CONCRETE PERFORMANCE IN GRAND COULEE FOREBAY DAM, WASHINGTON: 1-YEAR CORE REPORT

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16. ABSTRACT

Results of physical properties tests on 150-mm (6-in) and 255-mm (10-in) diameter cores extracted from interior and exterior mass concrete in Grand Coulee Forebay Dam, Washington, at 6 months' and 1 year's age indicate a good quality, uniform, well-consolidated concrete exceeding established design criteria. This study is part of a series in the Bureau's long-term evaluation of strength and elastic properties of concrete in various dams. Tensile strength tests to study bond strength of the horizontal construction joints show the bond to be as good as the adjacent concrete. Combined results of 150- and 255-mm cores show: (1) average compressive strengths of 31.6 MPa (4590 lb/in^2) at combined results of 150- and 255-mm cores show: 6 months and 32.4 MPa (4700 lb/in^2) at 1 year for interior concrete and 33.8 MPa (4900 lb/in^2) at 6 months and 37.5 MPa (5440 lb/in^2) at 1 year for exterior concrete, (2) average strength gain of 8 percent from 6 months to 1 year, (3) average tensile strength equal to 3.9 percent of compressive strength, (4) average modulus of elasticity of 35.5 GPa (5.15×10^6 lb/in^2), (5) average Poisson's ratio of 0.18, (6) average density of 2480 kg/m^3 (155 lb/ft^3), (7) shearing strength of jointed cores, at zero normal stress, equal to 83 percent of nonjointed cores, and (8) overall coefficient of variation of strength of cores of 17.5 percent. Compressive and tensile strengths of 150-mm (6-in) diameter cores averaged higher than those of the 255-mm (10-in) diameter cores; whereas the modulus of elasticity and Poisson's ratio averaged lower.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Division of General Research
Engineering and Research Center
Denver, Colorado
December 1977

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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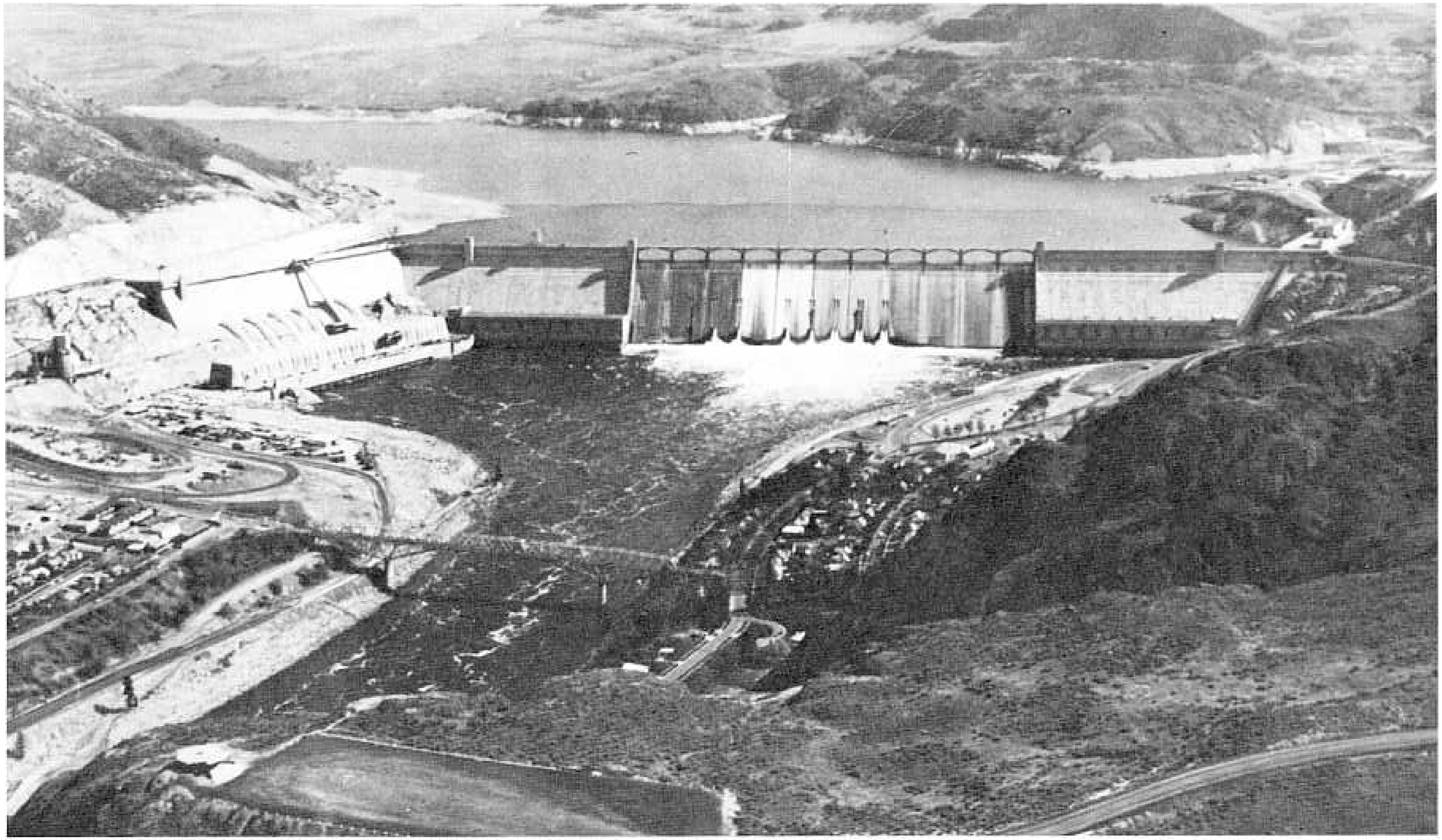
This study was conducted by personnel of the Concrete and Structural Branch, Division of General Research. The assistance of many people in the investigation and report of this study is greatly appreciated, particularly E. R. Dunstan, Jr., and V. R. Guy.

Note: The data reported in this document were measured in U.S. customary units and converted to SI metric units.



Grand Coulee Dam, Left Powerplant, Pumping/Generating Plant, Right Powerplant, and Third Powerplant.
Photo P222-117-34733

CONTENTS

APPENDIXES

TABLES

FIGURES

INTRODUCTION

This report covers a concrete core testing program conducted during the construction of Grand Coulee Third Powerplant and Forebay Dam, Columbia Basin Project, Wash., under Specifications No. DC-6790. Construction of the dam was started in March 1970 and completed in August 1973.

The Third Powerplant and Forebay Dam are situated on the right bank of the Columbia River downstream from and adjacent to Grand Coulee Dam, near the town of Grand Coulee, Wash. The principal features are a concrete forebay dam, six 12.2-m (40-ft) diameter concrete-encased penstocks, a powerplant with six generators, a visitors facility, service road, and switchyards.

The forebay dam from which the cores for this investigation were taken is a gravity-type structure with a maximum height of approximately 60 m (200 ft) above the foundation and a crest length of approximately 390 m (1275 ft). The dam contains about 463 000 m^3 (605 000 yd^3) of mass concrete. The concrete in the dam is divided into blocks by vertical transverse contraction joints. Galleries and adits provide access to selected locations in the interior of the dam.

Concrete in the Forebay Dam contains type II, low-alkali cement; Class F pozzolan; natural sand; and 150-mm (6-in) maximum size aggregate. A portion of the coarse aggregate was crushed. An air-entraining admixture and a lignin-type water-reducing, set-controlling admixture were used in the concrete. Average concrete in the interior sections of the Forebay Dam contains 112 kg/m^3 (188 lb/yd^3) of cement and 47 kg/m^3 (80 lb/yd^3) of pozzolan. For exterior concrete, on the exposed surfaces of the dam, typical mass concrete contains 133 kg/m^3 (224 lb/yd^3) of cement and 57 kg/m^3 (96 lb/yd^3) of pozzolan.

The specifications provided for a concrete core drilling program to obtain cores for a study of the effects of age and loading on the strengths and elastic properties of the interior and exterior mass concretes. After starting construction, an additional drilling program was instituted to obtain cores for a study of the bond strength at the horizontal construction joints. The concrete was approximately 6 months old and 1 year old when the cores were extracted and tested. This report presents the results of the tests performed on 150- and 255-mm (6- and 10-in) diameter cores. Additional cores probably will be extracted in later years to further evaluate the properties of the concrete in this structure.

CORE DRILLING PROGRAM

The core drilling program, as outlined by the construction specifications, required extraction of 255-mm (10-in) diameter cores from the hardened concrete at locations designated by the Bureau. The cores representing the interior concrete were to be taken from galleries in the dam. Cores representing the exterior concrete were to be taken from the floor of the elevator room at elevation 388.6 m (1275 ft), the floor of the gate hoist chamber at elevation 395.5 m (1297.5 ft), and the top of the fillet downstream from the dam and adjacent to the existing dam at elevation 341.4 m (1120 ft). Locations for all cores are shown on figure 1.

A total of thirty-six 255-mm-diameter cores were to be extracted. Eighteen cores were to be extracted during each of the two major construction seasons. Twelve of the 18 cores were to be extracted from interior concrete and 6 from exterior concrete. Half the cores were to be drilled when the concrete was between 140 to 160 days of age so that the 6-month tests could be made on schedule,

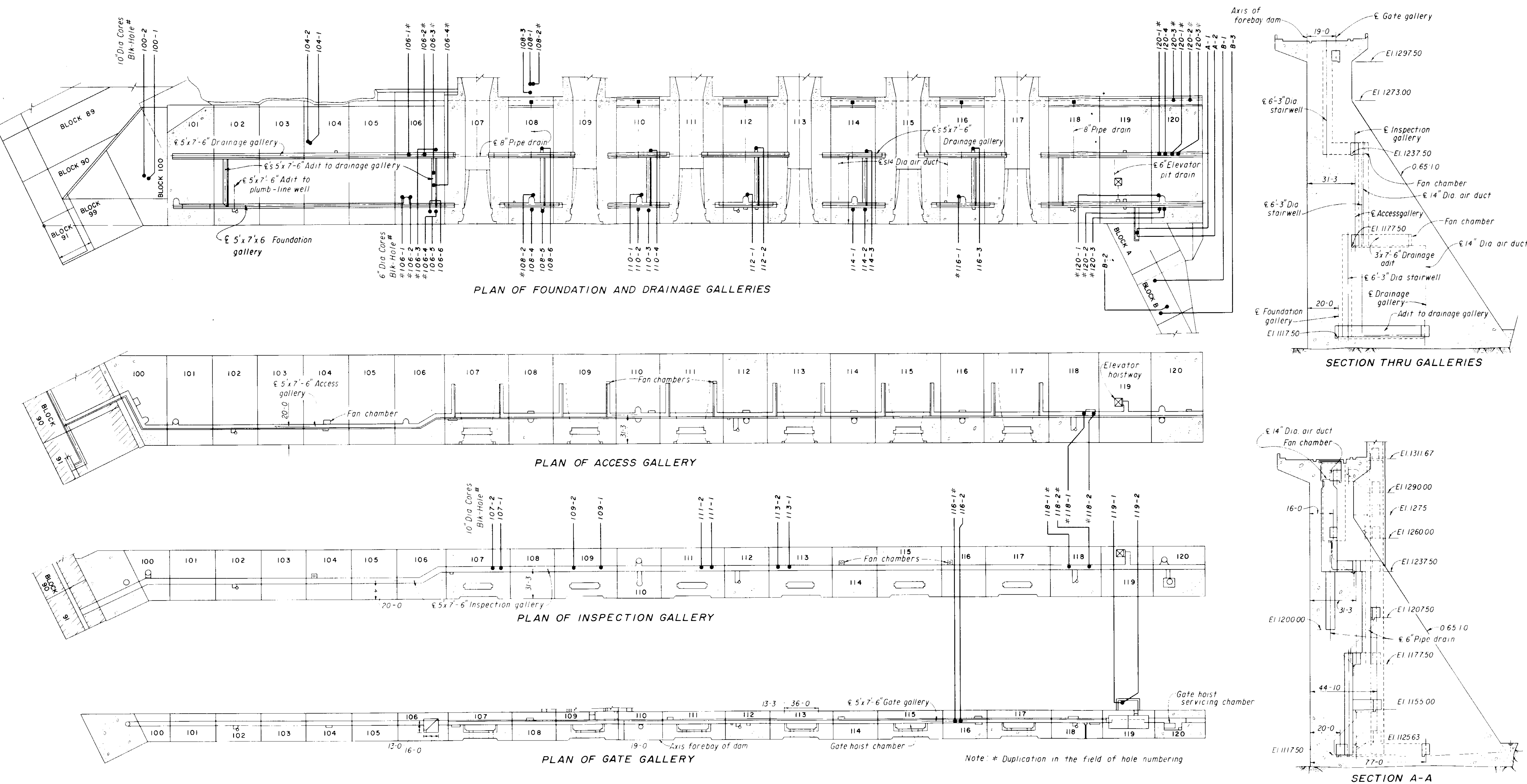


Figure 1. - Hole locations for 150- and 255-mm (6- and 10-in) diameter cores - Grand Coulee Forebay Dam

and the other half were to be drilled at the same locations when the concrete was between 325 and 345 days old so that the 1-year tests could be made. The cores were to be drilled vertically with diamond drills to a depth sufficient to permit extraction of two lengths of core 660 mm (26 in) long, whereupon each could be cut effectively into 510-mm (20-in) lengths. None of the holes was to be drilled more than 4.6 m (15 ft) deep.

The specifications also required the prime contractor to cure three horizontal construction joints in the wing dam above elevation 393.2 m (1290 ft) with a pigmented, resin-base membrane, bonding and curing compound similar to one found suitable in laboratory tests.[1] This was to evaluate the bonding effectiveness of this type of curing compound when it was left in place for the succeeding placement. The bonding and curing compound used was a chlorinated rubber material conforming to Bureau of Reclamation requirements.[2] As a means of evaluating the effectiveness of the bonding and curing compound, cores were drilled through the joints.

In May 1971, an additional core drilling program was established. The purpose of this program was to enhance the Bureau's knowledge of the bond strength of horizontal construction joints in concrete dams. To accomplish this, 20 cores, which crossed construction joints in the Forebay Dam, were extracted.

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[1]Graham, James R., "Use of Curing Compounds on Horizontal Construction Joints," Proc. Engineering Foundation Conf., Economical Construction of Concrete Dams, Asilomar, Pacific Grove, Calif., May 1972.

[2]"Method of Test and Test Requirements for Shear Strength of Bonding Agents for Bonded Concrete Construction Joints," Bureau of Reclamation, Denver, Colo., Sept. 1969.

The cores were approximately 150 mm (6 in) in diameter and a minimum of 355 mm (14 in) long, with the joint near the center of the specimen. The cores were drilled at about a 30° dip from the horizontal construction joints. Cores with large aggregate near the construction joint which might adversely affect the test results were discarded.

EXTRACTION OF CORES

The extraction of the 150-mm-diameter cores was started on July 7, 1971, and was completed by August 24, 1971, except for one hole which was drilled on March 10, 1972. A total of twenty-six 150-mm-diameter holes were drilled; however, the core from hole 3 in block 108 was broken during drilling and discarded. The core from hole 3 in block 106 broke at the construction joint during extraction, but was submitted to the Denver laboratories for visual inspection. The core from hole 2 in block B of the wing dam parted at the construction joint during drilling due to lack of bond at the joint. Twenty-four of the holes were drilled from the foundation and drainage galleries in the Forebay Dam and one was drilled from the top of the wing dam in block B. The cores in the Forebay Dam were drilled in blocks 106, 108, 110, 112, 114, 116, and 120 and were all in interior concrete. The core from the top of the wing dam was in exterior concrete and was drilled to check the construction joint on which the chlorinated rubber-base bonding and curing compound had been used. The holes were drilled approximately 1.8 m (6 ft) deep.

The extraction of the 255-mm-diameter cores was started on July 13, 1971, and was completed January 29, 1974. A total of 37 holes were drilled. The holes were drilled in various galleries and adits, and also in the top of the dam. Cores for interior concrete at 6 months' age were drilled in blocks 104, 106, 107, 109, 111, 113, 118, 120, and block A in the wing dam. Cores for the exterior concrete at 6 months of age were drilled in blocks 100, 108, 116, 119, 120, and block B of the wing dam. The two holes in block B of the wing dam were drilled to check the construction joint on which the chlorinated rubber-base bonding and curing compound had been used. Six of the 37 cores broke at the construction joint during drilling, including the 2 holes drilled in block B.

Core holes for the interior and exterior concrete at 1 year's age were drilled at the same location as those drilled for the 6 months' age cores. Initially, the 255-mm-diameter holes were drilled approximately 2.7 m (9 ft) deep. This was changed, however, when it was determined that there was a need for more tensile strength data on mass concrete to correlate structural behavior studies with current design concepts. On March 8, 1972, the project office was directed to increase the hole depth to 3.7 m (12 ft), thereby providing two compression test specimens: one construction joint tensile test specimen, and one nonjointed tensile test specimen. The core for the jointed specimen was to extend about 455 mm (18 in) on either side of the joint. The nonjointed tensile specimen on the lower end of the core was to be about 760 mm (30 in) long. The drilling rate for the 255-mm (10-in) cores ranged from 0.4 to 0.8 m/h (1.3 to 2.6 ft/h) with an average of 0.6 m/h (2.0 ft/h).

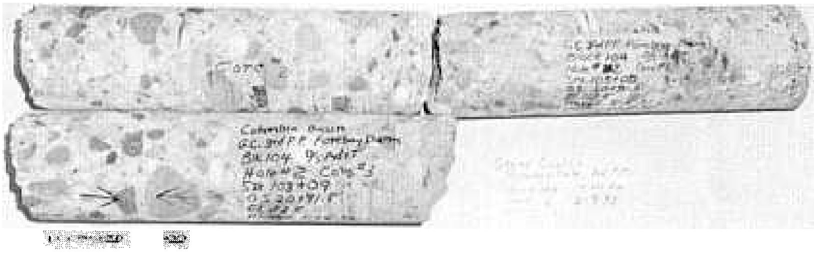
In several instances, while drilling cores, cooling pipes which were still in use were inadvertently cut. Whenever this occurred, the core hole was backfilled with fresh concrete to the elevation of the construction joint. A space approximately 75 mm (3 in) high was then formed using metal chairs or spacers with a wood form across the top, and the remainder of the hole was backfilled with concrete. This left a passageway for the water during concrete cooling which was later filled with grout when the cooling pipes were grouted.

The prime contractor used an air-operated drill with 165-mm (6.5-in) diameter and 265-mm (10.5-in) diameter diamond core bits. The core barrels were of sufficient lengths so that 760-mm (30-in) long cores for compressive strength tests and 1015-mm (40-in) long cores for tensile strength tests could be removed intact.

SHIPPING AND RECEIVING

After the cores were extracted, they were labeled with the name of the project, block number, hole number, core number, elevation, and the date drilled. Then they were wrapped in paper, packed in wet sawdust in substantial wooden boxes with one core to a box, and shipped to the Bureau's Division of General Research for testing. The cores were received in Denver in good condition.

In the Denver laboratories, the cores were first logged to provide a record of specimen lengths and unusual characteristics such as embedded reinforcing steel, rock pockets, construction joints, etc. The cores were then marked for the type of test to be conducted. Photographs were taken of the cores in groups and individually as needed to show detail. Figures 2, 3, and 4 are photographs of some typical specimens.



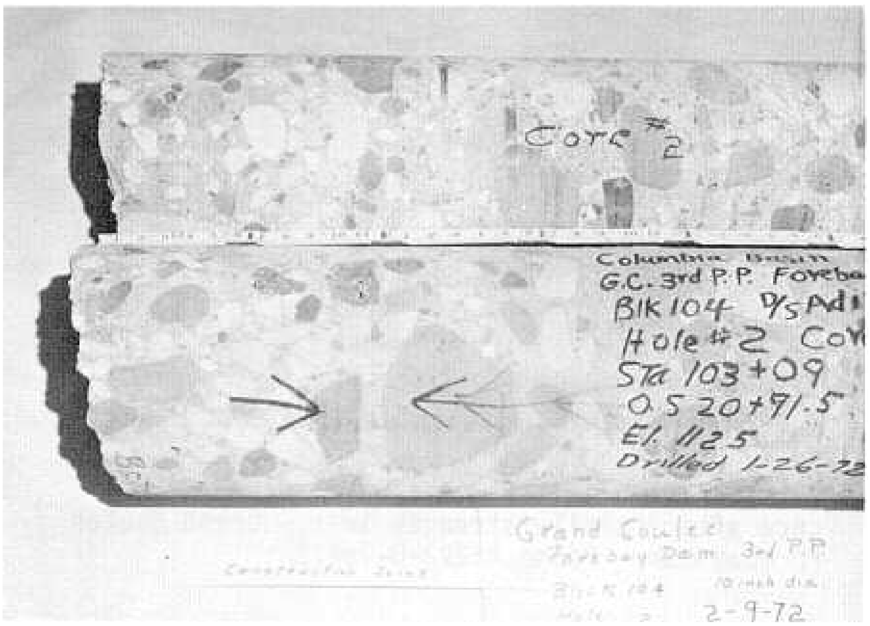


Figure 2. - Typical 255-mm (10-in) diameter cores showing a construction joint - Grand Coulee Forebay Dam. Photos P1222-D-78276 and P1222-D-78277

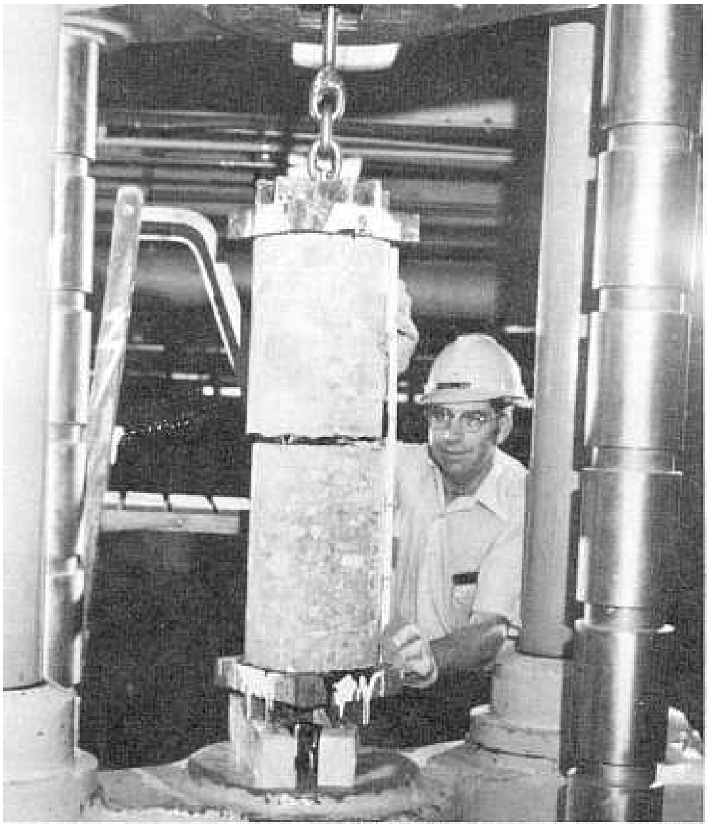
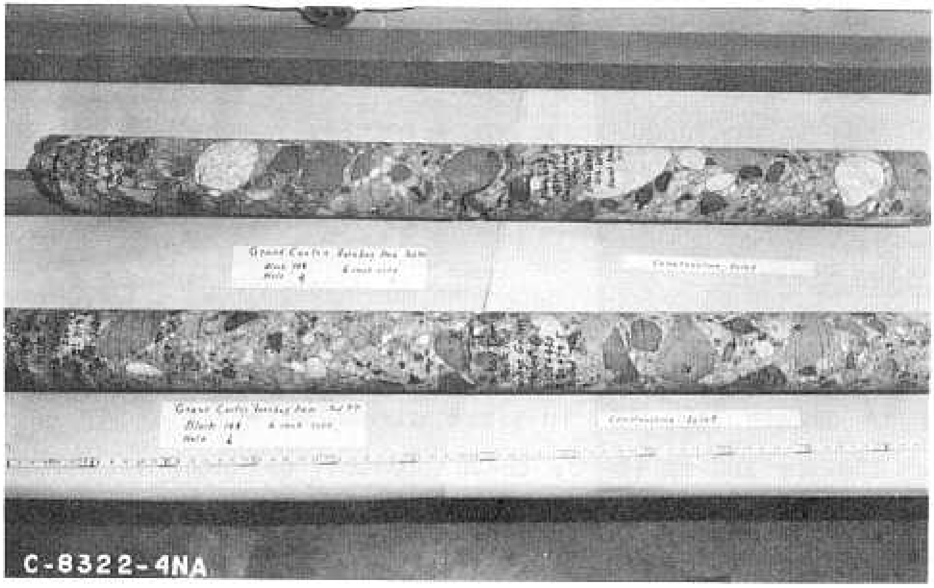


Figure 3. - Typical 255-mm (10-in) diameter core after tensile strength test - Grand Coulee Forebay Dam. Photo P1222-D-78273



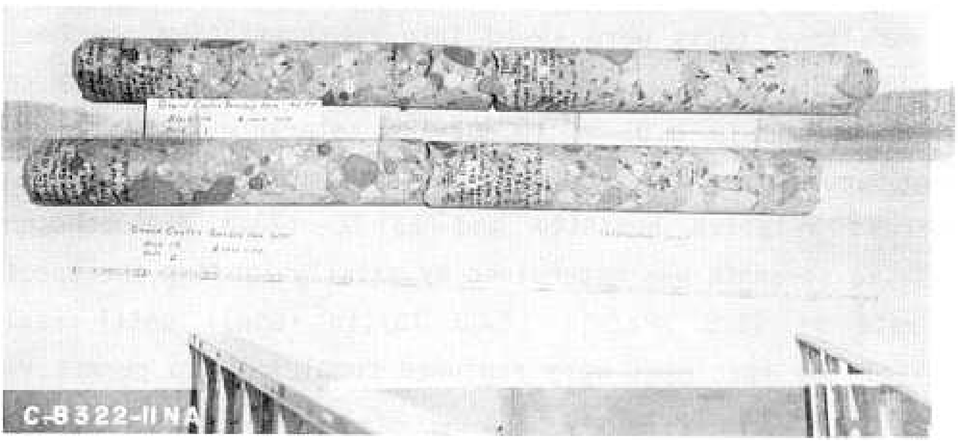


Figure 4. - Typical 150-mm (6-in) diameter cores showing construction joints - Grand Coulee Forebay Dam. Photos P1222-D-78274 and P1222-D-78275

TESTING PROGRAM FOR 255-MILLIMETER (10-INCH) DIAMETER CORES

General

Cores were extracted so that studies could be made of the interior and exterior concretes at 6 months' and 1 year's age. The actual testing program included tests to determine compressive strength, elastic properties, density, tensile strength, and shear strength.

Compressive Strength

Compressive strength tests on the cores were conducted on selected samples to obtain apparent in-place strengths which could be compared to 150- by 300-mm (6- by 12-in) control cylinder strengths and to determine the strength development of the concrete in the dam over a period of 1 year. In general, the cores selected for compression testing did not contain construction joints.

Cores for these tests were sawed into representative specimens of 510-mm (20-in) lengths and then the ends were ground until square and flat to within 0.05-mm (0.002-in) tolerance. Subsequent to grinding and prior to testing, the specimens were stored in a 100-percent relative humidity and 23 °C (73.4 °F) atmosphere. Compressive strength was determined by axially loading the specimens at a rate of 13.8 MPa/min (2000 $lb/(in^2 \cdot min)$) until failure. Several of the specimens were ruptured completely to permit visual observation of the fractures.

Elastic Properties

Elastic property tests were made on the same core specimens selected for the compressive strength tests. Data obtained from these tests may be used later in structural behavior studies. The modulus of elasticity and Poisson's ratio were determined on the specimens using an extensometer-compressometer frame, with dial gages mounted so that longitudinal and lateral deformations were monitored as the actual load was applied. All specimens underwent preloading and then strain readings were taken at 0, 35.6, and 355.9 kN (0, 8000, and 80 000 lb) total load. Computations for modulus of elasticity and Poisson's ratio were based on the net strain occurring between the 35.6-kN and 355.9-kN loads.

Density

Prior to conducting the compressive strength tests, "as is" densities of the core specimens were determined. Obtaining the density of hardened concrete provided a quick qualitative evaluation of concrete quality.

Tensile Strength

Tensile strength tests were made on cores which intercepted the horizontal construction joints and were in a plane normal to the vertical axis of the core. These tests were performed primarily to determine the bond strength of the construction joint. Some core specimens without construction joints also were tested for tensile strength comparisons.

The cores to be used in evaluation of the construction joints were sawed into approximately 760-mm (30-in) long specimens with 380 mm (15 in) of concrete on each side of the joint. After the ends were cleaned with acetone, a 50-mm (2-in) thick by 255-mm (10-in) square steel plate was cemented to each end of the specimen with an epoxy resin and allowed to cure for 24 hours. The specimens were then subjected to direct tension through a flexible, self-centering, loading apparatus mounted in a 1780-kN (400 000-lb) universal testing machine.

Dynamic Tension

Fourteen core specimens were selected for dynamic tensile strength testing to study the effects of dynamic loadings on the concrete. In the past, static tensile strengths have been used when analyzing the response of Bureau structures to dynamic loading. When designing for nonstatic loading, these strengths may not take into account the changes in properties which occur when a structure is subjected to dynamic loadings such as those caused by earthquake conditions and vibrations from rotating equipment.

For the dynamic tension tests, 255-mm (10-in) diameter by 510-mm (20-in) long specimens were used. These specimens were tested in the Denver laboratories vibration test facility. The cores were first instrumented for length change and then epoxied into a load frame which contained a load-measuring device and a servocontrolled hydraulic actuator. Each core was subjected to sinusoidal loadings which passed from compression through zero into the tension zone. Load and displacement data were recorded and results computed. These tests will be included in a separate report. The core specimens selected for dynamic tension testing are:

Cores for dynamic tension test

Block	Hole	Core	Type of concrete	Type of joint
111	1	3	Interior	Jointed
111	1	4	"	Unjointed
107	1	3	"	Jointed
107	1	4	"	Unjointed
113	1	2	"	"
118	1	5	"	"
109	2	3	"	Jointed
118	2	3	"	"
118	2	4	"	Unjointed
118	2	1	"	"
118	1	4	"	"
100	2	5	Exterior	"
116	2	4	"	"
B	3	5	"	"

Direct Shear

Eight core specimens were selected for shear testing. These specimens were taken from sections of cores without construction joints and were representative of both interior and exterior concretes. The specimens were cut into 150-mm (6-in) lengths and stored for later testing. The shear tests will be made when fabrication of the equipment for handling 255-mm-diameter specimens is completed.

The samples selected for shear tests are:

Cores for direct shear test

Block	Hole	Core	Type of concrete
100	2	4	Exterior
116	1	4	"
116	2	2	"
118	1	4	Interior
118	1	2	"
119	1	1	Exterior
120	3	3	Interior
B	3	3	Exterior

TEST RESULTS OF 255-MILLIMETER (10-INCH) DIAMETER CORES

Compressive Strength

The results of the individual tests are shown in tables 1 and 2. Summaries of results are shown in tables 3 and 4. The average compressive strength for the interior concrete was 30.2 MPa (4380 lb/in^2) at 6 months' age and 32.4 MPa (4700 lb/in^2) at 1 year's age. The average strength for the exterior concrete was 33.8 MPa (4900 lb/in^2) at 6 months' age and 37.5 MPa (5440 lb/in^2) at 1 year's age. This shows an increase in strength from 6 months to 1 year of 7 percent for interior concrete and 11 percent for exterior concrete, which is slightly above average for strength development in mass concrete.

The compressive strengths of the cores extracted from interior concrete ranged from 20.5 to 40.3 MPa (2980 to 5850 lb/in^2) at 6 months' age and from 23.1 MPa (3350 lb/in^2) to 44.4 MPa (6440 lb/in^2) at 1 year's age. The corresponding coefficients of variation were 17.5 and 17.0 percent, respectively. Compressive strengths of the cores extracted from exterior concrete ranged from 22.3 MPa (3240 lb/in^2) to 44.5 MPa (6460 lb/in^2) at 6 months' age and from 21.2 MPa (3080 lb/in^2) to 54.6 MPa (7920 lb/in^2) at 1 year's age. The corresponding coefficients of variation were 19.2 and 21.0 percent, respectively. The higher coefficient of variation in exterior concrete at 1 year's age largely is due to one low core strength which resulted from failure along a large aggregate particle. When that low strength is deleted from the data, the coefficient of variation for exterior concrete is 16.9 percent at 1 year's age.

In only one case was the core compressive strength below the design strength of 20.7 MPa (3000 lb/in^2) at 180 days.

In general, compressive strength development of the cores was in direct correlation with that of the 28-day control cylinders, with an overall ratio of core strength to 28-day control cylinder strength of 121 percent at 6 months' age and 135 percent at 1 year's age. The strength ratio was higher for interior concrete than for exterior concrete at both 6 months' and 1 year's age. For several of the core specimens there were no 28-day control cylinder strengths available for comparison. For some reason, 6 of the 13 cores extracted from exterior concrete and tested at 6 months' age had compressive strengths below the control cylinder strengths. However, cores extracted from approximately the same locations and tested at 1 year's age did not reflect this trend. The comparisons between core strengths and the 150- by 300-mm (6- by 12-in) control cylinders are shown graphically on figure 5.

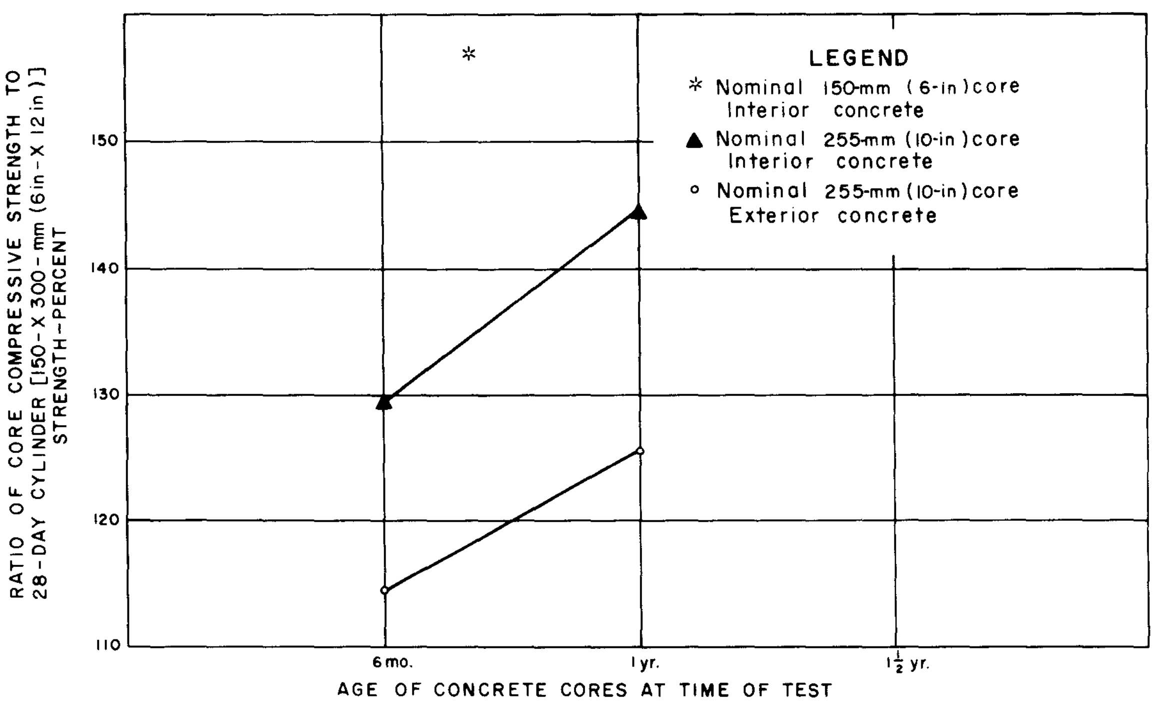


Figure 5. - Comparison of compressive strength of concrete cores and control cylinders, Grand Coulee Forebay Dam.

Elastic Properties

Results of elastic property tests are summarized in tables 3 and 4. The results showed very little difference in modulus of elasticity between 6 months' and 1 year's age or between interior and exterior concrete.

The modulus of elasticity ranged from 21.0 GPa (3.05 x 10^6 lb/in^2) to 44.3 GPa (6.43 x 10^6 lb/in^2) with an overall average of 35.7 GPa (5.18 x 10^6 lb/in^2).

Poisson's ratio averaged 0.19 for all the tests with no significant differences between 6 months and 1 year or between exterior and interior concrete.

Density

Density valves are shown in tables 1 and 2. For all tests the density averaged 2480 kg/m^3 (155 lb/ft^3), which is within the expected range. There were no significant differences between densities for 6 months and 1 year nor between the interior and exterior concretes.

Tensile Stength

Thirty of the 37 cores extracted from the Forebay Dam intersected horizontal construction joints. All of these construction joints had been cleaned by the wet-sandblast method, except for those in block B of the wing dam which had been treated with a chlorinated rubber-base bonding and curing compound. Six of the 30 cores which intersected construction joints broke at the joint during drilling, including the 2 cores across the construction joints in block B of the wing dam. Excluding the joints where the bonding and curing material was used, the remainder of the cores appeared to have very good construction joints.

Fifteen core specimens from 12 drill holes were selected for tensile strength testing at 6 months' age. Nine of the specimens were from interior concrete and six from exterior concrete. Four specimens from both exterior and interior concretes contained construction joints.

Twenty-two specimens from 17 drill holes were selected for tensile strength testing at 1 year's age. Fifteen of the specimens were taken from interior concrete and seven from exterior concrete. Five of the specimens from exterior concrete and six from interior concrete contained construction joints.

The individual test results are shown in tables 1 and 2 and are summarized in tables 5 and 6. Of the 19 tested specimens which contained construction joints, only 4 broke at the construction joint. All others broke at varying distances from the joint. Of the four specimens which broke at the construction joints, two were in cores tested at 6 months' age and two were in cores tested at 1 year's age. The tensile strength of the specimens which broke at the joint averaged 1.21 MPa (175 lb/in^2) at 6 months' age and 1.45 MPa (210 lb/in^2) at 1 year's age. The remainder of both the unjointed and jointed specimens averaged 1.21 MPa (175 lb/in^2) at both 6 months' and 1 year's age. There was little significant difference between interior and exterior concrete tensile strengths at 6 months' age, but at 1 year's age, the exterior concrete developed about 20 percent more tensile strength.

The tensile strength tests were not very indicative of the actual bond strength of the construction joint since most of the tested specimens broke in the concrete away from the joint, rather than at the joint. The areas of disbonding between paste and aggregate were estimated for each test specimen; however, there was poor correlation between the tensile strength and the area of disbonding. The tests did show that the tensile strength of the construction joints was as good or better than that of the adjacent concrete.

The tensile strength for all specimens averaged 3.7 percent of the compressive strength, with little significant differences between interior and exterior concretes or between 6 months' and 1 year's ages. This strength ratio is average for mass concrete.

The construction joint in block B of the wing dam which was painted experimentally with chlorinated rubber-base bonding and curing compound showed little or no bond. Both of the 255-mm-diameter cores which were drilled through the construction joint parted at the joint during drilling.

Table 1. - *Compilation of 255-mm (10-in) diameter core data - Interior and exterior concrete at 6 months' age - Grand Coulee Forebay Dam*

Core No. 1/	Location of hole: Station No.	Offset from axis	Elevation top of hole, ft	Location in dam	Lift in block No.	Core data: Date drilled	Depth of core, ft	Joint elevation, ft	Direction drilled	Condition of concrete in core	Concrete data when placed: Date placed	Max size aggr, in	Temperatures, °F: Conc	H_2O	Air Max	Air Min	$\frac{W}{C+P}$	Cement, lb/yd³	Pozzolan, lb/yd³	Water, lb/yd³	Sand, %	Unit weight, lb/ft³	Slump, in	Air content, %	6" x 12" control cylinders compressive strength, 4/ lb/in²: 7-d	28-d	90-d	180-d	1 yr	Test data on concrete cores: Compressive strength, lb/in²	Elastic properties: E x10⁻⁶ lb/in²	r	Specific gravity	Unit weight lb/ft³	Tensile test: Strength, lb/in²	% area disbonded	Distance of break from end, in	Remarks
																Interior Concrete																						
104-1-1	103+10	20+90	1125.0	Downstream adit	26	7-13-71	0.0- 2.6		Vertical		2-16-71	6	49	37	40	39	0.51	190	80	137	25	157.1	1.75	2.1	-	3,075	4,800	-	-	-	-	-	-	-	-	-	-	
-2	103+10	20+90	1125.0	Downstream adit	26	7-13-71	2.6- 6.0		Vertical	Some small air voids	2-16-71	6	48	37	46	30	0.49	187	80	132	25	155.3	2.00	3.3	-	2,570	-	-	-	4,000	5.75	0.20	2.57	160	-	-	-	
-3	103+10	20+90	1125.0	Downstream adit	26/27	7-14-71	6.0- 8.2	1116.9	Vertical	Cut cooling coil @ 8.0', cj @ 8.2' good	2-16-71	6	48	37	46	30	0.49	187	80	132	25	155.3	2.00	3.3	-	2,570	-	-	-	3,590	5.53	0.20	2.50	156	-	-	-	
106-1-1	103+95.5	20+77.5	1117.5	Drainage gallery	27	9-27-71	0.0- 2.4	-	Vertical	Good concrete	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	5,850	5.56	0.21	2.47	154	-	-	-	
-2	103+95.5	20+77.5	1117.5	Drainage gallery	27	9-27-71	2.4- 4.4	-	Vertical	Good concrete	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	4,610	6.18	0.11	2.44	152				
-3	103+95.5	20+77.5	1117.5	Drainage gallery	27/27 B	9-27-71	4.4- 5.8	1112.5	Vertical	Good concrete	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	-	-	-	-	-	170	50	4	
106-2-1	104+09.5	20+77.5	1117.5	Drainage gallery	27	9-28-71	0.0- 2.6	-	Vertical	Good concrete	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	4,820	5.02	0.20	2.42	151	-	-	-	
-2	104+09.5	20+77.5	1117.5	Drainage gallery	27/27 B	9-28-71	2.6- 5.7	1112.5	Vertical	Good concrete, cut cooling coil @ 5.0'	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	4,770	6.07	0.13	2.55	159	-	-	-	
107-1-1	104+99.7	20+32	1237.5	Inspection gallery	11	4-17-73	0.0- 3.1	-	Vertical	Good concrete	11-29-72	3	49	64	37	32	0.51	196	83	143	25	159.0	0.75	1.9	2,845	-	-	-	-	4,170	4.54	0.17	2.41	151	-	-	-	
-2	104+99.7	20+32	1237.5	Inspection gallery	11	4-17-73	3.1- 5.8	-	Vertical	Good concrete, core broke @ 5.8'	11-29-72	3	49	64	37	32	0.51	196	83	143	25	159.0	0.75	1.9	2,845	-	-	-	-	-	-	-	-	-	220*	0	10	*Nonjointed
-3	104+99.7	20+32	1237.5	Inspection gallery	11-12	4-17-73	5.8- 8.5	1230.0	Vertical	Good cj @ 7.5'	11-29-72	6	49	64	37	32	0.51	196	83	143	25	159.0	0.75	1.9	2,845	-	-	-	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
-4	104+99.7	20+32	1237.5	Inspection gallery	12	4-18-73	8.5-11.5	-	Vertical		11-17-72	6	48	54	47	38	0.52	184	80	136	25	153.8	3.50	3.5	1,805	-	-	-	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
109-1-1	106+12.2	20+31.3	1237.5	Inspection gallery	11	2-20-73	0.0- 2.9	-	Vertical	Good concrete	8-30-72	6	45	46	76	62	0.51	185	80	127	25	154.8	2.50	3.8	2,300	-	-	6,010	-	4,810	4.87	0.18	2.40	150	-	-	-	
-2	106+12.2	20+31.3	1237.5	Inspection gallery	11	2-20-73	2.9- 6.0	-	Vertical	Good concrete	8-30-72	6	45	46	76	62	0.51	185	80	127	25	154.8	2.50	3.8	2,300	-	-	-	-	4,560	5.32	0.17	2.47	154	-	-	-	
-3	106+12.2	20+31.3	1237.5	Inspection gallery	11-12	2-20-73	6.0- 8.9	1230.0	Vertical	Small void @ 6.6' & @ 7.5 cj	8-30-72	6	45	46	76	62	0.51	185	80	127	25	154.8	2.50	3.8	2,300	-	-	-	-	-	-	-	-	-	130	20	14*	*Broke at cj
-4	106+12.2	20+31.3	1237.5	Inspection gallery	12	2-20-73	8.9-11.8	-	Vertical	Good concrete	8-24-72	6	45	42	86	60	0.46	186	80	123	26	155.9	2.50	3.4	2,165	-	-	5,770	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
111-1-1	107+36.6	20+32	1237.5	Inspection gallery	11	4-16-73	0.0- 3.0	-	Vertical	Good concrete	11-22-72	3	48	54	-	-	0.49	188	81	131	25	155.4	1.50	2.6	2,220	-	5,510	-	-	4,160	4.80	0.21	2.45	153	-	-	-	
-2	107+36.6	20+32	1237.5	Inspection gallery	11	4-16-73	3.0- 6.0	-	Vertical	Good concrete	11-22-72	3	48	54	-	-	0.49	188	81	131	25	155.4	1.50	2.6	2,220	-	5,510	-	-	-	-	-	-	-	225*	0	20	*Nonjointed
-3	107+36.6	20+32	1237.5	Inspection gallery	11-12	4-16-73	6.0- 9.0	1230.0	Vertical	Good cj	11-22-72	3	48	54	-	-	0.49	188	81	131	25	155.4	1.50	2.6	2,220	-	5,510	-	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
-4	107+36.6	20+32	1237.5	Inspection gallery	12	4-17-73	9.0-11.7	-	Vertical	Good concrete	10 19-72	3	46	61	64	39	0.48	190	82	129	25	158.0	1.25	2.3	2,405	-	-	6,685	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
113-1-1	108+01.5	20+31.7	1237.5	Inspection gallery	11	7-12-73	0.0- 3.0	-	Vertical	Good concrete	2- 2-73	6	48	129	44	30	0.49	187	81	131	25	156.5	1.75	3.9	1,790	3,430	-	-	-	5,100	5.01	0.21	2.42	151	-	-	-	
-2	108+01.5	20+31.7	1237.5	Inspection gallery	11	7-16-73	3.0- 6.0	-	Vertical	Broke @ large aggregate @ 4.9'	2- 2-73	6	48	129	44	30	0.49	187	81	131	25	156.5	1.75	3.9	1,790	3,430	-	-	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
-3	108+01.5	20+31.7	1237.5	Inspection gallery	11-12	7-16-73	6.0- 9.0	1230.0	Vertical	Good cj, broke on large aggregate @ 9.0'	2- 2-73	6	48	129	44	30	0.49	187	81	131	25	156.5	1.75	3.9	1,790	3,430	-	-	-	-	-	-	-	-	140	100	10	
-4	108+01.5	20+31.7	1237.5	Inspection gallery	12	7-17-73	9.0-11.8	-	Vertical	Core broke on large aggregate @ 11.8'	1-24-73	6	45	117	44	36	0.52	183	80	136	25	152.2	1.25	3.0	1,935	-	-	5,490	-	-	-	-	-	-	145*	99	17	*Nonjointed
118-1-1 3/	111+47.5	20+31.25	1177.5	Access gallery	19	11-16-72	0.0- 2.9	-	Vertical	Good concrete	6-10-72	6	46	41	65	57	0.51	188	80	137	24	155.2	1.00	2.1	2,155	3,705	-	-	-	4,020	6.05	0.19	2.55	159	-	-	-	
-2	111+47.5	20+31.25	1177.5	Access gallery	19	11-16-72	2.9- 6.0	-	Vertical	Good concrete	6-10-72	6	46	41	65	57	0.51	188	80	137	24	155.2	1.00	2.1	2,155	3,705	-	-	-	-	-	-	-	-	130*	45	4	*Nonjointed
-3	111+47.5	20+31.25	1177.5	Access gallery	19	11-17-72	6.0- 7.5	1170.0	Vertical	Core broke @ cj, poor consolidation above joint	6-10-72	6	46	41	65	57	0.51	188	80	137	24	155.2	1.00	2.1	2,155	3,705	-	-	-	5,760	-	-	2.51	156	-	-	-	
-4	111+47.5	20+31.25	1177.5	Access gallery	20	11-17-72	7.5- 9.0	-	Vertical		6- 6-72	6	46	40	57	52	0.41	192	80	112	25	155.5	1.75	2.7	2,405	-	-	7,275	-	-	-	-	-	-	-	-	-	Saved for shear test
-5	111+47.5	20+31.25	1177.5	Access gallery	20	11-17-72	9.0-12.0	-	Vertical	Good concrete	6- 6-72	6	46	40	57	52	0.41	192	80	112	25	155.5	1.75	2.7	2,405	-	-	7,275	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
118-1-1 3/	111+24.5	20+31	1237.5	Inspection gallery	11	1- 8-73	0.0- 3.0	-	Vertical	Good concrete	7-31-72	6	48	37	93	67	0.48	186	81	127	25	154.8	2.00	3.2	2,190	-	-	-	-	5,120	4.95	0.20	2.43	151	-	-	-	
-2	111+24.5	20+31	1237.5	Inspection gallery	11	1- 8-73	3.0- 6.0	-	Vertical	Good concrete	7-31-72	6	48	37	93	67	0.48	186	81	127	25	154.8	2.00	3.2	2,190	-	-	-	-	5,310	5.39	0.19	2.51	156	-	-	-	Portion saved for shear test
-3	111+24.5	20+31	1237.5	Inspection gallery	11-12	1- 8-73	6.0- 8.6	1230.0	Vertical	Good cj	7-31-72	6	48	37	93	67	0.48	186	81	127	25	154.8	2.00	3.2	2,190	-	-	-	-	-	-	-	-	-	220	25	13*	*Broke at construction joint
-4	111+24.5	20+31	1237.5	Inspection gallery	12	1- 8-73	8.6-12.0	-	Vertical	Good concrete	7-25-72	6	43	42	84	57	0.48	191	82	130	26	156.0	3.25	3.1	2,475	-	-	6,260	-	-	-	-	-	-	-	-	-	Saved for dynamic tension

1/ First number is block number in the dam, second is hole number, third is core number
2/ Wing dam
3/ Duplication in numbering
4/ Average of two cylinders

Table 1. - *Compilation of 255-mm (10-in) diameter core data - Interior and exterior concrete at 6 months' age - Grand Coulee Forebay Dam - Continued*

Core No. 1/	Location of hole: Station No.	Offset from axis	Elevation top of hole, ft	Location in dam	Lift in block No.	Core data: Date drilled	Depth of core, ft	Joint elevation, ft	Direction drilled	Condition of concrete in core	Concrete data when placed: Date placed	Max size aggr., in	Temperatures, F: Conc	H2O	Air Max	Air Min	W/C+P	Cement lb/yd3	Pozzolan lb/yd3	Water lb/yd3	Sand %	Unit weight, lb/ft3	Slump, in	Air content %	6" x 12" control cylinders compressive strength 4/, lb/in2: 7-d	28-d	90-d	180-d	1 yr	Test data on concrete cores: Compressive strength, lb/in2	Elastic properties: E x10-6 lb/in2	r	Specific gravity	Unit weight, lb/ft3	Tensile test: Strength, lb/in2	% area dis-bonded	Distance of break from end, in	Remarks
													Interior Concrete																									
120-1-1	112+49.5	20+77.5	1117.5	Drainage gallery	27	9-29-71	0.0- 3.0	-	Vertical		4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	2,980	5.00	0.20	2.52	157	-	-	-	
-2	112+49.5	20+77.5	1117.5	Drainage gallery	27	9-29-71	3.0- 6.0	-	Vertical	Broke in shipment	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	-	-	-	No tests run
-3	112+49.5	20+77.5	1117.5	Drainage gallery	27	9-29/30-71	6.0- 9.0	None	Vertical	Rock contact @ 8.7'	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	3,840	5.70	0.20	2.52	157	-	-	-	
120-2-1	112+29	20+77.5	1117.5	Drainage gallery	27	9-30-71	0.0- 3.0	-	Vertical	Good concrete	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	3,580	5.36	0.21	2.54	158	-	-	-	
-2	112+29	20+77.5	1117.5	Drainage gallery	27	9-30-71	3.0- 6.0	-	Vertical	Good concrete	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	3,450	5.24	0.27	2.56	159	-	-	-	
-3	112+29	20+77.5	1117.5	Drainage gallery	27	9-30-71	6.0- 9.0	None	Vertical	Good concrete	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	195*	65	2	*Nonjointed
Wing Dam																																						
A-1-1	112+00.96	19+91	1117.5	Foundation adit	27	9- 7-71	0.0- 2.6	-	Vertical	Good concrete	4-14-71	6	50	34	63	41	0.46	187	80	123	25	154.9	0.75	2.3	1,840	3,110	-	-	-	3,800	4.99	0.23	-	-	-	-	-	
-2	112+00.96	19+91	1117.5	Foundation adit	27	9- 7-71	2.6- 5.9	-	Vertical	Good concrete	4-14-71	6	50	34	63	41	0.46	187	80	123	25	154.9	0.75	2.3	1,840	3,110	-	-	-	3,580	5.48	0.20	-	-	-	-	-	
-3	112+00.96	19+91	1117.5	Foundation adit	27	9- 8-71	5.9- 8.6	None	Vertical	Good joint, rock contact @7.3'	4-14-71	6	50	34	63	41	0.46	187	80	123	25	154.9	0.75	2.3	1,840	3,110	-	-	-	-	-	-	-	-	-	-	-	
													Exterior Concrete																									
100-1-1	101+12.25	20+25.15	1311.2	Crest of dam	1	7-10-72	0.0- 1.5	-	Vertical	Rebar @ 0.5' & 1.0'	2-10-72	1.5	51	110	29	23	0.35	431	143	201	33	149.3	2.75	5.4	3,790	5,470	-	7,550	-	-	-	-	-	-	-	-	-	
-2	101+12.25	20+25.15	1311.2	Crest of dam	1	7-10-72	1.5- 4.5	-	Vertical	Good core	2-10-72	3	47	102	29	23	0.37	280	120	147	27	153.4	3.25	3.5	3,120	5,110	-	-	-	5,050	5.55	0.16	2.39	149	-	-	-	
-3	101+12.25	20+25.15	1311.2	Crest of dam	1-2	7-10-72	4.5- 7.2	1305±	Vertical	Good core	2-10-72	3	47	102	29	23	0.37	280	120	147	27	153.4	3.25	3.5	3,120	5,110	-	-	-	-	-	-	-	-	115	5	20	
-4	101+12.25	20+25.15	1311.2	Crest of dam	2	7-11-72	7.2-10.1	-	Vertical	Good core	1-18 72	3	54	128	28	22	0.36	281	122	145	28	156.3	1.00	3.3	3,270	5,180	6,570	7,270	-	-	-	-	-	-	225*	15	17	*Nonjointed
-5	101+12.25	20+25.15	1311.2	Crest of dam	2	7-11-72	10.1-13.0	-	Vertical	Good core	1-18-72	3	54	128	28	22	0.36	281	122	145	28	156.3	1.00	3.3	3,270	5,180	6,570	7,270	-	3,870	4.03	0.19	2.39	149	-	-	-	
108-1-1	105+35	21+12.2	1145.8	Downstream adit	23	8-27-71	0.0- 3.2	-	Vertical	Good concrete	3-25-71	6	50	38	47	33	0.40	223	95	127	24	155.1	2.25	3.0	-	3,630	-	6,435	-	5,020	5.71	0.21	2.54	158	-	-	-	
-2	105+35	21+12.2	1145.8	Downstream adit	23-24	8-27-71	3.2- 5.8	1140.0	Vertical	Broke @ cj	3-25-71	6	50	38	47	33	0.40	223	95	127	24	155.1	2.25	3.0	-	3,630	-	6,435	-	5,350	6.43	0.21	2.60	162	-	-	-	
-3	105+35	21+12.2	1145.8	Downstream adit	24	8-27-71	5.8- 7.7	-	Vertical	Good concrete	3-19-71	6						-	No test batch	-										4,530	5.49	0.17	2.56	159	-	-	-	
116-1-1	110+05.0	20+18.5	1297.5	Gate gallery	3	7-19-72	0.0- 2.4	-	Vertical	Rebar @ 1.1', 1.2', 1.3'	3- 4-72	6	42	73	33	22	0.37	230	97	121	24	157.9	1.25	3.0	3,110	4,850	-	-	-	6,140	5.09	0.18	2.43	151				
-2	110+05.0	20+18.5	1297.5	Gate gallery	3	7-19-72	2.4- 6.0	-	Vertical		3- 4-72	6	42	73	33	22	0.37	230	97	121	24	157.9	1.25	3.0	3,110	4,850	-	-	-	-	-	-	-	-	130*	20	12	*Nonjointed
-3	110+05.0	20+18.5	1297.5	Gate gallery	3-4	7-19/20-72	6.0- 8.7	1290.0	Vertical		3- 4-72	6	42	73	33	22	0.37	230	97	121	24	157.9	1.25	3.0	3,110	4,850	-	-	-	-	-	-	-	-	285	40	16	
-4	110+05.0	20+18.5	1297.5	Gate gallery	4	7-19/20-72	8.7-11.7	-	Vertical	Horiz crack @ 10.6	2-18-72	6	36	40	38	28	0.47	189	79	126	25	153.0	1.50	3.0	2,445	4,115	-	-	-	4,870	5.40	0.19	2.53	158	-	-	-	Portion saved for shear test
-5	110+05.0	20+18.5	1297.5	Gate gallery	4	7-19/20-72	11.7-14.3	-	Vertical		2-18-72	6	36	40	38	28	0.47	189	79	126	25	153.0	1.50	3.0	2,445	4,115	-	-	-	3,770	4.55	0.17	2.51	156	-	-	-	
119-1-1	111+94.4	20+47.1	1260.0	Elevator lobby	8	7-12-72	0.0- 3.0	-	Vertical	Rebar @ 0.4'	2-26-72	3	46	90	40	33	0.45	228	99	147	29	153.5	1.50	3.5	-	3,800	-	-	-	4,860	4.92	0.18	2.19	137	-	-	-	Portion saved for shear test
-2	111+94.4	20+47.1	1260.0	Elevator lobby	8	7-12-72	3.0- 6.0	-	Vertical		2-26-72	3	51	100	42	32	0.37	359	120	176	34	149.7	2.00	4.7	3,195	4,980	-	-	-	6,460	4.54	0.16	2.41	150	-	-	-	
-3	111+94.4	20+47.1	1260.0	Elevator lobby	8-9	7-12-72	6.0- 9.0	1252.5	Vertical		2-26-72	3	51	100	42	32	0.37	359	120	176	34	149.7	2.00	4.7	3,195	4,980	-	-	-	-	-	-	-	-	150	30	3	
-4	111+94.4	20+47.1	1260.0	Elevator lobby	9	7-12-72	9.0-11.6	-	Vertical		2-16-72	3	46	120	32	25	0.36	280	118	144	28	154.4	1.50	3.5	-	5,120	-	-	8,290	4,940	5.18	0.20	2.44	152	-	-	-	
120-3-1	112+40	21+31	1125	Downstream fillet	26	10- 4-71	0.0- 3.0	-	Vertical	Good concrete	5- 6-71	6	48	47	68	53	0.39	224	96	126	24	157.2	1.50	3.3	2,300	3,995	5,265	6,500	7,300	3,240	4.87	0.19	2.49	155	-	-	-	
-2	112+40	21+31	1125	Downstream fillet	26	10- 4-71	3.0- 6.0	-	Vertical	Cut ½" steel @ 3.7'	5- 6-71	6	48	47	68	53	0.39	224	96	126	24	157.2	1.50	3.3	2,300	3,995	5,265	6,500	7,300	3,700	5.25	0.22	2.52	157	-	-	-	
-3	112+40	21+31	1125	Downstream fillet	26-27	10- 4-71	6.0- 9.0	1117.5	Vertical	Good cj	5- 6-71	6	48	47	68	53	0.39	224	96	126	24	157.2	1.50	3.3	2,300	3,995	5,265	6,500	7,300	-	-	-	-	-	120	75	3	
B-1-1 2/	0+77	9' from d/s parapet	1311.0	Top of block	1	3- 9-72	0.0- 2.5	-	Vertical	Rebar @ 0.5'	10-14-71	1.5	50	37	54	39	0.38	361	119	183	34	150.5	3.25	4.4	2,705	4,350	-	-	-	5,320	4.96	0.19	2.44	153	-	-	-	
-2	0+77	9' from d/s parapet	1311.0	Top of block	1	3- 9-72	2.5- 4.9	-	Vertical		10-14-71	1.5	50	37	54	39	0.38	361	119	183	34	150.5	3.25	4.4	2,705	4,350	-	-	-	6,3[illegible]0	4.80	0.18	2.38	148	-	-	-	
-3	0+77	9' from d/s parapet	1311.0	Top of block	1-2	3- 9-72	4.9- 7.5	1305.0	Vertical	Broke at cj, joint painted with resin base bonding compound	10-14-71	1.5	50	37	54	39	0.38	361	119	183	34	150.5	3.25	4.4	2,705	4,350	-	-	-	-	-	-	-	-	-	-	-	No tests run

1/ First number is block in the dam, second is hole number, third is core number
2/ Wing dam
3/ Duplication in numbering
4/ Average of two cylinders

Table 2. - *Compilation of 255-mm (10-in) diameter core data - Interior and exterior concrete at 1 year's age - Grand Coulee Forebay Dam*

Core No. 1/	Location of hole: Station No.	Offset from axis	Elevation top of hole, ft	Location in dam	Lift in block No.	Core data: Date drilled	Depth of core, ft	Joint elevation, ft	Direction drilled	Condition of concrete in core	Concrete data when placed: Date placed	Max size aggr, in	Temperatures, °F: Conc	H_2O	Air Max	Air Min	$\frac{W}{C+P}$	Cement, lb/yd^3	Pozzolan, lb/yd^3	Water, lb/yd^3	Sand, %	Unit weight, lb/ft^3	Slump, in	Air content, %	6" x 12" Control cylinders compressive strength, 2/ lb/in^2: 7-d	28-d	90-d	180-d	1 yr	Test data on concrete cores: Compressive strength, lb/in^2	Elastic properties: E x 10^{-6} lb/in^2	r	Specific gravity	Unit weight, lb/ft^3	Tensile test: Strength, lb/in^2	% area disbonded	Distance of break from end, in	Remarks
															Interior concrete																							
104-2-1	103+09	20+91.5	1125	Downstream adit	26	1-26-72	0.0- 2.8	-	Vertical	Angle iron @ 2.25' - voids of 1/2"	2-16-71	6	49	48	40	29	0.51	190	80	137	25	157.1	1.75	2.1	-	3,075	4,800	-	-	4,660	4.92	0.19	2.39	149	-	-	-	
-2	103+09	20+91.5	1125	Downstream adit	26	1-26-72	2.8- 5.9	-	Vertical	Voids up to 1/2"	2-16-71	6	48	37	46	30	0.49	187	80	132	25	155.3	2.00	3.3	-	2,710	-	5,020	-	4,550	5.22	0.18	2.49	155	-	-	-	
-3	103+09	20+91.5	1125	Downstream adit	26-27	1-26-72	5.9- 9.0	1117.5	Vertical	Rebar at 6.1' and 6.9'	2-16-71	6	48	37	46	30	0.49	187	80	132	25	155.3	2.00	3.3	-	2,710	-	5,020	-	-	-	-	-	-	200	50	9*	*Broke at cj.
106-3-1	104+26.2	20+52	1117.5	Foundation adit	27	3-13-72	0.0- 1.9	-	Vertical	Good concrete, broke @ cluster of aggregate	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	6,440	5.32	0.14	2.48	155	-	-	-	
-2	104+26.2	20+52	1117.5	Foundation adit	27	3-13-72	1.9- 4.5	-	Vertical	Good concrete	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	5,310	4.88	0.17	2.53	158	-	-	-	
-3	104+26.2	20+52	1117.5	Foundation adit	27-27B	3-14-72	4.5- 6.0	1112.5	Vertical	Good cj, cooling coil @ 5.0'	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	-	-	-	-	-	-	-	-	No tests run.
-4	104+26.2	20+52	1117.5	Foundation adit	27B	3-14-72	6.0- 9.0	-	Vertical	Good concrete	4-16-71	6	47	-	54	20	0.46	190	80	126	25	153.1	1.25	2.8	-	3,025	4,700	-	-	-	-	-	-	-	85*	70	7	*Nonjointed.
-5	104+26.2	20+52	1117.5	Foundation adit	27B	3-14-72	9.0-11.8	1107.9	Vertical	Good cj, cooling coil @ 9.6'	4-16-71	6	47	-	54	20	0.46	190	80	126	25	153.1	1.25	2.8	-	3,025	4,700	-	-	-	-	-	-	-	190	85	2	
106-4-1	104+27.5	20+42	1117.5	Foundation access adit	27	3-15-72	0.0- 2.0	-	Vertical	Good concrete	4-24-71	6	48	37	58	44	0.49	186	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	5,650	4.44	0.16	2.41	150	-	-	-	
-2	104+27.5	20+42	1117.5	Foundation access adit	27-27B	3-15-72	2.0- 5.0	1112.5	Vertical	Broke at cj, appeared well bonded	4-24-71	6	48	37	58	44	0.49	188	81	133	25	154.9	1.50	3.2	-	3,395	5,225	-	-	-	-	-	-	-	130*	50	17	*Nonjointed.
-3	104+27.5	20+42	1117.5	Foundation access adit	27B	3-15-72	5.0- 7.7	-	Vertical	Good concrete	4-16-71	6	47	-	54	20	0.46	190	80	126	25	153.1	1.25	2.8	-	3,025	4,700	-	-	4,340	4.84	0.14	2.52	157	-	-	-	
-4	104+27.5	20+42	1117.5	Foundation access adit	27B	3-15-72	7.7-11.0	1108.0	Vertical	Good cj @ 9.5',cracked in shipment	4-16-71	6	47	-	54	20	0.46	190	80	126	25	153.1	1.25	2.8	-	3,025	4,700	-	-	-	-	-	-	-	-	-	-	No tests run.
107-2-1	104+92.7	20+31.9	1237.5	Inspection gallery	11	10-18-73	0.0- 3.0	-	Vertical	Good concrete	11-30-72	6	49	64	37	32	0.51	196	83	143	25	159.0	0.75	1.9	2,845	-	-	-	-	5,970*	4.87	0.25	2.40	150	-	-	-	*Rebar in test specimen
-2	104+92.7	20+31.9	1237.5	Inspection gallery	11	10-18-73	3.0- 5.8	-	Vertical	Fair concrete	11-30-72	6	49	64	37	32	0.51	196	83	143	25	159.0	0.75	1.9	2,845	-	-	-	-	-	-	-	-	-	95*	60	18	*Failure occurred at bond between large aggregate matrix.
-3	104+92.7	20+31.9	1237.5	Inspection gallery	11-12	10-18/19-1973	5.8- 9.0	1230	Vertical	Broke at cj, poor consolidation	11-30-72	6	49	64	37	32	0.51	196	83	143	25	159.0	0.75	1.9	2,845	-	-	-	-	3.840	5.78	0.22	2.54	158	-	-	-	
-4	104+92.7	20+31.9	1237.5	Inspection gallery	12	10-19-73	9.0-12.0	-	Vertical	Good concrete	11-17-72	6	48	54	47	38	0.52	184	80	136	25	153.8	3.50	3.5	1,805		-	5,385	-	4,770	5.22	0.20	2.49	155	-	-	-	
109-2-1	105+78.2	20+32.2	1237.5	Inspection gallery	11	7-11-73	0.0- 3.0	-	Vertical	Core broke in handling	8-30-72	6	45	46	76	62	0.51	185	80	127	25	154.8	2.50	3.8	2,300	-	-	6,010	-	-	-	-	-	-	-	-	-	Core broke - No tests.
-2	105+78.2	20+32.2	1237.5	Inspection gallery	11	7-11-73	3.0- 6.0	-	Vertical	Good concrete	8-30-72	6	45	46	76	62	0.51	185	80	127	25	154.8	2.50	3.8	2,300	-	-	-	-	-	-	-	-	-	205*	95	13	*Nonjointed.
-3	105+78.2	20+32.2	1237.5	Inspection gallery	11-12	7-11-73	6.0- 8.8	1230	Vertical	Good cj, broke @ large aggregate @ 8.8'	8-30-72	6	45	46	76	62	0.51	185	80	127	25	154.8	2.50	3.8	2,300	-	-	6,010	-	-	-	-	-	-	-	-	-	Saved for dynamic tension.
-4	105+78.2	20+32.2	1237.5	Inspection gallery	12	7-11-73	8.8-12.0	-	Vertical	Good concrete	8-24-72	6	45	42	86	60	0.46	186	80	123	26	155.9	2.50	3.4	2,165	-	-	5,770	-	4,140	5.34	0.23	2.51	157	-	-	-	
111-2-1	107+24.8	20+32	1237.5	Inspection gallery	11	10-17-73	0.0- 3.0	-	Vertical	Good concrete	11-23-72	6	48	54	-	-	0.49	188	81	131	25	155.4	1.50	2.6	2,220	-	5,510	-	-	4,850	5.43	0.22	2.45	153	-	-	-	
-2	107+24.8	20+32	1237.5	Inspection gallery	11	10-17-73	3.0- 6.0	-	Vertical	Good concrete	11-23-72	6	48	54	-	-	0.49	188	81	131	25	155.4	1.50	2.6	2,220	-	5,510	-	-	-	-	-	-	-	260*	95	20	*Nonjointed.
-3	107+24.8	20+32	1237.5	Inspection gallery	11-12	10-17-73	6.0- 9.0	1230	Vertical	Broke @ large aggr.	11-23-72	6	48	54	-	-	0.49	188	81	131	25	155.4	1.50	2.6	2,220	-	5,510	-	-	-	-	-	-	-	150	99	14	
-4	107+24.8	20+32	1237.5	Inspection gallery	12	10-17-73	9.0-12.0	-	Vertical	Broke @ large aggr.	10-19-72	6	46	61	64	39	0.48	190	82	129	25	158.0	1.25	2.3	2,405	-		6,685	-	4,790	4.81	0.21	2.49	155	-	-	-	
113-2-1	108+07.5	20+31.7	1237.5	Inspection gallery	11	1-29-74	0.0- 3.0	-	Vertical		2- 2-73	6	48	129	44	30	0.49	187	81	131	25	156.5	1.75	3.9	1,790	3,430	-	-	-	5,860	5.86	0.21	2.44	152	-	-	-	
-2	108+07.5	20+31.7	1237.5	Inspection gallery	11	1-29-74	3.0- 5.9	-	Vertical		2- 2-73	6	48	129	44	30	0.49	187	81	131	25	156.5	1.75	3.9	1,790	3,430	-	-	-	-	-	-	-	-	180*	100	6	*Nonjointed.
-3	108+07.5	20+31.7	1237.5	Inspection gallery	11-12	1-29-74	5.9- 9.1	1230	Vertical	Good construction joint	2- 2-73	6	48	129	44	30	0.49	187	81	131	25	156.5	1.75	3.9	1,790	3,430	-	-	-	-	-	-	-	-	150	85	12	
-4	108+07.5	20+31.7	1237.5	Inspection gallery	12	1-29-74	9.1-12.4	-	Vertical		1-24-73	6	45	117	44	36	0.52	183	80	136	25	152.2	1.25	3.0	1,935	-	-	5,490	-	4,000	4.75	0.19	2.49	155	-	-	-	
3/ 118-2-1	111+57	20+31.25	1177.5	Access gallery	19	5- 8-73	0.0- 2.5	-	Vertical	Core broke @ 2.5'	6-10-72	6	46	41	65	57	0.51	188	80	137	24	155.2	1.00	2.1	2,155	3,705	-	-	-	4,910	5.37	0.21	2.50	156	-	-	-	
-2	111+57	20+31.25	1177.5	Access gallery	19	5- 9-73	2.5- 5.7	-	Vertical	Good concrete	6-10-72	6	46	41	65	57	0.51	188	80	137	24	155.2	1.00	2.1	2,155	3,705	-	-	-	4,580	5.94	0.19	2.51	156	-	-	-	
-3	111+57	20+31.25	1177.5	Access gallery	19-20	5- 9-73	5.7- 8.8	1170.0	Vertical	Good construction joint	6-10-72	6	46	41	65	57	0.51	188	80	137	24	155.2	1.00	2.1	2,155	3,705	-	-	-	-	-	-	-	-	-	-	-	Saved for dynamic tension.
-4	111+57	20+31.25	1177.5	Access gallery	20	5- 9-73	8.8-11.7	-	Vertical	Good concrete	6- 6-72	6	46	40	57	52	0.41	192	80	112	25	155.5	1.75	2.7	2,405	-	-	7,275	-	-	-	-	-	-	-	-	-	Saved for dynamic tension.
3/ 118-2-1	111+48.5	20+31	1237.5	Inspection gallery	11	7- 9-73	0.0- 2.8	-	Vertical	Several small air voids	7-31-72	6	48	41	94	59	0.48	186	81	127	25	154.8	2.00	3.2	2,190	-	-	5,275	-	-	-	-	-	-	-	-	-	Saved for dynamic tension.
-2	111+48.5	20+31	1237.5	Inspection gallery	11	7- 9-73	2.8- 5.7	-	Vertical	Good concrete	7-31-72	6	48	41	94	59	0.48	186	81	127	25	154.8	2.00	3.2	2,190	-	-	5,275	-	4,740	5.93	0.11	2.54	158	-	-	-	
-3	111+48.5	20+31	1237.5	Inspection gallery	11-12	7- 9-73	5.7- 8.5	1230	Vertical	Good construction joint	7-31-72	6	48	41	94	59	0.48	186	81	127	25	154.8	2.00	3.2	2,190	-	-	5,275	-	-	-	-	-	-	80*	98	2	*Broke @ 8" aggregate.
-4	111+48.5	20+31	1237.5	Inspection gallery	12	7- 9-73	8.5-11.1	-	Vertical	Good concrete	7-25-72	6	43	42	84	57	0.48	191	82	130	26	156.0	3.25	3.1	2,475	-	-	6,260	-	-	-	-	-	-	195*	99	3	*Nonjointed.

1/ First number is block in the dam, second is hole number, third is core number
2/ Average of two cylinders
3/ Duplication in field numbering

Table 2. - *Compilation of 255-mm (10-in) diameter core data -*
Interior and exterior concrete at 1 year's age -
Grand Coulee Forebay - Continued

Core No. 1/	Location of hole: Station No.	Offset from axis	Elevation top of hole, ft	Location in dam	Lift in block No.	Core data: Date drilled	Depth of core, ft	Joint elevation, ft	Direction drilled	Condition of concrete in core	Concrete data when placed: Date placed	Max size aggr, in	Temperatures, F: Conc	H_2O	Air Max	Air Min	$\frac{W}{C+P}$	Cement, lb/yd³	Pozzolan, lb/yd³	Water, lb/yd³	Sand, %	Unit weight, lb/ft³	Slump, in	Air content, %	6" x 12" control cylinders compressive strength, 2/ lb/in²: 7-d	28-d	90-d	180-d	1 yr	Test data on concrete cores: Compressive strength, lb/in²	Elastic properties: E x10⁻⁶ lb/in²	r	Specific gravity	Unit weight, lb/ft³	Tensile test: Strength, lb/in²	% area disbonded	Distance of break from end, in	Remarks
																	Interior concrete																					
120-3-1	112+57	20+77.5	1117.5	Drainage gallery	27	3-17-72	0.0- 2.4	-	Vertical	Good concrete	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	3,510	4.59	0.19	2.51	156	-	-	-	
-2	112+57	20+77.5	1117.5	Drainage gallery	27	3-17-72	2.4- 5.0	-	Vertical	Good concrete	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	150*	80	19	*Nonjointed.
-3	112+57	20+77.5	1117.5	Drainage gallery	27	3-17-72	5.0- 6.5	-	Vertical	Core broke @ 6.5'	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	-	-	-	Saved for shear test.
-4	112+57	20+77.5	1117.5	Drainage gallery	27	3-17-72	6.5- 8.0	-	Vertical	Good concrete	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	-	-	-	No tests run.
120-4-1	112+39	20+77.5	1117.5	Drainage gallery	27	3-20-72	0.0- 2.4	-	Vertical	Good concrete	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	3,350	4.21	0.15	2.49	155	-	-	-	
-2	112+39	20+77.5	1117.5	Drainage gallery	27	3-20-72	2.4- 5.0	-	Vertical	Broke @ 5.0'	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	155*	80	11	*Nonjointed.
-3	112+39	20+77.5	1117.5	Drainage gallery	27	3-20-72	5.0- 7.2	-	Vertical	Vertical crack 5.6' to 7.2'	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	-	-	-	Core cracked - No tests.
-4	112+39	20+77.5	1117.5	Drainage gallery	27	3-21-72	7.2- 9.1	1108.4	Vertical	Crack in core 7.9' to 8.5'	4-28-71	6	46	37	62	47	0.51	189	83	137	25	156.4	2.00	2.4	1,830	3,450	-	-	-	-	-	-	-	-	-	-	-	Core cracked - No tests.
4/ A-2-1	112+01	19+89.5	1117.5	Foundation gallery	27	3- 7-72	0.0- 3.0	-	Vertical	Broke @ angle iron @ 2.2'	4-14-71	6	50	34	63	41	0.46	187	80	123	24	154.9	0.75	2.3	1,840	3,110	-	-	-	3,670	4.17	0.19	2.33	145	-	-	-	
-2	112+01	19+89.5	1117.5	Foundation gallery	27	3- 7-72	3.0- 5.7	-	Vertical	Good concrete	4-14-71	6	50	37	54	39	0.46	187	80	123	24	154.9	0.75	2.3	1,840	3,110	-	-	-	-	-	-	-	-	175*	60	14	*Nonjointed.
-3	112+01	19+89.5	1117.5	Foundation gallery	27	3- 7-72	5.7- 8.2	-	Vertical	Bedrock @ 7.6'; good concrete	4-14-71	6	50	37	54	39	0.46	187	80	123	24	154.9	0.75	2.3	1,840	3,110	-	-	-	4,770	5.90	0.19	2.56	160	-	-	-	
																	Exterior concrete																					
100-2-1	101+10	20+24	1311.0	Crest of dam	1	1-11-73	0.0- 1.5	-	Vertical	Rebar @ 0.5' and 1.0'	2-10-72	1.5	51	110	29	23	0.35	431	143	201	33	149.3	2.75	5.4	3,795	5,470	-	7,550	-	-	-	-	-	-	-	-	-	Rebar in core - No tests.
-2	101+10	20+24	1311.0	Crest of dam	1	1-11-73	1.5- 4.4	-	Vertical	Good concrete	2-10-72	3	47	102	29	23	0.37	280	120	147	27	153.4	3.25	3.5	3,120	5,110	-	-	-	6,370	5.48	0.18	2.47	154	-	-	-	
-3	101+10	20+24	1311.0	Crest of dam	1-2	1-11-73	4.4- 7.4	1305	Vertical	Good cj @ 6.2'	2-10-72	3	47	102	29	23	0.37	280	120	147	27	153.4	3.25	3.5	3,120	5,110	-	-	-	-	-	-	-	-	220	30	14*	*Broke at construction joint.
-4	101+10	20+24	1311.0	Crest of dam	2	1-11-73	7.4-10.5	-	Vertical	Good concrete	1-18-72	3	54	128	28	22	0.36	281	122	145	28	156.3	1.00	3.3	3,270	5,180	6,570	7,270	8,260	5,390	5.19	0.22	2.45	153	-	-	-	Part saved for shear.
-5	101+10	20+24	1311.0	Crest of dam	2	1-11-73	10.5-13.5	-	Vertical	Good concrete	1-18-72	1.5	54	128	28	22	0.36	281	122	145	28	156.3	1.00	3.3	3,270	5,180	6,570	7,270	8,260	-	-	-	-	-	-	-	-	Saved for dynamic tension.
108-2-1	105+33	21+12.2	1145.8	Downstream adit	23	3- 3-72	0.0- 2.9	-	Vertical	Good concrete	3-26-71	6	50	38	47	33	0.40	223	95	127	24	155.1	2.25	3.0	-	3,630	-	6,435	-	6,120	5.59	0.15	2.53	157	-	-	-	
-2	105+33	21+12.2	1145.8	Downstream adit	23	3- 3-72	2.9- 4.4	-	Vertical	Good concrete	3-26-71	6	50	38	47	33	0.40	223	95	127	24	155.1	2.25	3.0	-	3,630	-	6,435	-	-	-	-	-	-	-	-	-	Short specimen - No tests.
-3	105+33	21+12.2	1145.8	Downstream adit	23-24	3- 3-72	4.4- 6.8	1140.0	Vertical	Broke @ large aggregate @ 6.8'	3-26-71	6	50	38	47	33	0.40	223	95	127	24	155.1	2.25	3.0	-	3,630	-	6,435	-	-	-	-	-	-	200	85	4	
108-3-1	105+33	21+10.2	1146.8	Downstream adit	23	3- 6-72	0.0- 2.9	-	Vertical	3/4" rebar at 0.8' and 2.9'	3-26-71	6	50	38	47	33	0.40	223	95	127	24	155.1	2.25	3.0	-	3,630	-	6,435	-	4,180	4.96	0.17	2.53	157	-	-	-	
116-2-1	110+15	20+18.5	1297.5	Gate gallery	3	2- 7-73	0.0- 3.2	-	Vertical	Cut rebar @ 1.2' and 1.25'	3- 4-72	6	42	73	33	22	0.37	230	97	121	24	157.9	1.25	3.0	3,110	4,850	-	-	-	5,340	5.50	0.17	2.53	158	-	-	-	
-2	110+15	20+18.5	1297.5	Gate gallery	3	2-7/8-73	3.2- 6.0	-	Vertical		3- 4-72	6	42	73	33	22	0.37	230	97	121	24	157.9	1.25	3.0	3,110	4,850	-	-	-	4,860	5.68	0.19	2.49	155	-	-	-	Part saved for shear.
-3	110+15	20+18.5	1297.5	Gate gallery	3-4	2- 8-73	6.0- 9.0	1290.0	Vertical	Good cj @ 7.5'	3- 4-72	6	42	73	33	22	0.37	230	97	121	24	157.9	1.25	3.0	3,110	4,850	-	-	-	-	-	-	-	-	295	25	23	
-4	110+15	20+18.5	1297.5	Gate gallery	4	2- 8-73	9.0-12.1	-	Vertical		2-18-72	6	36	40	38	28	0.47	189	79	126	25	153.9	1.50	3.0	2,445	4,115	-	-	-	-	-	-	-	-	-	-	-	Saved for dynamic tension
119-2-1	111+94.9	20+45.9	1260	Elevator lobby	8	1-12-73	0.0- 3.0	-	Vertical	Good concrete; rebar @ 0.4'	2-26-72	1.5	46	90	40	33	0.45	228	99	147	29	153.5	1.50	3.5	-	3,800	-	-	-	5,210	4.87	0.20	2.37	148	-	-	-	
-2	111+94.9	20+45.9	1260	Elevator lobby	8	1-16-73	3.0- 6.0	-	Vertical	Good concrete	2-26-72	1.5	51	100	42	32	0.37	359	120	176	34	149.7	2.00	4.7	-	3,195	4,980	-	-	-	-	-	-	-	230	10	4	
-3	111+94.9	20+45.9	1260	Elevator lobby	8-9	1-16-73	6.0- 7.4	1252.5	Vertical	Broke diagonally @ 7.4'	2-26-72	1.5	51	100	42	32	0.37	359	120	176	34	149.7	2.00	4.7	-	3,195	4,980	-	-	-	-	-	-	-	-	-	-	No tests run.
-4	111+94.9	20+45.9	1260	Elevator lobby	9	1-16-73	7.4- 8.9	-	Vertical		2-16-72	6	46	120	32	25	0.36	280	118	144	28	154.4	1.50	3.5	-	5,120		-	8,290	-	-	-	-	-	-	-	-	No tests run.
-5	111+94.9	20+45.9	1260	Elevator lobby	9	1-16-73	8.9-12.0	-	Vertical	Good concrete	2-16-72	6	46	120	32	25	0.36	280	118	144	28	154.4	1.50	3.5	-	5,120	-	-	8,290	5,260	5.42	0.17	2.49	155	-	-	-	Structural concrete.
120-2-1	112+69.5	21+31.5	1125	Downstream fillet	26	3-22-72	0.0- 2.5	-	Vertical	Good concrete	5- 6-71	6	48	37	67	53	0.39	224	96	126	24	157.2	1.50	3.3	2,305	3,995	5,270	6,500	7,300	5,040	5.62	0.22	2.45	152	-	-	-	
-2	112+69.5	21+31.5	1125	Downstream fillet	26	3-22-72	2.5- 3.5	-	Vertical	Good concrete	5- 6-71	6	48	37	67	53	0.39	224	96	126	24	157.2	1.50	3.3	2,305	3,995	5,270	6,500	7,300	-	-	-	-	-	-	-	-	No tests run.
-3	112+69.5	21+31.5	1125	Downstream fillet	26	3-22-72	3.5- 5.5	-	Vertical	Good concrete	5- 6-71	6	48	37	67	53	0.39	224	96	126	24	157.2	1.50	3.3	2,305	3,995	5,270	6,500	7,300	3,080*	4.49	0.15	2.49	155	-	-	-	*Failed along large aggregate.
-4	112+69.5	21+31.5	1125	Downstream fillet	26-27	3-23/28-72	5.5- 8.2	1117.5	Vertical	Good construction joint	5- 6-71	6	48	37	67	53	0.39	224	96	126	24	157.2	1.50	3.3	2,305	3,995	5,270	6,500	7,300	-	-	-	-	-	95	75	6	
-5	112+69.5	21+31.5	1125	Downstream fillet	27	3-28-72	8.2-11.2	-	Vertical	Good concrete	4-27-71	6								No test batch										-	-	-	-	-	175*	40	23	*Nonjointed.
4/ B-3-1	1+10	7.5' rt	1311	Crest of dam	1	9- 5-72	0.0- 2.3	-	Vertical	Good concrete	10-14-71	1.5	50	37	54	39	0.38	361	119	183	34	150.5	3.25	4.4	2,705	4,350	-	-	-	6,720	3.05	0.16	-	-	-	-	-	
-2	1+10	7.5' rt	1311	Crest of dam	1	9- 5-72	2.3- 4.5	-	Vertical	Good concrete	10-14-71	1.5	50	37	54	39	0.38	361	119	183	34	150.5	3.25	4.4	2,705	4,350	-	-	-	7,920	5.47	0.17	-	-	-	-	-	
-3	1+10	7.5' rt	1311	Crest of dam	1-2	9- 6-72	4.5- 7.5	1305	Vertical	Broke at cj, joint painted with resin-base bonding and curing compound	10-14-71	1.5	50	37	54	39	0.38	361	119	183	34	150.5	3.25	4.4	2,705	4,350	-	-	-	-	-	-	-	-	-	-	-	Saved for two shear tests.
-4	1+10	7.5' rt	1311	Crest of dam	2	9- 6-72	7.5- 9.8	-	Vertical	Good concrete	10- 2-71	6	52	38	66	50	0.35	223	96	113	24	155.3	1.25	3.0	2,585	4,245	-	-	-	5,240	5.54	0.21	2.36	147	-	-	-	
-5	1+10	7.5' rt	1311	Crest of dam	2	9- 6-72	9.8-12.0	-	Vertical	Good concrete	10- 2-71	6	52	38	66	50	0.35	223	96	113	24	155.3	1.25	3.0	2,585	4,245	-	-	-	-	-	-	-	-	-	-	-	**Saved for dynamic tension.**
-6	1+10	7.5' rt	1311	Crest of dam	2	9- 6-72	12.0-15.0	1297.5	Vertical	Good construction joint	10- 2-71	6	52	38	66	50	0.35	223	96	113	24	155.3	1.25	3.0	2,585	4,245	-	-	-	-	-	-	-	-	150	42	20	

1/ First number is block in the dam, second is hole number, third is core number
2/ Average of two cylinders
3/ Duplication in field numbering
4/ Wing dam

Table 3. - *Summary of compressive strength and elastic properties test results on 255-mm (10-in) diameter cores at 6 months' age - Grand Coulee Forebay Dam*

Core No.	Date tested	Age, days	Compressive strength, MPa (lb/in^2)		Strength ratio: core / 28-day cyl., percent	Modulus of elasticity, GPa ($lb/in^2 x10^6$)		Poisson's ratio
					Interior Concrete			
104-1-2	8-16-71	180	27.6	(4000)	146	39.6	(5.75)	0.20
-3	8-16-71	180	24.8	(3590)	131	38.1	(5.53)	.20
106-1-1	10-21-71	180	40.3	(5850)	172	38.3	(5.56)	.21
-2	10-29-71	188	31.8	(4610)	136	42.6	(6.18)	.11
106-2-1	10-29-71	188	33.2	(4820)	142	34.6	(5.02)	.20
-2	10-29-71	188	32.9	(4770)	141	41.9	(6.07)	.13
107-1-1	5-23-73	180	28.8	(4170)	4/	31.3	(4.54)	.17
109-1-1	3-15-73	180	33.2	(4810)	4/	33.6	(4.87)	.18
-2	3-15-73	180	31.4	(4560)	4/	36.7	(5.32)	.17
111-1-1	5-22-73	180	28.7	(4160)	4/	33.1	(4.80)	.21
113-1-1	8-09-73	188	35.2	(5100)	149	34.5	(5.01)	.21
118-1-1 1/	12-13-72	186	27.7	(4020)	109	41.7	(6.05)	.19
-3	12-13-72	186	39.7	(5760)	155	-	-	-
118-1-1 1/	3-15-73	180	35.3	(5120)	4/	34.1	(4.95)	.20
-2	3-15-73	180	36.6	(5310)	4/	37.2	(5.39)	.19
120-1-1	11-02-71	188	20.5	(2980)	86	34.5	(5.00)	.20
-3	11-02-71	188	26.5	(3840)	111	39.3	(5.70)	.20
120-2-1	11-02-71	188	24.7	(3580)	104	37.0	(5.36)	.21
-2	11-02-71	188	23.8	(3450)	100	36.1	(5.24)	.27
A-1-1 2/	10-14-71	180	26.2	(3800)	122	34.4	(4.99)	.23
-2	10-14-71	180	24.7	(3580)	115	37.8	(5.48)	.20
Average			30.2	(4380)	128	36.8	(5.34)	.19
Coefficient of variation			17.5					
					Exterior Concrete			
100-1-2	8-08-72	180	34.8	(5050)	99	38.3	(5.55)	.16
-5	7-16-72	180	26.7	(3870)	75	27.8	(4.03)	.19
108-1-1	11-17-71	237	34.6	(5020)	138	39.4	(5.71)	.21
-2	9-24-71	180	36.9	(5350)	147	44.3	(6.43)	.21
-3	9-24-71	180	31.2	(4530)	4/	37.9	(5.49)	.17
116-1-1	8-31-72	180	42.3	(6140) 3/	127	35.1	(5.09)	.18
-4	8-31-72	180	33.6	(4870)	118	37.2	(5.40)	.19
-5	8-15-72	180	26.0	(3770)	92	31.4	(4.55)	.17
119-1-1	8-24-72	180	33.5	(4860)	128	33.9	(4.92)	.18
-2	8-24-72	180	44.5	(6460)	130	31.3	(4.54)	.16
-4	8-14-72	180	34.1	(4940)	96	35.7	(5.18)	.20
120-3-1	11-02-71	180	22.3	(3240)	81	33.6	(4.87)	.19
-2	11-02-71	180	25.5	(3700)	93	36.2	(5.25)	.22
B-1-1 2/	4-14-72	180	36.7	(5320)	122	34.2	(4.96)	.19
-2	4-14-72	180	44.1	(6390)	147	33.1	(4.80)	.18
Average			33.8	(4900)	114	35.3	(5.12)	.19
Coefficient of variation			19.2					

1/ Duplication in numbering
2/ Wing dam
3/ Test specimen contained rebar
4/ 28-day cylinder strength not available

Table 4. - *Summary of compressive strength and elastic properties test results on 255-mm (10-in) diameter cores at 1 year's age - Grand Coulee Forebay Dam*

Core No.	Date tested	Age, days	Compressive strength, MPa	(lb/in²)	Strength ratio: core / 28-day cyl., percent	Modulus of elasticity, GPa	(lb/in²x10⁶)	Poisson's ratio
				Interior Concrete				
104-2-1	2-16-72	365	32.1	(4660)	152	33.9	(4.92)	0.19
-2	2-16-72	365	31.4	(4550)	168	36.0	(5.22)	.18
106-3-1	4-24-72	365	44.4	(6440)	190	36.7	(5.32)	.14
-2	4-24-72	365	36.6	(5310)	156	33.6	(4.88)	.17
106-4-1	4-24-72	365	39.0	(5650)	166	30.6	(4.44)	.16
-3	4-24-72	365	29.9	(4340)	143	33.4	(4.84)	.14
107-2-1	11-30-73	365	41.2	(5970) 1/	2/	33.6	(4.87)	.25
-3	11-30-73	365	26.5	(3840)	2/	39.9	(5.78)	.22
-4	11-30-73	365	32.9	(4770)	2/	36.0	(5.22)	.20
109-2-4	8-09-73	344	28.5	(4140)	2/	36.8	(5.34)	.23
111-2-1	11-23-73	365	33.4	(4850)	2/	37.4	(5.43)	.22
-4	11-23-73	365	33.0	(4790)	2/	33.2	(4.81)	.21
113-2-1	2-25-74	365	40.4	(5860)	171	40.4	(5.86)	.21
-4	2-25-74	365	27.6	(4000)	2/	32.8	(4.75)	.19
118-2-1 3/	6-10-73	365	33.9	(4910)	133	37.0	(5.37)	.21
-2	6-10-73	365	31.6	(4580)	124	41.0	(5.94)	.19
118-2-2 3/	8-09-73	380	32.7	(4740)	2/	40.9	(5.93)	.11
120-3-1	4-28-72	365	24.2	(3510)	102	31.6	(4.59)	.19
120-4-1	4-28-72	365	23.1	(3350)	97	29.0	(4.21)	.15
A-2-1	4-14-72	365	25.3	(3670)	118	28.8	(4.17)	.19
-3	4-14-72	365	32.9	(4770)	153	40.7	(5.90)	.19
Average			32.4	(4700)	144	35.4	(5.13)	.19
Coefficient of variation			17.0					
				Exterior Concrete				
100-2-2	2-14-73	365	43.9	(6370)	125	37.8	(5.48)	0.18
-4	2-14-73	365	37.2	(5390)	104	35.8	(5.19)	.22
108-2-1	3-26-72	365	42.2	(6120)	169	38.5	(5.59)	.15
108-3-1	3-26-72	365	28.8	(4180)	115	34.2	(4.96)	.17
116-2-1	3-15-73	365	36.8	(5340)	110	37.9	(5.50)	.17
-2	3-15-73	365	33.5	(4860)	100	39.2	(5.68)	.19
119-2-1	2-14-73	365	35.9	(5210)	137	33.6	(4.87)	.20
-5	2-14-73	365	36.3	(5260)	103	37.4	(5.42)	.17
120-2-1	4-28-72	365	34.8	(5040)	126	38.7	(5.62)	.22
-3	4-28-72	365	21.2	(3080) 4/	77	31.0	(4.49)	.15
B-3-1	10-13-72	365	46.3	(6720)	154	21.0	(3.05)	.16
-2	10-13-72	365	54.6	(7920)	182	37.7	(5.47)	.17
-4	10-02-72	365	36.1	(5240)	123	38.2	(5.54)	.21
Average			37.5	(5440)	125	35.4	(5.14)	.18
Coefficient of variation			21.0					

1/ Rebar in test specimen
2/ 28-day cylinder strength not available
3/ Duplication in numbering
4/ Broke along large aggregate

Table 5. - *Summary of tensile strength test results on 255-mm (10-in) diameter cores at 6 months' age - Grand Coulee Forebay Dam*

Core No.	Length of specimen, mm (in)	Date tested	Age, days	Tensile strength, MPa (lb/in^2)	Core strength ratio: tensile / compressive, percent	Disbonded area, percent	Distance of break from end, mm (in)
				Interior Concrete			
106-1-3	405 (16)	11-03-71	193	1.17 (170) 2/	3.4	50	100 (4)
107-1-2	735 (29)	5-22-73	180	1.52 (220) 3/	5.3	0	255 (10)
109-1-3	760 (30)	3-15-73	180	.90 (130) 2/	2.8	20	4/
111-1-2	760 (30)	5-22-73	180	1.55 (225) 3/	5.4	0	510 (20)
113-1-3	760 (30)	8-09-73	188	.97 (140) 2/	2.7	100	255 (10)
-4	760 (30)	8-09-73	188	1.00 (145) 3/	5/	99	430 (17)
118-1-2 1/	760 (30)	12-13-72	183	.90 (130) 3/	2.7	45	100 (4)
118-1-3 1/	710 (28)	2-14-73	195	1.52 (220) 2/	4.2	25	4/
120-2-3	760 (30)	11-03-71	193	1.34 (195) 3/	5.5	65	50 (2)
Average (Specimens that broke at construction joint not included)				1.21 (175)	4.0		
				Exterior Concrete			
100-1-3	760 (30)	7-16-72	180	0.79 (115) 2/	2.3	5	510 (20)
-4	760 (30)	7-16-72	180	1.55 (225) 3/	5.8	15	430 (17)
116-1-2	760 (30)	8-31-72	180	.90 (130) 3/	2.1	20	305 (12)
-3	760 (30)	8-31-72	180	1.97 (285) 2/	4.6	40	405 (16)
119-1-3	760 (30)	8-14-72	180	1.03 (150) 2/	2.7	30	75 (3)
120-3-3	760 (30)	11-02-71	180	.83 (120) 2/	3.5	75	75 (3)
Average				1.17 (170)	3.5		

1/ Duplication in numbering
2/ Jointed
3/ Nonjointed
4/ Broke at construction joint
5/ No core compressive strength available for correlation

Table 6. - *Summary of tensile strength test results on 255-mm (10-in) diameter cores at 1 year's age - Grand Coulee Forebay Dam*

Core No.	Length of specimen, mm (in)	Date tested	Age, days	Tensile strength, MPa (lb/in^2)	Core strength ratio: tensile / compressive, percent	Disbonded area, percent	Distance of break from end, mm (in)
				Interior Concrete			
104-2-3	510 (20)	2-16-72	365	1.38 (200)	4.3	50	3/
106-3-4	760 (30)	4-24-72	365	.59 (85) 1/	4/	70	180 (7)
-5	760 (30)	4-24-72	365	1.31 (190)	4/	85	50 (2)
106-4-2	760 (30)	4-24-72	365	.90 (130) 1/	2.3	50	430 (17)
107-2-2	760 (30)	11-21-73	365	.66 (95) 1/	1.9	60	455 (18) 5/
109-2-2	760 (30)	8-09-73	344	1.41 (205) 1/	4/	95	330 (13)
111-2-2	760 (30)	11-21-73	365	1.79 (260) 1/	5.4	95	510 (20)
-3	760 (30)	11-21-73	365	1.03 (150)	3.1	99	355 (14)
113-2-2	760 (30)	2-25-74	365	1.24 (180) 1/	3.1	100	150 (6)
-3	760 (30)	2-25-74	365	1.03 (150)	2.6	85	305 (12)
118-2-3	710 (28)	8-09-73	380	.55 (80)	1.7	98	50 (2) 5/
-4	710 (28)	8-09-73	380	1.34 (195) 1/	4/	99	75 (3)
120-3-2	685 (27)	4-28-72	365	1.03 (150) 1/	4.3	80	485 (19)
120-4-2	760 (30)	4-28-72	365	1.07 (155) 1/	4.6	80	280 (11)
A-2-2 2/	710 (28)	4-14-72	365	1.21 (175) 1/	4.1	60	355 (14)
Average 6/				1.07 (155)	3.4		
				Exterior Concrete			
100-2-3	760 (30)	2-14-73	365	1.52 (220)	3.5	30	3/
108-2-3	510 (20)	3-26-72	365	1.38 (200)	3.9	85	100 (4)
116-2-3	760 (30)	3-15-73	365	2.03 (295)	5.8	25	585 (23)
119-2-2	760 (30)	2-14-73	365	1.59 (230)	4.4	10	100 (4)
120-2-4	685 (27)	4-28-72	365	.66 (95)	2.3	75	150 (6)
-5	760 (30)	4-28-72	365	1.21 (175) 1/	4/	40	585 (23)
B-3-6 2/	760 (30)	10-02-72	365	1.03 (150)	2.9	42	510 (20)
Average 6/				1.31 (190)	3.8		

1/ Nonjointed
2/ Wing dam
3/ Broke at construction joint
4/ No core compressive strength available for correlation
5/ Failure occurred at large aggregate
6/ Specimens that broke at construction joint not included

TESTING PROGRAM FOR 150-MILLIMETER (6-INCH) DIAMETER CORES

General

The testing program for the 150-mm-diameter cores was primarily aimed toward testing the bond strength of the horizontal construction joints in the Forebay Dam. However, other testing was incorporated into the program to determine mode of failure, tensile strength, shear strength, compressive strength, modulus of elasticity, Poisson's ratio, and density of the concrete. All testing was done when the cores reached a minimum 6 months' age. All cores from the main dam were extracted from interior concrete.

Triaxial Shear

The triaxial shear test was used as the main test to determine the bond strength between the lifts. Cores from 19 of the 25 holes drilled were selected for the triaxial shear test. Any cores containing cooling pipe or other metals adjacent to the construction joint were not used. Triaxial shear tests were also conducted on nine concrete cores without joints to provide a comparison of the jointed shearing strength to the nonjointed shearing or bond strength of the concrete. The unjointed core specimens used for this comparison came from the same drill holes as the jointed specimens. The cores were intentionally drilled to obtain an angle of 30° between the construction joint plane and the longitudinal axis of the cores because this was the approximate expected angle of failure in triaxial shear.

A description of the testing procedure and results is contained in appendix A.

Petrographic Examination

Following the triaxial shear tests, the test specimens were examined petrographically to describe the mode of failure of the jointed concrete as a result of the triaxial tests.

A discussion of the petrographic examination and test results is contained in appendix B.

Compressive Strength

Compressive strength tests were conducted on three of the jointed core specimens for comparison with triaxial shear tests at zero lateral pressure. Also, tests were conducted on 12 of the unjointed core specimens for comparison with 150- by 300-mm (6- by 12-in) compressive strength control cylinders.

The core specimens for the compressive strength tests were selected at random. However, in most cases the specimens were taken from the top portion of the core. The specimens were prepared and tested the same as the 255-mm specimens.

Elastic Properties

Modulus of elasticity and Poisson's ratio were determined so correlations could be made with similar tests conducted on the 255-mm-diameter cores. These tests were made on the same specimens selected for the compressive strength tests. The method of testing and specimen preparation was the same as described for the 255-mm cores.

Tensile Strength

Tensile strength tests were conducted on 12 specimens to determine the relationship between compressive strength and tensile strength of the concrete.

All test specimens were taken from the top core of the hole and were on the unjointed specimens. The specimens were cut approximately 455 mm (18 in) long to obtain a length-to-diameter ratio of three. The extra length was to minimize the effects of the end plates which were cemented to the samples.

Density

As with the 255-mm-diameter cores, "as is" densities were determined for the same specimens selected for the compressive strength tests.

Direct Shear

Shear tests to determine direct shear strength of the concrete may be made on 14 core specimens when the equipment for testing becomes available. Samples selected and prepared for the shear test are:

Cores for direct shear test

Block	Hole	Core	Block	Hole	Core	Block	Hole	Core
106	2	1	110	3	1	116	1	2
106	3	2	112	1	2	116	3	2
108	2	2	112	2	2	120	1	2
108	5	2	114	2	2	120	2	2
110	1	2	114	3	2			

TEST RESULTS OF 150-MILLIMETER (6-INCH) DIAMETER CORES

Triaxial Shear Strength

The results of the triaxial shear tests and petrographic examination are discussed in appendixes A and B, respectively. The results summarized here were extracted from those appendixes.

The average unconfined compressive strength of cores containing construction joints [28.3 MPa (4110 lb/in^2)] was about 85 percent of that for cores without joints [33.2 MPa (4810 lb/in^2)]. The cohesive strength (shearing strength at zero normal stress) of jointed cores [5.1 MPa (735 lb/in^2)] was 75 percent of that for the unjointed cores [6.8 MPa (980 lb/in^2)] using the straight-line solution of Mohr's envelope. The curvilinear solution of Mohr's envelope shows the cohesive strength of jointed cores [5.0 MPa (730 lb/in^2)] to be about 83 percent of that for the unjointed cores [6.1 MPa (880 lb/in^2)]. Measured angles of failure ranged from 20° to 32° from the longitudinal axis of the core.

Petrographic examination (app. B) of the cores, following shear tests, revealed that the jointed cores failed mainly along the joint plane and the breaks occurred predominantly as bond failure between paste and aggregate.

Compressive Strength

The results of the individual compressive strength tests conducted on the 150-mm (6-in) diameter cores are shown in table 7 and are summarized in table 8. The results are representative of the compressive strength of the interior concrete in the Forebay Dam at 6 months' age.

The average compressive strength for the 15 cores tested was 33.1 MPa (4800 lb/in^2). This is considerably higher than the design strength of 20.7 MPa (3000 lb/in^2) at 180 days and is about 9 percent higher than the compressive strength for the 255-mm (10-in) diameter cores taken from the interior concrete tested at 6 months' age.

The compressive strength of the cores averaged 156 percent of the compressive strength of the 150- by 300-mm (6- by 12-in) control cylinders tested at 28 days' age. This compares with 128 percent for 255-mm-diameter cores. The comparison between the control cylinder strengths and the core strengths is shown graphically on figure 2.

The compressive strength of the 3 specimens containing a construction joint averaged 31.5 MPa (4570 lb/in^2) as compared to 33.4 MPa (4850 lb/in^2) for the 12 unjointed specimens. Since the joint in the specimen was at a 30° angle to the vertical axis of the test specimen, the 31.5 MPa compressive strength should be an indicator of good construction joints. The compressive strength of the three jointed specimens was reasonably close to that obtained in the triaxial strength test with zero lateral stress on the jointed specimens.

Elastic Properties

The individual and average test results are shown in table 8. The modulus of elasticity of the interior concrete at 6 months' age averaged 34.7 GPa (5.03 x 10^6 lb/in^2) for the 12 specimens tested. This compares favorably with a modulus of elasticity of 36.8 GPa (5.34 x 10^6 lb/in^2) for the 255-mm-diameter cores extracted from interior concrete and tested at 6 months' age.

Poisson's ratio averaged 0.17 for the interior concrete as compared to 0.19 for the 255-mm-diameter cores. The individual and average test results are shown in table 8.

Tensile Strength

The results of the 12 tensile strength tests are shown in table 9. All the tensile strength tests were made on nonjointed specimens and averaged 1.52 MPa (220 lb/in^2). The strength ranged from 0.72 to 2.67 MPa (105 to 390 lb/in^2).

Tensile strengths of the nonjointed specimens averaged 4.6 percent of the compressive strength. This is average for mass concrete and corresponds to 4.0 percent for 255-mm-diameter unjointed cores extracted from interior concrete and tested at 6 months' age. When tested in direct tension, the breaks did not occur at the midpoint of the specimens but occurred more predominantly in the lower one-third of the specimens. The total area which showed disbonding between aggregate and paste was estimated for each specimen tested. Between 55 and 80 percent of the break area showed disbonding rather than aggregate failure. The estimated areas of disbonding did not correlate well with the tensile strengths obtained.

Density

The density of the nine core specimens tested ranged from 2480 to 2550 kg/m^3 (155 to 159 lb/ft^3) with an average of 2500 kg/m^3 (156 lb/ft^3).

Table 7. - *Compilation of 150-mm (6-in) diameter core data - Interior and exterior concrete at 6 months' age - Grand Coulee Forebay Dam*

Interior concrete

Core No. 1/	Location of hole: Station No.	Location of hole: Offset from axis	Location of hole: Elevation top of hole, ft	Location of hole: Location in dam	Location of hole: Lift in block No.	Core data: Date drilled	Core data: Depth of core, ft	Core data: Joint elevation, ft	Core data: Direction drilled	Core data: Condition of concrete in core
106-1-1	103+96	20+28.4	1119.6	Foundation gallery - stairwell	26	8-17-71	0.0-3.0	-	S86 W-30 dip	
-2	103+96	20+28.4	1119.6	Foundation gallery - stairwell	26-27	8-17-71	3.0-6.0	1117.5	S86 W-30 dip	Good joint
106-2-1	103+99	20+28.4	1119.6	Foundation gallery - stairwell	26	8-17-71	0.0-3.0	-	N37 W-30 dip	
-2	103+99	20+28.4	1119.6	Foundation gallery - stairwell	26-27	8-17/18-71	3.0-6.0	1117.5	N37 W-30 dip	Cut through cooling coil @ 4.3'; good construction joint
106-3-1	104+28	20+79.5	1119.6	Drainage gallery	26	8-19-71	0.0-3.0	-	N64 W-30 dip	Core broke @ 2.6'
-2	104+28	20+79.5	1119.6	Drainage gallery	26-27	8-19-71	3.0-6.0	1117.5	N64 W-30 dip	Broke @ construction joint @ 4.4'
106-4-1	104+28	20+17.5	1119.6	Foundation gallery - u/s wall	26	8-19/20-71	0.0-3.0	-	S64 E-30 dip	Core broke @ 0.9' due to drill bit; core broke @ 2.8'
-2	104+28	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	8-20-71	3.0-6.0	1117.5	S64 E-30 dip	Cooling coil @ 3.8'; small rock pocket @ 4.1' to 4.3'
106-5-1	104+28	20+17.5	1118.5	Foundation gallery - u/s wall	26	8-20-71	0.0-3.0	1117.5	S64 E-30 dip	Only one core taken
106-6-1	104+27	20+17.5	1118.5	Foundation gallery - u/s wall	26	8-20-71	0.0-3.0	1117.5	S64 E-30 dip	Good joint @ 1.1' to 2.2'
108-2-1	105+36	20+29	1119.6	Foundation gallery - stairwell	26	7- 7-71	0.0-2.1	-	N30 W-30 dip	Concrete broke @ large aggregate at 2.5'
-2	105+36	20+29	1119.6	Foundation gallery - stairwell	26	7- 7-71	2.1-2.8	-	N30 W-30 dip	
-3	105+36	20+29	1119.6	Foundation gallery - stairwell	26-27	7- 7-71	2.8-5.5	1117.5	N30 W-30 dip	Good construction joint
108-4-1	105+36	20+17.5	1119.6	Foundation gallery - u/s wall	26	7- 7-71	0.0-2.8	-	S64 W-30 dip	
-2	105+36	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	7- 7-71	2.8-5.5	1117.5	S64 W-30 dip	Good construction joint
108-5-1	105+44	20+17.5	1119.6	Foundation gallery - u/s wall	26	7- 8-71	0.0-2.6	-	S64 E-30 dip	Core broke at large aggregate at start of hole, steel rod at 0.1'
-2	105+44	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	7- 8-71	2.6-5.5	1117.5	S64 E-30 dip	Good concrete, good construction joint
108-6-1	105+43.8	20+79.5	1119.6	Drainage gallery - d/s wall	26	7- 8-71	0.0-2.8	-	N64 W-30 dip	Good concrete
-2	105+43.8	20+79.5	1119.6	Drainage gallery - d/s wall	26-27	7- 8-71	2.8-5.8	1117.5	N64 W-30 dip	Good concrete, good construction joint
110-1-1	106+55	20+28	1119.6	Foundation gallery - stairwell	26	7- 9-71	0.0-3.0	-	N28 W-30 dip	Good concrete
-2	106+55	20+28	1119.6	Foundation gallery - stairwell	26-27	7- 9-71	3.0-5.8	1117.5	N28 W-30 dip	Good construction joint
110-2-1	106+53.4	20+17.5	1119.6	Foundation gallery - u/s wall	26	7- 9-71	0.0-3.0	-	S60 E-30 dip	Good concrete
-2	106+53.4	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	7- 9-71	3.0-5.7	1117.5	S60 E-30 dip	Good concrete
110-3-1	106+64	20+17.5	1119.6	Foundation gallery - u/s wall	26	7-12-71	0.0-3.0	-	S64 E-30 dip	Broke @ 2.6' during removal
-2	106+64	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	7-12-71	3.0-6.0	1117.5	S64 E-30 dip	Good construction joint - hard to find
110-4-1	106+65.5	20+79.5	1119.6	Drainage gallery - d/s wall	26	7-12-71	0.0-3.0	-	N64 W-30 dip	Broke from 2.7' to 3.0' on recovery
-2	106+65.5	20+79.5	1119.6	Drainage gallery - d/s wall	26-27	7-12-71	3.0-5.8	1117.5	N64 W-30 dip	Good construction joint

Core No. 1/	Date placed	Max size aggr, in	Temperatures, F: Conc	Temperatures, F: H_2O	Temperatures, F: Air Max	Temperatures, F: Air Min	$\frac{W}{C+P}$	Cement, lb/yd³	Pozzolan, lb/yd³	Water, lb/yd³	Sand, %	Unit weight, lb/ft³	Slump, in	Air content, %	6" x 12" control cylinders, compressive strength, 3/ lb/in²: 7-d	28-d	90-d	180-d	1 yr
106-1-1	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
-2	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
106-2-1	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
-2	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
106-3-1	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
-2	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
106-4-1	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
-2	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
106-5-1	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
106-6-1	5- 1-71	6	51	59	68	52	0.47	187	80	126	26	153.4	1.00	2.7	-	2,950	-	5,030	-
108-2-1	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
-2	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
-3	3- 4-71	6	48	47	47	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
108-4-1	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
-2	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
108-5-1	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
-2	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
108-6-1	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
-2	3- 4-71	6	48	47	37	23	0.47	186	79	125	25	153.9	1.50	3.3	1,875	3,315	5,150	-	-
110-1-1	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	-
-2	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	
110-2-1	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	-
-2	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	-
110-3-1	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	-
-2	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	-
110-4-1	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	-
-2	3-12-71	6	45	37	45	36	0.45	187	80	120	25	155.1	1.25	3.0	2,230	3,915	-	-	-

Core No. 1/	Test data on concrete cores: Compressive strength, lb/in²	Elastic properties: E x10⁻⁶ lb/in²	Elastic properties: r	Specific gravity	Unit weight, lb/ft³	Tensile test: Strength, lb/in²	Tensile test: % area dis-bonded	Tensile test: Distance of break from end, in	Other tests: 1. Triaxial 2. Shear 3. Petrographic
106-1-1	6,290	5.13	0.18	2.50	155	-	-	-	1
-2	4,370	4.48	0.20	-	-	-	-	-	1
106-2-1	-	-	-	-	-	-	-	-	1,2
-2	-	-	-	-	-	-	-	-	
106-3-1	-	-	-	-	-	265	70	8	-
-2	-	-	-	-	-	-	-	-	2
106-4-1	-	-	-	-	-	215	65	3	-
-2	-	-	-	-	-	-	-	-	
106-5-1	4,540	-	-	-	-	-	-	-	1,3
106-6-1	-	-	-	-	-	-	-	-	1
108-2-1	-	-	-	-	-	315	50	3	-
-2	-	-	-	-	-	-	-	-	2
-3	4,150	5.29	0.17	-	-	-	-	-	1,3
108-4-1	-	-	-	-	-	155	65	6.5	-
-2	-	-	-	-	-	-	-	-	1,3
108-5-1	-	-	-	-	-	105	80	1.5	-
-2	4,450	-	-	-	-	-	-	-	1,2,3
108-6-1	4,320	4.63	0.18	2.45	152	-	-	-	-
-2	-	-	-	-	-	310	60	4	1,3
110-1-1	4,670	5.36	0.15	2.56	159	-	-	-	1
-2	-	-	-	-	-	-	-	-	1,2
110-2-1	4,800	4.32	0.16	2.52	157	-	-	-	-
-2	-	-	-	-	-	290	55	4.5	1
110-3-1	-	-	-	-	-	-	-	-	2
-2	-	-	-	-	-	-	-	-	1
110-4-1	-	-	-	-	-	200	65	5	-
-2	-	-	-	-	-	-	-	-	1,3

1/ First number is block in the dam, second is hole number, third is core number
2/ Wing dam
3/ Average of two cylinders

Note: u/s = upstream; d/s = downstream

Table 7. - *Compilation of 150-mm (6-in) diameter core data - Interior and exterior concrete at 6 months' age - Grand Coulee Forebay Dam - Continued*

Core No. 1/	Location of hole: Station No.	Offset from axis	Elevation top of hole, ft	Location in dam	Lift in block No.	Core data: Date drilled	Depth of core, ft	Joint elevation, ft	Direction drilled	Condition of concrete in core	Concrete data when placed: Date placed	Max size aggr, in	Temperatures, °F: Conc	H_2O	Air Max	Air Min	W/C+P	Cement, lb/yd³	Pozzolan, lb/yd³	Water, lb/yd³	Sand, %	Unit weight, lb/ft³	Slump, in	Air content, %	6" x 12" control cylinders compressive strength, 3/ lb/in²: 7-d	28-d	90-d	180-d	1 yr	Test data on concrete cores: Compressive strength, lb/in²	Elastic properties Ex10⁻⁶ lb/in²	Elastic properties r	Specific gravity	Unit weight lb/ft³	Tensile test: Strength, lb/in²	% area disbonded	Distance of break from end	Other tests 1. Triaxial 2. Shear 3. Petrographic
																		Interior concrete																				
112-1-1	107+74	20+28	1119.6	Foundation gallery - stairwell	26	7-15-71	0.0-3.1	1117.5	N34°W-30 dip	3/4" rebar @ 2.4'	3-27-71	6	-	-	-	-	0.45	186	79	119	25	152.6	1.50	2.9	-	2,740	4,410	-	-	-	-	-	-	-	390	65	1	-
-2	107+74	20+28	1119.6	Foundation gallery - stairwell	26-27	7-15-71	3.1-5.9	1117.5	N34°W-30 dip	Small void near bottom; good construction joint @ 2.1'	3-27-71	6	-	-	-	-	0.45	186	79	119	25	152.6	1.50	2.9	-	2,740	4,410	-	-	4,880	-	-	2.49	155	-	-	-	1,2,3
112-2-1	107+84.5	20+79.5	1119.6	Drainage gallery - d/s wall	26	7-15-71	0.0-2.9	1117.5	N64 W-30 dip		3-27-71	6	-	-	-	-	0.45	186	79	119	25	152.6	1.00	2.9	-	2,740	4,410	-	-	4,920	5.75	0.14	2.53	157	-	-	-	1
-2	107+84.5	20+79.5	1119.6	Drainage gallery - d/s wall	26-27	7-16-71	2.9-5.8	1117.5	N64 W-30 dip	Good construction joint @ 2.0'	3-27-71	6	-	-	-	-	0.45	186	79	119	25	152.6	1.00	2.9	-	2,740	4,410	-	-	-	-	-	-	-	-	-	-	1,2,3
114-1-1	108+91	20+17.5	1119.6	Foundation gallery - u/s wall	26	7-20-71	0.0-3.0	1117.5	S60°E-30 dip	Break at 2.4'	4- 2-71	6	46	40	56	42	0.51	184	80	135	26	153.9	1.25	2.8	-	3,410	-	-	-	5,860	4.62	0.17	-	-	-	-	-	1,3
-2	108+91	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	7-20-71	3.0-6.0	1117.5	S60 E-30 dip		4- 2-71	6	46	40	56	42	0.51	184	80	135	26	153.9	1.25	2.8	-	3,410	-	-	-	-	-	-	-	-	-	-	-	1,3
114-2-1	109+03	20+17.5	1119.6	Foundation gallery - u/s wall	26	7-21-71	0.0-3.0	1117.5	S60°E-30 dip	Broke at 2.4'	4- 2-71	6	46	40	56	42	0.51	184	80	135	26	153.9	1.25	2.8	-	3,410	-	-	-	-	-	-	-	-	160	60	10	-
-2	109+03	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	7-21-71	3.0-6.0	1117.5	S60 E-30 dip	Good concrete	4- 2-71	6	46	40	56	42	0.51	184	80	135	26	153.9	1.25	2.8	-	3,410	-	-	-	4,720	-	-	-	-	-	-	-	1,2
114-3-1	109+03	20+79.5	1119.6	Drainage gallery - d/s wall	26	7-21-71	0.0-3.0	1117.5	N64 W-30 dip		4- 2-71	6	46	40	56	42	0.51	184	80	135	26	153.9	1.25	2.8	-	3,410	-	-	-	-	-	-	-	-	110	65	5	-
-2	109+03	20+79.5	1119.6	Drainage gallery - d/s wall	26-27	7-21-71	3.0-6.0	1117.5	N64 W-30°dip	Good concrete - joint hard to find	4- 2-71	6	46	40	56	42	0.51	184	80	135	26	153.9	1.25	2.8	-	3,410	-	-	-	-	-	-	-	-	-	-	-	1,2,3
116-1-1	110+08	20+23	1119.6	Foundation gallery - stairwell	26	7-23-71	0.0-3.0	1117.5	N66°E-30 dip	Core broke @ 2.3'	4- 9-71	6	47	40	54	41	0.49	188	81	132	25	154.9	1.50	3.1	-	3,475	5,895	-	-	-	-	-	-	-	130	65	8	-
-2	110+08	20+23	1119.6	Foundation gallery - stairwell	26-27	7-23-71	3.0-6.0	1117.5	N66°E-30 dip	Steel @ 3.5', 4.0', and 4.2'	4- 9-71	6	47	40	54	41	0.49	188	81	132	25	154.9	1.50	3.1	-	3,475	5,895	-	-	-	-	-	-	-	-	-	-	2
116-3-1	110+29.46	20+79.5	1119.6	Drainage gallery	26	7-28-71	0.0-3.0	1117.5	N56°E-30 dip	Core broke @ 2.6'	4- 9-71	6	47	40	54	41	0.49	188	81	132	25	154.9	1.50	3.1	-	3,475	5,895	-	-	5,480	5.14	0.17	2.50	155	-	-	-	1
-2	110+29.46	20+79.5	1119.6	Drainage gallery	26-27	7-28-71	3.0-6.0	1117.5	N56°E-30 dip		4- 9-71	6	47	40	54	41	0.49	188	81	132	25	154.9	1.50	3.1	-	3,475	5,895	-	-	-	-	-	-	-	-	-	-	1,2,3
120-1-1	112+29	20+28	1119.6	Foundation gallery - stairwell	26	8-23-71	0.0-2.7	1117.5	S84°W-30 dip	Good concrete	5- 6-71	6	50	60	67	53	0.49	186	79	129	25	153.1	2.25	3.6	1,350	2,300	-	-	-	4,000	5.18	0.19	2.50	156	-	-	-	1,3
-2	112+29	20+28	1119.6	Foundation gallery - stairwell	26-27	8-23-71	2.7-5.7	1117.5	S84 W-30 dip	Small rock pocket @ cj	5- 6-71	6	50	60	67	53	0.49	186	79	129	25	153.1	2.25	3.6	1,350	2,300	-	-	-	4,500	5.22	0.15	2.55	159	-	-	-	1,2,3
120-2-1	112+31	20+17.5	1119.6	Foundation gallery	26	8-24-71	0.0-2.9	1117.5	S64 E-30 dip	Good concrete	5- 6-71	6	50	60	67	53	0.49	186	79	129	25	153.1	2.25	3.6	1,350	2,300	-	-	-	-	-	-	-	-	-	-	-	-
-2	112+31	20+17.5	1119.6	Foundation gallery	26-27	3-24-71	2.9-5.9	1117.5	S64 E-30 dip	Good construction joint @ 4.8'; broke below cj - 6" aggregate at cj	5- 6-71	6	50	60	67	53	0.49	186	79	129	25	153.1	2.25	3.6	1,350	2,300	-	-	-	-	-	-	-	-	-	-	-	1,2,3
120-3-1	112+32	20+17.5	1119.6	Foundation gallery - u/s wall	26	8-24-71	0.0-3.0	1117.5	S64 E-30 dip	Core broke @ 2.1'	5- 6-71	6	50	60	67	53	0.49	186	79	129	25	153.1	2.25	3.6	1,350	2,300	-	-	-	-	-	-	-	-	-	-	-	-
-2	112+32	20+17.5	1119.6	Foundation gallery - u/s wall	26-27	8-24-71	3.0-5.9	1117.5	S64 E-30 dip	Good concrete to cj @ 3.7' to 4.8'; cut form tie @ 3.3', 4.4', 4.9'; lower 1/3 poor concrete	5- 6-71	6	50	60	67	53	0.49	186	79	129	25	153.1	2.25	3.6	1,350	2,300	-	-	-	-	-	-	-	-	-	-	-	-
																		Exterior concrete																				
B-2-1 2/	1+08.8	7.9' lt	1311.0	Top of block	1	3-10-72	0.0-1.8	-	Vertical	Broke @ 1.8'	10- 4-71	1.5	50	37	54	39	0.38	361	119	183	34	150.5	3.25	4.4	2,705	4,350	-	-		No tests								

1/ First number is block in the dam, second is hole number, and third is core number
2/ Wing dam
3/ Average of two cylinders

Table 8. - *Summary of compressive strength and elastic properties test results on 150-mm (6-in) diameter cores at 6 months' age - Grand Coulee Forebay Dam*

Core No.	Date tested	Age, days	Compressive strength, MPa	(lb/in²)		Strength ratio: core / 28-day cyl., percent	Modulus of elasticity, GPa	(lb/in²x10⁶)	Poisson's ratio
				Interior Concrete					
106-1-1	12-20-71	233	43.4	(6290)		213	35.4	(5.13)	0.18
-2	11-10-71	193	30.1	(4370)		148	30.9	(4.48)	.20
106-5-1	11-10-71	193	31.3	(4540)	1/	154	-	-	-
108-2-3	11-10-71	251	28.6	(4150)		125	36.5	(5.29)	.17
-5-2	11-10-71	251	30.7	(4450)	1/	134	-	-	-
-6-1	12-20-71	291	29.8	(4320)		130	31.9	(4.63)	.18
110-1-1	12-20-71	283	32.2	(4670)		119	37.0	(5.36)	.15
-2-1	12-20-71	283	33.1	(4800)		123	31.2	(4.52)	.16
112-1-2	12-20-71	268	33.6	(4880)		178	-	-	-
-2-1	12-20-71	268	33.9	(4920)		180	39.6	(5.75)	.14
114-1-1	11-10-71	226	40.4	(5860)		172	31.9	(4.62)	.17
-2-2	11-10-71	226	32.5	(4720)	1/	138	-	-	-
116-3-1	12-20-71	255	37.8	(5480)		158	35.4	(5.14)	.17
120-1-1	12-20-71	238	27.6	(4000)		174	35.7	(5.18)	.19
-2	12-20-71	238	31.0	(4500)		196	36.0	(5.22)	.15
Average			33.1	(4800)		156	34.7	(5.03)	.17
Coefficient of variation			12.7						

1/ Test across construction joint

Table 9. - *Summary of tensile strength test results on 150-mm (6-in) diameter cores at 6 months' age - Grand Coulee Forebay Dam*

Core No.	Length of specimen, mm	(in)	Date tested	Age, days	Tensile strength, MPa 1/	(lb/in²)	Core strength ratio: tensile / compressive, percent	Disbonded area, percent	Distance of break from end, mm	(in)
				Interior Concrete						
106-3-1	416	(16-3/8)	12-22-71	235	1.83	(265)	5.2	70	205	(8)
-4-1	457	(18)	12-22-71	235	1.48	(215)	4.2	65	75	(3)
108-2-1	457	(18)	12-13-71	284	2.17	(315)	7.3	50	75	(3)
-4-1	457	(18)	12-22-71	293	1.07	(155)	3.6	65	165	(6-1/2)
-5-1	464	(18-1/4)	12-22-71	293	.72	(105)	2.4	80	40	(1-1/2)
-6-2	464	(18-1/4)	12-22-71	293	2.14	(310)	7.2	60	100	(4)
110-2-2	467	(18-3/8)	12-13-71	276	2.00	(290)	6.1	55	115	(4-1/2)
-4-1	467	(18-3/8)	12-13-71	276	1.38	(200)	4.2	65	125	(5)
112-1-1	464	(18-1/4)	12-13-71	261	2.67	(390)	8.0	65	25	(1)
114-2-1	459	(18-1/16)	12-13-71	259	1.10	(160)	3.0	60	255	(10)
-3-1	462	(18-3/16)	12-13-71	259	.76	(110)	2.1	65	125	(5)
116-1-1	435	(17-1/8)	12-13-71	248	.90	(130)	2.4	65	205	(8)
Average					1.52	(220)	4.6			

1/ All tests were on nonjointed specimens

CONCLUSIONS

Based on results obtained from testing the 255-mm (10-in) and 150-mm (6-in) diameter cores at 6 months' and 1 year's age, the following conclusions can be made:

1. The interior and exterior concretes in the Forebay Dam are of good quality, uniform, well consolidated, and have strength properties which exceed the design compressive strength of 20.7 MPa (3000 lb/in^2) at 6 months' age.

2. The average compressive strength increase from 6 months to 1 year for both interior and exterior concrete was 9 percent. This increase exceeds the average 2-percent gains obtained for Glen Canyon and Yellowtail Dams.

3. The apparent tensile strength of the concrete averaged about 4 percent of the compressive strength and is considered about average for mass concrete. The ratio of tensile to compressive strength for interior concrete averaged slightly higher than that for exterior concrete and this same ratio of 6 months' age concrete also averaged slightly higher than at 1 year's age.

4. The modulus of elasticity of the concrete represented by these cores averaged 35.5 GPa (5.15×10^6 lb/in^2). This substantiates the modulus of elasticity used in the design of the dam for the dynamic stress response and for the stated stress analysis. There were no significant differences in moduli of elasticity between 6 months' and 1 year's age, or between the exterior and interior concretes.

5. The bond strength of the horizontal construction joints in the 255-mm-diameter cores was at least equal to the tensile strength of the adjoining concrete. This is based on the fact that 15 of the 19 specimens tested failed at points other than the construction joint. The shearing strength at the construction joints of 150-mm-diameter cores, when tested by triaxial shear tests, was within 83 percent of that of unjointed cores, further indicating that good constuction joints were obtained. The cohesive strength of the jointed 150-mm cores was less than that of unjointed cores.

6. There was a complete lack of bond at the construction joint where special chlorinated rubber-base bonding and curing compound was used experimentally.

7. Other properties of the mass concrete such as Poisson's ratio and density were within expected ranges.

Appendix A

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

UNITED STATES GOVERNMENT

Memorandum

Memorandum

Denver, Colorado

TO : Head, Concrete Section

DATE: January 7, 1972

THROUGH: Acting Chief, Concrete and Structural Branch

FROM : Acting Head, Polymer Concrete and Structural Section

SUBJECT : Bond strength between lifts of concrete and shearing strength of concrete in Grand Coulee Forebay Dam

Triaxial strength tests were made on nineteen 6- by 12-inch concrete cores to determine the bond strength between lifts in the Forebay Dam. These cores were drilled to obtain an angle of 30° between the joint plane and the longitudinal axis of the core, this being the approximate expected angle of failure in triaxial shear. Most of the joints were imperceptable to the eye. Triaxial tests were also conducted on nine 6- by 12-inch concrete cores without joints selected from the same drill holes as the jointed specimens. This provided a comparison between the shearing strength of the concrete and the shearing or bond strength of the joints between lifts of concrete. Cores were identified by block number, drill hole number, and the depth in feet to the center of the core from the collar.

All of the cores were tested in the air-dry condition. Tests of jointed cores were made using all suitable specimens. These specimens containing cooling pipe and other pieces of metal in the joint were not used. A minimum number of unjointed cores were tested to determine shearing strength of the concrete. Lateral pressures of 0, 200, 450, 700, and 1,000 psi were used in testing jointed cores. To encompass the same range, the unjointed cores were tested at lateral pressures of 0, 450, and 1,000 psi. The lateral pressure was applied first and held constant while the axial pressure was increased gradually until failure occurred. Results for each type of core are compiled in Tables 1 and 2. Figures 1 and 2 show the principal stress relationships. Mohr's diagrams for straight line solution are shown in Figures 3 and 4. (Values of S_1 were taken from Figures 1 and 2.) The curvilinear solution of Mohr's envelope is shown in Figures 5 and 6 which include tabulated values of normal stress (x), shearing strength (Y), and coefficient of friction ($\tan \phi$).

The average unconfined compressive strength of cores containing joints (4,110 psi) was about 85 percent of that for cores without joints (4,810 psi). Field control tests of 6-inch maximum-size aggregate concrete showed about 3,000- to 3,500-psi compressive strength at 28 days' age. The cohesive strength (shearing strength at zero normal stress) of jointed cores (735 psi) was about 75 percent of that for the unjointed cores (980 psi) using the straight line solution of Mohr's envelope.

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The curvilinear solution of Mohr's envelope gives a closer value to the true cohesive strength than the straight line solution. Mohr's envelope as a curve shows the cohesive strength of jointed cores (730 psi) to be about 83 percent of that for the unjointed cores (880 psi).

Variation in the test data for both types of cores can partially be attributed to the small size of the core from concrete having 6-inch maximum aggregate. Acceptable maximum-size aggregate in a 6-inch-diameter specimen is 1-1/2 inches; however, 6-inch diameter is the largest size that we are equipped to test under triaxial loading conditions. One jointed core (No. 120-1-4.2) contained a significant amount of air voids in the joint, thereby contributing to the variation. Since the cores did not fail by crushing the aggregate, the average data reported should be fairly representative of the concrete and joint characteristics.

Jointed cores under lateral pressure failed generally along or on the joint plane. One core (No. 108-6-4.3) failed across the joint, as marked by field personnel; however, the strength value obtained was not unusual when compared to other jointed cores tested at the same lateral pressure (450 psi). Measured failure angles varied from 20° to 32° with an average of 26.5° from the longitudional axis of the core. Cores at zero lateral pressure exhibited conical-type failure and almost vertical cracking with the exception of the core with voids in the joint (No. 120-1-4.2) which failed on the joint at a measured 27.5°. Unjointed cores showed generally conical failures and almost vertical cracking. Only two of these cores showed a measurable shear failure at about 25°. Figures 7 through 14 show the concrete cores after failure. The black arrows and lines marked on the cores show the general location of the joint plane. Theoretical angle of failure was about 21° for jointed cores and 22° for unjointed cores using the relationship $\phi = 90 - 2\alpha$ where ϕ is the angle of inclination of Mohr's envelope and α is the angle of failure (straight line solution). Variations in measured and theoretical angles of failure are also partially attributable to the effect of the very large aggregate particles in the concrete. Additional information concerning mode of failure including photographs of the failure planes will be reported by the Chemistry and Physics Section (Petrographic Laboratory).

James T. Aikin

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221

Table 1

TRIAXIAL COMPRESSIVE STRENGTH
TESTS OF 6- BY 12-INCH CONCRETE CORES
Grand Coulee Forebay Dam

	Jointed cores - Air dry		
Core No.*	Lateral stress S_3, psi	Axial stress S_1, psi	Average axial stress psi
106-5-1.6	0	4,570	
108-5-4.3	0	4,470	4,110
114-2-4.2	0	4,740	
120-1-4.2	0	2,650	
106-1-4.4	200	5,650	
108-2-4.5	200	5,360	4,960
110-3-4.15	200	4,750	
114-1-4.3	200	4,070	
106-6-1.8	450	6,990	
108-6-4.3	450	7,390	6,870
110-4-4.2	450	7,490	
114-3-4.2	450	5,600	
108-4-4.25	700	7,550	
110-1-4.25	700	9,420	8,550
112-1-4.2	700	8,030	
120-2-4.3	700	9,210	
110-2-4.3	1,000	10,280	
112-2-4.25	1,000	11,480	10,870
116-3-4.15	1,000	10,860	

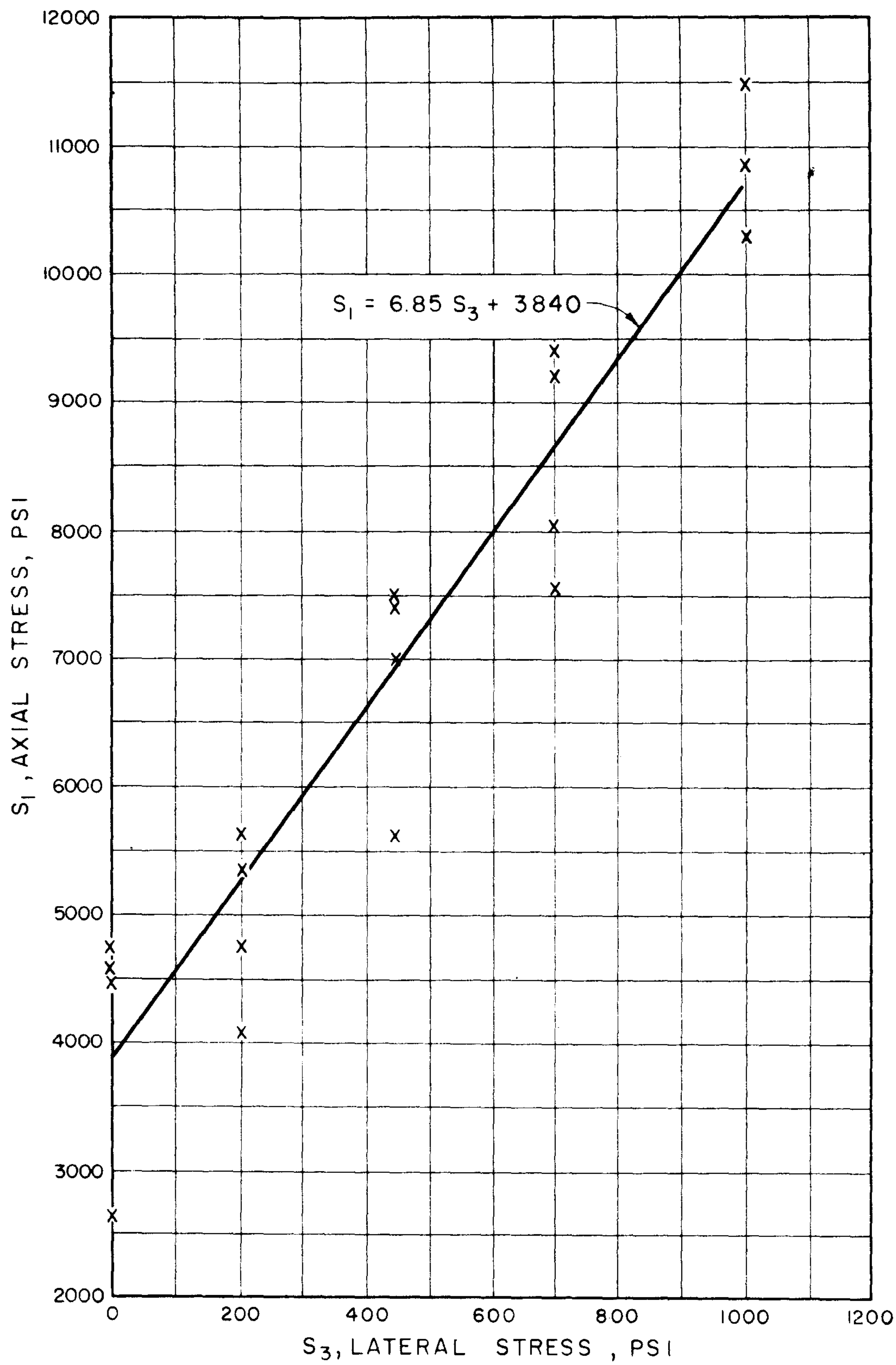
*The first number designates the block number; the second number is the drill hole number; and the third number is the depth in feet to the center of the core from the collar.

Table 2

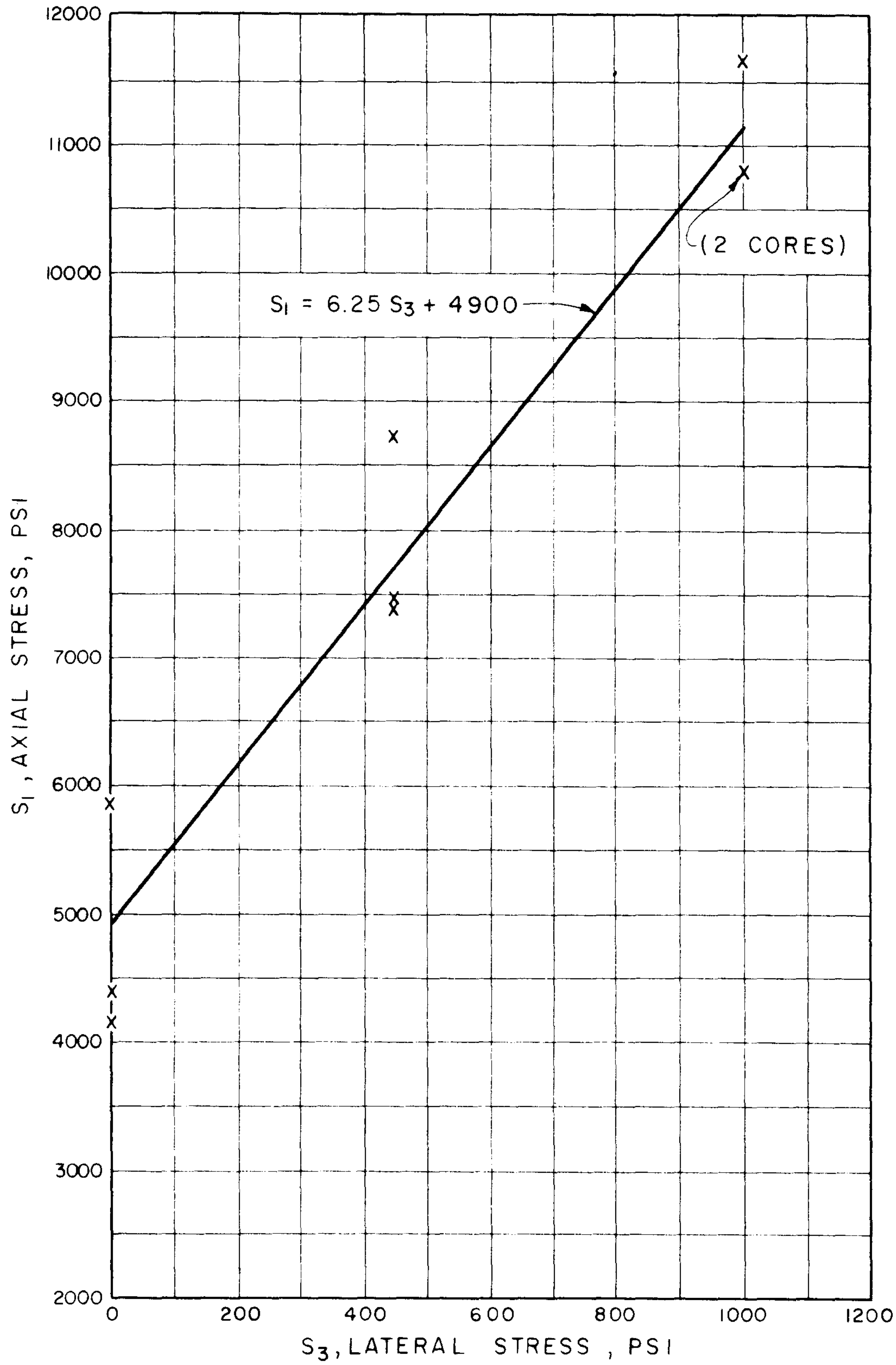
TRIAXIAL COMPRESSIVE STRENGTH
TESTS OF 6- BY 12-INCH CONCRETE CORES
Grand Coulee Forebay Dam

	Unjointed cores - Air dry		
Core No.*	Lateral stress S_3, psi	Axial stress S_1, psi	Average axial stress psi
106-1-2.2	0	4,390	
108-2-3.5	0	4,170	4,810
114-1-1.3	0	5,870	
106-2-2.2	450	7,480	
108-5-3.25	450	7,390	7,870
116-3-1.8	450	8,740	
110-1-2.15	1,000	11,670	
112-2-1.85	1,000	10,780	11,080
120-1-2.0	1,000	10,780	

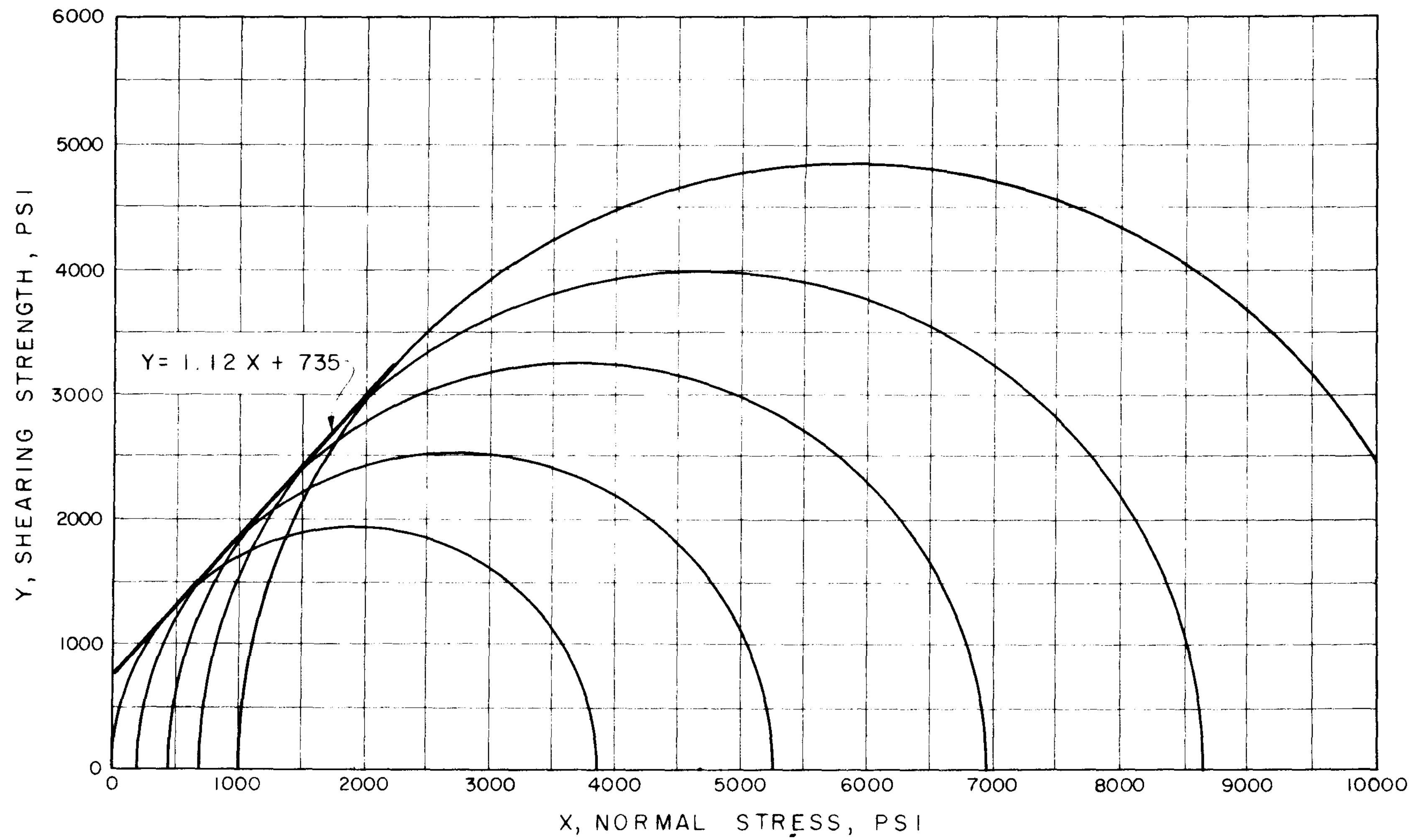
*The first number designates the block number; the second number is the drill hole number; and the third number is the depth in feet to the center of the core from the collar.



PRINCIPAL STRESS RELATIONSHIP
FOR GRAND COULEE FOREBAY DAM CONCRETE
JOINTED CORES - AIR DRY

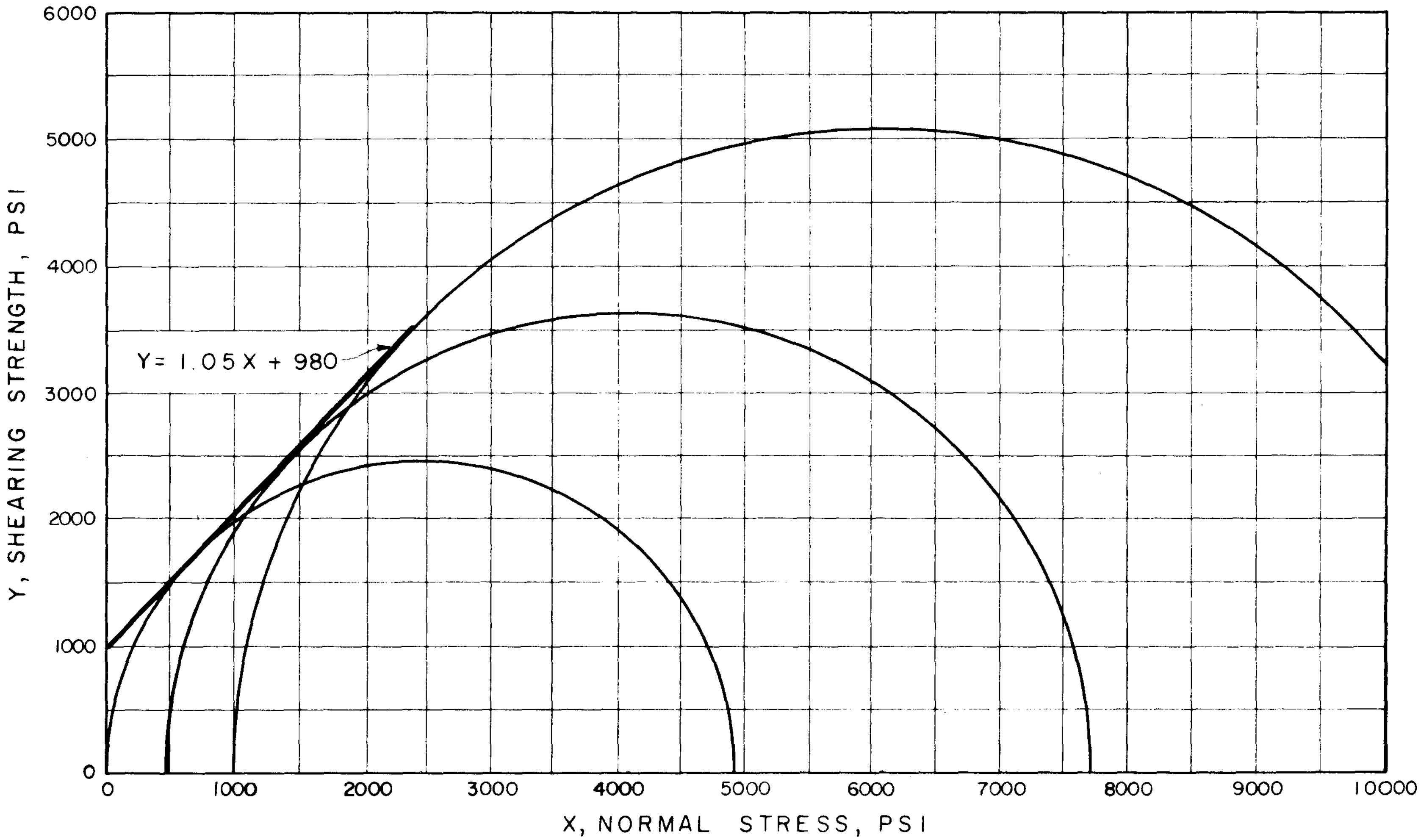


PRINCIPAL STRESS RELATIONSHIP
FOR GRAND COULEE FOREBAY DAM CONCRETE
UNJOINTED CORES - AIR DRY



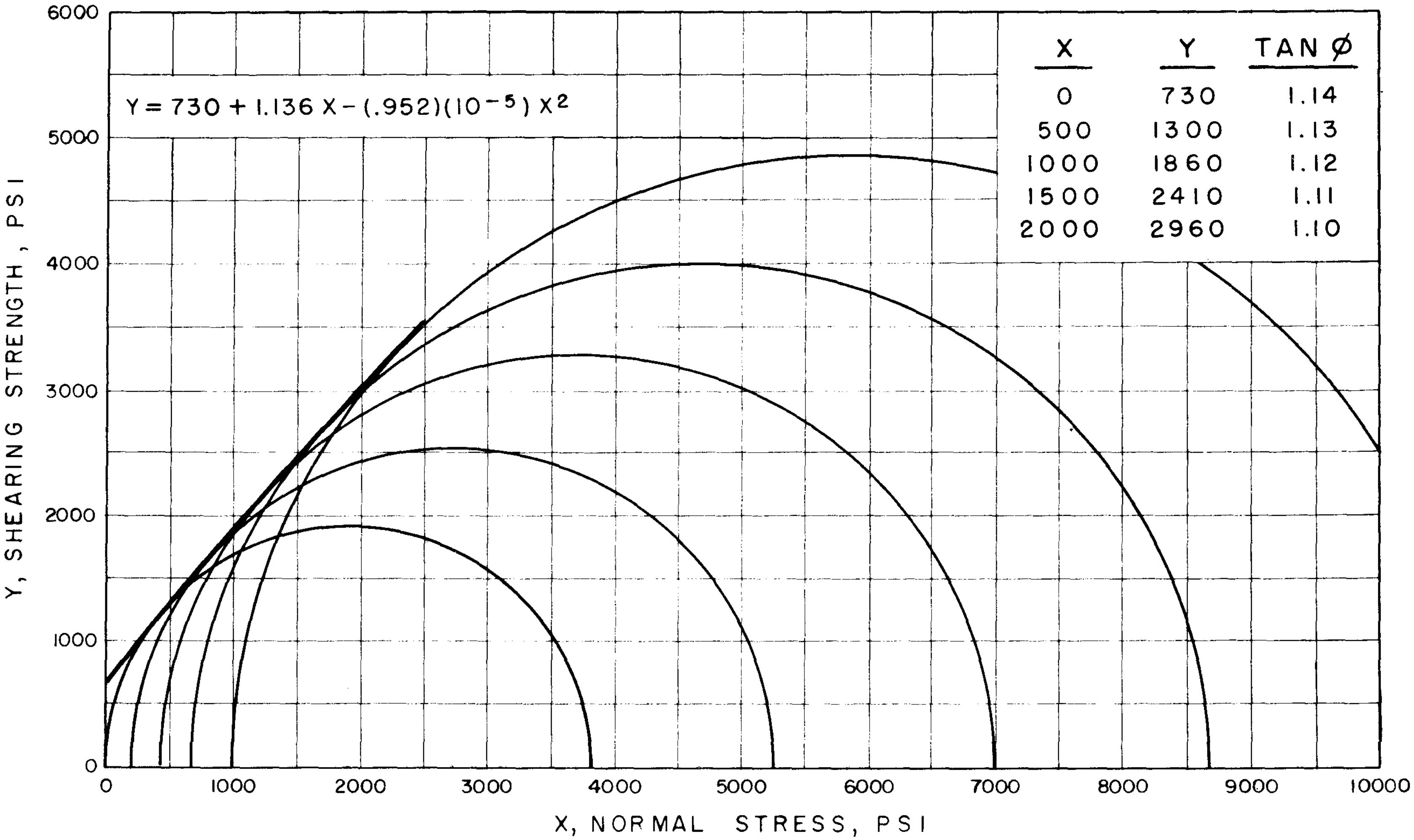
MOHR'S DIAGRAM FOR GRAND COULEE FORBAY DAM CONCRETE
JOINTED CORES - AIR DRY

FIGURE 3



MOHR'S DIAGRAM FOR GRAND COULEE FORBAY DAM CONCRETE
UNJOINTED CORES - AIR DRY

FIGURE 4



MOHR'S DIAGRAM FOR GRAND COULEE FORBAY DAM CONCRETE
JOINTED CORES - AIR DRY
(CURVED SOLUTION)

FIGURE 5

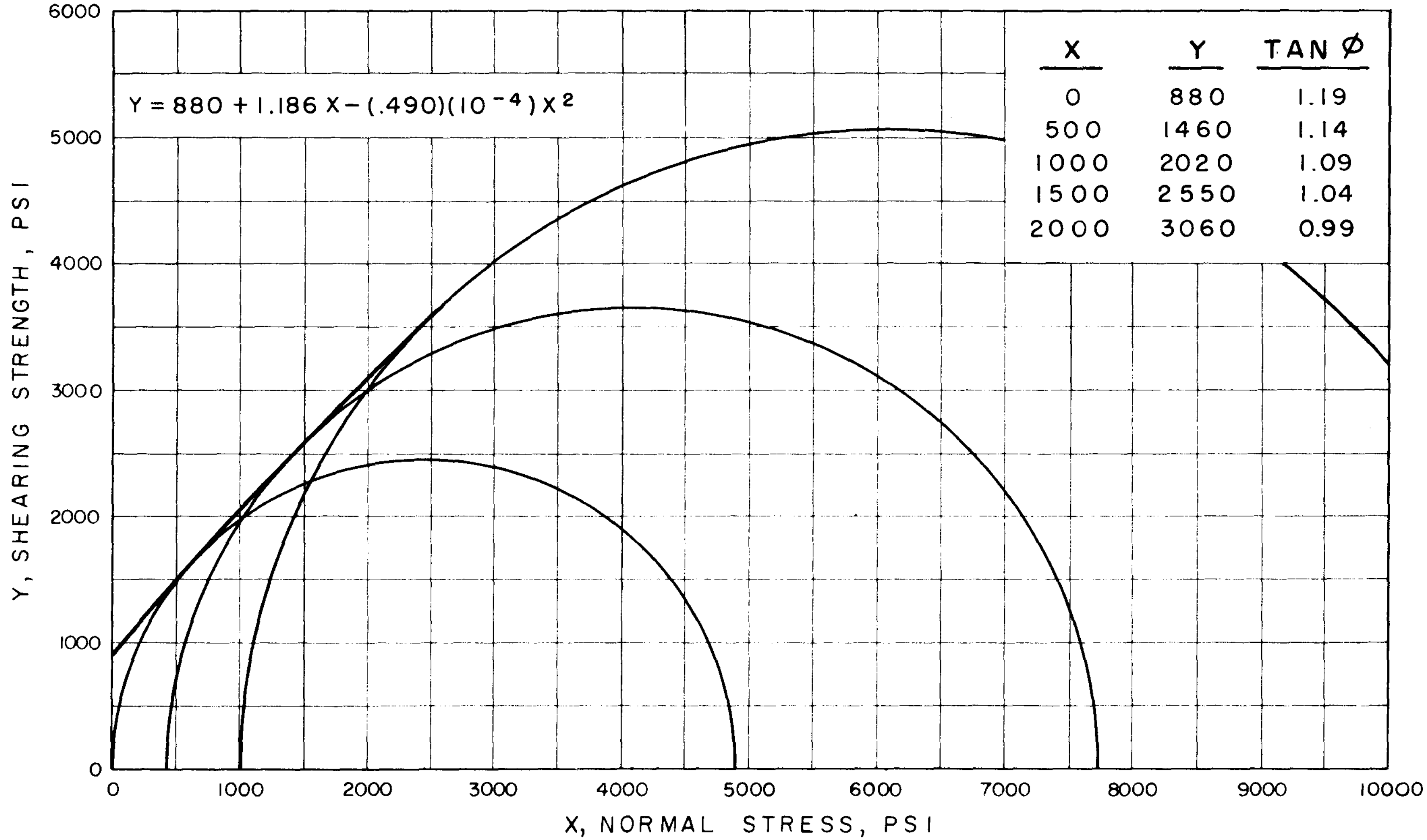
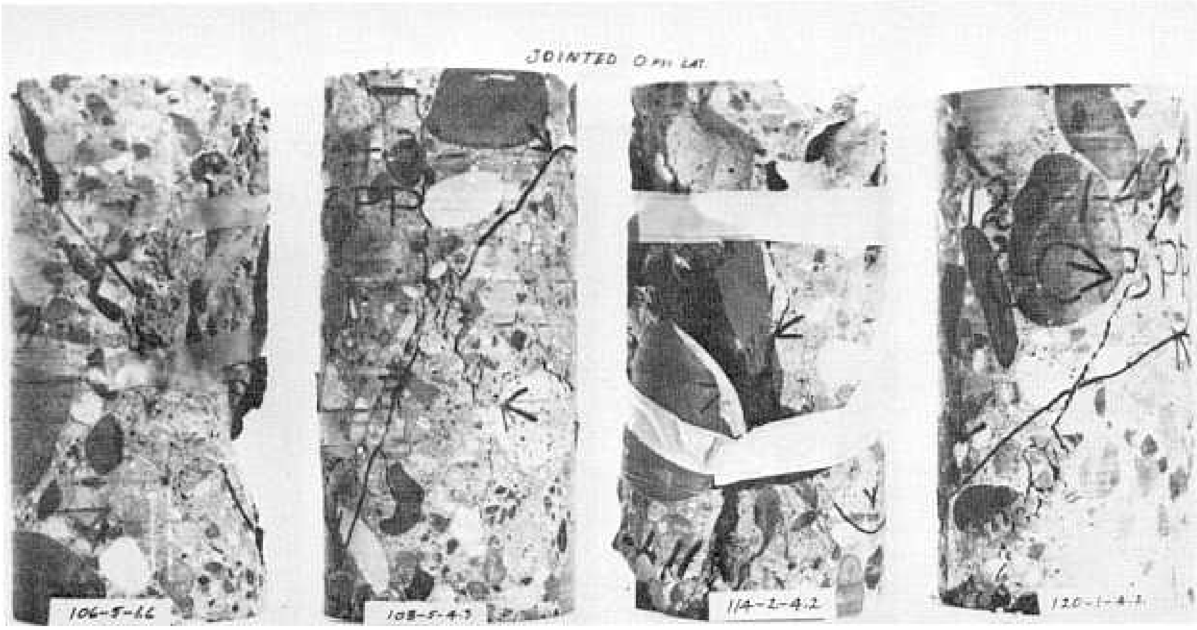


FIGURE 6

MOHR'S DIAGRAM FOR GRAND COULEE FORBAY DAM CONCRETE
UNJOINTED CORES – AIR DRY
(CURVED SOLUTION)



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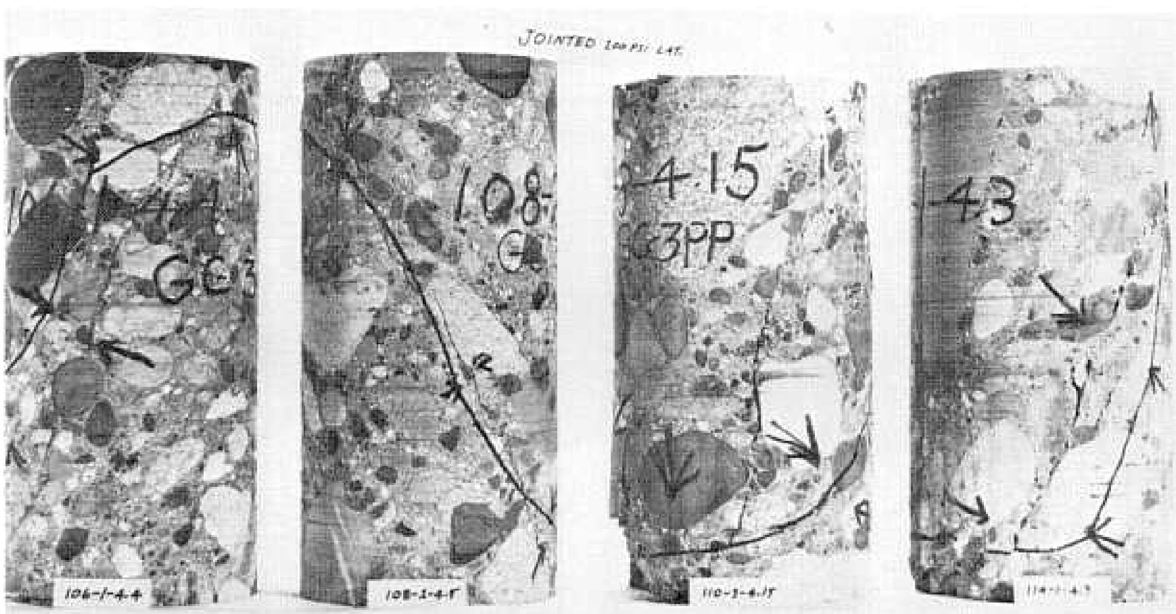

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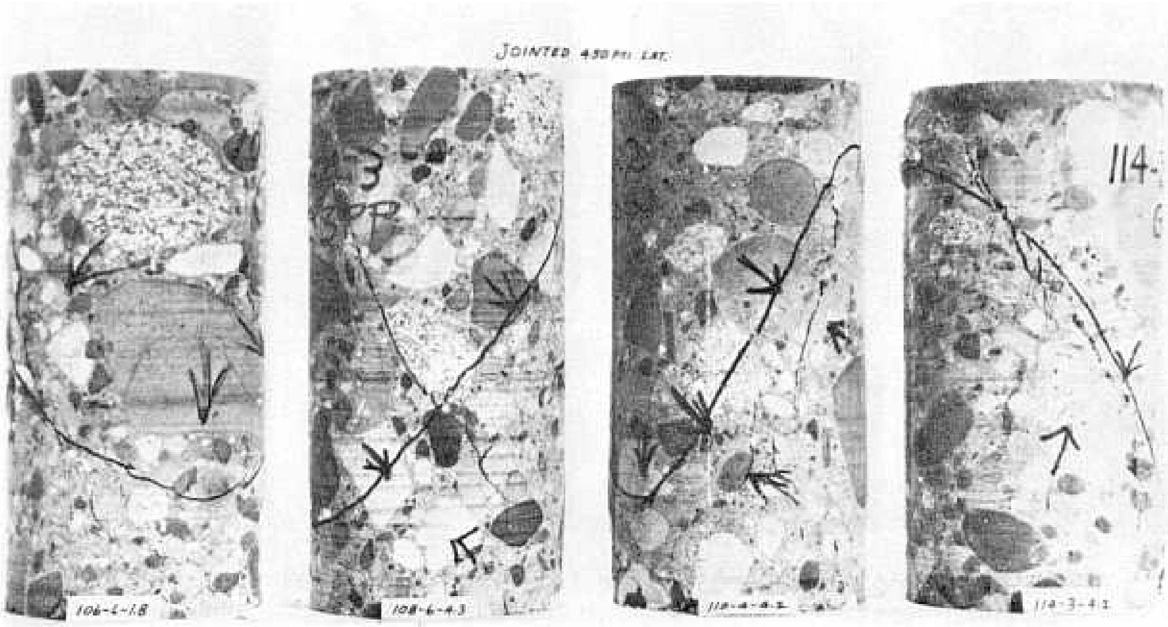

Figure 9. - Jointed cores after failure in triaxial test at 450-lb/in^2 lateral pressure.

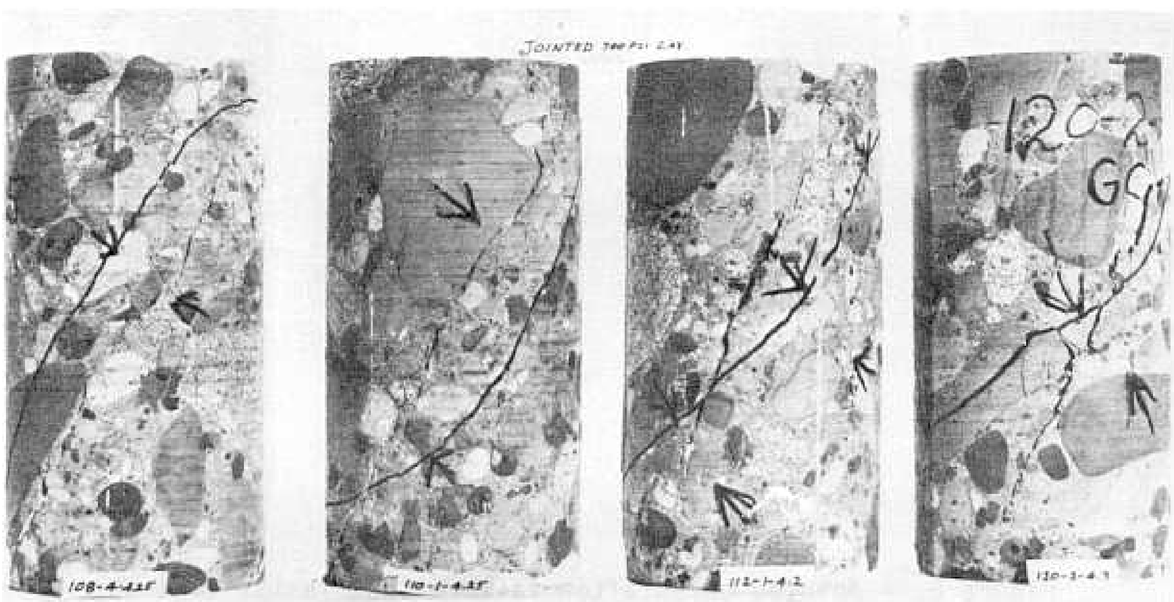

Figure 10. - Jointed cores after failure in triaxial test at 700-lb/in^2 lateral pressure.

Figure 11. - Jointed cores after failure in triaxial test at 1,000 lb/in^2 lateral pressure.

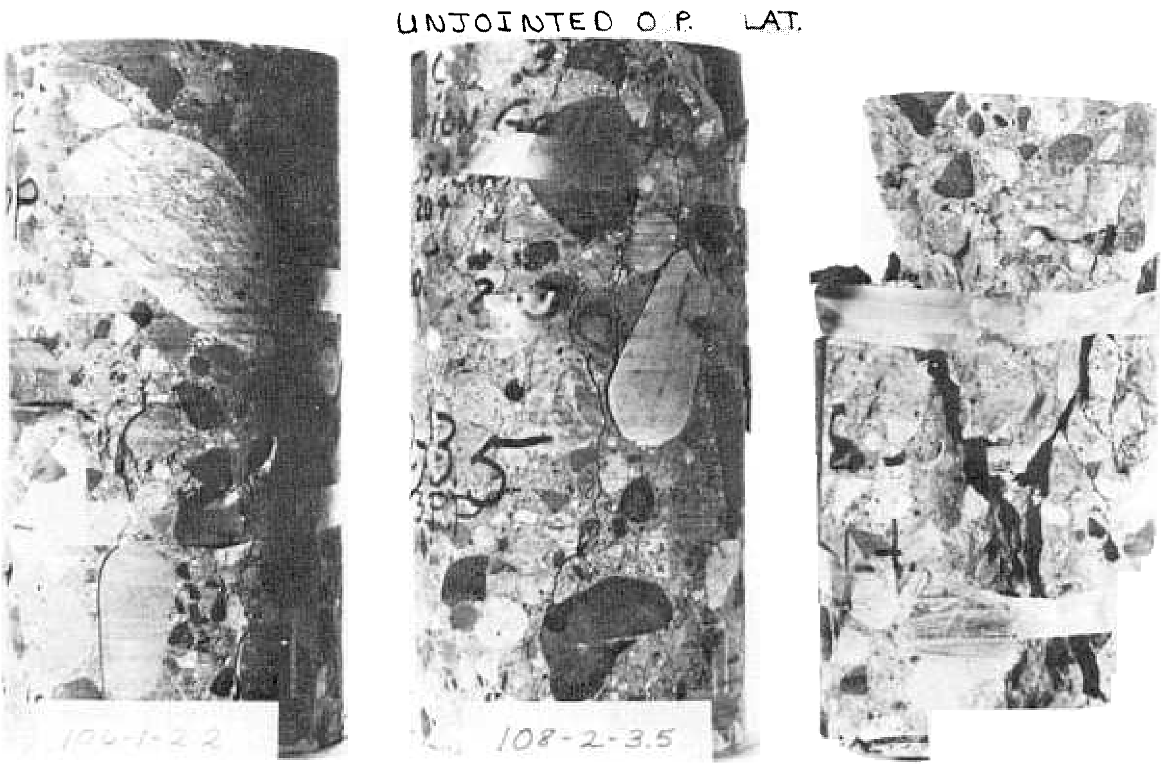

Figure 12. - Unjointed cores after failure in uniaxial compression test.

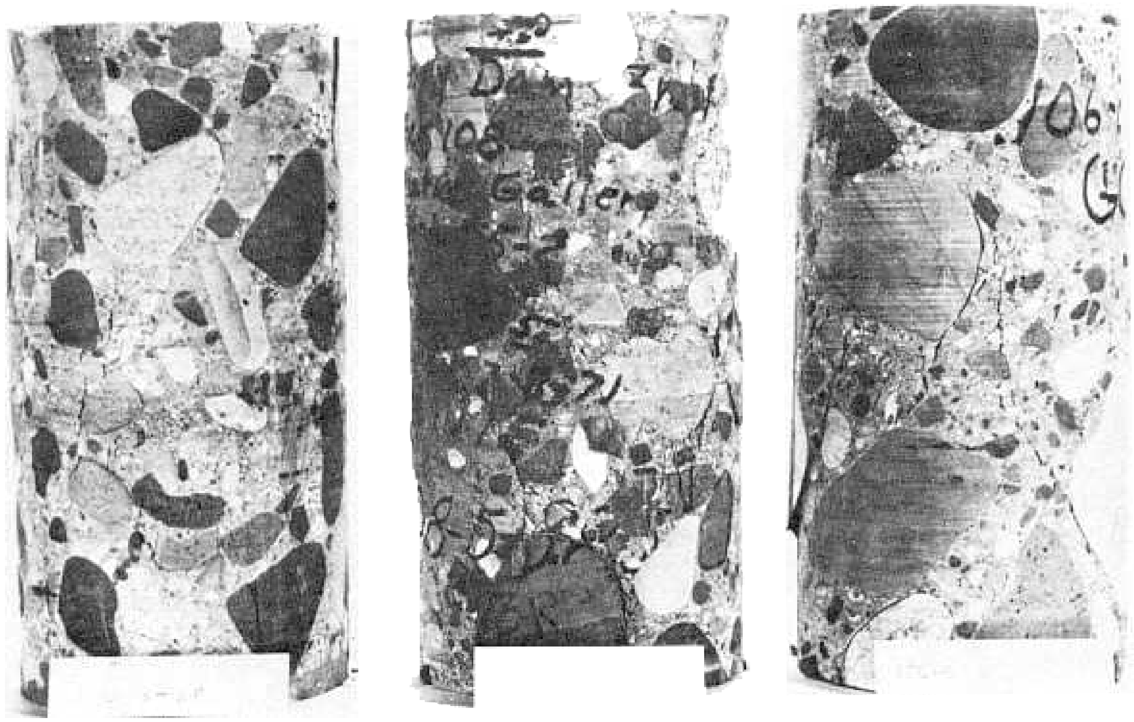

Figure 13. - Unjointed cores after failure n triaxial test at 450-lb/in^2 lateral pressure.

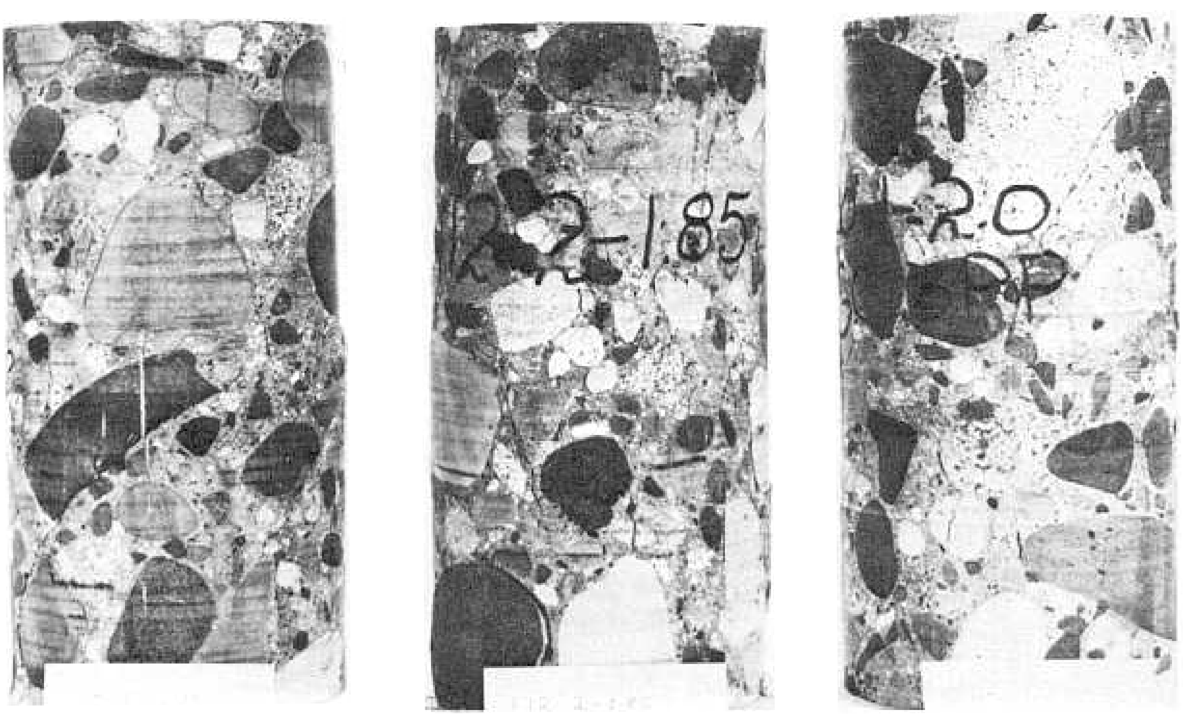

Figure 14. - Unjointed cores after failure in triaxial test at 1,000-lb/in^2 lateral pressure.

Appendix B

Form DFC-11
(12-61)
Bureau of Reclamation

INFORMATIONAL ROUTING

Memorandum
Chief, Concrete and Structural Branch

Denver, Colorado
December 22, 1971

ACTING
Chief, Applied Sciences Branch

Examination of afterbreak specimens of 6-inch-diameter concrete triaxial tests - Grand Coulee Forebay Dam Third Powerplant

Examination by: S. Rubenstein

Petrographic Referral Code: 71-33

Introduction

Twenty-eight samples of 6-inch diameter by 12-inch concrete cores were submitted by the Concrete and Structural Branch to the petrographic laboratory for examination. Fifteen of the samples were selected as representative of the afterbreak specimens of the triaxial test. The samples were from the foundation and drainage galleries of Grand Coulee Third Powerplant Forebay Dam. Table 1 contains a list of the samples and location. The concrete was 6 months to 1 year old. The concrete was drilled at a dip of 30° to intersect the lift joint at a 30° angle. Specimens of unjointed core were also tested for comparison.

GPO 832-606

Scope of Examination

The purpose of the examination was to describe the mode of failure of the jointed concrete as a result of the triaxial test. The concrete was received in a cracked condition after triaxial testing (the before and after condition is shown in photographs which appear in the portion of this report prepared by the Concrete and Structural Branch). The cylinders were then split with a 4-inch chisel along the predominant plane of failure to uncover the surface of the plane. Photographs were taken of the split cores to illustrate the mode of failure and show a comparison with the estimated joint plane. Photographs and staining tests were also made to define the joint before structural tests.

Table 2 contains a summary of the examination and includes block number, drill hole, depth, mode of failure, angle of break, jointing, fracturing, poor bond, air voids, and other features associated with failure.

Twelve photographs which indicated representative mode of failure, surface features relating to jointing and fracturing and air voids were taken (Figures 1 to 6). In addition, two enlarged photographs showed the size of aggregate and distribution near the unbroken joint (Figure 7) and two photographs showed the results of the staining tests to delineate the unbroken joint (Figure 8). The stain did penetrate the underside of the concrete slab in voids subparallel to joint plane, but the results were not too conclusive. A photograph of a joint at right angles which separated was also included (Figure 6).

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Table 1

LIST OF SAMPLES

Block	Drill hole	Depth	Location*
106	5	1.6	Foundation gallery U/S wall
108	5	3.25	Foundation gallery U/S wall
108	2	4.5	Foundation gallery stairwell
108	6	4.3	Drainage gallery D/S wall
108	4	4.25	Foundation gallery
110	4	4.2	Drainage gallery D/S wall
112	1	4.2	Foundation gallery stairwell
112	2	4.15	Drainage gallery D/S wall
114	1	1.3	Foundation gallery
114	1	4.3	Foundation gallery
114	3	4.2	Drainage gallery D/S wall
116	3	4.15	Drainage gallery D/S wall
120	1	2.0	Foundation gallery stairwell
120	1	4.2	Foundation gallery stairwell
120	2	4.3	Foundation gallery

* The samples were drilled at an elevation of 1119.6 feet.

Table 2

Summary of Examination of Afterbreak Specimens of 6-inch-diameter Concrete Lift-joint Study Grand Coulee Third Powerplant

Spec No.	S_3	S_1	Angle of break	Mode of failure	Feature associated with failure
Unjointed					
114-1-1.3	0	5870	-	Cone-shaped break	Breaks around aggregate across cement
108-5-3.25	450	7390	25°	Broke tangent to surface of large aggregate	Breaks around aggregate across cement
120-1-2.0	1000	10,780	-	Irregular break	Breaks around aggregate
Jointed					
120-1-4.2	0	2650	-	Breaks along joint plane, smooth surface	Poor bond, large entrapped air void delineating joint
106-5-1.6	0	4750	-	Breaks along joint plane with jagged surface	Breaks around aggregate across cement
108-2-4.5	200	5360	30°	Breaks along joint plane, smooth surface	Shallow entrapped air void
114-1-4.3	200	4070	27°	Breaks along joint, jagged surface	Breaks around aggregate across cement
108-6-4.3	450	7390	25°	Breaks along joint (at right angles to estimated joint, jagged surface)	Breaks around aggregate
110-4-4.2	450	7490	20°	Breaks along joint plane, jagged surface	Breaks around aggregate

Table 2 (Continued)

Spec No.	S3	S1	Angle of break	Mode of failure	Feature associated with failure
114-3-4.2	450	5600	25°	Breaks along joint, jagged surface	Breaks around aggregate across cement
108-4-4.25	700	7550	31°	Breaks along joint, jagged surface	Breaks around aggregate across cement, entrapped air void in joint plane
120-2-4.3	700	9210	30°	Breaks along joint, smooth surface	Breaks around aggregate across cement
112-1-4.2	700	8030	30°	Breaks along joint, jagged surface	Some broken aggregate
116-3-4.15	1000	10,860	32°	Breaks along joint, jagged surface	Breaks around aggregate
112-2-4.15	1000	11,400	30°	Breaks along joint, jagged surface	Breaks around aggregate

Note: Drilled at 30° dip to intersect the joint at a 30° angle. Elevation 1119.6 feet.

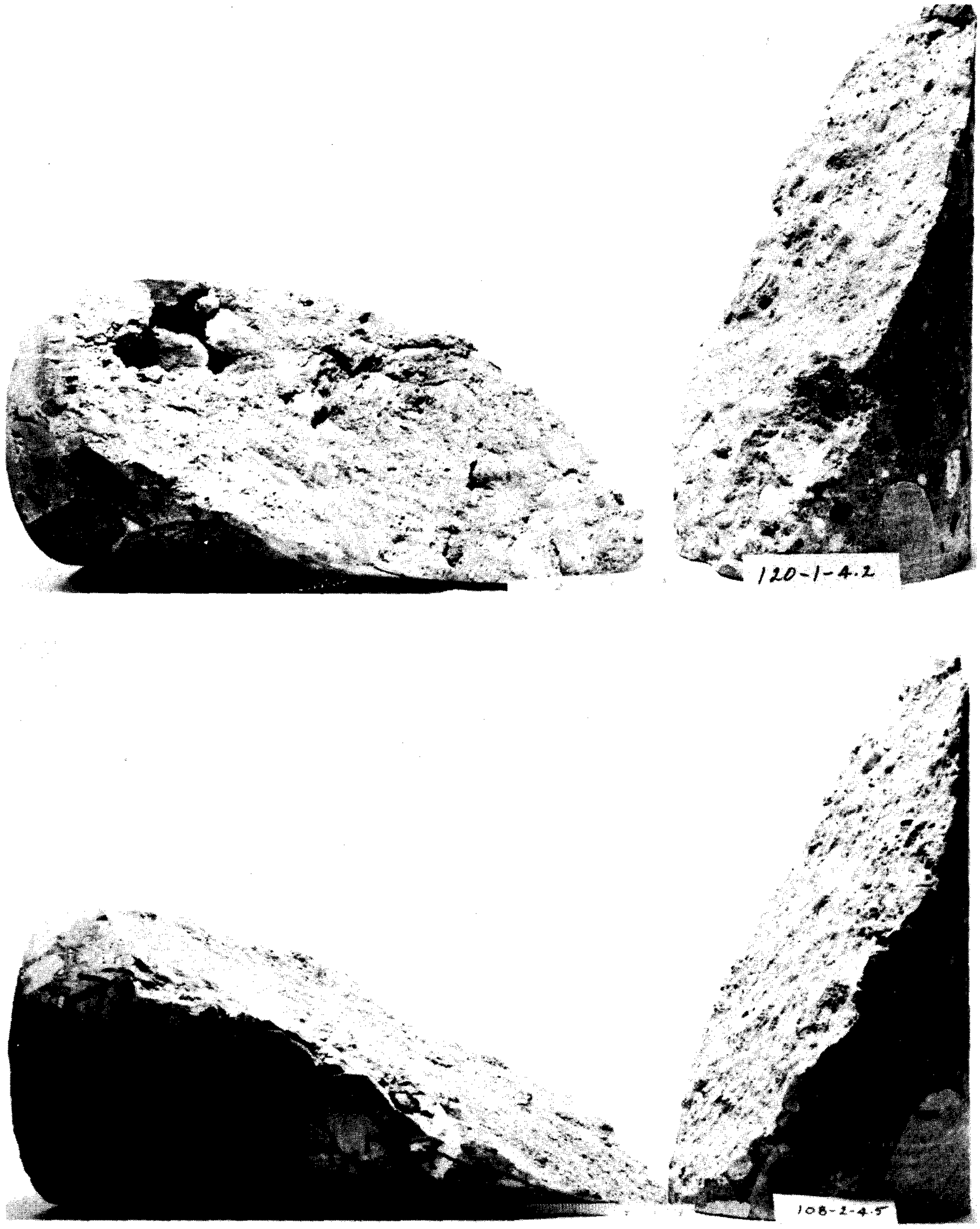

Figure 1. - Photograph of jointed concrete showing failure surface
Top - at "0" lateral load (note hole in horizontal piece and smooth plane indicating poor bond)

Bottom at 200 lb/in^2 lateral load (note smooth plane)
C-8322-49 C-8322-54

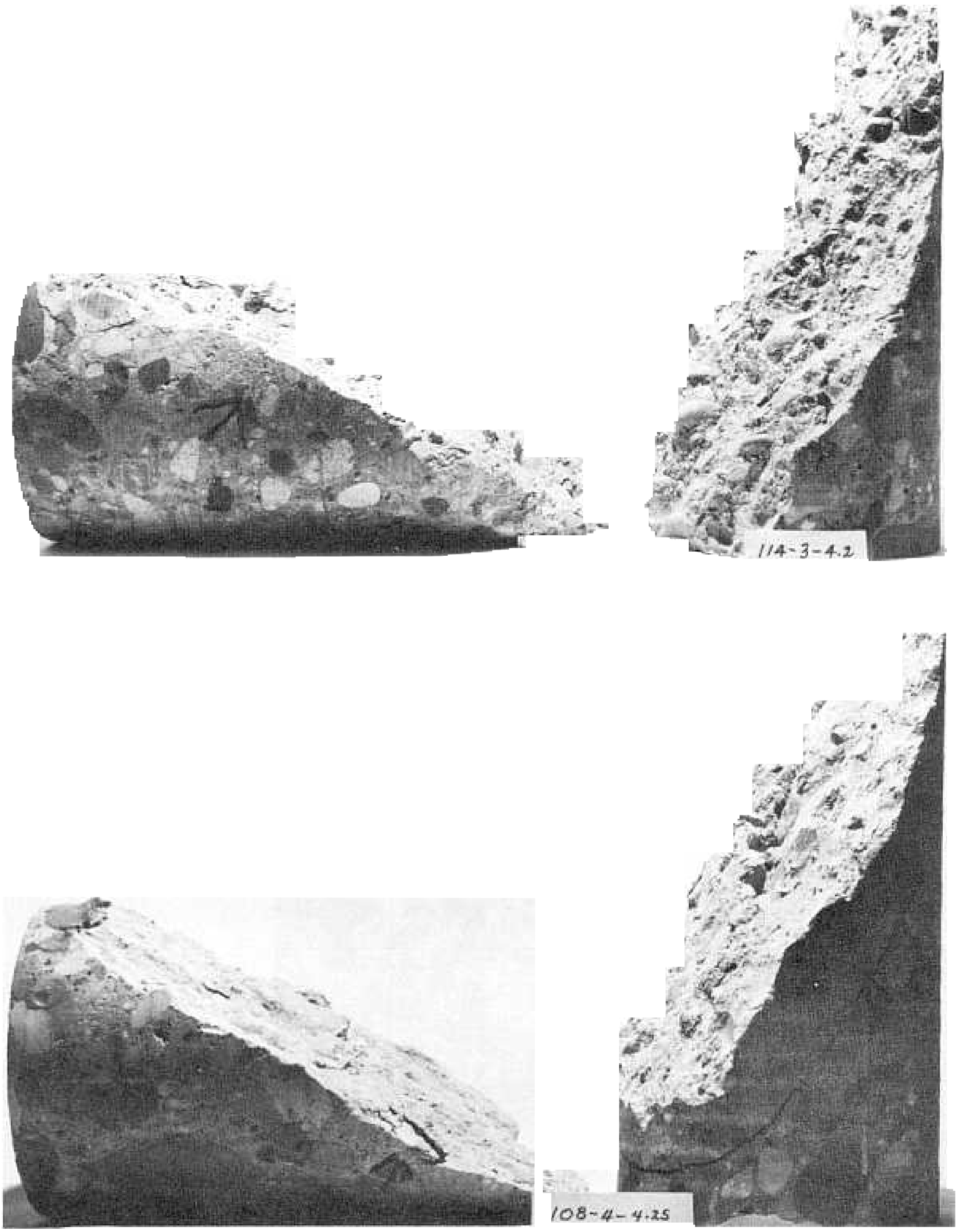

Figure 2. - Photograph of jointed concrete showing failure surface
Top - at 450 lb/in^2 load (note jagged type of break)
Bottom at 700 lb/in^2 load (note jagged break and hole)
C-8322-51 C-8322-62

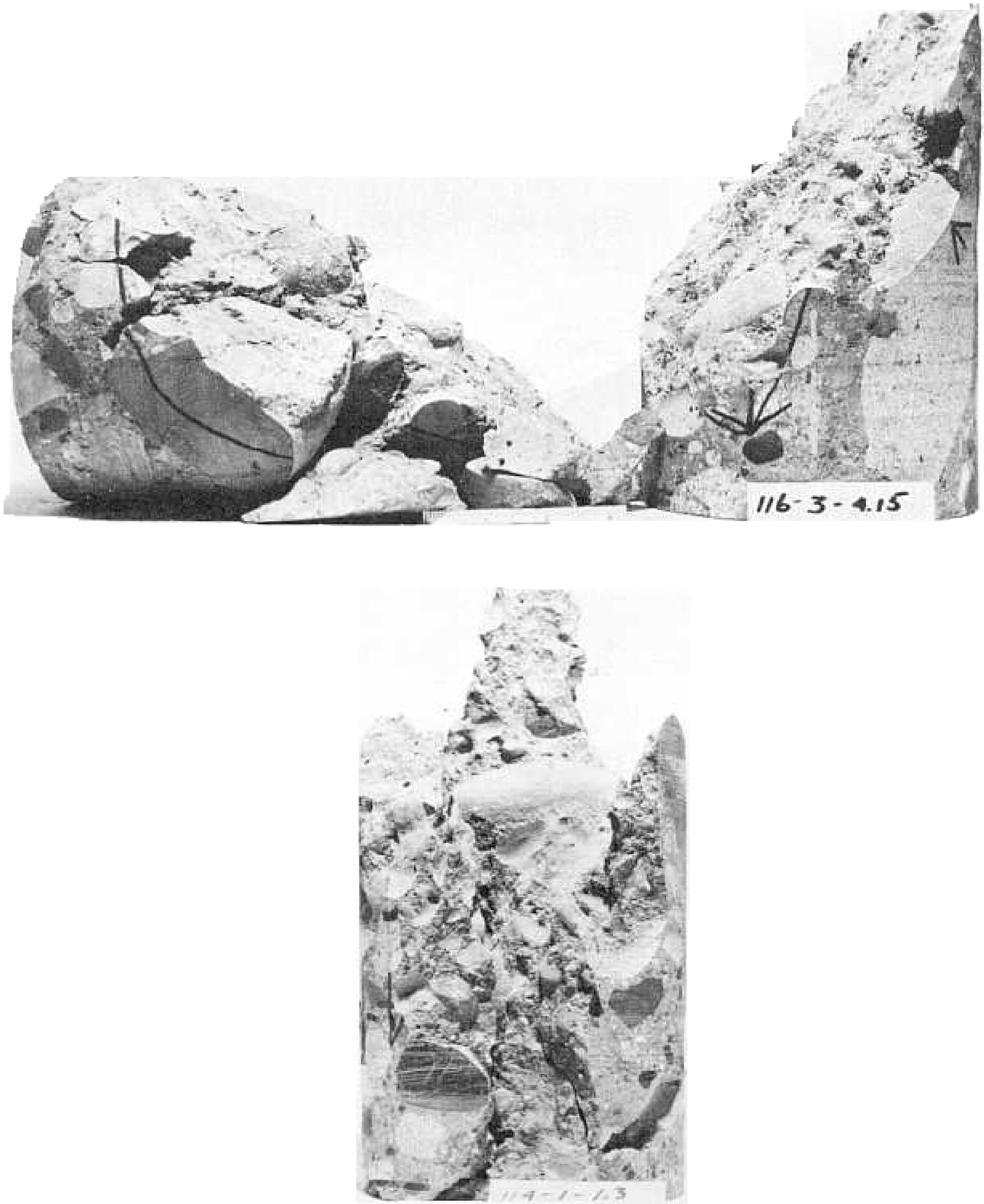

Figure 3 - Photograph of concrete showing failure surface
Top - jointed concrete 1,000 psi lateral load (note jagged break
Bottom - unjointed concrete "0" lateral load (cone shaped break)
C-8322-57 C-8322-56

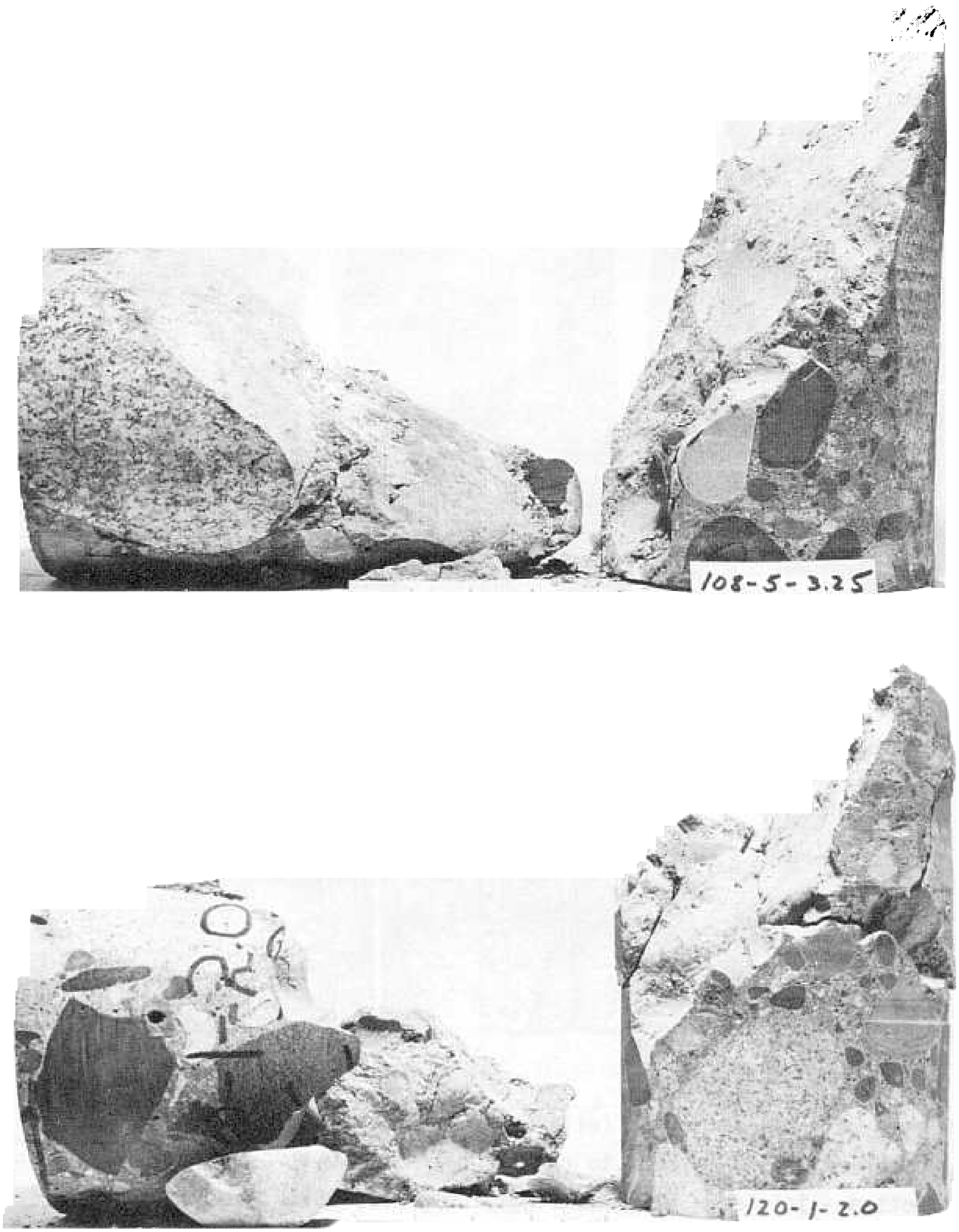

Figure 4. - Photograph of unjointed concrete showing failure surface
Top - at 450 lb/in^2 lateral load (note splitting tangent to large aggregate)
Bottom at 1,000 lb/in^2 lateral load (irregular break)
C-8322-58 C-8322-59

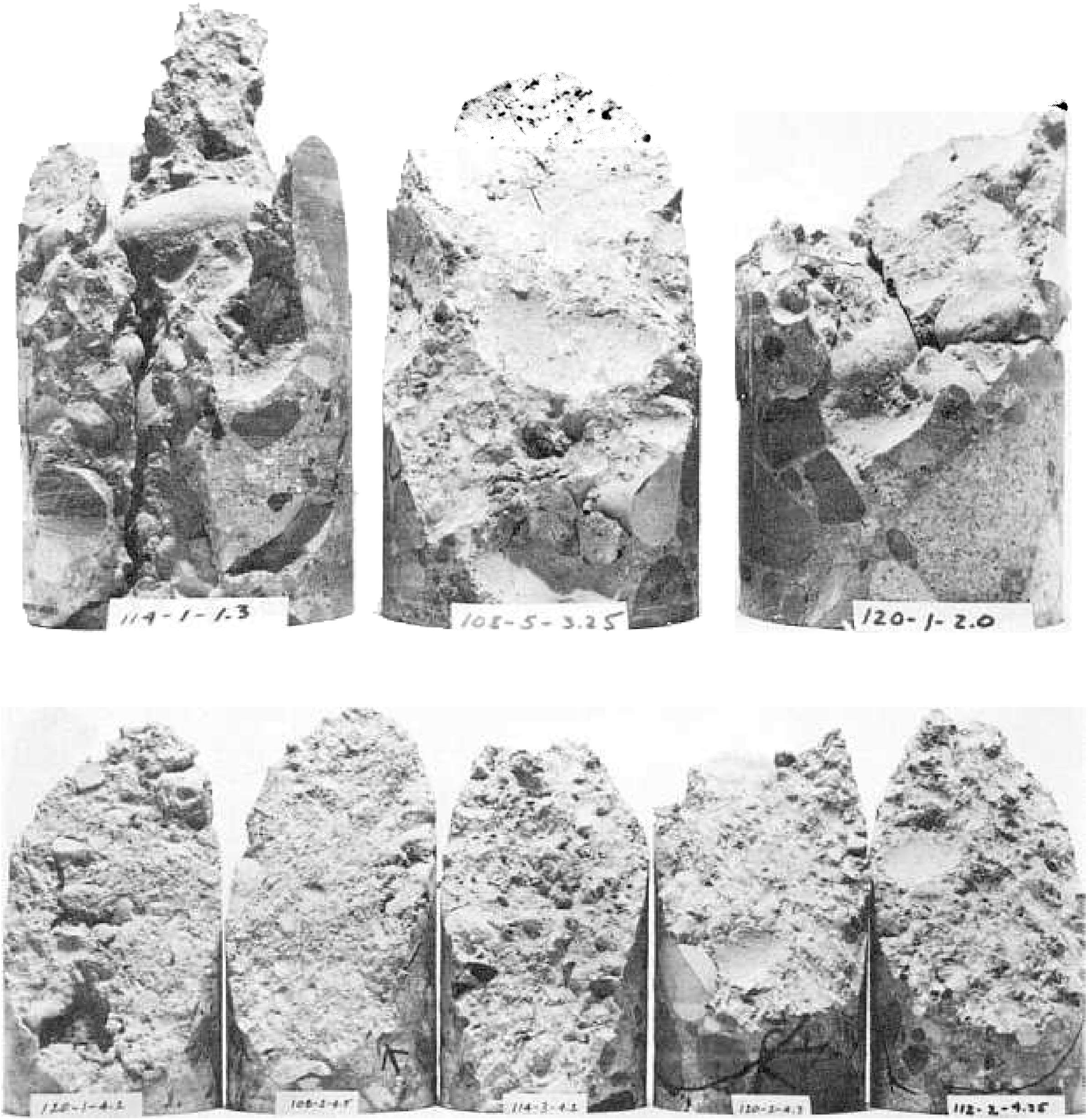

Figure 5. - Comparison of failure of unjointed and jointed concrete
Top - unjointed - (left to right) "0", 450 and 1,000 lb/in^2 lateral load
Bottom - jointed - (left to right) "0", 200, 450, 700, and 1,000 lb/in^2 lateral load
C-8322-47 C-8322-48

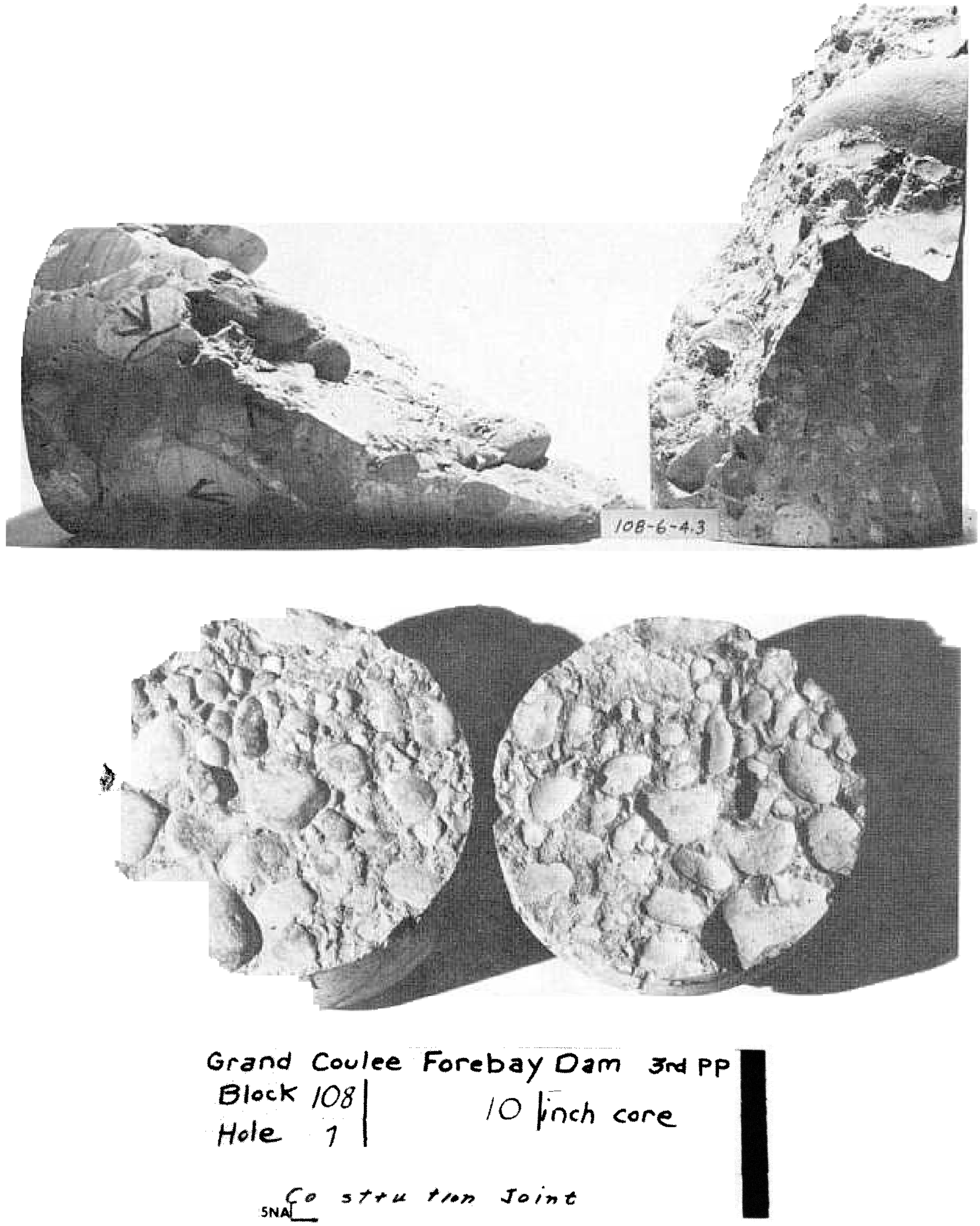

Figure 6. - Photograph of jointed concrete failure surface
Top - split at right angles to approximate joint (shown by arrows)
Bottom - showing separation at right angles to the axis of the core (not subjected to triaxial test)
C-8322-63 C-8322-25

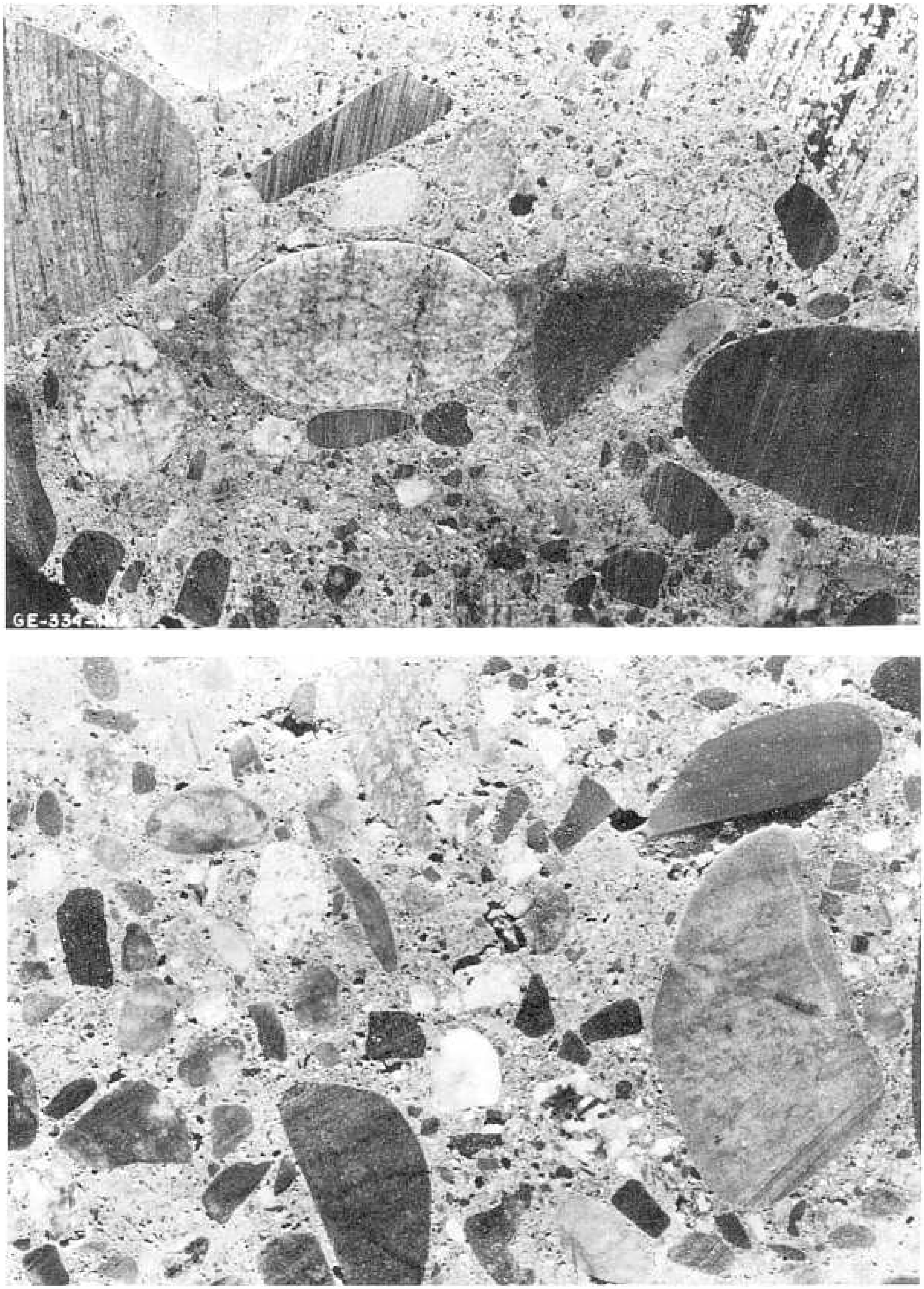

Figure 7. - Photograph of concrete showing size of aggregate and distribution indicating possible joint planes
Top - sample 106-3-4
Bottom - sample 106-1
GE-334-1 GE-334-2

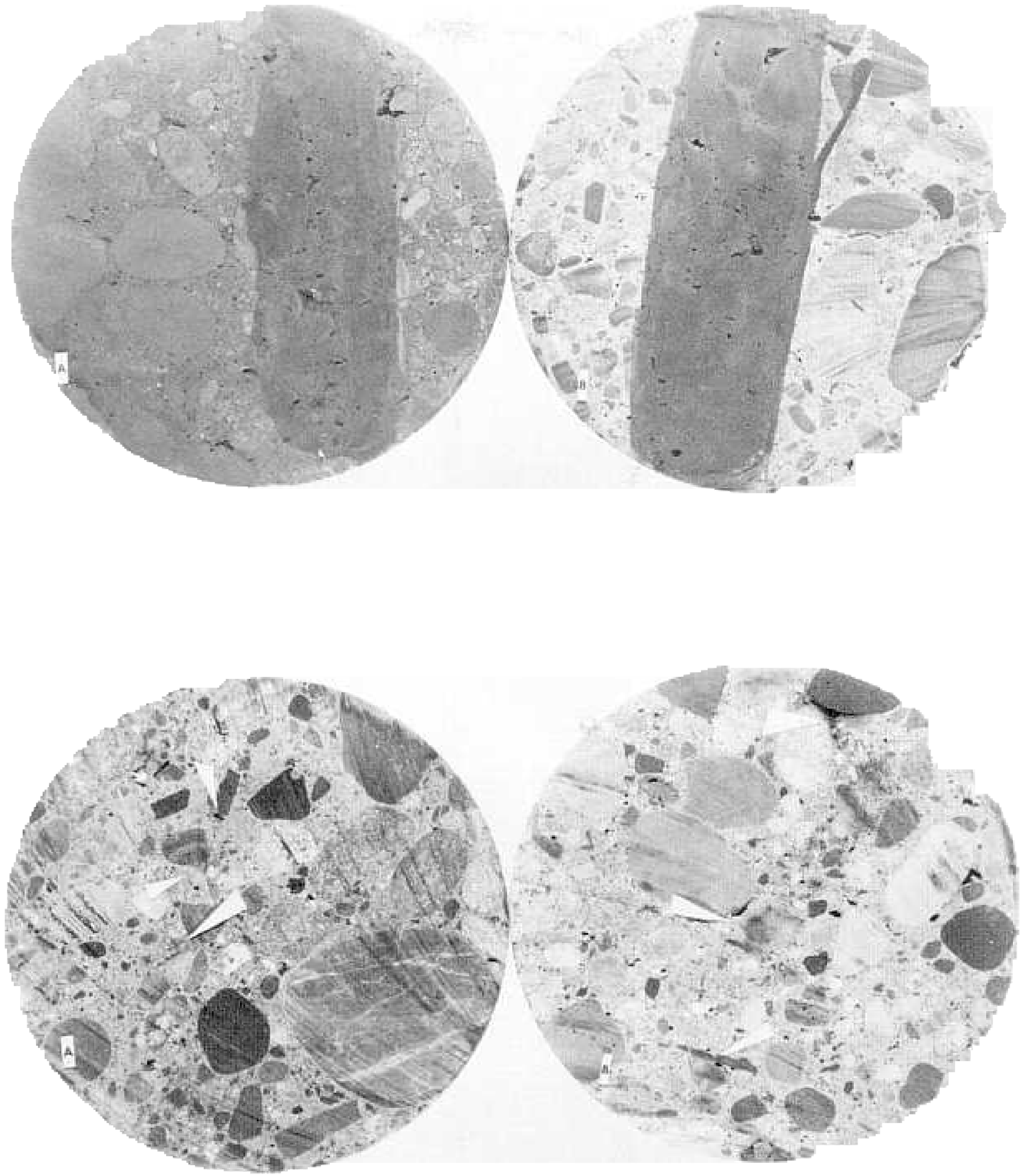

Figure 8. - Photograph of results of staining test to delineate unbroken joint (sample 106-3-4)
Top - stained top of concrete
Bottom - underside penetration of stain (white arrows) in voids subparallel to joint plane
C-8322-64 C-8322-65