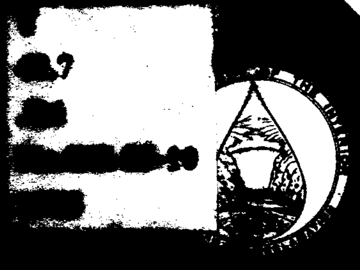
GR-85-10

CONCRETE PERFORMANCE IN GRAND COULEE FOREBAY DAM, WASHINGTON:
10-YEAR CORE REPORT

November 1985
Engineering and Research Center



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16. ABSTRACT

This study is a continuation of the long-term evaluation of the strength and elastic properties of the concrete in Grand Coulee Dam. Previously, cores were evaluated when the concrete was approximately 6-months and 1-year old. The results of tests on the physical properties of 250-mm (10-in) diameter cores extracted from interior and exterior mass concrete in Grand Coulee Forebay Dam, Washington, at 10-years' age indicate good quality, uniform, well-consolidated concrete, with no evidence of chemical attack or alkali silica reaction.

The tensile strength of the interior concrete averaged 0.36 MPa (52.2 lb/in^2) for jointed specimens and 1.1 MPa (160 lb/in^2) for unjointed specimens. The average 10-year compressive strength of the interior concrete was 34.2 MPa (4955 lb/in^2), which is 1.1 MPa (160 lb/in^2) above the 1-year average. For the interior concrete, the average 10-year modulus of elasticity was 38.8 GPa (5.62 x 10^6 lb/in^2), and the average Poisson's ratio was 0.18.

The average 10-year compressive strength of the exterior concrete was 37.4 MPa (5420 lb/in^2), which is 0.1 MPa (14.5 lb/in^2) below the 1-year average. For the exterior concrete, the average 10-year modulus of elasticity was 41.6 GPa (6.06 x 10^6 lb/in^2), and the average Poisson's ratio was 0.16.

17. KEY WORDS AND DOCUMENT ANALYSIS

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CONCRETE PERFORMANCE IN GRAND COULEE FOREBAY DAM, WASHINGTON: 10-YEAR CORE REPORT

by

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W. Ray Willingham

Performed by
U.S. Army Engineer Laboratory
U.S. Army Corps of Engineers
South Atlantic Division
Marietta, Georgia

Concrete and Structural Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

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Vinton Guy, the principal investigator for the Bureau of Reclamation, coordinated the work performed by the U.S. Army Corps of Engineers, SADL (South Atlantic Division Laboratory). The work was performed from August 1983, through September 1984, under the direction of William L. Tison, P. E. and W. Ray Willingham, Registered Professional Geologist. Harvey L. Mayes, Civil Engineering Technician, directly supervised the various phases of the work. The report was prepared by William L. Tison and W. Ray Willingham.

The research covered by this report was funded under the Bureau of Reclamation PRESS (Program Related Engineering and Scientific Studies) allocation No. DB-14, Longtime Concrete Studies.

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TABLES

FIGURE

INTRODUCTION

A program investigating the effects of age and loading on strength and elastic properties of concrete from Grand Coulee Forebay Dam was authorized by an interagency agreement, fund obligation No: 3-04540, dated August 5, 1983, between the U.S. Department of the Interior, Bureau of Reclamation, and the U.S. Army Corps of Engineers, SADL (South Atlantic Division Laboratory). The details of the investigation were outlined in the interagency agreement.

Background

The Grand Coulee Forebay Dam is located on the right bank of the Columbia River, downstream from and adjacent to Grand Coulee Dam, near Grand Coulee, Washington. It is a 61-m (201-ft) high gravity dam containing 463 000 m^3 (605 000 yd^3) of mass concrete. The dam is divided into monoliths by vertical transverse contraction joints. Galleries and adits provide access to selected locations inside the dam.

The effects of age and loading on the strengths and elastic properties of the interior and exterior concrete of the Forebay Dam had been studied previously. Cores were extracted and tested when the concrete was approximately 6 months old and 1 year old. USBR (Bureau of Reclamation) Laboratory Report No. GR-13-77 presents data and conclusions based on those tests.

Purpose

When the Forebay Dam concrete was 10 years old, 250-mm (10-in) diameter cores were extracted to test the uniformity of the concrete; to determine its physical properties; and to evaluate its structural behavior.

Scope

Thirty-three meters (109 ft) of 250-mm (10-in) diameter cores were extracted from 10 different holes and tested. All of these cores were logged and photographed. The unit weights of 31 selected specimens were measured. Twenty-three of these were tested for compressive strength, and their modulus of elasticity and Poisson's ratio were determined. The other eight selected cores were tested for direct tensile strength; four of these cores were jointed and four were unjointed. After testing, a cursory petrographic examination was performed on each compressive and tensile strength specimen, and two interior and two exterior specimens were selected for detailed petrographic examination. All results were then compared with the results of previous tests.

CONCLUSIONS

Based on the analysis of the test results, visual observations, and petrographic analyses, the following conclusions are offered.

1. After 10 years, the concrete is in good condition. There is no evidence of chemical attack, alkali silica reaction, or damage from cyclic freezing and thawing.
2. The fact that the average 10-year compressive strength was less than the average 1-year strength in the exterior concrete seems reasonable.
3. The fact that the average 10-year compressive strength was greater than the average 1-year strength in the interior concrete also seems reasonable.
4. The average 10-year tensile strength of the interior concrete was less than the 1-year average. This is strictly a function of the specimens tested rather than an indication of a decrease in the tensile strength.
5. Elastic stiffening of the concrete is indicated by an increase from the 1-year to the 10-year modulus of elasticity for both interior and exterior concrete.

DESCRIPTION OF THE STUDY

Samples

Table 1 summarizes the pertinent location information for the cores (from the 10 holes) furnished for testing.

The cores were received at Marietta, Georgia, on August 17, 1983, packed in 44 wooden boxes each 4 ft long. The cores were wrapped in brown waterproof paper and packed in sawdust. The sawdust and the cores were dry when they were received.

Selection of Specimens

All of the cores were removed from the boxes and stripped of the brown paper. The pieces from each hole were fitted together into their full length. The individual pieces were then assigned

Table 1. – Core location data.

Hole No.	Block No.	No. of test specimens	Specimen length m	Specimen length ft	Location
		Interior concrete			
106-1	106	3	2.7	9	Foundation adit
109-1	109	6	5.8	19	Inspection gallery
113-1	113	5	4.3	14	Inspection gallery
113-1a	113	4	2.7	9	Inspection gallery
116-1	116	4	2.7	9	Gate gallery
118-2	118	7	2.7	9	Access gallery
119-2	119	3	2.7	9	Downstream adit
120-1	120	4	2.7	9	Foundation gallery
		Exterior concrete			
100-1	100	3	2.7	9	Crest of dam
WDB-1	Wing dam B	7	4.0	13	Crest of dam

laboratory identification numbers (SADL Lab. Nos.). The cores were logged by a petrographer, and photographs were taken (See app. A and app. B). These photographs and logs were used for selecting the test specimens. Specimens were selected in the following way:

1. First, compressive and tensile specimens were selected from lifts that had been tested previously, so that comparisons could be made.

2. Second, intact specimens containing construction joints were selected, particularly for the direct tensile tests.

3. Finally, additional specimens were selected to complete the required 21 compressive and 8 direct tensile tests.

Twenty-three compressive strength specimens and eight direct tensile specimens were ultimately selected. Two intact joint specimens were sent back to Denver for direct shear testing by USBR personnel. This testing was done to define the shear strength displacement characteristics of the construction joints (app. G). All selected specimens were then marked with yellow tape before the final photographs were taken (See app. A).

PHYSICAL PROPERTY TESTS AND PETROGRAPHIC ANALYSIS

Preparation of Specimens

The specimens selected for the compressive and the direct tensile tests were sawed to the required nominal test length of 510 mm (20 in). The length of the compressive strength specimens ranged from 455 mm (17.9 in) to 530 mm (20.9 in). The lengths of the direct tensile test specimens ranged from 495 mm (19.5 in) to 515 mm (20.25 in). All specimens were sawed with a 610-mm (24-in) diameter Felker continuous rim diamond blade. The sawed ends were smooth, but not exactly perpendicular to the core axis. Tensile specimens with construction joints were sawed so the joint was positioned in the center. After sawing, the specimens were weighed in air and under water to determine their density (unit weight). The specimens were stored in a moist curing room before they were tested.

No equipment was available for lapping specimens of this size. Therefore, all specimens were capped with a thin, high-strength sulfur mortar cap. This was done in accordance with ASTM C 617, Standard Method of Capping Cylindrical Specimens (See fig. F1 in app. F).

Compressive Strength

Compressive strength was determined in accordance with ASTM C 39, Standard Method for Compressive Strength of Cylindrical Concrete Specimens. The specimens were tested using a Tinius-Olsen Universal hydraulic testing machine with a capacity of 1957 kN (440 000 lbf) (See fig. F3). The compressive strength of two specimens exceeded this capacity. These specimens were then tested on a 4448-kN (1 000 000-lbf) capacity Baldwin compression machine at the nearby Lockheed Georgia Aircraft Company.

Elastic Properties

The elastic properties, modulus of elasticity, and Poisson's ratio were determined for each compressive strength test in accordance with ASTM C 469, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. The longitudinal and transverse strains were measured using a compressometer-extensometer furnished by the USBR Laboratory (See fig. F4).

Direct Tension

Direct tension specimens were attached to steel end-plates with epoxy adhesive (See fig. F2). The plates were then connected with chain links to two spherical rod end bearings. Tensile force was then applied until failure to these rod end bearings, using the same Tinius-Olsen testing machine. The plates used for these tests were furnished by the USBR Laboratory.

Petrographic Analysis

Each specimen subjected to strength testing received a cursory petrographic examination after the test. The failed specimens were photographed, and each failure was described by the nature of the structural surfaces, the percentage of broken aggregate, chemical deposits, and other characteristics. In addition, four specimens, two representative of interior and two representative of exterior concrete, were selected for detailed petrographic examination. This examination was performed in accordance with ASTM C 856, Petrographic Examination of Hardened Concrete.

ANALYSIS OF RESULTS

Density

Density determinations made on the 23 compressive strength specimens and on the 8 direct tensile specimens are shown in table C1. For the specimens tested, the density averaged 2499 kg/m^3 (156.0 lb/ft^3) and ranged from 2419 kg/m^3 (151.0 lb/ft^3) to 2595 kg/m^3 (162.0 lb/ft^3). This compares well with the average of 2483 kg/m^3 (155 lb/ft^3) for the 6-month and 1-year cores. There were no significant differences between the densities of the exterior and interior specimens.

Compressive Strength

The results of the individual compressive strength tests are shown in table C1. The results are summarized in tables 2 and 3.

The average compressive strength for the seven exterior concrete specimens tested was 37.4 MPa (5420 lb/in^2). Results ranged from 32.5 MPa (4710 lb/in^2) to 46.0 MPa (6665 lb/in^2) with a coefficient of variation of 11.8 percent. The average strength is slightly less than the 1-year average of 37.5 MPa (5440 lb/in^2) (See table 4 and fig. 1). There is no obvious explanation

Table 2. – Summary of compressive strength and elastic properties test results on 250-mm (10-in) diameter cores at 10 years' age – Grand Coulee Forebay Dam.

Core No.	Compressive strength		Strength ratio: core/28-day 6-in by 12-in cyl., %	Modulus of elasticity		Poisson's ratio
	MPa	lb/in²		GPa	lb/in² X 10⁶	
			Exterior concrete			
WDB-1-1	33.3	4830	111	37.3	5.40	0.17
WDB-1-2	37.2	5390	124	40.0	5.80	.17
WDB-1-3	46.0	6665	153	43.8	6.35	.13
WDB-1B-E	32.5	4710	111	46.2	6.70	.16
WDB-1B-5	37.8	5480	129	41.7	6.05	.14
100-1a-2	41.1	5955	117	44.2	6.40	.16
100-1a-3	33.9	4920	105	39.7	5.75	.19
Average	37.4	5420		41.8	6.06	0.16
			Interior concrete			
106-1-2	38.3	5560	151	49.0	7.10	0.13
109-1-2	36.3	5270	—	35.9	5.20	.14
109-1-5	25.2	3660	116	35.0	5.07	.14
113-1-1	32.6	4720	138	30.7	4.45	.14
113-1-2	30.5	4420	129	33.8	4.90	.24
113-1-4	34.6	5020	—	34.4	4.99	.16
113-1a-2	36.3	5260	153	33.1	4.80	.16
113-1a-3	30.8	4470	130	34.5	5.00	.23
116-1-2	34.3	4980	103	46.4	6.72	.25
116-1-3	38.2	5540	114	40.8	5.91	.21
118-2-2	34.1	4940	—	42.8	6.20	.22
118-2-3	35.8	5040	—	40.0	5.80	.11
118-2-7	39.2	5680	—	45.4	6.58	.22
119-2-1	34.3	4970	102	38.8	5.62	.21
119-2-2	34.3	4980	102	40.7	5.90	.20
120-1-1	33.0	4790	139	39.7	5.76	.19
Average	34.2	4955		38.8	5.62	0.18

Table 3. – Summary of direct tensile strength test results on 250-mm (10-in) diameter cores at 10 years' age – Grand Coulee Forebay Dam.

Core No.	Tensile strength		Core strength ratio: tensile/avg. compressive,	Disbonded area,	Distance of break from end		Remarks
	MPa	lb/in²	%	%	mm	in	
			Interior concrete				
106-1-3	0.41	60	1.2	75	280	11	Jointed
109-1-3	0.31	45	0.9	90	50	2	Jointed
109-1-4	0.96	140	2.8	95	75	3	Unjointed
113-1-3	0.55	80	1.6	80	75	3	Unjointed
116-1-4	1.79	260	5.2	50	25	1	Unjointed
118-2-7	1.38	200	4.0	40	25	1	Unjointed
Average	0.90	130					

Table 4. – Comparison of average compressive strengths of 250-mm (10-in) diameter cores at various ages.

Age	Number of Specimens	Average compressive strength		Coefficient of variation,
		MPa	lb/in²	%
		Exterior concrete		
6 months	15	33.8	4900	19.2
1 year	13	37.5	5440	21.0
10 years	7	37.4	5420	11.8
		Interior concrete		
6 months	21	30.2	4380	17.5
1 year	21	32.4	4700	17.0
10 years	16	34.2	4955	8.7

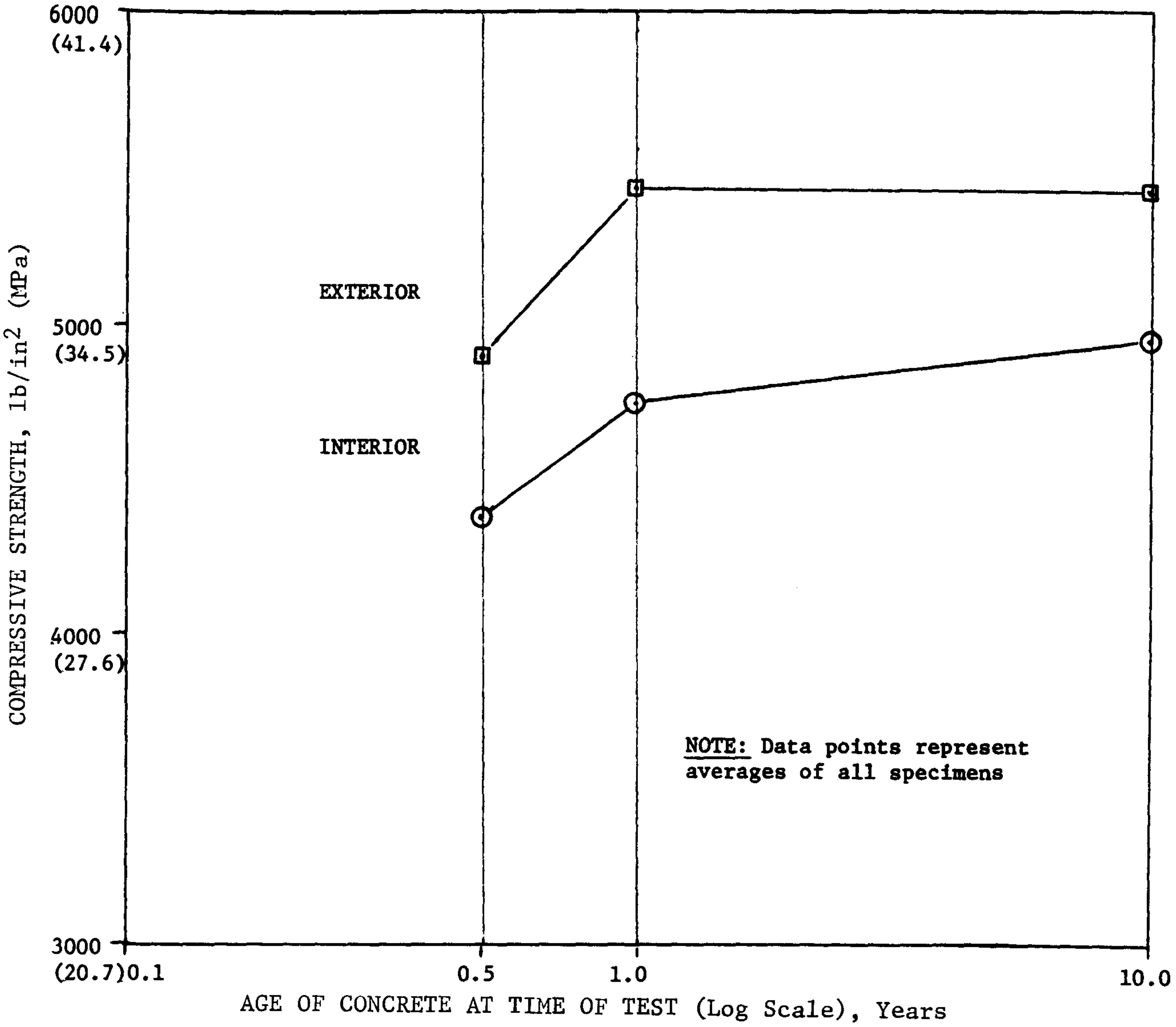

Figure 1. – Compressive strength development – Grand Coulee Forebay Dam.

for this fact, but the results do indicate that there has been no strength gain in the exterior concrete after 1 year. This may be reasonable because the exterior concrete had higher early strengths and may have been subject to moisture and temperature variations that slowed or stopped hydration. As expected, the coefficient of variation for these cores was less than that for either the 6-month or 1-year test results. The most obvious reason for strength differences or variations is the size and distribution of coarse aggregate in the various cores. Some of the cores, such as WDB-1-3, contained only 38-mm (1½-in) maximum size aggregate; which resulted in higher strength. The lowest strength exterior core, 32.5 MPa (4710 lb/in²), contained plus 76-mm (3-in) aggregate, several pieces of which were on the outside of the core where they induced stress concentrations.

The 16 compressive strength specimens from interior concrete averaged 34.2 MPa (4955 lb/in^2). They ranged from 25.2 MPa (3660 lb/in^2) to 39.2 MPa (5680 lb/in^2). The specimen that failed at 25.2 MPa (3660 lb/in^2) had a large, 150-mm (6-in), piece of aggregate on the surface, which probably precipitated the failure. The coefficient of variation was 8.7 percent. There was a 2.2 MPa (155 lb/in^2) strength gain between the 1-year-old and the 10-year-old samples of interior concrete (See table 4 and fig. 1). This may indicate that hydration and strength gain are continuing in the lower strength mixtures where moisture and temperature variation are small. The coefficient of variation at 10 years is half that of the 6-month and 1-year test results for both the interior and the exterior mixes.

The small variation in density may indicate that there is very little variation in the uniformity or quality of the concrete from various locations. The variation in strengths seems to be related to the size and distribution of aggregate within the various cores. Low breaks are often caused by large aggregates on the outside of the core "popping out," resulting in a reduced cross-section and early failure. This phenomenon can be observed in some of the failure photographs (See app. D).

Elastic Properties

The results of the tests on elastic properties are summarized in table 3. The modulus of elasticity for the exterior concrete ranged from 37.3 GPa (5.40 x 10^6 lb/in^2) to 46.2 GPa (6.70 x 10^6 lb/in^2), with an average of 41.6 GPa (6.06 x 10^6 lb/in^2). This is an increase from the 35.7 GPa (5.18 x 10^6 lb/in^2) modulus of elasticity measured at 1 year. The modulus of elasticity for interior concrete ranged from 30.7 GPa (4.45 x 10^6 lb/in^2) to 49.0 GPa (7.10 x 10^6 lb/in^2), with an average of 38.8 GPa (5.62 x 10^6 lb/in^2). This is an increase from the overall average of 35.7 GPa (5.18 x 10^6 lb/in^2) measured at 1 year.

The Poisson's ratio averaged 0.16 for the exterior concrete and 0.18 for the interior concrete. This is a decrease from the 0.19 overall average at 1 year.

Tensile Strength

The results of the individual direct tensile strength tests are listed in table C1 and summarized in table 3. No specimens from the exterior concrete were tested in tension because there were no suitable jointed specimens. Six specimens from interior concrete were tested. The two jointed specimens averaged 0.36 MPa (53 lb/in^2) tensile strength. The four unjointed specimens averaged

1.1 MPa (170 lb/in^2) tensile strength. This average includes core No. 113-1-3, which broke at 0.55 MPa (80 lb/in^2), probably because of a piece of weathered aggregate and a large piece of aggregate in the failure section (See photograph in app. D).

The average 10-year tensile strengths of the unjointed specimens was 3.4 percent of the average 10-year compressive strength. If the low break were not included, it would have been 4.0 percent greater than the 3.7-percent average at 1 year and comparable to other results for mass concrete. Most of the specimens, including the two jointed specimens, broke in the lower third. Both jointed specimens broke at the joints, which were in the lower third. As expected, the strength was inversely proportional to the amount of aggregate disbonding.

The few results obtained indicate that the bond strength of the joints is less than the tensile strength. This is contrary to the 1-year results.

Petrographic

Concrete specimens from two interior cores and two exterior cores were examined petrographically. The concrete was found to be of good quality with no evidence of chemical attack, alkali silica reaction, or deterioration from cyclic freezing and thawing (See app. E).

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APPENDIX A

CONCRETE CORE PHOTOGRAPHS

Figure A1. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. WDB-1

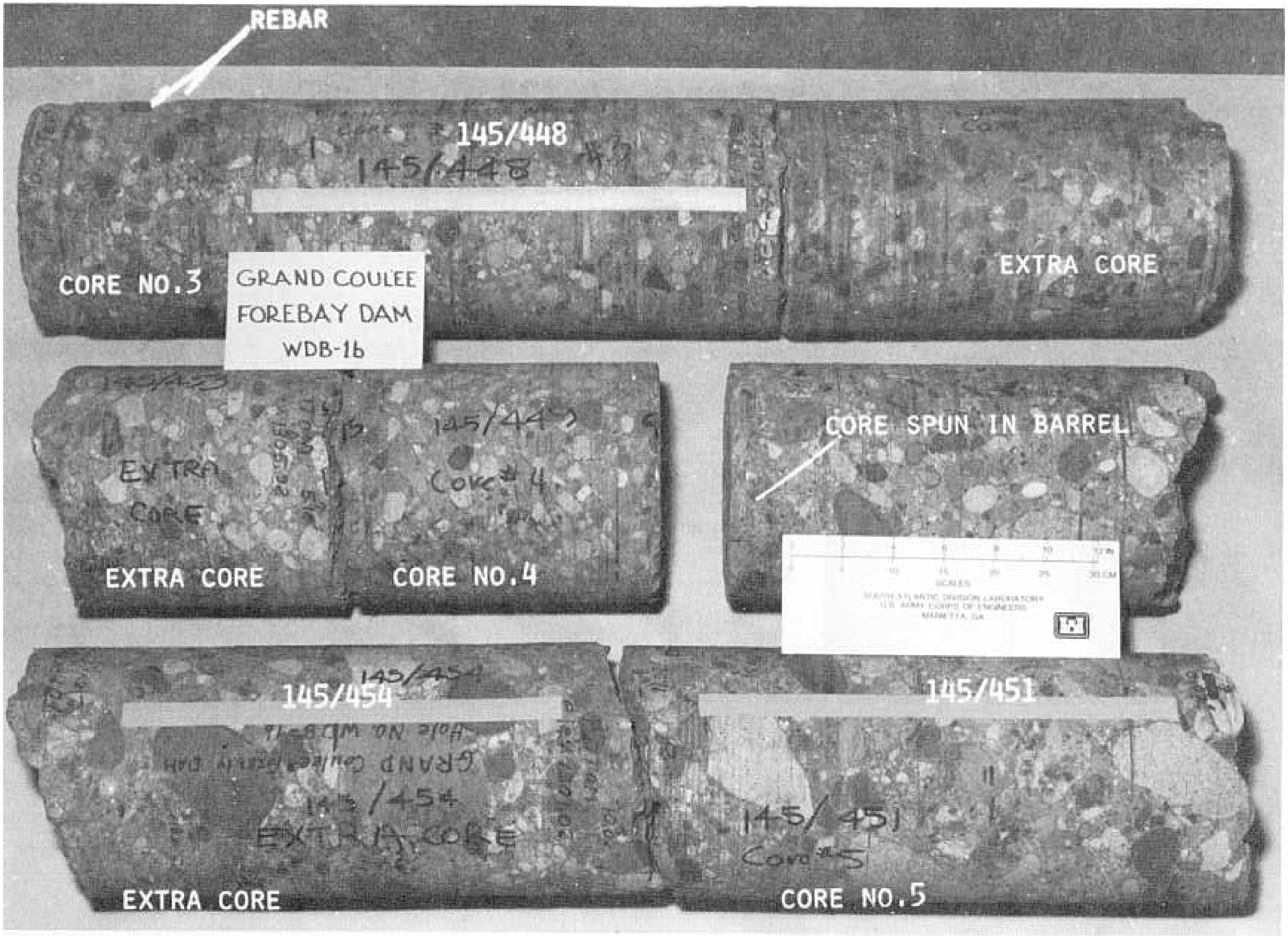
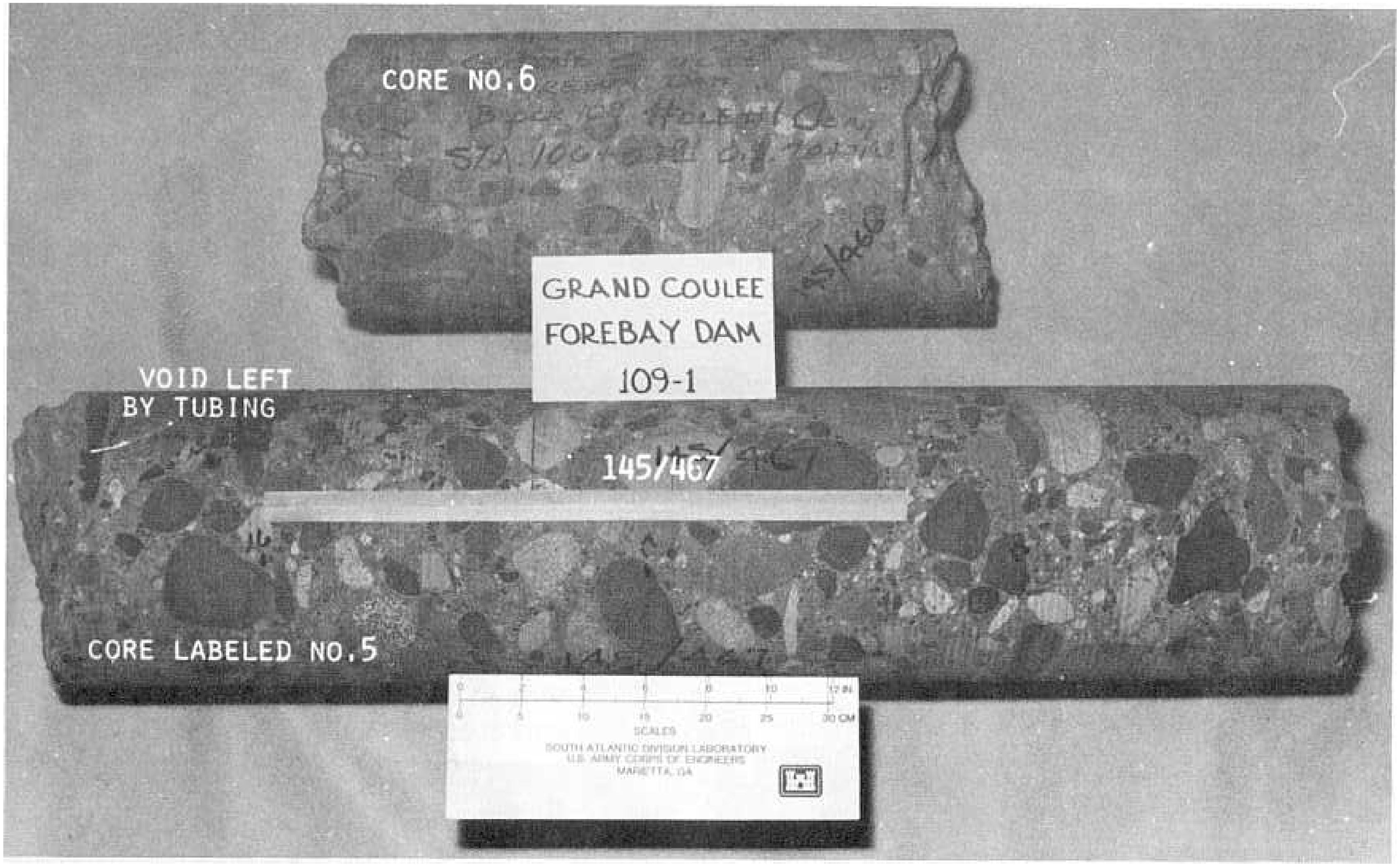


Figure A2. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. WDB-lb.

Figure A3. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. 100-1a.

Figure Forebay 0-in) diameter cores from hole No.

Figure A5. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. 109-1.



Figur ebay Dam. 250-mm (10-in) diameter cores from hole No. 109.

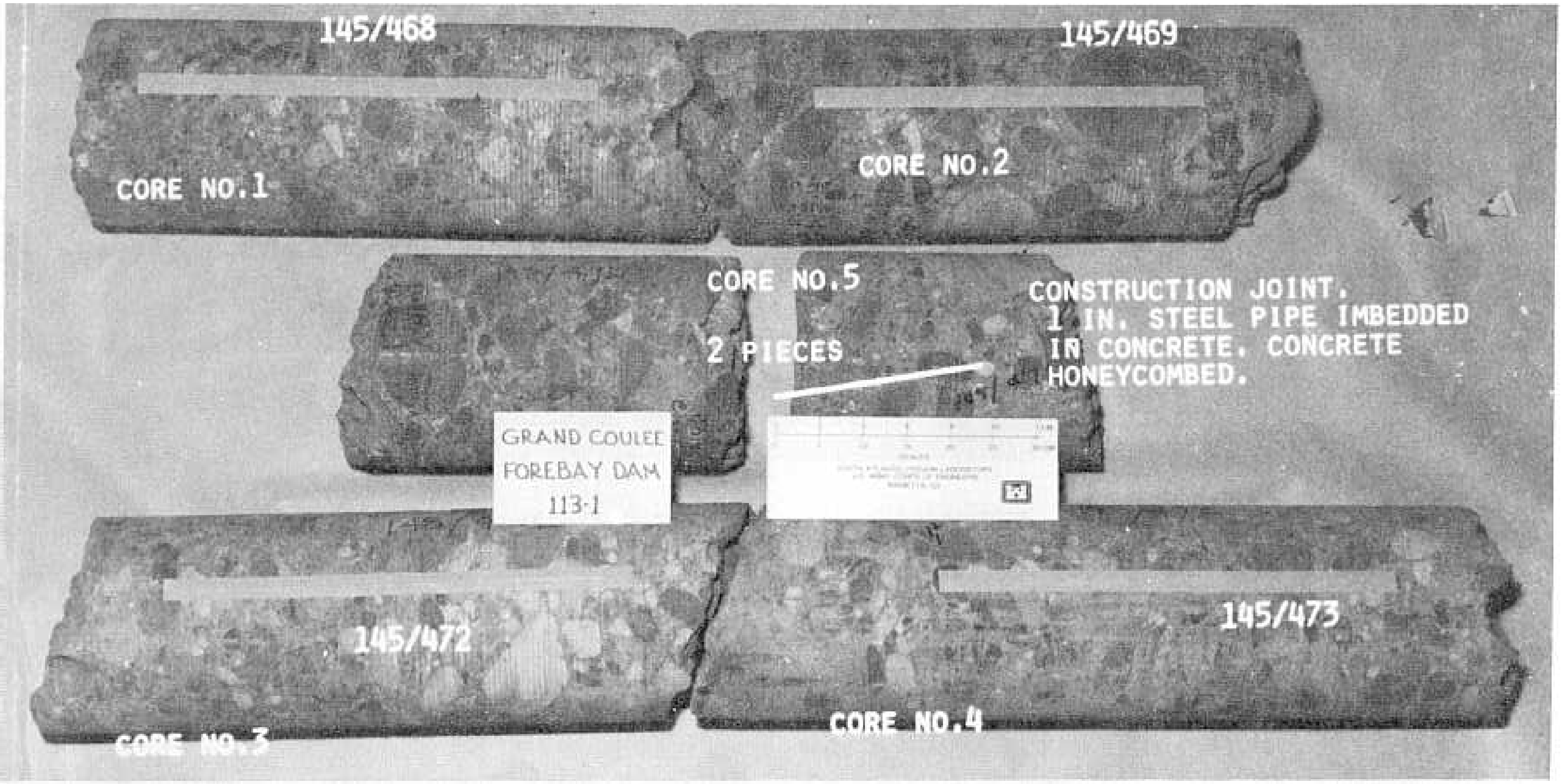


Figure A7. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. 113-1.

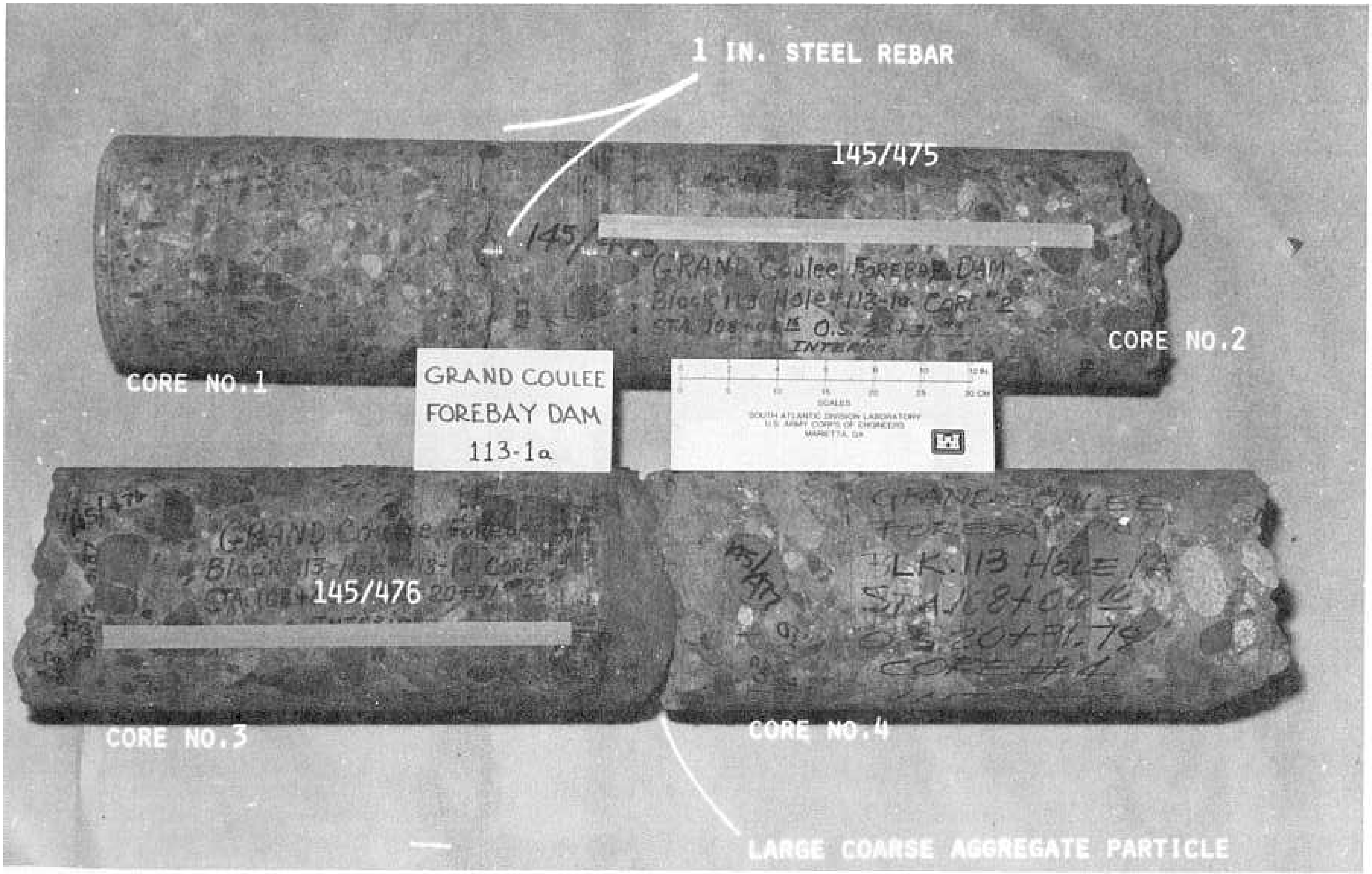


Figure A8. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. 113-1a.

Figure Grand Coulee Forebay 0-in) om hole No.

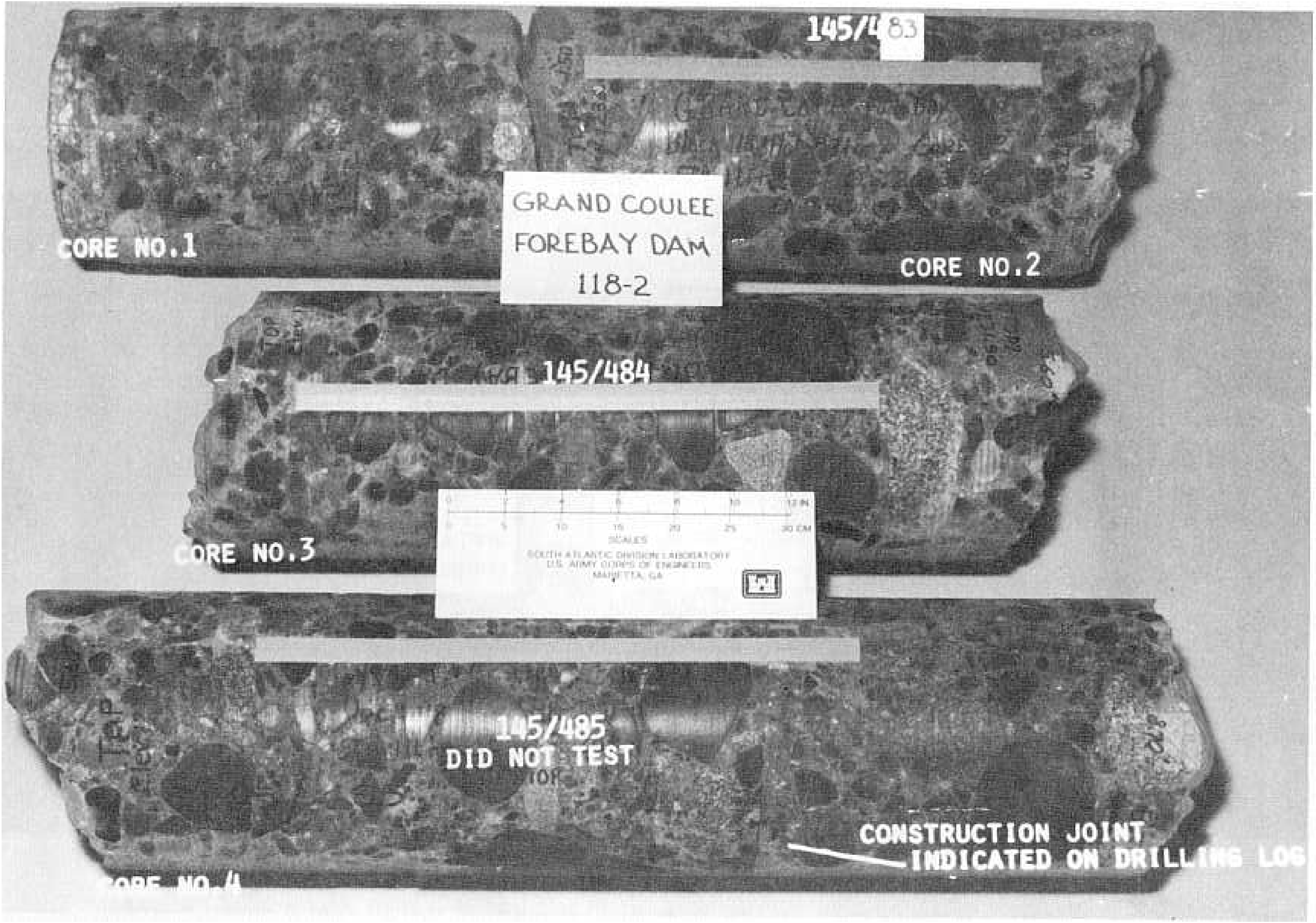


Figure A10. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. 18-2.

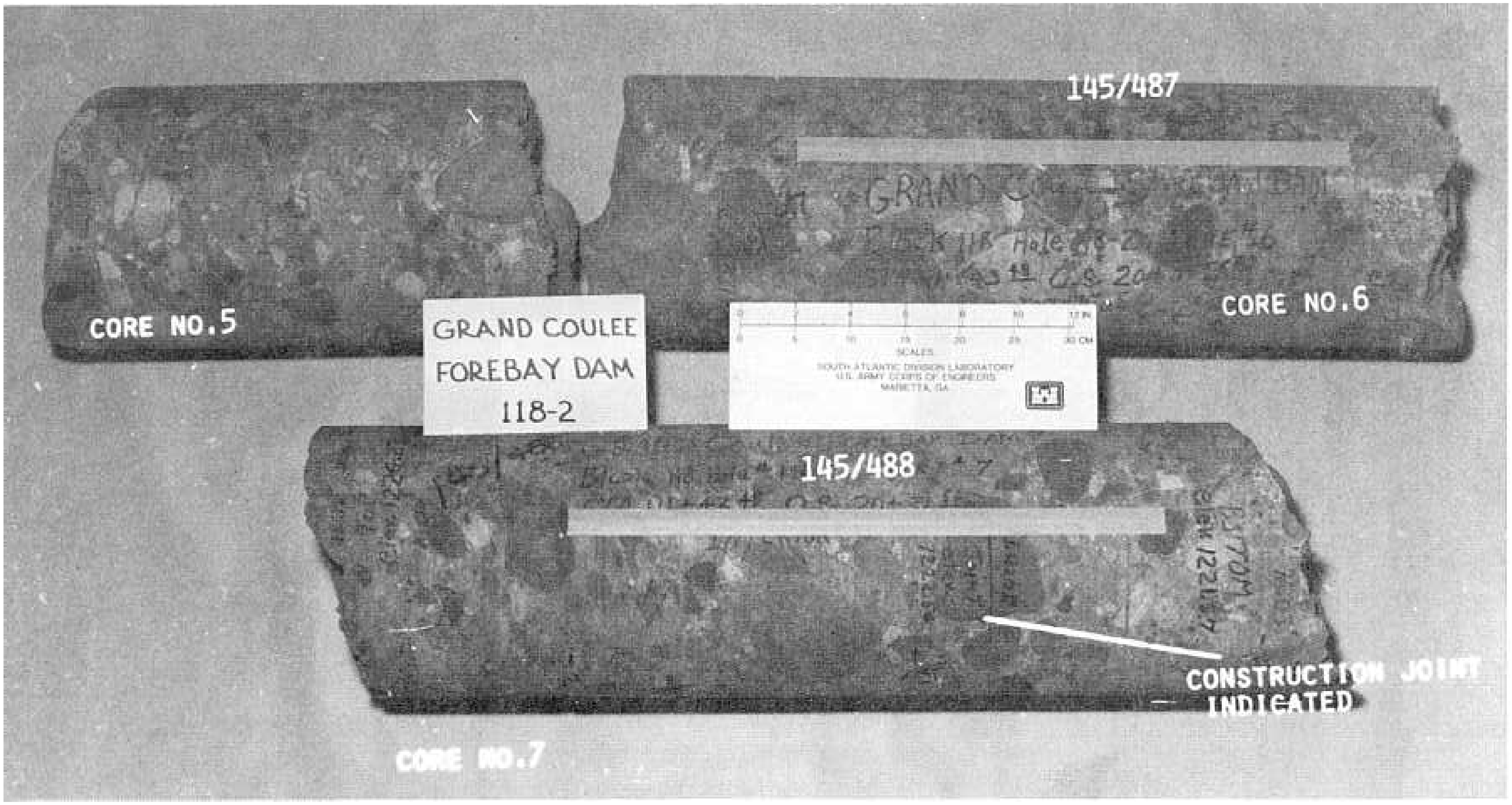


Figure A11. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. 118-2.

Forebay Dam. 250-mm 0 in) diameter cores from hole No.

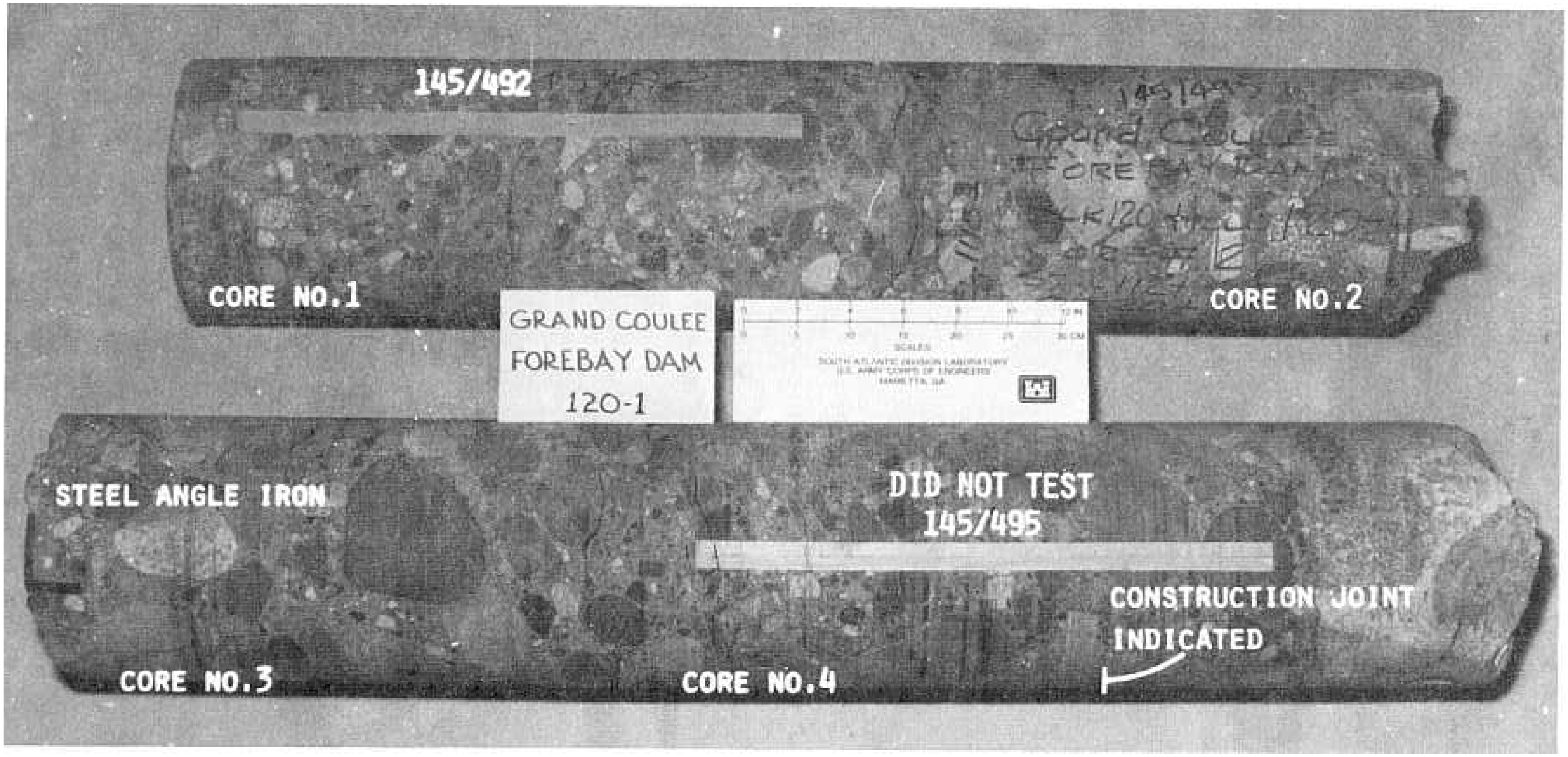


Figure A13. – Grand Coulee Forebay Dam. 250-mm (10-in) diameter cores from hole No. 120-1.

APPENDIX B

CONCRETE CORE LOGS

Hole No. WDB-1

DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 1 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta. 112 +24.92, Offset Sta. 19+44.57
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) WDB-1
5. ~~NAME OF DRILLER~~ ~~xxxxxxxxxx~~ Type of Concrete: Exterior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 14.80 ft.
10. SIZE AND TYPE OF BIT 10 in.
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6-3-82 COMPLETED 6-7-82
17. ELEVATION TOP OF HOLE 1311.0
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
						Top of Boring
1303.0	8.0					Drilling Record (ft.)
			Concrete is fresh, sound, and well consolidated. 6-in max. size well rounded aggregate. Few trapped air Voids. No obvious reaction of any kind. Rims on some particles but appears to be weathering.		Core No.1	
						9.2
					145/446	Compression
						10.9
1299.7	11.3					d.11.3
					Core No. 2	
						12.9
					145/447	Compression
						14.6
1296.2	14.8					d.14.80
			Contractor Drilling Record Incomplete			Bottom of Boring

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam | HOLE NO. WDB-1

Hole No. WDB-1b

DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 2 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta 112+42.92, Offset 19+36.57 (ext.)
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) WDB-1b
5. NAXXXXXXXXX Type of Concrete: Exterior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 13.33
10. SIZE AND TYPE OF BIT 10 in.
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6-9-82 COMPLETED 6-10-82
17. ELEVATION TOP OF HOLE 1311.00
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
						Drilling Record (ft.) Top of Boring
1311.00	0.0		Rebar Concrete is fresh, sound and well consolidated. Max. size 1½" down to about 6.0 ft. Aggregate particles mostly well rounded. Cement paste gray, no visible reaction products. No excessive voids.		Core No.3 145/448	0.8 Compression
1308.42	2.58				Core 145/452	d.2.58 2.5
1306.87	4.13		d.4.13 Break in Core		Extra 145/453	
1305.92	5.18		d.5.18 Break in Core		145/449	d.5.18 pulled bottom
1305.0	6.0		d.6.0, joint, open. Core spun in barrel. Apparent loss of core based on depths marked on core.		Core No. 4	
1304.5	6.5				145/450	
1302.98	8.02					d.8.02 Bottom of Run 8.3
						Log continued

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam

HOLE NO. WDB-1b

DRILLING LOG (Cont Sheet)	ELEVATION TOP OF HOLE 1311.00	Hole No. WDB-1b
PROJECT Grand Coulee Forebay Dam	INSTALLATION Bureau of Reclamation	SHEET 2 OF 2 SHEETS

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1302.5	8.5					Continuation
					Extra Core 145/454	Compression 9.7 d.10.02
1300.98	10.02 *				Core No. 5 145/451	10.1 Compression 11.6 d.11.9
1299.1	11.9 **		d.11.9" to 13.33" missing			Bottom of Core
1297.67	13.33					d.13.33
			*Note: Drill record shows d.11.02', core labeled 10.02' on "extra core" but 11.02' on core #5—measurement indicates that correct depth is 10.02 ft. ** Labeled 13.33' in drill record-13.03' on core, 11.9' measured.			Depth drilled into rock

Hole No. 100-1a

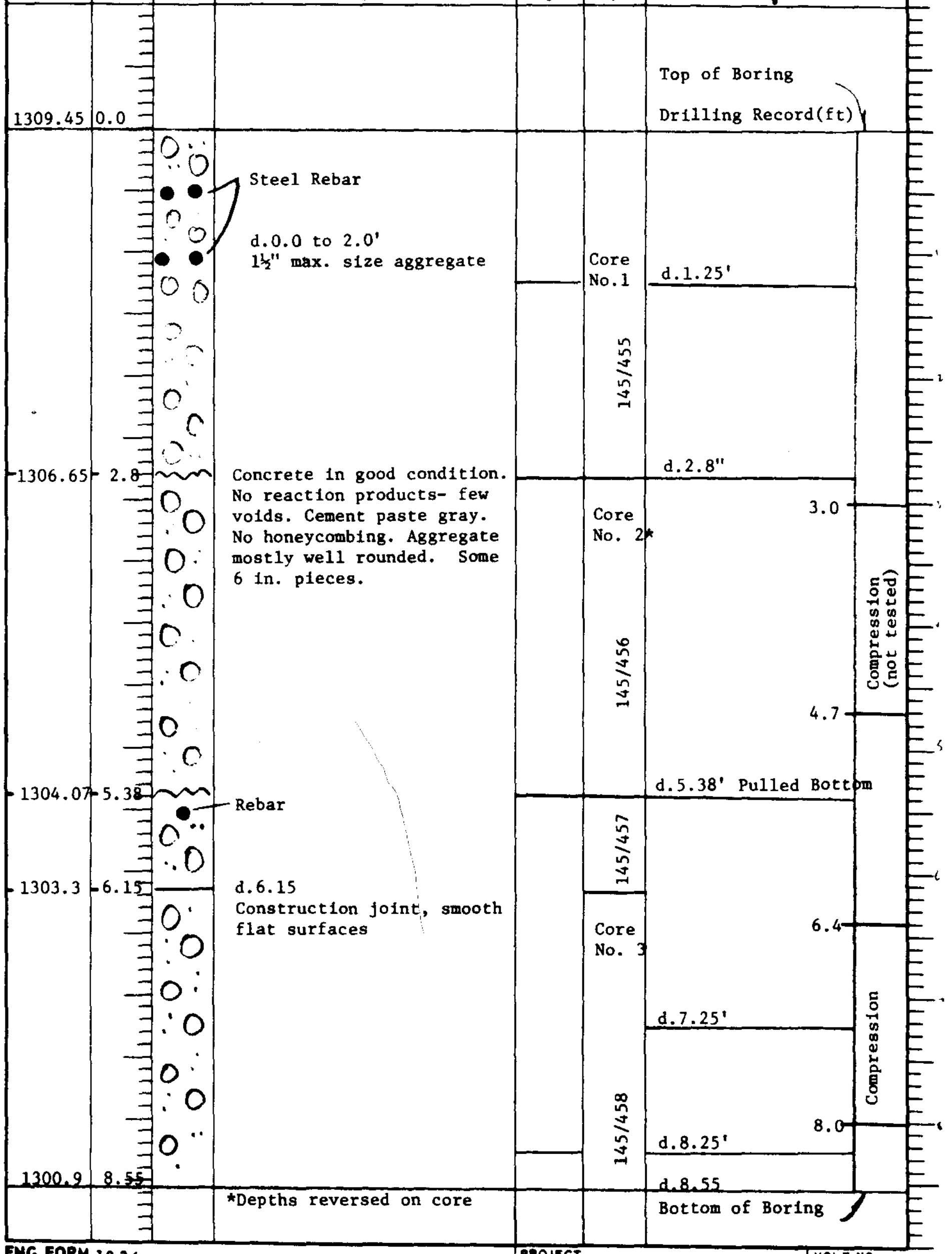
DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 1 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta 101+-9, Offset 20+26.31
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 100 Hole 100-1a
5. ~~NAME OF DRILLER~~ Type of Concrete: Exteriod
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 8.55 ft.
10. SIZE AND TYPE OF BIT 10 in
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6/11/82 COMPLETED 6/16/82
17. ELEVATION TOP OF HOLE 1309.45 ft.
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR



ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
						Top of Boring Drilling Record(ft)
1309.45	0.0		Steel Rebar d.0.0 to 2.0' 1½" max. size aggregate		Core No.1	d.1.25'
					145/455	
1306.65	2.8		Concrete in good condition. No reaction products- few voids. Cement paste gray. No honeycombing. Aggregate mostly well rounded. Some 6 in. pieces.			d.2.8"
					Core No. 2*	3.0 Compression (not tested)
					145/456	4.7
1304.07	5.38		Rebar			d.5.38' Pulled Bottom
					145/457	
1303.3	6.15		d.6.15 Construction joint, smooth flat surfaces			
					Core No. 3	6.4 d.7.25' Compression
					145/458	8.0 d.8.25'
1300.9	8.55					d.8.55
			*Depths reversed on core			Bottom of Boring

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam HOLE NO. 100-1a

Hole No. 106-1

DRILLING LOG	DIVISION	INSTALLATION Bureau of Reclamation	SHEET 1 OF 1 SHEETS

1. PROJECT Grand Coulee Forebay Dam

2. LOCATION *(Coordinates or Station)* Sta. 103+97.61, Offset 20+77.5

3. DRILLING AGENCY Contract

4. HOLE NO. *(As shown on drawing title and file number)* Block 106 Hole 106-1

5. Type of Concrete: Interior

6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.

7. THICKNESS OF OVERBURDEN

8. DEPTH DRILLED INTO ROCK

9. TOTAL DEPTH OF HOLE 9.0 ft.

10. SIZE AND TYPE OF BIT 10-in

11. ~~DATUM FOR ELEVATION SHOWN (TBM or MSL)~~

12. MANUFACTURER'S DESIGNATION OF DRILL

13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED

14. TOTAL NUMBER CORE BOXES

15. ELEVATION GROUND WATER

16. DATE HOLE | STARTED 7/8/82 | COMPLETED 7/8/82

17. ELEVATION TOP OF HOLE 1117.5

18. TOTAL CORE RECOVERY FOR BORING %

19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
1117.5	0.0					Drilling Record (ft.) Top of Boring
			0.0 to 1.7 ft. 1½" max. size of coarse aggregate Concrete Sound. Cement paste gray. Few voids. No reactions noted. Aggregate predominantly well rounded with smooth surfaces.		Core No. 2 145/459	
1114.75	2.75					d.3.0
			d.2.75' & 5.25' Breaks in Core		Core No. 2 145/460	3.4 Compression 5.0
1112.25	5.25		1/2" voids			
						d.6.0
			Construction joint indicated on drill record at about 7 ft. Joint not distinguishable on core.		145/461	Tension 7.7
1109.35	8.15					d.8.15 Bottom of Core
1108.5	9.0					9.0 Bottom of Hole

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE.

(TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam | HOLE NO. 106-1

Hole No. 109-1

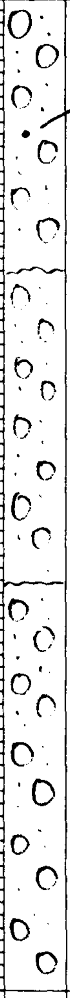
DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 2 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta 106+ 07.91, Offset 20+31.63
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 109 109-1
5. ~~NAME OF DRILLER~~ Type of Concrete: Interior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 19.0 ft.
10. SIZE AND TYPE OF BIT 10 in.
11. ~~DATUM FOR ELEVATION SHOWN (TBM or MSL)~~
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6/18/82 COMPLETED 6/21/82
17. ELEVATION TOP OF HOLE 1237.5
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1237.5	0.0					Drilling Record (ft.) Top of Boring
			0.0-1.2' 1½" Max. size aggregate Rebar Fresh sound concrete,well consolidated. Cement paste is gray. Few trapped air voids. Aggregate maximum size is 6 in, generally smooth surfaces, few somewhat flat pieces.		CORE No. 1 145/462	
1335.25	2.25				Core No. 2 145/463	2.5 d.2.83' Compression 4.2
1232.8	4.7				Core No. 3 145/464	d.5.0' d.6.33 6.2
1230.5	7.0		d.7.0 No visible construction joint.			Tension 7.9

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT)

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PROJECT Grand Coulee Forebay Dam

HOLE NO. 109-1

DRILLING LOG (Cont Sheet)

ELEVATION TOP OF HOLE

Hole No. 109-1

PROJECT: Grand Coulee Forebay Dam

INSTALLATION: Bureau of Reclamation

SHEET 2 OF 2 SHEETS

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1228.80	8.70					
					Core No. 4	d.9.00' 9.0
					145/465	Tension
			void ½"			11.0
						d.11.50'
1226.00	11.50	No Core			No Core	
1224.00	13.5		NOTE: Elevation marking 1224.00 was the only depth control on core to bottom of hole		Core No. 6	d.14.00
					145/466	d.15.10
1222.0	15.50		Void left by Tubing		Core Labeled No. 5*	16.0
						d.16.50
						*Labeled No. 5 on core Out of proper Position Compression
						17.7
					145/467	
1218.5	19.00					d.19.00' Bottom of Boring

ENG FORM 1836-A JUN 67

GPO: 1966 OF—229-249

PROJECT: Grand Coulee Forebay Dam

HOLE NO. 109-1

Hole No. 113-1

DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 2 SHEETS

1. PROJECT GRAND COULEE FOREBAY DAM
2. LOCATION (Coordinates or Station) Sta 108+04.16, Offset 20 + 31.79
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 113 Hole 113-1
5. NAME OF DRILLER Type of Concrete: Interior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 17.17 ft.
10. SIZE AND TYPE OF BIT 10 in.
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6-22-82 COMPLETED 6-23-82
17. ELEVATION TOP OF HOLE 1237.5
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g		
1237.5	0.0					Drilling Record (ft.) Top of Boring		0
1236.15	1.35		d. 0.0' - 1.35' Core Missing			d. 1.35 Top of Core		1
1233.8	3.7		3/4 in. air void loose 6 in. aggregate		CORE NO.1* 145/468	1.7 * labeled #2 on core 3.4 d. 3.7	Compression	2 3
1231.65	5.85		Concrete is fresh, sound and well consolidated. Max. aggregate size is 6 in. Particles are typically well rounded with smooth surfaces. Paste is gray and contains a few voids. Some rimming on coarse aggregate but appears to be weathering.		CORE NO.2 145/469	4.2 d. 5.85 5.7	Compression	4 5
1230.35	7.15		d. 5.85' to 7.15' Numerous small air voids 1/16" and smaller		145/469 CORE NO.5 2 pcs			6 7
1229.3	8.2		d. 7.15 Construction joint, open. Core spun in barrel. 1 in. steel inbedded in concrete. Honeycombed in area.		145/471			8
1228.5	9.0		d. 8.2 Break in core.			d. 9.0		
						Continued		

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT GRAND COULEE FOREBAY DAM

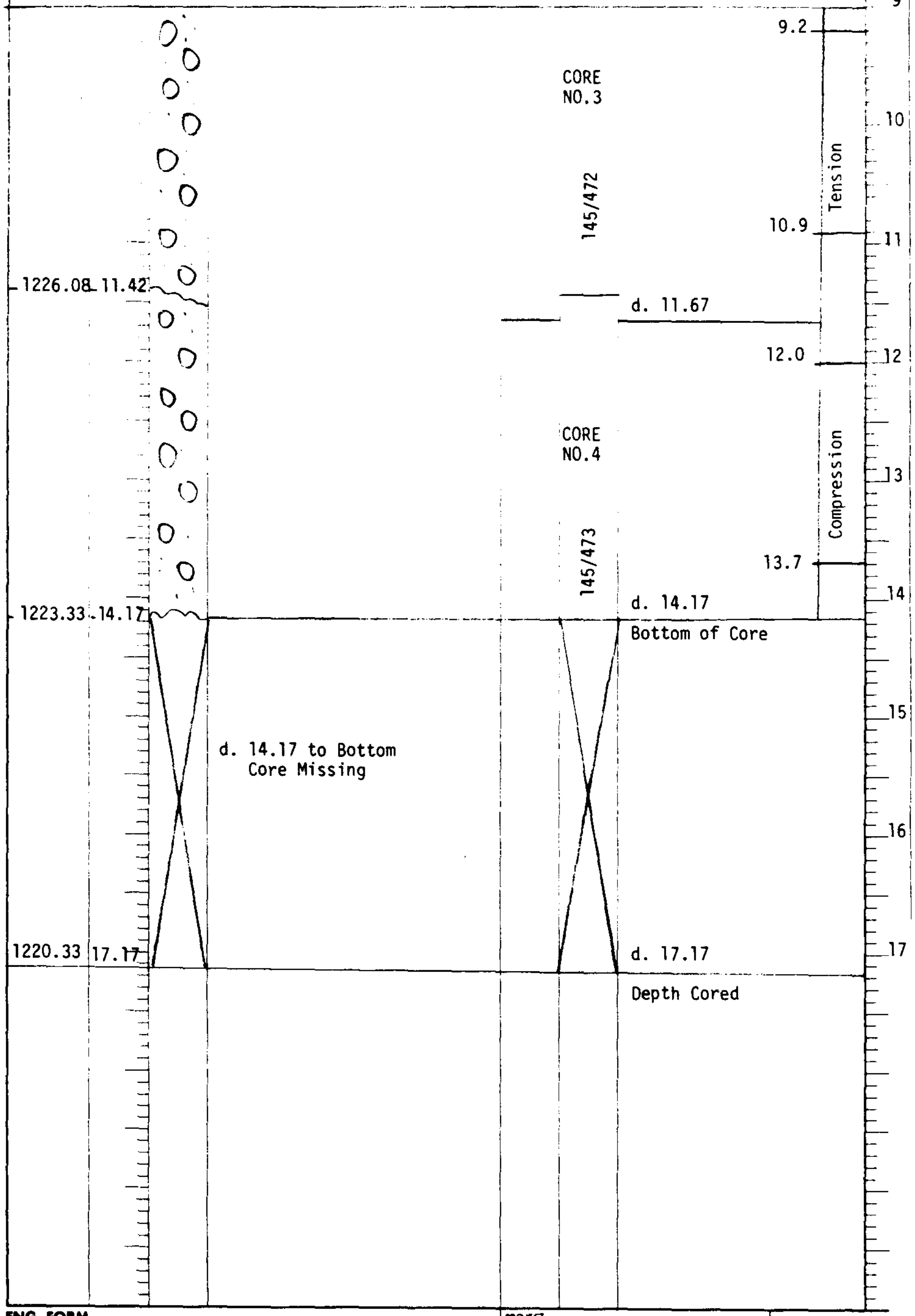
HOLE NO. 113-1

DRILLING LOG (Cont Sheet) ELEVATION TOP OF HOLE 1237.5 **Hole No.** 113-1

PROJECT GRAND COULEE FOREBAY DAM
INSTALLATION Bureau of Reclamation
SHEET 2 OF 2 SHEETS

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g

Con't from sheet 1



1226.08 11.42
1223.33 14.17
1220.33 17.17

d. 14.17 to Bottom
Core Missing

CORE NO.3
145/472

CORE NO.4
145/473

d. 11.67
d. 14.17
Bottom of Core
d. 17.17
Depth Cored

ENG FORM 1836-A JUN 67
GPO. 1969 OF—325-243
PROJECT GRAND COULEE FOREBAY DAM
HOLE NO. 113-1

Hole No. 113-1a

DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 1 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta 108+ 06.14, offset 20+31.79
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 113 Hole No. 113-1a
5. Type of Concrete: Interior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 9.0 ft
10. SIZE AND TYPE OF BIT 10 in.
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6/23/82 COMPLETED 6/23/82
17. ELEVATION TOP OF HOLE 1237.5
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1237.5	0.0					Drilling Record (ft.) Top of Boring
			0.0 to 1.5 ft. 1½ in. max. agg. size		Core No.1 145/474	
1236.17	1.33		Steel Rebar 1"(2) Concrete is fresh, sound and well consolidated. Few trapped air voids. No visible reaction products. Few rimmed coarse aggregate particles - appears to be weathering. Coarse aggregate well rounded with smooth surfaces. Cement paste gray.			d.1.50
					Core No. 2 145/475	1.7 Compression 3.4
1233.9	3.60					
					Core No. 3 145/476	d.4.0 3.9 Compression 5.4
1231.87	5.63		Large aggregate (6 in.)			
					Core No. 4 145/477	d.6.5
1230.0	7.5		d.7.5 Construction joint indicated on drilling record.			
1229.87	7.63		d.7.63 to 9.0 ft. Core missing (Left in Hole)			d.7.63 Bottom of Core
1228.5	9.0					Bottom of Hole

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam | HOLE NO. 113-1a

Hole No. 116-1

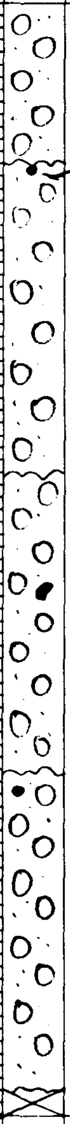
DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 1 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta 110+01.88, Offset 20 + 18.60
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 116 Hole no. 116-1
5. Type of Concrete: Interior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 9.0 ft.
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6/29/82 COMPLETED 7/2/82
17. ELEVATION TOP OF HOLE 1297.5
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR



ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1297.5	0.0					Drilling Record (ft.) Top of Core 0
			0.0 to 1.5 ft. 1½ in. max. size aggregate		Core No. 1 145/478	1
1296.17	1.33		Rebar			d.1.5
					Core No. 2 145/479	1.7 2 Compression 3 3.4
1293.67	3.83		Concrete generally well consolidated, fresh, sound. 6 in. max. size aggregate. Typically well rounded with smooth surfaces. Cement paste is gray, few scattered air voids, no noticeable reaction products or void filling material.			d.4.0 4
			d.4.7 ft. 1½ in. air void		Core No. 3 145/480	4.2 5 Compression 5.85 6
1291.25	6.25		½" void			d.6.5 6.5
			No visible construction Joint at 7.0"		Core No. 4 145/481	7 Tension 8 8.2
1288.7	8.8		Bottom of Core actually 8.8 ft.			
1288.5	9.0					d.9.0 Bottom of Hole

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE.

(TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam

HOLE NO. 116-1

Hole No. 118-2

DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 2 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta 111+43.48, Offset 20 +31.56
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 118 Hole No. 118-2
5. NAME OF DRILLER Type of Concrete: Interior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 16.03 ft.
10. SIZE AND TYPE OF BIT 10 in.
11. ~~DATUM FOR ELEVATION SHOWN (TBM or MSL)~~
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 6/24/82 COMPLETED 6/28/82
17. ELEVATION TOP OF HOLE 1237.5
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1237.5	0.0					Drilling Record (ft.) Top of core
			12 in. long tight fracture. Top 1.5' has 1½" max. size stone		Core No. 1 145/482	d.1.5
1236.0	1.5		Cement paste is gray, good condition. Concrete well consolidated, no visible reaction products although there are a few rimmed (weathering) coarse aggregate particles. Max. agg. size is 6 in. NOTE: Drilling record incomplete below d.10.0		Core No.2 145/483	1.6 Compression 3.0
1234.3	3.2				Core No. 3	3.4 d.4.0
					145/484	Compression 5.1
1231.9	5.6				Core No. 4	d.6.5
			d.7.0 Construction joint indicated in drilling record.		145/485	
1230.5	7.0					

Continued on Sheet #2

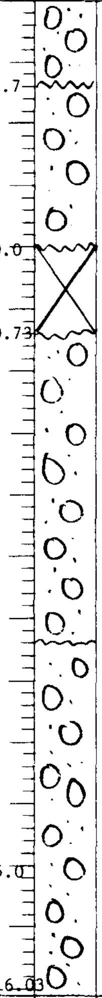
ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam

HOLE NO. 118-2

DRILLING LOG (Cont Sheet) | ELEVATION TOP OF HOLE | **Hole No.** 118-2

PROJECT Grand Coulee Forebay Dam | INSTALLATION Bureau of Reclamation | SHEET 2 OF 2 SHEETS



ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
						Continued
1228.8	8.7					
					Core No. 5	d.9.0
					145/486	
1227.5	10.0		Apparent loss or missing core, ends do not match up			
1226.77	10.73					10.73
					Core No. 6	11.37
					145/487	Tension
						13.0
						d.13.33
					Core No. 7	14.0
						Compression
1222.5	15.0		d.15.0 ft Construction joing indicated on core with marking pen but is not apparent		145/488	
						15.7
1221.47	16.03					d.16.03
						Bottom of Core

ENG FORM JUN 67 **1836-A** GPO: 1969 OF—329 243 PROJECT Grand Coulee Forebay Dam HOLE NO. 118-2

Hole No. 119-2

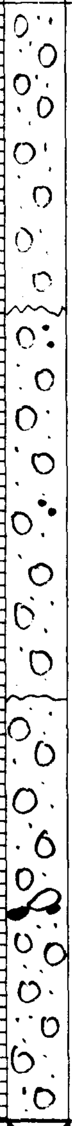
DRILLING LOG

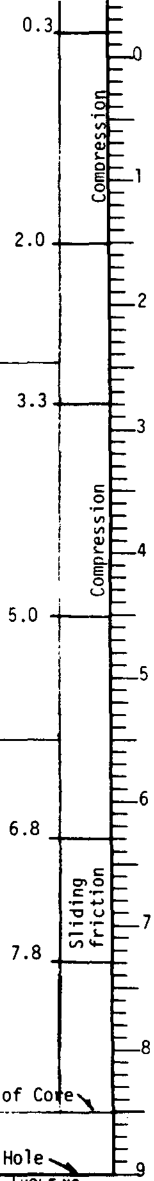
DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF SHEETS

1. PROJECT GRAND COULEE FOREBAY DAM
2. LOCATION (Coordinates or Station) STA. 111+89.88, OFFSET 21+04.98
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 119 Hole No. 119-2
5. NAME OF DRILLER Type of Concrete: Interior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 9.0 ft.
10. SIZE AND TYPE OF BIT 10 inch
11. ~~DATUM FOR ELEVATION SHOWN (TBM or MSL)~~
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 7-7-82 COMPLETED 7-7-82
17. ELEVATION TOP OF HOLE 1155.0
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1155.0	0.0					Drilling Record (ft.) Top of Core
			0.0' to 1.5' Max. coarse agg. size 1½ in. Sound, well consolidated concrete. Cement paste is gray. Well rounded coarse aggregate particles with smooth surfaces. No visible reaction products or evidence of concrete deterioration.		CORE NO.1 145/489	
1125.50	2.5		-1/2 in. voids			d. 3.0
			- 1/2 in. voids		CORE NO.2 145/490	
1149.40	5.6					d. 6.0
					CORE No. 3 145/491	
1147.7	7.3		d. 7.3 Large trapped air voids at bottom of large coarse aggregate particle.			
1146.4	8.6					d. 8.6 Bottom of Core
1146.0	9.0		Left 0.4' in Hole			9.0 Bottom of Hole



ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE.

(TRANSLUCENT)

PROJECT GRAND COULEE FOREBAY DAM

HOLE NO. 119-2

Hole No. 120-1

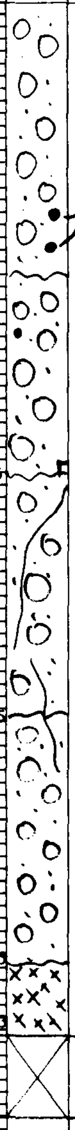
DRILLING LOG

DIVISION

INSTALLATION Bureau of Reclamation

SHEET 1 OF 1 SHEETS

1. PROJECT Grand Coulee Forebay Dam
2. LOCATION (Coordinates or Station) Sta112+40.36, Offset 20+20.33
3. DRILLING AGENCY Contract
4. HOLE NO. (As shown on drawing title and file number) Block 120 Hole No. 120-1
5. Type of Concrete: Interior
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE 9.0
10. SIZE AND TYPE OF BIT 10 in.
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 7/6/82 COMPLETED 7/7/82
17. ELEVATION TOP OF HOLE 1117.5
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1117.5	0.0					Drilling Record (ft.) Top of Core
1115.3	2.2		0.0 to 1.5 Ft. Max. size coarse aggregate is 1½ in. 1/2 in air voids Well consolidated, fresh, sound concrete. Cement paste is gray. No visible reaction products or alteration. 6-in. max. size aggregate. Particle shape typically well rounded with smooth surface.		Core No. 1 145/492	0.2 Compression 1.9
1113.65	3.85		d.3.85 Construction joint. Steel angle iron (1-3/4 x 1-3/4") inbedded in concrete. No honeycombing.		Core No. 2 145/493	d.3.0
1111.75	5.75		d.3.85 to 5.75 Several tight fractures in this area. Concrete broke around aggregate		Core No. 3 145/494	d.5.75
1110.4	7.1		d.7.1 Construction joint indicated in drilling record. No visible evidence in core.		Core No. 4 145/495	5.9 Tension (Did not test) 7.5
1109.75	7.75		d.7.75. Top of bedrock according to drilling record.			
1109.17	8.33					8.33 Bottom of Core
1108.5	9.0					d.9.0 Bottom of Hole

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Grand Coulee Forebay Dam

HOLE NO. 120-1

APPENDIX C

PHYSICAL TEST RESULTS

TABLE C1

SUMMARY OF RESULTS OBTAINED FROM TESTS PERFORMED ON 10-INCH-DIAMETER CONCRETE CORES

(INTERIOR AND EXTERIOR) AT 10 YEARS OF AGE

GRAND COULEE FOREBAY DAM

CORE NO. 1	Sta. No.	Off-Set	Elevation Top of Hole (ft)	Location in Dam	Lift in Block	Date Drilled	Depth of Core (ft)	Joint Elev.	Condition of Concrete in Core	Properties of Fresh Concrete					PROPERTIES OF HARDENED CONCRETE												SAD Lab No.	Remarks
															CONTROL CYLINDERS					CONCRETE CORES								
										Max. Size Aggr. (in.)	Sand (%)	Cement/Pozzolan lb/yd³	WATER CONTENT (lb/yd³)	Air Content (%)	DENSITY (lb/yd³)	COMPRESSIVE STRENGTH (lb/in²)				COMPRESSIVE STRENGTH (lb/in²)	MODULUS OF ELASTICITY E x 10⁶ (lb/in²)	POISSON'S RATIO	DENSITY (lb/ft³)	Tensile Test				
																28-Day	90-DAY	180-DAY	1-YEAR					Strength lb/in.²	% Area Disbonded	Distance of Break From End in.		
													Exterior Concrete															
WDB-1-1	112+24.92	19+44.57	1311.0	Wing Dam B	1	6-7-82	8.0-11.3	-	Good Concrete	1½	34	361/119	183	4.4	150.5	4350	--	--	--	4830	5.40	.17	160				145/446	
WDB-1-2	"	"	"	"	1	"	11.3-14.8	-	Good Concrete											5390	5.80	.17	158				447	
WDB-1B-3	112+22.92	19+36.57	1311.0	Wing Dam B	1	6-9-82	0.0-2.6	-	Good Concrete	1½	34	361/119	183	4.4	150.5	4350				6665	6.35	.13	151				448	Petro Exam.
WDB-1B-E	"	"	"	"	1	"	2.6-4.1																				452	
WDB-1B-E	"	"	"	"	1	"	4.1-5.2																				453	
WDB-1B-E	"	"	"	"	1	6-10-82	5.2-6.0																				449	
WDB-1B-4	"	"	"	"	1/2	"	6.0-8.0	1304.5	Good Concrete	6	24	223/96	113	3.0	155.3	4245	--	--	--								450	
WDB-1B-E	"	"	"	"	2	"	8.5-10.0		Good Concrete											4710	6.70	.16	158				454	Petro Exam.
WDB-1B-5	"	"	"	"	2	"	10.0-11.9		Good Concrete											5480	6.05	.14	157				451	
100-1a-1	101+09	20+26.31	1309.45	Crest of Dam	1	6-15-82	0.0-2.8	-		1½	33	431/143	201	5.4	149.3	5470	7550	--	--								455	
100-1a-2	101+09	20+26.31	1309.45	Crest of Dam	1	6-15-82	2.8-5.4	-		3	27	280/120	147	3.5	153.4	5110	--	--	--	5955	6.40	.16	155				456	
100-a-2	101+09	20+26.31	1309.45	Crest of Dam	1	6-15-82	5.4-6.2	1303.8																			457	
100-1a-3	101+09	20+26.31	1309.45	Crest of Dam	2	6-16-82	6.2-8.5	-	Good Concrete	3	28	281/122	145	3.3	156.3	5180	6570	7270	8260	4920	5.75	.19	152				458	
													Interior Concrete															
106-1-1	103+97.6	20+77.45	1117.5	Foundation Adit	27A	7-8-82	0.0-2.8	-		6	25	194/83	133	3.5	158.5	3690	--	--	--								459	
106-1-2	103+97.6	20+77.45	1117.5	"	27A	7-8-82	2.8-5.3	-	Good Concrete											5560	7.10	.13	159				460	
106-1-3	103+97.6	20+77.45	1117.5	"	27A/27B	7-8-82	5.3-8.2	1110.5	Const. Joint	6	25	190/82	125	2.5	157.1	2705	4570	--	--				155	60	75	11	461	
109-1-1	106+07.9	20+31.63	1237.5	Inspection Gallery	11	6-18-82	0.0-2.3	-		6	25	185/80	127	3.8	154.8	--	--	6010	--								462	
109-1-2	106+07.9	20+31.63	1237.5	"	11	6-18-82	2.3-4.7	-												5270	5.20	.14	158				463	
109-1-3	106+07.9	20+31.63	1237.5	"	11/12	6-21-82	4.7-8.7	1230.0	Const Joint														161	45	90	2	464	
109-1-4	106+07.9	20+31.63	1237.5	"	12	6-21-82	8.7-11.5	-	Good Concrete	6	26	186/80	123	3.4	155.9	--	--	5770	--				157	140	95	3	465	
109-1-6	106+07.9	20+31.63	1237.5	"	12/13	6-21-82	13.5-15.5	1222.0																			466	
109-1-5	106+07.9	20+31.63	1237.5	"	13	6-21-82	15.5-17.	-	Broke around large piece of Agg.	6	25	185/80	135	3.3	155.3	3165				3660	5.07	.14	156				467	Petro Exam.
113-1-1	108+04.2	20+31.79	1237.5	Inspection Gallery	11	6-22-82	1.4-3.7	-	Mostly minus 1½-in. agg.	6	25	187/81	131	3.9	156.5	3430	--	--	-	4720	4.45	.14	152				468	
113-1-2	"	"	"	"	11	6-22-82	3.7-5.9	-	Good Concrete											4420	4.90	.24	156				469	
113-1-5a	"	"	"	"	11	6-23-82	5.9-7.2																				470	
113-1-5B	"	"	"	"	12	6-23-82	7.2-8.2	1230.2		6	25	183/80	136	3.0	152.2	--	--	5490	--								471	
113-1-3	"	"	"	"	12	6-23-82	8.2-11.4	-	Good Concrete														156	80	80	3 Avg.	472	
113-1-4	"	"	"	"	12	6-23-82	11.4-14.	-	Good Concrete											5020	4.99	.16	155				473	
113-1a-1	108+06.14	20+31.79	1237.5	Inspection Gallery	11	6-23-82	0.0-1.3	-		6	25	187/81	131	3.9	156.5	3430	-	--	--								474	

1.First No. is block number in dam, second is Hole No., third is Core No.
2.All cores drilled vertically.
3.E - Extra (no Core No.).

TABLE C1 (CONTINUED)

SUMMARY OF RESULTS OBTAINED FROM TESTS PERFORMED ON 10-INCH-DIAMETER CONCRETE CORES

(INTERIOR AND EXTERIOR) AT 10 YEARS OF AGE

GRAND COULEE FOREBAY DAM

CORE NO. 1	Sta. No.	Off-Set	Elevation Top of Hole (ft)	Location in Dam	Lift in Block	Date Drilled	Depth of Core (ft)	Joint Elev.	Condition of Concrete in Core	Properties of Fresh Concrete					PROPERTIES OF HARDENED CONCRETE												SAD Lab No.	Remarks
										Max. Size Aggr. (in.)	Sand (%)	Cement/ Pozzolan lb/yd^3	Water Content (lb/yd^3)	Air Content (%)	CONTROL CYLINDERS					CONCRETE CORES								
															Density (lb/yd^3)	COMPRESSIVE STRENGTH (lb/in^2)				COMPRESSIVE STRENGTH (lb/in^2)	MODULUS OF ELASTICITY E X 10^6 (lb/in^2)	POISSON'S RATIO	DENSITY (lb/ft^3)	Tensile Test				
																28-Day	90-DAY	180-DAY	1-YEAR					Strength lb/in.^{2}	% Area Disbonded	Distance of Break From End In.		
113-1a-2	108+06.14	20+31.79	1237.5	Inspection Gallery	11	6-24-82	1.3-3.6	--												5260	4.80	.16	151				145/475	
113-1a-3	"	"	"	"	11	6-24-82	3.6-5.	--	Good Concrete											4470	5.00	.23	156				476	
113-1a-4	108+06.14	20+31.79	1237.5	"	11	6-24-82	5.6-7.6	--																			477	
116-1-1	110+01.88	20+18.60	1297.50	Gate Chamber Gallery	3	6-27-82	0.0-1.	--		6	24	230/97	121	3.0	157.9	4850											478	
116-1-2	"	"		"	3	6-30-82	1.3-3.	--	Broke around large pieces of aggr.											4980	6.72	0.25	157				479	
116-1-3	"	"		"	3	7-1-82	3.8-6.	--	Good Concrete											5540	5.91	0.21	155				480	
116-1-4	"	"		"	3/4	7-2-82	6.3-8.	1290.	Constr. Joint	6	25	189/79	126	3.0	153.9	4110							153	260	50	1.0	481	
118-2-1	111+43.48	20+31.56	1237.5	Inspection Gallery	11	6-24-82	0.0-1.	--		6	25	186/81	127	3.2	154.8	--	--	5280	--								482	
118-2-2	"	"	"	"	11	6-24-82	1.5-3.	--	Good Concrete											4940	6.20	0.22	158				483	
118-2-3	"	"	"	"	11	6-25-82	3.2-5.	--	Good Concrete											5040	5.80	0.11	158				484	
118-2-4	"	"	"	"	11/12	6-25-82	5.6-8.	1230.																			485	
118-2-5	"	"	"	"	12	6-25-82	8.7-10.0	--		6	26	191/82	130	3.1	156.0	--	--	6260									486	
118-2-6	"	"	"	"	12	6-25-82	10.7-13.2	--	Broke at large piece of agg. near bottom														159	200	40	1.0	487	
118-2-7	"	"	"	"	12	6-25-82	13.2-15.0	1222.	large aggregate											5680	6.58	0.22	162				488	Petro Exam.
119-2-1	111+89.88	21+04.97	1155.0	Forebay Dam Downstream Adit	22	7-7-82	0.0-2.5	--	Large aggregate particle near top	6	24	225/94	121	1.9	158.4	4890	6385	7770	8210	4970	5.62	0.21	152				489	
119-2-2	"	"	"	Forebay Dam Downstream Adit	22	7-7-82	2.5-5.6	--	Large aggregate particle near top											4980	5.90	0.20	157				490	
119-2-3	"	"	"	"	22/23	7-7-82	5.6-8.6	1147.		6	24	254/65	125	2.5	154.1	4790	6430	7055	8160				158				491	Returned for Sliding Friction
120-1-1	112+40.36	20+20.33	1117.50	Forebay Dam Drainage Gal-	27	7-6-82	0.0-2.2	--	Mostly Minus 1½-in. aggregate	6	25	189/83	137	2.4	156.4	3450	--	--	--	4790	5.76	0.19	151				492	
120-1-2	"	"	"	lery.	27	7-6-82	2.2-3.9	--																			493	
120-1-3	"	"	"	"	27	7-6-82	3.9-5.8	--																			494	
120-1-4	"	"	"	"	27	7-7-82	5.8-8.3	1110.	Bedrock at bottom of core														157				495	Cracked at joint Returned for Sliding Friction

APPENDIX D

CURSORY PETROGRAPHIC REPORTS

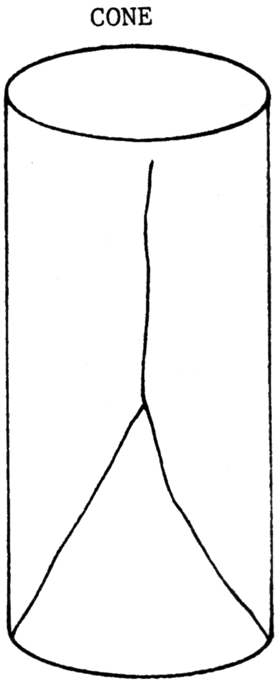
DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

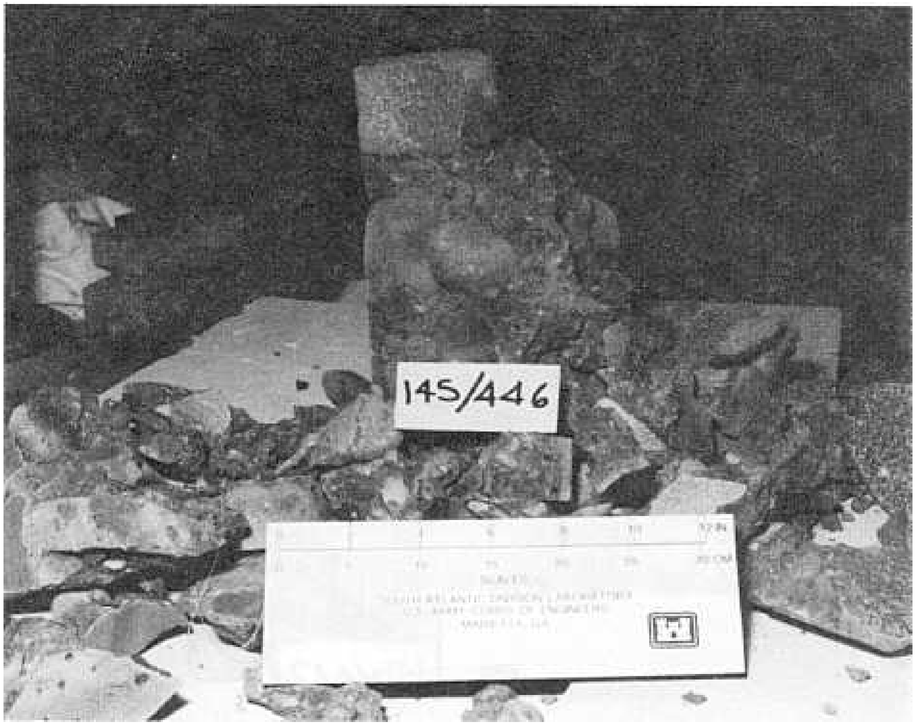
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. WDB-1 Block
TYPE CONCRETE: Exterior
COMPRESSIVE STRENGTH:(PSI) 4830
SAD LABORATORY NO. 145/446
DEPTH (FT.) 9.2 -10.9 Core No. 1

REMARKS:

Explosive break. Broke across large 6 in. aggregate particle (see photograph). Trapped air voids up to 3/8" in. visible in sockets of large aggregate particles. Cement matrix appears normal. No visible reaction products. Bond failure typical around larger coarse aggregate particles, however, many of the smaller coarse aggregate particles broke through. Percent of fractured particles estimated to be between 5-10%. Aggregate particles greater than 3 in. represent about 30% of total area of fracture surface.
Coarse aggregate typically well rounded with smooth surfaces.





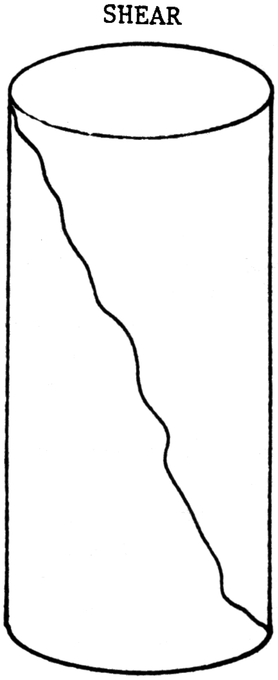
DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. WDB-1 BLOCK
TYPE CONCRETE: Exterior
COMPRESSIVE STRENGTH:(PSI) 5390
SAD LABORATORY NO. 145/447
DEPTH (FT.) 12.9-14.6 CORE NO. 2

REMARKS:

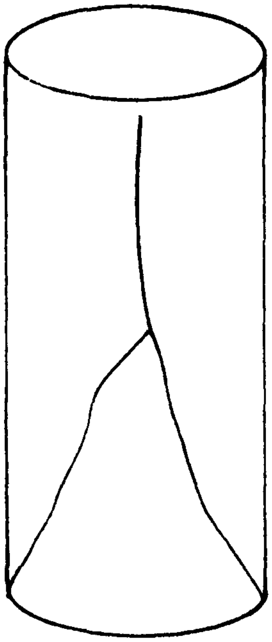
Explosive break. Well consolidated. No honeycombing or excessive trapped air. Cement matrix normal, no visible reaction products or deterioration. 10-15% coarse aggregate particles (1-1½ in.) broke across. 10% of coarse aggregate pieces larger than 3 in. Coarse aggregate typically well rounded with smooth surfaces. Few subangular pieces.



DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO: WDB-1 BLOCK
TYPE CONCRETE: Exterior
COMPRESSIVE STRENGTH (PSI) 6665
SAD LABORATORY NO. 145/448
DEPTH (FT.) 0.8-2.5 CORE NO. 3



CONE

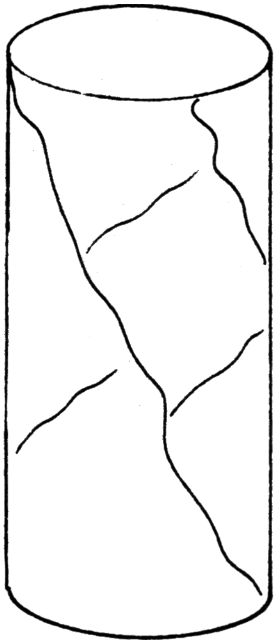
REMARKS:

Explosive break. Relatively good bonding characteristics - abundance of particles broken through (estimate 40%). Few aggregate pieces larger than 1 inch. Cement matrix appears normal - no visible reaction products. No pieces larger than 3 in. Coarse aggregate typically well rounded with smooth surfaces.

DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. WDB-1b BLOCK
TYPE CONCRETE: Exterior
COMPRESSIVE STRENGTH (PSI) 5480
SAD LABORATORY NO. 145/451
DEPTH (FT.) 10.1 - 11.6 CORE NO. 5



SHEAR SPLIT

REMARKS:

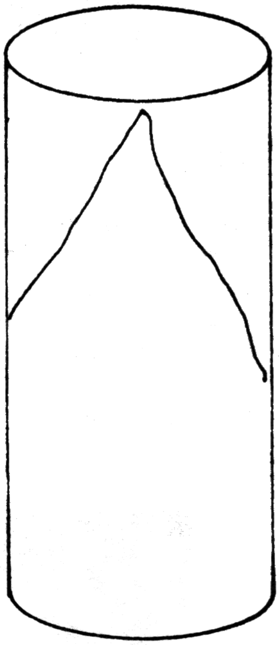
Explosive break. A few large 6 in. pieces. Break occured through a 6 in. quartzite aggregate as well as around other large ones. Nature of break dictated by larger aggregate pieces. About 25% of pieces larger than 3 in.—about 10% broken through. Cement matrix normal. No reactions or signs of deterioration. Coarse aggregate typically well rounded with smooth surface texture.

DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. WDB-1b BLOCK
TYPE CONCRETE: Exterior
COMPRESSIVE STRENGTH (PSI) 4710
SAD LABORATORY NO. 145/454
DEPTH (Ft.) 8.3-9.7 CORE NO. "Extra"

CONE SHEAR



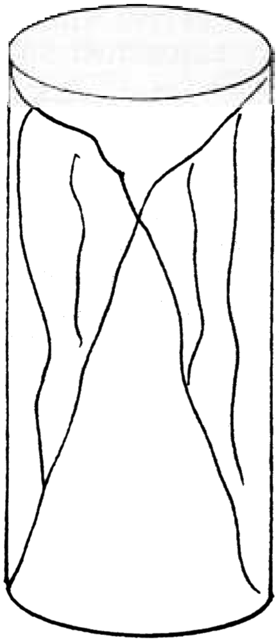
REMARKS:

Explosive break. Cement matrix normal, no reactions or excessive voids in sockets. Particles greater than 3 in. represent about 15% of exposed surface. About 10% of coarse aggregate pieces broken through. Coarse aggregate shape is well rounded with smooth surfaces.

DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 100-1a BLOCK: 100
TYPE CONCRETE: Exterior
COMPRESSIVE STRENGTH (PSI) 4920
SAD LABORATORY NO. 145/458
DEPTH (Ft.) 6.4-8.0 CORE NO. 3



CONE SHEAR

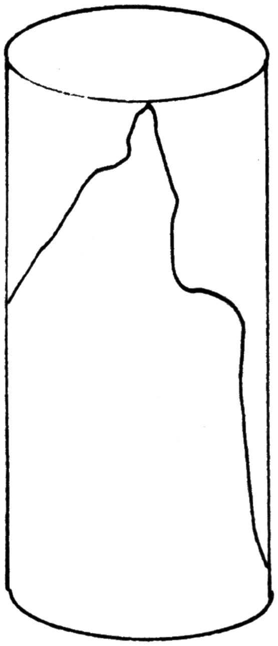
REMARKS:

Explosive break. Well rounded coarse aggregate 1½ in. maximum size. Break occured mostly around particles. Only about 5% broke through. No coarse aggregate particles over 3 in. in size. Cement matrix normal, no excessive trapped air voids or reaction products noted.

DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

CURSORY PETROGRAPHIC EXAMINATION

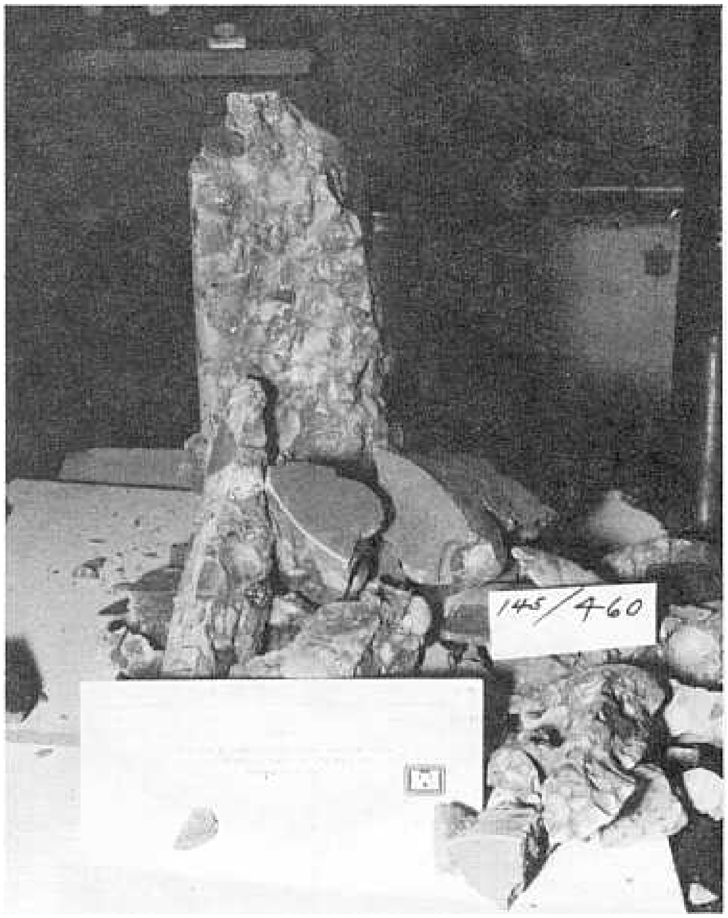
PROJECT: Grand Coulee Forebay Dam
BORING NO. 106-1 BLOCK 106
TYPE CONCRETE: Exterior
COMPRESSIVE STRENGTH (PSI) 5560
SAD LABORATORY NO. 145/460
DEPTH (Ft.) 3.4-5.0 CORE NO. 2



CONE SHEAR

REMARKS:

Explosive break. Coarse aggregate well rounded with smooth surfaces. Maximum size up to 3 in. Cement matrix normal, no excessive air in sockets, no visible reaction products or deterioration. About 10% of coarse aggregate pieces broke through. Only about 5% are 3 inches in size or larger.



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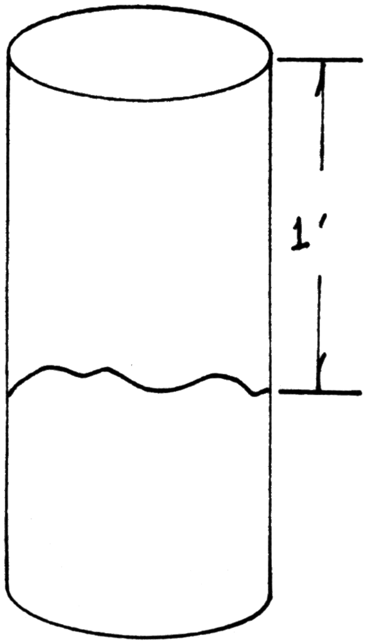
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060-3112

CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 106-1 BLOCK 106
TYPE CONCRETE: Interior
TENSILE STRENGTH (PSI) 60
SAD LABORATORY NO. 145/461
DEPTH (Ft.) 6.0-7.7 CORE NO 3

REMARKS:

This core contains several large coarse aggregate particles which dictated break as shown in the photograph below. Note trapped air voids in sockets (right piece in photograph is botton segment). Cement matrix looks normal. Less than 1% of aggregate broke through. Pieces over 3 in. in size make up about 40% of exposed surface. Coarse aggregate typically rounded with smooth surfaces.



TENSION BREAK.

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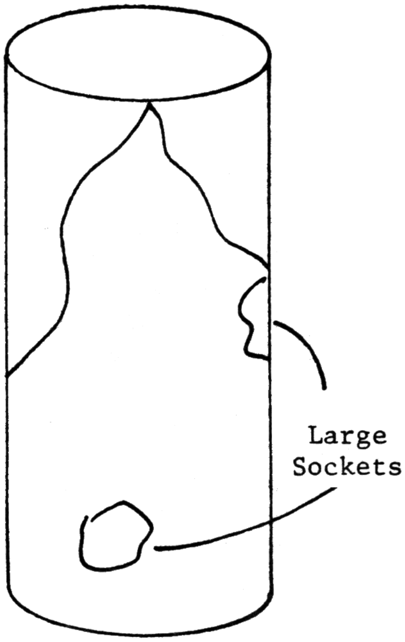
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 109-1 BLOCK 109
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 5270
SAD LABORATORY NO. 145/463
DEPTH(Ft.) 2.5-4.2 CORE NO. 2



CONE SHEAR

REMARKS:

Explosive break. Only about 2% of coarse aggregate particles broke through. About 15% of pieces are 3 in. or greater in size. Two large sockets remained in the intact core after testing. These did not have excessive trapped air voids. Cement matrix appears normal. No reaction products or signs of deterioration noted. Coarse aggregate pieces generally well rounded with smooth surfaces.

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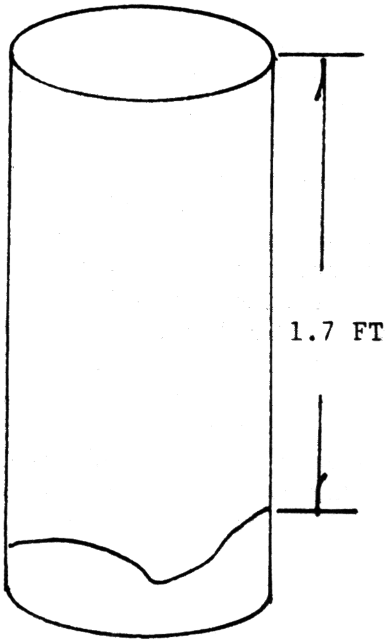
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 145/464 BLOCK: 109
TYPE CONCRETE: Interior
TENSILE STRENGTH (PSI) 45
SAD LABORATORY No. 145/464
DEPTH (Ft.) 6.2-7.9 CORE No. 3



REMARKS:

This core broke in tension close to the bottom where 1½ to plus 3 in. aggregate pieces were numerous. Numerous sockets left by the rounded coarse aggregate particles appear in the photograph below. Note moderate amount of trapped air voids and numerous rounded pieces. Only one aggregate particles broke. The cement matrix appears normal, no reaction products were noted. The voids were clean. About 50% of fracture surface appears to be 3 in. or larger.

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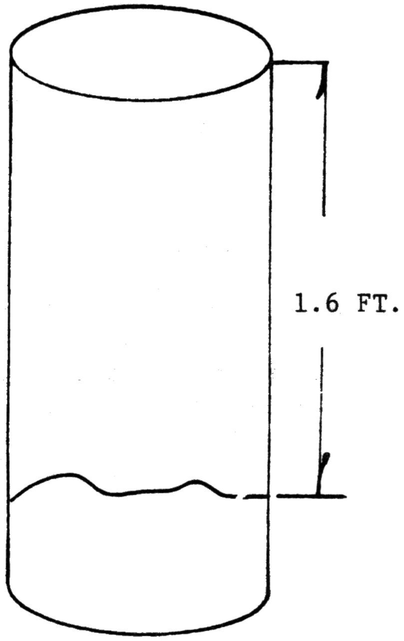
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 109-1 BLOCK 109
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 140
SAD LABORATORY NO. 145/465
DEPTH (Ft.) 9.0-11.0 CORE NO. 4



REMARKS:

Core pulled apart about 0.4 ft. from bottom. Only a small percent (∿2) of the coarse aggregate pieces broke apart in the test. About 20% of the coarse aggregate appears to be 3 in. or larger (see photograph). Core piece on right in photograph is the bottom portion. Note small amount of trapped air voids in sockets (this would be the bottom of the coarse aggregate pieces). Since more matrix and a greater quantity of smaller particles are present, the tensile strength is higher than most of the cores tested in tension.

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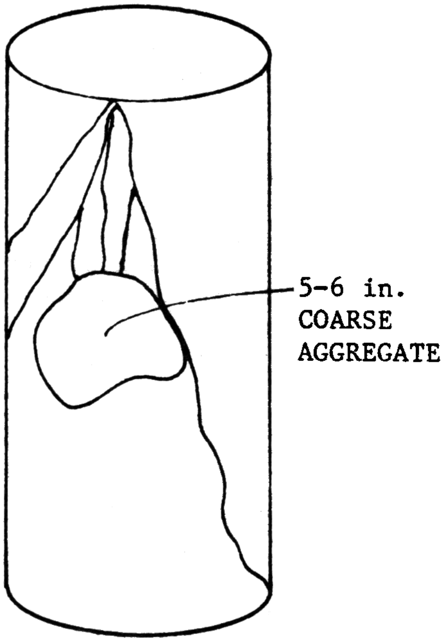
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 109-1 BLOCK 109
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 3660
SAD LABORATORY NO. 145/467
DEPTH (Ft.) 16.0-17.7 CORE NO. 5

REMARKS:

Explosive break. Bond failure around larger coarse aggregate particles common (see photograph). On fracture surface these represent about 15% of the surface area. Trapped air voids common but not excessive. When present they are clean. Cement matrix looks normal - no reaction or alteration products noted. Percent of fractured coarse aggregate particles small (about 2%).



CONE SHEAR

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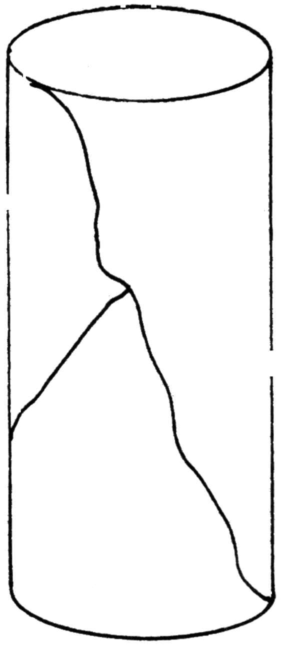
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 113-1 BLOCK 113
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 4720
SAD LABROATORY NO. 145/468
DEPTH (Ft.) 17.7-3.4 CORE NO. 1*

REMARKS:

Explosive break. About 10% of coarse aggregate pieces broke across (sheared) during test. There were no pieces 3 in. or larger in size. Coarse aggregate well rounded with smooth surfaces. Cement matrix looks normal. No reaction or alteration products noted. Voids are clean.

labeled No. 2 on core in error.



CONE SHEAR

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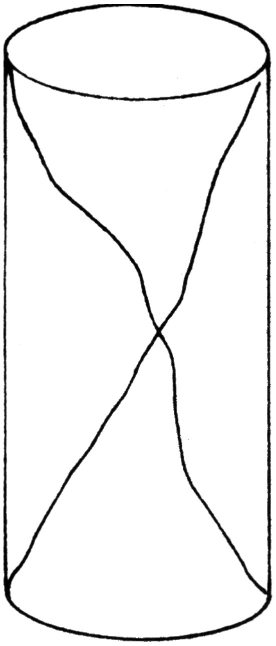
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 113-1 BLOCK: 113
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 4420
SAD LABORATORY NO. 145/469
DEPTH (Ft) 4.2 - 5.7 CORE No. 2



CONE

REMARKS:

Explosive break. Very small percent (5%) of broken coarse aggregate particles. Aggregate 3 in. or larger represents about 10% of fracture surfaces. Cement matrix appears normal - no visible reaction or deterioration products. No excessive voids but when present they are clean. Coarse aggregate is typically well rounded with smooth surface.

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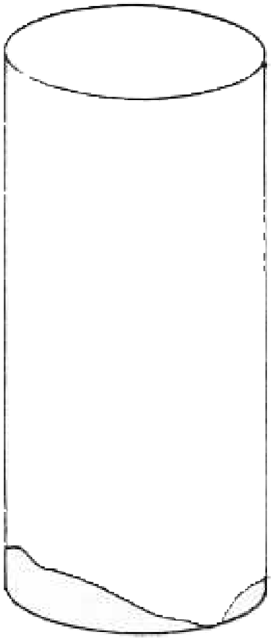
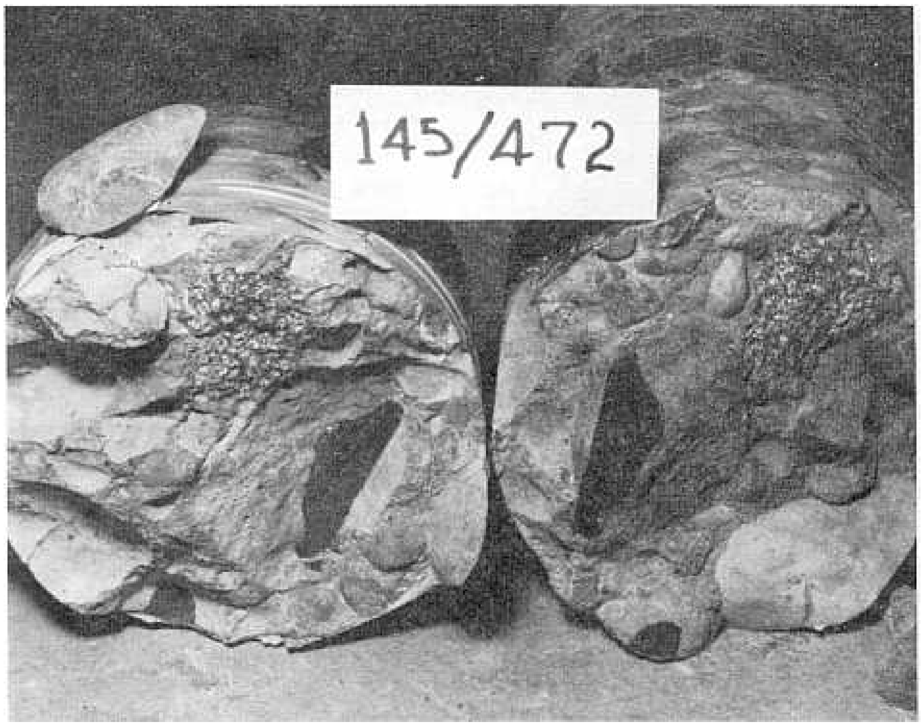
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 113-1 BLOCK 113
TYPE CONCRETE: Interior
TENSILE STRENGTH (PSI) 80
SAD LABORATORY NO. 145/472
DEPTH (Ft.) 9.2 - 10.9 CORE NO. 3



REMARKS:

Core contains an abundance of large (> 3 in.) coarse aggregate particles. Core broke in tension at bottom about 1-2 in. from steel plate. The photograph shows areas of epoxy failure and abundance of large aggregate. Large aggregate particles cover about 40% of fracture surface. Note yellow brown weathered particle and smooth sockets in photograph.



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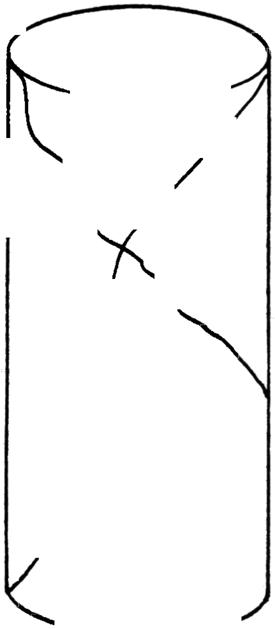
RSOTY PETROGRAPH EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 113-1 BLOCK 113
TYPE CONCRETE : Interior
COMPRESSIVE STRENGTH (PSI) 5020
SAD LABORATORY NO. 145/473
DEPTH (Ft.) 12.0 to 13.7 CORE NO



CON

REMARKS

Explosive break. Some large coarse aggregate particles (about 15%) are present. These left smooth sockets. Air voids were not abundant but when present they were clean and free of reaction products. Only about 5% of the coarse aggregate particles broke (sheared) during the test. Cement matrix appears normal.

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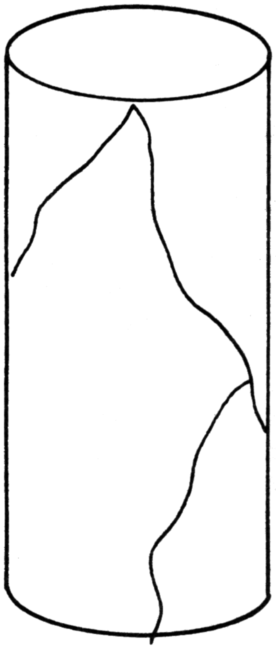
CURSORY PETROGRAPHIC EXAMINATION

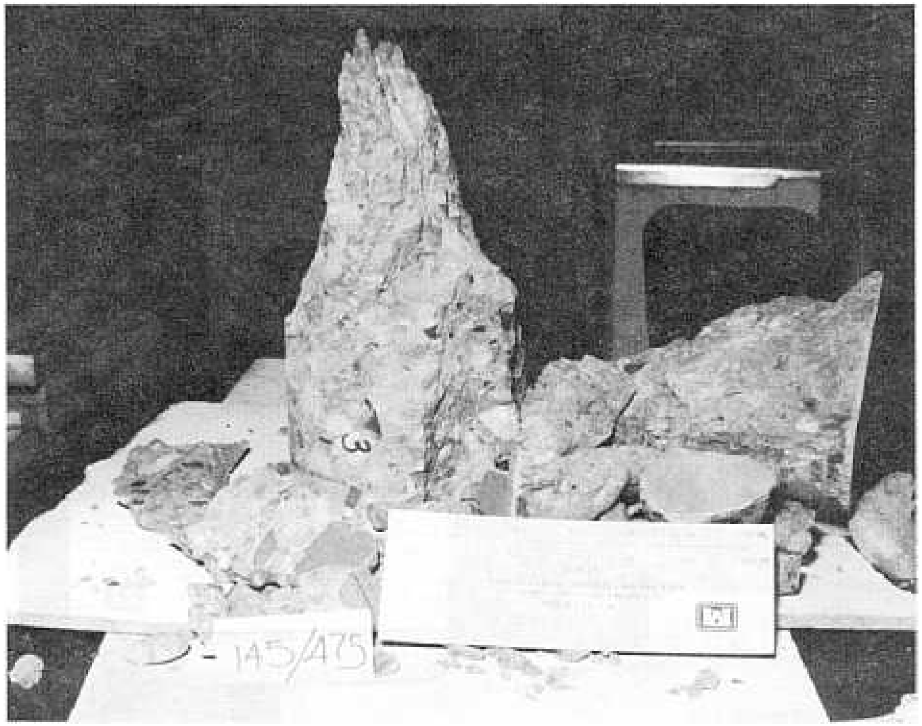
PROJECT: Grand Coulee Forebay Dam
BORING NO. 113-1a BLOCK 113
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 5260
SAD LABORATORY NO. 145/475
DEPTH(Ft.) 1.7 to 3.4 CORE NO. 2



CONE

REMARKS:

Explosive break. Well consolidated, sound concrete. Cement matrix appear normal. No evidence of reaction products or concrete deterioration. About 5% of coarse aggregate is 3 in. or larger. About 10% of the exposed aggregate are fractured or sheared. Few angular coarse aggregate particles but most are well rounded with smooth surfaces.



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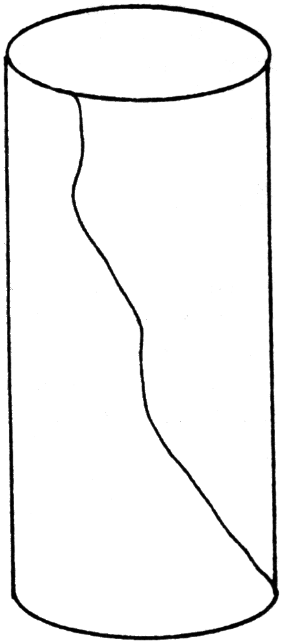
CURSORY PETROGRAPHIC EXAMINATION

PROJECT : Grand Coulee Forebay Dam
BORING NO. 113-1a BLOCK 113
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 4470
SAD LABORATORY NO. 145/476
DEPTH (Ft.) 3.9 to 5.4 CORE NO. 3

REMARKS:

Explosive break. Sound well consolidated concrete. No evidence of concrete deterioration or reaction products. Cement matrix appears normal. Aggregate well rounded with smooth surfaces. Pieces 3 in. or larger represent about 20% of exposed fracture furface. About 5% of aggregate (all sizes) particles sheared.



SHEAR

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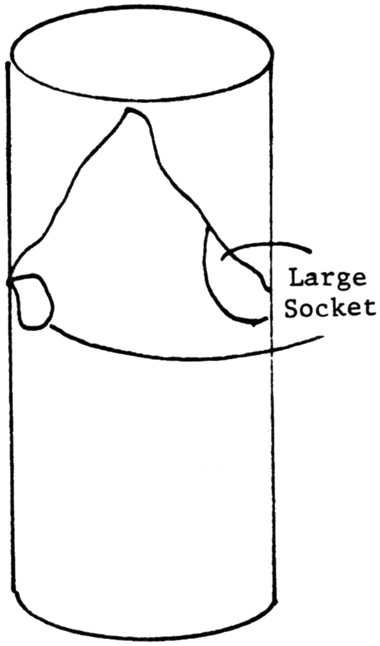
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 116-1 BLOCK 116
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 4980
SAD LABORATORY NO. 145/479
DEPTH (Ft.) 1.7 to 3.4 CORE No. 2

REMARKS:

Explosive break. Numerous large sockets on intact core. Aggregate pieces 3 in. or larger make up about 25% of fracture surfaces. These are typically well rounded in shape. Only about 2% of the aggregate broke (sheared) during the test. The cement matrix appears normal. No gel or deterioration noted. Note smooth sockets on core outer surfaces.



CONE

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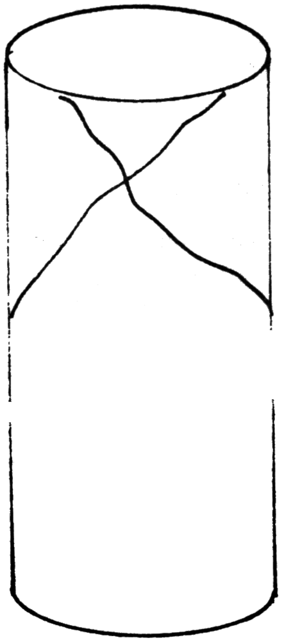
CURSORY PETROGRAPHIC EXAMINATION

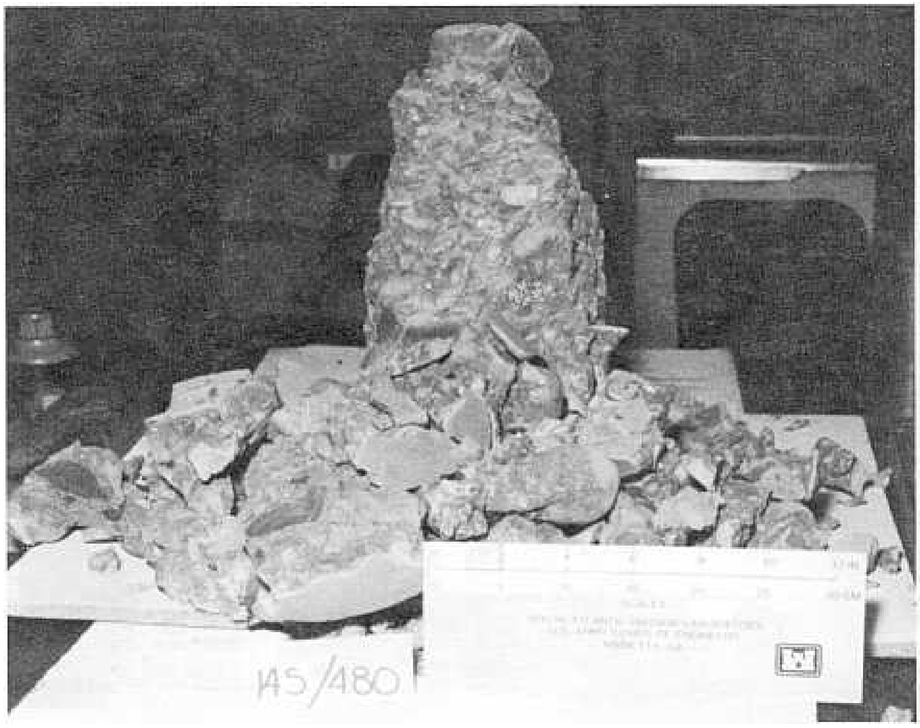
PROJECT: Grand Coulee Forebay Dam
BORING NO. 116-1 BLOCK: 116
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 5540
SAD LABORATORY NO. 145/480
DEPTH (Ft.) 4.2 to 5.8 CORE NO. 3

REMARKS:

Explosive break. About 10% of coarse aggregate 3 in. or larger. Aggregate shape is well rounded. Aggregate surfaces are typically smooth. Few subangular particles. About 2% of particles sheared in test. Cement matrix appears normal. No excessive air or trapped air around aggregate. Concrete well consolidated.



CONE



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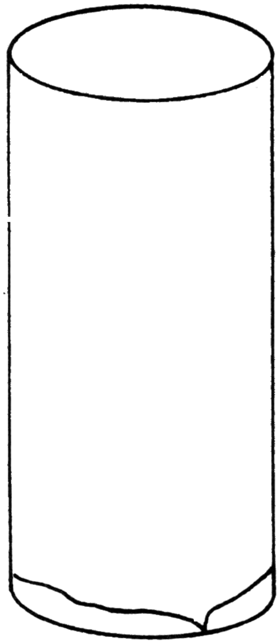
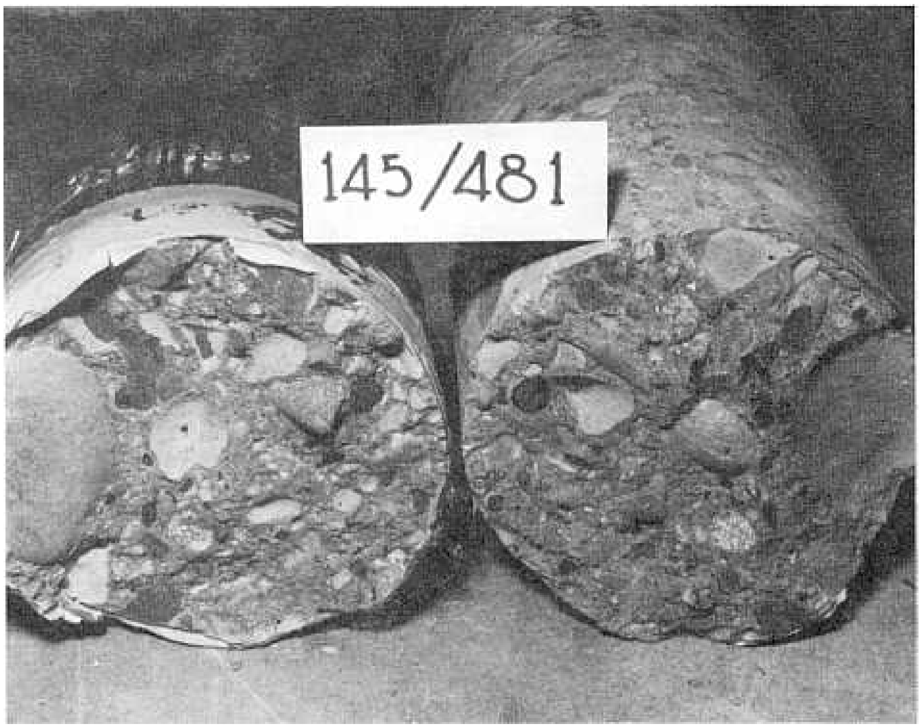
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 116-1 BLOCK 116
TYPE CONCRETE: Interior
TENSILE STRENGTH (PSI) 260
SAD LABORATORY NO. 145/481
DEPTH (FT.) 6.5 to 8.2 CORE NO. 4



REMARKS:

Core broke in tension near bottom where attached to steel plate. Reddish brown area in photograph is where the epoxy-concrete bond failed. Core contains an abundance of 1½ in. and smaller aggregate particles. About 10% of aggregate sheared in test. On fracture surface one 3 in. piece of aggregate is exposed. This piece makes up about 10% of surface area. No excessive air in sockets- Cement matrix appears normal.



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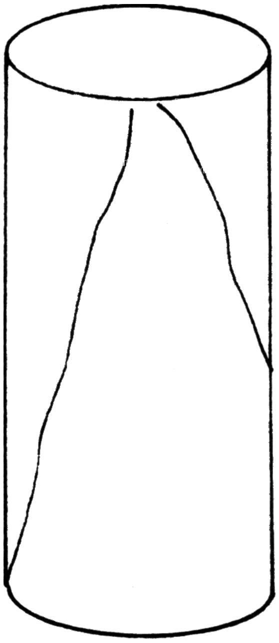
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 118-2 BLOCK 118
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 4940
SAD LABORATORY NO. 145/483
DEPTH (Ft.) 1.6 to 3.0 CORE No. 2



CONE

REMARKS:

Explosive break. General trend to break around larger coarse aggregate particles. Sockets have a moderate amount of trapped air voids. Note large sockets in photograph. Estimate about 15% of aggregate is 3 in. or larger. Cement matrix appears normal. No gel exduations or concrete deterioration noted. Sheared broken aggregate is about 10% of aggregate pcs.

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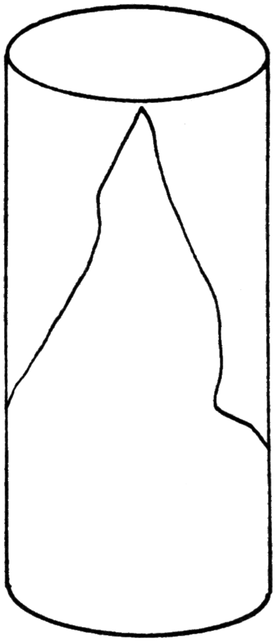
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 118-2 BLOCK 118
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 5040
SAD LABORATORY NO. 145/484
DEPTH(Ft.) 3.4 to 5.1 CORE NO. 3



CONE

REMARKS:

Explosive break. Core contains an abundance of 1½ in. to 3 in. coarse aggregate particles. These are usually well rounded with smooth surfaces. About 15% of the aggregate exceed 3 in. in size on fracture surfaces. Sheared, fractured pieces are about 10%. Cement matrix normal - no signs of deterioration or chemical reactions (e.g., siliceous gel, etc.

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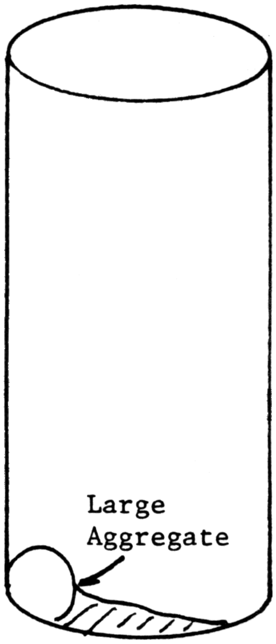
CURSORY PETROGRAPHIC EXAMINATION

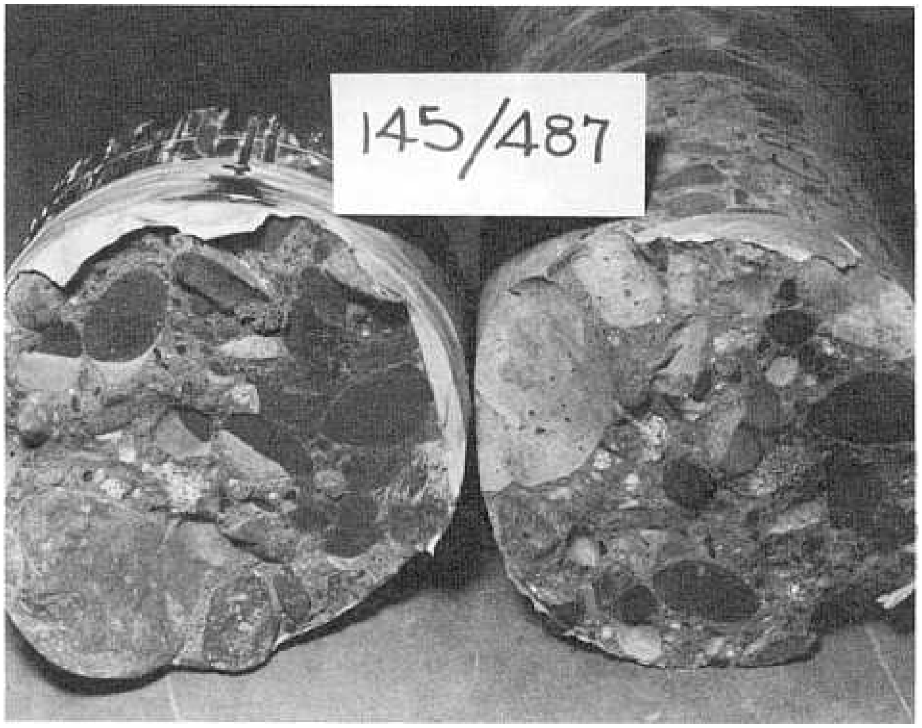
PROJECT: Grand Coulee Forebay Dam
BORING NO. 118-2 BLOCK 118
TYPE CONCRETE: Interior
TENSILE STRENGTH (PSI) 200
SAD LABORATORY NO. 145/487
DEPTH (Ft.) 11.3 to 13.0 CORE NO. 6

REMARKS:

Epoxy - concrete bond failure occured near bottom of core where attached to steel plate. Reddish brown area is the epoxy on steel plate (see photograph below). One large coarse aggregate piece on fracture surface covers about 10% of area. Only about 2% of the aggregate broke across. Sockets contain a few trapped air voids. Cement matrix appear normal. No exudations or signs of deterioration.



Shaded area remained glued to bottom plate.



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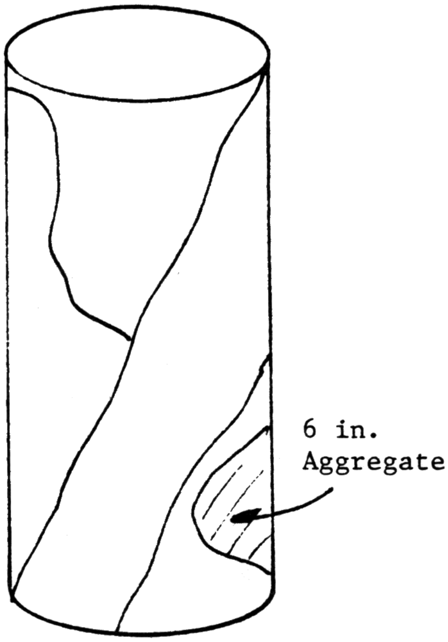
CURSORY PETROGRAPHIC EXAMINATION

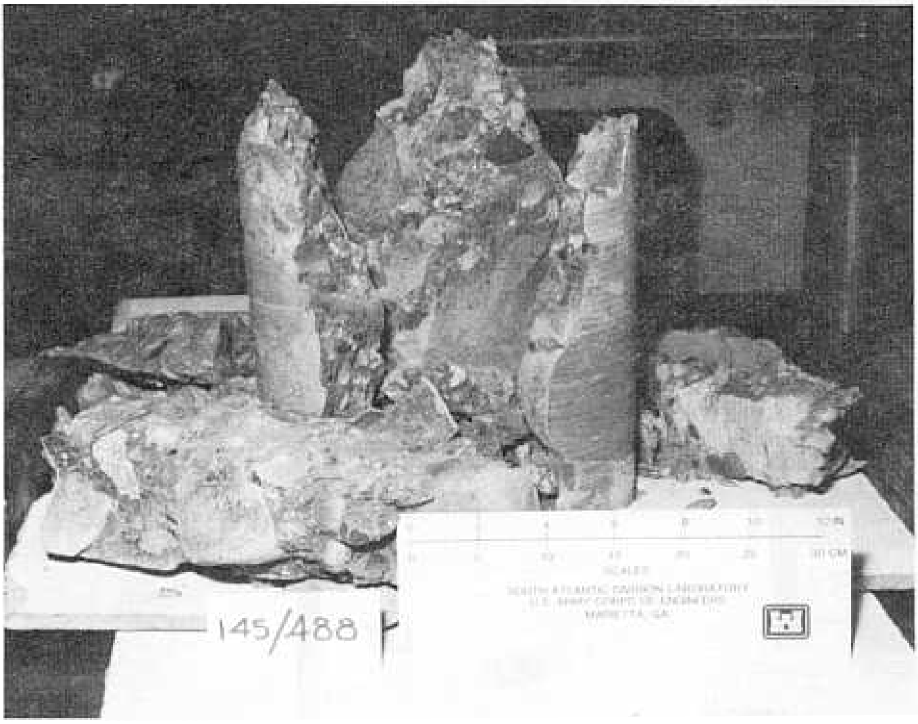
PROJECT: Grand Coulee Forebay Dam
BORING NO. 118-2 BLOCK 118
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 5680
SAD LABORATORY NO. 145/488
DEPTH (FT.) 14.0 to 15.7 CORE No. 7



CONE SHEAR

REMARKS:

Explosive break. Some large (about 20%) coarse aggregate pieces are present. Break occured around most of these but also through one 4 in piece. Sheared broken pieces represent about 15% of total aggregate exposed. Some sockets contain moderate amounts of trapped air voids. All are clean, that is, they have the color of normal cement No signs of concrete deterioration.



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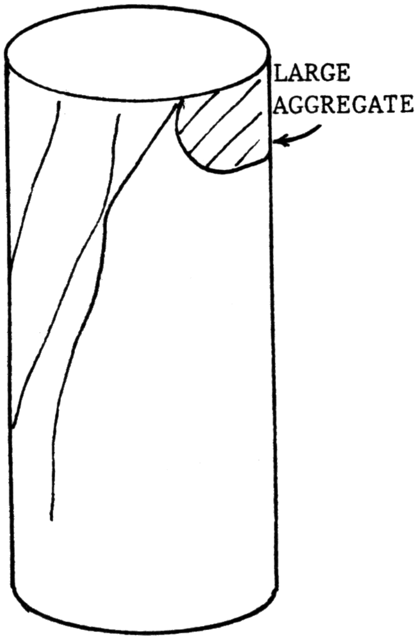
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 119-2 BLOCK 119
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH: 4970
SAD LABORATORY No. 145/489
DEPTH (Ft.) 0.3 to 2.0 CORE No. 1*

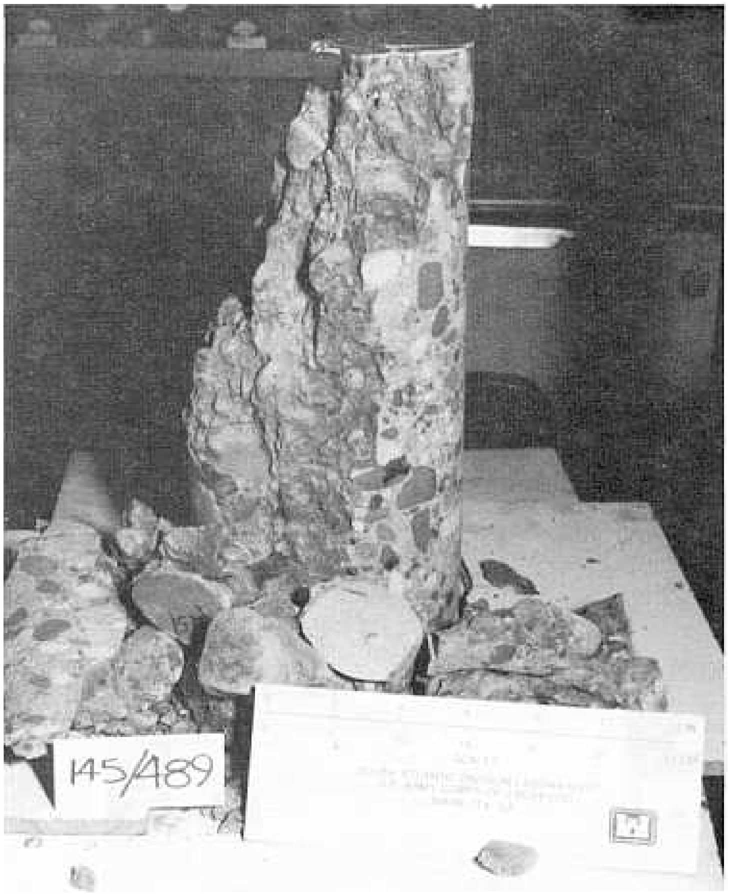
REMARKS:

Explosive break. Core sheared about 68° from the horizontal. Large coarse aggregate at top dictated break. Concrete is sound and well consolidated. Matrix appears normal- no excessive air. Percent of sheared, broken aggregate about 2%; pieces 3 in. or larger make up about 5% of exposed fracture surface.

*Extra Core.



SHEAR SPLIT



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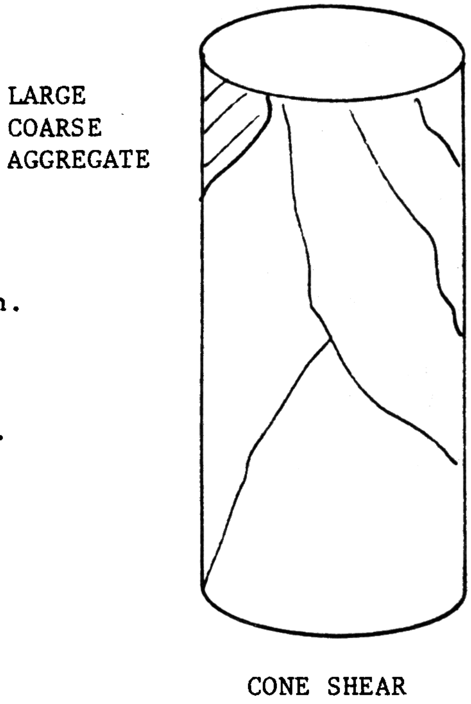
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING NO. 119-2 BLOCK 119
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 4980
SAD LABORATORY NO. 145/490
DEPTH (Ft.) 3.3 to 5.0 CORE NO. 2

REMARKS:

Explosive break. Large coarse aggregate at top appears to have dictated fracture pattern. 15-20% of exposed aggregate is 3 in. or more in size. It is estimated that 30% of the aggregate sheared or broke across particle. Aggregates well rounded with smooth surfaces. Cement matrix appears normal - no excessive trapped air or signs of deterioration.



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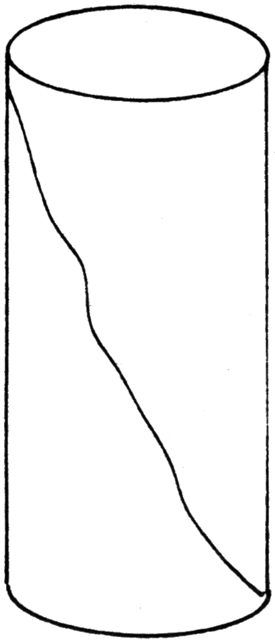
CURSORY PETROGRAPHIC EXAMINATION

PROJECT: Grand Coulee Forebay Dam
BORING No. 120-1 BLOCK 120
TYPE CONCRETE: Interior
COMPRESSIVE STRENGTH (PSI) 4790
SAD LABORATORY NO. 145/492
DEPTH (Ft.) 0.2 to 1.9 CORE NO. 1



SHEAR

REMARKS:

Explosive break. This core contains abundant aggregate 1½ in. and below. Only a few larger than 1½ in. None 3 in. or larger. About 2% of aggregate broke across or sheared during test. Aggregates generally subangular to well round. No signs of concrete deterioration or gel exudations. Concrete sound.

APPENDIX E

REPORT OF PETROGRAPHIC ANALYSIS

SADEN-FL 25 October 1984

DEPARTMENT OF THE ARMY
SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS
611 SOUTH COBB DRIVE
MARIETTA, GEORGIA 30060

PETROGRAPHIC REPORT
GRAND COULEE FOREBAY DAM, WASHINGTON
10-Year Core Study

Project: Grand Coulee Forebay Dam

Performed For: Concrete and Structural Branch
Engineering and Research Center
Bureau of Reclamation

SAD Work Order No. 3710
SAD Lab. No. 145/448, 454, 467, 488
Interagency Agreement D-1511

SUMMARY

The concrete from two interior and two exterior concrete cores used in the unconfined compression tests and examined in this study appeared to be of good quality. The coarse and fine aggregates are sound and dense for the most part although the coarse aggregate is typically well-rounded in shape with smooth surfaces. Mode of failure in the compression tests was usually paste-aggregate bond failure. The low strengths recorded in the compression tests were usually due to bond failure around large coarse aggregate particles.

No evidence of chemical attack or alkali-silica reaction between aggregate and cement was found.

Prepared by: Ray Willingham Reviewed by: Lane Tison

INTRODUCTION

1. This is the report of the petrographic analyses conducted on four ten-inch (255 mm) diameter concrete core specimens from Grand Coulee Forebay Dam, Grand Coulee, Washington. This examination is part of the ten year concrete evaluation program being conducted by this laboratory in connection with an interagency agreement (D-1511) between the Bureau of Reclamation* and U.S. Army Corps of Engineers, South Atlantic Division Laboratory.

2. The four cores examined represent mass concrete from the interior and exterior concrete as stipulated in the interagency agreement. These are identified in Table 1 below:

TABLE 1

SPECIMENS SELECTED FOR PETROGRAPHIC ANALYSES

SAD Lab No.	Bureau Designation	Location	Depth (ft.)	Type of Concrete (Exterior or Interior)
145/448	WDB-1b, Core No. 3	Sta. 112+42.92 Offset 19+36.57	0.8-2.5	Exterior
145/454	WDB-1b, Extra Core	Sta. 112+42.92 Offset 19+36.57	8.3-9.7	Exterior
145/467	109-1, Block 109, Core No. 5	Sta. 106+07.91 Offset 20+31.63	16.0-17.7	Interior
145/488	118-2, Block 118, Core No. 7	Sta. 111+43.48 Offset 20+31.56	14.0-15.7	Interior

---

*Engineering and Research Center, Division of Research

3. The concrete cores listed in Table 1 were selected based on their performance in the unconfined compressive (UC) tests. Concrete cores with the highest and lowest compressive strengths representative of both exterior and interior concrete were examined. For example, specimen 145/448 had the highest UC strength whereas 145/454 had the lowest of all the exterior concrete cores tested. A total of 28 concrete cores were tested. It should be noted that only seven cores representative of exterior concrete were used in the UC tests whereas 16 interior concrete cores were tested in compression. Six cores were also tested in tensile strength. The inequity in number is due essentially to a lack of exterior concrete submitted in the original sample.

PURPOSE AND SCOPE OF EXAMINATION

4. The primary purpose of this study was to describe in detail the concrete cores tested in UC and listed in Table 1 using petrographic techniques proposed in ASTM C 856*. Secondary in importance was to determine if variations in the compressive strengths were the result of concrete quality (e.g., excessive air, alkali-silica reaction, etc.).

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*Standard Recommended Practice for "Petrographic Examination of Hardened Concrete".

5. To accomplish the above, the following techniques were employed:

Visual Examination
Stereomicroscopic Examination
Thin Section/Grain Mount Study (Polarizing Microscope)
X-Ray Diffraction Analysis

DETAILED FINDINGS

Coarse Aggregate

6. The coarse aggregate used in this structure is from natural river deposits. These are typically clean, hard, dense, well rounded coarse aggregate particles with smooth surfaces. Maximum size of aggregate was 6-inches (152 mm). Most are fresh although a few weathered and surface weathered pieces were noted. Often the weathering appears as thin light or dark rims on particle surfaces.

7. A wide variety of igneous and volcanic rock types make up the bulk of the aggregate, however, dark gray to black rock particles are more prevalent. These are glassy basalts which are typically dense, sound rocks. However, a few vesicular types are present. Other rock types noted were granite, quartzite, gneiss and some sedimentary varieties.

8. The coarse aggregate being essentially round in shape tends to separate from the cement paste when tested to failure in

compression, that is, the concrete core broke around the coarse aggregate particles more often than through them. This was the general trend especially when large aggregate pieces were present in the test specimens. However, there were several exceptions. Aggregate sockets contained some trapped air voids but these were not excessive in quantity or size. The smaller aggregate particles broke through more frequently. This usually resulted in higher strengths for these cores with higher percentages of smaller particles.

9. The concrete cores do not appear to have an abundance of a particular size range, that is, there was no deficiency of sizes. This is also true of the concrete cores as a whole. The interior concrete cores contained aggregate pieces up to six inches (152 mm) in size. Maximum size of coarse aggregate in exterior concrete was typically 1½-inches (38 mm). However, specimen WDB-1b (d. 8.3-9.7) contained a large coarse aggregate piece approximately five inches in size*. In general, grading of coarse aggregate appeared normal. There was no honeycombing or excessive trapped air voids surrounding coarse aggregate particles. A summary of the concrete core UC strengths and general mode of failure appears in Table 2.

10. From the petrographic viewpoint a couple of coarse aggregate

---

*Maximum size of coarse aggregate in exterior concrete is reported to be 1½-inch.

TABLE 2
SUMMARY OF CONCRETE COMPRESSIVE STRENGTHS AND MODES OF FAILURE

Bureau Designation	SAD Lab No.	Compressive Strength (PSI)	Type Concrete	Nature of Break	Features Associated with Failure
Hole WDB-1b, Core No. 3 (d. 0.8' to 2.5')	145/448	6665	Exterior	Explosive Break, cone-shaped.	Relatively good bonding-abundance of particles broken through. Few aggregate pieces larger than 1-inch.
Hole WDB-1b, Extra Core (d. 8.3' to 9.7')	145/454	4710	Exterior	Explosive Break, cone-shear.	Bond failure - broke around large coarse aggregate particles. 10 - 15% of particles broken through. Abundance of 1½-inch and down (coarse aggregate pieces). No excessive air in sockets.
Hole 109-1, Block 109 Core No. 5 (d. 16.0' to 17.7')	145/467	3660	Interior	Explosive Break, cone shear.	Bond failure - numerous sockets - broke around most of larger particles. Low strength due to bond failure around 6-inch stone near center of core.
Hole 118-2, Block 118 Core No. 7 (d. 14.0' to 15.7')	145/488	5680	Interior	Explosive Break, cone shear.	Generally good bond. Broke across some large coarse aggregate particles. No excessive air in sockets.

rock characteristics were noted that warrant mentioning. One was the presence of natural glass in the basalts. These rocks contain an abundance of brown natural glass. The index of refraction was found to be less than 1.57. Glasses, having an index of refraction lower than 1.57, are considered potentially reactive with "high alkali" portland cement. Also in recent years rocks containing strained quartz (quartz grains exhibiting undulose extinction in polarized microscopic light have been recognized as potentially alkali-silica reactive. Dolar-Mantuani's[1] technique for measuring the extinction angle is used. A few rock particles were noted during the thin section study that contained strained quartz (e.g., the quartzites). No extinction angles were recorded since an insignificant number of particles were observed. Since low alkali cement was used in this structure, strained quartz should not be a problem.

11. Both of the characteristics mentioned often warrant the use of low-alkali and/or a pozzolan according to our criteria. Since Type II low-alkali cement and Class F pozzolan were used in the structure, it was interesting to note that no reactions (formation of alkali-silica gel, rimming, etc.) were noted in this ten year old concrete.

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[1] Dolar-Mantuani, L.M.M., "Undulatory Extincion in Quartz Used for Identifying Potentially Alkali-Reactive Rocks," Proceedings of Conference on Alakli-Aggregate Reaction in Concrete, Capetown, S. Africa, 1981, paper No. S252/36, 6pp.

12. In paragraph 6 the presence of dark rims on coarse aggregate particles was mentioned. This feature was noted on a few coarse aggregate particles. Rims can be an indication of alkali-silica reaction if it can be assumed with some degree of accuracy that they formed after placement of the concrete. Rims can also be a result of weathering prior to placement. The rimmed particle shown in Figure 1 is the result of oxidation of the iron bearing carbonate mineral (probably ankerite) which is scattered throughout this particular rock particle.

Fine Aggregate

13. The fine aggregate particles appear to be essentially from natural sources. Rock types noted in the coarse aggregate examination also make up the bulk of the fine aggregate population. Individual mineral grains (e.g., quartz and feldspar) make up a significant portion of these grains. Shape varies from round to angular and in general the fine aggregate particles are clean, sound, and fresh. Distribution and grading appear satisfactory.

Cement Paste

14. The cement paste or matrix is uniformly gray and in general good quality. There was no evidence of mottling or gradational color changes. Slight concentrations of calcium hydroxide were noted along the undersides of a few coarse and fine aggregate

particles which is considered normal. Relict cement grains were noted in the stereoscopic examination along with dark spheres (flyash) and other residual grains. Examination of several concrete thin sections revealed the presence of partially hydrated cement grains (alite, C_3S and belite, C_2S), flyash (hollow and solid spheres), scattered calcium hydroxide crystals and some calcium carbonate. X-ray diffraction analysis of cement concentrates indicated a number of normal compounds present. Besides the constituents noted in thin section, a few normal compounds, mainly hydrated calcium aluminate and carboaluminate were detected. In summary no unusual compounds or deterioration products with exception of calcium carbonate were noted. Some calcium carbonate, in this case calcite, is considered normal due to carbonation. No evidence of sulfate attack or alkali-silica reaction was noted.

Air Voids

15. There were no areas or zones in the cores with excessive air (entrained or trapped). Air voids under particles were normal but in most all cases these were not excessively large nor numerous. Shape of entrained air was essentially spherical, however, trapped air varied from spherical to ellipsoidal. Most all air voids present in the concrete cores were clean and there was no color difference between voids and mortar or any reaction products.

16. The air-void content, specific surface and spacing factor were determined by microscopical examination (using the Modified Point Method, ASTM C 457). The concrete slabs that were subsequently polished and used in this part of the study were cut parallel to the placed concrete. The results appear in Table 3 below.

TABLE 3

MISCROSCOPICAL DETERMINATION OF AIR-VOID PARAMETERS*

SAD Lab. No.	Hole No.	Depth (ft.)	Air**	Specific Surface	Spacing Factor
145/448	WDB-1b	2.7	6.55	16.610	0.201
145/454	WDB-1b	8.0	3.52	16.949	0.358
145/467	109-1	17.9	7.12	14.803	0.185
145/488	118-2	15.9	6.89	13.976	0.157

*Values in millimeters, 50X magnification.
**Entrained and Trapped Air.

---

17. There appears to be no correlation between the amount of air in the cores and their compressive strengths. The failure in most all cases, as mentioned previously, was bond failure around coarse aggregate particles. This mode of failure is understandable

due to the rounded shape and smooth surface texture charactistic of the aggregate in general.

CONCLUSIONS

18. Based on this examination, the concrete appears to be of good quality. No evidence of chemical attack or deleterious reactions between cement and paste were observed. The variations noted in the unconfined compression tests was usually due to bond failure around larger coarse aggregate particles.

Ray Willingham

RAY WILLINGHAM
Geologist

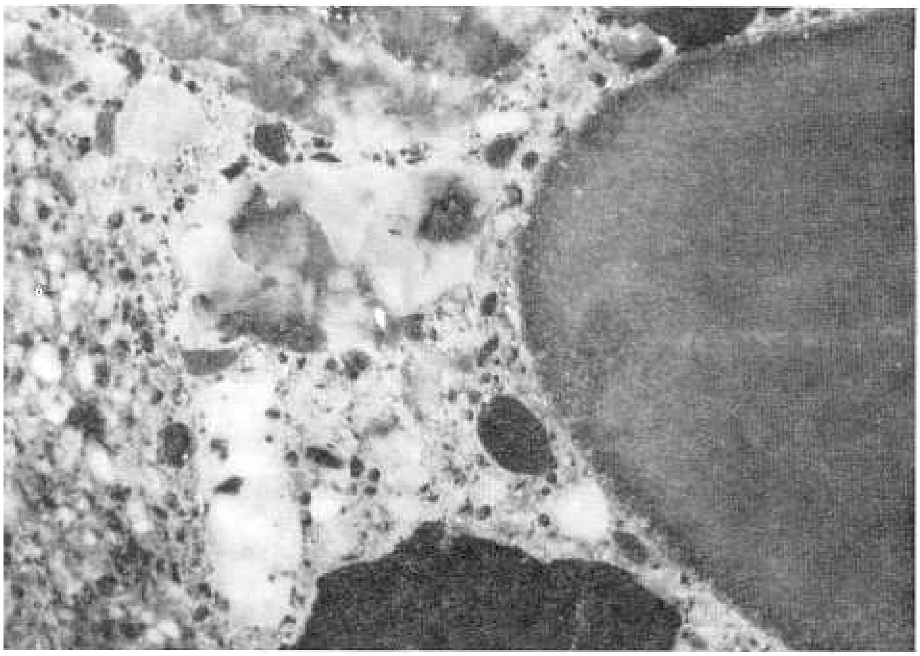


Figure 1. Polished surface (approx. 6.5x). Concrete core from Hole 109-1, Block 109. The rim on the particle to the right is the result of oxidation of the iron bearing carbonate mineral (probably ankerite) scattered throughout this rock particle.

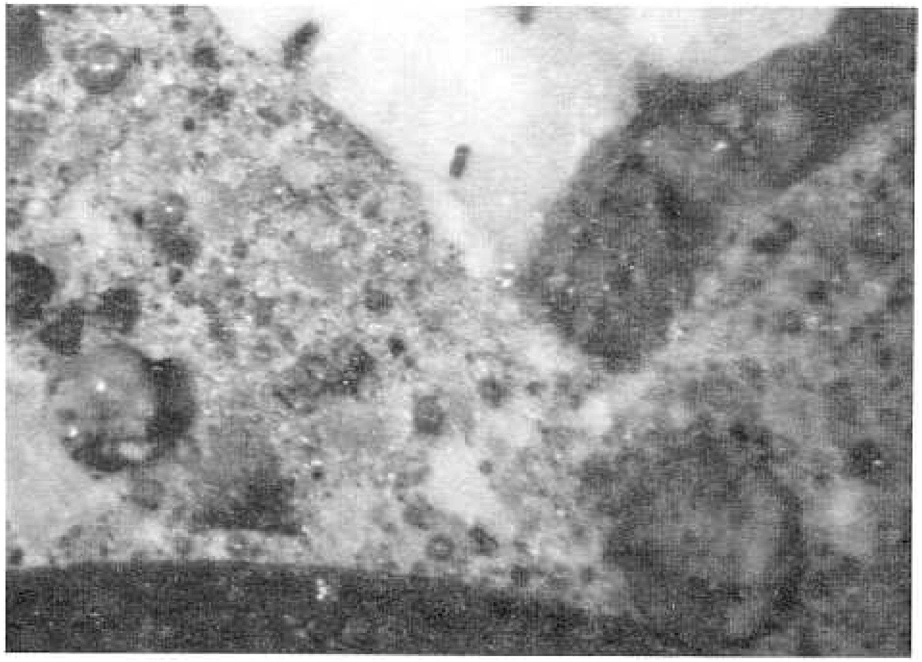


Figure 2. Polished surface (approx. 16x). Concrete from Hole 118-2, Block 118. Characteristics of the cement paste are discernable in this view. Small dark specks are flyash grains. Two large voids occur near edges of photograph.

APPENDIX F

TESTING PHOTOGRAPHS

Figure F1. Typical concrete core after capping for Compression testing. Shows method used for handling cores for capping and testing.

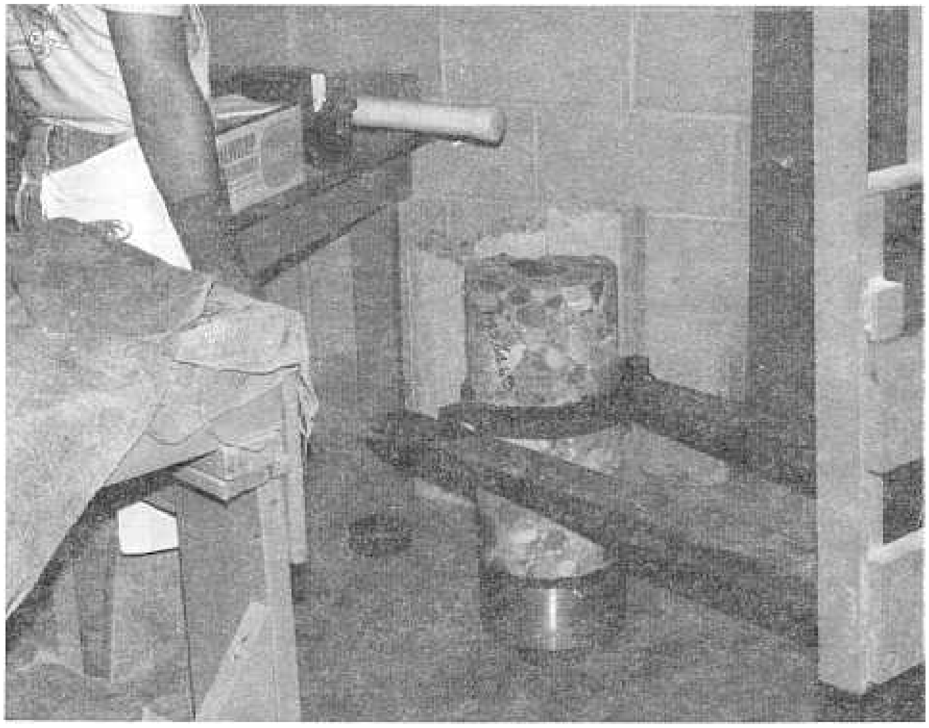


Figure F2. Typical concrete core being prepared for tensile testing.

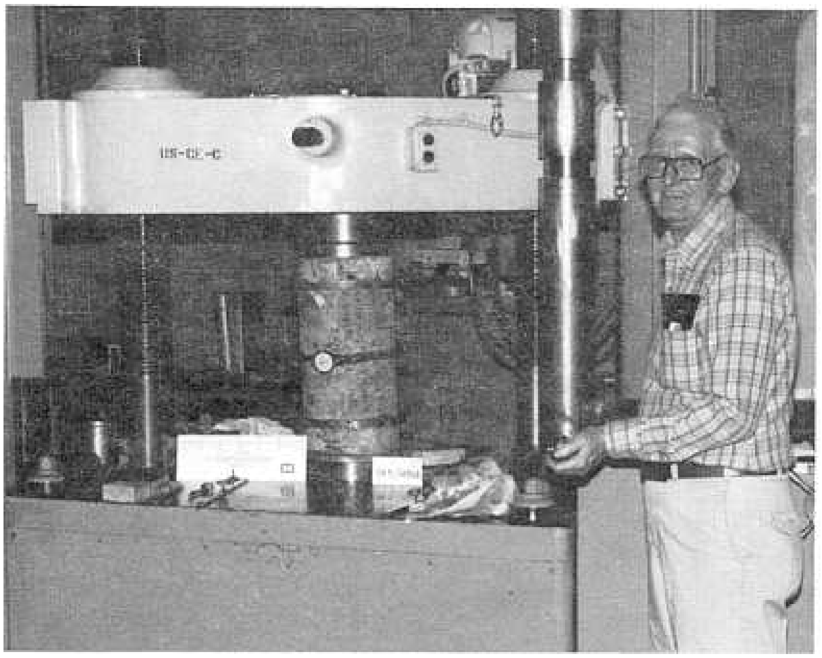


Figure F3. Typical concrete core in testing machine prior to Compression Test.

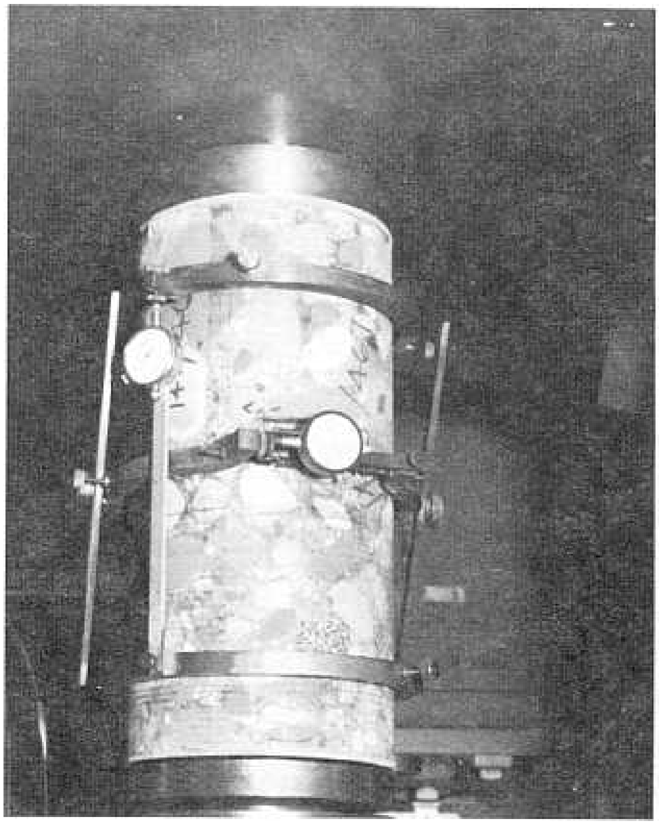


Figure F4. Close up of typical concrete core in testing machine prior to Compression Test.

APPENDIX G

DIRECT SHEAR TESTS

OPTIONAL FORM NO. 10 (O/P 4-65) 5010-107
MAY 1962 EDITION
GSA GEN. REG. NO. 27

UNITED STATES GOVERNMENT

Memorandum

Memorandum
TO : Head, Concrete Section

Denver, Colorado
DATE: April 1, 1985

THROUGH: ACTING Chief, Concrete and Structural Branch CAf 4-2-85
Chief, Geotechnical Branch PCL 4-1-85

FROM : Head, Rock Mechanics Section

SUBJECT : Direct Shear Tests on Concrete Core from Grand Coulee Forebay Dam

Geotechnical Branch Memorandum Reference No. 85-34

Investigated and written by: R. Kelsic, R. Brammer, and J. Montgomery

PURPOSE

This memorandum transmits results from the following:

Date of D-1511 testing memorandum: January 15, 1985

Laboratory test results (and analyses) attached: Direct shear tests on core from Grand Coulee Forebay Dam.

Specimen(s) No.: 119, 120

Purpose of testing (analyses): To evaluate concrete lift joints at Grand Coulee Forebay Dam.

Date testing (analyses) completed: January 21, 1985

DISCUSSION

In response to a two-way memorandum dated January 15, 1985, direct shear tests were conducted on concrete cores from Grand Coulee Forebay Dam, Washington. Two 10-inch-diameter specimens from construction blocks 119 and 120 were tested to evaluate the shear strength along visible bonded construction joints in the dam. Ten direct shear runs were performed to define the shear strength-displacement characteristics of the construction joints.

Results of linear regression analyses on data for each specimen are summarized in table 1. Photographs of cores before and after testing, plots of shear stress versus displacement, plots of normal stress versus shear stress, and results of linear regression analysis summary sheet are shown in the appendix for each specimen. A linear regression analysis was also used to analyze combined sliding friction data from both specimens. These results are summarized in table 2 and shown graphically in figure 1.

Since only two specimens were tested, the combined break bond data have no statistical correlation. Results from recent large diameter concrete direct shear programs generally indicate the that angle of internal friction, ϕ_b, for break bond tests is between 40° and 60°, with a cohesion between 300 and 500 lb/in^2. Specimen 119, which was tested at an initial normal stress of 130 lb/in^2, broke at a peak shear stress of 591 lb/in^2. The resulting slide surface was smooth and showed very little disturbance in the form of sheared or loose aggregate. Specimen 120 was tested at an initial normal stress of 255 lb/in^2 and broke at a peak shear stress of 1,015 lb/in^2. The resulting slide surface was inclined and wavy, and subsequent sliding shear strength may have been influenced by the encapsulation material at one end of the slide surface (see photograph in the appendix).

The combined sliding friction data show a high correlation coefficient which indicates a close statistical fit of linear regression analysis of the data. The angle of sliding friction, ϕ_s, of 47° and cohesion of 93 lb/in^2 are typical values for sliding friction test results based on the results of other large diameter concrete direct shear programs. For many design situations, it is not unreasonable to assume zero cohesion for joint or plane of weakness in situ even though laboratory shear testing may indicate a small value of cohesion. Such an assumption for the sliding friction case is based on the fact that a joint can experience progressive failure in which cohesive bonds are broken. Therefore, it is more conservative to use zero cohesion rather than the 93 lb/in^2 indicated by the sliding friction data.

CONCLUSIONS

Test results should be used with discretion because of the limited number of test specimens (two) employed in this test program. Before applying these test results, a thorough review of available drill logs and construction reports should be conducted to locate areas of joint contact similar to those found in these laboratory test specimens. It is considered essential to identify those areas where these shear strength parameters might be applicable.

W. G. Austin

Attachment

Copy to: D-1511
D-1540
D-1542
D-1543 (2)

Table 1. - Direct shear test results - summary

Specimen No.	Feature	Surface condition	Area (in^2)	Shear[1] stress (lb/in^2)	Cohesion (lb/in^2)	Friction angle (degrees)	Comments[2]
Block 119	Intact joint	Smooth	77.44	591	95	43	130, 65, 130, 255, 380, 637
Block 120	Intact joint	Inclined and wavy	77.44	1,015	92	49	255, 65, 130, 255, 380, 637

---

[1] Peak shearing stress developed at the first applied normal stress.

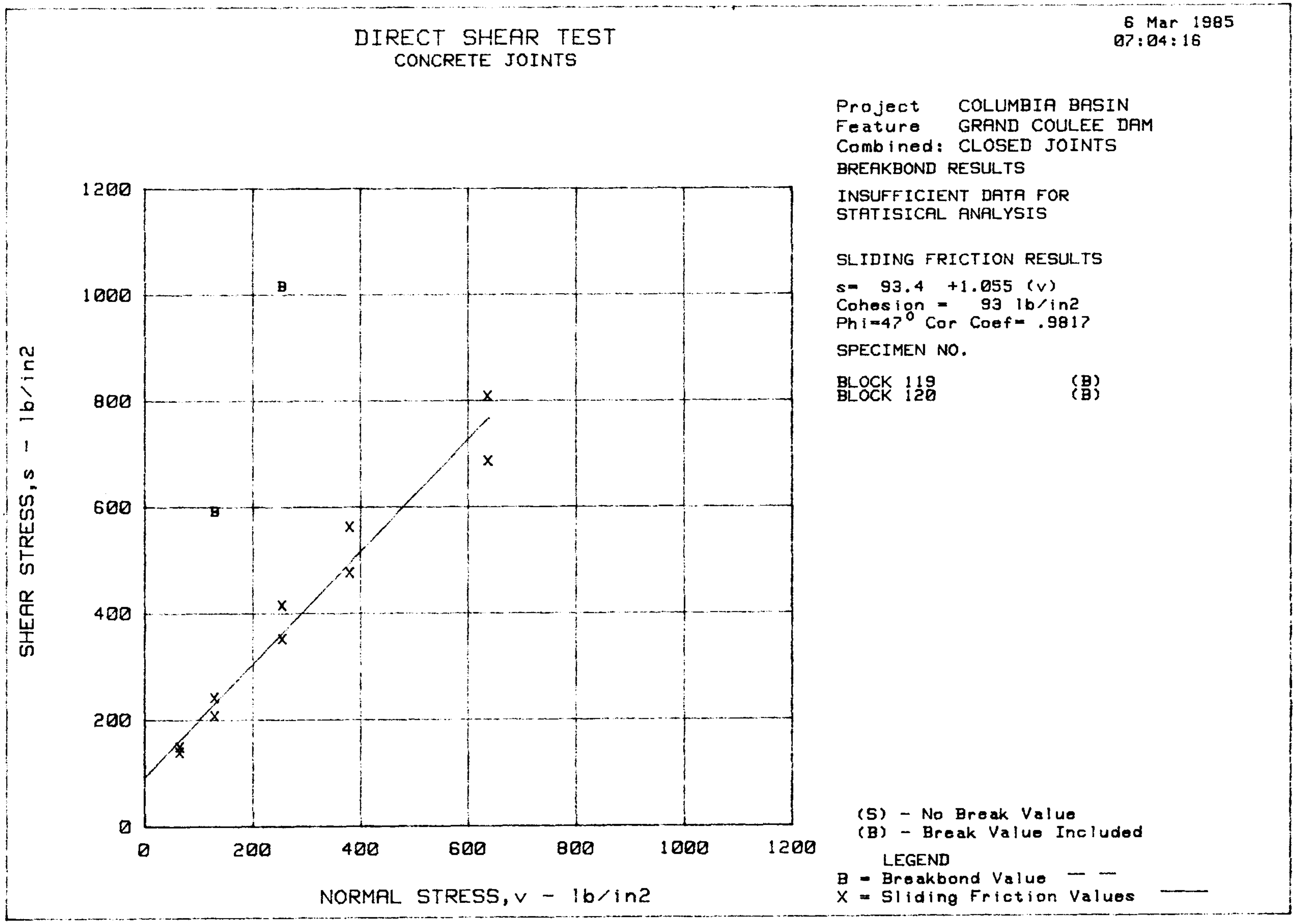
[2] Loading sequence (normal stress in lb/in^2).

Table 2. - Combined test data summary

Feature	Break bond linear regression results		Sliding friction linear regression results	
	Angle of internal friction (degrees)	Cohesion (lb/in^2)	Angle of sliding friction (degrees)	Cohesion (lb/in^2)
Closed joints	1/	1/	47	93

---

[1] Insufficient number of specimens for statistical analysis.



DIRECT SHEAR TEST
CONCRETE JOINTS

6 Mar 1985
07:04:16

Project COLUMBIA BASIN
Feature GRAND COULEE DAM
Combined: CLOSED JOINTS
BREAKBOND RESULTS
INSUFFICIENT DATA FOR
STATISICAL ANALYSIS

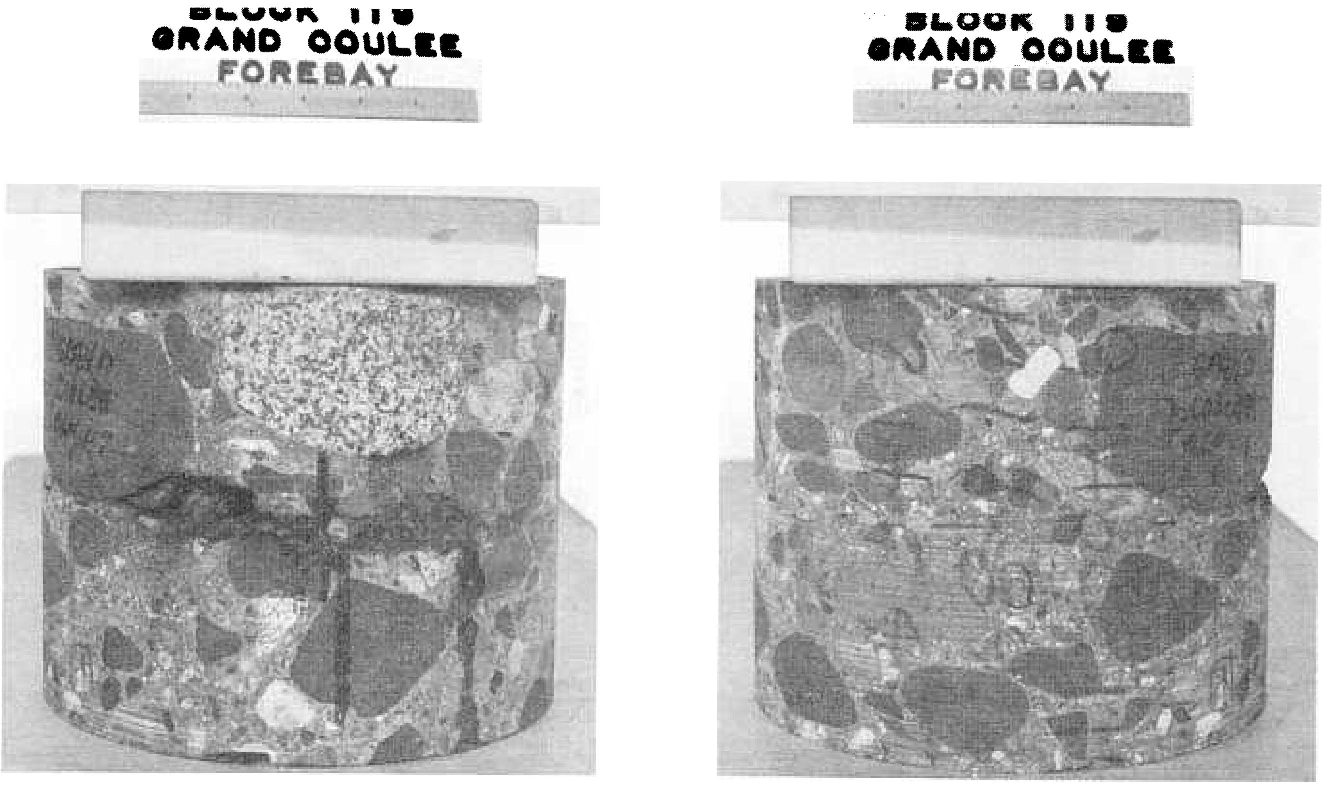
SLIDING FRICTION RESULTS
s= 93.4 +1.055 (v)
Cohesion = 93 lb/in2
Phi=47° Cor Coef= .9817
SPECIMEN NO.

BLOCK 119	(B)
BLOCK 120	(B)

(S) - No Break Value
(B) - Break Value Included
LEGEND
B = Breakbond Value — —
X = Sliding Friction Values ——

Figure 1

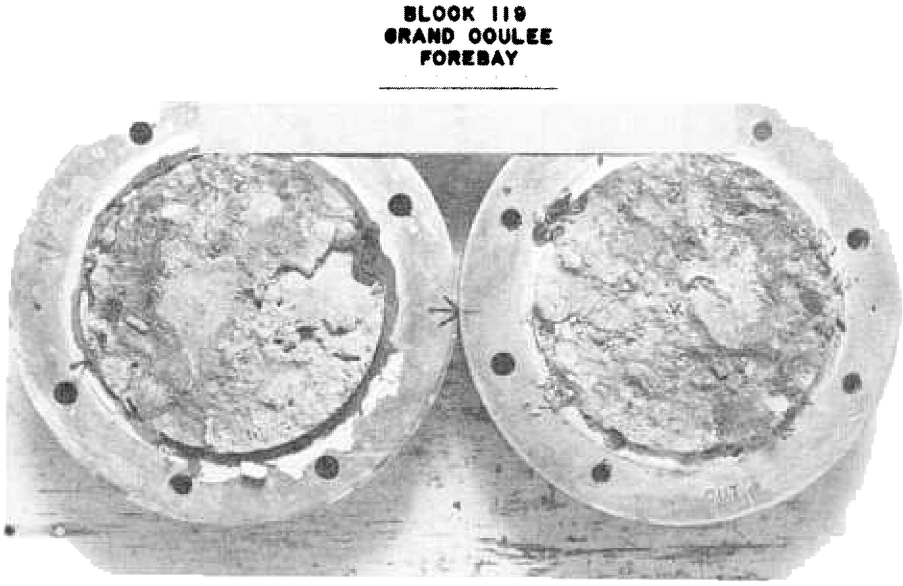
APPENDIX



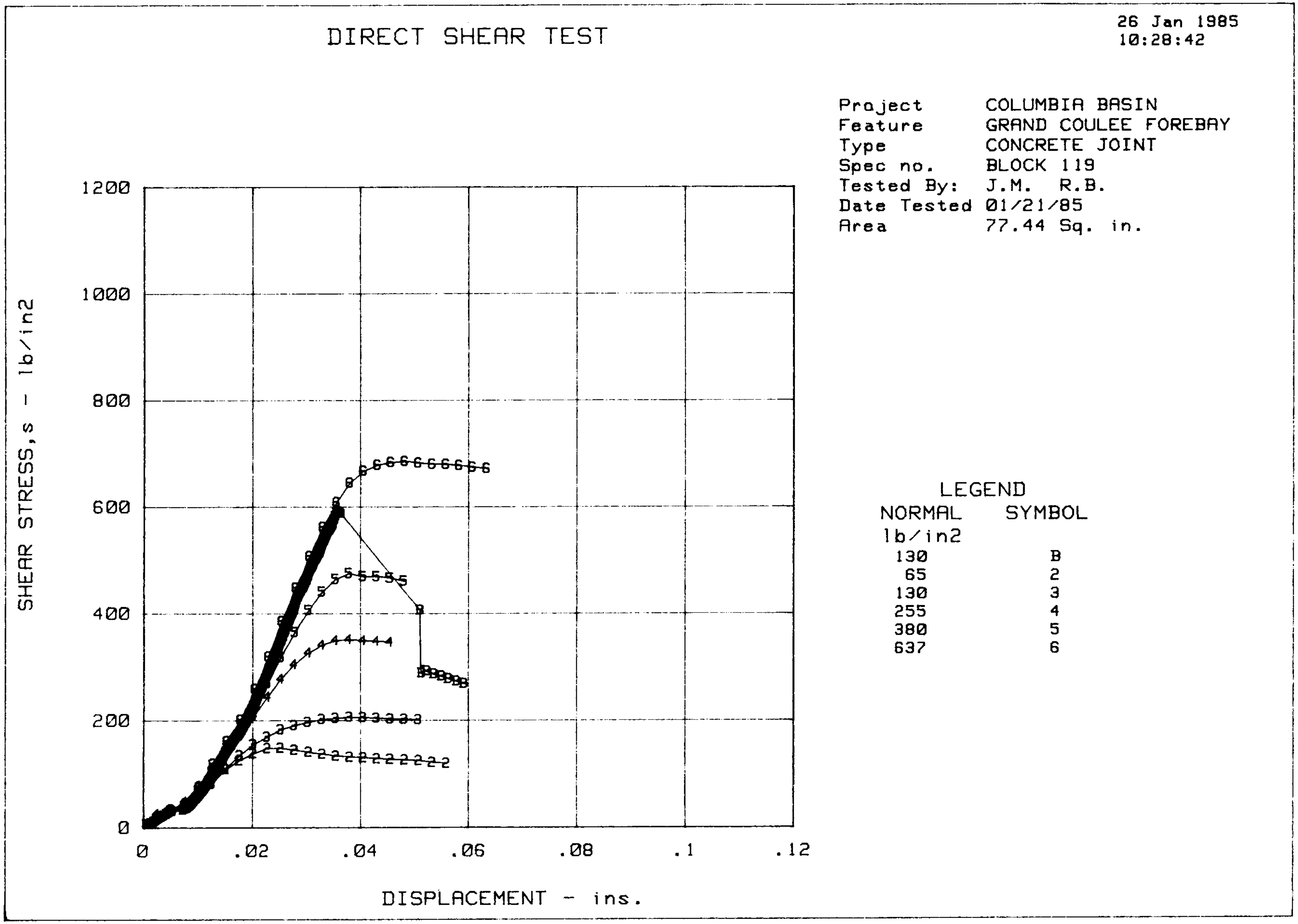
Parallel to sliding direction

Perpendicular to sliding direction

Specimen before testing



Specimen after testing



DIRECT SHEAR TEST

26 Jan 1985
10:28:42

Project COLUMBIA BASIN
Feature GRAND COULEE FOREBAY
Type CONCRETE JOINT
Spec no. BLOCK 119
Tested By: J.M. R.B.
Date Tested 01/21/85
Area 77.44 Sq. in.

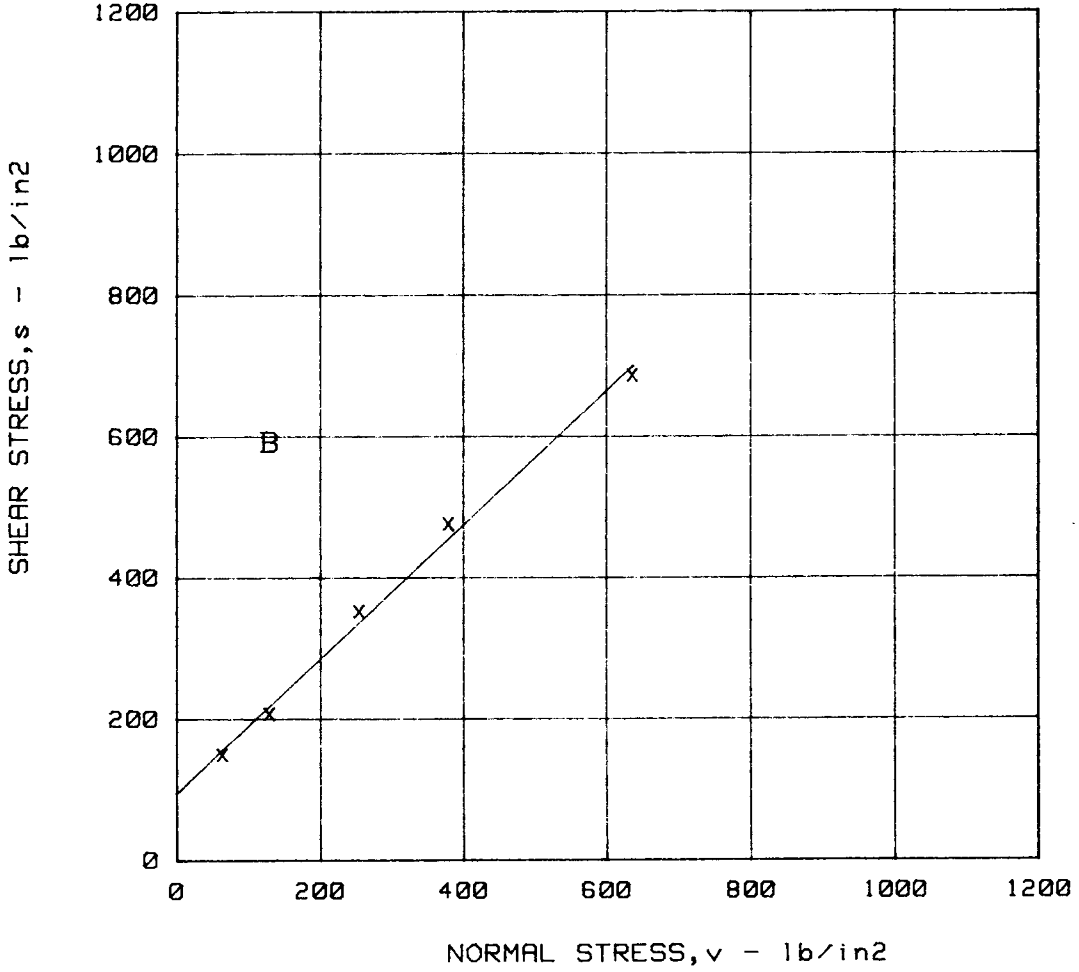
LEGEND

NORMAL lb/in2	SYMBOL
130	B
65	2
130	3
255	4
380	5
637	6

DIRECT SHEAR TEST

26 Jan 1985
10:31:17

Project	COLUMBIA BASIN
Feature	GRAND COULEE FOREBAY
Type	CONCRETE JOINT
Spec no.	BLOCK 119
Tested By:	J.M. R.B.
Date Tested	01/21/85
Area	77.44 Sq. in.



v lb/in2	s lb/in2
130	591
65	149
130	207
255	351
380	475
637	685

SLIDING FRICTION RESULTS

s= 95.1 + .949 (v)

COHESION = 95 lb/in2

PHI= 43^0 COR COEF= .9973

LEGEND
B = BREAKBOND VALUE
X = SLIDING FRICTION VALUES

```
26 Jan 1985          10:56:12

FINAL DATA

Project      COLUMBIA BASIN
Feature      GRAND COULEE FOREBAY
Type         CONCRETE JOINT
Spec no.     BLOCK 119
Tested By:   J.M.  R.B.
Date Tested  01/21/85
Area         77.44 Sq. in.


  NORMAL    SHEAR    DISPLACEMENT
  STRESS    STRESS
  lb/in2    lb/in2     inches

     130        2     0.0000
     130        5      .0007
     130        8      .0014
     130       11      .0020
     130       14      .0025
     130       17      .0029
     130       20      .0034
     130       23      .0038
     130       26      .0043
     130       28      .0047
     130       31      .0053
     130       34      .0074
     130       36      .0080
     130       39      .0083
     130       42      .0087
     130       45      .0089
     130       47      .0091
     130       50      .0094
     130       53      .0096
     130       56      .0099
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     130      251      .0213
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     130      267      .0220
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     130      273      .0223
     130      275      .0224
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     130      281      .0226
     130      283      .0227
     130      286      .0228
     130      289      .0229
     130      292      .0230
     130      294      .0232
     130      297      .0233
     130      300      .0234
     130      302      .0235
     130      305      .0236
     130      308      .0236
     130      311      .0237
     130      313      .0238
     130      316      .0240
     130      319      .0241
     130      322      .0242
     130      324      .0243
     130      327      .0245
```

130	330	.0246
130	333	.0247
130	335	.0248
130	338	.0249
130	341	.0250
130	343	.0251
130	346	.0253
130	349	.0254
130	352	.0255
130	354	.0256
130	357	.0257
130	360	.0257
130	362	.0258
130	365	.0260
130	368	.0261
130	370	.0261
130	373	.0262
130	376	.0264
130	379	.0265
130	382	.0267
130	384	.0267
130	387	.0269
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130	400	.0275
130	403	.0276
130	406	.0277
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130	411	.0278
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130	417	.0280
130	420	.0280
130	423	.0281
130	425	.0282
130	428	.0283
130	431	.0284
130	434	.0285
130	436	.0287
130	439	.0288
130	442	.0290
130	444	.0291
130	447	.0293
130	450	.0295
130	453	.0296
130	456	.0297
130	459	.0298
130	462	.0300
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130	467	.0302
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130	569	.0349
130	575	.0351
130	582	.0353
130	588	.0355
130	591	.0359
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130	273	.0577
-130	269	.0591

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65	126	.0177
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65	137	.0330
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130	156	.0202
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130	202	.0329
130	204	.0354
130	207	.0380
130	206	.0405
130	204	.0430
130	203	.0456
130	202	.0481
-130	201	.0507

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255	26	.0025
255	34	.0051
255	49	.0076
255	79	.0101
255	113	.0126
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255	341	.0329
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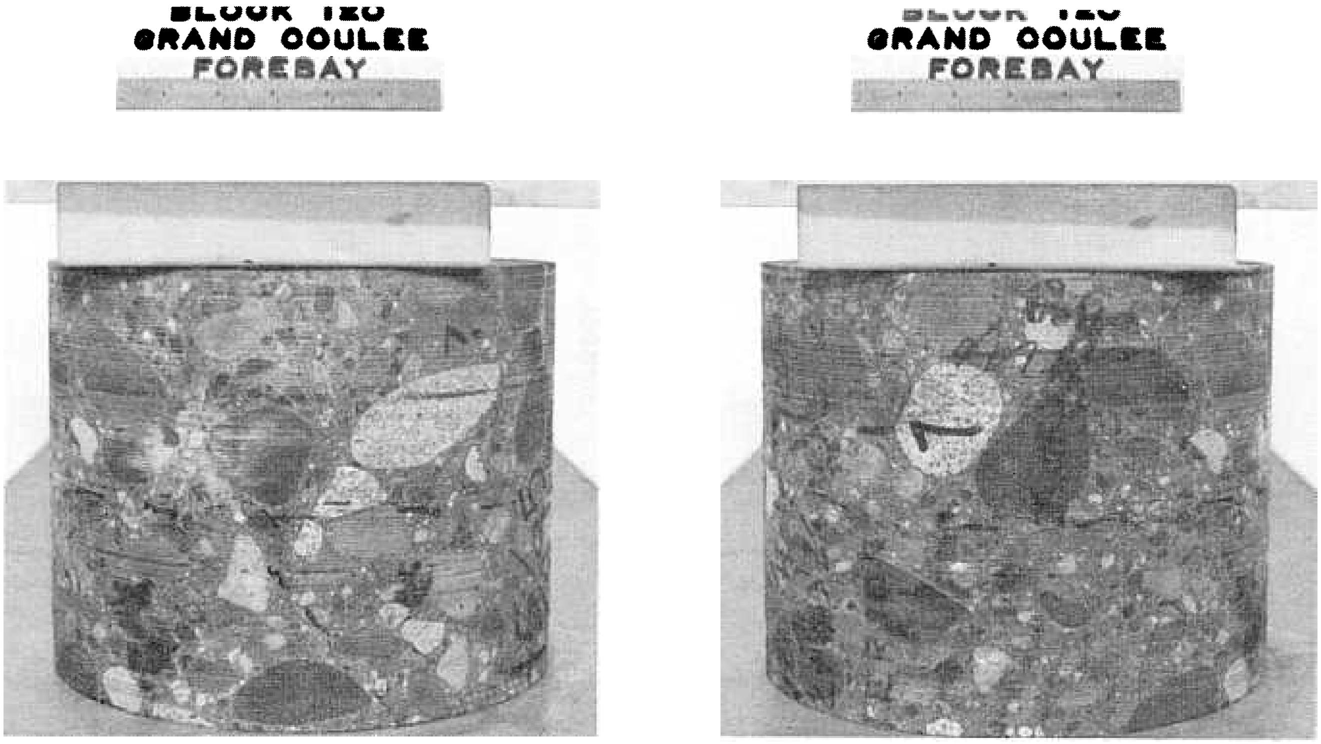
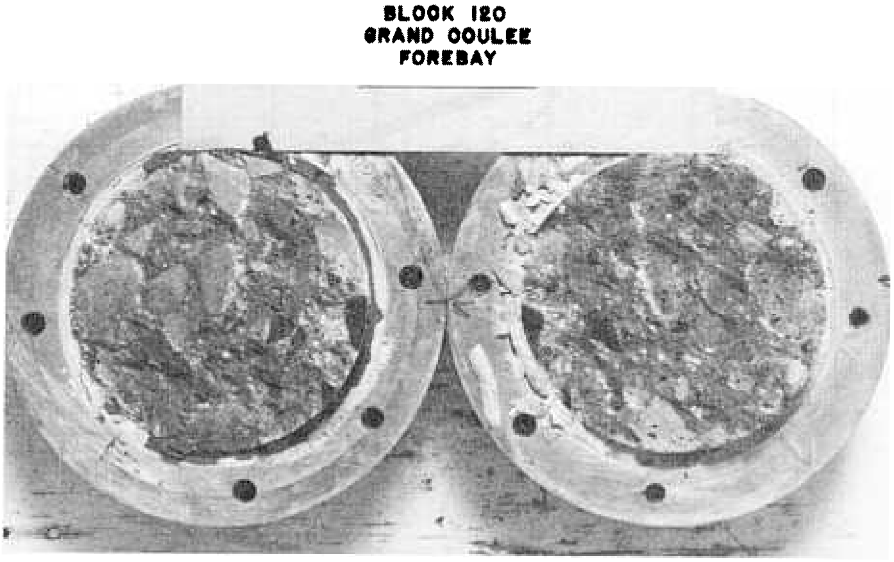


Parallel to sliding direction

Perpendicular to sliding direction

Specimen before testing

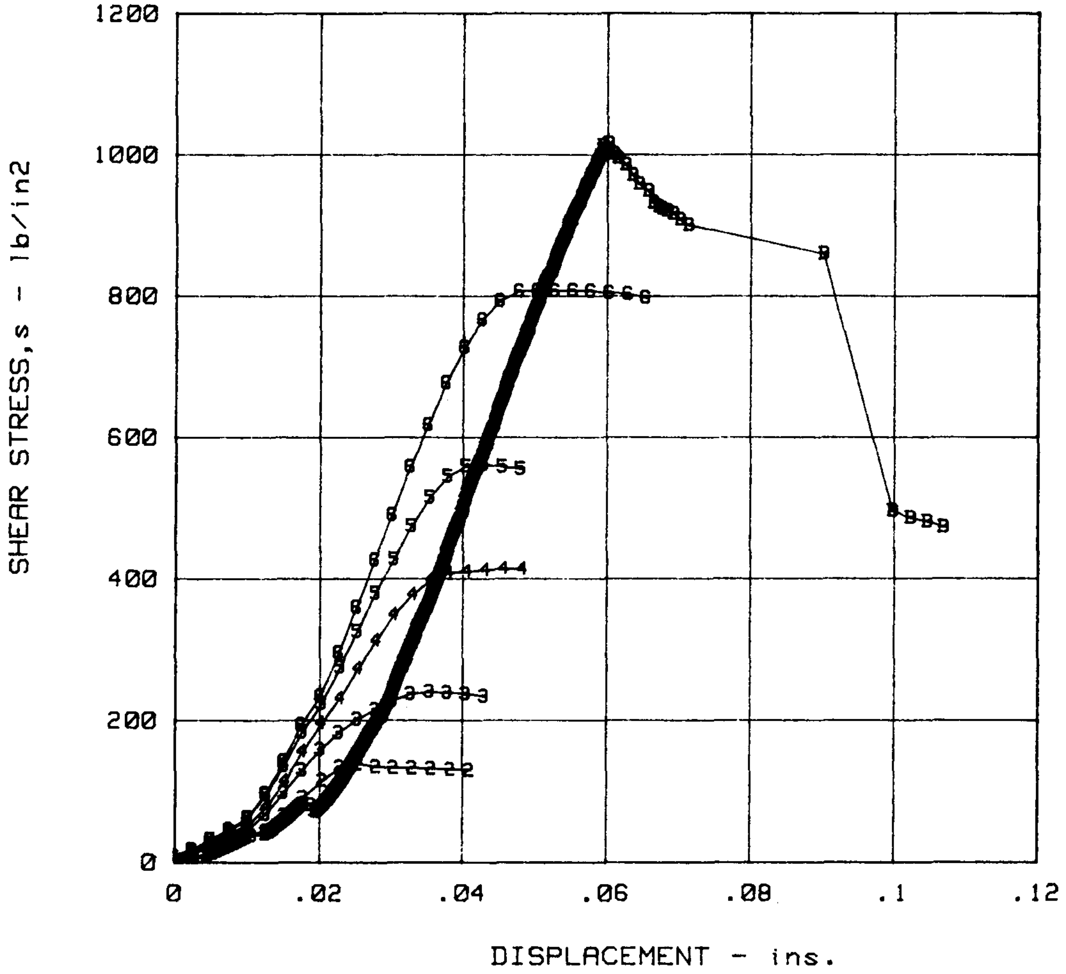


Specimen after testing

DIRECT SHEAR TEST

26 Jan 1985
10:46:43

Project	COLUMBIA BASIN
Feature	GRAND COULEE FOREBAY
Type	CONCRETE JOINT
Spec no.	BLOCK 120
Tested By:	J.M. R.B.
Date Tested	01/21/85
Area	77.44 Sq. in.



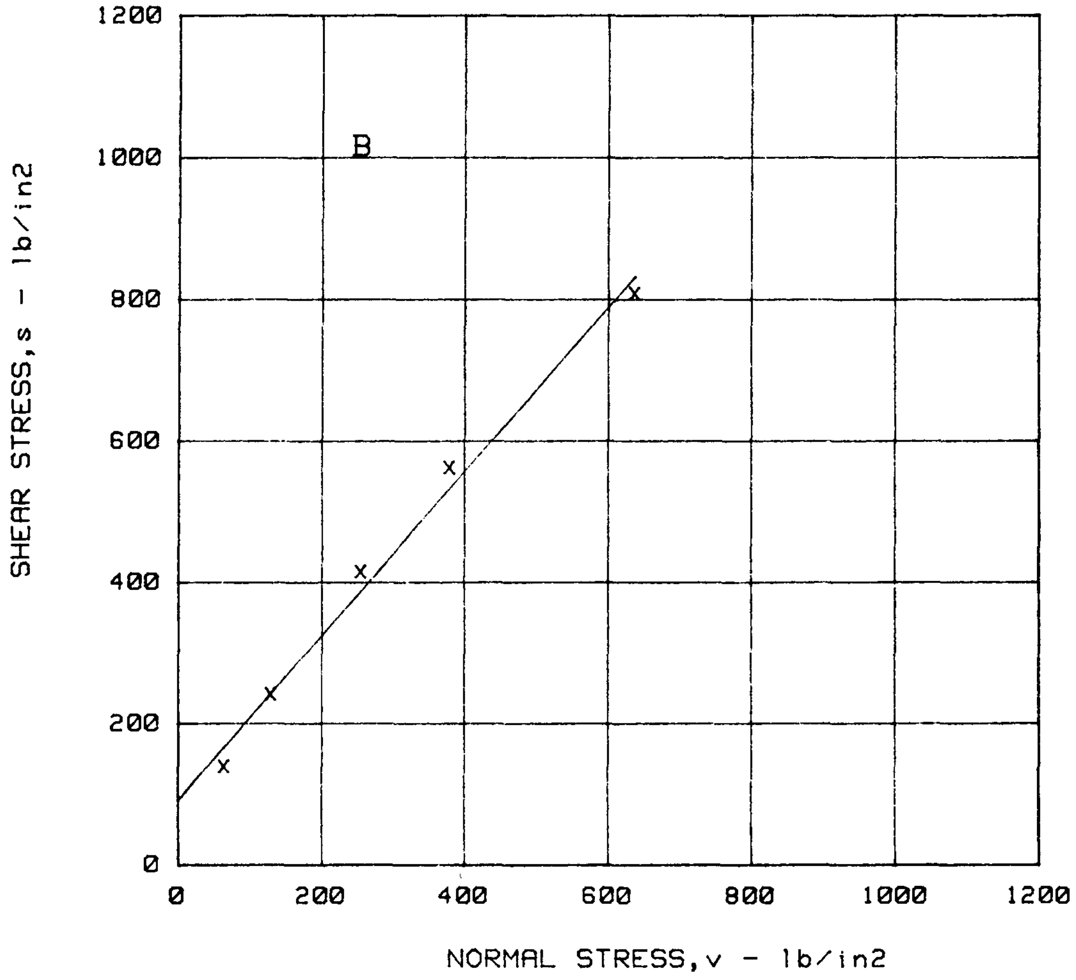
LEGEND

NORMAL lb/in2	SYMBOL
255	B
65	2
130	3
255	4
380	5
637	6

DIRECT SHEAR TEST

26 Jan 1985
10:49:18

Project	COLUMBIA BASIN
Feature	GRAND COULEE FOREBAY
Type	CONCRETE JOINT
Spec no.	BLOCK 120
Tested By:	J.M. R.B.
Date Tested	01/21/85
Area	77.44 Sq. in.



v lb/in2	s lb/in2
255	1015
65	139
130	241
255	414
380	561
637	808

SLIDING FRICTION RESULTS

s= 91.7 +1.162 (v)

COHESION = 92 lb/in2

PHI= 49^{0} COR COEF= .9949

LEGEND
B = BREAKBOND VALUE
X = SLIDING FRICTION VALUES

```
26 Jan 1985          10:58:55

FINAL DATA

Project      COLUMBIA BASIN
Feature      GRAND COULEE FOREBAY
Type         CONCRETE JOINT
Spec no.     BLOCK 120
Tested By:   J.M.   R.B.
Date Tested  01/21/85
Area         77.44 Sq. in.


  NORMAL    SHEAR   DISPLACEMENT
  STRESS    STRESS
  lb/in2    lb/in2     inches

     255         2    0.0000
     255         5     .0024
     255         8     .0037
     255        10     .0046
     255        13     .0053
     255        16     .0059
     255        18     .0065
     255        21     .0071
     255        24     .0077
     255        27     .0083
     255        29     .0088
     255        32     .0094
     255        35     .0099
     255        38     .0106
     255        40     .0126
     255        43     .0132
     255        46     .0136
     255        49     .0140
     255        52     .0143
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     255        82     .0177
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     255        74     .0193
     255        72     .0196
     255        74     .0199
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     255        80     .0205
     255        83     .0207
     255        86     .0209
     255        88     .0212
     255        91     .0214
     255        94     .0216
     255        96     .0218
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     255       105     .0224
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     255       206     .0288
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Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-822A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.