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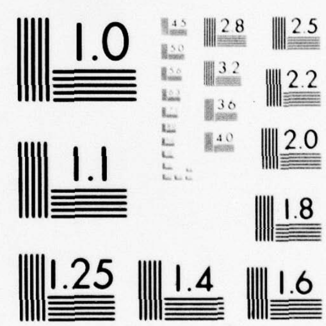

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MISCELLANEOUS PAPER SL-79-17

TESTING OF 6-IN.-DIAMETER CONCRETE CORES FROM MARTIN DAM ALABAMA POWER COMPANY

by

Donnie L. Ainsworth, Alan D. Buck
Steven A. Ragan, Katharine Mather

Structures Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

August 1979

Final Report

Prepared for Alabama Power Company
Birmingham, Ala. 35291

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) WES-MP- ~~Miscellaneous Paper~~ SL-79-17	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) TESTING OF 6-IN.-DIAMETER CONCRETE CORES FROM MARTIN DAM, ALABAMA POWER COMPANY.		5. TYPE OF REPORT & PERIOD COVERED (9) Final report.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Donnie L. Ainsworth, Steven A. Ragan, Alan D. Buck, Katharine Mather		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Structures Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Alabama Power Company P. O. Box 2461 Birmingham, Ala. 35291	(11)	12. REPORT DATE August 1979
		13. NUMBER OF PAGES 82
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (12) 90p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(18) (19)

18. SUPPLEMENTARY NOTES

This is CTIAC Report No. 38

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Alkali aggregate reactions	Martin Dam
Concrete cores	Petrographic analysis
Concrete test specimens	Ultrasonic tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thirty-three lengths of 6-in.-diameter concrete core from three drill holes in Martin Dam were examined. All three drill holes ran from the crest of the dam to the foundation. Part of the core from each hole was retained by the Alabama Power Co. The lengths received at the Structures Laboratory, U. S. Army Engineer Waterways Experiment Station, were examined petrographically. Twenty were tested ultrasonically to measure compressional and shear wave velocities. Of these

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20. **ABSTRACT (Continued)**

20 lengths, 6 were tested in unconfined compression; 9 were tested in triaxial loading in 3 groups of 3 cores each at 3 confining pressures; and 5 were tested for strength in direct tension. The petrographic report presents evidence of the occurrence of alkali-silica reaction in concrete from all three drill holes; however, alkali-silica reaction gel was not found in the lower part of hole S-7. The core from the lower part of hole S-7 contained large flakes of tetracalcium aluminate monosulfate-12-hydrate ($C_4A\overline{S}H_{12}$). This is the first instance, to our knowledge, of the presence of this compound in concrete in crystals large enough to be visible to the naked eye. Although the evidence of alkali-silica reaction is clear, it did not extend to cracks in the mortar except to a minor extent.

The compressional wave velocities ranged from 13,400 to 14,920 fps; shear wave velocities ranged from 7870 to 9290 fps. Calculated dynamic moduli of elasticity ranged from 4.9 to 6.3 x 10^6 psi. Compressive strengths ranged from 3040 to 8450 psi; static moduli of elasticity ranged from 2.17 to 4.18 x 10^6 psi, and Poisson's ratios from 0.08 to 0.17. Triaxial compression tests at minimum principal stresses of 2500, 5000, and 9000 psi yielded cohesion values from 500 to 800 psi and angles of internal friction from 41°00' to 38°45'.

Despite the presence of alkali-silica reaction, the Martin Dam concrete appears to be in acceptable condition and in better condition than some younger structures that are still in service.

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PREFACE

Tests and examinations of concrete cores from Martin Dam located near Montgomery, Alabama, were made for Alabama Power Co. by the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), as a result of a request from the Director, Office of Electric Power Regulation, Federal Energy Regulatory Commission. The test program was authorized by the Technical Director, WES. The project engineer for Alabama Power Co. was Mr. Phillip R. Weidmeyer.

The work was accomplished during the period June 1978 to October 1978 under the direction of Mr. Bryant Mather, Acting Chief, SL; Mrs. Katharine Mather, Chief, Engineering Sciences Division; Mr. Billy R. Sullivan, Chief, Engineering Physics Branch; and Mr. Donnie L. Ainsworth, Project Leader. Messrs. Alan D. Buck and Steven A. Ragan were responsible for the petrographic study and the destructive tests, respectively. The report was prepared by Messrs. Ainsworth, Buck, and Ragan, and Mrs. Mather.

Funds for the publication of this paper were provided from those made available for operation of the Concrete Technology Information Analysis Center (CTIAC). This is CTIAC Report No. 38.

The Commanders and Directors of WES during the conduct of this study and preparation of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. The Technical Director was Mr. Fred R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
pounds (force)	4.44822	newtons
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic inch	27679.90	kilograms per cubic metre
inches per second	0.0254	metres per second
feet per second	0.3048	metres per second
cubic yards	0.7645549	cubic metres

TESTING OF 6-IN.-DIAMETER CONCRETE CORES FROM MARTIN DAM, ALABAMA POWER COMPANY

PART I: INTRODUCTION

Background

1. On 18 April 1978, Mr. Bob Hudson, Alabama Power Co., telephoned the U. S. Army Engineer Waterways Experiment Station, Structures Laboratory (WES, SL), regarding testing concrete cores from Martin Dam located near Montgomery, Alabama. His call was a result of a request from the Federal Energy Regulatory Commission (FERC) to Alabama Power to obtain additional tests on the concrete because of an earlier petrographic examination that showed evidence of alkali-silica reaction. FERC wanted additional petrographic information, triaxial tests, unconfined compression tests, and measurements of static and dynamic E. FERC also wanted the dynamic E determined in situ.

Authority

2. Since Alabama Power Co. was not able to get these tests done elsewhere and as a result of a letter to the Commander and Director, WES, requesting WES assistance from the Director, Office of Electric Power Regulation, Federal Energy Regulatory Commission, the Technical Director, WES, approved the test program. The Structures Laboratory, WES, was authorized to do such tests as they could with existing resources and without interference to ongoing work for the United States Government.

Proposed testing program

3. With this authorization WES proposed to accomplish the following:

a. Measure ultrasonic pulse velocity on twenty 6-in.-diameter* by 12-in.-long concrete cores. Compute the dynamic Young's modulus of elasticity (E) and compare with in situ velocity measurements to be made by Weston Geophysical Corp.

b. Make triaxial tests on three sets of three 6-in. by 12-in. cores with confining pressures up to 10,000 psi.

c. Determine Poisson's ratio, static modulus of elasticity, stress-strain relationship, and compressive strength in unconfined compression tests of six 6-in. by 12-in. cores instrumented with strain gages.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

d. Determine tensile strength from direct tensile tests on five 6-in. by 12-in. cores.

e. Make a comprehensive petrographic analysis of three 6-in. diameter cores about 8 ft long to be taken either at points on the crest of the dam or three cores 8 ft long to be taken from the upper, middle, and lower parts of the dam, respectively.

f. Analyze chemically samples of alkali-silica gel, if present, for CaO, Na_2O, K_2O, MgO, SiO_2, SO_3, Al_2O_3, Fe_2O_3, moisture loss at 105° C, and at 575° C.

PART II: TESTING PROCEDURE

Concrete core

4. Six-inch diameter concrete core from three core holes on the Martin Dam, Holes H-3, S-6, and S-7, were delivered to the WES on 29 June 1978, 27 July 1978, and 25 August 1978, respectively. Upon receipt, the core was examined and logged by a representative of the Petrography and X-Ray Branch. After examination, a 6-in. by 12-in. cylinder was cut from each piece and both ends were surface ground. Table 1 lists the core received from each hole and shows the schedule testing plan and numbering.

Petrographic analysis

5. All the 6-in.-diameter concrete core received from Martin Dam was examined before testing. A detailed petrographic examination was made on pieces of core representing the concrete from the top, middle, and bottom of each hole. Freshly broken pieces were examined with a stereomicroscope. Pieces were ground to pass the 45-μm (No. 325) sieve and examined by X-ray diffraction. Cores were also examined with a stereomicroscope to detect reaction products and to aid in sampling alkali-silica gel for chemical and petrographic analysis. The gel concentrate was examined with a polarizing microscope and by X-ray diffraction. A petrographic report is given in Appendix A.

Ultrasonic pulse velocity measurements and dynamic E determination

6. Ultrasonic pulse velocity measurements were made on all 20 of the 6-in. by 12-in. cores. The travel times of both the compressional (p) wave and shear (s) wave through the 12-in. long specimen were measured and the p and s velocities were calculated. Using these parameters, the dynamic Young's modulus of elasticity (E) was calculated using the following relationship:

$$E = \frac{eVs^2(3Vp^2 - 4Vs^2)}{Vp^2 - Vs^2}$$

where:

Vp = Compressional wave velocity, in./s

Vs = Shear wave velocity, in./s

e = Density, lb mass/in.^{3}

E = Young's modulus of elasticity, psi

The detailed discussion of this test and test results are included as Appendix B.

Unconfined compression, triaxial
compression, and direct tensile tests

7. These tests were made using the following relevant portions of the Handbook for Concrete and Cement. The corresponding American Society for Testing and Materials (ASTM) methods are also cited.

a. CRD-C 27-69 (WES 1969); ASTM C 42-77 (ASTM 1978a).

b. CRD-C 19-75 (WES 1975); ASTM C 469-65 (ASTM 1978b).

c. CRD-C 93-76 (WES 1976); ASTM C 801-75 (ASTM 1978c).

d. CRD-C 149-77 (WES 1977); ASTM D 2936-71 (ASTM 1978d).

Electrical resistance wire strain gages were put on 15 specimens for measurement of strain in both vertical and diametral directions. The unconfined compression test specimens were axially loaded with a 440,000-lb force (lbf) capacity universal testing machine. The triaxial compression test specimens were axially loaded with a 2.4- by 10^6-lbf capacity testing machine and confining pressures were applied with a hand-operated, electro-hydraulic pump. The direct tensile test specimens were also loaded with the 440,000-lbf testing machine. A more detailed discussion of these tests and test results is included in Appendix C.

Chemical analysis of
alkali-silica reaction product

8. A sample of the alkali-silica gel was received by the Chemistry and Plastics Branch from the Petrography and X-Ray Branch. The sample was chemically analyzed for CaO, K_2O, Na_2O, MgO, SiO_2, Al_2O_3, Fe_2O_3, SO_3, and moisture loss at 105°C and 575°C. The results obtained from the analysis are shown below:

Constituent	%
SiO_2	50.93
CaO	10.99
MgO	0.12
Fe_2O_3	0.16
Al_2O_3	0.70
Na_2O	3.27
K_2O	8.91
SO_3	< 0.10 (not detectable)
Moisture loss at 105°C	12.59
Moisture loss between 105°C and 575°C	11.14

A fusion was made of 0.2 g with lithium borate; all oxides were determined by atomic absorption except silica which was determined gravimetrically.

PART III: DISCUSSION

Results

9. The petrographic examination revealed clear evidence that alkali-silica reaction had occurred in all three cores that were examined. For cores examined, similar evidence was found at all depths from holes H-3 and S-6 while it decreased with depth in hole S-7. The evidence was white to translucent alkali-silica gel in voids, in aggregate sockets, and in cracks. X-Ray examination of the gel indicated both amorphous material and some crystalline reaction product.

10. The ultrasonic pulse velocity tests conducted in the laboratory on core from holes H-3, S-6, and S-7 gave values that ranged from 13,401 to 14,925 fps for the p-wave and 7870 to 9290 fps for the s-wave. These values are within the range that is normally accepted as an indication of good quality concrete. The calculated values for dynamic E ranged from 4.9×10^6 to 6.3×10^6 psi.

11. The p-wave velocities measured in the laboratory were greater, as expected, than the cross-hole velocities measured in the field by Weston Geophysical Corp. There was a much greater scatter in calculated values of dynamic E, primarily because of the scatter in s-wave data.

12. The destructive tests on the 6-in. by 12-in. concrete cores consisted of determining unconfined compressive strength, direct tensile strength, stress-strain relationship, static E, Poisson's ratio, and triaxial compression properties. The unconfined compressive strength of concrete near the top of the dam ranged from 5360 to 8450 psi, and near the bottom ranged from 3040 to 5360 psi. The lower values were from hole S-7. The direct tensile strengths ranged from 290 to 140 psi. Two of the tensile tests are considered unsatisfactory, reducing the range to 255 to 160 psi.

13. Triaxial tests were conducted on nine 6-in. by 12-in. concrete cores using confining pressures (σ_3) of 2500, 5000, and 9000 psi. The deviator stresses within each group of three specimens ranged from approximately 15,000 psi to 21,000 psi. The average maximum axial strain exhibited by each test group is approximately 2 percent.

Conclusion

14. From the results and discussions of results as set forth in the attached appendixes, the general consensus of those performing the tests is that the condition of the concrete examined from Martin Dam can be considered acceptable. It does show alkali-silica reaction but not as much as some other younger structures that are still in service. It appears that the Martin Dam should continue to be a serviceable structure for many more years.

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TABLE 1

CORE LOCATION AND TESTING SCHEDULE

Hole No.	Core No. (AL Power)	Core No. (WES)	Elevation ft msl*	Elevation of 6 x 12 Core ft msl	Scheduled Tests**
CH H-3	1	DC-1A	496.0-493.9	495.8-494.8	PE, UT, UC
	2	DC-2A	477.4-476.0	477.2-476.2	PE, UT, TX
	3	DC-3A	461.0-458.6	460.9-459.9	PE, UT, TD
	4	DC-4A	420.5-418.6	420.2-419.2	PE, UT, TX
	5	DC-5A	408.8-407.5		PE
		DC-6A	407.5-404.2		PE
		DC-7A	404.2-402.5		PE
		DC-8A	402.5-400.5	402.3-401.3	PE, UT, TD
		DC-9A	400.5-397.5		PE
	6	DC-10A	397.5-394.9	397.4-396.4	PE, UT, TX
	7	DC-11A	386.3-384.5	386.1-385.1	PE, UT, UC
CH S-6	1	DC-1B	501.5-500.5	501.5-500.5	PE, UT, UC
		DC-2B	497.4-496.5		PE
	2	DC-3B	490.0-488.2	489.8-488.8	PE, UT, TX
	3	DC-4B	485.1-482.9	485.0-484.0	PE, UT, TD
		DC-5B	472.5-471.6		PE
	4	DC-6B	452.2-450.1	452.0-451.0	PE, UT, TX
	5	DC-7B	439.1-437.8	439.0-438.0	PE, UT, TX
		DC-8B	430.1-429.1		PE
	6	DC-9B	406.6-404.9	406.1-405.1	PE, UT, UC
		DC-10B	399.6-398.7		PE
CH S-7	1	DC-1C	491.0-488.9	490.7-489.7	PE, UT, UC
	2	DC-2C	470.2-468.5	469.9-468.9	PE, UT, TX
	3	DC-3C	453.5-451.0	453.3-452.3	PE, UT, TD
		DC-4C	434.1-432.0		PE
	4	DC-5C	423.5-422.1	423.3-422.3	PE, UT, TX
		DC-6C	405.0-403.7		PE
	5	DC-7C	385.7-384.1	385.5-384.5	PE, UT, TD
		DC-8C	377.7-376.1		PE
	6	DC-9C	355.3-353.2	355.2-354.2	PE, UT, TX
	7	DC-10C	336.6-334.5	336.4-335.4	PE, UT, UC
		DC-11C	456.1-454.9		PE
		DC-12C	454.9-453.4		PE

* All elevations cited herein are in feet referenced to mean sea level.

** Test abbreviations: UT - Ultrasonic Testing, p-wave and s-wave; PE - Petrographic Examination; UC - Unconfined Compressive Testing; TX - Triaxial Testing; TD - Direct Tensile Testing.

Corps of Engineers, USAE Waterways Experiment Station	APPENDIX A PETROGRAPHIC REPORT	Structures Laboratory P. O. Box 631 Vicksburg, Mississippi
Project Examination of Concrete from Martin Dam near Tallassee, Alabama		Date 5 October 1978 GSW

1. Martin Dam, completed in 1926, is an arch gravity dam used for hydroelectric power production, located on the Tallapoosa River near Tallassee, in east central Alabama about 25 miles northeast of Montgomery.

a. The Alabama Power Company drilled three 6-in.-diameter concrete cores for petrographic examination and other tests. The location of the cores and other identifying data are shown below:

Structures Laboratory Serial No.	Depth, ft	Elevation ft msl	Field Designation: Piece No.	Field Designation
Received 29 June 1978				
CL-24 DC-1A	5.5-7.6	496.0-493.9	1	CH No. H-3
2A	24.1-25.5	477.4-476.0	2	
3A	40.5-42.9	461.0-458.6	3	Near inlet to unit
4A	81.0-82.9	420.5-418.6	4	No. 1; westernmost core.
5A	92.7-94.0	408.8-407.5	5	
6A	94.0-97.3	407.5-404.2	1	Petrographic samples
7A	97.3-99.0	404.2-402.5	2	Petrographic samples
8A	99.0-101.0	402.5-400.5	3	Petrographic samples
9A	101.0-103.0	400.5-398.5	4	Petrographic samples
10A	104.0-106.6	396.5-394.9	6	
11A	115.2-117.0	386.3-384.5	7	
Received 27 July 1978				
CL-24 DC-1B	0.0-1.0	501.5-500.5	1	CH No. S-6 on Block 14 northwest of S-4 on dam.
2B	4.1-5.0	497.4-496.5		Petrographic sample
3B	11.5-13.3	490.0-488.2	2	
4B	16.4-18.6	485.1-482.9	3	Petrographic sample
5B	29.0-29.9	472.5-471.6		Petrographic sample
6B	49.3-51.4	452.2-450.1	4	Petrographic sample
7B	62.4-63.7	439.1-437.8	5	
8B	71.4-72.4	430.1-429.1		Petrographic sample
9B	94.9-96.6	406.6-404.9	6	Petrographic sample
10B	101.9-102.9	399.6-398.7		Petrographic sample
Received 25 August 1978				CH No. S-7 on the west end of Block 3 east of powerhouse.
CL-24 DC-1C	10.5-12.6	491.0-488.9	1	Petrographic sample
2C	31.3-33.0	470.2-468.5	2	
3C	48.0-50.5	453.3-451.5	3	Petrographic sample
4C	67.4-68.9	434.1-432.6	8	Petrographic sample

Structures Laboratory Serial No.	Depth, ft	Elevation ft msl	Field Designation Piece No.	
CL-24 DC-5C	78.0-79.4	423.5-422.1	4	
6C	96.5-97.8	405.0-403.7	9	Petrographic sample
7C	115.8-117.4	385.7-384.1	5	
8C	123.8-125.4	377.7-376.1	10	Petrographic sample
9C	146.2-148.3	355.3-353.2	6	Petrographic sample
10C	164.9-167.0	336.6-334.5	7	Petrographic sample
Received 6 September 1978				
CL-24 DC-11C		456.1-454.9		CH No. S-7
DC-12C		454.9-453.4		

b. Pieces 11C and 12C are from the interval between 2C and 3C in hole CH No. S-7. They were received by request at a later date than the other pieces from CH No. S-7 to resolve an anomaly.

c. All of the cores from the dam were drilled at the crest; all three cores from the inlet works were drilled slightly upstream of the projection of the crest location.

Test procedure

2. A preliminary examination was made of all cores received before they were tested. A more detailed petrographic examination was made on pieces of cores representing the concrete from the top, middle, and bottom of each hole. The type of examination depended on the homogeneity of the concrete and the nature of the paste and aggregate. In most cases the concrete was homogeneous.

3. Pieces of core were broken to allow examination of freshly broken surfaces with a stereomicroscope. The color of the paste from different depths was dark greenish black (5G 2/1) or very light gray (N8) to light gray (N7)(Rock Color Chart Committee 1975).* Paste concentrates were made and ground to pass a 45-μm (No. 325) sieve. These powders were then examined by X-ray diffraction.

4. All X-ray diffraction patterns were made with an X-ray diffractometer using nickel-filtered copper radiation.

5. A stereomicroscope was used to examine selected cores to detect reaction products and to aid in obtaining samples of alkali-silica gel for chemical and petrographic analysis. Part of the gel concentrate was examined with a polarizing microscope and by X-ray diffraction before the chemical analysis was made. The gel sample was ground in water; the slurry was allowed to dry on an aluminum surface before it was examined by X-ray diffraction.

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* References are cited alphabetically in the list of references following the main text on page 10.

6. Photographs were made of a sawed surface and a broken surface to illustrate cracking and the nature of the gel and the associated coarse aggregate.

7. Coarse aggregate particles associated with the alkali-silica gel were examined in thin sections using a petrographic microscope and by X-ray diffraction.

8. Platy crystals found in some voids were concentrated by hand picking. The sample was ground and examined by X-ray diffraction. Some of the same crystals were examined with a scanning electron microscope and micrographs taken.

Results

9. Martin Dam is the oldest concrete structure from which we have had the opportunity to examine core samples from near the crest to near the base. Several aspects of the dam are quite different from more modern dams and it would be easy to become confused about the quality of the concrete by reading this report or the driller's logs. The features that are quite different from modern dams built with quality control include the following:

a. The maximum size of the coarse aggregate and its grading fluctuates irregularly from about 4.75 mm (No. 4) to 75 mm (3 in.) and there are larger plumstones, about which it can only be said that their dimensions were over 150 mm (6 in.).

b. Reading the driller's log one has the impression that the builders placed concrete until they ran out of aggregate and then stopped placing concrete until a new supply of aggregate was accumulated.

c. The impression described in (b) tends to explain the observation made by the drillers, and the petrographers here, that the color of the concrete which supposedly contained 25 percent Magnolia slag cement, ranges from very light gray to greenish black, and the colors alternate within a core so that it is just as probable to find light gray concrete in the middle and greenish black above it as the reverse.

d. The possibility that construction may have been intermittent is supported by the thin sections made and examined here. They came from a piece of core (DC-3A) that ranged from light to medium gray to mottled black. The sections from the gray and light gray concrete contained slag, visible in plane light as irregularly shaped green and white crystals. With crossed nicols, the slag showed no birefringence and was apparently completely hydrated. Some of the larger grains of portland-cement clinker retained their birefringence and were not completely hydrated. The presence of slag in the thin sections from pale and medium gray concrete leads us to believe that all the concrete that was supposed to contain slag probably did, but that concrete that was left exposed during construction or cracked after construction so that oxygen was available oxidized to the color of concrete made with portland cement alone.

10. The results of the preliminary examination of the cores are shown in Plates A1 through A33. Despite the irregular grading of the aggregate, all of the concrete was well consolidated and showed no signs of segregation. The maximum aggregate size in the cores examined here was generally smaller than 1-1/2 in. with only occasional particles larger than 3 in. The coarse aggregate consisted largely of quartzite and quartz particles. The fine aggregate was natural siliceous sand.

11. A trace of chert was present in the coarse aggregate. None of the particles of chalcedonic chert were found associated with alkali-silica reaction gel. The freshly broken surfaces showed that quartz and quartzite particles had reacted with the alkalies and hydroxyl in the paste resulting in the development of reaction rims on the periphery of the particles and white reaction gel filling nearby voids (Photo A1).

12. "Main cracks" in the coarse aggregate are shown in Photo A2. Main cracks were described and illustrated by Idorn (1964). Photo A2, at 1X, has every piece of coarse aggregate marked in which either main cracks or disintegration of the siliceous cement in the center of quartzite particles could be recognized at 10X to 30X. Main cracks were much more abundant than disintegration of the siliceous cement. The extension of main cracks into the mortar represents a more advanced degree of reaction than was often found in the cores from Martin Dam examined here. Two plates reproduced from Idorn's report are shown as Figures A1 and A2 to clarify the concept and details of main cracks in aggregate and mortar. Alkali-silica gel was found coating the surfaces of the crack shown in the upper left-hand corner of Photo A2.

13. The condition of the concrete from each core is described in the following paragraphs:

a. CL-24 DC-1A through 11A (CH No. H-3). This core came from the western part of the inlet works to the powerhouse. According to the driller's log construction joints and fractures were common and the fractures suggest some movement had taken place. The concrete samples from this core hole examined in the laboratory appeared to be in good physical condition. It was well consolidated nonair-entrained concrete with some small entrapped air voids. Most of the broken ends of the pieces of core were new breaks or breaks along lift joints. The inclined break at a depth of about 7.5 ft was an old break coated with alkali-silica reaction gel. The aggregates exposed at this surface included quartz and quartzite particles with well developed reaction rims. Alkali-silica reaction gel coated a fracture surface of piece CL-24 DC-10A (Photo A1). Alkali-silica-reaction gel was detected in all of the pieces of this core that were examined. The alkali-silica gel was found in air voids lining or totally filling the void. Other alkali-silica gel was found around the aggregate particles at the paste-aggregate interface. The amount of gel was consistent throughout the core and is considered a significant amount even though only a small number of fractures were present. The majority of the paste was medium gray but some freshly exposed mortar surfaces were greenish black (CL-24 DC-10A, Plate A10). The dark mortar showed the characteristic greenish black color of unoxidized concrete containing blast-furnace slag cement. There were no apparent differences between the gray and greenish black paste with respect to the amount of alkali-silica reaction gel in the concrete.

b. CL-24 DC-1B through 10B (CH No. S-6). Hole S-6 was drilled in block 14 of the dam. The concrete from this hole was like the concrete from hole H-3. In addition to the alkali-silica gel, small clusters of needle-like ettringite crystals were found in the voids and other openings in the concrete. Examination of the cement paste indicated that only small amounts of ettringite were present. The relatively small amount of ettringite is considered normal.

c. CL-24 DC-1C through 12C (CH No. S-7). This core (S-7) came from block 3 of the dam. The concrete in this core was like that found in the other two cores. The lengths of concrete core were intact and had no outward signs of reaction except for the presence of some gel-filled voids in the upper part of the core. A broken surface which was coated with algae (Plate A26) was found at a depth of 48 ft. The surface appeared to be an open lift joint on which water flows. The amount of alkali-silica gel was less in this core than in the other two cores, and the development of ettringite was more abundant in the voids of the upper 69 ft of this core than in the two other cores examined. The deeper concrete contained very little gel, but elongated plates of tetracalcium aluminate monosulfate-12-hydrate became common in the voids. The highest concentration of these crystals was in piece CL-24 DC-7C. Scanning electron micrographs of some of these crystals are shown in Photos A3 and A4. Ettringite, $Ca_6Al_2(OH)_{12}(SO_4)_3 \cdot 26H_2O$, and tetracalcium aluminate monosulfate-12-hydrate ($Ca_4Al_2(OH)_{12}(SO_4) \cdot 6H_2O$ or $C_4A\bar{S} \cdot H_{12}$) are both normal hydration products of portland cement. Ettringite can also be produced by the hydration of blast-furnace slag. It is common to find ettringite in the voids in concrete a few years old, sometimes in coatings and rosettes visible to the naked eye. We have not previously seen $C_4A\bar{S} \cdot H_{12}$ in flakes visible to the naked eye in voids in concrete, nor have we seen it in immersion mounts or thin sections. While its presence is not important to the stability of the concrete, this is the first instance that we know of in which $C_4A\bar{S} \cdot H_{12}$ has been seen in concrete in such large crystals. Probably a slightly lower lime content in the total cementitious material, a higher alumina content, and a lower sulfate content produced in the concrete in the lower part of this core, resulting from the presence of the 25 percent slag cement with a high alumina, low sulfate portland cement combined to favor production of $C_4A\bar{S} \cdot H_{12}$. The concrete higher in the core where ettringite was found in the voids may have contained another portland cement or may not have contained the intended proportion of slag cement.

14. Samples chosen for X-ray diffraction study of cement paste concentrates were taken from CL-24 DC-2B, light gray paste resembling that in CL-24 DC-1A through DC-11A; CL-24 DC-10B, greenish-black paste; and light gray paste

from CL-24 DC-4C. Table A1 shows the composition of the paste concentrate in samples from the two cores. Quartz from the aggregate, calcium hydroxide which is a normal hydration product of portland cement, and calcite, a normal alteration product of hydrated portland cement, were present in all the samples. Ettringite ($Ca_6Al_2(OH)_{12}(SO_4)_3 \cdot 26H_2O$), usually the first hydration product of tricalcium aluminate ($Ca_3Al_2O_6$), was present in CL-24 DC-12B and DC-4C; tetracalcium aluminate monosulfate-12-hydrate was present in DC-10B and DC-4C; tetracalcium aluminate carbonate-11-hydrate was present only in DC-4C. All of these compounds are normal constituents of hydrated portland cement paste.

15. The alkali-silica reaction gel in these cores was white to translucent gel filling voids or coating particle surfaces and fractures. Often the gel was cracked because of drying shrinkage and in many cases a clear or translucent outer zone bordered a white inner core (Photo A1). Three types of gel were recognized. Some of the gel appeared between crossed nicols as fine-grained black and white particles; others were banded and the bands extinguished alternately; some pieces were amorphous.

16. X-ray examination of the gel indicated both amorphous material and some crystalline reaction product. X-ray peaks were: 1.34, 10.9, 9.1, and 6.7 nm. These peaks are like those reported by Buck and Mather (1978) and confirm that this is alkali-silica gel.

17. The coarse aggregate used in this concrete was natural gravel composed mainly of quartzite and quartz particles and a few pieces of chalcedonic chert. There was not enough chalcedony present to account for the amount of alkali-silica reaction that was found. A consistent association of gel with quartz and quartzite particles was considered significant, as well as the rims found on many of the particles. Photo A1 demonstrates that the rim formation took place when the reactive aggregate and the paste were in contact; Photo A2 shows rims and main cracks. All of the quartzite and quartz had been metamorphosed as indicated by undulatory extinction seen in thin sections. Measurements of eight extinction angles in a piece of quartz gave a range of 8 to 42 degrees. Seventeen similar measurements for two pieces of quartzite gave a range of 13 to 28 degrees. A large enough number of quartzite and quartz thin sections to give a valid estimate of the range and mean of the undulatory extinction angles in this aggregate was not made.

Discussion

18. Most of the fractures found in the cores appeared to be new and produced by drilling, but there was clear evidence that alkali-silica reaction had occurred in all three cores that were examined. The evidence was similar at all depths in cores CL-24 DC-1A through 11A (CH No. H-3) and CL-24 DC-1B through 10B (CH No. S-6) while it decreased with depth in core CL-24 DC-1C through 12C (CH No. S-7). Core CL-24 DC-1A through 11A showed most evidence of reaction; core CL-24 DC-1C through 12C the least, and core CL-24 DC-1B through 10B showed intermediate evidence of reaction.

The evidence was white to translucent alkali-silica gel in voids, in aggregate sockets, and in cracks; reaction rims on quartz and quartzite particles; and as cracks that could be traced across these aggregate particles into the paste (Photo A2).

19. The old cracks that were found were also believed to be the result of alkali-silica reaction. The driller's logs of NX core holes H-1, H-2, S-1 through S-5, and 6-in. core holes H-3, S-6, and S-7 give the impression that more fractures were found in core holes H-1 through H-3 (CL-24 DC-1A through 11A) in the inlet works than in S-1 through S-5 and S-6 (CL-24 DC-1B through 10B) and S-7 (CL-24 DC-1C through 12C) in the spillway. Core CL-24 DC-1A through 11A (core H-3) as logged by the driller suggested more fracturing than CL-24 DC-1B through 10B (core S-6); the log for core CL-24 DC-1C through 12C suggests less fracturing and friable regions than DC-1A to 11A and about the same amount as DC-1B through 10B. The portland cement came from four sources (Universal Atlas, Leeds, Ala.; National (Coosa) Portland; Lehigh Portland; Warrior Portland). The slag cement was used throughout the mass concrete and the powerhouse, up to the bridge decks of the spillway section and the stream control openings; these openings were located as shown below:

Bay No. 1, at elevation 361
Bay No. 3, at elevation 370
Bay No. 5, at elevation 366
Bay No. 7, at elevation 366
Bay No. 9, at elevation 362.5

Portland cement with no slag cement admixture was used in those blocks above the elevations listed for an unstated distance. Since some greenish-black cement paste was found in core CL-24 DC-1C through 12C from block 3 it is assumed that above the stream control openings the use of the 25 percent slag cement admixture was resumed.

20. Martin Dam was completed in 1926 and thus the concrete is 52 to 54 years old. This is the oldest concrete affected by alkali-silica reaction that has been examined here. The Oliver Lock, at Tuscaloosa, Ala., built by the Corps of Engineers and completed in 1939, was regarded in 1947 as containing parts in an advanced state of disintegration. A thorough examination of the lock was made with the soniscope and by coring and it was concluded that although very extensive alkali-silica reaction had taken place, the lock was structurally safe. While some cosmetic repairs have been made, the structure is still in service. Charleston Naval Shipyard Dry Dock No. 2 was built in 1942 and was investigated in 1965-1966 when it was 24 years old (Buck and Mather 1969). Eight cores from the north and south walls were examined; concrete showing gel and cracked coarse aggregate was found in five cores while three did not show evidence of reaction. The coarse and fine aggregates were quartzite and quartz; no chert could be detected. The alkali content and source or sources of the cement were unknown. The reacted cores showed wider and more abundant

cracking than was found in the cores from Martin Dam examined here. The question regarding the dry dock was whether the reacted concrete in the long walls should be left in place and used in the planned enlargement of the dry dock. It was concluded in our report that the economic advantages of retaining the long walls although they contained a cracked region at about midheight was reasonable from an engineering point of view and the performance of the walls was expected to be satisfactory.

21. On 23 February 1978 Mr. R. H. Hudson of the Alabama Power Company received a report of a petrographic examination of two 12-in. lengths of NX core from CH-1, depth 10 ft, and hole S-2, depth 21.4 ft. Hole CH-1 is located near H-3 in the upstream inlet works and S-2 in block 6 of the spillway section. The petrographer concluded that conspicuous ettringite growth was found in voids and with gel on crack surfaces. He reported the presence of slag and observed the very dark appearance of the paste between crossed nicols, a result of the low calcium hydroxide content of the thin sections. The petrographer concluded that the concrete had been weakened and should not be regarded as stable if there were further crystallization of ettringite. He observed the shattered aggregate and fractures filled with alteration products.

22. As a consequence of this report, the FERC and the Alabama Power Company required further investigation, and arrangements were made for tests and examinations to be conducted at the Structures Laboratory, WES. This report describes the petrographic examination and observations made here.

23. It should be noted that all of the combinations of ingredients that produce ettringite produce a smaller final product than the volume of the constituents reacting to produce it. Ettringite that crystallizes in open space--voids or cracks--does not exert an expansive force. However, the petrographer who reported on 23 February 1978, like the petrographers here, found gel, cracking, main cracks in aggregate, and evidence of alkali-silica reaction which is an expansive reaction. We did not find alkali-silica reaction in the lower part of core CL-24 DC-1C through 12C.

24. The concrete in the three cores examined here does not appear to be unusually permeable. At 52 years, it shows less alkali-silica reaction than the Oliver Lock showed at 10 years and Charleston Naval Dry Dock No. 2 at 24 years. It seems reasonable to anticipate from the condition of the concrete considered petrographically that the Martin Dam should continue to be a serviceable structure for many more years. It may be desirable to grout some of the fractures in the upstream part of the inlet works. The stability analysis and engineering tests will be more important than this report in deciding the future of the structure. It is still a fact that, as far as we know, no structure in the eastern half of the United States has been replaced because of damage developed entirely from alkali-silica reaction. Drum Afterbay Dam (Pirtz, Strassburger, and Mielenz, 1969), a structure of 6000 cu yd of concrete, was replaced because of low compressive strengths, low soniscope velocities, alkali-silica reation, sulfate attack, freezing and thawing damage, and a

safety factor between 1 and 2, but the paper describing the investigation shows that every factor including a very high water-cement ratio worked against that dam. Martin Dam is affected by alkali-silica reaction but still appears, in the cores examined here, to be acceptable concrete.

Table A1

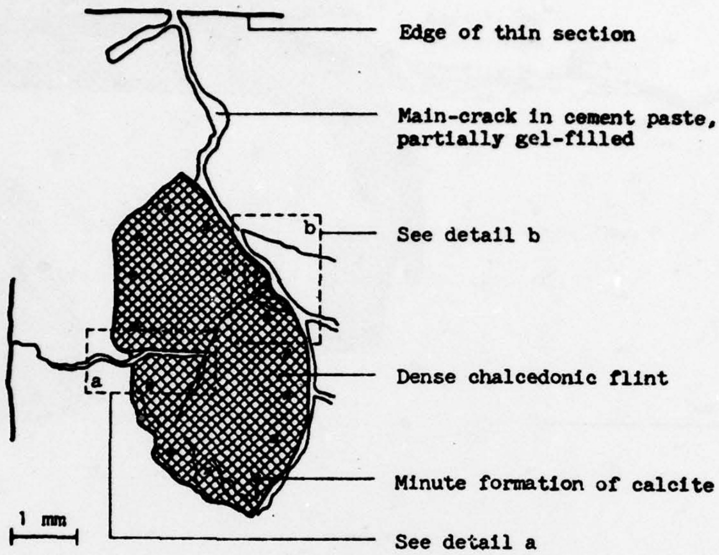
Composition of Cement Paste from Martin Dam

Determined by X-Ray Diffraction

	CL-24 DC-2B Light Gray	CL-24 DC-10B Greenish-Black	CL-24 DC-4C Light Gray
Quartz (aggregate)	X	X	X
Calcium hydroxide	X	X	X
Calcite*	X	X	X
Ettringite	X	-	X
Tetracalcium aluminate monosulfate-12-hydrate	-	X	X
Tetracalcium aluminate carbonate-11-hydrate**	-	-	X

* Probably produced by carbonation of calcium silicate hydrate or calcium hydroxide.

** A normal hydration product of Type I cements.



NOTE: Details a and b are sketched in Figure A2.

Figure A1. Sketch of dense, heterogeneous flint in thin section with a wide main crack transversing the pebble (Idorn 1964)

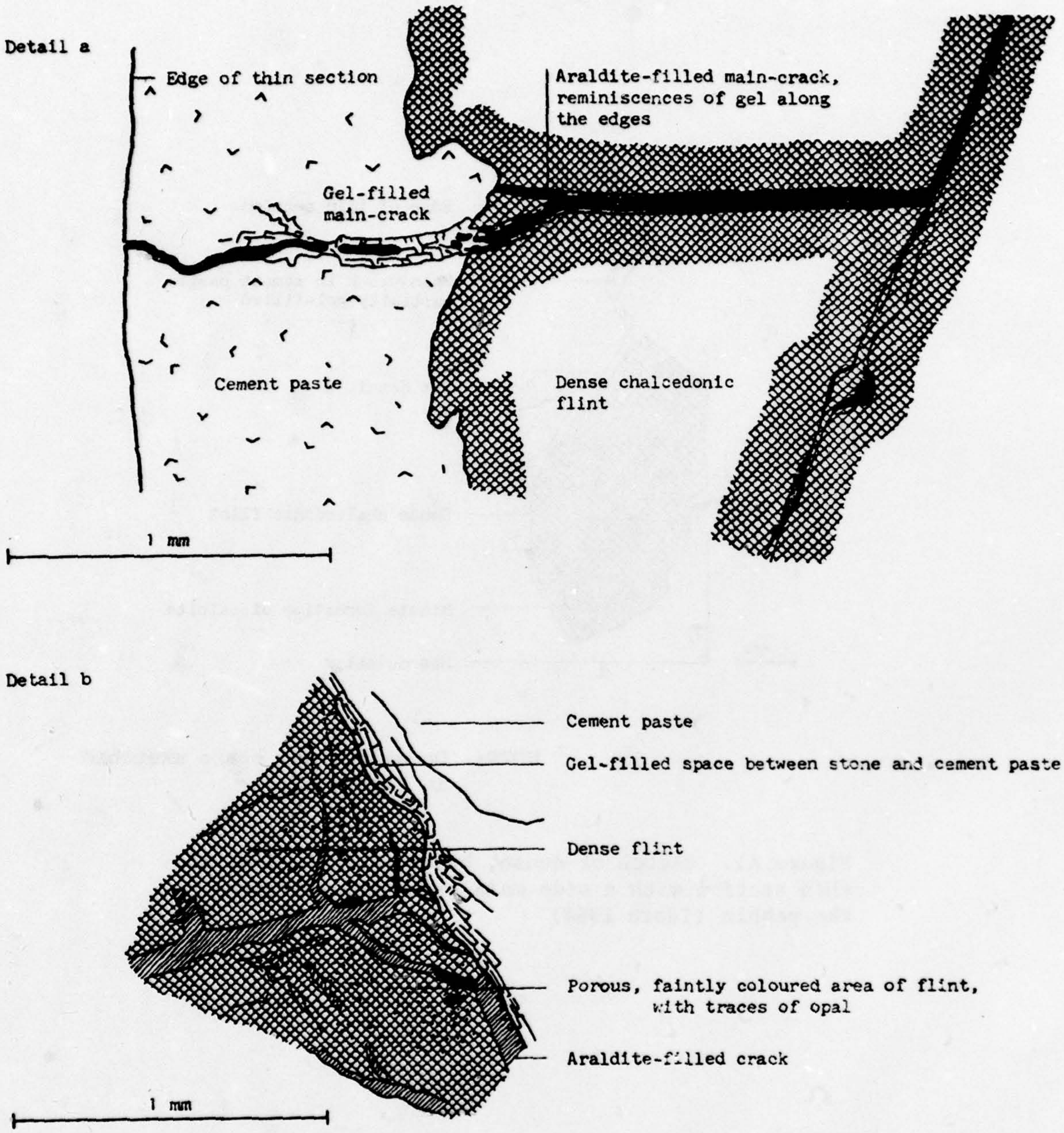


Figure A2. Details a and b of dense, heterogeneous flint. The details show the appearance of the traversing crack as it passes the edges of the particles. The difference in appearance is striking and seems to be related to the structure of the flint. (Idorn 1964)

Photo A1. Fractured surface of concrete (CL-24 DC-10A) from Martin Dam. White alkali-silica reaction gel has filled an entrapped air void between a rimmed sandstone coarse aggregate particle (bottom) and a rimmed quartz particle (above). The reaction rim on the sandstone formed only where the rock was in contact with the paste, not where it bordered the entrapped air void. 12X.

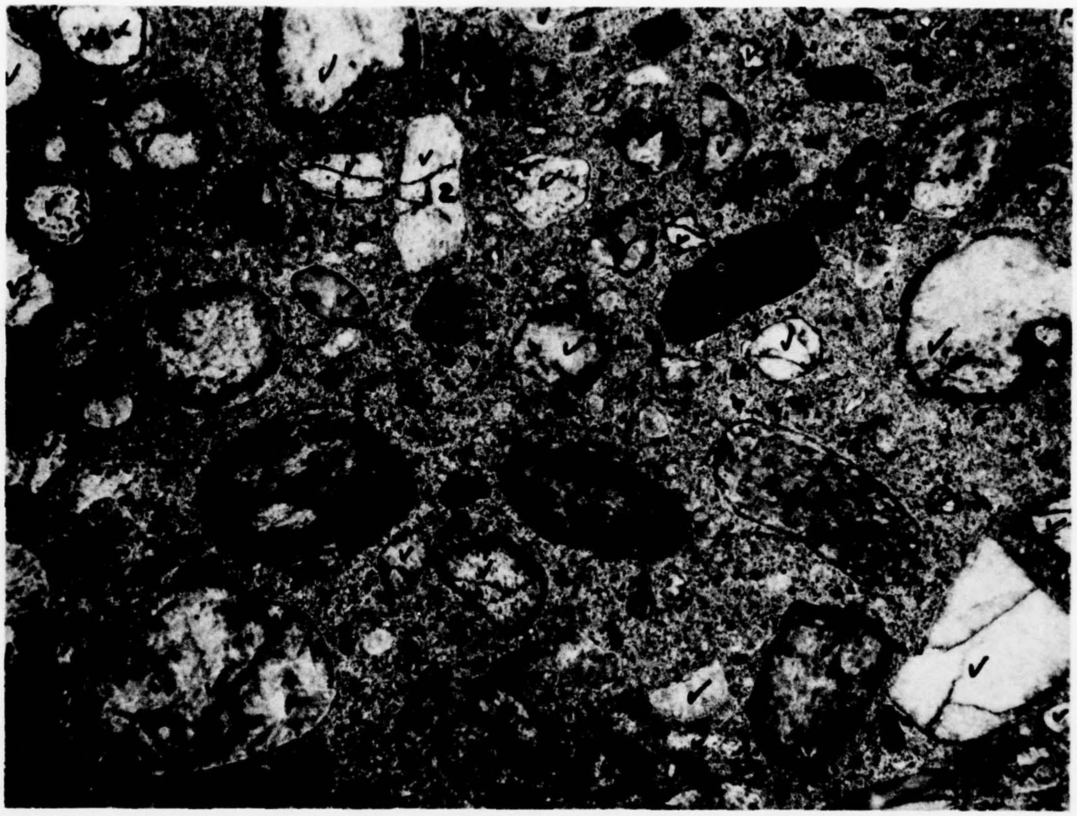


Photo A2. Sawed ground surface of CL-24 DC-10A illustrates main cracks, 1X. Every particle with a check mark shows a main crack or disintegration of the interior of the aggregate at a magnification of 10X - 20X. At the upper left margin of the left side a crack in the mortar runs subparallel to the upper margin and is probably related to the main cracks in the particles marked 1 and 2. Rims or partial rims are common.

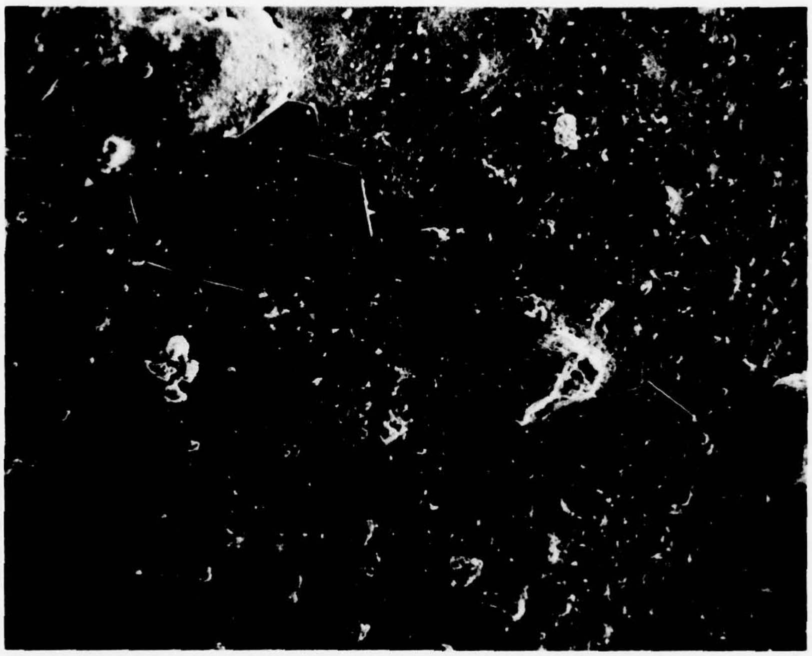


Photo A3. SEM photomicrograph of several elongated and platy monosulfoaluminate crystals found in a void in piece CL-24(3) DC-7C, 52X.

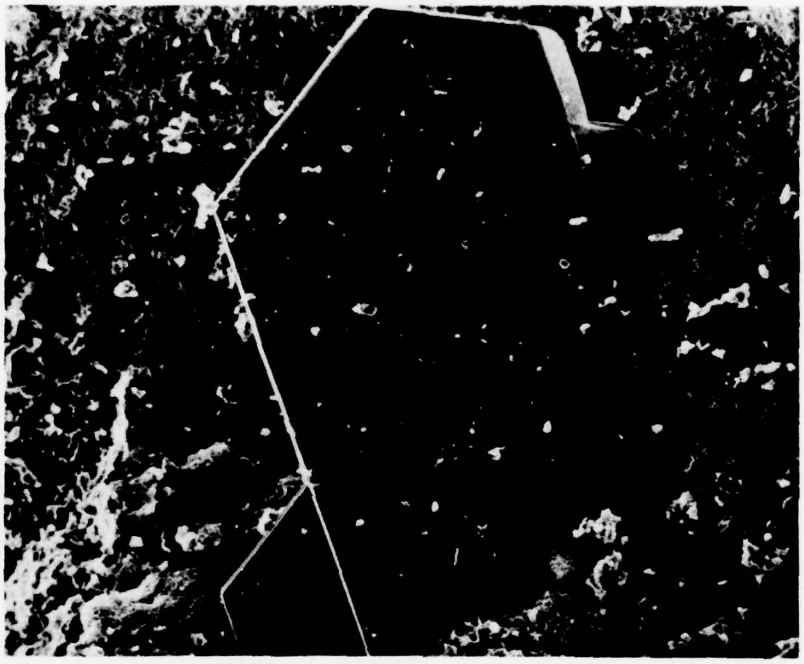


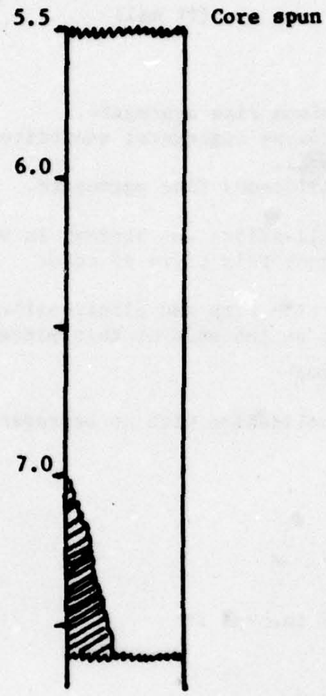
Photo A4. SEM photomicrograph of another group of monosulfoaluminate crystals found in a void in piece CL-24(3) DC-7C, 194X.

Martin Dam, Alabama Power Co. (CL-24 DC-1A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 5.5 - 7.6
Elevation 496.0 - 493.9
(ft msl)

Depth, ft



2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel was present in voids throughout this piece of core. Gel was of the pepper and salt type.

High angle break; surface is coated with gel and aggregate shows development of reaction rims.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A1

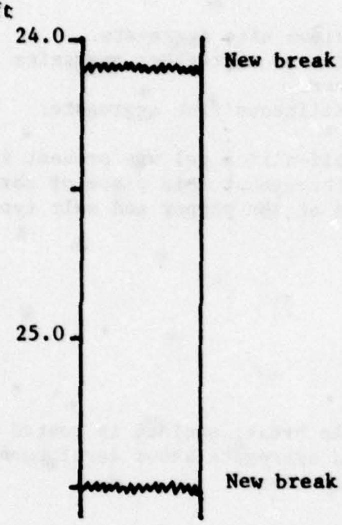
WES FORM NO. 1253
REV OCT [illegible]

Martin Dam, Alabama Power Co. (CL-24 DC-2A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 24.1 - 25.5
Elevation 477.4 - 476.0
(ft msl)

Depth, ft



3-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core.

Some reaction rims and alkali-silica gel present on the ends of this piece of core.

Gray paste.

Good consolidation with no segregation.

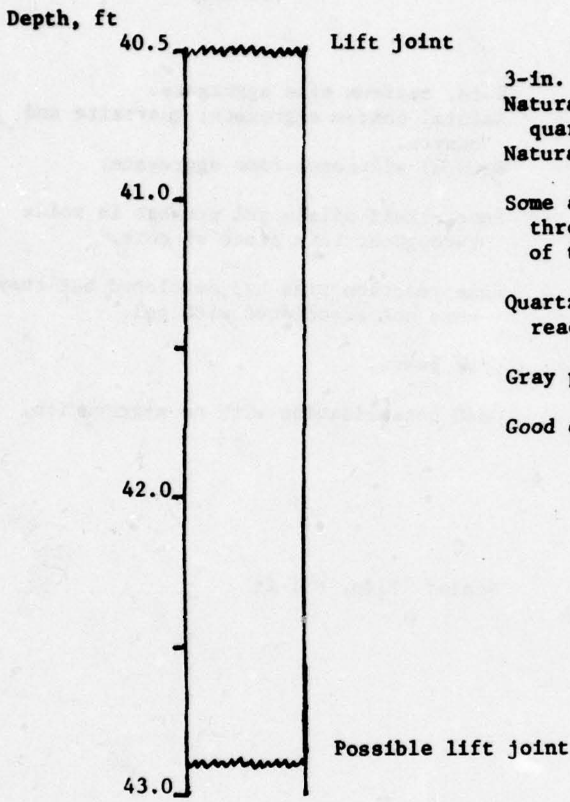
Scale: 2 in. = 1 ft

PLATE A2

Martin Dam, Alabama Power Co. (CL-24 DC-3A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 40.5 - 42.9
Elevation 461.0 - 458.6
(ft msl)



3-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core. Gel was of the banded type.

Quartz coarse aggregate displayed some reaction rims.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A3

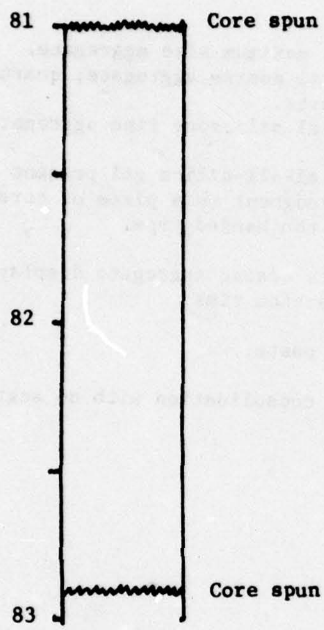
WES FORM NO. 1253
REV OCT 1966

Martin Dam, Alabama Power Co. (CL-24 DC-4A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 81.0 - 82.9
Elevation 420.5 - 418.6
(ft msl)

Depth, ft



6-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core.

Some reaction rims had developed but they were not associated with gel.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A4

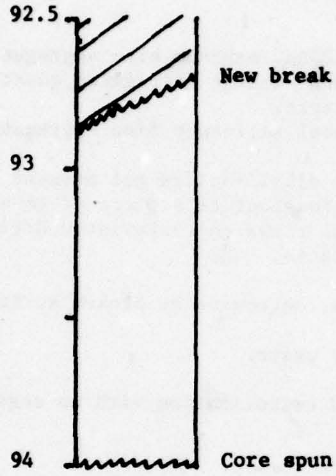
WES FORM NO. 1253
REV OCT 1966

Martin Dam, Alabama Power Co. (CL-24 DC-5A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 92.7 - 94.0
Elevation 408.8 - 407.5
(ft msl)

Depth, ft



4-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A5

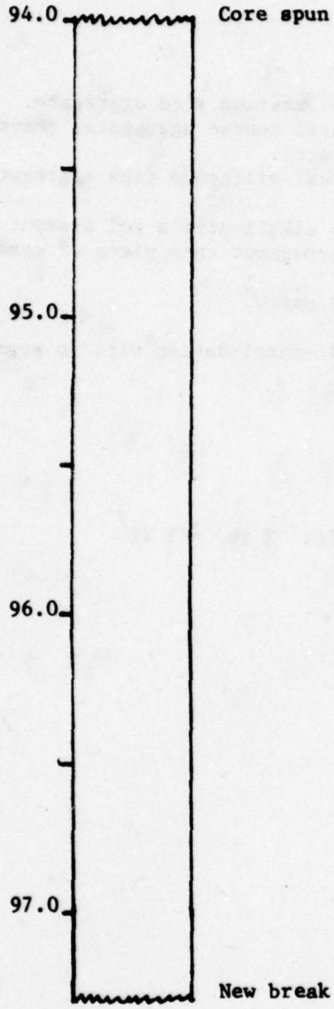
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24 DC-6A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 94.0 - 97.3
Elevation 407.5 - 404.2
(ft msl)

Depth, ft



1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core. Some gel shows characteristic drying shrinkage cracks.

4-in. aggregate at broken surface.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A6

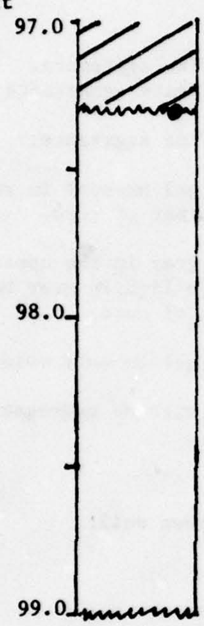
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24 DC-7A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 97.3 - 99.0
Elevation 404.2 - 402.5
(ft msl)

Depth, ft



1-in. diameter steel cable; possible lift joint

1-in. maximum size aggregate.
Natural coarse aggregate composed of quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core.

Many voids filled with alkali-silica gel and some aggregate particles coated with alkali-silica gel.

Gray paste.

Good consolidation with no segregation.

New break

Scale: 2 in. = 1 ft

PLATE A7

WES FORM NO. 1253
REV OCT 1968

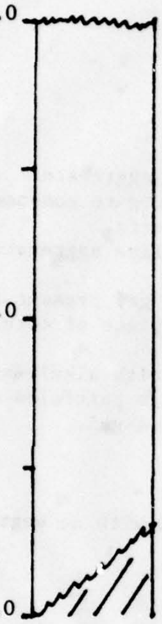
Martin Dam, Alabama Power Co. (CL-24 DC-8A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 99.0 - 101.0
Elevation 402.5 - 400.5
(ft msl)

Depth, ft

99.0 New break



1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core.

Paste changes from gray in the upper portion of core to lighter gray near the lower portion of core.

100.0

Some alkali-silica gel in some voids.

Good consolidation with no segregation.

Old break, partly covered with brown soil.

101.0

Scale: 2 in. = 1 ft

PLATE A8

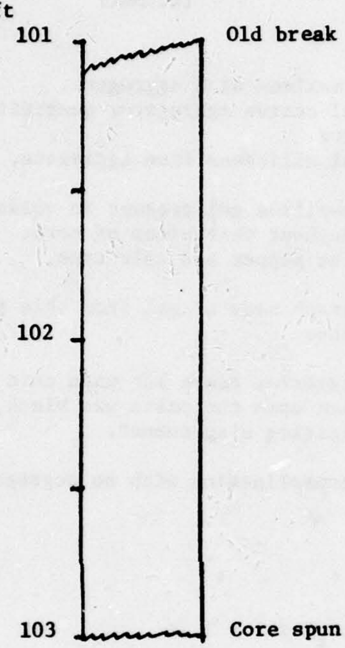
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24 DC-9A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 101.0 - 103.0
Elevation 400.5 - 398.5
(ft msl)

Depth, ft



1-1/2-in. maximum size aggregate.

Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

Abundant alkali-silica gel in voids throughout this piece of core.

Gray paste.

Voids are up to 1/2-in. maximum size.

Scale: 2 in. = 1 ft

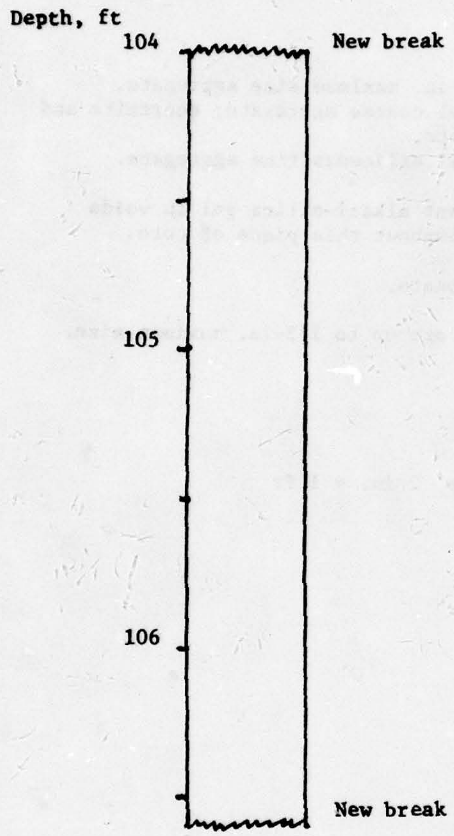
PLATE A9

WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24 DC-10A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 104.0 - 106.6
Elevation 396.5 - 394.9
(ft msl)



2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Alkali-silica gel present in voids throughout this piece of core. Gel was of the pepper and salt type.

Photograph made of gel from this piece of core.

Gray exterior paste but when core was broken open the paste was black, indicating slag cement.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

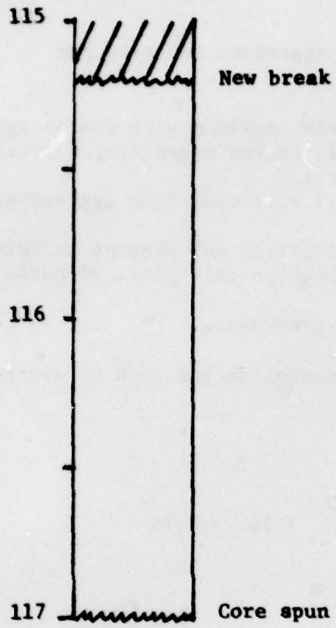
PLATE A10

Martin Dam, Alabama Power Co. (CL-24 DC-11A)

Boring CH No. H3 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 115.2 - 117.0
Elevation 386.3 - 384.5
(ft msl)

Depth, ft



1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A11

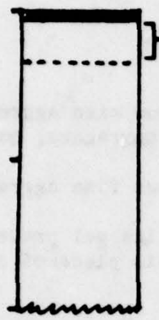
Martin Dam, Alabama Power Co. (CL-24(2) DC-1B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 0.0 - 1.0
Elevation 501.5 - 500.5
(ft msl)

Depth, ft

0.0 Asphalt cap



Smaller size coarse aggregate concrete cap

Incipient crack

1.0 New break

1-1/2-in. maximum size coarse aggregate. Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

Alkali-silica gel present in voids throughout this piece of core.

Light gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A12

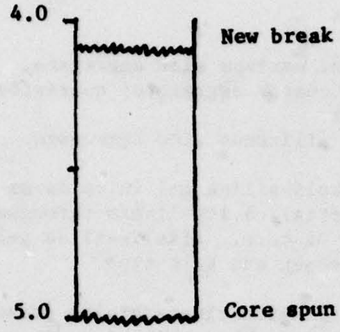
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(2) DC-2B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 4.1 - 5.0
Elevation 497.4 - 496.5
(ft msl)

Depth, ft



2-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core.

Some needle-like crystals of ettringite also present in voids throughout this piece of core.

Light gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

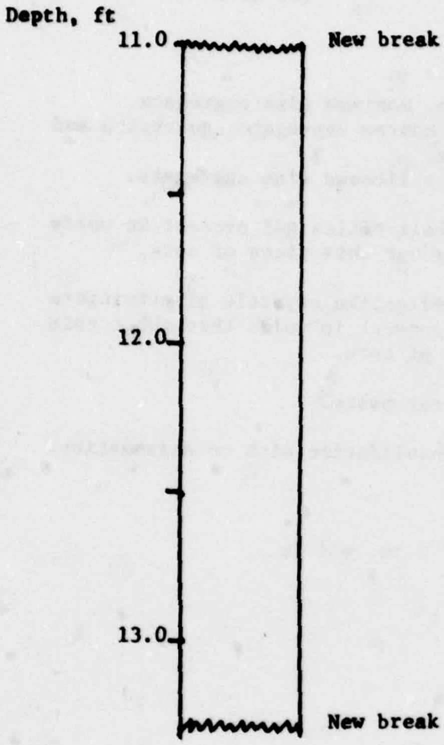
PLATE A13

WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(2) DC-3B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 11.5 - 13.3
Elevation 490.0 - 488.2
(ft msl)



1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel in voids as fillings or partial cavity liners throughout this piece of core. Alkali-silica gel is of the pepper and salt type.

Some ettringite clusters also present in voids throughout this piece of core.

Gray paste.

Some voids up to 3/8-in. maximum dimension.

Scale: 2 in. = 1 ft

NOTE: THIS PIECE OF CORE WAS ACTUALLY 0.5-FT LONGER THAN WAS INDICATED BY DEPTH AND ELEVATION.

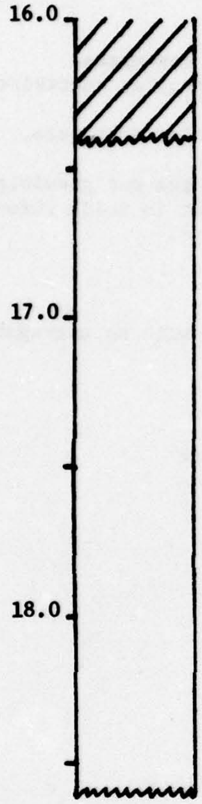
PLATE A14

WES FORM NO. 1253
REV OCT 1966

Martin Dam, Alabama Power Co. (CL-24(2) DC-4B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 16.4 - 18.6
Elevation 485.1 - 482.9
(ft msl)



2-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some white gel product in only a few voids throughout this piece of core.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A15

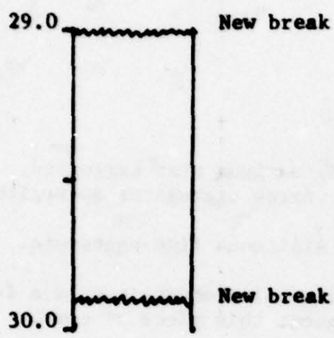
WES FORM NO. 1253
REV OCT 1958

Martin Dam, Alabama Power Co. (CL-24(2) DC-5B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 29.0 - 29.9
Elevation 472.5 - 471.6
(ft msl)

Depth, ft



3-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel and possibly some ettringite present in voids throughout this piece of core.

Light gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

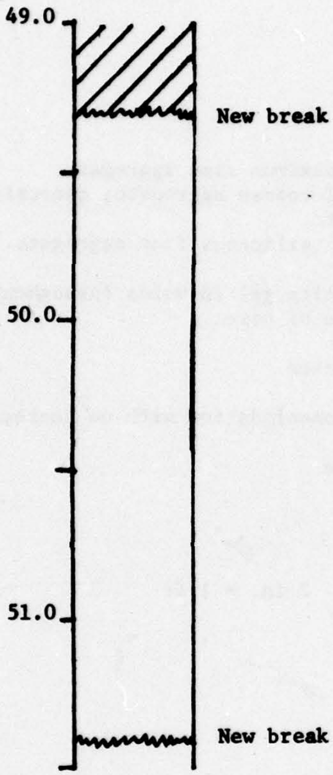
PLATE A16

Martin Dam, Alabama Power Co. (CL-24(2) DC-6B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 49.3 - 51.4
Elevation 452.2 - 450.1
(ft msl)

Depth, ft



Plumstone at ends of core.

Center portion 1-1/2-in. maximum size aggregate.

Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

Some alkali-silica gel and possibly some ettringite in voids throughout this piece of core. Alkali-silica gel is of the pepper and salt type.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

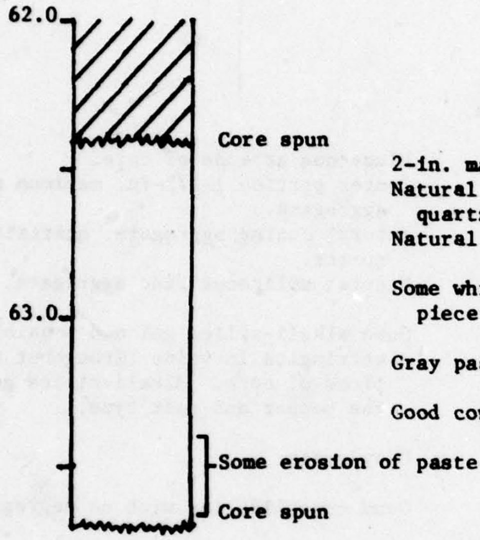
PLATE A17

Martin Dam, Alabama Power Co. (CL-24(2) DC-7B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 62.4 - 63.7
Elevation 439.1 - 437.8
(ft msl)

Depth, ft



2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some white gel in voids throughout this piece of core.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A18

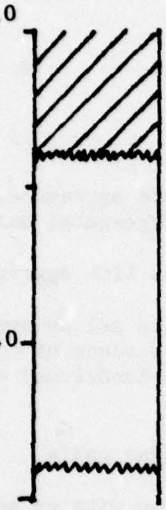
Martin Dam, Alabama Power Co. (CL-24(2) DC-8B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 71.4 - 72.4
Elevation 430.1 - 429.1
(ft msl)

Depth, ft

71.0



72.0

Old lift joint

2-1/2-in. maximum size aggregate.

Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

Some white gel in voids throughout this piece of core.

Gray paste, but when core was broken open the paste was greenish black, indicating slag cement.

New break along large aggregate to paste interface

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A19

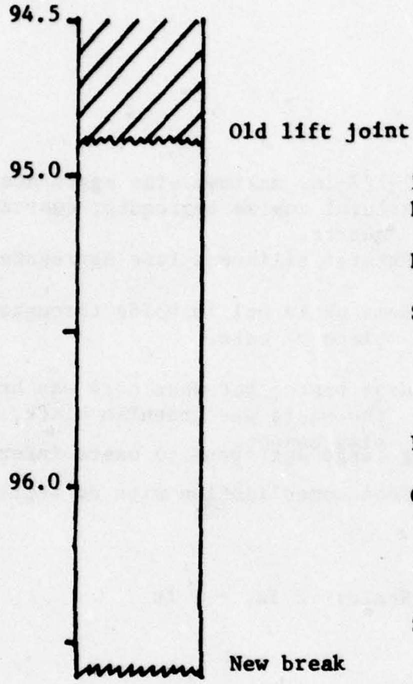
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(2) DC-9B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 94.9 - 96.6
Elevation 406.6 - 404.9
(ft msl)

Depth, ft



5-in. maximum size aggregate.

Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

Some alkali-silica gel present in voids throughout this piece of core. The gel is of both the banded and pepper and salt types.

Light gray and gray paste.

Good consolidation with no segregation.

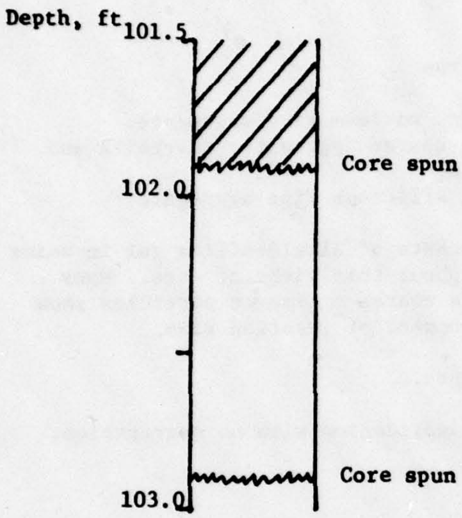
Scale: 2 in. = 1 ft

PLATE A20

Martin Dam, Alabama Power Co. (CL-24(2) DC-10B)

Boring CH No. S6 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 101.9 - 102.9
Elevation 399.6 - 398.7
(ft msl)



1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Very limited amount of alkali-silica gel present in voids throughout this piece of core. Gel is of the pepper and salt type. The aggregate shows some rim development.

Gray paste but when the core was broken open the paste was greenish black, indicating slag cement.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A21

WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(3) DC-1C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 10.5 - 12.6
Elevation 491.0 - 488.9
(ft msl)

1-1/2-in. maximum size aggregate.

Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

Many pockets of alkali-silica gel in voids throughout this piece of core. Many of the coarse aggregate particles show development of reaction rims.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A22

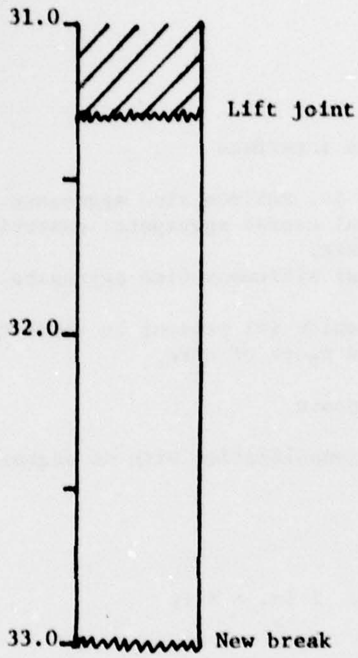
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(3) DC-2C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 31.3 - 33.0
Elevation 470.2 - 468.5
(ft msl)

Depth, ft



2-in. maximum size aggregate but most are 1 in. and smaller.

Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

Some alkali-silica reaction products present in voids on cored surface. Some coarse aggregate shows the development of reaction rims.

Gray paste.

Good consolidation with no segregation.

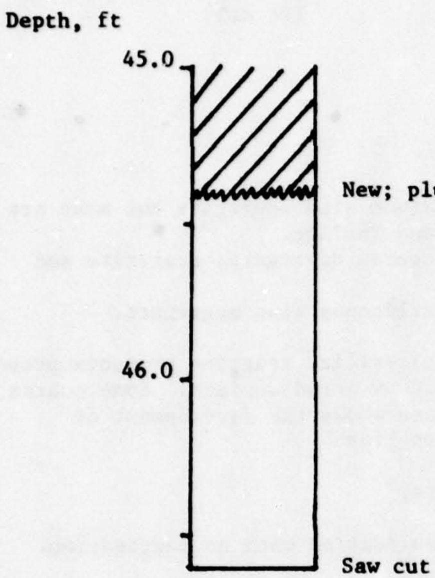
Scale: 2 in. = 1 ft

PLATE A23

Martin Dam, Alabama Power Co. (CL-24(4) DC-11C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 45.4 - 46.6
Elevation 456.1 - 454.9
(ft msl)



2-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some white gel present in voids throughout this piece of core.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A24

Martin Dam, Alabama Power Co. (CL-24(4) DC-12C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 46.6 - 48.1
Elevation 454.9 - 453.4
(ft msl)

Depth, ft 46.5

Saw cut

4-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

47.0

High-angle incipient crack

Some alkali-silica gel in voids and coating some aggregates. The gel showed some shrinkage cracking. Other voids were filled with needles of ettringite.

Gray paste.

48.0

Good consolidation with no segregation.

Old

Scale: 2 in. = 1 ft

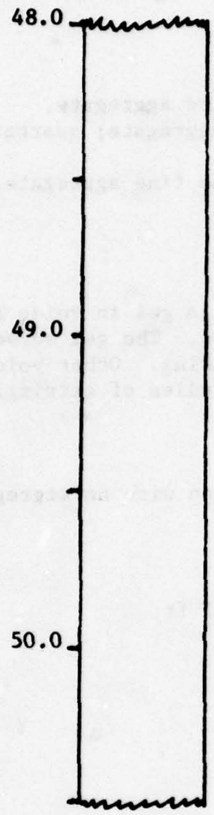
PLATE A25

Martin Dam, Alabama Power Co. (CL-24(3) DC-3C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 48.0 - 50.5
Elevation 453.5 - 451.0
(ft msl)

Depth, ft



Old surface coated with algae

2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Alkali-silica gel present in voids throughout this piece of core.

Light gray paste 48.0 - 48.8 ft.
Gray paste 48.8 - 50.5 ft.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

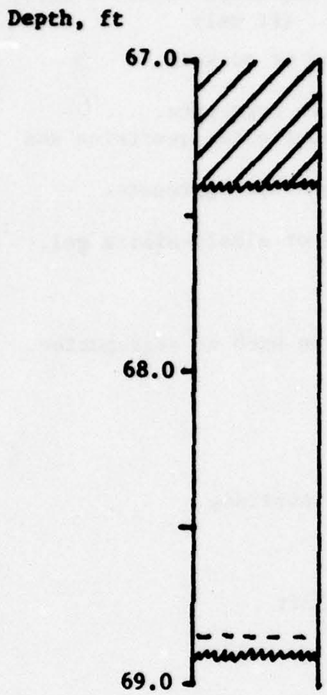
New break, across plumstone

PLATE A26

Martin Dam, Alabama Power Co. (CL-24(3) DC-4C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 67.4 - 68.9
Elevation 434.1 - 432.6
(ft msl)



New break

1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

A limited amount of alkali-silica gel was present. Most of the white deposits in the voids were ettringite and plates of tetracalcium aluminate monosulfate hydrate.

Gray paste but when core was broken open the paste was greenish black, indicating slag cement.

Good consolidation with no segregation.

Subparallel incipient cracking
New break with half an old formed surface

Scale: 2 in. = 1 ft

PLATE A27

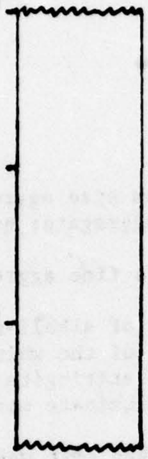
Martin Dam, Alabama Power Co. (CL-24(3) DC-5C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 78.0 - 79.4
Elevation 423.5 - 422.1
(ft msl)

Depth, ft

78.0



79.0

Old break? aggregate pulled out of sockets

1-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

No visible signs of alkali-silica gel.

Gray paste.

Good consolidation with no segregation.

New break, at plumstone-paste interface

Scale: 2 in. = 1 ft

PLATE A28

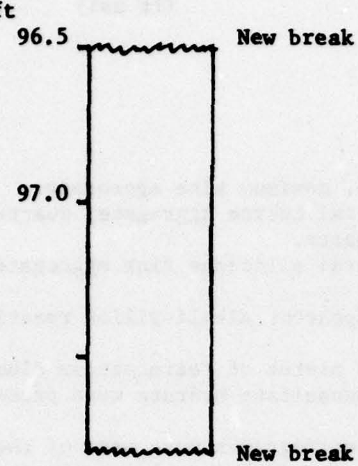
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(3) DC-6C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 96.5 - 97.8
Elevation 405.0 - 403.7
(ft msl)

Depth, ft



3-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

No alkali-silica reaction products detected.

Some plates of tetracalcium aluminate monosulfate hydrate present in voids.

Blackish paste on fresh surfaces indicates slag in cement.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

PLATE A29

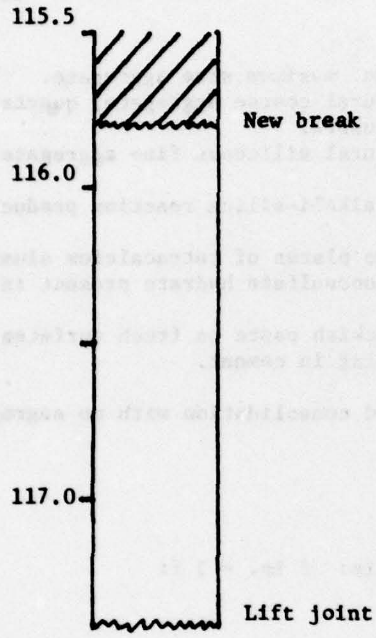
WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(3) DC-7C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 115.8 - 117.4
Elevation 385.7 - 384.1
(ft msl)

Depth, ft



1-in. maximum size aggregate.

Natural coarse aggregate; quartzite and quartz.

Natural siliceous fine aggregate.

No apparent alkali-silica reaction products.

Some plates of tetracalcium aluminate monosulfate hydrate were present in voids.

SEM micrographs were made of the elongated plates of tetracalcium aluminate monosulfate hydrate.

Gray paste.

Good consolidation with no segregation.

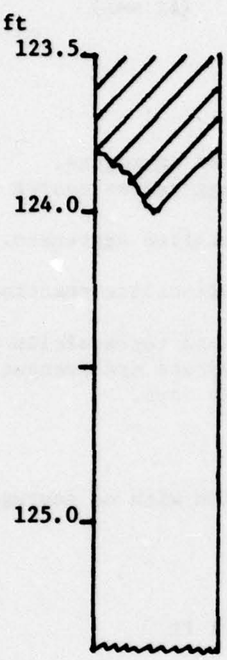
Scale: 2 in. = 1 ft

PLATE A30

Martin Dam, Alabama Power Co. (CL-24(3) DC-8C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 123.8 - 125.4
Elevation 377.7 - 376.1
(ft msl)



1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

Some alkali-silica gel present. Some tetracalcium aluminate monosulfate hydrate present in voids.

Blackish paste on fresh surfaces indicates slag cement.

Some small vugs, otherwise consolidation is good with no segregation.

Scale: 2 in. = 1 ft

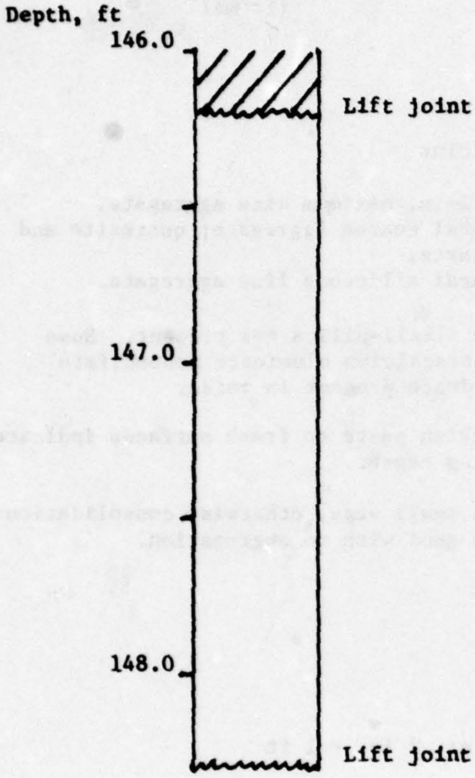
PLATE A31

WES FORM NO. 1253
REV OCT 1968

Martin Dam, Alabama Power Co. (CL-24(3) DC-9C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 146.2 - 148.3
Elevation 355.3 - 353.2
(ft msl)



1-in. maximum size aggregate.
Natural coarse aggregate; quartz and quartzite.
Natural siliceous fine aggregate.

No apparent alkali-silica reaction product.

Some ettringite and tetracalcium aluminate monosulfate hydrate are present in voids throughout this core.

Gray paste.

Good consolidation with no segregation.

Scale: 2 in. = 1 ft

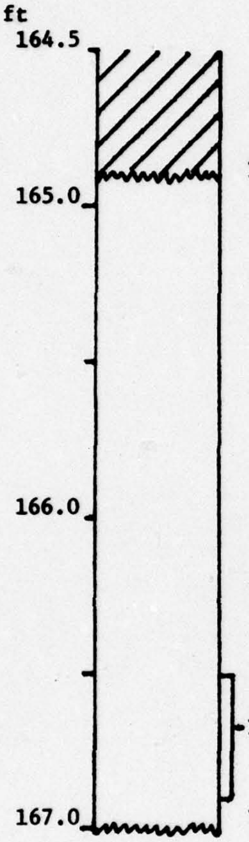
FIGURE A32

Martin Dam, Alabama Power Co. (CL-24(3) DC-10C)

Boring CH No. S7 (6-in. Diameter Vertical Concrete Core)

Depth (ft) 164.9 - 167.0
Elevation 336.6 - 334.5
(ft msl)

Depth, ft



New break at large aggregate-paste interface

1-1/2-in. maximum size aggregate.
Natural coarse aggregate; quartzite and quartz.
Natural siliceous fine aggregate.

No apparent alkali-silica reaction products.

Ettringite fills many of the voids but no tetracalcium aluminate monosulfate hydrate is present.

Light gray paste.

Good consolidation with no segregation.

Numerous small voids

Lift joint

Scale: 2 in. = 1 ft

PLATE A33

Corps of Engineers, USAE Waterways Experiment Station	APPENDIX B ULTRASONIC TESTING REPORT	Structures Laboratory P. O. Box 631 Vicksburg, Mississippi
Project Martin Dam Concrete Core, Alabama Power Co.		Date 20 September 1978 DLA

Introduction

1. Ultrasonic pulse velocity data can be useful in determining the condition of concrete and concrete structures. In situ measurements on concrete structures are useful in locating problem areas within mass concrete, such as those produced by improper vibration (honeycombing), severe cracking, depth of cracks, concrete deterioration, and extent of damage to concrete from fire, freezing and thawing, and other causes. "Excellent quality" concrete usually produces ultrasonic compressional (p) wave velocities of 15,000 to 16,000 fps. Velocities of 12,000 to 15,000 fps indicate concrete of generally good quality. Values from 10,000 to 12,000 fps usually indicate concrete of questionable quality; values of 7,000 to 10,000 fps indicate concrete of poor quality.

2. Laboratory measurements of velocities on concrete core from a concrete structure are useful for predicting the condition of the mass concrete in the general area of the core hole. Dynamic modulus of elasticity (E) can be calculated using either the compressional wave (p) and shear wave (s) velocities or the p wave velocity and the fundamental frequency of the concrete specimen.

Ultrasonic pulse velocity method used for laboratory measurements

3. The ultrasonic pulse velocities were measured in the laboratory using the following test equipment: (a) the pulsing circuit of a seismic timer; (b) signal amplifier; (c) variable resistor; (d) digital oscilloscope with amplitude and time to 0.5 μsec, numerical display on cathode-ray tube; and (e) two PZT, 1 MHz, transducers. For compressional wave measurements the PZT crystals are polarized so that movement is in the axial direction. The shear PZT crystals are polarized so that movement is in the radial direction. The p-wave transducers are coupled to the ends of the concrete specimen with an oil or grease. A repetitive pulse from the seismic timer is sent through cable to the transmitting transducer and the resulting ultrasonic signal propagates through the specimen at a velocity depending upon the material and its condition. The receiving transducer picks up the ultrasonic wave and sends it to the digital oscilloscope through an in-line signal amplifier. The repetitive pulse from the seismic timer is also sent to the oscilloscope through a variable resistor and displayed on the cathode-ray tube with the signal from the receiving transducer. The time of travel of the ultrasonic wave through the specimen is determined from the cathode-ray display by aligning a marker on the beginning pulse from the seismic timer and the first arrival wave from the receiving transducer. These times are displayed numerically on the face of the oscilloscope. The difference between these times less the transducer zero time is the time of travel through the specimen. The compressional wave

velocity is determined from the equation: $Vp = \frac{d}{t}$ where d is the length of the specimen. The shear wave velocity is determined in the same manner using the shear transducer. Instead of an oil or grease couplant, the shear transducer is bonded to the surfaces of the specimens.

Laboratory measurements of ultrasonic pulse velocities and dynamic E calculations

4. Twenty 6-in. by 12-in. concrete cores from Martin Dam core holes H-3, S-6, and S-7 were subjected to nondestructive ultrasonic pulse velocity testing to analyze the condition of the concrete and make a comparison with in situ pulse velocities obtained by Weston Geophysical Corp. Compressional (p) wave and shear (s) wave velocities were measured on the twenty 6- by 12-in. cylinders (seven from borehole H-3, six from borehole S-6, and seven from borehole S-7). Dynamic modulus of elasticity was calculated for each core using the measured compressional and shear wave velocities and density of the concrete (Table B1). Mean wave velocities and standard deviations are shown for each group in Tables B1 and B2.

5. The compressional wave velocities for cores from hole H-3 ranged from 13,400 to 14,170 fps with an average of 13,724 fps, and the shear wave velocities ranged from 7870 to 8980 fps with an average of 8446 fps. The calculated values of dynamic E ranged from 4.9×10^6 to 5.6×10^6 psi with an average of 5.39×10^6 psi. The velocity and E data indicate the concrete condition at this location to be of good to very good quality.

6. The measured velocities and calculated E's for cores from holes S-6 and S-7 were higher than those from hole H-3. The average compressional and shear wave velocities and dynamic E's for hole S-6 were 14,243 fps, 8980 fps, and 5.9×10^6 psi. The average data for hole S-7 were 14,210 fps, 8714 fps, and 5.7×10^6 psi.

Discussion of in situ pulse velocities and dynamic E calculations

7. The in situ pulse velocities made by Weston Geophysical Corp. were lower than those obtained in the laboratory. The in situ measurements were made over considerably longer path lengths and were probably lower due to the presence of cracks and microcracks. Table B2 is a summary of the in situ pulse velocities and calculated dynamic E's using average densities obtained from cores tested in the laboratory.

8. Weston Geophysical accounts for the low velocities on cross-hole measurements from hole H-3 to H-1 on the ground that there is a vertical shaft between the two boreholes which may have affected the travel time. The measurements from H-3 hole to the dam face yielded velocities more in line with those expected.

9. The cross-hole velocities for S-6 to S-4 and S-7 to S-1 do not indicate severe cracking or deterioration of the concrete. The compressional wave velocities for S-6 to the dam face range from 11,800 to 12,600 fps averaging on the low side of good condition which may be considered to warrant further investigation. The p-wave velocities for S-7 to the dam face range from 11,800 to 14,300 fps. The lowest compressional velocity accompanies a shear wave velocity that yields a dynamic E of 5.0×10^{-6} psi. Weston Geophysical Corp. suggests that the low velocities may be a result of errors in path lengths used since these values were taken from drawings of the dam.

10. There is considerable scatter in the calculated values for dynamic modulus (E) that can be directly related to the scatter in s-wave data. Not knowing the degree of reliability or the method of the s-wave measurement in Weston Geophysical's results, it is difficult to compare these with the laboratory measurements on 6- by 12-in. concrete cores. Looking at the in situ data as a whole, it appears that the region from S-6 to the dam face may warrant further investigation.

11. Since the driller's logs relating to the holes in the upstream area of the inlet works indicate that the concrete here was the most fractured in any part of the structure, and since this region is probably the least massive part, grouting in that region may be considered.

TABLE B1

ULTRASONIC PULSE VELOCITY MEASUREMENTS

MARTIN DAM CONCRETE CORE

Core Hole No.	Elevation ft msl	Wave Velocity Compressional fps	Wave Velocity Shear fps	Dynamic E (Calculated) x 10^6 psi
H-3	495.8-494.8	13,970	8480	5.6
	477.2-476.2	14,170	8480	5.6
	460.9-459.9	13,770	8480	5.4
	420.2-419.2	13,830	8510	5.4
	402.3-401.3	13,400	7870	4.9
	397.4-396.4	13,400	8330	5.2
	386.1-385.1	13,500	8980	5.5
$\overline{X}$		13,720; σ'=298	8447; σ'=326	
S-6	501.5-500.5	13,470	8700	5.4
	489.8-488.8	13,400	8780	5.3
	485.0-484.0	14,920	8970	6.2
	452.0-451.0	14,490	9090	6.3
	439.0-438.0	14,290	9050	6.0
	406.1-405.1	14,890	9290	6.3
$\overline{X}$		14,243; σ'=671	8980; σ'=215	
S-7	490.7-489.7	14,270	8490	5.5
	469.9-468.9	14,750	9180	6.3
	453.3-452.3	13,770	8060	4.9
	423.3-422.3	14,530	9070	6.0
	385.5-384.5	14,050	8670	5.6
	355.2-354.2	14,290	8960	6.1
	336.4-335.4	13,810	8570	5.4
$\overline{X}$		14,210; σ'=361	8714; σ'=388	

TABLE B2

IN SITU SEISMIC VELOCITY MEASUREMENTS - MARTIN DAM

(SUMMARY OF MEASUREMENTS MADE BY WESTON GEOPHYSICAL CORP.)

Core Hole No.	Elevation ft msl	Wave Velocity Compressional fps	Wave Velocity Shear fps	Dynamic E* (Calculated) x 10^6 psi
H-3 to H-1	471.5	10,800	6900	4.7
	460.0	8,100	5600	4.9
	451.5	12,000	7200	4.1
	441.5	11,800	7200	4.3
	431.5	12,000	7700	6.0
	419.5	11,500	7600	6.7
	408.0	11,700	6500	2.7
	401.5	12,600	--	--
$\overline{X}$		n=8 11,312;σ'=1394	n=7 6957;σ'=723	
S-6 to S-4	473.0	13,400	6800	2.5
	462.0	13,500	6900	2.8
	451.1	13,700	7950**	~4.5
	438.4	13,400	7400	3.5
	427.4	13,800	7600	3.7
	416.4	13,500	7200**	~3.1
	405.7	13,700	7500	3.5
$\overline{X}$		n=7 13,571;σ'=160	n=7 7336;σ'=403	
S-7 to S-1	469.0	13,500	8200	5.5
	461.5	13,400	8900	9.4
	454.5	13,500	8150**	~5.3
	443.5	13,500	--	--
	433.5	13,800	8500**	~6.2
	423.0	13,700	8200**	~5.2
	416.5	13,600	7050**	~2.8
	404.5	13,400	8500**	~6.9
	396.5	13,300	8000	5.1
	385.0	13,600	7600**	~3.9
	377.0	13,300	7800	4.5
	366.5	13,400	7900	4.7
	354.5	13,400	8000	4.9
	346.5	13,400	8400	6.4
	335.5	13,300	--	--
	326.0	12,900	7300	3.9
$\overline{X}$		n=16 13,438;σ'=203	n=14 8036;σ'=493	
H-3 to Dam Face	484.0	15,500	6750**	~2.1
	476.7	14,400	9400	9.6
	471.5	14,300	9300	9.3
	460.0	14,300	9150**	~8.3
	451.5	15,000	--	--
$\overline{X}$		n=5 14,700;σ'=534	n=4 8650;σ'=1270	

(Continued)

* Calculated values determined by WES using average density determined in laboratory from cores from each hole.

** Average value.

TABLE B2 (Concluded)

Core Hole No.	Elevation ft msl		Wave Velocity Compressional fps		Shear fps	Dynamic E (Calculated) x 10^6 psi
S-6 to Dam Face	484.0		12,400		--	--
	473.0		11,900		6600	2.8
	462.0		12,000		4800	1.8
	451.1		12,100		5850**	~1.0
	438.4		12,600		--	--
	427.4		11,800		--	--
$\overline{X}$		n=6	12,133; σ'=308	n=3	5750; σ'=904	
S-7 to Dam Face	469.5		12,700		7750**	~5.0
	461.5		12,100		--	--
	454.5		11,800		7400	5.0
	443.5		12,700		8000	5.9
	433.5		12,800		--	--
	423.0		12,800		8300	7.2
	416.5		13,200		9000	11.3
	404.5		13,600		--	--
	396.5		13,600		9300	12.3
	385.0		13,600		7800	4.2
	377.0		14,000		--	--
	366.5		13,900		--	--
	354.5		14,300		--	--
$\overline{X}$		n=13	13,162; σ'=752	n=7	8221; σ'=695	

** Average value.

Corps of Engineers, USAE Waterways Experiment Station	APPENDIX C REPORT OF RESULTS OF DESTRUCTIVE TESTS ON 6-IN.-DIAMETER CONCRETE CORES	Structures Laboratory P. O. Box 631 Vicksburg, Mississippi
Project Martin Dam, Alabama Power Co.		Date 22 September 1978 SAR

Introduction

1. The tests reported herein were started in July 1978. The type and number of tests and test methods are given below.

Tests required

2. a. CRD-C 19-75 (ASTM C 469-65), Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (WES 1975 and ASTM 1978b), including unconfined compressive strength of six cores.

b. CRD-C 93-76 (ASTM C 801-75), Practice for Determining the Mechanical Properties of Hardened Concrete Under Triaxial Loads (WES 1976 and ASTM 1978c), on three groups of three cores each at three confining pressures.

c. CRD-C 149-77 (ASTM D 2936-71e), Direct Tensile Strength of Intact Rock Core Specimens (WES 1977 and ASTM 1978d), on five cores.

Samples

3. The cores were 6-in. diameter diamond-drilled cores from core holes H-3, S-6, and S-7, in Martin Dam. The elevations of the sections tested are shown in the tables of test results.

Test procedures

4. The cores were sawed and the ends ground to produce nominal 6-in.-diameter by 12-in.-long specimens. Two electrical resistance-wire strain gages were mounted parallel to the long axis and two parallel to the diameter on the 15 cores to be used in tests for static modulus and in triaxial compression tests. While resistance wire strain gages fail in triaxial loadingsfairly frequently, when they do not fail they provide information about the axial and diametral strains. The static modulus of elasticity was computed for each of the six cores tested in unconfined compression on the slope of the axial stress-strain curve at 40 percent of the ultimate stress. Poisson's ratio (ν) was computed for each of these cores from the axial and diametral stress-strain curves at 40 percent of the ultimate stress. The uniaxial specimens were loaded using a 440,000-lbf universal testing machine. The cores were not soaked in lime water for 40 hr as the test method directs, but were tested after storage in laboratory air. The six unconfined cores came from elevations near the top and the bottom of each of the three core holes. The triaxial specimen load was applied with a 2.4 x 10^6-lbf testing machine. Confining pressures for each triaxial test were applied with a hand-operated, electro-hydraulic pump. The direct tensile test specimens were prepared according to method CRD-C 149 (WES 1977). Tensile load was applied continuously and without shock to failure using the 440,000-lbf universal testing machine.

Results and discussion

5. Results from the tests for static modulus, Poisson's Ratio, and compressive strength are presented in Table C1; triaxial compression tests in Table C2; and direct tensile tests in Table C3.

6. Six tests of static modulus, Poisson's ratio, and compressive strength were made. The specimens came from near the tops and bottoms of each hole. The axial and diametral stress-strain curves are shown in Plates C1 and C2. The stress-strain curves are grouped according to elevation in the core holes for comparison. The average compressive strength for the three specimens from the tops of the holes is 6860 psi, while the average compressive strength for the three bottom of hole specimens is 4350 psi. Alkali-silica reaction was present in all the sections of core from H-3 and S-6 but none was found in the lower sections of S-7. It seems probable that inconsistencies of batching and mixing may be responsible for the range of compressive strengths. The static moduli of elasticity (Table C1) ranged from 2.17 to 4.18 x 10^6 psi. Those specimens with lower moduli of elasticity have corresponding low Poisson's ratios; the range of Poisson's ratios is 0.08 to 0.17.

7. Three triaxial test series were conducted on the cores using confining pressures (σ_3) of 2500, 5000, and 9000 psi. The specimen groupings represented recovery from holes at depths ranging from shallow to intermediate to fairly deep. The principal stresses (σ_1 and σ_3) and deviator stresses (σ_1-σ_3) are presented in Table C2. The deviator stress versus axial and radial strain curves are plotted in Plates C3-C5; the minimum principal stress is given for each curve. Strain-gage malfunctions prevented the presentation of six stress-strain relations. The deviator stresses within each suite of specimens range from approximately 15,000 psi to 21,000 psi. The average maximum axial strain in each test group is approximately 2 percent, which suggests that similar strain capacities may exist at different depths when the concrete is subjected to triaxial stress.

8. Mohr's diagrams for the test suites are shown in Plates C6-C8. The stress circles for each grouping lent themselves to well-fitted failure envelopes. The angle of internal friction (ϕ) at normal stress levels from 5000 psi down, for each test group, is approximately 38 to 41 degrees. The cohesion (c), as indicated by the Mohr's diagram, ranges from 800 psi for top of hole cores to 500 psi for bottom of hole cores (Table C2, Plates C6-C8). The reduced friction angles, approximately 14.5 to 21 degrees, at normal stresses from 5000 psi to 17,000 psi indicate that the rate of shear-strength gain decreases at higher normal stresses. The stress circle obtained from drill hole CH-S7, elevation 469.9'-468.9, is not shown in Plate C6 because the confining membrane failed, saturating the specimen before failure. The stress circles with minimum principal stresses of 0 psi, shown in the plots of suites 1 and 3, were obtained by selecting maximum principal stresses equal to the average compressive strengths from the top of the hole in suite 1 and the bottom of the hole in suite 3.

9. Five direct tensile tests were made. The values are shown in Table C3, with the failure conditions. The first and third tests in Table C3 are regarded as unacceptable because the concrete failed very near to the epoxy, cementing the core to the cap. The second, fourth, and fifth

tests failed on underside voids or underside voids and through reacted aggregates. The tensile stress circles at the left of the shear stress axis assist in defining the failure envelope more extensively, as illustrated in the Mohr's diagram presented in Plates C6-C8.

10. The pressure-volume relations for three of the specimens are presented in Plate C9. These curves result from the hydrostatic load phase of the triaxial tests conducted on the specimens. The volumetric strain ($\Delta V/V$) was computed at several mean normal stresses from the equation $\Delta V/V = \varepsilon_a + 2\varepsilon_r$, where ε_a = axial strain and ε_r = diametral strain. The slope of each curve at some given mean normal stress level provides a value for the bulk modulus (k) or "compressibility" of each specimen at that stress.

TABLE C1

UNCONFINED COMPRESSIVE STRENGTHS, AND STATIC MODULI OF ELASTICITY, AND POISSON's RATIOS OF CORES FROM MARTIN DAM*

Drill Hole No.	Elevation ft msl	Compressive Strength, psi	Modulus of Elasticity (psi x 10^{-6})	Poisson's Ratio
CH-H3	495.8-494.8	8450	4.18	0.15
CH-S6	501.5-500.5	6760	2.17	0.09
CH-S7	490.7-489.7	5360	2.60	0.14
CH-H3	386.1-385.1	5310	3.01	0.15
CH-S6	406.1-405.1	4710	3.29	0.17
CH-S7	336.4-335.4	3040	2.73	0.08

**Cores were tested dry, with ends ground rather than capped.*

TABLE C2

TRIAXIAL COMPRESSION TESTS OF THREE SUITES OF CORES FROM MARTIN DAM*

Suite No.	Drill Hole No.	Elevation ft msl	Minimum Principal Stress σ_3, psi	Maximum Principal Stress σ_1, psi	Deviator Stress $\sigma_1-\sigma_3$ psi	Angle of Internal Friction ϕ^o	Cohesion psi
1	CH-H3	477.2-476.2	2500	17250	14750	38°45'	800
	CH-S6	489.9-488.8	9000	28750	19750		
	CH-S7	469.9-468.9	Membrane failed before specimen				
2	CH-S6	452.0-451.0	2500	17875	15375		
	CH-H3	420.2-419.2	5000	23250	18250	41°10'	750
	CH-S7	423.3-422.3	9000	30375	21375		
3	CH-S6	439.0-438.0	2500	16250	13750		
	CH-S7	355.2-354.2	5000	23000	18000	41°00'	500
	CH-H3	397.4-396.4	9000	31375	22375		

* Drilled cores, nominally 6 in. in diameter and 12 in. long, with ground ends were tested after storage in laboratory air.

TABLE C3

DIRECT TENSILE TESTS OF CORES FROM MARTIN DAM*

Drill Hole No.	Elevation ft msl	Direct Tensile Strength psi
CH-S6	485.0-484.0	290**
CH-H3	460.9-459.9	255†
CH-S7	453.3-452.3	200††
CH-H3	402.3-401.3	160‡
CH-S7	385.5-384.5	140‡‡

* Cores of nominal 6-in. diameter and 12-in. length with ground ends were tested, after storage in laboratory air.

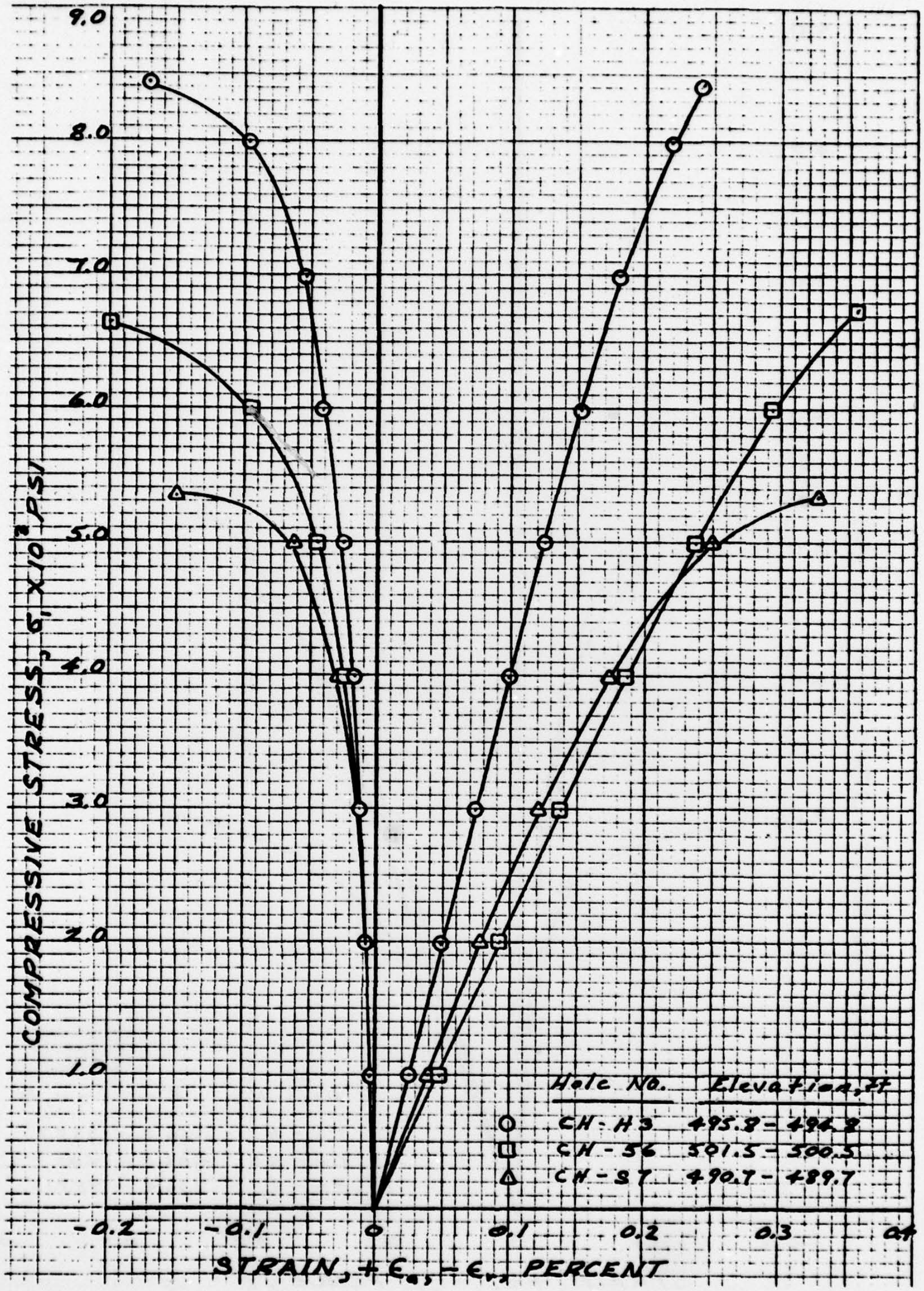
** Broke just below epoxy film on end of specimen. Not a good test.

† Failed on 8 underside bleeding voids, 17 broken aggregate particles, broke around 12 coarse aggregate particles.

†† Broke near top of core and at top of core; failure in concrete on undersides; very doubtful test.

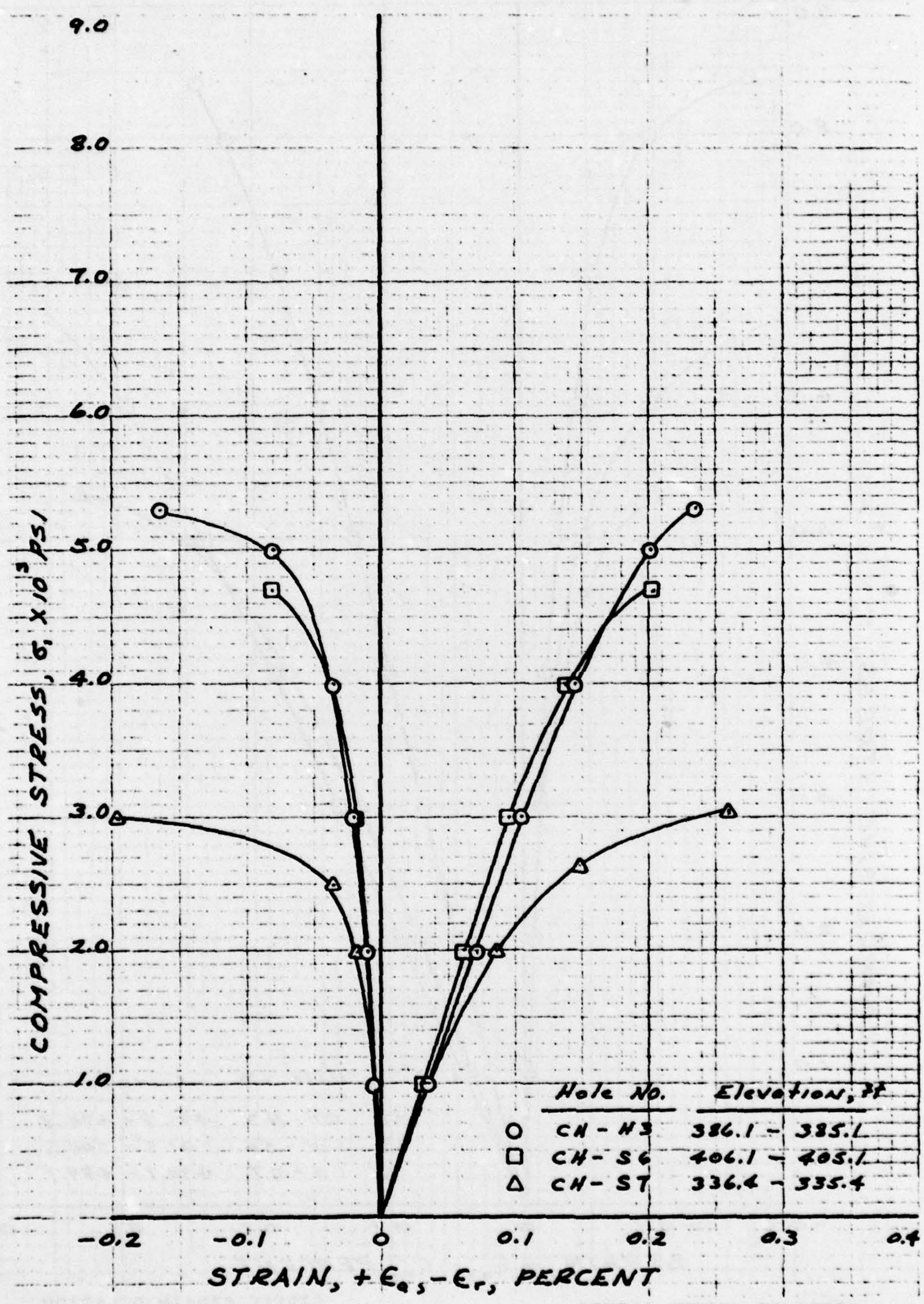
‡ Failed on one underside; some knobs present; most of aggregate broken with reaction rims.

‡‡ Failed on undersides; two broken pieces of coarse aggregate.



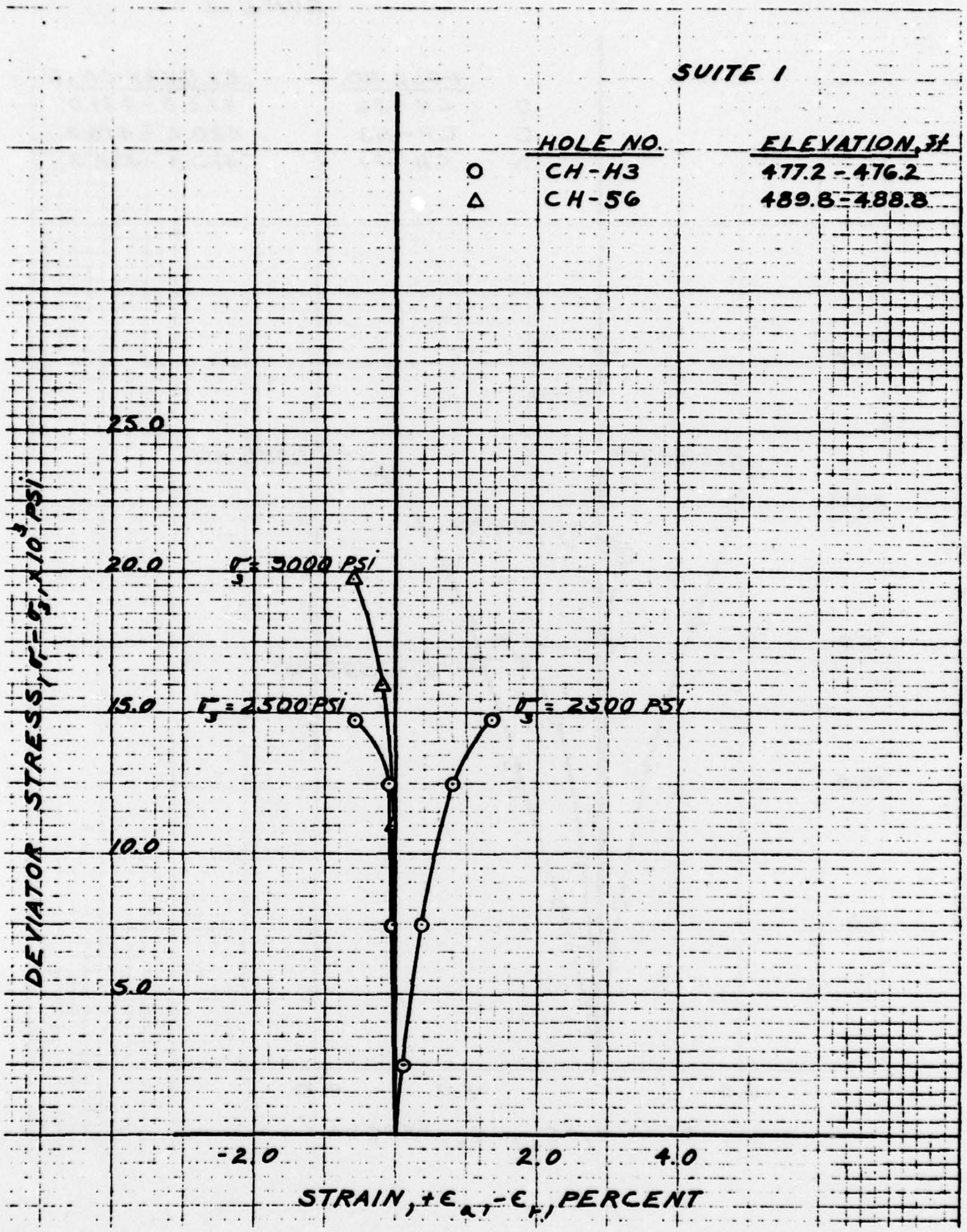
STRESS-STRAIN RELATION
OF CONCRETE CORES
Martin Dam, Ala. Power Co.

PLATE C1



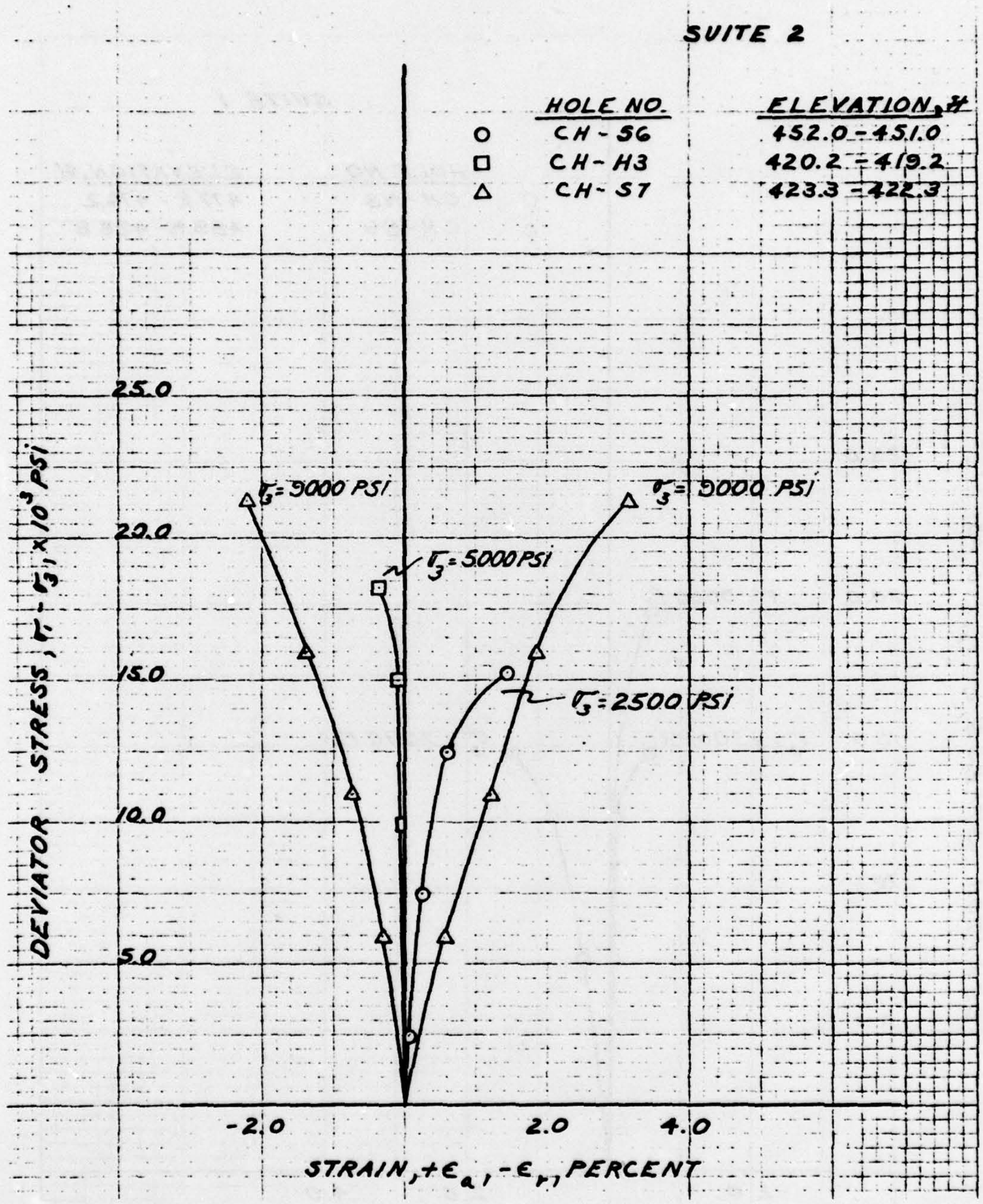
STRESS-STRAIN RELATION
OF CONCRETE CORES
Martin Dam, Ala. Power Co.

PLATE C2



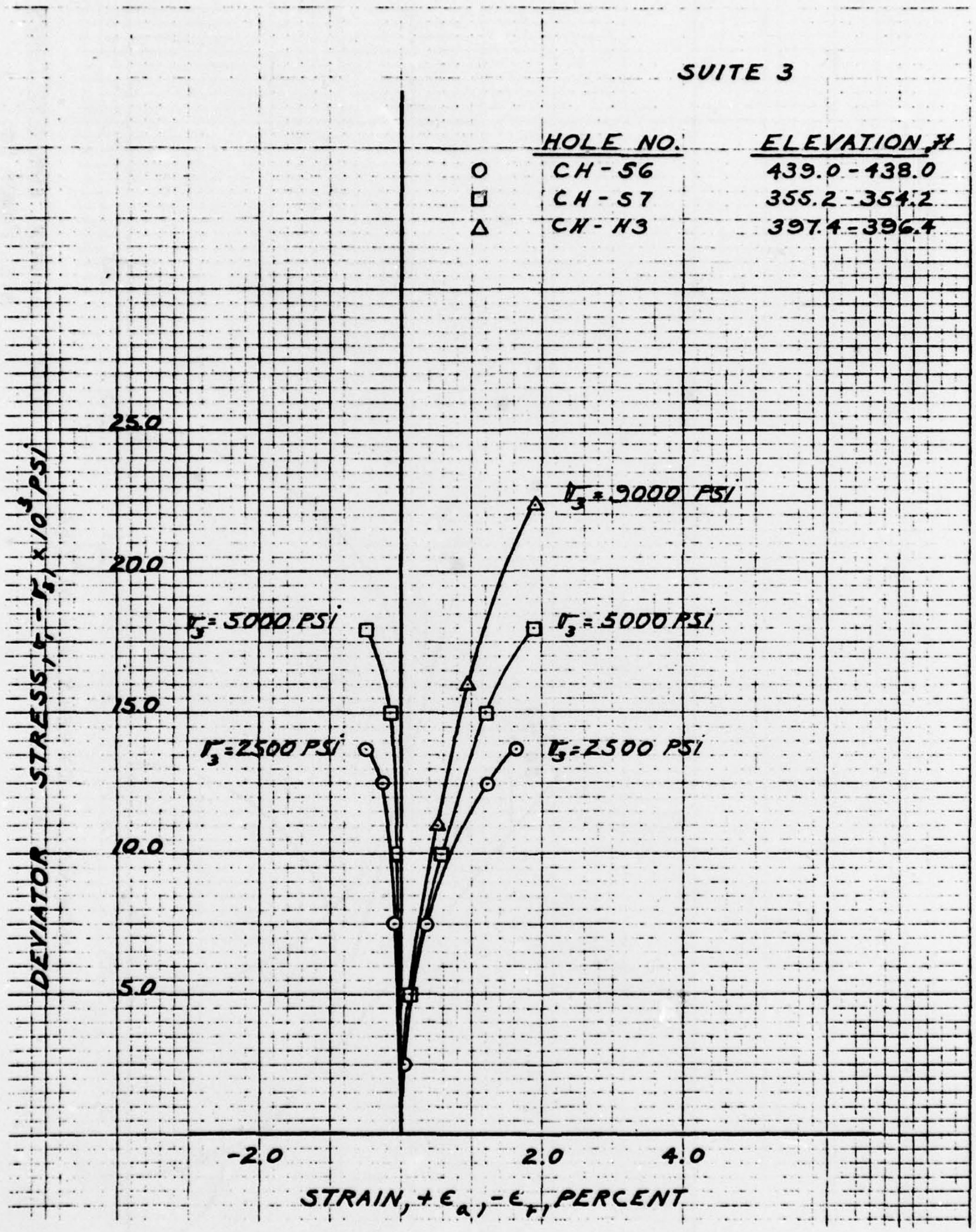
DEVIATOR STRESS-STRAIN
RELATION OF CONCRETE CORES
Martin Dam, Ala. Power Co.

PLATE C3



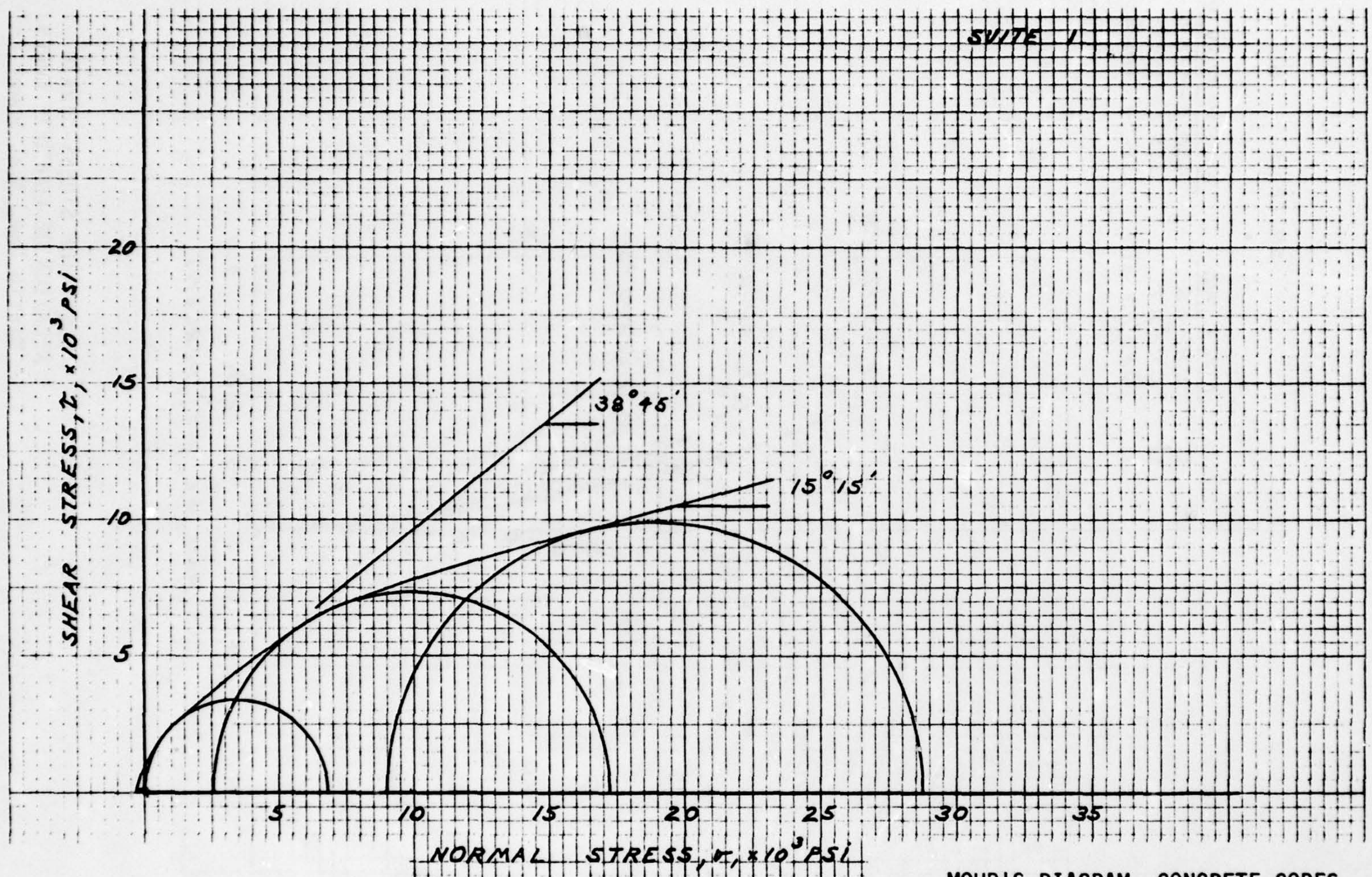
DEVIATOR STRESS-STRAIN
RELATION OF CONCRETE CORES
Martin Dam, Ala. Power Co.

PLATE C4

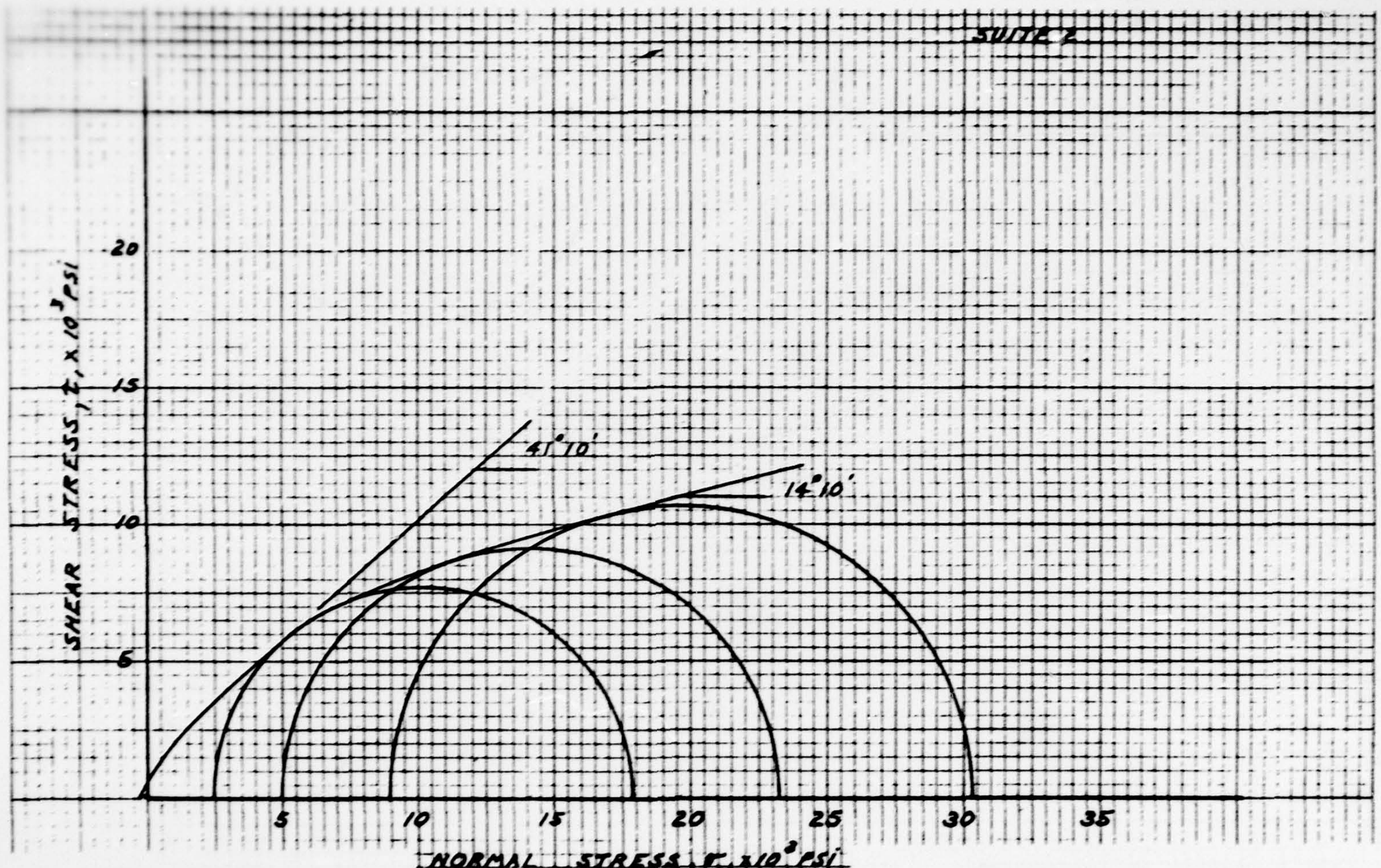


DEVIATOR STRESS-STRAIN
RELATION OF CONCRETE CORES
Martin Dam, Ala. Power Co.

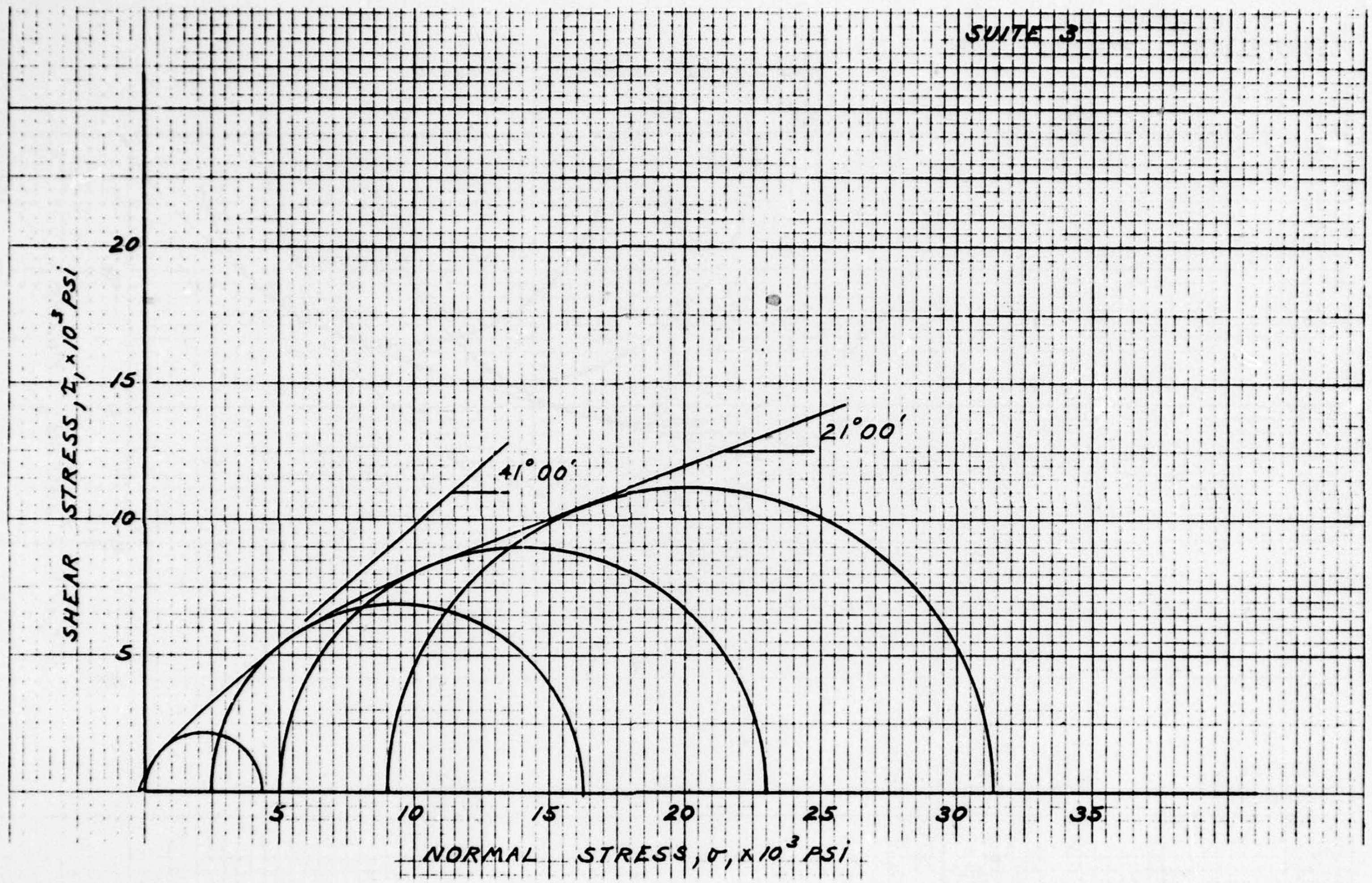
PLATE C5



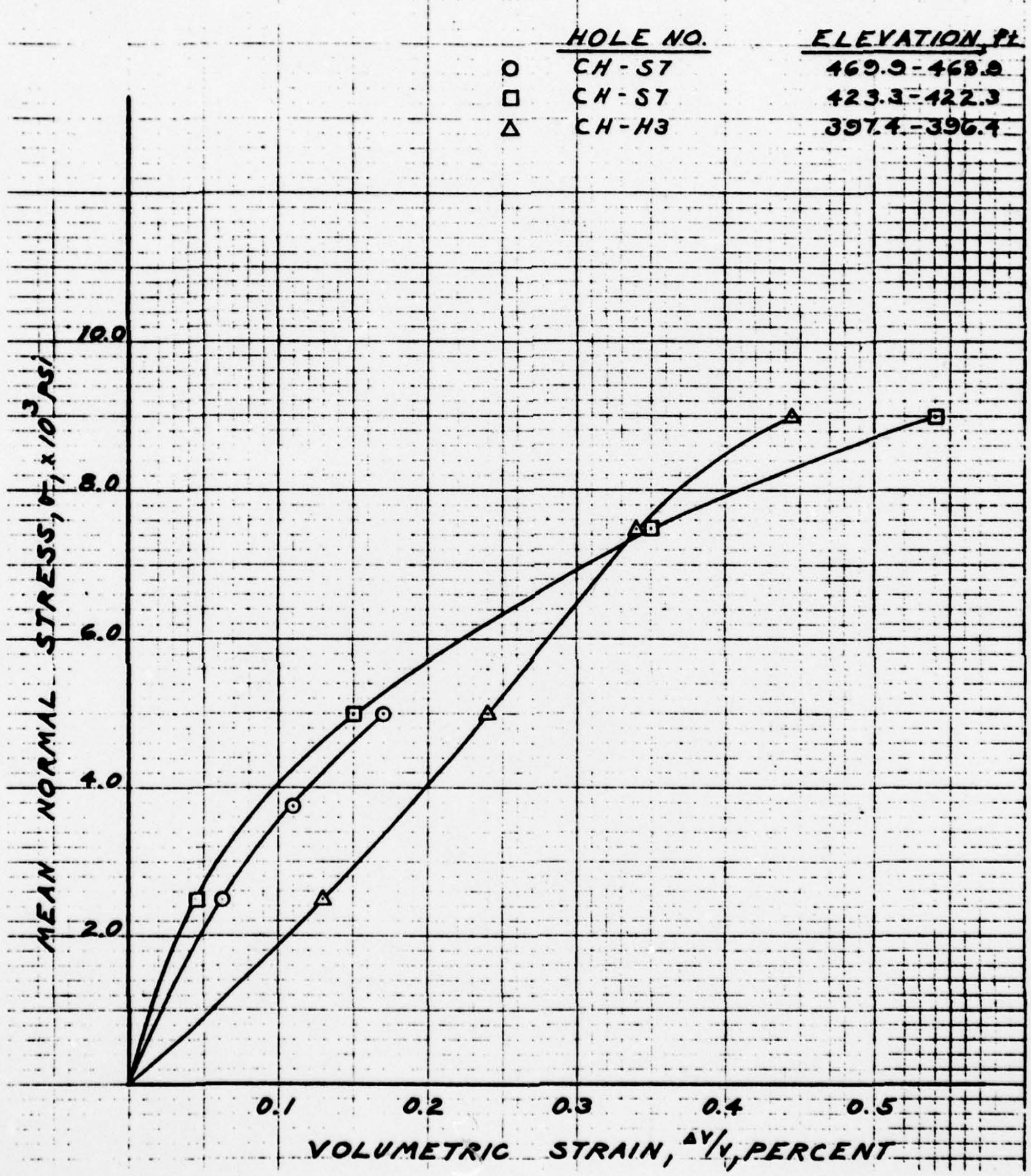
MOHR'S DIAGRAM, CONCRETE CORES
Ala. Power Co.



MOHR'S DIAGRAM, CONCRETE CORES
Ala. Power Co.



MOHR'S DIAGRAM, CONCRETE CORES
Ala. Power Co.



HYDROSTATIC STRESS-VOLUMETRIC
STRAIN RELATION OF CONCRETE CORES
Martin Dam, Ala. Power Co.

PLATE C9

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.

Ainsworth, Donnie L

Testing of 6-in.-diameter concrete cores from Martin Dam, Alabama Power Company / by Donnie L. Ainsworth ... [et al.]. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

11, [28] p., [42] leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; SL-79-17)

Prepared for Alabama Power Company, Birmingham, Ala.

CTIAC Report No. 38.

References: p. 10-11.

1. Alkali aggregate reactions. 2. Concrete cores. 3. Concrete test specimens. 4. Martin Dam. 5. Petrographic analysis. 6. Ultrasonic tests. I. Alabama Power Company. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; SL-79-17.

TA7.W34m no.SL-79-17