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19 ABSTRACT (Continue on reverse if necessary and identify by block number) A condition survey was performed at Locks and Dam No. 3 on the Monongahela River in Pennsylvania to evaluate the concrete condition at the locks and dam, and to make a projection of the concrete condition of selected project features to approximately year 2010. Data from the original construction of the locks, and major rehabilitation of the locks and dam between 1978 and 1980 were evaluated. A visual field investigation was conducted to determine the present concrete condition in the locks. Freezing and thawing of the older nonair-entrained concrete is the major deteriorating mechanism in the structure. A maximum vertical rate of deterioration for exposed original concrete was calculated to be 1.06 in. per year: a horizontal rate of deterioration of 0.90 in. per year was determined with a new concrete overlay serving as low-permeability cover. Where original concrete is exposed on vertical faces, the worst case damage of an additional 32 in. is estimated by the year 2010. Sections of the walls refaced with high quality air-entrained concrete should be serviceable until the year 2010, while local high stress areas may require repairs as deficiencies are formed.					
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PREFACE

This report was based on a one-day site visit made in the fall of 1987 and analysis of engineering documents concerning the lock structure. The work was performed by the US Army Engineer Waterways Experiment Station (WES) sponsored by the US Army Engineer District, Pittsburgh.

The work was conducted under the supervision of Mr. Bryant Mather, Chief, Structures Laboratory (SL), WES; Mr. James T. Ballard, Assistant Chief, SL; and Mr. Kenneth L. Saucier, Chief of the Concrete Technology Division.

Mr. G. Sam Wong, SL, performed the site investigation and he and Mr. R. L. Stowe, SL, prepared the report.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is the 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:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	25.4	millimetres

CONDITION SURVEY
LOCKS AND DAM 3
MONONGAHELA RIVER

PART I: INTRODUCTION

1. The project description, construction history, maintenance and repair history, along with other pertinent drawings and engineering information and data are not presented in this report. Such information was used in preparation of this report. The best references were the Feature Design Memorandum* (USAE District, Pittsburgh, 1976) and an engineering condition survey report** (Engineering Condition Survey and Structural Investigation of Locks and Dam 3, Monongahela River, 1976).

Background

2. On 15 March 1985, the Waterways Experiment Station (WES) was requested by the U.S. Army Engineer District, Pittsburgh, to support the District's navigation planning studies for the lower Monongahela (Mon) and the Upper Ohio Rivers by conducting condition surveys of six existing structures within these two study reaches. A one-day site inspection and an analysis and evaluation of pertinent engineering documents concerning Locks and Dam 3 were the only work efforts involved in this study.

Objectives

3. The objectives of this work are: (a) to make an evaluation of the concrete condition at the locks and dam and (b) to make a projection of the concrete condition of selected project features to a time, approximately

* US Army Engineer District, Pittsburgh, CE. 1976. "Locks and Dam 3, Monongahela River, Rehabilitation - Plan Formulation, Feature Design Memorandum," Pittsburgh, Pa.

** Engineering Condition Survey and Structural Investigation of Locks and Dam 3, Monongahela River, February 1976, USACE Waterways Experiment Station and US Army Engineer District, Pittsburgh, Pittsburgh, Pa.

year 2010, when further major rehabilitation and upgrading alternatives would be required to assure an additional 50-year service life.

Scope

4. This report presents an evaluation of information and data dealing with the original construction of the locks, the major rehabilitation of the locks and dam between 1978 and 1980, and the present condition of the concrete in various project features. Projections of the concrete condition in the year 2010 were made based upon engineering judgement and evaluations of the quality of the concrete in project features, degradation factors, rates of deterioration, and the effect that air-entrained cementitious overlays and refacings would have on the older nonair-entrained concrete.

PART II: ASSESSMENT OF CONCRETE CONDITION

5. WES staff met with Mr. William Nagy, Lock Master, on 13 November 1987 for an overview of the major rehabilitation performed in 1978-1980. Afterwards, an inspection of the lock walls was conducted for purposes of identifying and locating concrete deficiencies that may exist in the original (1905-1907) concrete and the cementitious repair materials used during the 1978-1980 rehabilitation.

6. Photographs were taken of selected portions of the lock walls to illustrate typical concrete conditions (Figures 1-12). Each of the major lock elements will be discussed separately in the following paragraphs.

Upper Guide Wall

7. Some of the top surface concrete appeared new while a majority of the surface concrete appeared to be old concrete. The new concrete was in good condition with minor signs of weathering while the old concrete consisted of 60 percent severe scaling and 10 percent very severe scaling. Spalling of concrete was observed in about 20 percent of the monolith joints. A longitudinal crack ran along the top of the guide wall.

8. Vertical surfaces were repaired with shotcrete. The monoliths are armored with the exception of two or three. The shotcrete is severely scaled or spalled in 11 monoliths. The remaining monoliths have medium to light scaling. Small spalls exist in all monolith joints with a high concentration 2-3 ft* above the water level.

Land Wall

9. The upper gate recess had been shotcreted and appeared in good condition. Six to eight horizontal cracks with little efflorescence were observed. The shotcrete had some light scaling. The lock chamber was dewatered so that refacing and associated work within the lock chambers were made to some short distance below lower pool elevation.

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

10. The lock chamber wall was refaced with high quality air-entrained reinforced concrete, however it contained numerous vertical cracks. These cracks were generally small with minimal weathering along them. The surface contains severe scaling in less than 2 percent of the surface area and less than 2 percent very severe scaling. The monolith joints were generally in good condition with some minor spalling at each joint. Some voids in the river face were observed in the concrete located at the 200 ft to 150 ft marker. The voids were 3-4 in. deep and appeared to possibly be eroded honeycomb areas that were formed during the rehabilitation work.

11. The lower gate recess appeared in good condition with most of the shotcrete intact and with only light scaling. Two horizontal cracks with efflorescence were observed. The cracks were fine and approximately 8 ft in length.

12. Downstream of the gate at the lower pool elevation concrete was severely eroded. The lock attendant reported that the area was not rehabilitated. Severe to very severe scaling along monolith joints was observed in the land wall to the lower guide wall. The armor near the gates was in good condition.

Lower Guide Wall

13. Some small spalls had developed at all monolith joints in the lower guide wall. The disaggregation of the shotcrete was most severe at or near the lower pool elevation. Peeling and delamination of shotcrete were evident where the shotcrete was applied to a thickness of less than 1 in.

14. Scaling of the surface was evident with 30 percent very severely scaled, 50 percent severely scaled and 20 percent moderately scaled. A few diagonal and vertical cracks were observed. Cracking was generally infrequent and did not tend to be open. Some shotcrete was spalled due to barge impact, but this spalling was localized.

15. The top surface of the lower guide wall generally contained medium scaling with some large spalls at the end of the wall. Numerous fine transverse cracks propagated across the wall. These cracks could be traced down the vertical face of the wall as the cracks were reflected through the shotcrete surface.

Middle Wall

16. The top surface of the middle wall was raised approximately 1.0 ft at similar locations to the raised portions of the land wall. A double set of corner armor is present from near the upper gate to approximately 50 ft below the control building on the middle wall. The contact between the overlay and old concrete was in good condition as observed along the cold joint formed when the overlay was placed. The top surface concrete was intact and in good condition. Transverse cracks were observed with a frequency of three per monolith, mostly propagating from the intersection of armor or corners of flumes (pipe channels). The cracks did not appear to extend down the vertical face.

17. The land face of the middle wall had numerous small areas where shotcrete had dropped off the wall. In the areas where shotcrete was less than 1 in. thick, 20-40 percent of the surface was peeled. A few joints contained minor spalling but most looked to be in good condition except for where shotcrete was missing. Several of the joints have large spalls.

18. The formed surface of the concrete wall began at the end of the double corner armor and continued downstream to the gate. The formed concrete appeared to be in better condition than the shotcrete surfaces. Joints were good with only minor spalling while the vertical surfaces consisted of 40 percent medium scaling and 60 percent light scaling.

19. Shotcrete-repaired gate recesses had no apparent surface weathering with some lightly scaled areas. There was some horizontal and vertical cracking, mostly propagated from structural features such as cutouts.

20. The river face of the middle wall in the river chamber showed light to medium scaling. An estimated 60 percent of the wall had light scaling and approximately 40 percent had medium scaling. Small spalls were present at monolith joints with few horizontal and vertical cracks on the vertical face. There were several large areas where exposed reinforcing steel was observed. These areas were approximately 1 ft deep or more and probably were honeycombed areas developed during refacing of the wall. The top 18 in. of the surface concrete had vertical cracks with efflorescence. It also contained some fine horizontal cracks with efflorescence.

Upper Guard Wall

21. The land face and the top surface of the upper guard wall were the only two surfaces observed during this site visit. Because of limited time at the site we were unable to schedule floating support for inspection of the river face of the upper guard wall.

22. The top concrete surface was intact and in good condition with no deficiencies except infrequent cracks. Approximately one transverse crack per monolith was observed with the crack going through the thickness of the concrete about 1 to 1.5 ft in most places.

23. The land face was resurfaced using shotcrete application. Forty percent of the shotcrete showed signs of delamination exposing some reinforcing steel. Sixty percent of the surface had medium scaling. Original concrete is exposed in several areas at the upper pool elevation. The shotcrete that was placed during the 1978-1980 rehabilitation work has dropped off the wall in these areas; thickness of missing shotcrete is 3 in. Large spalls were observed at the ends of the guard wall where barges had impacted the wall.

River Wall

24. The top surface of concrete showed light scaling and is in good condition. Transverse cracks at a frequency of 3 to 4 per monolith extended vertically through the resurfaced layer.

25. At the upper gate recess area a large horizontal crack with efflorescence was observed. The face contained no scaling to light scaling. Just upstream of the gate, the concrete placed during the recent rehabilitation was severely scaled at the upper pool elevation.

26. The land face of the river wall had 20 percent moderate scaling and 80 percent light scaling. Few vertical cracks from the top to approximately 2-ft down from the top were observed. The cracks appeared in the resurfaced top concrete. Efflorescence was observed in some cracks.

27. Shotcrete at the lower gate recess had no scaling to light scaling. Some fine vertical and horizontal cracks were present and oil seepage could be seen in some cracks. One vertical crack could be traced to the concrete beneath the gate machinery. The middle third of the recess appeared to have a shotcrete coating with less than 1 percent peeling.

28. The river wall river face was repaired using shotcrete from the top of the wall to the water level. A work flat was tied to the wall near the upper gate and a closer look was taken at the repair near the upper pool elevation. Some 3-ft deep voids that were not repaired were observed. The shotcrete was scaled to 0.5- to 0.75-in. depth. Some reinforcement and mesh were exposed.

29. The river face of the river wall below the dam was shotcreted from the top of the wall to the lower pool elevation. Generally the shotcrete was in good condition with some delamination near the top of the wall and some horizontal and vertical cracks with efflorescence.

PART III: CONCRETE DETERIORATION RATES AND EFFECT OF MAJOR
REHABILITATION ON CONCRETE CONDITION IN THE YEAR 2010

30. Depth of deterioration was converted to a rate of deterioration by dividing by the number of years between the construction date (mean) and the date the structure was cored. These rates were expressed in terms of inches per year.

31. Rates of deterioration from about 1906 to 1974 were 0.34 to 1.06 in. per year (23 in./68 yr; 72 in./68 yr) downward from the tops of the lock walls. It is assumed that all this deterioration was due to frost damage.

32. Therefore, the worst case would be another 38 in. of deterioration in 36 years from about 1974 to the year 2010 if the tops of the walls had not been overlaid with a high quality air-entrained concrete. Where such overlays exist, the lock walls are effectively covered with a low permeability cover so that there would be little or no additional damage to the underlying original concrete, since frost damage is an external effect, that would now be blocked from the top of the wall. This same rationale holds for vertical surfaces faced with the same high quality air-entrained concrete. The foregoing is based on the concept that susceptibility to frost damage arises due to critical saturation resulting from ingress of water from precipitation on the surface. If, on the other hand, critical saturation arises from entry of water into permeable pore space by surface diffusion or capillary rise--which seems more probable; in this event the susceptibility of the subjacent nonair-entrained concrete to frost damage will depend on frequency and duration of episodes of frost penetration to depths into the old concrete.

33. Although details of depths of concrete deterioration from horizontal core borings are lacking, a rate of deterioration in the horizontal direction is suggested using the following information:

- a. Extensive evaluation of the concrete integrity at Lock and Dam 3 resulted in the statement that depth of concrete deterioration is likely the same beneath horizontal and vertical surfaces (Engineering Condition Survey...Lock and Dam 3, 1976, page 17).
- b. There are definite similarities between the overall advanced surface deterioration at Dashields Locks and Dam and Lock and

Dam 3 (Wong and Stowe*, September 1985, and reference given in a. above).

- c. There are similarities in the depth of deteriorated concrete in cores recovered from vertical borings, i.e. 4 ft at Dashields and 6 ft at Lock and Dam 3.

This information suggests that the ratio of the horizontal to vertical rate of deterioration calculated at Dashields (0.85) is applicable at Lock and Dam 3. The report** by Stowe and Poole, 1986, contains rates of deterioration for five structures in the vicinity of Pittsburgh.

34. Using the vertical rate of deterioration calculated for the original concrete (Lock and Dam 3) and the ratio of horizontal to vertical rate of deterioration calculated for Dashields, a horizontal rate of deterioration ($R_{H.O.}$) for Lock and Dam 3 is obtained:

$$R_{H.O.} = 1.06 \text{ in./yr} \times 0.85 = 0.90 \text{ in./yr}$$

A mean horizontal rate of deterioration calculated from data from the five structures in the Pittsburgh vicinity is not suggested because the concrete deterioration reported at Lock and Dam 3, prior to the rehabilitation completed in 1980, was much more advanced than the concrete at most other structures in the area.

35. The worst case of deterioration inward from vertical faces would be another 32 in. in 36 years from about 1974 to the year 2010 where original concrete is exposed or if the walls were not faced with a high quality repair material. Much of the shotcrete placed during the 1978-80 rehabilitation is now not serving its intended purpose and 27 in. of additional deterioration in the horizontal direction will likely occur in areas where shotcrete is delaminated or missing. This amount of damage will be added to whatever existing deteriorated concrete was present when the shotcrete coating was applied. The existing depth of damaged concrete in the walls at any particular location

* Wong, G. S. and Stowe, R. L. "Condition Survey of Dashields Locks, Ohio River," USACE Waterways Experiment Station, with letter of transmittal addressed to Commander US Army Engineer District, Pittsburgh, sent on 4 September 1985.

** Stowe, R. L. and Poole, T. S. 1986 (June). "Condition Survey of Emsworth Locks and Dams, Ohio River," USACE Waterways Experiment Station, in Publication.

would have to be determined with 6-in.-diameter core borings before the effect of the projected depth of damage is useful for determining reduced structural sections.

36. During the December 1987 condition survey by WES, the new high quality air-entrained concrete placed on both vertical and horizontal surfaces was observed to be in good condition. The only durability problem observed, other than occasional thin cracking, was light to medium scaling over about 80 percent of this new concrete. Light scaling is defined in ACI 201.1R-68 as "loss of surface mortar without exposure of coarse aggregate," indicating a loss of mortar to a depth of about 5mm. The majority of the new concrete has weathered, over about an 8-year period since the 1978-1980 major rehabilitation, a total of 0.19 inches. This amounts to a rate of deterioration of 0.02 in./yr. This magnitude of deterioration for high quality air-entrained concrete does not seem to be unreasonable considering the severe weathering conditions in the Pittsburgh area. It is likely that this rate of deterioration has or will soon stabilize.

PART IV: SUMMARY

Present Concrete Conditions

37. The concrete placed in 1978-1980, on horizontal surfaces, was in good condition as evidenced by few concrete deficiencies and slight weathering. A few areas were deteriorated, however these were localized areas where thin surface overlays had debonded and where original concrete existed. An area of delamination exists near the office building on the land wall where Sika topping was placed and 30 percent has delaminated or is visibly cracked.

38. Cracks in the overlay concrete were routed and sealed with a gray colored substance. Top surface cracks appear to be temperature cracks as they are regular and do not tend to go into the section any further than the thickness of the overlays.

39. The concrete used to reface the lock walls is in good condition. Some isolated defects in the walls were noted; however, the majority of these existed prior to the rehabilitation and were not repaired. They do not appear to have been sources of accelerated deterioration as the deterioration has remained localized. The worst deficiency observed in the newer concrete on the chamber wall is medium scaling.

40. Cracks in the gate machinery recesses are mostly reflection cracks from the original concrete. Oil can be seen outlining some of these cracks at the surface. Cracking in the other areas of the lock walls, guide walls, and guard walls tends to be minor and not a source of major deterioration.

41. The riverside of the river wall, the lower guide wall, all existing gate recesses and selected areas on the upper guide wall and middle wall were treated with a thin layer of shotcrete. It was reported in the 1981 Periodic Inspection Report that shotcrete in areas subjected to tow abrasion and impact was unsatisfactory. In June 1982 it was reported that the failure of the shotcrete overlay appeared to be progressing. In July 1985 it was reported that additional failures of the shotcrete repairs were occurring. In December 1987 an inspection at Lock 3 by WES staff revealed that the shotcrete applied during the 1978-80 rehabilitation has indeed deteriorated to a point where it is questionable whether it is protecting the underlying concrete as originally intended. In many small areas it has delaminated or fallen off.

42. Deterioration continues to be significant in the non-rehabilitated original concrete. A depth of 3 ft was measured in one void in the river wall.

Projected Concrete Condition

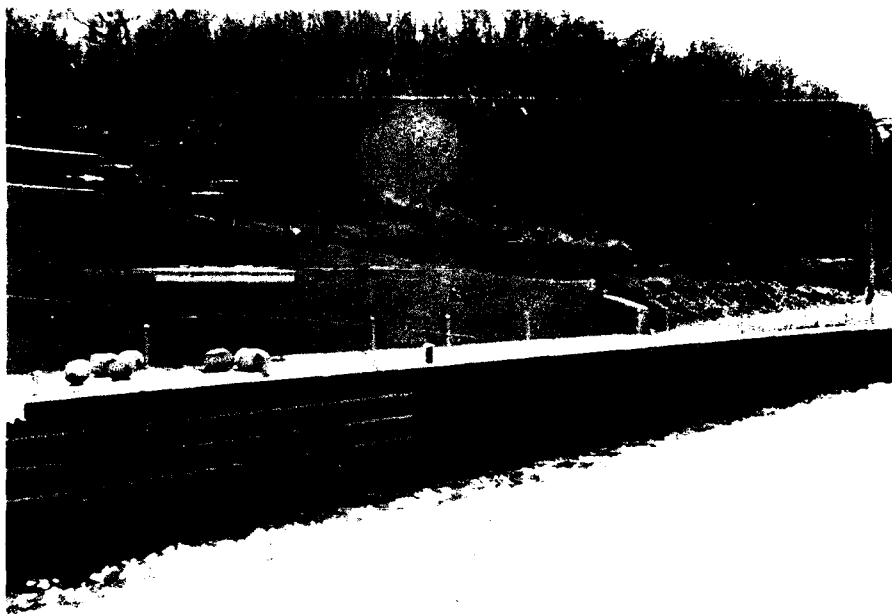
43. Freezing and thawing of the older nonair-entrained concrete is the major deteriorating mechanism likely to degrade the concrete at the locks during the next 25 years.

44. A vertical rate of deterioration for a period of 68 years (1906 to 1974) was calculated for the lock walls; a maximum of 1.06 in. per year is the worst case for exposed original concrete. A rate of deterioration for the concrete in the overflow dam could not be determined.

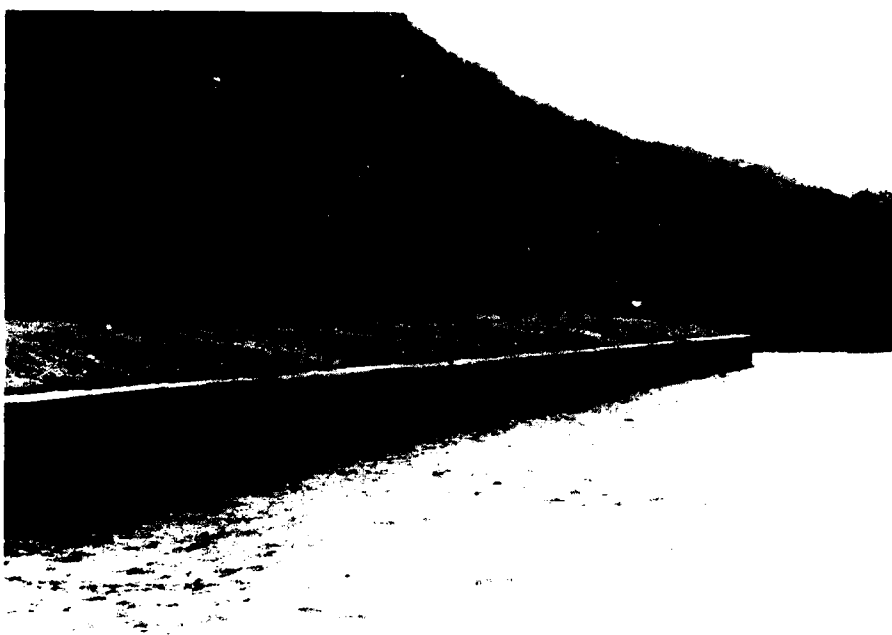
45. Where new concrete overlays were placed on lock walls during the major rehabilitation, the overlay will serve as a low permeability cover. A horizontal rate of deterioration, 0.90 in. per year, was calculated using results of an evaluation of concrete quality at Locks and Dam 3 and Dashields Locks and Dam. A ratio of horizontal to vertical rate of deterioration calculated at Dashields was applied to a vertical rate of deterioration calculated for Lock and Dam 3 to obtain the 0.90 in. per year rate.

46. Where the original concrete is exposed on vertical faces of the lock walls, i.e. not refaced or refaced with shotcrete during the 1978-80 major rehabilitation and where the shotcrete has delaminated or dropped off the wall, the worst case damage of an additional 32 in. is estimated by the year 2010.

47. The sections of the walls refaced with the high quality air-entrained concrete should be serviceable at least until the year 2010. Local high stress areas may require repairs as deficiencies are formed such as cracks and spalls occurring from the action of freezing and thawing cycles in the older nonair-entrained concrete.



a. Monoliths L-23 to L-18



b. Monoliths L-10 to L-1

Figure 1. Upper guide wall (continued)



c. Typical top surface

Figure 1. (Concluded)

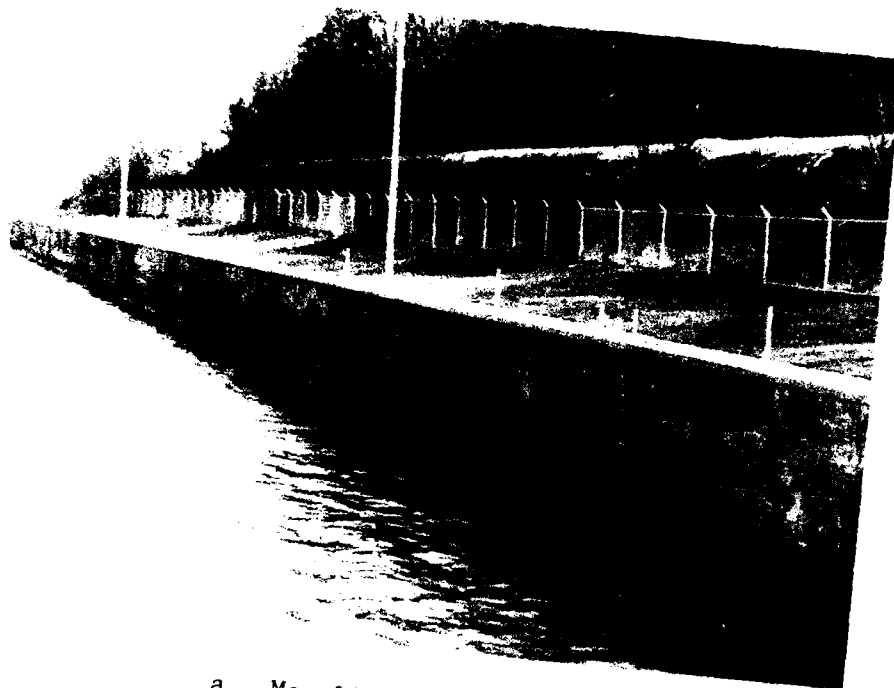


a. Adjacent to power house

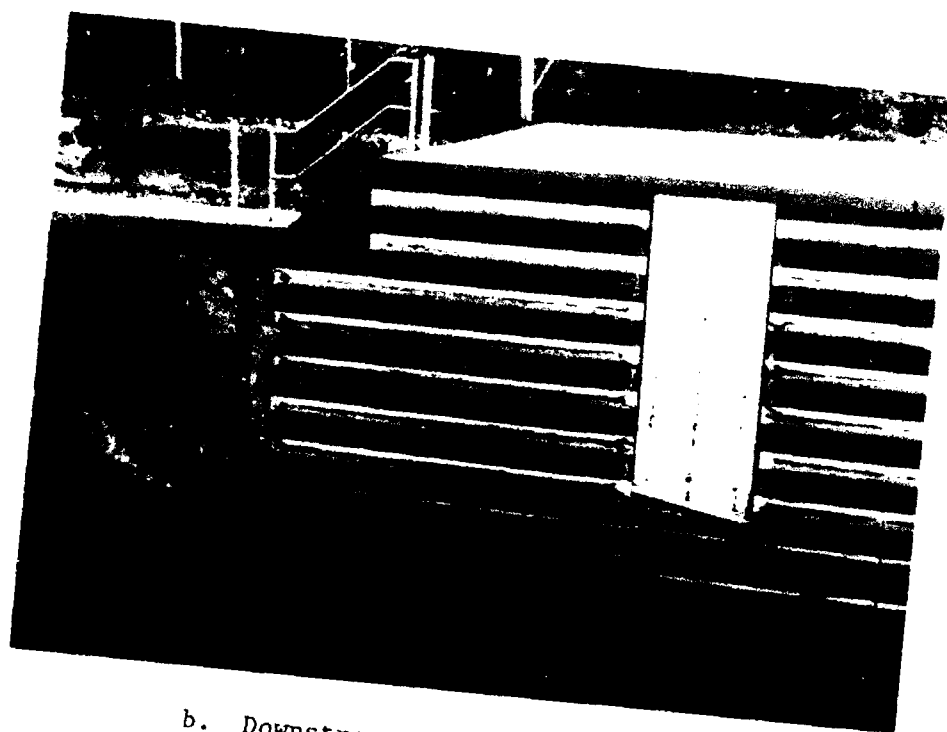


b. Upstream of power house

Figure 2. Surface repairs of spalling near power house



a. Monoliths 48 to L-62



b. Downstream of lower gate recess

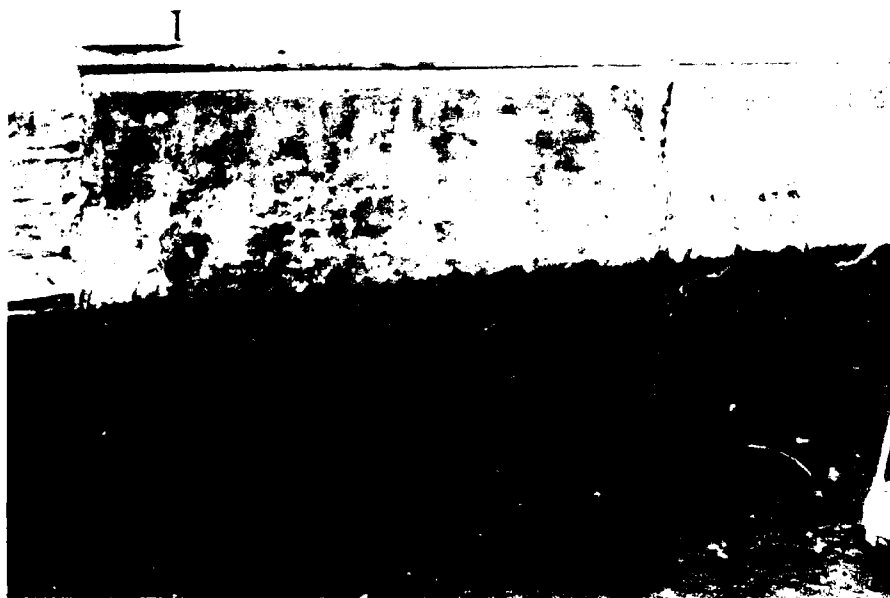
Figure 3. Lower guide wall



Figure 4. Lower gate recess land wall



a. Single corner armor shows formed repair, double corner armor shows shotcrete repair



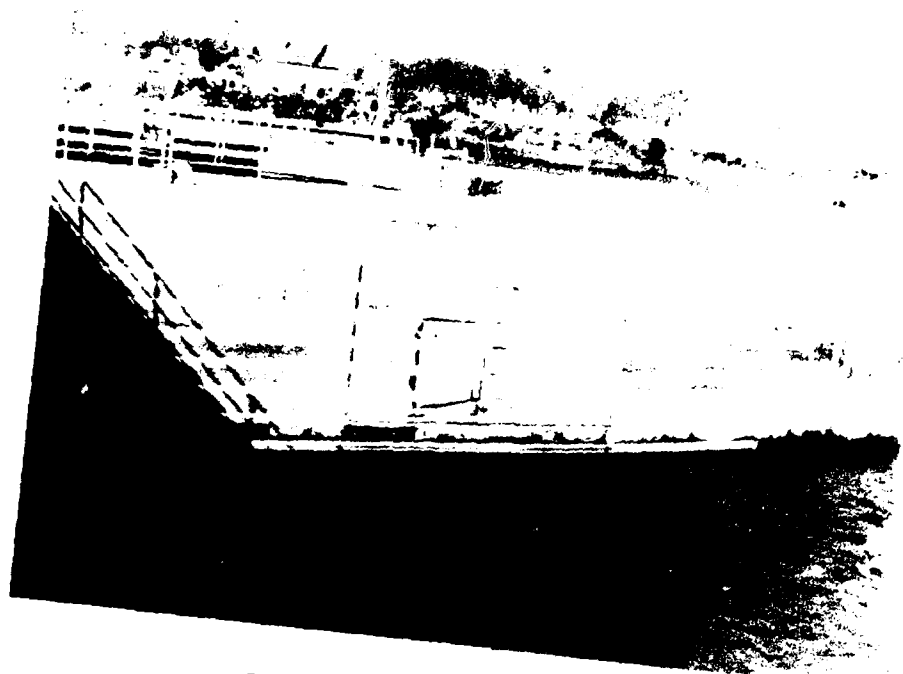
b. Peeling of shotcrete repair

Figure 5. Land face of middle wall (continued)

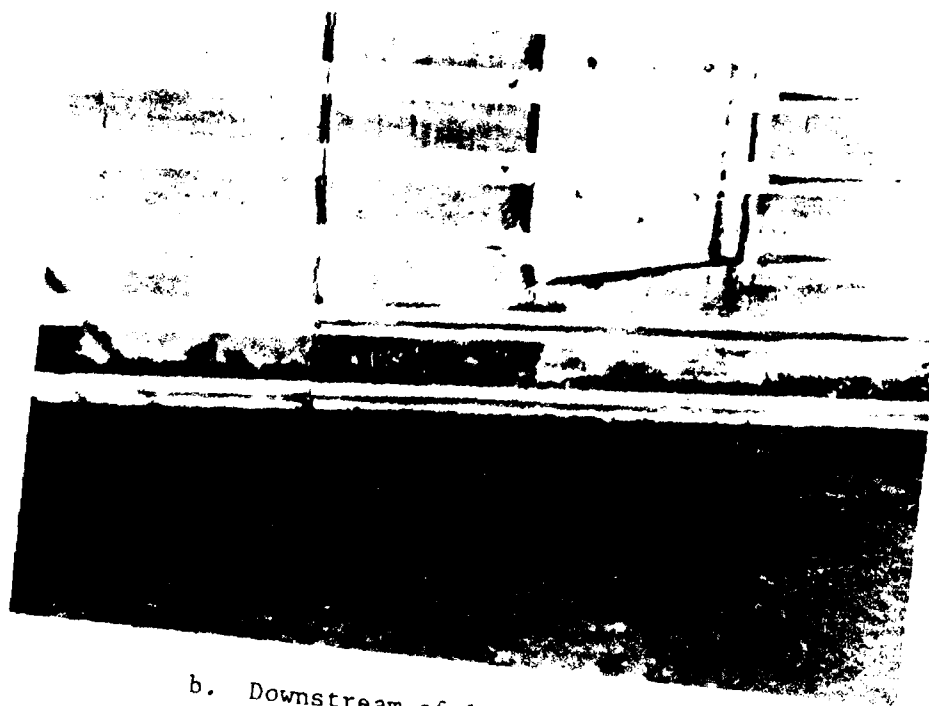


c. Spalling at monolith joints

Figure 5. (Concluded)

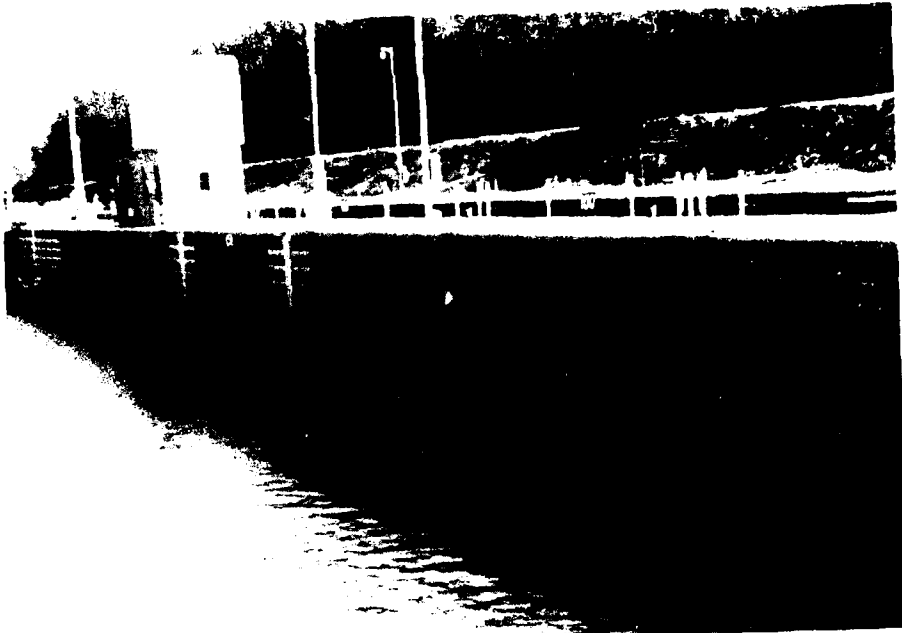


a. Monoliths M-24 to M-27

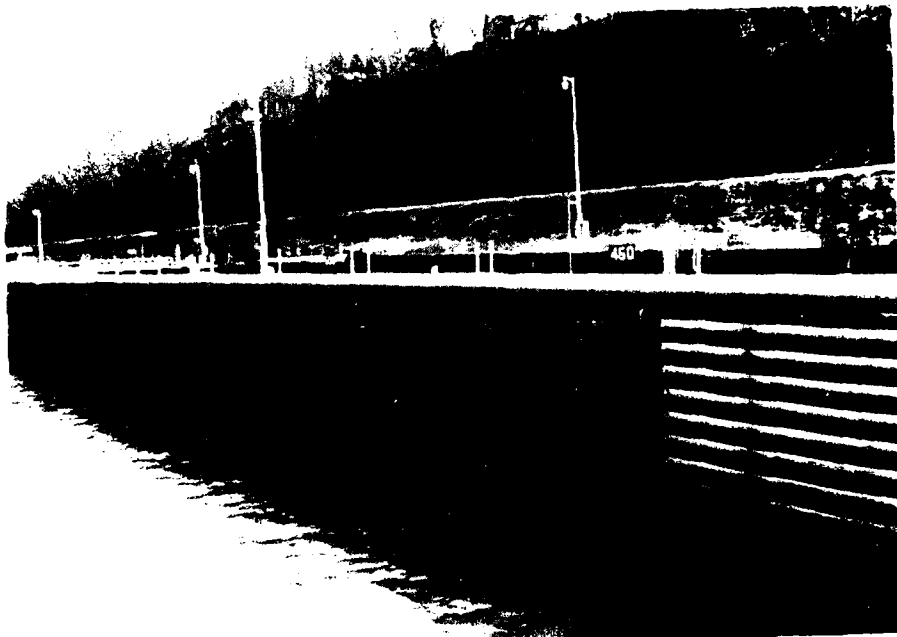


b. Downstream of lower gate recess

Figure 6. Concrete in the land face of lower end of middle wall

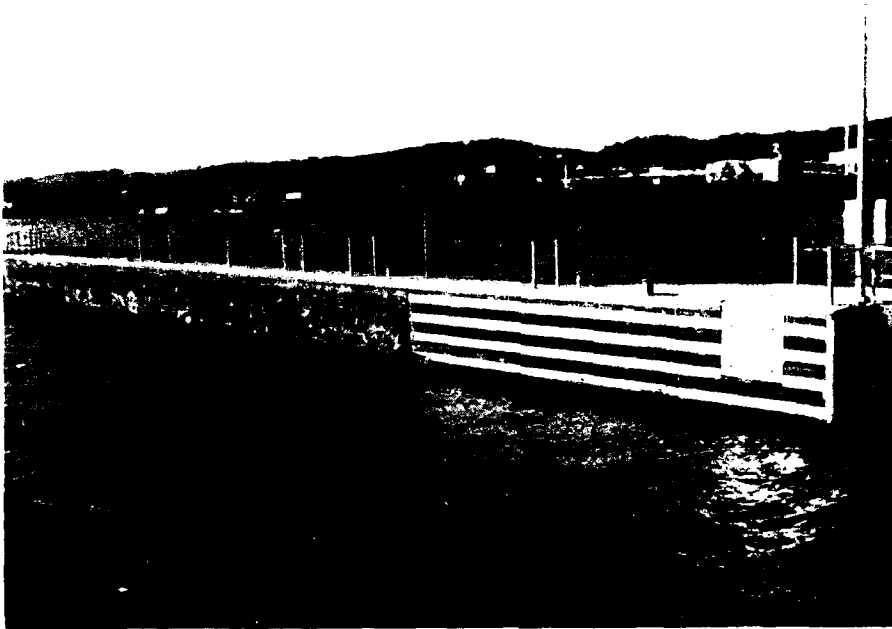


a. Monoliths M-10 to M-14



b. Monoliths M-17 to M-24

Figure 7. Middle wall river face

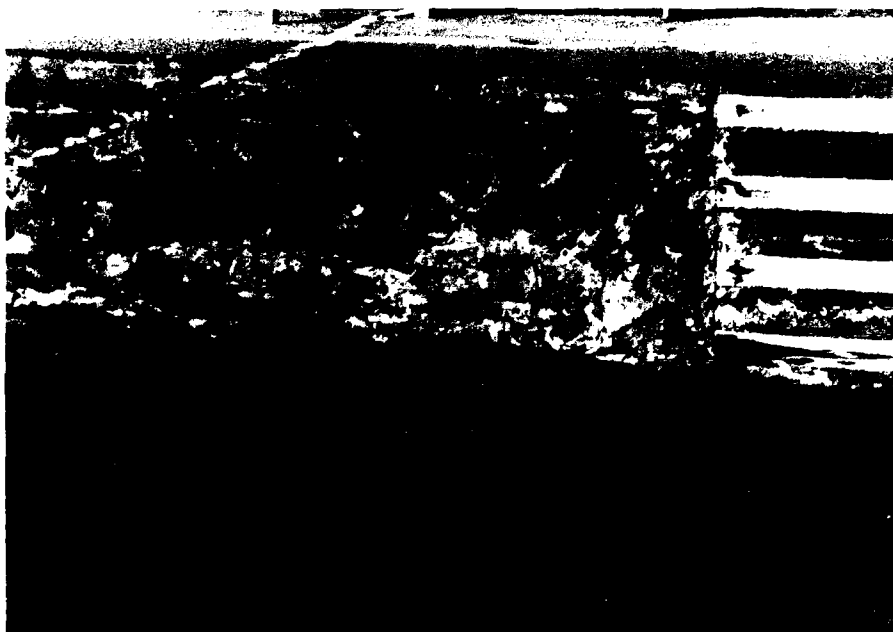


a. Monoliths R-1 to R-11



b. Monoliths R-5 to R-9

Figure 8. Concrete in the upper guard wall land face (continued)



c. Monoliths R-8 to R-10

Figure 8. (Concluded)

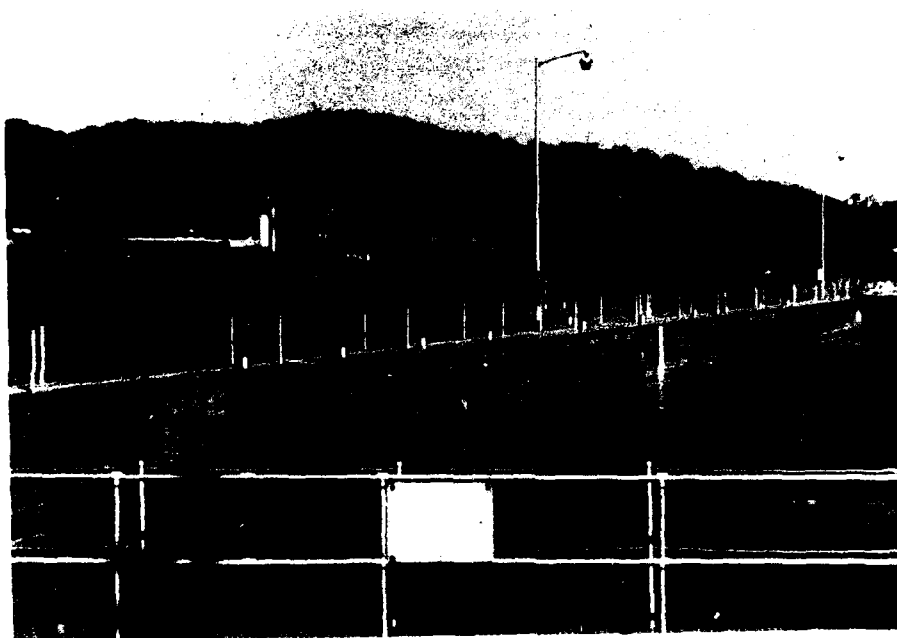
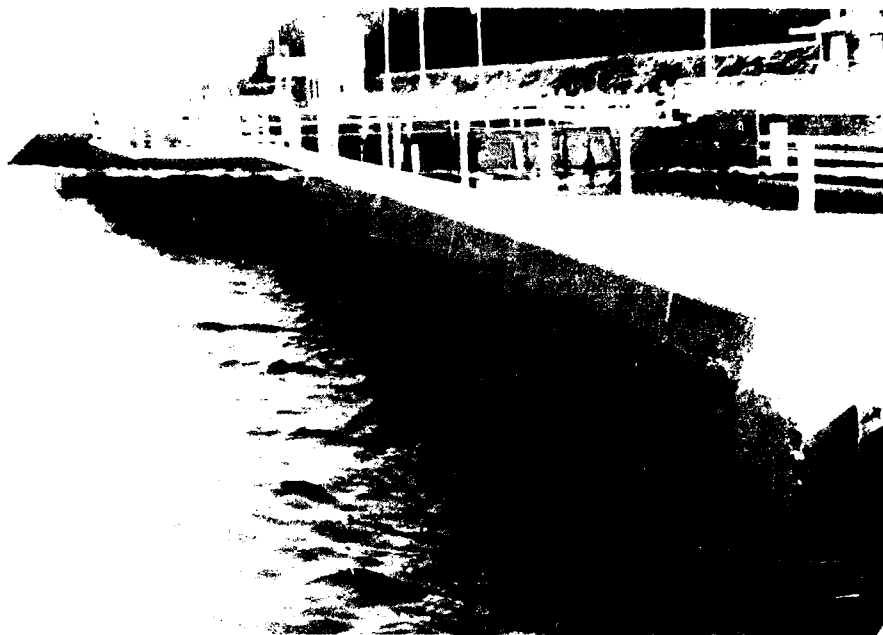


Figure 9. River wall lock chamber



a. Monoliths R-12 to R-7



b. Monolith R-12 at water level

Figure 10. River face, river wall

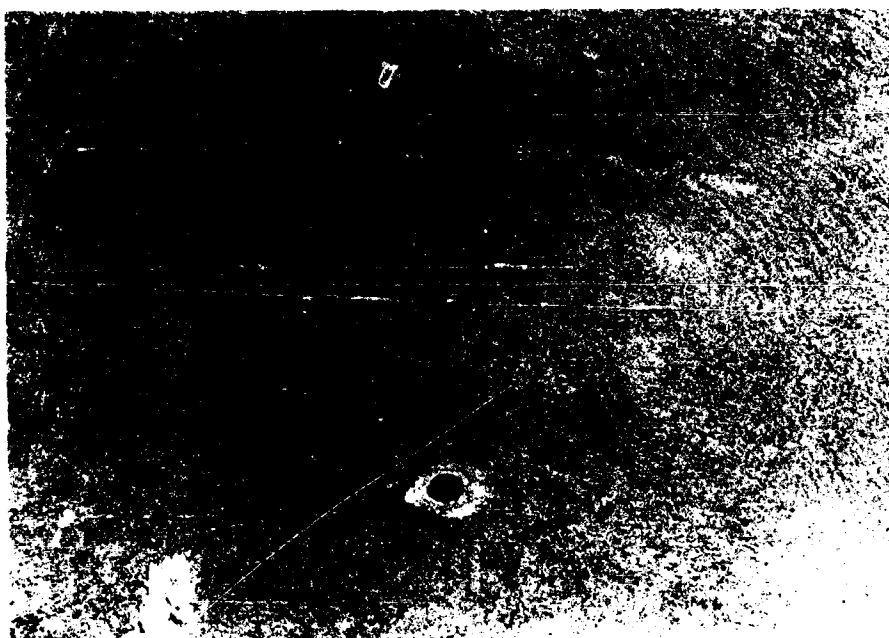
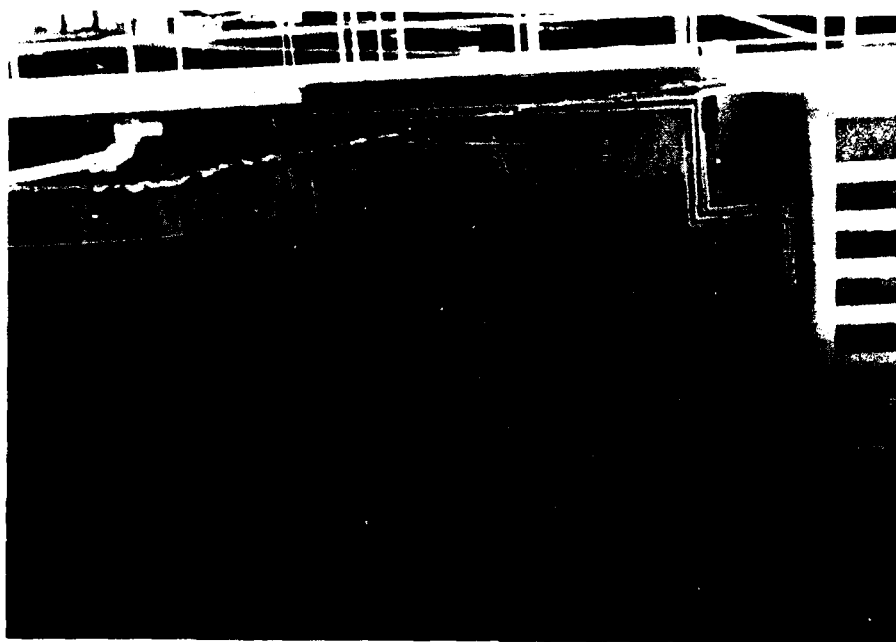


Figure 11. Typical top surfaces of repaired walls



a. Upper gate recess, middle wall



b. Lower gate recess, river wall

Figure 12. Typical of most gate recesses