled with white substance
300	filled with white substance
392	bad condition at water
508	white substance
509	white substance
521	white substance

Piles with Moderate Damage

District Baton Rouge 61
Bridge ID 4500614952
Roadway I-10
Direction West Bound

Number of Bents West from Whiskey Bay Launch	Damage
34	seam look to be splitting
80	filled in at water
83	filled in at water
222	chunk missing, not a hole

Piles with Moderate Damage

District Baton Rouge 61
Bridge ID 4500614951
Roadway I-10
Direction East Bound

Number of Bents East from Furthest West Reachable Point From Whiskey Bay Launch	Damage
75	bad crack at water
132	noticable crack
136	line of missing chunks
180	a dent near the water

Hairline Crack Occurances

District New Orleans 2
Bridge ID 4501400002
Roadway Bonnet Carrie Spillway
Direction West Bound
Number of Bents with Hairline Cracks 6

Number Marked on Bent

162	183	186	199	208	209

Hairline Crack Occurances

District New Orleans 2

Bridge ID 4501400001

Roadway Bonnet Carrie Spillway

Direction East Bound

Number of Bents with Hairline Cracks 22

Number Marked on Bent

93	94	94	97	102	104	105
110	113	114	118	119	129	132
139	147	153	154	164	168	198
203						

Hairline Crack Occurances

District Baton Rouge 61

Bridge ID 4500700652

Roadway I-10

Direction West Bound

Number of Bents with Hairline Cracks 31

Number of Bents West from Ramah Launch

193	194	199	200	205	237	238
241	253	427	428	429	430	465
466	468	469	476	477	481	497
498	500	503	505	506	508	510
512	514	530				

Hairline Crack Occurances

District Baton Rouge 61

Bridge ID 4500700651

Roadway I-10

Direction East Bound

Number of Bents with Hairline Cracks 186

Number of Bents East from Whiskey Bay Launch

00	01	02	03	04	05	06
07	11	12	13	14	16	17
18	19	20	21	24	25	27
28	32	33	34	36	41	43
44	45	46	47	48	50	54
55	56	57	60	73	79	86
88	89	91	92	97	100	104
113	115	141	147	148	149	150
151	152	153	154	159	160	161
162	163	164	165	167	168	169
170	171	172	173	174	177	178
179	180	181	182	183	184	185
186	187	189	190	191	192	193
194	195	196	197	200	201	202
203	204	205	211	215	217	220
221	222	223	224	225	242	251
256	257	258	260	261	262	263
264	268	273	279	280	288	290
297	301	303	304	307	309	311
320	328	345	351	352	353	371
387	394	408	410	413	414	420
421	428	431	432	436	439	440
446	447	449	451	452	455	460
461	462	464	465	466	468	470
471	472	475	479	480	481	488
492	496	499	500	501	519	525
529	530	532	535			

Hairline Crack Occurances

District Baton Rouge 61
Bridge ID 4500614952
Roadway I-10
Direction West Bound
Number of Bents with Hairline Cracks 27

Number of Bents West from Whiskey Bay Launch

27	45	48	51	54	56	57
62	63	64	65	86	100	103
104	106	107	115	116	148	151
168	170	215	233	244	249	

Hairline Crack Occurances

District Baton Rouge 61

Bridge ID 4500614951

Roadway I-10

Direction East Bound

Number of Bents with Hairline Cracks 101

Number of Bents East from Furthest West Reachable Point From Whiskey Bay Launch

28	30	35	36	37	38	39
40	41	42	43	44	46	48
55	56	60	77	85	88	89
94	95	101	103	107	108	109
124	135	139	140	141	143	150
152	153	160	164	165	173	176
179	181	186	192	197	200	201
204	205	208	209	210	211	212
213	214	215	216	217	218	219
220	221	222	223	224	225	226
227	228	229	230	231	232	233
234	235	236	237	238	239	240
241	242	243	244	245	246	247
248	249	250	251	252	253	254
255	256	257				