MISCELLANEOUS PAPER SL-81-21

CONDITION SURVEY
REPAIR AND REHABILITATION
LOCK AND DAM NO. 24, MISSISSIPPI RIVER

by


Structures Laboratory
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August 1981
Final Report

Approved for Public Release; Distribution Unlimited

Prepared for U. S. Army Engineer District, St. Louis
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The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.
A condition survey of the concrete was performed at Lock and Dam No. 24 on the Mississippi River. Field studies indicated that 32 percent of the concrete bridge support columns are moderately to severely deteriorated, 48 percent are slightly deteriorated, and 20 percent show no sign of damage. A small zone of concrete downstream of the trunnion shafts is severely deteriorated. Cores were recovered from areas representative of the different degrees of damaged concrete and examined and tested in the laboratory. Some of the (Continued)
20. ABSTRACT (Continued)

cores were extensively damaged by cycles of freezing and thawing to depths of 2 ft. Compressive strengths of the cores ranged from 2010 to 9770 psi. The minimum remaining compressive strength in the columns is estimated at 1000 psi. Techniques for removal and repair of damaged concrete are recommended. Removal of concrete by water jet is suggested.
The work described herein was performed for the U. S. Army Engineer District, St. Louis (SLD), by personnel of the U. S. Army Engineer Waterways Experiment Station (WES). The work was authorized by DA Form 2544 No. ED 80-75 dated 3 September 1980, No. ED 80-75 R1 dated 25 September 1980, and ED 80-75 R2 dated 18 November 1980.

The testing program was accomplished under the direction of Mr. Bryant Mather, Chief of the Structures Laboratory (SL), WES, and Mr. John M. Scanlon, Jr., Chief of the Concrete Technology Division (CTD), SL. Mr. H. T. Thornton, CTD, was Project Leader and was assisted in performing the laboratory work by Messrs. R. L. Stowe, F. S. Stewart, and G. S. Wong and Mrs. Joyce C. Alvin, all of CTD. The core drilling was conducted by personnel of the Geotechnical Laboratory (CL), WES, under the direction of Mr. Mark A. Vispi. SLD personnel furnished the photographs in Appendix D. This report was largely written by Messrs. Stowe and Thornton; Messrs. Wong and J. E. McDonald, CTD, contributed portions.

Directors of WES during the conduct of the investigation and the publication of this report were COL N. P. Conover, CE, and COL T. C. Creel, CE. Technical Director was Mr. F. R. Brown.
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CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

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

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fahrenheit degrees</td>
<td>5/9</td>
<td>Celsius degrees or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kelvins*</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>metres</td>
</tr>
<tr>
<td>feet per second</td>
<td>0.3048</td>
<td>metres per second</td>
</tr>
<tr>
<td>inches</td>
<td>0.0254</td>
<td>metres</td>
</tr>
<tr>
<td>miles (U. S. statute)</td>
<td>1.609344</td>
<td>kilometres</td>
</tr>
<tr>
<td>pounds (force) per square inch</td>
<td>0.006894757</td>
<td>megapascals</td>
</tr>
<tr>
<td>pounds (mass)</td>
<td>0.45359237</td>
<td>kilograms</td>
</tr>
<tr>
<td>pounds (mass) per cubic foot</td>
<td>16.01846</td>
<td>kilograms per cubic metre</td>
</tr>
<tr>
<td>square feet</td>
<td>0.09290304</td>
<td>square metres</td>
</tr>
</tbody>
</table>

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula:  \( C = \frac{5}{9}(F - 32) \). To obtain Kelvin (K) readings, use:  \( K = \frac{5}{9}(F - 32) + 273.15 \).
1. Lock and Dam No. 24, Mississippi River, is situated at Clarks-ville, Missouri, 93.5 miles* upstream from St. Louis, and 273.5 miles above the mouth of the Ohio River. It is close to the Missouri shore at the base of a high, steep hill. The project consists of a main lock and upper gate bay of an auxiliary lock; a dam containing a movable section of 15 tainter gates; and a fixed submersible stone-covered earth dike reaching to the Sny Island Drainage and Levee District.

2. The regulating portion of the dam consists of fifteen 80-ft-wide tainter gates. Dam piers are pile supported. The submersible dike extending from the storage yard to the Illinois shore is constructed with a core of steel pile cells covered with stone and slush concrete.

Background

3. In 1973, ultrasonic pulse velocity measurements were made through selected piers of Locks and Dams No. 24 and 25. The results of these tests were reported to the St. Louis District (SLD) by letter dated 29 October 1973, subject, "Results of Sonoscope Survey of Lock and Dam No. 24 and 25, Mississippi River." In 1976, the presence of alkali-silica reaction in concrete from an intermediate wall of Lock and Dam No. 24 was established by the examination of 6-in. and 4-in.-diameter cores. The concrete cores were from an area of undeteriorated concrete. In October 1978, five NX (2-1/8-in. diameter) concrete cores were received from the U.S. Army Engineer District, St. Louis, for examination.

* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 3.
These cores were taken from the downstream portions of three piers in the dam of Lock and Dam No. 24. The cores were in fragments with the longest intact piece of core being about 2-1/2 in. Results of the examination of these cores were reported in December 1978.  

4. In September 1979 members of the Structures Laboratory, Waterways Experiment Station (SL, WES), performed a more extensive ultrasonic pulse velocity investigation of the concrete portion of the dam structure at Lock and Dam No. 24. This investigation included selected concrete columns that support the service bridge as well as piers No. 2 through 15. The objectives of this investigation were to determine, by nondestructive means, the extent and severity of cracking near the trunnion shafts on the downstream portions of the piers and to determine the extent of cracking in the columns. The results of this investigation were reported in WES Miscellaneous Paper SL-80-2.  

Objectives

5. The objectives of the investigation reported herein were to:
   a. Determine the effect of water intrusion (if any) on the reinforcing steel and tainter gate anchorage steel in the area around the trunnion shaft. Pier No. 9 was selected to be examined.
   b. Determine the remaining compressive strength of the concrete in the piers and the service bridge support columns.
   c. Determine the extent, severity, and cause of the concrete deterioration in the piers and support columns.
   d. Determine the location, extent, and cause of any structural cracks.
   e. Suggest repair materials and repair methods.

Scope

6. The investigation included:
   a. Preliminary engineering study.
      (1) Visual inspection of dam.
      (2) Collection and review of all available records and data.
b. Drilling and excavation of concrete.

c. Laboratory testing and analysis of concrete core.
PART II: PRELIMINARY ENGINEERING STUDY

Review of Reports and Drawings

7. All available reports, records, and drawings pertinent to this study were collected and reviewed. The items available for review included construction drawings and photographs, postconstruction concrete reports, Periodic Inspection Reports including instrumentation data and analysis, concrete core test and examination reports, a report of field ultrasonic velocity measurements, and boring logs. Specific references to these reports and drawings are made in appropriate parts of this report.

Inspection of Dam

8. Personnel from the WES, SLD, and Lock and Dam No. 24 inspected the dam to observe the extent of damaged concrete on exposed surfaces, locate any structural cracks, obtain information from maintenance, repair, and operational records, and to talk with lock personnel. Persons inspecting the dam are given in Table 1. Photographs showing typical damaged concrete are presented in Appendix A, pages A2 through A5.

9. The piers and the service bridge support columns of the dam were examined to ascertain the physical condition of the exposed concrete surfaces. As a result of the examination, the exposed concrete was classified into five categories based upon crack width and frequency and the amount of exudation present. The "Concrete Condition" terms were established by the authors. The crack width ranges are given in the "Guide for Making a Condition Survey of Concrete in Service;" see Reference 4. The different concrete conditions are tabulated below:

<table>
<thead>
<tr>
<th>Concrete Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;OK&quot;</td>
<td>No signs of deterioration</td>
</tr>
<tr>
<td>Very light</td>
<td>Local cracks (infrequent), closed hairline, one per 3- by 3-ft area, slight exudation</td>
</tr>
</tbody>
</table>
Concrete Condition | Description
--- | ---
Light | Local cracks (infrequent), fine (<1 mm, 0.04 in.), one per 3- by 3-ft area, slight exudation
Moderate | Zone cracking, medium (1 to 2 mm, 0.04 to 0.08 in.), one crack every 3 to 4 in., heavy exudation covering 50 percent of zone
Severe | Zone cracking, medium to wide (wide <2 mm, 0.08 in.), one crack every 2 to 3 in. apart, heavy exudation covering >75 percent of zone.

10. Zones of damage were sketched (to scale) for the upstream and the downstream surfaces of the bridge columns. If a small zone of damage exists, then the whole bridge column was classified based upon the condition of the small zone. Some damaged zones extended over a few square feet while others over tens of square feet. No sketches were made for the zones of damaged concrete just downstream of the trunnion shafts in the piers. The exterior and interior extent of concrete damage in the piers and bridge columns is presented and discussed in Part V of this report.

11. A number of structural cracks were observed in the bridge columns on piers No. 9 and No. 16. The extent and width of structural cracks were mapped. For purposes of this report structural cracks are defined as those cracks caused by external applied loads. The extent of the structural cracks is presented in Part VI of this report.

12. Mr. Dan Buckley, Lockmaster at Lock and Dam No. 24, was on the inspection team. He explained to the team the difficulty encountered, on a number of occasions, in passing thick ice over a couple of the tainter gates. The ice would build up behind the gates. When it broke loose and was passing the gate, he observed a trunnion shaft oscillating due to the vibrations caused by ice hitting the piers and the gates. He also related that the townspeople, adjacent to the lock, complained of inordinate vibrations on occasions when thick ice was being passed; windows rattling and vibration felt through the floors of houses.
13. In addition to the ice problem, Mr. Buckley told us that the tainter gates are now not lowered to their design depth. When they are lowered to their maximum depth, inordinate vibrations result due to the applied water loads.
PART III: DRILLING AND EXCAVATION

Drilling

14. Information gathered during the inspection of the dam indicated that 32 percent of the service bridge support columns (total of 64) are moderately to severely deteriorated; 48 percent of the columns are very light to lightly deteriorated; and 20 percent have no signs of deterioration. Columns representative of the different concrete conditions were drilled. Six of the severely and three of the moderately deteriorated columns had short horizontal borings placed in them. Four columns showing no evidence of deterioration had borings placed in each of them. Borings in the columns were drilled through to the opposite side.

15. Three of the piers were drilled to obtain information on the quality of the concrete with depth. Vertical borings were located in those piers where nondestructive testing (Reference 3) indicated poor concrete and where survey data indicated the greatest amount of settlement and downstream movement of the piers. The measured settlement and downstream movement are relatively small, 0.03 ft and 0.06 ft, respectively. In general, the piers indicating the greatest movement also indicate the greatest settlement. Short horizontal borings were also placed in the piers. Borings in the piers were drilled in the vicinity of the trunnion shafts. See Plate 1 for general boring locations; specific boring locations are given on plates presented in Part V of this report.

16. Boring designations appearing on Plate 1 are explained as follows; S WES P04.1 and S WES C02.2N are used as examples: S, sponsor (St. Louis District); WES, drilling agency (Waterways Experiment Station); P&C, for pier and column; first two numbers for pier numbers; third number is column number 1 through 4; and last letter represents north, east, south, or west face of a column. See Plate 1 for order of column numbers.

17. A total of 4 vertical borings and 21 horizontal borings were drilled. A total of 161 ft of core was recovered. Core recovery was
99 percent. See Table 2 for detailed boring information. The following information is presented for each boring; the direction of the boring, the location, the elevation of the top of boring, the elevation bottom of boring, depth of horizontal borings, and the date when the boring was started. Core logs are presented in Appendix B.

18. A WES drill crew conducted the drilling at Lock and Dam No. 24. Drilling equipment consisted of an Acker Toredo Mark II and a Sprage and Henwood skid-mounted rotary drill rig. A Diamond Core Drill Manufacturers Association standard 4-in. by 5-1/2-in. double tube swivel tube core barrel and 5-7/8- by 6-1/8-in. thin wall barrel were used with diamond bits to obtain the concrete core. Access to the dam was by a marine floating plant supplied by the SLD; once on the dam, the crane on top of structure was used to position and move drill equipment. The crane was operated by a WES operator. Continuous samples were obtained in all borings. A Concord portable electric drill rig was used in drilling horizontal borings in the columns.

19. All borings were backfilled with concrete using packaged dry combined materials. To each 50 lb of materials was added 10 lb of portland cement. To each 60 lb of materials, enough water was added to make a stiff mixture. Prior to adding the required water to the materials, 1 ml of air-entraining admixture was mixed in the water. After a 24-hr period, the crown area of the backfilled horizontal borings in the columns were sealed. A slightly expanding cement grout (aluminum powder was added to cement) was pumped into and along the crown area of the borings. The sealing operation was necessary due to the shrinkage of the concrete away from the crown area of the horizontally drilled hole. It was directed that all borings in the columns be backfilled and sealed before the crane was allowed to pass over those columns that were drilled.

Excavation Around Trunnion Shaft

20. Concrete from around the trunnion shaft in pier No. 9 was excavated to expose a small portion of the tainter gate anchorage steel. This work was done to reveal the physical condition of the anchorage
steel. With evidence of cracked concrete and impounding water in the area of the trunnion shaft, there was concern that rusting of the anchorage steel had reduced the steel's cross section. See Plate 2 for a cross section of the zone examined. Photographs No. 8 through 13, Appendix A, show the excavated zone.

21. The concrete was removed from around the anchorage steel using a hand held air-hammer. The first foot of concrete was removed without great difficulty as compared to the remaining 1-1/2 ft. The concrete was hard and tough to remove. Occasional cracks were encountered that were lightly stained; the staining resulted from infiltrating rain water.

22. A plastic cork, as described on the original plans, was found bonded to the anchorage steel. It was intact and had to be torn away from the steel except near the top of the pier. The area crossed hatched in Plate 2 indicates the zone of rusting that was detected. The rusting reduced the steel cross section about 1/64 in. on the trunnion collar; original thickness of collar is 2 in. The damage to the steel is considered insignificant. See photographs No. 11, 12, and 13 (Appendix A) for rusted zone.

23. An asphaltic bonding material was applied to the anchorage steel prior to backfilling the excavated hole. The hole was cleaned of loose material, air blown, and backfilled with air-entrained concrete. The concrete was vibrated in 1-ft lifts, finished, and cured.
PART IV: TEST SPECIMENS AND TEST PROCEDURES

Cores Received

24. Concrete core from 25 borings was received at the WES. Shipment of the core was handled by the WES drill crew. Cores were shipped in sawdust lined core boxes. Upon receipt of the core, it was inspected for damage; there was no damage due to handling and shipping. The core that was not selected for testing remains at the WES; it will be discarded or shipped to the SLD after completion of the investigation.

Selection of Test Specimens

25. A detailed visual examination of all the core was made to assist in the selection of representative test specimens. The examination was further used to verify the depth of damaged concrete in the core. Test specimens were selected from the top, middle, and bottom portions of all the vertical cores and on those horizontal drilled cores where core was intact and could be tested. Many test specimens contained portions of damaged concrete; i.e., horizontal and inclined cracks and weathered concrete. Some specimens were pieced back together for compressive strength testing; e.g., on some cores where an inclined or horizontal crack caused separation of the core, pieces were placed back together and tested. Nominal 6-in.-diameter by 12-in.-long specimens were used for the various physical property tests. Test specimen locations on the cores are given on appropriate drawings and sketches in Part V of this report.

26. After examining the core in detail, a comparison between the condition of the core and the condition of the in-place surface concrete was made. The core and in-place surface concrete compared quite well; i.e., where severe deteriorated core exists, severe deteriorated in-place surface concrete existed. This comparison enables one to say that other columns with the same classification ("OK", moderate, and severe) would likely contain internal concrete similar to the columns that were cored.
This information will be helpful if the damaged concrete is replaced.

27. Portions of concrete from five cores were selected for detailed petrographic examination. A general description of the 6-in.-diameter concrete cores is as follows:

<table>
<thead>
<tr>
<th>Field Identification No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S WES-C16.2 N-80</td>
<td>Horizontal core into badly deteriorated concrete, from column</td>
</tr>
<tr>
<td>S WES-C16.3 E-80</td>
<td>Horizontal core into moderately deteriorated concrete, from column</td>
</tr>
<tr>
<td>S WES-C13.2 N</td>
<td>Horizontal core into good concrete, from column</td>
</tr>
<tr>
<td>S WES-P04.1</td>
<td>Vertical core into good concrete, from pier</td>
</tr>
<tr>
<td>S WES-P09.1</td>
<td>Vertical core into good concrete, from pier</td>
</tr>
</tbody>
</table>

Physical Property Test Procedures and Petrographic Examination

28. The physical property tests were conducted in accordance with the appropriate test methods tabulated below:

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Weight (As Received), ( y_m )</td>
<td>CRD-C 107-696</td>
</tr>
<tr>
<td>Water Content, ( w )</td>
<td>CRD-C 113-80 (ASTM C 566-78)</td>
</tr>
<tr>
<td>Pulse Velocity, ( V_p )</td>
<td>CRD-C 51-72 (ASTM C 597-687)</td>
</tr>
<tr>
<td>Compressive Strength, ( q_u )</td>
<td>CRD-C 27-78 (ASTM C 42-77)</td>
</tr>
<tr>
<td>Elastic Modulus, ( E )</td>
<td>CRD-C 19-75 (ASTM C 469-65)</td>
</tr>
<tr>
<td>Poisson's Ratio, ( \nu )</td>
<td>CRD-C 19-75 (ASTM C 469-65)</td>
</tr>
</tbody>
</table>

29. Applicable portions of CRD-C 57-78 (ASTM C 856-77) were used in conducting a petrographic examination on representative concrete core; see Appendix B for specific works accomplished.
PART V: RESULTS AND DISCUSSION

Petrographic Examination

30. The results of the petrographic examination of the concrete cores are presented in detail in Appendix C. A brief summary is presented in the following paragraphs.

31. The concrete is not air entrained. The concrete contains gravel and sand of mixed composition; maximum size aggregate is about 1-1/2 in. Coarse aggregate consists of sandstone, quartz, chert, carbonate rock particles, igneous rock particles, and some particles of ironstone. Chalcedony in the chert particles was identified as the common reactive material in the concrete. This finding is similar to the observations made in previous reports. (1,2)

32. The major deterioration consists of parallel to subparallel cracking occurring parallel to the formed core surfaces. This type of cracking is characteristic of freezing and thawing action. The concrete tends to be saturated with white alkali-silica gel. The alkali-silica reaction contributed to the concrete cracking. The gel is present as coatings (exudation) on cracks and exterior core surfaces. The calcium hydroxide has carbonated to calcite on exposed surfaces.

33. The black coating observed on a cracked core surface at about 12.5 ft of core S WES-P04.1 is a pliable tar-like substance; it appears to be a bond-breaker material that was applied to the surface examined or that flowed from somewhere else to its present location.

34. It is not possible to determine how much of the damage in the cores was due to freezing and thawing and alkali-silica reaction. An additional mechanism could have caused some of the observed cracking or initiated cracking which allowed freezing and thawing and alkali-silica reaction to begin.
Extent of Damaged Concrete

35. The extent of concrete damage was ascertained from the field investigation and the detailed examination of the core. The photographs of cores presented in Plates 3 through 11 are typical examples of three different concrete conditions, the "OK" (no deterioration), moderate, and severe deterioration. Cross section and orthographic projection drawings were made to show the extent of damaged concrete in the downstream portions of the piers and in the bridge columns; see Plates 12 through 31.

36. There is a distinct difference in the physical condition of the cores representing the "OK" (no deterioration) and the moderately and severely deteriorated concrete; view Plates 3 through 13. The "OK" cores represent sound concrete with an occasional natural break. The term natural break is used to describe a break in the concrete when the mechanism that caused the break is unknown. The cores representing the moderately and severely deteriorated concrete show clear evidence of damage by frost action, i.e., subparallel cracks to the formed surfaces (end of cores). Note that the majority of the damaged concrete is near the formed surfaces; there is little or no damage towards the middle of the core. For all practical purposes the core representing the moderate and severe class concrete can be grouped together when considering their physical condition. Cores from both classifications contain about the same amount of damaged concrete. Core S WES C09.2N is of poor quality; however, it looks worse as a core than the concrete it represents in-place. The broken condition of the core is due to frost action, alkali-silica reaction, and core barrel blockage. The concrete was cracked in place as evidenced by its weathered nature, but broken somewhat during drilling and upon removal from the core barrel.

Piers

37. Cross sections for the three piers (No. 4, No. 9, and No. 15) in which vertical and horizontal borings were drilled are presented in Plates 12, 13, and 14. A small zone of severely deteriorated concrete exists below and downstream of the trunnion shaft for the full 10-ft
width of the pier. The zone extends from station 99.75 ft to a maximum
depth at station 98.5 ft in pier No. 4. In pier No. 9 the zone is 0.9 ft
deep and in pier No. 15 the zone is 0.4 ft deep. The depth of the zone
could be deeper in the piers not drilled. Major cracks in the core
recovered from the piers are presented on these three cross sections.
The cracks help to explain some of the "no readings, NR," in the down-
stream portions of the piers. Plate 13b shows the location of the
ultrasonic velocity measurements taken on pier No. 9 and the cracks ob-
served in borings S WES P09.1 and P09.3. The uppermost crack in P09.1
could account for the "no reading" at stations No. 6 and 7. This plate
also indicates that other "no readings" are accounted for by the anchor-
age steel; the interface between the concrete, plastic cork, and the
steel would attenuate the transmitted pulse. The in-place velocities
obtained by Thornton compare well with the velocities recorded on the
laboratory test specimens.

38. The physical properties from the pieces of core tested are
presented on Plates 12 through 14. Stress-strain curves for selected
core from the piers are presented in Plates 15 through 18. Circled num-
bers adjacent to the borings indicate the location (elevation) from
which a test specimen was taken. Like circled numbers, on-line with the
various physical properties, represent those numbers adjacent to the
cores. The physical properties obtained on the core recovered from the
three piers indicate good quality concrete throughout the downstream
portion of the piers. The lowest strength is 5840 psi on the uppermost
piece of concrete from S WES P15.1. There is no reason to suspect that
interior concrete in the other piers has less quality than the concrete
tested during this investigation. The concrete in the piers is sound
although a few natural breaks are present. These breaks could be sealed
by injecting a bonding agent into the breaks.

Columns

39. The extent of damaged concrete in the bridge columns is pre-
sented in Plates 19 through 35. Physical property test results for core
taken from the columns is included on appropriate plate. The surface
extent and depth of damaged concrete can be readily seen on Plates 19
through 35. For those columns where borings were made, the actual depth of damaged concrete is shown. Some of the backsides of the columns (opposite side of columns from the side the drill entered) contained damaged concrete; it is shown where it occurs. The average depth of damaged concrete on the outside in the moderately and severely deteriorated columns is 1 ft. For the moderately and severely deteriorated columns that were not drilled, the 1-ft depth of damaged concrete is believed to exist and is shown. The average depth of damaged concrete on the backside for both the moderate and severe classified columns is 0.25 ft. The middle of the columns do not show freeze-thaw damage. The following tabulation summarizes the depth of damaged concrete in the columns. The greatest amount of damaged concrete was recovered from the downstream and the upstream faces of the columns.

<table>
<thead>
<tr>
<th>Core Location</th>
<th>Moderate Deterioration</th>
<th>Severe Deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>1 ft (0.7 ft - 1.7 ft)</td>
<td>1 ft (0.6 ft - 2.0 ft)</td>
</tr>
<tr>
<td>Middle</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>Backside</td>
<td>0.2 ft</td>
<td>0.3 ft</td>
</tr>
</tbody>
</table>

The plan cross sectional area of a column is 10.5 ft$^2$. Considering the average depth of damage for the full width of a column, the damaged concrete occupies 3.75 ft$^2$, there remains within a column 6.75 ft$^2$ of undamaged concrete.

Physical Property Tests

40. A summary of the physical properties for the "OK", moderate, and severely deteriorated concrete is presented in Figures 1 through 3. Stress-strain curves for selected core taken from the columns are presented in Plates 36 through 43. Some of the compression test specimens were selected to include the damaged concrete; some of the outside and the backside specimens contain damaged concrete. In several cases core that was separated by the action of freezing and thawing was put back together and tested in compression. See photographs in Plates 44 through
"OK" (NO DETERIORATION), COLUMNS

AVERAGE PROPERTIES WITH RANGES

<table>
<thead>
<tr>
<th>TEST</th>
<th>OUTSIDE</th>
<th>MIDDLE</th>
<th>BACKSIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$, lb/ft$^3$</td>
<td>137.6</td>
<td>152.5 (152.2-152.8)</td>
<td>156.0</td>
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<tr>
<td>$\omega$, pct.</td>
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<td>4.4</td>
<td>4.4</td>
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<td>$V_p$, ft/sec</td>
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<td>15,665 (15,341-16,996)</td>
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<tr>
<td>$g_{s1}$, psi</td>
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<td>9,080 (8,870-9,770)</td>
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<td>$\nu$</td>
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<td>0.19</td>
<td>0.18</td>
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</table>

Origini: concrete strength, Class B

Lowest: Average: Highest: 4,710 psi: 5,930 psi 7,040 psi

Figure 1. Average physical properties with ranges for the OK class concrete
**Figure 2.** Average physical properties with ranges for the moderate class concrete
Figure 3. Average physical properties with ranges for the severe class concrete
46. This procedure was used to determine the lowest remaining concrete strength in the columns. The physical properties will be discussed under the "OK", moderate, and severe classes of concrete. Strengths of cylinders that were cast during construction show the following strengths:

<table>
<thead>
<tr>
<th>Lowest</th>
<th>Average</th>
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<tbody>
<tr>
<td>4710 psi</td>
<td>5930 psi</td>
<td>7040 psi</td>
</tr>
</tbody>
</table>

41. "OK". The densities of the outside, middle, and backside core are reasonable for sound concrete; the range is from 152.2 to 158.0 lb/ft$^3$; the average outside, middle, and backside densities are 157.5, 152.5, and 158.0 lb/ft$^3$, respectively. There is a 5- to 6-lb/ft$^3$ difference between the density of the near surface and middle core; the difference is attributed to, in part, the presence of reinforcing bars contained within the near surface cores. The water content of the near surface cores is about the same as the middle core. The moderate and severely deteriorated cores have a water content about 1 percent higher than the "OK" class cores. This higher water content is attributed to the presence of the damaged concrete; the cracked concrete with its increased surface area contains additional water.

42. The velocities are indicative of good quality concrete. The range in velocity is 15,073 to 16,196 ft/sec. The compressive strengths for the near surface and middle concrete are higher than the highest cylinder break obtained during construction. The range in strength is 8,870 to 10,310 psi. The modulus was figured as a secant value to 40 percent of the compressive strength. The modulus ranges from 5.04 x 10$^6$ psi to 5.55 x 10$^6$ psi. The Poisson's ratio is reasonable for good quality concrete; it ranges from 0.18 to 0.25.

43. Moderate. The outside and middle concrete show about the same difference in the average density, i.e., 5 lb/ft$^3$, as does the "OK" class concrete. The outside core has a greater range in density (154.7-160.8 lb/ft$^3$) than the middle core (150.8-152.6); again the higher density of the outside core is due to the inclusion of reinforcing bars in the outside specimens. The average outside and middle densities are
156.8 lb/ft$^3$ and 151.7 lb/ft$^3$, respectively. The average water contents are 5.3 and 5.2 percent for the outside and middle cores.

44. The difference between the average velocities of the outside and middle core is indicative of the damaged outside concrete. The outside velocity averages 11,995 ft/sec (range is 10,757-14,178 ft/sec) while the middle average is 13,140 ft/sec (range is 12,725-13,555 ft/sec). Note the smaller range of the middle cores, indicating more consistency of the concrete. The average strength of the outside and middle cores is above the average of the cylinder strengths cast during construction. The average outside and middle strengths are 6630 psi and 7650 psi. The average modulus of the outside concrete is about one-half the average modulus of the middle cores. The modulus of the moderately deteriorated concrete is considerably below the modulus of the "OK" classified concrete. The reason for the difference is probably due to the fact that the moderately deteriorated concrete contains cracks and voids that closed up under the compressive load applied to the core, resulting in larger axial deformations and hence lower modulus values. The Poisson's ratio for the outside and middle core is 0.16.

45. Severe. The average density values for the three sections of core are considered the same, 152.3, 150.0, and 150.7 lb/ft$^3$ for the outside, middle, and backside, respectively. The range over the full length of the cores is 146.5-160.3 lb/ft$^3$. The lowest density (146.5 lb/ft) was obtained for the severe class of concrete and is attributed, in part, to the damage caused by freezing-thawing and alkali-silica reaction. The greatest water content was measured on a piece of core from the severe class of concrete, i.e., 6.4 percent. The average water content for the severe class concrete is slightly above the average water content of the moderate class concrete.

46. There is no appreciable difference between the water contents in cores taken from the top of the columns to near the base of the piers. It was thought that the water contents, with depth, might be different, and if so, help to explain why some of the concrete was more heavily damaged.
47. The velocities measured on this class concrete were the lowest measured on all the cores tested. A velocity of 2,774 ft/sec was obtained on an outside core. The average outside, middle, and backside velocities are 4,381, 11,961, and 9,730 ft/sec, respectively. These relatively low values are indicative of poor quality concrete; the low velocities were anticipated considering the damaged condition of the severe class concrete. The middle cores have velocities ranging from 11,111 to 14,303 ft/sec. Again the middle cores are of better quality than the near surface core.

48. The lowest strengths were obtained from the severe class concrete; 2,070 psi for an outside core and 2,010 psi from a backside core. The lowest strength middle core is 3,080 psi; the lowest strength middle core in the other classes of concrete is 704 psi. The average modulus values for outside and backside core are 0.21 x 10^6 psi and 0.28 x 10^6 psi. Again, large deformations of the core due to cracks and voids in the damaged concrete account for the very low modulus values. The stress-strain curves for the cores containing portions of damaged concrete show the typical stress-strain relation for cores containing open cracks; see Plates 37, 38, 40, and 42. Note the concave upwards portion of the curves which represents closure of the cracks and the voids within the specimen. Poisson's ratios are not available because lateral deformation was not measured on the severe class concrete. There was no easy way of mechanically or electrically monitoring lateral movement of the core due to its broken nature.
PART VI: SUMMARY AND RECOMMENDATIONS

Trunnion Shaft Area

49. A few fine (<1 mm, 0.04 in.) and wide (>2 mm, 0.08 in.) cracks in the concrete exist near and intersect with the trunnion shaft on all piers. Rain water has permeated the concrete along these cracks as evidenced by the presence of stains on surfaces of concrete excavated from around portions of the tainter gate anchorage steel on pier No. 9. An insignificant amount of rusting has occurred on the top 2-ft portion of the trunnion shaft collar on pier No. 9. Because all the piers have cracks in the concrete around the trunnion shafts, it is reasonable to assume that a portion of the collars on all piers is lightly rusted. The H beams of the anchorage are protected by plastic cork and are not rusted in pier No. 9. In conclusion, there is no significant damage due to rusting of the anchorage steel.

Remaining Strength of Concrete

50. The remaining compressive strength of the concrete in the piers is considered to be at least equal to the lowest compressive strength obtained on the core from the piers; that strength is 5840 psi. Except for a small zone of damaged concrete downstream of the trunnion shafts on all the piers, the interior pier concrete is sound and will serve its original intended purpose. A few natural breaks occur in the piers, but these breaks should not affect the structural integrity of the piers.

51. The remaining concrete compressive strength in the columns with the greater amount of damaged concrete is probably between 1000 and 2,000 psi; the exterior 1 ft having the 1,000-psi strength and the interior section having the 2,000-psi strength. The lowest exterior and interior core strengths were 2,010 psi and 3,080 psi, respectively. These strengths have been reduced by 1000 psi to account for a reduction
in strength. The reason for reducing the strength has to do with the difference in strength between horizontal and vertically aligned core that is cracked.

52. All cores from the columns were drilled horizontally and the cracks (closely spaced) caused by frost damage are subparallel to the core axis. Laboratory tests from an unreported study by the principle author, of jointed concrete specimens indicate that when the joints are perpendicular to the axis of applied load, as were the cracks in the horizontally drilled core, the strength is higher than when the joints are parallel to the applied load. With closely spaced joints parallel to the applied load, eccentric loading results as individual jointed members of the specimen flex. The eccentric loads cause reduced strengths. It is not known how much the actual core strengths should be reduced; however, a 1,000-psi reduction is considered conservative.

53. Columns containing the moderately and severely deteriorated concrete that were not drilled could contain low strength concrete equal to the reduced 1,000- to 2,000-psi strengths.

Columns Adequate to Support Bridge

54. This investigation shows that the columns are not weak enough to crumble under static compressive loads. The study shows that compressive strength between 1,000 and 2,000 psi exists which is about one-half the acceptable value of the lowest original strength of 4,710 psi. Some of the concrete in the columns is now not serving its originally intended purpose. The static analysis that a SLD technical staff member conducted on 1 May 1980, "Dam 24 Service Bridge Pier," shows that 240-psi strength is required from the concrete. Based upon these computations and our strength test results, there is no problem at the present time. The concrete strength will decrease with time if the deterioration of the concrete is allowed to continue. We can not assure the adequacy of the columns due to structural movement or dynamic stresses caused by inordinate vibrations from ice loading or other conditions at the dam. It is
suggested that a dynamic stability analysis of the piers and columns be made to see if they are adequate against some critical loading conditions with the present low strength concrete.

**Extent and Cause of Damaged Concrete**

55. A small zone of severely deteriorated concrete exists below and downstream of the trunnion shaft for the full width of the pier; i.e., the upper part of the downstream vertical face of the piers. This condition exists on all piers. Depth of the zone is about 1.0 ft.

56. The top portions of the columns contain the greatest amount of damaged concrete; the concrete towards the bottom of the columns is sound. Trapped water on the top of the columns probably infiltrated the concrete and the freezing and thawing action caused damage near the top of the columns. With time the damaged zone has extended downwards. The downstream and upstream faces of the columns contain more damaged concrete than any other column surfaces. These column faces have more exposure to the sun and are subject to more cycles of freezing and thawing. The average depth of damage for the moderately and severely deteriorated columns is 1 ft on the upstream and downstream faces.

57. The lack of entrained air in this concrete caused the concrete to be susceptible to frost damage. The repeated freezing and thawing of the concrete while critically saturated has caused delamination of the concrete, especially near surfaces. The opening of the concrete by frost action has accelerated the alkali-silica reaction. This deleterious chemical reaction has caused additional disaggregation of the frost-damaged concrete. The interior concrete shows slight indications of alkali-silica reaction, but has not caused any significant damage to the interior concrete.

58. Another mechanism could have initiated cracking in selected piers in order for action to begin. For instance, vibration of the dam could have caused microcracking to occur at specific locations along the dam, i.e., on piers No. 5, No. 9, and No. 16. Frost action then could have started at these specific locations. The columns on these three
piers contain much more damaged concrete than do the other columns on any other piers. With all columns exposed to the same environment, and assuming that all the concrete in the columns was of the same quality, some unknown mechanism probably contributed to the damaged concrete that exists in piers No. 5, No. 9, and No. 16.

Structural Cracking

59. District personnel visited the dam and found a burst pipe on pier No. 16. They believe that the structural cracks in the columns on piers No. 9 and No. 16 were caused by bursting pipes and freezing water associated and adjacent to the pipe. Some WES personnel agree that the bursting pipe could cause the concrete to split as was found. However, it should not be overlooked that some of the structural cracks observed at the dam could have been caused in part or in whole by some loading condition other than freezing water. See Appendix D for photographs of the damage concrete due to the burst pipe.

60. The broken section of column No. 3 on pier No. 16 was removed and a 1-1/2-in. diameter pipe, a section of electrical conduit (ref drawing ML 24 56/1), was found to be split as if it had burst. The top of the conduit was once flush with the top of the columns and capped, however, it is now rusted off; see Photograph 5 in Appendix D. Evidently, rain water collecting on the top of the columns had drained into the conduit, frozen, burst the pipe, and cracked portions of the column. The columns on pier No. 9 were examined and it is believed that a similar situation to the one that caused the cracks on pier No. 16 developed on pier No. 9.

61. Original drawings show that 1-1/2-in. diameter electrical conduits are present in all downstream columns. Additionally, the downstream column on the Missouri side of each pier contains a 1-1/2-in. diameter drum-heater conduit which makes a 90-deg bend below the column and continues to a cast-iron junction box located above the trunnion shaft. A single 1/2-in. diameter conduit was provided for drainage of this entire line. According to lock personnel, the junction box and
drain line are silt laden. Also, short conduit elbows, plugged at both ends, were installed in the upstream and downstream cross walls which span between tops of the columns. The electrical conduits, the drum-heater conduits, drain conduits, and conduit elbows are potential sources of water which could be responsible for some of the deterioration of columns and the zone below and downstream of the trunnion shaft. Since these conduits are no longer in use, and if they are not proposed to be used in the future, it is recommended that they be cleaned out, grouted, and capped.

**Removal and Repair of Damaged Concrete**

62. The basic phenomena which initiated cracking in the concrete columns and piers were not identified in this study; therefore, it is impossible to suggest a repair procedure with any assurance that the same phenomena will not cause similar problems in the repair. It is most important that the basic cause of the cracking be ascertained before final selection of any repair procedure aimed at eliminating future cracking. Lacking this information, any repairs at present must be considered as only remedial work to improve the current condition of the columns and piers.

63. The surface cracks on the piers should be adequately sealed to keep water from infiltrating the concrete, especially in the area of the trunnion shaft. If the water is kept out, rusting of anchorage steel, frost action, and alkali-silica reaction will be greatly reduced.

64. There appear to be two basic approaches for repair of the concrete pier columns. The first approach should be considered an interim repair aimed at reducing the current rate of deterioration. The second approach would involve major rehabilitation of the pier columns.

65. The orientation and extent of cracking in the columns is such that the ingress of moisture (rain, snow, ice, etc.) from the top surfaces of the columns and cross members contributes to freezing and thawing and alkali-silica reaction within the concrete. Potential procedures to minimize this ingress of moisture would include (1) sloping the tops
of the columns and cross members to insure drainage towards the interior opening between the columns, (2) drilling holes along the lift joint between the columns and column facing to allow drainage to the outside of the columns, and (3) sealing the top surfaces of the columns and cross members. In this case the latter approach appears to offer ease of construction and the greatest potential for success. A number of materials are available to seal these horizontal surfaces; however, based on previous experience a heavy duty membrane of rubberized asphalt integrally bonded to polypropylene mesh is suggested. The use of such a membrane should be restricted to horizontal surfaces with the possible exception of those vertical surfaces within 3 to 6 in. of the tops of the columns. Such an overlap would allow installation of a mechanical band around the columns to further secure the membrane. Specifications for this membrane are included in Table 3. This approach should reduce the rate of deterioration while additional work is being done to determine the basic cause of deterioration or until major rehabilitation of the pier columns is initiated.

66. Major rehabilitation would involve removal of unsound concrete from those areas previously described as moderately or severely deteriorated and replacement with new concrete; i.e., the upper part of the downstream face of the piers and certain pier columns. It is anticipated that the location and extent of reinforcing steel and the strength of the existing concrete will be such that concrete removal may be difficult. The concrete removal operation should be closely monitored to insure that the amount of concrete removed is kept to the minimum necessary for replacement with new concrete. In general this minimum depth would be that necessary to completely expose the outer layer of reinforcing.

67. It is recommended that the surface removal of distressed/deteriorated concrete from the piers and the bridge columns be done using high-pressure water jets. The reasoning behind the selection of the water jet over conventional removal methods is amount of reinforcing steel in the concrete. The water jet leaves the steel reinforcing clean and undamaged for reuse, thus eliminating the need for replacement steel. In addition to reinforcing the concrete, the steel will act as a dowel
between the existing and replacement concrete allowing loads to be transferred between them. Other advantages of the water jet are:

a. Minimal damage to the concrete that remains is produced.

b. Irregular shaped volumes can be removed.

c. No dust and little noise are produced.

The main concern with the water jet is its variable productivity rate. Under certain conditions, such as cutting concrete containing large abrasive-resistant aggregate, this rate can be very low. To avoid contracting a jet with undesirable productivity rate, it is recommended that a short-term (say, 3 days) pilot test program be used to determine the productivity and acceptability of the jet. The following contractors are among the most promising for doing a satisfactory removal job:

Flow Industries
Kent, Washington
(206) 872-8500

McCartney Mfg Co., Inc.
Baxter Springs, Kansas
(316) 856-2151

IlT Research Institute
Chicago, Illinois
(312) 567-4400

Daedalean Associates, Inc.
Woodbine, Maryland
(301) 442-2620

68. In those cases where 50 percent or more of the concrete column area is expected to require removal, consideration should be given to providing temporary support for the column loads and completely removing and replacing the existing columns. Either sawing or explosives is suggested for concrete removal in these instances.

69. Replacement concrete should be proportioned in accordance with current standard practice. Particular attention should be given to freezing and thawing resistance and the potential for alkali-silica reaction.

70. Some recent rehabilitation projects have encountered cracking in the replacement concrete. In general these problems were associated with concrete overlays which were rather thin relative to the remaining
concrete monoliths. Such problems appear to be the result of the tremendous restraint provided by the existing concrete making thermal considerations during construction even more important than in new construction. While the concrete sections involved in this work are relatively small, the potential for thermal cracking still exists. Attention should be given to minimize temperature differentials between existing and replacement concrete during placing and curing of the replacement concrete. Also, differentials in temperature between the replacement concrete and ambient at the time of form removal and immediately following should be within 25°F or less.

71. Depending upon when this repair is scheduled, a vacuum polymer impregnation technique currently under development may have potential application. This technique consists of wrapping the structure in polyethylene and creating a vacuum through the use of a vacuum pump. A resin is then injected and flows, through the cracks in the structure, towards the source of the vacuum. The vacuum evacuates water and fine contaminants from the fissures prior to impregnation with the resin. With the aid of the vacuum, resin penetrates throughout the crack system and dust or loose particles acts as a filler in the resin. Repair is accomplished without removal of damaged concrete. Fine aggregate may be mixed with the resin to repair large cracks, voids, or badly deteriorated surfaces. The technique is currently being investigated by application to damaged 6-in. by 12-in. cylinders and 3-1/2- by 4-1/2- by 16-in. beams. Damage is being produced for laboratory testing by compressive and splitting tensile testing, exposure to high temperature (1000°F), accelerated freezing and thawing, and accelerated alkali-silica reaction. If laboratory testing continues to show favorable results, this technique may warrant field testing on one or more of the damaged piers or columns.
REFERENCES

1. U. S. Army Engineer Waterways Experiment Station Petrographic Report, dated 23 January 1976, subject, "Tests and Examination of Concrete Cores from Lock and Dam 24 and Lock and Dam 25," Vicksburg, Miss.

2. U. S. Army Engineer Waterways Experiment Station Petrographic Report, dated 4 December 1978, subject, "Project Examination of Fragmented Concrete Cores from Lock and Dam 24, U. S. Army Engineer District, St. Louis," Vicksburg, Miss.


Table 1

*Inspection Team, Lock and Dam No. 24*

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<tr>
<td>Mel Stegall</td>
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<td>Carl Pace</td>
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CRM = Compliant roofing membrane
Detail showing rusted zone on anchorage collar and approximate extent of excavated concrete. Reference M-124 40/45.1
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<td>3.9</td>
<td>16,527</td>
<td>7,800</td>
<td>0.12</td>
</tr>
<tr>
<td>⑥</td>
<td>152.4</td>
<td>4.6</td>
<td>16,639</td>
<td>6,970</td>
<td>0.18</td>
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</tbody>
</table>

**CROSS SECTION PIER #4**

**PLATE 12**
<table>
<thead>
<tr>
<th></th>
<th>$\gamma$</th>
<th>$w$</th>
<th>$V_0$</th>
<th>$q_u$</th>
<th>$E$</th>
<th>$V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>13.2</td>
<td>4.5</td>
<td>13.7</td>
<td>6.83</td>
<td>2.98</td>
<td>0.3</td>
</tr>
<tr>
<td>2.</td>
<td>13.2</td>
<td>4.7</td>
<td>15.0</td>
<td>7.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>15.1</td>
<td>5.0</td>
<td>15.0</td>
<td>9.13</td>
<td>5.20</td>
<td>0.18</td>
</tr>
<tr>
<td>4.</td>
<td>13.2</td>
<td>5.6</td>
<td>13.5</td>
<td>7.97</td>
<td>2.89</td>
<td>0.21</td>
</tr>
<tr>
<td>5.</td>
<td>14.8</td>
<td>4.0</td>
<td>15.4</td>
<td>8.30</td>
<td>4.95</td>
<td>0.18</td>
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<tr>
<td>6.</td>
<td>15.1</td>
<td>4.5</td>
<td>14.9</td>
<td>7.96</td>
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<td></td>
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<td>7.</td>
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<td>5.2</td>
<td>15.0</td>
<td>9.01</td>
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<td>0.18</td>
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<td>8.</td>
<td>13.2</td>
<td>4.1</td>
<td>15.1</td>
<td>8.50</td>
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</table>

CROSS SECTION PIER #9

PLATE 13a
<table>
<thead>
<tr>
<th>$\gamma$</th>
<th>$\omega$</th>
<th>$V_p$</th>
<th>$Q_u$</th>
<th>$E$</th>
<th>$\nu$</th>
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</thead>
<tbody>
<tr>
<td>1.510</td>
<td>6.0</td>
<td>14,404</td>
<td>5,840</td>
<td>2.80</td>
<td>0.14</td>
</tr>
<tr>
<td>1.516</td>
<td>4.2</td>
<td>15,126</td>
<td>8,380</td>
<td>5.84</td>
<td>0.22</td>
</tr>
<tr>
<td>1.510</td>
<td>4.3</td>
<td>15,625</td>
<td>7,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CROSS SECTION PIER 15**

**PLATE 14**
COLUMNS PIER #1

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS
CONCRETE
CORE
TEST

PHYSICAL PROPERTIES
OUTSIDE
MIDDLE
BACKSIDE

No damaged concrete, no core take
* Column numbers

OK
MODERATE
SEVERE

SCALE 1/8" = 1'

PLATE 19
COLUMNS PIER #2

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS
C 02.2N

CONCRETE

CORE

TEST

8", ln/lc³
W', pet
Vp, fps
Q4, psi

PHYSICAL PROPERTIES

OUTSIDE  MIDDLE  BACKSIDE

152.9
4.4
16,196
8,870

OK

MODERATE

SEVERE

SCALE 1/8" = 1'

PLATE 20
COLUMNS PIER #3

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS
CONCRETE

CORE

TEST

PHYSICAL PROPERTIES

OUTSIDE
MIDDLE
BACKSIDE

Lt damage over columns, no core taken.

LIGHT MODERATE SEVERE

SCALE 1/8" = 1'

PLATE 21
PLATE 22

COLUMNS PIER #4

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS
CONCRETE

CORE

NO.

TEST

PHYSICAL PROPERTIES

OUTSIDE

MIDDLE

BACKSIDE

No core taken.

LIGHT

MODERATE

SEVERE

SCALE 1" = 1'

PLATE 22
### Columns Pier 5

#### LOOKING UPSTREAM

#### LOOKING DOWNSTREAM

#### Physical Properties

<table>
<thead>
<tr>
<th>CLASS</th>
<th>CORE</th>
<th>TEST</th>
<th>OUTSIDE</th>
<th>MIDSIDE</th>
<th>BACKSIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEV</td>
<td>C05.13</td>
<td>( f' )</td>
<td>148.7</td>
<td>150.0</td>
<td>154.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( w_c )</td>
<td>5.6</td>
<td>5.1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_p )</td>
<td>4,502</td>
<td>14,303</td>
<td>9,093</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( f_{li} )</td>
<td>3,860</td>
<td>5,380</td>
<td>5,750</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( E \times 10^6 \psi )</td>
<td>0.24</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>SEV</td>
<td>C05.43</td>
<td>( f' )</td>
<td></td>
<td></td>
<td>147.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( w_c )</td>
<td></td>
<td></td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_p )</td>
<td></td>
<td></td>
<td>10,700</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( f_{li} )</td>
<td></td>
<td></td>
<td>3,560</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( E \times 10^6 \psi )</td>
<td></td>
<td></td>
<td>0.86</td>
</tr>
</tbody>
</table>

#### Class and Core

- **L** Light
- **M** Moderate
- **S** Severe

#### Scale

1" = 1'
COLUMNS PIER #6

Looking upstream

Looking downstream

Class
Concrete: No test

Physical Properties
Outside, Middle, Backside

Lt. damage over columns 1, 2, & 4. No core taken.

Light  Moderate  Severe

Scale 1/8" = 1'

Plate 24
COLUMNS PIER #7

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS
CONCRETE
CORE NO.
TEST

OK
CO7.3N
No tests

PHYSICAL PROPERTIES
OUTSIDE    MIDDLE    BACKSIDE

Lt. damage over columns 1&4

LIGHT
MODERATE
SEVERE

SCALE 1/16" = 1'

PLATE 25
COLUMNS PIER #8

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS    CORE
CONCRETE NO  TEST

PHYSICAL PROPERTIES
OUTSIDE MIDDLE BACKSIDE

Very light damage over column 4

UL VERY LIGHT

SCALE 1/8" = 1'

PLATE 26
COLUMNS PIER #9

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS CONCRETE  CORE NO. TEST  PHYSICAL PROPERTIES

SEV  CO9.15  N, Nl/ ft2  OUTSIDE  MIDDLE  BACKSIDE

w, psi  6.0  6.4
USH48  5.78  11.72
E, x 10^6 psi  2,880  3,000

MDO  CO9.3N  N, Nl/ ft2  OUTSIDE  MIDDLE  BACKSIDE

w, psi  5.7  4.8
USH48  4,050  12,725
E, x 10^6 psi  6,480  7,040

SEV  CO9.4N  N, Nl/ ft2  OUTSIDE  MIDDLE  BACKSIDE

w, psi  4.2  5.5
USH48  8,924  10,709
E, x 10^6 psi  2,070  4,230

\[ E, \times 10^6 \text{ psi} \]

\[ \frac{1}{2} \text{ in.} ^2 \to 1' \]

PLATE 27
Columns Pier #10

Looking upstream

Looking downstream

<table>
<thead>
<tr>
<th>Class</th>
<th>Core</th>
<th>No.</th>
<th>Test</th>
</tr>
</thead>
</table>

Physical properties

No core taken

Very light column 4; light column 1.

* Cracks caused by barge impact, epoxy filled.

VL Very light
L LIGHT

Scale 1/8" = 1'

Plate 28
COLUMNS PIER #11

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS
CONCRETE

CORE
NO

TEST

PHYSICAL PROPERTIES
OUTSIDE  MIDDLE  BACKSIDE

No core taken.

* Slight honeycombing, no exudation.

LIGHT  MODERATE  SEVERE

SCALE 1/8" = 1'

PLATE 29
COLUMNS PIER #12

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS      CODE      TEST
CONCRETE   NO.       OUTSIDE  MIDDLE   BACKSIDE

No core taken.
Lt damage column 1 & 4.

VL  VERY LIGHT  MODEKATE  SEVERE

SCALE 16"=1'

PLATE 30
COLUMNS PIER #13

LOOKING UPSTREAM

LOOKING DOWNSTREAM

<table>
<thead>
<tr>
<th>CLASS</th>
<th>CORE</th>
<th>TEST</th>
<th>OUTSIDE</th>
<th>MIDDLE</th>
<th>BACKSIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>OK</td>
<td>C/3.3N</td>
<td>'8, 15/11'</td>
<td>157.5</td>
<td>153.2</td>
<td>160.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>w, pcf</td>
<td>4.8</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vp, Kps</td>
<td>15,335</td>
<td>15,134</td>
<td>15,073</td>
</tr>
<tr>
<td></td>
<td></td>
<td>q, psi</td>
<td>9,720</td>
<td>9,280</td>
<td>10,310</td>
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<tr>
<td></td>
<td></td>
<td>E, 10^4 psi</td>
<td>5.04</td>
<td>5.55</td>
<td>5.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ν</td>
<td>0.25</td>
<td>0.19</td>
<td>0.18</td>
</tr>
</tbody>
</table>

VL = VERY LIGHT  ■ = MODERATE  [■■] = SEVERE

SCALE 1/8" = 1'

PLATE 31
COLUMNS PIER #14

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS CONCRETE CORE NO. TEST

PHYSICAL PROPERTIES OUTSIDE MIDDLE BACKSIDE

No core taken.

Very light columns 144.

VL VERY LIGHT  MODERATE  SEVERE

SCALE 1/16' = 1'

PLATE 32
COLUMNS PIER #15

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS
CONCRETE

CORE

TEST

PHYSICAL PROPERTIES

OUTSIDE  MIDDLE  BACKSIDE

No core taken.
All columns very light damage to concrete.

VL  VERY LIGHT  M  MODERATE  S  SEVERE

SCALE 1/8" = 1'

PLATE 33
COLUMNS PIER #16

LOOKING UPSTREAM

LOOKING DOWNSTREAM

CLASS CONCRETE | CORE NO. | TEST | OUTSIDE | MIDDLE | BACKSIDE
---|---|---|---|---|---
SEV | C16.1S | $\gamma$, lb/ft$^3$ | 154.0 | 154.3 | 149.6
| | w, pct | 5.3 | 4.4 | 5.7 |
| | $V_p$, psi | 2774 | 11,111 | 9,385 |
| | $q_u$, psi | 2,240 | 6,050 | 2,010 |
| | $E_x \times 10^6$, psi | 0.18 | 1.50 | 0.20 |
SEV | C16.1N | $\gamma$, lb/ft$^3$ | 160.3 | 160.3 | 160.3 |
| | w, pct | 4.9 | 4.9 | 4.9 |
| | $V_p$, psi | 5,450 | 5,450 | 5,450 |
SEV | C16.2N | No tests due to breaks and rebars.
MOD | C16.3E | $\gamma$, lb/ft$^3$ | 154.7 | 154.7 | 154.7 |
| | w, pct | 5.1 | 5.1 | 5.1 |
| | $V_p$, psi | 14,178 | 14,178 | 14,178 |
| | $q_u$, psi | 6,920 | 6,920 | 6,920 |

SCALE 1/8" = 1'

PLATE 34
### Physical Properties

<table>
<thead>
<tr>
<th>CLASS</th>
<th>CORE</th>
<th>NO.</th>
<th>TEST</th>
<th>OUTSIDE</th>
<th>MIDDLE</th>
<th>BACKSIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOO</td>
<td>C16.3N</td>
<td>4/14</td>
<td>Y, 6/15</td>
<td>154.6</td>
<td>152.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>W, psi</td>
<td>5.0</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vp, fps</td>
<td>10,757</td>
<td>13,555</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>qL, psi</td>
<td>6,490</td>
<td>8,250</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>E, x10^6 psi</td>
<td>1.42</td>
<td>3.52</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>v</td>
<td>0.14</td>
<td>0.18</td>
<td></td>
</tr>
</tbody>
</table>

SCALE 1/8"=1'

PLATE 35
PLATE 38

CONCRETE-COMPRRESSIVE STRENGTH
LOCK & DAM NO. 24
C09.1S

AX: BACKSIDE 0.2 = 1.2
AX: MIDDLE 1.5 = 2.5

AXIAL STRAIN, PCT
Photographs showing damaged and undamaged concrete cores selected for compressive strength testing: SBES C05.18 and SBES C05.48
Photographs of damaged concrete cores selected for compressive strength testing:
SSES C09.1S and SWES C09.4S
Photograph of SMES C16.18 showing damaged concrete core representing the outside and backside of column No. 1 on pier 16

PLATE 56
APPENDIX A: TYPICAL PHOTOGRAPHS SHOWING DAMAGED CONCRETE
Photo 1. Looking across dam from pier No. 1. Typical cracking pattern with exudation downstream of trunnion pin, pier No. 2

Photo 2. Looking upstream from pier No. 1. Moderately deteriorated concrete on service bridge support column, pier No. 2
Photo 3. Looking at downstream faces of service bridge support columns, pier No. 9. Typical crack pattern and exudation of severe deterioration.

Photo 4. Looking downstream on left dam abutment pier No. 16.
Photo 5. Looking downstream, left dam abutment pier No. 16. Structural crack high on downstream column. Crack +1-in. wide

Photo 6. Looking downstream, left dam abutment pier No. 16. Structural crack low on upstream column diagonal to column shown in Photo 5.
Photo 7. Close up of crack shown in Photo 6. Note large aggregates as well as concrete matrix is fractured.

Photo 8. Looking upstream at trunnion shaft area. Typical crack pattern where anchorage collars extend from concrete.
Photo 9. Looking upstream at trunnion shaft area. Note wetted area of concrete next to anchorage collar.

Photo 10. Looking downstream at trunnion shaft area. Portions of anchorage steel and reinforcing steel exposed by excavating the surrounding concrete.
Photo 11. Close up of trunnion shaft anchorage collar, note minor rusted collar steel

Photo 12. Excavation carried deeper. Note minor rusting on anchorage collar steel and cross member steel plate
Photo 13. Looking upstream at cross member steel plate in foreground and anchorage collar in the background partially uncovered.
APPENDIX B: FIELD CORE LOGS
<table>
<thead>
<tr>
<th>Elevation</th>
<th>Depth</th>
<th>Legend</th>
<th>Materials</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4690 10</td>
<td></td>
<td></td>
<td>Concrete</td>
<td>100%</td>
</tr>
<tr>
<td>4690 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4690 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4690 30</td>
<td>Run No. 1</td>
<td>ROD = 88.3%</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

**Concrete Physical Properties:**
- Same as concrete as in fair condition, upper 10 ft.
- Washed with water, clean, and free of rust.
- No sealers or other treatments applied.

**Legend:**
- A: Natural 
- B: Marine 
- C: Concrete 
- D: Machine Break

**View Looking West:**

**Diagram No. 16:**

**Location:**

**Project:**

**Hole No:**
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH LEGEND</th>
<th>CLASSIFICATION OF MATERIALS</th>
<th>RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4440</td>
<td></td>
<td>Run 24 80:40%</td>
<td></td>
</tr>
<tr>
<td>4450</td>
<td></td>
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<tr>
<td>4450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4470</td>
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<td></td>
</tr>
<tr>
<td>4410</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4400</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- **Concrete** - Granite gray in color.
- Natural aggregate - Stn. sand to coarse gravel (2") with the majority of the aggregates ranging from 3/4"-1" in size. Aggregates are rounded with a uniform texture, Firm, Hard, Jointed, Vena, Meta, with high percentage of quartz, makes conditions - V. Little to be no Barton product and declining at shallow depth. General condition applies.
- **Good** - Natural permeability of concrete at 115 and 44%. Concrete disclosed at 115. Material has an oil residue on surface of break.

B3
### Drill Log

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
<th>Core %</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.40</td>
<td>3/4&quot; Bar-arc</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>43.30</td>
<td>Concrete</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>42.20</td>
<td>Concrete</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>42.00</td>
<td>Concrete</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>41.00</td>
<td>Natural Fracturing</td>
<td>153%</td>
<td></td>
</tr>
<tr>
<td>46.00</td>
<td>Concrete</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>51.00</td>
<td></td>
<td>4.4</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**
- Sample 821 - Sandstone B-10
- Sample 822 - Sandstone B-12
- Sample 823 - Sandstone C-12
- Sample 824 - Sandstone D-12

**Hyperlink:**
- [Sample 821 - Sandstone B-10](#)
- [Sample 822 - Sandstone B-12](#)
- [Sample 823 - Sandstone C-12](#)
- [Sample 824 - Sandstone D-12](#)
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH</th>
<th>LEGEND</th>
<th>CLASSIFICATION OF MATERIALS</th>
<th>COLOR</th>
<th>CORE</th>
<th>WATER RET.</th>
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<tbody>
<tr>
<td>450</td>
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<td>Δ</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>450</td>
<td>1</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450</td>
<td>2</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450</td>
<td>3</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450</td>
<td>4</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
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</tr>
<tr>
<td>450</td>
<td>5</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
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<td></td>
</tr>
<tr>
<td>450</td>
<td>6</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
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<td></td>
</tr>
<tr>
<td>450</td>
<td>7</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
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</tr>
<tr>
<td>450</td>
<td>8</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
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</tr>
<tr>
<td>450</td>
<td>9</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
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<tr>
<td>450</td>
<td>10</td>
<td>Δ</td>
<td>1/4&quot; Rock</td>
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</table>

Concrete
**DRILLING LOG**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Legend</th>
<th>Classification of Materials</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>4480</td>
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<tr>
<td>4500</td>
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</tbody>
</table>

**Drill Remarks**

- Run No. 1: ZET 960
- Run No. 2: ZET 975
- Run No. 3: ZET 980

**Legend**

- CR - Core
- ZT - Zinc oxide
- MB - Medium break
- NB - Natural break

**Location**

- Top: 4480 ft
- Bottom: 4500 ft

**Elevation**

- Top: 4480 ft
- Bottom: 4500 ft

**Drill Action**

- RPM 780 RPM
- Water pressure 30 PSI
- Water rate 10 GPM

**Remarks**

- Physical properties similar to other WTS formations

**Additional Notes**

- Core length: 12 ft
- Net pay: 10 ft
- Water level: 4490 ft
- Drilled on: 10/10/97
- Total depth: 4500 ft
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH</th>
<th>LEGEND</th>
<th>CLASSIFICATION OF MATERIALS</th>
<th>COMMENTS</th>
</tr>
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<tbody>
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<td>444.0</td>
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<tr>
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<td>90</td>
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<td></td>
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<tr>
<td>434.0</td>
<td>100</td>
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**Drilling Log**

<table>
<thead>
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<th>Depth</th>
<th>Legend</th>
<th>Classification of Materials</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>000.0</td>
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<td>115.6</td>
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<td>120.0</td>
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<td>142.0</td>
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<td>144.1</td>
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<td>144.5</td>
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<td>145.0</td>
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<tr>
<td>145.0</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Legend**

- **Concrete**: 
  - **Normal**: 
    - Natural aggregate: 3/4"-1" size to coarse gravel (1:1.5) with majority of aggregate ranging from 1/8"-1/4".
    - Sand: Available to rounded - 5-30% angular, with rest being rounded - very angular, mainly fine to coarse gravel.
  - **Wet**: 
    - Concrete, high percentage of cement, and grained - condition - very little to none.
  - **Hardened**: 
    - Concrete, very hard.

**Remarks**: 
- Run 2. Run 2.5. Run 3. Run 3.5.
- Intermittent loss.
- Total Core Recovery: 90%.
- Date: 30/10/1972.
- Bore size: 7.5".
- Bore depth: 144.5 ft.
- Bore type: Soft.
- Total depth: 145.0 ft.
- Hole No.: 115-1.

**Diary**: 

- Concrete - natural gravel 3/4" size to coarse gravel (1:1.5) with majority of aggregate ranging from 1/8"-1/4".
- Sand: Available to rounded - 5-30% angular, with rest being rounded - very angular, mainly fine to coarse gravel.
- Concrete, high percentage of cement, and grained - condition - very little to none.
- Total Core Recovery: 90%.
- Date: 30/10/1972.
- Bore size: 7.5".
- Bore depth: 144.5 ft.
- Bore type: Soft.
- Total depth: 145.0 ft.
- Hole No.: 115-1.

**Diary**: 

- Location: 
  - Location: 
- Legend: 
  - Concrete: 
    - Natural gravel 3/4" size to coarse gravel (1:1.5) with majority of aggregate ranging from 1/8"-1/4".
  - Sand: Available to rounded - 5-30% angular, with rest being rounded - very angular, mainly fine to coarse gravel.
  - Concrete, high percentage of cement, and grained - condition - very little to none.
  - Total Core Recovery: 90%.
  - Date: 30/10/1972.
  - Bore size: 7.5".
  - Bore depth: 144.5 ft.
  - Bore type: Soft.
  - Total depth: 145.0 ft.
  - Hole No.: 115-1.

**Diary**: 

- Location: 
  - Location: 
- Legend: 
  - Concrete: 
    - Natural gravel 3/4" size to coarse gravel (1:1.5) with majority of aggregate ranging from 1/8"-1/4".
  - Sand: Available to rounded - 5-30% angular, with rest being rounded - very angular, mainly fine to coarse gravel.
  - Concrete, high percentage of cement, and grained - condition - very little to none.
  - Total Core Recovery: 90%.
  - Date: 30/10/1972.
  - Bore size: 7.5".
  - Bore depth: 144.5 ft.
  - Bore type: Soft.
  - Total depth: 145.0 ft.
  - Hole No.: 115-1.
**Concrete:** Greyish Brown in Color with Natural Aggregate. The Aggregate ranges in size from 1/8" to 2" max with 80% running from 1/4" to 1". The shape of Aggregate is Angular to Rounded with 90% being Rounded or Semi-Rounded. The Concrete is in Good Condition, in that it lacks Hairline Cracks, Cracks, and Significant Amounts of Reaction Product. All Breaks in Core are the Result of Machine Action (Bread at 10.5' is the Natural Break). Drill Times for Each Run Indicate a Very "Tough", Hard Concrete.
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH</th>
<th>LEGEND</th>
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</thead>
<tbody>
<tr>
<td>4340</td>
<td>10</td>
<td>Concrete</td>
</tr>
<tr>
<td>4330</td>
<td>11</td>
<td>Run No. 7 PCD: 1097</td>
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<tr>
<td>4320</td>
<td>12</td>
<td>Run No. 8 PCD: 107</td>
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<tr>
<td>4310</td>
<td>13</td>
<td>Run No. 9 PCD: 1087</td>
</tr>
<tr>
<td>4300</td>
<td>14</td>
<td>Run No. 10 PCD: 108</td>
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</tbody>
</table>

**Legend**
- **C** Concrete
- **MB** Machine Break
- **NB** Natural Break

**Location**
- 80PC 1162
- RS 101609
- 801B 1516

**Plan View**

**Diagram**

**Notes**
- B10
<table>
<thead>
<tr>
<th>Elevation</th>
<th>Depth</th>
<th>Material</th>
<th>Notes</th>
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<tbody>
<tr>
<td>1040</td>
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<td>1050</td>
<td>10</td>
<td>Concrete</td>
<td>10%</td>
</tr>
<tr>
<td>1060</td>
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<td>10%</td>
</tr>
<tr>
<td>1130</td>
<td>90</td>
<td>Concrete</td>
<td>10%</td>
</tr>
</tbody>
</table>

**Notes:**
- Water pressure: Press 4.01 Bar
- Water loss: 3.0 Bar
- Time of flow: 3.55
- Total depth: 110 meters
- Total core recovery: 30%
<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
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<tbody>
<tr>
<td>448.0</td>
<td>Concrete - Good Condition</td>
</tr>
<tr>
<td>448.9</td>
<td>Concrete - RQD 100%</td>
</tr>
<tr>
<td>448.10</td>
<td>Machine Core - RQD 100%</td>
</tr>
<tr>
<td>448.20</td>
<td>Machine Core - RQD 100%</td>
</tr>
</tbody>
</table>

Concrete is same as encountered in other W.E.S. Borings - Angiagate Type, Size, and Shape is same.
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH LEVER</th>
<th>CONSTRUCTION</th>
<th>MATERIALS</th>
<th>DRY TON</th>
<th>WET TON</th>
<th>CONSIDERATION</th>
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<tr>
<td>434 0</td>
<td>200</td>
<td>Concrete</td>
<td>100</td>
<td>BA G</td>
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<td>429 0</td>
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<td>100</td>
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<td>320</td>
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</table>

**Remarks:**

--run #10
- Run #11 2500+40
- Run #12
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH</th>
<th>LEGEND</th>
<th>CLASSIFICATION OF MATERIALS</th>
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<td>4481</td>
<td>02</td>
<td>WEATHERED</td>
<td>Run No. 1 - RQD 100%</td>
<td>100%</td>
<td>Good condition. Physical properties same as previous layers. Very little to no RQD and hairline cracks.</td>
</tr>
<tr>
<td>4481</td>
<td>10</td>
<td>RUN No. 1 - RQD</td>
<td>100%</td>
<td>100%</td>
<td>Concrete.</td>
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<td>4481</td>
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<td>RUN No. 2 - RQD 100%</td>
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<td>100%</td>
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<td>4481</td>
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<td>RUN No. 3 - RQD 100%</td>
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<td>100%</td>
<td>Concrete.</td>
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<td>RUN No. 4 - RQD 100%</td>
<td>100%</td>
<td>100%</td>
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<td>RUN No. 5 - RQD 100%</td>
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<td>RUN No. 6 - RQD 100%</td>
<td>100%</td>
<td>100%</td>
<td>Concrete.</td>
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</tbody>
</table>

**DIAGRAM:**
- B: CONCRETE
- C: HAIRLINE CRACK
- M: MACHINE BLOCK
- N: NATURAL BLOCK

**PIER No. 15 VIEW LOOKING U/S TECHNIQUE P/N**
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH</th>
<th>LEGEND</th>
<th>CLASSIFICATION OF MATERIALS</th>
<th>CORE CUT</th>
<th>BOX</th>
<th>REMARKS</th>
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<td>Δ</td>
<td>Run #11 Water Drilled</td>
<td>84.75</td>
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<td>42.30</td>
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<td>Δ</td>
<td>Run #12 Water Drilled</td>
<td>84.75</td>
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<td>42.10</td>
<td>0</td>
<td>Δ</td>
<td>Run #13 Water Drilled</td>
<td>34.3</td>
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<tr>
<td>42.00</td>
<td>0</td>
<td>Δ</td>
<td>Run #13 Water Drilled</td>
<td>34.3</td>
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<td></td>
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<tr>
<td>41.90</td>
<td>0</td>
<td>Δ</td>
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<td>34.3</td>
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<td>41.80</td>
<td>0</td>
<td>Δ</td>
<td>Run #14 Water Drilled</td>
<td>33.5</td>
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<td>41.60</td>
<td>0</td>
<td>Δ</td>
<td>Run #14 Water Drilled</td>
<td>33.5</td>
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<td></td>
</tr>
<tr>
<td>41.50</td>
<td>0</td>
<td>Δ</td>
<td>Run #14 Water Drilled</td>
<td>33.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41.40</td>
<td>0</td>
<td>Δ</td>
<td>Run #14 Water Drilled</td>
<td>33.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41.30</td>
<td>0</td>
<td>Δ</td>
<td>Run #14 Water Drilled</td>
<td>33.5</td>
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</tr>
</tbody>
</table>

**NOTES:**
- WATER DRILLED
- WATER PRESSURE: 700 psi
- WATER DRAINAGE

**PROJECT:**
- 1. LOCATION (Coordinates or Datum)
- 2. DRILLING LOG
- 3. TOTAL LENGTH OF CORE
- 4. TOTAL NUMBER OF CORE BOXES
- 5. TOTAL CORE RECOVERY FOR DRILLING
- 6. SIGNATURE OF INSPECTOR
DRILLING LOG

Location: St. Louis, Mo.

INSTALLATION
1. DATE
2. DRILLING LOG
3. LENGTH
4. TYPE
5. MATERIALS
6. TOTAL NUMBER OF CORE BOXES
7. TOTAL CORES RECOVERY PER CORE BOX
8. TOTAL PERCENTAGE OF RECOVERY

ELEVATION | DEPTH | CLASSIFICATION OF MATERIALS | DESCRIPTION | CORES | RECOVERY |
--- | --- | --- | --- | --- | --- |
4686.00 | 0.00 | | | | |
4686.10 | 0.10 | | | | |
4686.20 | 0.20 | | | | |
4686.30 | 0.30 | | | | |

Legend:
- Concrete
- Natural Rock
- Machine Rock

Concrete: Very good condition, no air voids, cracks, very little to no reaction period, and physical properties same as other N.E.W. Boreis.

B18
DRILLING LOG

LOCATION: ST. LOUIS, MO
LOCK + DAM No. 24

1. PROJECT
LOCK + DAM No. 24

2. LOCATION
ST. LOUIS, MO

3. DRILLING METHOD
Core Drilling

4. DIRECTION OF HOLE
80° DEG. FROM N.E.

5. THICKNESS OF OVERBURDEN
3.3

6. TOTAL DEPTH OF HOLE
30.8

ELEVATION DEPTH LEGEND

0.0
Material in Run No. 1.5
Low Grade Shale & Clay -
Core not visible from surface.

0.0
Concrete

0.0
Concrete - Physical Properties

DIAMOND BIT NO
81175

LEGEND
B1. Concrete
B2. Limestone Core
MA. Rock Core
81. Natural Core

LOCATION
Pick No. 5
CONVENTIONAL
5

PREVIOUS EDITIONS ARE COMPLETENED
(TRANSCRIPT)

B19
<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Sauc-205-1</th>
<th>Sheet 1</th>
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</thead>
</table>

### Drilling Log

#### Location
- Site: St. Louis, Mo.
- Loc: Dam No. 24

#### Objective
- To determine geological conditions and locate potential drilling sites.

#### Crew
- Drilling Crew: [Name]

#### Tools
- Drill Type: rotary
- Drilling Fluid: water

#### Drilling Data
- Initial Drilling Depth: 465.5 ft
- Total Drilled Depth: 500 ft

### Drilling Progress

#### Logs
- Geotechnical Log
- Bentonite Log

#### Test Results
- Core Recovery: 95%
- Water Flow: 0 GPM

### Drilling Equipment
- Drill Rig: [Model]
- Water Pump: [Model]

#### Notes
- Drilling was interrupted due to unexpected weather conditions.
- Further drilling will resume after weather improves.

---

### Diagram

- Drilling Diagram
- Site Layout
- Sample Locations

---
### Diagram and Notes

**Location:**
- View looking D/S
- Peer No.
- Legend:
  - [ ] Concretes
  - [ ] Machine Bore
  - [ ] Natural Gain

**Observations:**
- Concrete: Physical properties same.
- Consistency appears good, large
- Crack at 2.5" to 3.5" was found on core, very little reaction product was visible.

**Key Values:**
- **Elevation:**
  - 4647.86
  - 4647.10
  - 4647.30
- **Legend:**
  - Bit No. 72
  - Bit No. 75

**Additional Details:**
- Run No. 1: 1514 ft. 80
  - Rtg: 15.5
  - Begin: 3.5
  - End: 3.5
  - Time: 5 hours 50 mins.
  - DFL: 145 mm
  - Hyd Press: 380 psi
  - Water Press: 350 psi
  - Bit: Brown
  -Remarks: Diam. Bucking up at Start
  - Initials: T. D. J.
**Drilling Log**

- **Location**: St. Louis, Mo.
- **Date**: May 24
- **Type of Work**: Geotechnical

**Installation**

- **Date and Time**: 9:45 a.m.
- **Elevation**: 641.50

**Geological Information**

- **Weathering**: Poor Condition
- **Classification**: Concrete
- **Descriptive Notes**:
  - Concrete is in Poor Condition.
  - Numerous large cracks and breaks are present.
  - Moderately weathered upper surface (60-200')

**Legend**

- **Concrete**
- **Joint Crack**
- **Machine Break**
- **Natural Break**

**Location**

- **Column No. 1**
- **View Looking**

---

**B23**
### Drilling Log

**Location:** St. Louis, Mo  
**Project:** [Details not provided]**

<table>
<thead>
<tr>
<th>Elevation</th>
<th>Depth of Hole</th>
<th>Classification of Materials</th>
<th>Description of Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>469.2</td>
<td></td>
<td>24' East 48' North</td>
<td></td>
</tr>
<tr>
<td>469.2</td>
<td></td>
<td>16' East 48' North</td>
<td></td>
</tr>
<tr>
<td>469.2</td>
<td></td>
<td>16' East 48' North</td>
<td></td>
</tr>
<tr>
<td>469.2</td>
<td></td>
<td>16' East 48' North</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- **C:** Concrete
- **B:** Broken Up - Too Small To See Orientation of Pieces
- **M8:** Machine Break
- **N8:** Natural Break

**Concrete - Very Poor Quality**

- **Drill Action:** Motor

**Remarks:**
- **R1:** Interference with Reaction Product, Found a Entire Surface of Drilled Core - Core Cured As Rubble for Material Plan as Shown Above - Steel Was Connected and Fit by Table Above for Location

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**Diagram:**

- **Location:**
  - **Bar No. 9**
  - **Reinforcement:** 22 Bars
  - **Reinforcement Location:** 13" Down to Area of Mc Dowling

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**Notes:**

- [Additional notes not legible in image]
<table>
<thead>
<tr>
<th>Elevation</th>
<th>Depth</th>
<th>Legend</th>
<th>Classification of Materials</th>
<th>Method of Collection</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>465 7/0</td>
<td>465 7/0</td>
<td>Run No. 1</td>
<td>RUN 1</td>
<td>100%</td>
<td>19 Nov 50</td>
</tr>
<tr>
<td>100</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Concrete Physical Properties**

For conditions listed to no reaction product with no oxidation on steel surface. Ends are slightly weathered.

**Legend**

- **SIF**: Concrete
- **SIF**: Hardened Crack
- **SB**: Machine Break
- **NB**: Natural Bank

**Location**

- **Reck No. 1**
- **Location**: Ground Level

- **Reck No. 2**
- **Location**: Ground Level

- **Reck No. 3**
- **Location**: Ground Level
### Drilling Log
#### Location
St. Louis, Mo

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Core No.</th>
<th>Core Length</th>
<th>Core Diameter</th>
<th>Core Type</th>
<th>Core Width</th>
<th>Core Quality</th>
<th>Core Description</th>
<th>Core Color</th>
<th>Core Texture</th>
<th>Core Hardness</th>
<th>Core Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>E107-24</td>
<td>1</td>
<td>12 ft</td>
<td>2 in</td>
<td>Honeycomb</td>
<td>1.25</td>
<td>60</td>
<td>Wet-rolled</td>
<td>Brown</td>
<td>Rough</td>
<td>2</td>
<td>500 lbs</td>
</tr>
</tbody>
</table>

#### Core Notes
- Core was taken from a depth of 12 ft.
- Core was cut into 1-inch sections.
- Core was taken from a depth of 12 ft.
- Core was cut into 1-inch sections.

### Core Sample
- **Sample Details:**
  - Core: Concrete
  - Weight: 500 lbs
  - Length: 12 ft
  - Diameter: 2 in

### Core Analysis
- Analysis details are provided in the form of a diagram indicating the core's physical properties and any associated notes or observations.
- The core sample was taken from a depth of 12 ft and cut into 1-inch sections.

### Core Condition
- Core condition is noted as good, with no visible cracks or damages.
- Core was taken from a depth of 12 ft and cut into 1-inch sections.

### Core Description
- Core description includes a detailed examination of the core's physical properties, such as color, texture, and hardness.
- Core was taken from a depth of 12 ft and cut into 1-inch sections.

### Core Hardness
- Core hardness is noted as 2 on the Mohs scale.
- Core was taken from a depth of 12 ft and cut into 1-inch sections.

### Core Weight
- Core weight is recorded as 500 lbs.
- Core was taken from a depth of 12 ft and cut into 1-inch sections.

### Core Notes
- Core notes include any additional observations or comments about the core's condition or properties.
- Core was taken from a depth of 12 ft and cut into 1-inch sections.

---

**Diagram:**
- The diagram shows the core's location and orientation in the drilling site.
- The core is labeled with its respective number and depth.
- The core is oriented to show its physical characteristics and orientation within the drilling site.
<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>DEPTH</th>
<th>LEGEND</th>
</tr>
</thead>
<tbody>
<tr>
<td>4092</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4092</td>
<td>10</td>
<td>HAIRLINE - CLOSED</td>
</tr>
<tr>
<td>4092</td>
<td>21</td>
<td>AS VIEWED INSIDE BORE</td>
</tr>
</tbody>
</table>

NOTES: 
- CLOSED SPREAD - CEMENT
- HAIRLINE - CLOSED
- AS VIEWED INSIDE BORE
<table>
<thead>
<tr>
<th>Elevation</th>
<th>Depth</th>
<th>Materials</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4620</td>
<td>0</td>
<td>1/4&quot; wire</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1/4&quot; wire</td>
<td>Box</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Concrete</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1/4&quot; wire</td>
<td>5.5'</td>
</tr>
</tbody>
</table>

Concrete - Grey, Brown in color. Natural accretions (tie and hair) are observed in some locations. Steel appears unoxidized and condition of concrete is very good, little to no erosion and with no other visible signs of weathering.

**Legend**

- C - Concrete
- MB - Machine Break
- NA - Natural Break
- E - Erosion Product

**Location**

[Diagram of location]
## Drilling Log

<table>
<thead>
<tr>
<th>Location</th>
<th>Site and Type of Use</th>
<th>Cut-Off Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Louis, Mo</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Direction of Hole
- **Northing:** 342.3
- **Easting:** 4072.6
- **Depth:** 475' 45"
- **Index:** 475' 45"
- **Legend:** 
  - **Concrete:** Physical Properties Same as other Beams (Color, Aesthetic, etc.)
  - **Condition of Concrete:** Fair
  - **Numerous Hairline Cracks:** 1.5"

### Legend
- **Concrete:**
- **Hairline Cracks:** 1.5"
- **Natural Break:**
- **Machine Break:**
- **Location:** Near 75' 0" from Column #3
- **View Location:** 3/5

### Notes
- **Removal:**
  - **Numeral:** 475' 45"
  - **Depth:** 475' 45"
  - **Lift:** 475' 45"
  - **Side:** 475' 45"

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**Concrete:** By Physical Properties Same as Other Beams (Color, Aesthetic, etc.)

**Condition:** Fair

**Numerous Hairline Cracks:** 1.5"

**Location:** Near 75' 0" from Column #3

**View Location:** 3/5
<table>
<thead>
<tr>
<th>Elevation</th>
<th>Depth</th>
<th>Material</th>
<th>Color/Texture</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>467.45</td>
<td>0.0</td>
<td>Concrete</td>
<td>Mixture</td>
<td>Found 0.0% at 467.45, descending in condition, but still distinguishable as slight amount of reaction products. Steel reinforcing does not appear corroded. Condition is fair.</td>
</tr>
<tr>
<td>467.45</td>
<td>1.0</td>
<td>Concrete</td>
<td>Mixture</td>
<td>Found 1.0% at 467.45, descending in condition, but still distinguishable as slight amount of reaction products. Steel reinforcing does not appear corroded. Condition is fair.</td>
</tr>
<tr>
<td>467.45</td>
<td>2.0</td>
<td>Concrete</td>
<td>Mixture</td>
<td>Found 2.0% at 467.45, descending in condition, but still distinguishable as slight amount of reaction products. Steel reinforcing does not appear corroded. Condition is fair.</td>
</tr>
<tr>
<td>467.45</td>
<td>3.0</td>
<td>Concrete</td>
<td>Mixture</td>
<td>Found 3.0% at 467.45, descending in condition, but still distinguishable as slight amount of reaction products. Steel reinforcing does not appear corroded. Condition is fair.</td>
</tr>
</tbody>
</table>

**Legend**
- G: Concrete
- M: Machine Part
- N: Natural
- H: Hairline Crack

**Diagram**
- Location: [Diagram of location with coordinates and legend]
APPENDIX C: REPORT OF PETROGRAPHIC EXAMINATION OF CONCRETE CORES
Samples

1. Portions of concrete from five cores from Lock and Dam No. 24 were selected for detailed petrographic examination. A general description of the 6-in.-diameter concrete cores is as follows:

<table>
<thead>
<tr>
<th>Field Identification No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S WES-C16.2 N-80</td>
<td>Horizontal core into badly deteriorated concrete</td>
</tr>
<tr>
<td>S WES-C16.3 E-80</td>
<td>Horizontal core into moderately deteriorated concrete</td>
</tr>
<tr>
<td>S WES-C13.2 N</td>
<td>Horizontal core into good concrete</td>
</tr>
<tr>
<td>S WES-P04.1</td>
<td>Vertical core into good concrete</td>
</tr>
<tr>
<td>S WES-P09.1</td>
<td>Vertical core into good concrete</td>
</tr>
</tbody>
</table>

Test procedures

2. The concrete cores that were examined represented different visual physical conditions of the concrete. Some portions of the concrete examined were deep interior concrete while other concrete represented the near surface material.

3. The appearance and condition of this concrete was compared to that of the concrete previously examined from the same structure in 1976(1) and 1978.(2) The current samples are more representative of the general condition of the concrete deterioration and the extent of the damage.

4. Twenty-five cores were examined megascopically to determine the overall homogeneity of the concrete. Portions of the concrete cores described earlier were selected for further examination.

5. Several pieces of core were sawed longitudinally. One of each pair of sawed surfaces was ground smooth and examined with a stereomicroscope.

6. The core surfaces were examined for signs of deleterious chemical reaction and/or physical degradation. Fresh fracture surfaces were also examined. A stereomicroscope was used as needed to aid in the examination.
7. Reaction products from interior concrete surfaces and exudation from core surfaces were examined as oil immersion mounts using a polarizing microscope.

8. A black substance coating a break in core S WES-P04.1 at about 12.5-ft depth was also examined. Acetone was used to remove the coating from the break surface before the concrete was examined.

Results

9. Concrete from core S WES-C16.2 N-80 represented severely deteriorated concrete. This concrete was highly fractured and tended to disaggregate easily during drilling and handling. The concrete from boring S WES-C16.3 E-80 represented moderately deteriorated concrete. This concrete contained a major longitudinal crack in the center of the core in which a white exudation is collecting on the exposed surface of the concrete. All other concrete cores represented intact concrete from both the interior and near surface concrete of the structure.

10. The concrete in all the cores examined contained gravel and sand of mixed composition. The maximum size coarse aggregate was about 1-1/2 in. The aggregate consisted of sandstone, quartz, chert, carbonate rock particles, dark fine-grained igneous rock particles, coarse-grained igneous rock particles, and some particles of ironstone. Chalcedony in chert particles was identified as the most common reactive aggregate material in this group of concrete cores. This finding is similar to the observations made in the two earlier reports. (1,2)

11. Some of the concrete contained pale yellowish brown (10 YR 6/2) (3) paste while the remainder of the concrete contained medium light gray (N6) (3) paste. There was no apparent physical difference between the different colored pastes. White alkali silica gel was present in both colors of paste.

12. The general deterioration consisted of parallel to subparallel cracking occurring parallel to the formed surface of the cores. These partings tended to be closely spaced near the outer surface of the concrete and were absent in the interior concrete. The photographs in Figure C1 are a set of pictures of core S WES-C16.2 N-80 drilled through a column on pier No. 16. Deterioration was present at both ends of this core while the central portion of it remained relatively intact.

13. Examination of ground surfaces indicated that this concrete was not air entrained. The concrete contained a few entrapped air voids but generally the concrete was dense and intact.

14. The maximum depth of deterioration was to a depth of 1.5 ft as found in core S WES-C16.2 N-80. Most of the deterioration was confined to the exterior 0.6 ft of concrete.
15. This concrete also tended to be saturated with white alkali-silica gel. This gel was present coating the cracks and as surface exudation. Some calcium hydroxide was also carried to surfaces in solution and deposited as white deposits. The alkali-silica gel ranged from a thick white to a clear material totally encasing the reactive aggregate and penetrating into the adjacent paste.

16. The black material coating the broken surface of core S10-ES-P04.1 at about 12.5 ft was a pliable black tar-like substance. The concrete beneath the coating was undisturbed. The coating appeared to have been put on the concrete as some sort of a bond breaker.

Conclusions

17. The lack of entrained air in this concrete caused the concrete to be susceptible to frost damage. The repeated freezing and thawing of the concrete while critically saturated has caused delamination of the concrete, especially near surfaces.

18. The opening of the concrete by frost action has accelerated the alkali-silica reaction. This deleterious chemical reaction has caused additional disaggregation of the frost-damaged concrete. The interior concrete shows slight indications of alkali-silica reaction, but has not caused any significant damage to the interior concrete.
References Cited

1. U. S. Army Engineer Waterways Experiment Station petrographic report dated 30 January 1976 to the U. S. Army Engineer District, St. Louis, subject: "Test and Examination of Concrete Cores from Lock and Dam 24 and Lock and Dam 25."

2. U. S. Army Engineer Waterways Experiment Station petrographic report dated December 1978 to the U. S. Army Engineer District, St. Louis, subject: "Examination of Concrete Cores from Lock and Dam 24."

Figure C1. Opposite ends of core S WES-C16.2 X-80 drilled through a concrete column. The cracking is parallel to the formed surface and tends to go around the aggregate particles as well as through them.
APPENDIX D: PHOTOGRAPHS SHOWING BURST PIPE
Photo 7: Concrete wedge removed exposing burst pipe, reinforcing steel, and wetted concrete.
Photo 1. Close-up of area shown in Photo 2. Notice burst pipe and spatter concrete. Most all large aggregate show clean tensile failure surfaces.
Note 5. Wheel surface step on bridge support column.  A test plate was spot welded next to center bearing plate seen in upper left of photograph.  Dirt on floor is test plate wheel and plate, not in photograph.
In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Stowe, Richard L.
Condition survey repair and rehabilitation Lock and Dam No. 24, Mississippi River / by Richard L. Stowe, Henry T. Thornton, Jr. (Structures Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1981.
90 p. in various pagings; 46 p. of plates : ill.; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; SL-81-21)
Cover title.
"August 1981."
"Prepared for U.S. Army Engineer District, St. Louis."
Final report.
Bibliography: p. 33.


Stowe, Richard L.
Condition survey repair and rehabilitation : ... 1981. (Card 2)

Corps of Engineers, St. Louis District. III. U.S. Army Engineer Waterways Experiment Station. Structures Laboratory. IV. Title V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station); SL-81-21.
TA7.W34m no.SL-81-21