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CONCRETE PERFORMANCE IN CRYSTAL DAM, COLORADO: 1-YEAR CORE REPORT

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16. ABSTRACT
Results of physical properties tests conducted on cores extracted from mass concrete in Crystal Dam for testing at 70 days', 6 months', and 1 year's age indicate good quality, uniform, well-consolidated concrete. This report contains test data through 1 year's age and is a part of a series of reports on long-time evaluations of strength and elastic properties of concrete in major Bureau of Reclamation dams. The average compressive strengths at 6 months and 1 year were 33.7 and 35.0 MPa (4890 and 5080 lb/in^2), respectively, which represent an average strength gain of 3.9 percent. Paralleling the strength increase, the moduli of elasticity also increased slightly from 31.4 to 31.7 GPa (4.55×10^6 to 4.60×10^6 lb/in^2). Tensile strengths for jointed and nonjointed cores were comparable at 6 months, but the nonjointed 1-year tensile strengths averaged 40 percent higher. Ratios of tensile to compressive strengths were high, indicating good paste-aggregate bond. Discussions of test results, variations, construction joint bond, and Poisson's ratio are also included in the report.

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a. DESCRIPTORS-- /Modulus of elasticity/ tensile strength/ Poisson's ratio/ bonding strength/ compressive strength/ mass concrete/ concrete dams/ concrete tests/ cores/ physical properties/ concrete properties/ construction joints

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by
Thomas A. Gaeto

Concrete Laboratory
Fifty Years

SI METRIC

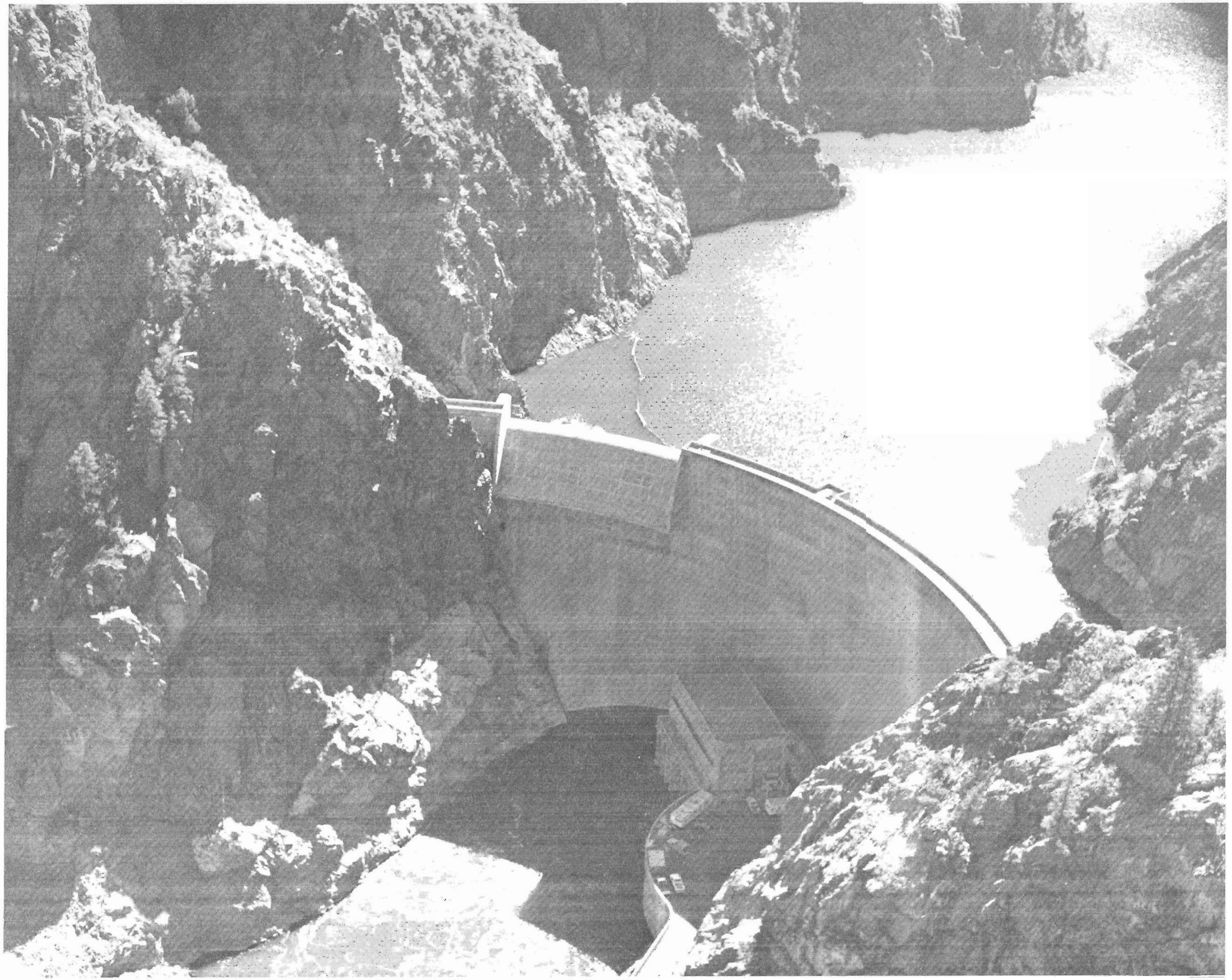
Concrete and Structural Branch
Division of Research
Engineering and Research Center
Denver, Colorado
June 1981

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

In May of 1981, the Secretary of the Interior approved changing the Water and Power Resources Service back to its former name, the Bureau of Reclamation.

The original work was accomplished using inch-pound units and converted to SI metric units.



Frontispiece. - Crystal Dam and Powerplant, Curecanti Unit, Colo. Photo P622C-427-15592 A.

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INTRODUCTION

Crystal Dam is located in the Black Canyon of the Gunnison River, about 40 km (25 mi) west of the city of Gunnison in Montrose County, Colorado. The principal construction features include the mass concrete dam with an overflow spillway, intake and outlet structures, and a powerplant. The double-curvature, thin-arch concrete dam has a structural height of 98 m (323 ft) and a crest length of 194 m (635 ft). The dam contains 112 390 m^3 (147 000 yd^3) of mass concrete.

As part of the Bureau of Reclamation's ongoing program to monitor and evaluate the strength and elastic properties of mass concrete in major dams, cores were extracted from Crystal Dam for testing at three different ages: approximately 70 days, 6 months, and 1 year. This report presents the results of laboratory tests on these cores. For further monitoring and evaluation of the properties of the concrete, additional cores will probably be extracted from the dam through 20 years' age.

Construction of the dam started in January 1974, and it was topped out in August 1976. The concrete in the dam is divided into blocks by means of vertical contraction joints. Galleries and shafts provide access to the interior of the dam, where most of the cores were extracted. Concrete in the dam contains type II low-alkali cement, natural river sand and coarse aggregate supplemented by crushed material, and air-entraining and water-reducing admixtures. Average cement content used in the dam concrete was 234 kg/m^3 (395 lb/yd^3) with a 0.47 water/cement ratio. The design of the dam was based on a minimum concrete compressive strength of 27.6 MPa (4000 lb/in^2) at 1 year's age.

CONCLUSIONS

Based on results obtained from testing the 250-mm (10-in) diameter cores at 70 days', 6 months', and 1 year's age, the following conclusions are made:

1. The overall condition of the concrete in Crystal Dam after 1 year is very good, which indicates that the concrete was properly proportioned, mixed, placed, consolidated, and cured.

2. The maximum compressive strength of the 1-year-old concrete in the dam was 46 percent greater than the design value.

3. The concrete in the dam became elastically stiffer between 6 months and 1 year, as indicated by slightly higher moduli of elasticity values.

4. The average ratio of tensile to compressive strength was 4.8 percent, which is considered normal for mass concrete [1, 2, 3]*.

5. The tensile bond strength at the horizontal construction joints is approximately equal to or slightly less than the tensile strength of the concrete itself. The tensile bond strength at the horizontal construction joints for the 1-year-old concrete averaged about 10 percent lower than the tensile strength of the surrounding concrete.

6. Although a petrographic examination was not conducted, no visible evidence of chemical attack on the concrete was apparent.

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* Numbers in brackets refer to entries in the Bibliography.

CORE EXTRACTION AND DRILLING PROGRAM

The construction specifications (No. DC-7000) for Crystal Dam required extraction of 250-mm (10-in) diameter cores at locations stipulated by Bureau of Reclamation. Nineteen cores were taken: three at approximately 70 days', eight at 6 months', and eight at 1 year's age. All except the three 70-day cores were taken from foundation and utility gallery floors. The three early cores were extracted from the downstream face of the dam. Core locations are shown on figure 1.

The concrete was cored with diamond-edged core barrels to a depth sufficient to permit extraction of two segments which could be effectively cut into at least 500-mm (20-in) lengths. None of the core holes was to be more than 4.6 m (15 ft) deep.

The extraction of the 250-mm-diameter cores began on October 14, 1974, and was completed by April 29, 1976. All cores were drilled vertically except core 10-47-1 which was drilled 12° from vertical and core 10-48-2 which was drilled 9-1/2° from vertical. These were two of the three cores removed from the downstream face of the dam.

ASTM Designation: C 42-77, "Obtaining and Testing Drilled Cores and Sawed Beams of Concrete," specifies that the diameter of concrete cores tested for compressive strength should be at least three times, and must be at least twice, the maximum nominal aggregate size. Since the maximum nominal size aggregate used in Crystal Dam was 75 mm (3 in), the diameter of cores should be at least 225 mm (9 in) and must be at least 150 mm (6 in). The actual diameters of the cores exceeded these criteria and ranged from 243 to 251 mm (9.6 to 9.9 in).

SHIPPING AND RECEIVING

After the cores were extracted, they were labeled with the project name, block number, hole number, core segment number, elevation, and date drilled. They were then wrapped in plastic, packed in sturdy wooden boxes with damp sawdust, and shipped to the Bureau's Division of Research in Denver for examination and testing.

When the cores arrived in Denver, they were unpacked and inspected (fig. 2). All cores were damp, and no shipping damage was evident. Only one construction joint was disbonded when received. Cores were then logged to provide a record of specimen lengths and any unusual characteristics, such as embedded reinforcing steel, rock pockets, construction joints, etc. Each core was marked for the type of test to be conducted. Photographs of the cores were taken to record details (fig. 3).

CORE TESTING PROGRAM

General

Cores were extracted so that studies could be made of the concrete at 70 days, 6 months, and 1 year. The studies included tests to determine compressive strengths, elastic properties, densities, and tensile strengths.

The early tests were conducted to evaluate the mix proportions and construction procedures and to permit any needed adjustments before too much concrete was placed.

Core Preparation

The cores tested for elastic properties and compressive strengths were sawed to 500-mm (20-in) lengths to conform to the standard length-diameter ratio of 2:1. After sawing, the cores were ground flat and smooth on a lapping machine. Cores tested in tension were sawed to 750-mm (30-in) lengths, the existing laboratory standard. Cores used in evaluating construction joints had at least 150 mm of core on each side of the joint. After grinding and before testing, all specimens were stored in a 100 percent relative humidity, 23 °C (73 °F), controlled atmosphere until testing was completed.

Density

The apparent density of each specimen to be tested in compression was determined prior to strength and elastic properties testing. Chapter 3, paragraphs 3.17 through 3.22 of the Material Laboratories Procedures Manual [4], were used for determining densities, except that the specimens were not ovendried because of concern that the required 107 °C (225 °F) drying temperature could have some effect on the physical behavior of the concrete during the subsequent testing process.

Elastic Properties

Elastic property tests were run on the same core specimens selected for the compressive strength tests. Modulus of elasticity and Poisson's ratio were determined 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 to reduce testing error. Each specimen was preloaded to an axial compressive stress of approximately 6.9 MPa (1000 lb/in^2).

Compressive Strength

Compressive strength tests were conducted on selected core segments to obtain apparent in-place strengths which could be compared to the 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.

Compressive strength was determined by axially loading the specimens at a rate of 14 MPa (2000 lb/in^2) per minute until failure. Several of the specimens were ruptured completely to permit visual observation of the fractures. No evidence of chemical attack of the concrete was observed.

Tensile Strength

Thirty-eight cores were used for tension tests. Twenty-three of these cores intersected horizontal construction joints. Steel plates, 50 mm (2 in) thick, were cemented with epoxy to the ends of each test specimen. Following a 24-hour cure of the epoxy at room temperature, the cores were placed in the testing machine with the end plates connected to the upper and lower platens through chain linkages. All specimens were loaded axially at a rate of 1.4 MPa (200 lb/in^2) per minute until failure occurred (fig. 4).

CORE TEST RESULTS

Density

The computed densities are shown in tables 1 and 1A. The density averaged 2458 kg/m^3 (153.4 lb/ft^3) for all tests.

Elastic Properties

Results of elastic properties tests are summarized in tables 1, 1A, and 2. The moduli of elasticity averaged 31.7 GPa (4.60×10^6 lb/in^2) at 1 year's age. As expected, there was some increase in the moduli from 70 days to 1 year (fig. 5).

Poisson's ratio averaged 0.20 for all the tests with no significant differences between 70 days and 1 year.

Compressive Strength

The results of the individual tests are shown in tables 1 and 1A. Summaries of results are shown in table 2 and figures 6 and 7. The average compressive strength for the concrete was 33.7 MPa (4890 lb/in^2) at 6 months' age and 35.0 MPa (5080 lb/in^2) at 1 year's age. This shows a 3.9-percent increase in strenth from 6 months' age to 1 year's age, which is slightly below average for typical strength development in mass concrete.

The compressive strengths of the cores ranged from 29.2 MPa (4230 lb/in^2) to 39.0 MPa (5660 lb/in^2) at 6 months' age and from 29.7 MPa (4300 lb/in^2) to 40.4 MPa (5860 lb/in^2) at 1 year's age. The corresponding coefficients of variation at 6 months and 1 year were 8.6 and 8.9 percent, respectively, which are excellent for general construction field quality control.

Tensile Strength

The bond strength of the horizontal construction joints appears to be slightly less than the tensile strength of the adjoining concrete (table 3 and figs. 8 and 9). The tensile strength of specimens with construction joints was about 94 percent of the tensile strength of specimens without construction joints. Of 23 specimens which contained construction joints, 14 failed in the joint during testing. The apparent and slight reduction in the tensile strength of jointed specimens from 6 to 12 months' age is not considered significant and likely results from variability of test specimens.

BIBLIOGRAPHY

[1] Riffle, H. C., and Smith, F. L., "Strength and Elastic Properties of Concrete in Flaming Gorge Dam, 10-Year Core Report," Bureau of Reclamation, Report No. GR-13-76, February 1976.

[2] Riffle, H. C., and Smith, F. L., "Concrete Performance in Glen Canyon Dam, 10-Year Core Report," Bureau of Reclamation, Report No. GR-22-76, November 1976.

[3] Werner, O. R., "Concrete Performance in Yellowtail Dam, Montana, 10-Year Core Report," Report No. GR-9-75, July 1975.

[4] Materials Laboratory Procedures Manual, Bureau of Reclamation, Commissioner's Office, Denver, Colorado, March 20, 1957.

Table 1. - *Summary of results obtained from tests performed on 250-mm (10-in) diameter concrete cores - Crystal Dam [SI METRIC UNITS]*

Core No. 1/	Elevation above sea level (m)	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Station (m)	Age tested	Properties of fresh concrete: W/C by mass	Cement content (kg/m³)	Water content (kg/m³)	Sand (%)	Density (kg/m³)	Air content (%)	Properties of hardened concrete: Control cylinders: Compressive strength (MPa): 7-day	28-day	90-day	Concrete cores: Compressive strength (MPa)	Elastic properties: F x 10⁻⁶ (GPa)	r	Density (kg/m³)	Tensile strength (MPa)	Joint 2/	Break 3/	Strength ratio core/28-d cyl (%)	Remarks
10-47-1A	1972	8-13-74	10-14-74	10-22-74	1+52.6	70 days	0.56	254	143	23	2398	4	21.4	34.0	-	25.4	27.3	0.24	2410				75	Core 10-47-1 drilled in D/S face 0.21 rad
10-47-1B		8-13-74	10-14-74	10-22-74	1+52.6	70 days	0.56	254	143	23	2398	4	21.4	34.0	-	19.4	28.6	0.19	2420				57	(12°) off vertical. Broke below the joint
10-47-1C		8-13-74	10-14-74	10-22-74	1+52.6	70 days	0.56	254	143	23	2398	4	21.4	34.0	-	31.2	24.8	0.19	2430				92	at elevation 2119.
10-47-1D		8-13-74	10-14-74	No test	1+52.6	No test	0.56	254	143	23	2398	4	21.4	34.0	-									
10-47-1E	1972	8-13-74	10-15-74	10-22-74	1+52.6	70 days	0.56	254	143	23	2398	4	21.4	34.0	-									
10-46-1E	1972	7-31-74	10-15-74	10-22-74	1+52.6	87 days	0.50	235	117	27	2430	4	23.4	34.1	-					1.31	Yes	No		
10-48-2A	1975	8-23-74	10-17-74	No test	1+49.4	No test	0.47	252	119	22	2418	4	20.9	31.6	37.6									Core 10-48-2 drilled in D/S face 0.17 rad
10-48-2B		8-23-74	10-17-74	10-31-74	1+49.4	69 days	0.47	252	119	22	2418	4	20.9	31.6	-	25.5	26.3	0.14	2440				81	(9.5°) off vertical. Broke above the joint
10-48-2C		8-23-74	10-18-74	10-31-74	1+49.4	69 days	0.47	252	119	22	2418	4	20.9	31.6	-					1.14	No			at elevation 2123.
10-48-2D	1972	8-23-74	10-18-74	10-31-74	1+49.4	69 days	0.47	252	119	22	2418	4	20.9	31.6	-					1.61	Yes	No		
10-47-2D	1972	8-13-74	10-18-74	10-31-74	1+49.4	79 days	*0.51	*275	*139	*26	2384	3	-	-	-									
8-48-3A	1974	8-19-74	10-21-74	No test	1+27.0	No test	0.50	275	136	23	2434	4	28.8	36.5	40.6									Core 8-48-3 drilled vertically D/S face.
8-48-3B		8-19-74	10-22-74	10-31-74	1+27.0	73 days	0.50	275	136	23	2434	4	28.8	36.5	-	32.1	30.1	0.21	2440				88	Curing compound found on joint at
8-48-3C		8-19-74	10-22-74	10-31-74	1+27.0	73 days	0.50	275	136	23	2434	4	28.8	36.5	-	34.3	28.5	0.21	2420				94	elevation 2123.
8-48-3D	1972	8-19-74	10-22-74	10-31-74	1+27.0	73 days	0.50	275	136	23	2434	4	28.8	36.5	-					0.57	Yes	Yes		
8-47-3D	1972	8-10-74	10-22-74	10-31-74	1+27.0	82 days	0.56	233	130	25	2377	5	15.7	25.5	-									
Average																28.0	27.6	0.20	2420	1.16				
8-49-4A	1978	8-29-74	1-29-75	3- 7-75	1+28.2	6 months	0.43	274	118	26	2350	5	23.7	34.4	42.5	30.9	32.2	0.19	2470				90	Concrete drilled vertically from foundation
8-49-4B		8-29-74	1-29-75	3- 7-75	1+28.2	6 months	0.43	274	118	26	2350	5	23.7	34.4	42.5					0.92	No			gallery floor. Broke 50 mm above joint
8-49-4C		8-29-74	1-29-75	3- 7-75	1+28.2	6 months	0.43	274	118	26	2350	5	23.7	34.4	42.5	35.1	34.3	-	2470				102	at elevation 2126.
8-49-4D	1975	8-29-74	1-30-75	3- 7-75	1+28.2	6 months	0.43	274	118	26	2350	5	23.7	34.4	42.5					1.12	Yes	No		
8-48-4D	1975	8-19-74	1-30-75	3- 7-75	1+28.2	6 months	0.50	276	136	23	2420	2	28.8	36.5	40.6									
12-49-5A	1978	8-31-74	1-31-75	3- 8-75	1+76.6	6 months	0.50	258	129	26	2370	4	17.3	26.1	32.2	32.6	29.2	0.23	2480				125	Concrete drilled vertically from foundation
12-49-5B		8-31-74	2- 3-75	3- 8-75	1+76.6	6 months	0.50	258	129	26	2370	4	17.3	26.1	32.2	36.3	33.0	0.24	2450				139	gallery floor. Broke 50 mm above joint
12-49-5C		8-31-74	2- 3-75	3- 8-75	1+76.6	6 months	0.50	258	129	26	2370	4	17.3	26.1	32.2					1.59	No			at elevation 2126.
12-49-5D	1975	8-31-74	2- 3-75	3- 8-75	1+76.6	6 months	0.50	258	129	26	2370	4	17.3	26.1	32.2					1.63	Yes	No		
12-48-5D	1975	8-21-74	2- 3-75	3- 8-75	1+76.6	6 months	0.46	275	127	22	2400	3	21.2	32.1	41.6									
10-49-6A	1978	9- 4-75	2- 4-75	3-10-75	1+49.2	6 months	0.49	270	132	24	2390	3	17.9	27.6	30.4	29.2	32.4	0.24	2490				105	Concrete drilled vertically from foundation
10-49-6B		9- 4-75	2- 4-75	3-10-75	1+49.2	6 months	0.49	270	132	24	2390	3	17.9	27.6	30.4					1.77	No			gallery floor. Joint at elevation 2126.
10-49-6C		9- 4-75	2- 4-75	3-10-75	1+49.2	6 months	0.49	270	132	24	2390	3	17.9	27.6	30.4	39.0	31.8	0.18	2440				141	
10-49-6D	1975	9- 4-75	2- 4-75	3-10-75	1+49.2	6 months	0.49	270	132	24	2390	3	17.9	27.6	30.4					1.26	Yes	Yes		
10-48-6D	1975	8-23-74	2- 4-75	3-10-75	1+49.2	6 months	0.47	252	119	22	2400	3	20.9	31.6	37.6									
9-49-7A	1978	9-26-74	2- 6-75	3-27-75	1+40.4	6 months	0.51	241	125	22	2420	3	18.7	27.4	-	33.2	31.4	0.18	2550				121	Concrete drilled vertically from foundation
9-49-7B		9-26-74	2- 6-75	3-27-75	1+40.4	6 months	0.51	241	125	22	2420	3	18.7	27.4	-	29.7	26.7	0.20	2450				109	gallery floor. Joint at elevation 2126.
9-49-7C		9-26-74	2- 6-75	3-27-75	1+40.4	6 months	0.51	241	125	22	2420	3	18.7	27.4	-					1.13	No			Joint had structural 38-mm MSA concrete
9-49-7D	1975	9-26-64	2- 6-75	3-27-75	1+40.4	6 months	0.51	241	125	22	2420	3	18.7	27.4	-					1.13	Yes	Yes		on joint.
9-48-7D	1975	9-13-74	2- 6-75	3-27-75	1+40.4	6 months	0.54	235	126	21	2400	3	12.4	24.6	31.8									
Average																33.3	31.4	0.21	2470	1.32				
8-49-8A	1978	8-29-74	8- 4-75	9- 4-75	1+26.6	1 year	0.43	274	118	26	2350	5	23.7	34.4	42.5	31.7	[illegible]	0.20	2430				92	Concrete drilled vertically from the
8-49-8B		8-29-74	8- 5-75	9- 4-75	1+26.6	1 year	0.43	274	118	26	2350	5	23.7	34.4	42.5	31.4	27.6	0.20	2410				91	foundation gallery floor. Construction
8-49-8C		8-29-74	8- 5-75	9- 4-75	1+26.6	1 year	0.43	274	118	26	2350	5	23.7	34.4	42.5					2.01	No			joint at elevation 2126.
8-49-8D	1975	8-29-74	8- 5-75	9- 4-75	1+26.6	1 year	0.43	274	118	26	2350	5	23.7	34.4	42.5					0.68	Yes	Yes		
8-48-8D	1975	8-19-74	8- 5-75	9- 4-75	1+26.6	1 year	0.50	275	136	23	2420	1	28.8	36.5	40.6									
12-49-9A	1978	8-31-74	8- 6-75	No test	1+78.2	No test	0.50	258	129	26	2370	4	17.3	26.1	32.2									Concrete drilled vertically from the
12-49-9B		8-31-74	8- 7-75	No test	1+78.2	1 year	0.50	258	129	26	2370	4	17.3	26.1	32.2	33.4	28.0	0.18	2440				128	foundation gallery floor. Construction
12-49-9C		8-31-74	8- 7-75	No test	1+78.2	1 year	0.50	258	129	26	2370	4	17.3	26.1	32.2					2.24	No			joint at elevation 2126.
12-49-9D	1975	8-31-74	8- 7-75	No test	1+78.2	1 year	0.50	258	129	26	2370	4	17.3	26.1	32.2					1.25	Yes	Yes		
12-48-9D	1975	8-21-75	8- 7-75	No test	1+78.2	1 year	0.46	275	127	22	2400	3	21.2	32.1	41.6									
10-49-10A	1978	9- 4-74	8- 8-75	No test	1+51.1	No test	0.49	270	132	24	2390	3	17.9	27.6	30.4									Concrete drilled vertically from the
10-49-10B		9- 4-74	8- 8-75	No test	1+51.1	1 year	0.49	270	132	24	2390	3	17.9	27.6	30.4	32.7	31.8	0.22	2470				118	foundation gallery floor. Construction
10-49-10C		9- 4-74	8- 8-75	No test	1+51.1	1 year	0.49	270	132	24	2390	3	17.9	27.6	30.4					1.97	No			joint at elevation 2126.
10-49-10D	1975	9- 4-74	8-11-75	No test	1+51.1	1 year	0.49	270	132	24	2390	3	17.9	27.6	30.4					1.65	Yes	No		
10-48-10D	1975	8-23-74	8-11-75	No test	1+51.1	1 year	0.47	252	119	22	2400	3	20.9	31.6	37.6									
9-49-11A	1978	9-26-74	8-12-75	9-26-75	1+38.5	1 year	0.51	241	125	22	2420	2	18.7	27.4	-	32.5	30.0	0.16	2470				119	Concrete drilled vertically from the
9-49-11B		9-26-74	8-12-75	9-26-75	1+38.5	1 year	0.51	241	125	22	2420	2	18.7	27.4	-	29.6	28.3	0.15	2460				108	foundation gallery. Thirty-eight-mm MSA
9-49-11C		9-26-74	8-12-75	9-26-75	1+38.5	1 year	0.51	241	125	22	2420	2	18.7	27.4	-					2.13	No			structural concrete used on joint at
9-49-11D	1975	9-26-64	8-12-75	9-26-75	1+38.5	1 year	0.51	241	125	22	2420	2	18.7	27.4	-					0.81	Yes	Yes		elevation 2126. Specimen 11D broke along
9-48-11D	1975	9-13-74	8-12-75	9-26-75	1+38.5	1 year	0.54	235	126	21	2400	3	12.4	24.6	31.8									cooling pipe on the joint.
Average																31.9	28.9	0.19	2450	1.59				

Table 1. - *Summary of results obtained from tests performed on 250-mm (10-in) diameter concrete cores - Crystal Dam [SI METRIC UNITS] - Continued*

Core No. 1/	Elevation above sea level (m)	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Station (m)	Age tested	Properties of fresh concrete: W/C by mass	Cement content (kg/m³)	Water content (kg/m³)	Sand (%)	Density (kg/m³)	Air content (%)	Properties of hardened concrete: Control cylinders: Compressive strength (MPa) 7-day	28-day	90-day	Concrete cores: Compressive strength (MPa)	Elastic properties: E x 10⁻⁶ (GPa)	r	Density (kg/m³)	Tensile strength (MPa)	Joint 2/	Break 3/	Strength ratio core/28-d cyl (%)	Remarks
8-57A-12A	2000	5- 7-75	10- 7-75	10-29-75	1+23.5	6 months	0.50	237	119	24	2420	3	20.0	30.2	36.5									Concrete drilled vertically from utility gallery floor. Construction joints at elevations 2152 and 2149.
8-56-12A	1999	4-29-75	10- 7-75	10-29-75	1+23.5	6 months	0.50	218	110	25	2430	3	16.1	32.9	42.7					0.62	Yes	Yes		
8-56-12B		4-29-75	10- 7-75	10-29-75	1+23.5	6 months	0.50	218	110	25	2430	3	16.1	32.9	42.7					1.17	No			
8-56-12C		4-29-75	10- 7-75	10-29-75	1+23.5	6 months	0.50	218	110	25	2430	3	16.1	32.9	42.7	32.2	33.0	0.22	2470				98	
8-56-12D	1996	4-29-75	10- 8-75	10-29-75	1+23.5	6 months	0.50	218	110	25	2430	3	16.1	32.9	42.7					1.47	Yes	Yes		
8-55-12D	1996	10-25-75	10- 8-75	10-29-75	1+23.5	6 months	0.53	239	128	23	2390	4	15.0	29.0	-									
12-57A-13A	2000	5-27-75	10- 9-75	11-21-75	1+77.2	6 months	0.46	235	107	24	2450	3	19.7	30.9	-									Concrete drilled vertically from utility gallery floor. Construction joints at elevations 2152 and 2149. A 5-mm by 30-mm by 65-mm void space on joint at elevation 2149.
12-56-13A	1999	5-19-75	10- 9-75	11-21-75	1+77.2	6 months	0.43	231	99	23	2420	5	19.7	30.9	-					1.45	Yes	Yes		
12-56-13B		5-19-75	10- 9-75	11-21-75	1+77.2	6 months	0.43	231	99	23	2420	5	19.7	30.9	-	38.1	31.4	0.20	2500				123	
12-56-13C		5-19-75	10- 9-75	11-21-75	1+77.2	6 months	0.43	231	99	23	2420	5	19.7	30.9	-					1.15	No			
12-56-13D	1996	5-19-75	10- 9-75	11-21-75	1+77.2	6 months	0.43	231	99	23	2420	5	19.7	30.9	-					1.34	Yes	Yes		
12-55-13D	1996	5- 9-75	10- 9-75	11-21-75	1+77.2	6 months	0.48	228	111	23	2400	4	23.0	32.1	39.8									
11-57A-14A	2000	6-24-75	11-18-75	12-18-75	1+59.7	6 months	0.42	234	98	23	2420	4	21.9	29.9	35.3									Concrete drilled vertically from utility gallery floor. Construction joints at elevations 2152 and 2149.
11-56-14A	1999	6-21-75	11-18-75	12-18-75	1+59.7	6 months	0.43	232	100	23	2430	4	25.1	32.1	36.4					1.70	Yes	No		
11-56-14B		6-21-75	11-18-75	12-18-75	1+59.7	6 months	0.43	232	100	23	2430	4	25.1	32.1	36.4	31.5	30.5	0.20	2440				98	
11-56-14C		6-21-75	11-19-75	12-18-75	1+59.7	6 months	0.43	232	100	23	2430	4	25.1	32.1	36.4	35.4	33.8	0.20	2480				110	
11-56-14D	1996	6-21-75	11-19-75	12-18-75	1+59.7	6 months	0.43	232	100	23	2430	4	25.1	32.1	36.4					1.95	Yes	No		
11-55-14D	1996	6-10-75	11-19-75	12-18-75	1+59.7	6 months	0.45	234	106	23	2420	4	-	34.3	-									
13-57A-15A	2000	6-28-75	11-19-75	12-18-75	1+90.4	6 months	*0.50	*229	*115	*23	2430	4	-	-	-	34.2	30.1	0.20	2550				100	Concrete drilled vertically from utility gallery floor. Construction joints at elevations 2152 and 2149. Joints at elevation 2152 disbonded when received in the laboratory.
13-56-15A	1999	6-24-75	11-19-75	12-18-75	1+90.4	6 months	0.48	237	113	23	2400	4	23.4	30.7	-									
13-56-15B		6-24-75	11-19-75	12-18-75	1+90.4	6 months	0.48	237	113	23	2400	4	23.4	30.7	-					0.90	No			
13-56-15C		6-24-75	11-20-75	12-18-75	1+90.4	6 months	0.48	237	113	23	2400	4	23.4	30.7	-	34.1	29.3	0.21	2450				111	
13-56-15D	1996	6-24-75	11-20-75	12-18-75	1+90.4	6 months	0.48	237	113	23	2400	4	23.4	30.7	-					1.29	Yes	Yes		
13-55-15D	1996	6-10-75	11-20-75	12-18-75	1+90.4	6 months	0.49	226	110	23	2390	5	-	25.9	-									
Average																34.3	31.4	0.21	2470	1.30				
8-57A-16A	2000	5- 7-75	3-18-76	5- 5-76	1+24.7	1 year	0.50	237	119	23	2420	3	20.0	30.2	36.5	37.8	34.6	0.22	2510				125	Concrete drilled vertically from utility gallery floor. Joint at elevation 2152 disbonded when received in the laboratory. Joints at elevations 2152 and 2149.
8-56-16A	1999	4-29-75	3-18-76	5- 5-76	1+24.7	1 year	0.50	218	110	25	2420	3	16.1	32.9	42.7									
8-56-16B		4-29-75	3-18-76	5- 5-76	1+24.7	1 year	0.50	218	110	25	2420	3	16.1	32.9	42.7					1.65	No			
8-56-16C		4-29-75	3-18-76	5- 5-76	1+24.7	1 year	0.50	218	110	25	2420	3	16.1	32.9	42.7					1.34	No			
8-56-16D	1996	4-29-75	3-18-76	5- 5-76	1+24.7	1 year	0.50	218	110	25	2420	3	16.1	32.9	42.7					0.76	Yes	Yes		
8-55-16D	1996	10-25-74	3-18-76	5- 5-76	1+24.7	1 year	0.53	239	128	23	2390	4	15.0	29.0	-									
12-57A-17A	2000	5-27-75	3-19-76	5-18-76	1+78.8	1 year	0.46	235	107	24	2450	3	19.7	30.9	-									Concrete drilled vertically from utility gallery floor. Joints at elevations 2152 and 2149. Joint at elevation 2152 disbonded when received in the laboratory.
12-56-17A	1999	5-19-75	3-19-76	5-18-76	1+78.8	1 year	0.43	231	99	22	2420	5	19.7	30.9	-					1.27	Yes	Yes		
12-56-17B		5-19-75	2-19-76	5-18-76	1+78.8	1 year	0.43	231	99	22	2420	5	19.7	30.9	-	39.4	31.0	0.18	2450				127	
12-56-17C		5-19-75	3-22-76	5-18-76	1+78.8	1 year	0.43	231	99	22	2420	5	19.7	30.9	-	38.1	46.4	0.25	2480				123	
12-56-17D	1996	5-19-75	3-22-76	No test	1+78.8	No test	0.43	231	99	22	2420	5	19.7	30.9	-									
12-55-17D	1996	5- 9-75	3-22-76	No test	1+78.8	No test	0.48	228	111	22	2400	4	23.0	32.1	39.8									
11-57A-18A	2000	6-24-75	4-20-76	6-21-76	1+61.4	1 year	0.42	234	98	22	2420	4	21.9	29.9	35.3	40.4	33.6	0.17	2530				135	Concrete drilled vertically from utility gallery floor. Joints at elevations 2152 and 2149. Joint 2152 broke during handling in the laboratory.
11-56-18A	1999	6-21-75	4-20-76	6-21-76	1+61.4	1 year	0.43	232	100	23	2430	4	25.1	32.1	36.4									
11-56-18B		6-21-75	4-20-76	6-21-76	1+61.4	1 year	0.43	232	100	23	2430	4	25.1	32.1	36.4	37.8	32.0	0.21	2510				118	
11-56-18C		6-21-75	4-20-76	6-21-76	1+61.4	1 year	0.43	232	100	23	2430	4	25.1	32.1	36.4	37.5	33.5	0.22	2480				117	
11-56-18D	1996	6-21-75	4-21-76	6-21-76	1+61.4	1 year	0.43	232	100	23	2430	4	25.1	32.1	36.4					1.74	Yes	Yes		
11-55-18D	1996	6-10-75	4-21-76	6-21-76	1+61.4	1 year	0.45	234	106	22	2420	4	-	34.3	-									
13-57A-19A	2000	6-28-75	4-29-76	6-24-76	1+93.7	1 year	*0.50	*229	*115	*23	2340	4	-	-	-									Concrete drilled vertically from utility gallery floor. Joints at elevations 2152 and 2149. Specimen 19A broke near a piece of angle iron running completely through the core.
13-56-19A	1999	6-24-75	4-29-76	6-24-76	1+93.7	1 year	0.48	237	113	23	2400	4	23.4	30.7	-					1.15	Yes	No		
13-56-19B-1		6-24-75	4-29-76	6-24-76	1+93.7	1 year	0.48	237	113	23	2400	4	23.4	30.7	-	36.9	30.5	0.17	2430				120	
13-56-19B-2		6-24-75	4-29-76	6-24-76	1+93.7	1 year	0.48	237	113	23	2400	4	23.4	30.7	-	30.6	28.4	0.20	2430				100	
13-56-19C		6-24-75	4-29-76	6-24-76	1+93.7	1 year	0.48	237	113	23	2400	4	23.4	30.7	-					1.42	No			
13-56-19D	1996	6-24-75	4-29-76	6-24-76	1+93.7	1 year	0.48	237	113	23	2400	4	23.4	30.7	-					2.38	Yes	No		
13-55-19D	1996	6-10-76	4-29-76	6-24-76	1+93.7	1 year	0.49	226	110	23	2390	5	-	25.9	-									
Average																37.3	33.8	0.20	2480	1.46				

* Design values rather than actual yield values.
1/ First number, block number; second, lift number; third, core specimen number.
2/ Did specimen contain a construction joint?
3/ Did joint break during construction?

Table 1A. - *Summary of results obtained from tests performed on 250-mm (10-in) diameter concrete cores - Crystal Dam* [*INCH-POUND UNITS*]

Core No. 1/	Elevation above sea level (ft)	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Station (ft)	Age tested	Properties of fresh concrete: W/C by wt	Cement content (lb/yd³)	Water content (lb/yd³)	Sand (%)	Density (lb/ft³)	Air content (%)	Properties of hardened concrete: Control cylinders: Compressive strength (lb/in²): 7-day	28-day	90-day	Concrete cores: Compressive strength (lb/in²)	Elastic properties: E x 10-6 (lb/in²)	r	Density (lb/ft³)	Tensile strength (lb/in²)	Joint 2/	Break 3/	Strength ratio core/28-d cyl (%)	Remarks
10-47-1A	6469	8-13-74	10-14-74	10-22-74	5+00.7	70 days	0.56	429	241	23	149	3	3110	4930	-	3690	3.97	0.24	150.5				75	Core 10-47-1 drilled in D/S face 12° off vertical. Broke below the joint. Joint at elevation 6460.
10-47-1B		8-13-74	10-14-74	10-22-74	5+00.7	70 days	0.56	429	241	23	149	3	3110	4930	-	2820	4.15	0.19	151.1				57	
10-47-1C		8-13-74	10-15-74	10-22-74	5+00.7	70 days	0.56	429	241	23	149	3	3110	4930	-	4520	3.60	0.19	151.7				92	
10-47-1D		8-13-74	10-15-74	No test	5+00.7	No test	0.56	429	241	23	149	3	3110	4930	-									
10-47-1E	6460	8-13-74	10-15-74	10-22-74	5+00.7	70 days	0.56	429	241	23	149	3	3110	4930	-									
10-46-1E	6460	7-31-74	10-15-74	10-22-74	5+00.7	87 days	0.50	396	197	27	151	3	3390	4950	-					190	Yes	No		
10-48-2A	6479	8-23-74	10-17-74	No test	4+90.1	No test	0.47	425	201	22	150	4	3030	4580	5460									Core 10-48-2 drilled in D/S face 9-1/2° off vertical. Broke above the joint. Joint at elevation 6470.
10-48-2B		8-23-74	10-17-74	10-31-74	4+90.1	69 days	0.47	425	201	22	150	4	3030	4580	-	3700	3.82	0.14	152.3				81	
10-48-2C		8-23-74	10-18-74	10-31-74	4+90.1	69 days	0.47	425	201	22	150	4	3030	4580	-					170	No			
10-48-2D	6470	8-23-74	10-18-74	10-31-74	4+90.1	69 days	0.47	425	201	22	150	4	3030	4580	-					230	Yes	No		
10-47-2D	6470	8-13-74	10-18-74	10-31-74	4+90.1	79 days	*0.51	*461	*235	*26	148	3	-	-	-									
8-48-3A	6477	8-19-74	10-21-74	No test	4+16.6	No test	0.50	463	229	23	152	4	4180	5290	5890									Core 8-48-3 drilled vertically. Curing compound found on joint at elevation 6470.
8-48-3B		8-19-74	10-22-74	10-31-74	4+16.6	73 days	0.50	463	229	23	152	4	4180	5290	-	4650	4.37	0.21	152.3				88	
8-48-3C		8-19-74	10-22-74	10-31-74	4+16.6	73 days	0.50	463	229	23	152	4	4180	5290	-	4980	4.14	0.21	151.1				94	
8-48-3D	6470	8-19-74	10-22-74	10-31-74	4+16.6	73 days	0.50	463	229	23	152	4	4180	5290	-					80	Yes	Yes		
8-47-3D	6470	8-10-74	10-22-74	10-31-74	4+16.6	82 days	0.56	393	219	25	148	5	2280	3700	-									
Average																4060	4.01	0.20	151.5	170				
8-49-4A	6490	8-29-74	1-29-75	3- 7-75	4+20.6	6 months	0.43	462	199	26	147	5	3440	4990	6160	4480	4.67	0.19	154.2				90	Concrete drilled vertically from foundation gallery floor. Broke 2 inches above joint. Joint at elevation 6480.
8-49-4B		8-29-74	1-29-75	3- 7-75	4+20.6	6 months	0.43	462	199	26	147	5	3440	4990	6160					130	No			
8-49-4C		8-29-74	1-29-75	3- 7-75	4+20.6	6 months	0.43	462	199	26	147	5	3440	4990	6160	5090	4.97	-	154.2				102	
8-49-4D	6480	8-29-74	1-30-75	3- 7-75	4+20.6	6 months	0.43	462	199	26	147	5	3440	4990	6160					160	Yes	No		
8-48-4D	6480	8-19-74	1-30-75	3- 7-75	4+20.6	6 months	0.50	463	229	23	151	1	4180	5290	5890									
12-49-5A	6490	8-31-74	1-31-75	3- 8-75	5+79.4	6 months	0.50	435	217	26	148	4	2510	3790	4670	4730	4.24	0.23	154.8				125	Concrete drilled vertically from foundation gallery floor. Broke 2 inches above joint at elevation 6480.
12-49-5B		8-31-74	2- 3-75	3- 8-75	5+79.4	6 months	0.50	435	217	26	148	4	2510	3790	4670	5270	4.78	0.24	153.0				139	
12-49-5C		8-31-74	2- 3-75	3- 8-75	5+79.4	6 months	0.50	435	217	26	148	4	2510	3790	4670					230	No			
12-49-5D	6480	8-31-74	2- 3-75	3- 8-75	5+79.4	6 months	0.50	435	217	26	148	4	2510	3790	4670					240	Yes	No		
12-48-5D	6480	8-21-74	2- 3-75	3- 8-75	5+79.4	6 months	0.46	464	214	22	150	3	3070	4650	6030									
10-49-6A	6490	9- 4-74	2- 4-75	3-10-75	4+89.5	6 months	0.49	455	223	24	149	3	2590	4010	4410	4230	4.70	0.24	155.5				105	Concrete drilled vertically from foundation gallery floor. Joint at elevation 6480.
10-49-6B		9- 4-74	2- 4-75	3-10-75	4+89.5	6 months	0.49	455	223	24	149	3	2590	4010	4410					260	No			
10-49-6C		9- 4-74	2- 4-75	3-10-75	4+89.5	6 months	0.49	455	223	24	149	3	2590	4010	4410	5660	4.61	0.18	152.3				141	
10-49-6D	6480	9- 4-74	2- 4-75	3-10-75	4+89.5	6 months	0.49	455	223	24	149	3	2590	4010	4410	180				180	Yes	Yes		
10-48-6D	6480	8-23-74	2- 4-75	3-10-75	4+89.5	6 months	0.47	425	201	22	150	3	3030	4580	5460									
9-49-7A	6490	9-26-74	2- 6-75	3-27-75	4+60.5	6 months	0.51	407	210	22	151	2	2720	3970	-	4810	4.55	0.18	156.1				121	Concrete drilled vertically from foundation gallery floor. Joint at elevation 6480. Joint had structural 1-1/2-inch MSA concrete on joint.
9-49-7B		9-26-74	2- 6-75	3-27-75	4-60.5	6 months	0.51	407	210	22	151	2	2720	3970	-	4310	3.87	0.20	153.0				109	
9-49-7C		9-26-74	2- 6-75	3-27-75	4+60.5	6 months	0.51	407	210	22	151	2	2720	3970	-					160	No			
9-49-7D	6480	9-26-74	2- 6-75	3-27-75	4+60.5	6 months	0.51	407	210	22	151	2	2720	3970	-					160	Yes	Yes		
9-48-7D	6480	9-13-74	2- 6-75	3-27-75	4+60.5	6 months	0.54	397	213	21	150	3	1800	3570	4610									
Average																4820	4.55	0.21	154.1	190				
8-49-8A	6490	8-29-74	8- 4-75	9- 4-75	4+15.4	1 year	0.43	462	199	26	147	5	3440	4990	6160	4600	4.05	0.20	151.7				92	Concrete drilled vertically from the foundation gallery floor. Construction joint at elevation 6480.
8-49-8B		8-29-74	8- 5-75	9- 4-75	4+15.4	1 year	0.43	462	199	26	147	5	3440	4990	6160	4550	4.01	0.20	150.5				91	
8-49-8C		8-29-74	8- 5-75	9- 4-75	4+15.4	1 year	0.43	462	199	26	147	5	3440	4990	6160					290	No			
8-49-8D	6480	8-29-74	8- 5-75	9- 4-75	4+15.4	1 year	0.43	462	199	26	147	5	3440	4990	6160					100	Yes	Yes		
8-48-8D	6480	8-19-74	8- 5-75	9- 4-75	4+15.4	1 year	0.50	463	229	23	151	1	4180	5290	5890									
12-49-9A	6490	8-31-74	8- 6-75	No test	5+84.6	No test	0.50	435	217	26	148	4	2510	3790	4670									Concrete drilled vertically from the foundation gallery floor. Construction joint at elevation 6480.
12-49-9B		8-31-74	8- 7-75	No test	5+84.6	1 year	0.50	435	217	26	148	4	2510	3790	4670	4850	4.06	0.18	152.3				178	
12-49-9C		8-31-74	8- 7-75	No test	5+84.6	1 year	0.50	435	217	26	148	4	2510	3790	4670					330	No			
12-49-9D	6480	8-31-74	8- 7-75	No test	5+84.6	1 year	0.50	435	217	26	148	4	2510	3790	4670					180	Yes	Yes		
12-48-9D	6480	8-21-75	8- 7-75	No test	5+84.6	1 year	0.46	464	214	22	150	3	3070	4650	6030									
10-49-10A	6490	9- 4-74	8- 8-75	No test	4+95.6	No test	0.49	455	223	24	149	3	2590	4010	4410									Concrete drilled vertically from the foundation gallery floor. Construction joint at elevation 6480.
10-49-10B		9- 4-74	8- 8-75	No test	4+95.6	1 year	0.49	455	223	24	149	3	2590	4010	4410	4740	4.61	0.22	154.2				118	
10-49-10C		9- 4-74	8- 8-75	No test	4+95.6	1 year	0.49	455	223	24	149	3	2590	4010	4410					290	No			
10-49-10D	6480	9- 4-74	8-11-75	No test	4+95.6	1 year	0.49	455	223	24	149	3	2590	4010	4410					240	Yes	No		
10-48-10D	6480	8-23-74	8-11-75	No test	4+95.6	1 year	0.47	425	201	22	150	3	3030	4580	5460									
9-49-11A	6490	9-26-74	8-12-75	9-26-75	4+54.4	1 year	0.51	407	210	22	151	2	2720	3970	-	4710	4.35	0.16	154.2				119	Concrete drilled vertically from the foundation gallery. One and one-half-inch MSA structural concrete used on joint at elevation 6480; specimen 11D broke along cooling pipe on the joint.
9-49-11B		9-26-74	8-12-75	9-26-75	4+54.4	1 year	0.51	407	210	22	151	2	2720	3970	-	4300	4.10	0.15	153.6				108	
9-49-11C		9-26-74	8-12-75	9-26-75	4+54.4	1 year	0.51	407	210	22	151	2	2720	3970	-					310	No			
9-49-11D	6480	9-26-64	8-12-75	9-26-75	4+54.4	1 year	0.51	407	210	22	151	2	2720	3970	-					120	Yes	Yes		
9-48-11D	6480	9-13-74	8-12-75	9-26-75	4+54.4	1 year	0.54	397	213	21	150	3	1800	3570	4610									
Average																4630	4.20	0.19	152.8	230				

Table 1A. - *Summary of results obtained from tests performed on 250-mm (10-in) diameter concrete cores - Crystal Dam* [INCH-POUND UNITS] - *Continued*

Core No. 1/	Elevation above sea level (ft)	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Station (ft)	Age tested	Properties of fresh concrete: W/C by wt	Cement content (lb/yd³)	Water content (lb/yd³)	Sand (%)	Density (lb/ft³)	Air content (%)	Properties of hardened concrete: Control cylinders: Compressive strength (lb/in²) 7-day	28-day	90-day	Concrete cores: Compressive strength (lb/in²)	Elastic properties: E x 10⁻⁶ (lb/in²)	r	Density (lb/ft³)	Tensile strength (lb/ft³)	Joint 2/	Break 3/	Strength ratio core / 28-d cyl (%)	Remarks
8-57A-12A	6562	5- 7-75	10- 7-75	10-29-75	4+05.2	6 months	0.50	400	201	24	151	3	2900	4380	5300									Concrete drilled vertically from utility gallery floor. Construction joints at elevation 6560 and 6550.
8-56-12A	6560	4-29-75	10- 7-75	10-29-75	4+05.2	6 months	0.50	368	185	25	152	3	2330	4770	6200					90	Yes	Yes		
8-56-12B		4-29-75	10- 7-75	10-29-75	4+05.2	6 months	0.50	368	185	25	152	3	2330	4770	6200					170	No			
8-56-12C		4-29-75	10- 7-75	10-29-75	4+05.2	6 months	0.50	368	185	25	152	3	2330	4770	6200	4670	4.79	0.22	154.2				98	
8-56-12D	6550	4-29-75	10- 8-75	10-29-75	4+05.2	6 months	0.50	368	185	25	152	3	2330	4770	6200					210	Yes	Yes		
8-55-12D	6550	10-25-74	10- 8-75	10-29-75	4+05.2	6 months	0.53	403	215	23	149	4	2180	4200	-									
12-57A-13A	6562	5-27-75	10- 9-75	11-21-75	5+81.3	6 months	0.46	396	181	24	153	3	2860	4480	-									Concrete drilled vertically from utility gallery floor. Construction joints at elevation 6560 and 6550. A 1/4- by 1-1/4- by 2-1/2-inch void space on joint at elevation 6550.
12-56-13A	6560	5-19-75	10- 9-75	11-21-75	5+81.3	6 months	0.43	389	167	23	151	5	2860	4480	-					210	Yes	Yes		
12-56-13B		5-19-75	10- 9-75	11-21-75	5+81.3	6 months	0.43	389	167	23	151	5	2860	4480	-	5530	4.56	0.20	156.1				123	
12-56-13C		5-19-75	10- 9-75	11-21-75	5+81.3	6 months	0.43	389	167	23	151	5	2860	4480	-					170	No			
12-56-13D	6550	5-19-75	10- 9-75	11-21-75	5+81.3	6 months	0.43	389	167	23	151	5	2860	4480	-					200	Yes	Yes		
12-55-13D	6550	5- 9-75	10- 9-75	11-21-75	5+81.3	6 months	0.48	385	187	23	150	5	3340	4660	5770									
11-57A-14A	6562	6-24-75	11-18-75	12-18-75	5+23.9	6 months	0.42	394	165	23	151	4	3170	4330	5120									Concrete drilled vertically from utility gallery floor. Construction joint at elevations 6560 and 6550.
11-56-14A	6560	6-21-75	11-18-75	12-18-75	5+23.9	6 months	0.43	391	168	23	152	4	3640	4660	5280					250	Yes	No		
11-56-14B		6-21-75	11-18-75	12-18-75	5+23.9	6 months	0.43	391	168	23	152	4	3640	4660	5280	4570	4.42	0.20	152.3				98	
11-56-14C		6-21-75	11-19-75	12-18-75	5+23.9	6 months	0.43	391	168	23	152	4	3640	4660	5280	5130	4.90	0.20	154.8				110	
11-56-14D	6550	6-21-75	11-19-75	12-18-75	5+23.9	6 months	0.43	391	168	23	152	4	3640	4660	5280					280	Yes	No		
11-55-14D	6550	6-10-75	11-19-75	12-18-75	5+23.9	6 months	0.45	395	179	23	151	4	-	4970	-									
13-57A-15A	6562	6-28-75	11-19-75	12-18-75	6+24.6	6 months	*0.50	*386	*193	*23	146	4	-	-	-	4960	4.37	0.20	156.1				100	Concrete drilled vertically from utility gallery floor. Construction joints at elevations 6560 and 6550. Joint at elevation 6560 disbonded when received in the laboratory.
13-56-15A	6560	6-24-75	11-19-75	12-18-75	6+24.6	6 months	0.48	400	190	23	150	4	3400	4460	-									
13-56-15B		6-24-75	11-19-75	12-18-75	6+24.6	6 months	0.48	400	190	23	150	4	3400	4460	-					130	No			
13-56-15C		6-24-75	11-20-75	12-18-75	6+24.6	6 months	0.48	400	190	23	150	4	3400	4460	-	4940	4.25	0.21	153.0				111	
13-56-15D	6550	6-24-75	11-20-75	12-18-75	6+24.6	6 months	0.48	400	190	23	150	4	3400	4460	-					190	Yes	Yes		
13-55-15D	6550	6-10-75	11-20-75	12-18-75	6+24.6	6 months	0.49	381	186	23	149	5	-	3750	-									
Average																4970	4.55	0.21	154.4	190				
8-57A-16A	6562	5- 7-75	3-18-76	5- 5-76	4+09.2	1 year	0.50	400	201	24	151	3	2900	4380	5300	5490	5.02	0.22	156.7				125	Concrete drilled vertically from utility gallery floor. Joint at elevation 6560 disbonded when received in the laboratory. Joints at elevations 6560 and 6550.
8-56-16A	6560	4-29-75	3-18-76	5- 5-76	4+09.2	1 year	0.50	368	185	25	151	3	2330	4770	6200									
8-56-16B		4-29-75	3-18-76	5- 5-76	4+09.2	1 year	0.50	368	185	25	151	3	2330	4770	6200					240	No			
8-56-16C		4-29-75	3-18-76	5- 5-76	4+09.2	1 year	0.50	368	185	25	151	3	2330	4770	6200					190	No			
8-56-16D	6550	4-29-75	3-18-76	5- 5-76	4+09.2	1 year	0.50	368	185	25	151	3	2330	4770	6200					110	Yes	Yes		
8-55-16D	6550	10-25-74	3-18-76	5- 5-76	4+09.2	1 year	0.53	403	215	23	149	4	2180	4200	-									
12-57A-17A	6562	5-27-75	3-19-76	5-18-76	5+86.6	1 year	0.46	396	181	24	153	3	2860	4480	-									Concrete drilled vertically from utility gallery floor. Joints at elevations 6560 and 6550. Joint at elevation 6560 disbonded when received in laboratory.
12-56-17A	6560	5-19-75	3-19-76	5-18-76	5+86.6	1 year	0.43	389	167	23	151	5	2860	4480	-					180	Yes	Yes		
12-56-17B		5-19-75	3-19-76	5-18-76	5+86.6	1 year	0.43	389	167	23	151	5	2860	4480	-	5710	4.50	0.18	153.0				127	
12-56-17C		5-19-75	3-22-76	5-18-76	5+86.6	1 year	0.43	389	167	23	151	5	2860	4480	-	5520	6.73	0.25	154.8				123	
12-56-17D	6550	5-19-75	3-22-76	No test	5+86.6	No test	0.43	389	167	23	151	5	2860	4480	-									
12-55-17D	6550	5- 9-75	3-22-76		5+86.6	No test	0.48	385	187	23	150	4	3340	4660	5770									
11-57A-18A	6562	6-24-75	4-20-76	6-21-76	5+29.5	1 year	0.42	394	165	23	151	4	3170	4330	5120	5860	4.87	0.17	157.9				135	Concrete drilled vertically from utility gallery floor. Joints at elevations 6560 and 6550. Joint 6560 broke during handling in the laboratory.
11-56-18A	6560	6-21-75	4-20-76	6-21-76	5+29.5	1 year	0.43	391	168	23	152	4	3640	4660	5280									
11-56-18B		6-21-75	4-20-76	6-21-76	5+29.5	1 year	0.43	391	168	23	152	4	3640	4660	5280	5490	4.64	0.21	156.7				118	
11-56-18C		6-21-75	4-20-76	6-21-76	5+29.5	1 year	0.43	391	168	23	152	4	3640	4660	5280	5440	4.86	0.22	154.8				117	
11-56-18D	6550	6-21-75	4-21-76	6-21-76	5+29.5	1 year	0.43	391	168	23	152	4	3640	4660	5280					250	Yes	Yes		
11-55-18D	6550	6-10-75	4-21-76	6-21-76	5+29.5	1 year	0.45	395	179	23	151	4	-	4970	-									
13-57A-19A	6562	6-28-75	4-29-76	6-24-76	6+35.6	1 year	*0.50	*386	*193	*23	146	4	-	-	-									Concrete drilled vertically from utility gallery floor. Joints at elevations 6560 and 6550. Specimen 19A broke near a piece of angle iron running completely through the core.
13-56-19A	6560	6-24-75	4-29-76	6-24-76	6+35.6	1 year	0.48	400	190	23	150	4	3400	4460	-					170	Yes	No		
13-56-19B-1		6-24-75	4-29-76	6-24-76	6+35.6	1 year	0.48	400	190	23	150	4	3400	4460	-	5350	4.43	0.17	151.7				120	
13-56-19B-2		6-24-75	4-29-76	6-24-76	6+35.6	1 year	0.48	400	190	23	150	4	3400	4460	-	4440	4.12	0.20	151.7				100	
13-56-19C		6-24-75	4-29-76	6-24-76	6+35.6	1 year	0.48	400	190	23	150	4	3400	4460	-					210	No			
13-56-19D	6550	6-24-75	4-29-76	6-24-76	6+35.6	1 year	0.48	400	190	23	150	4	3400	4460	-					350	Yes	No		
13-55-19D	6550	6-10-75	4-29-76	6-24-76	6+35.6	1 year	0.49	381	186	23	149	5	-	3750	-									
Average																5410	4.90	0.20	154.4	210				

* Design values rather than actual yield values.
1/ First number, block number; second, lift number; third, core specimen number.
2/ Did specimen contain a construction joint?
3/ Did joint break during construction?

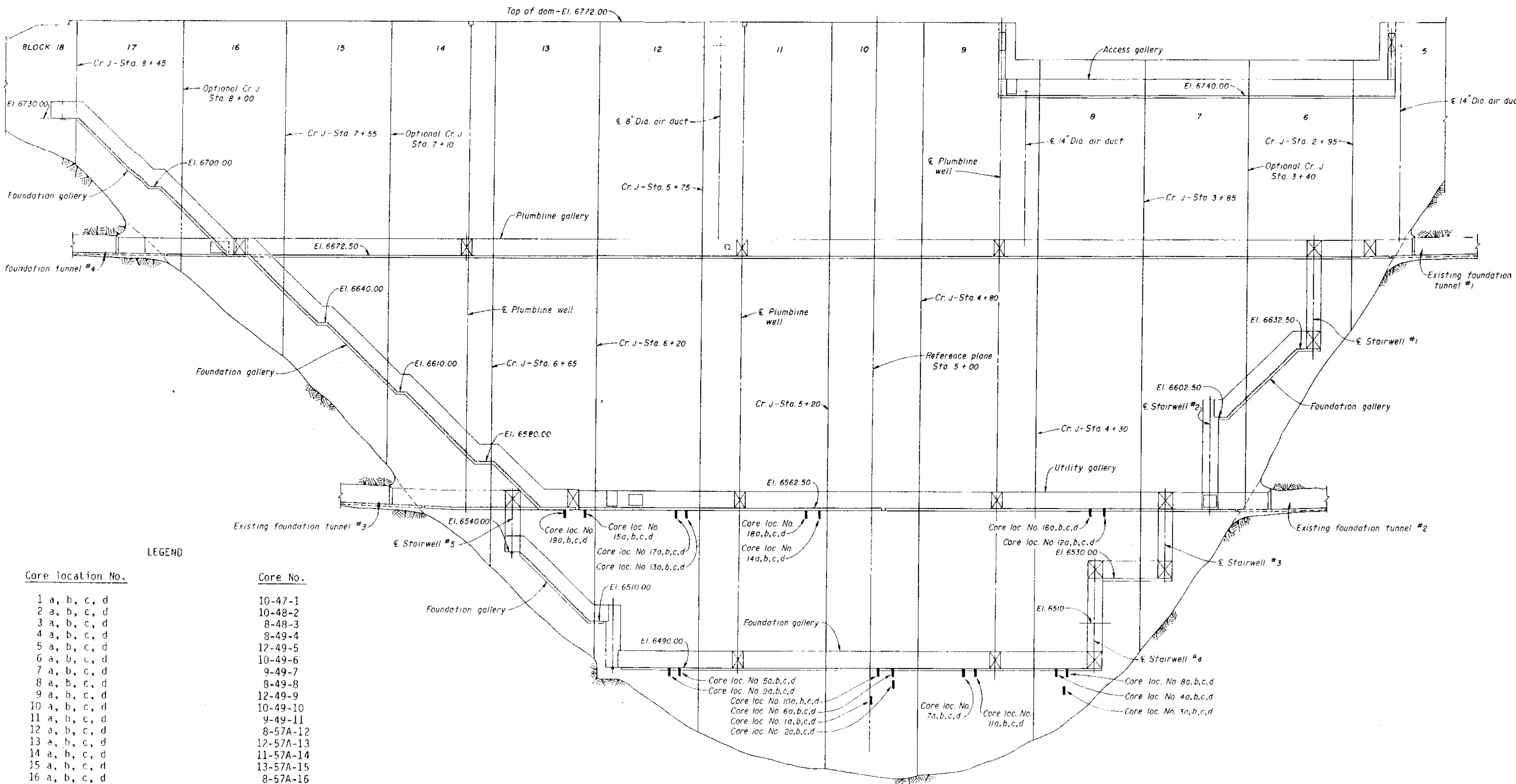
Table 2. - *Summary of test data - Crystal Dam concrete cores*

Average age	Number of specimens	Average compressive strength MPa	Average compressive strength lb/in^2	Coefficient of variation (%)	Strength ratio * (%)	Modulus of elasticity GPa	Modulus of elasticity lb/in^2	Poisson's ratio (average)
70 days	6	28.0	4060	19.7	81	27.6	4.00×10^6	0.20
6 months	14	33.7	4890	8.6	112	31.4	4.55×10^6	0.21
1 year	14	35.0	5080	8.9	116	31.7	4.60×10^6	0.20

$$* \text{ Strength ratio} = \frac{\text{core strength}}{\text{28-day cylinder strength}}$$

Table 3. - *Summary of test data - Crystal Dam concrete cores with and without construction joints*

Type of specimen	Average age	Number of specimens tested	Average tensile strength MPa	Average tensile strength lb/in^2	Average strength ratio tensile/compressive (%)	Number of failures at joints
Jointed	76 days	3	1.17	170	4	1
Nonjointed	69 days	1	1.17	170	4	-
Jointed	6 months	11	1.38	200	4	7
Nonjointed	6 months	7	1.24	180	4	-
Jointed	1 year	9	1.31	190	4	6
Nonjointed	1 year	7	1.79	260	5	-



LEGEND

Core location No.	Core No.
1 a, b, c, d	10-47-1
2 a, b, c, d	10-48-2
3 a, b, c, d	8-48-3
4 a, b, c, d	8-49-4
5 a, b, c, d	12-49-5
6 a, b, c, d	10-49-6
7 a, b, c, d	9-49-7
8 a, b, c, d	8-49-8
9 a, b, c, d	12-49-9
10 a, b, c, d	10-49-10
11 a, b, c, d	9-49-11
12 a, b, c, d	8-57A-12
13 a, b, c, d	12-57A-13
14 a, b, c, d	11-57A-14
15 a, b, c, d	13-57A-15
16 a, b, c, d	8-57A-16
17 a, b, c, d	12-57A-17
18 a, b, c, d	11-57A-18
19 a, b, c, d	13-57A-19

Figure 1. - Hole locations for 250-mm (10-in) diameter cores - Crystal Dam.

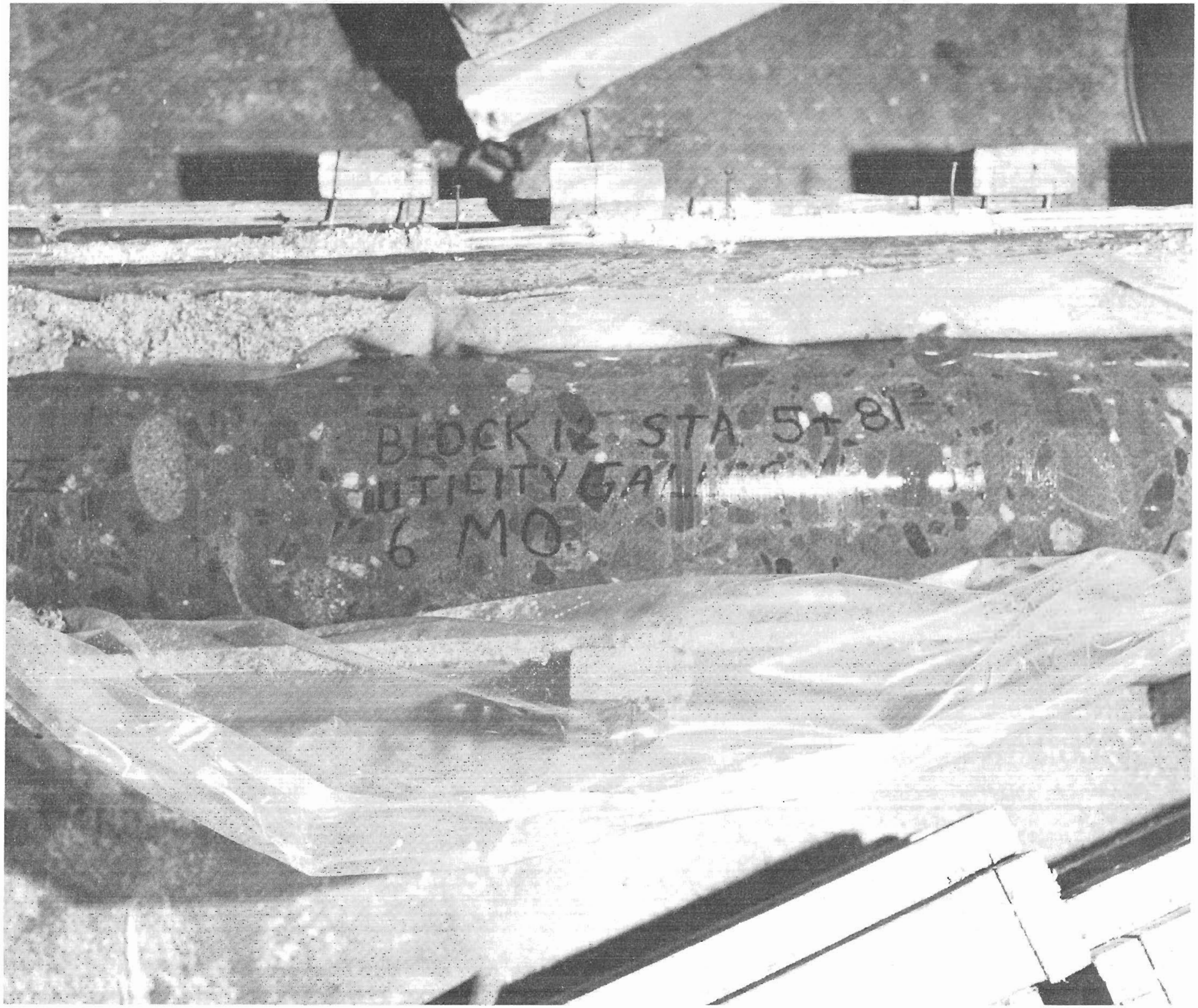


Figure 2. - Typical "as-received" condition of 250-mm (10-in) diameter cores - Crystal Dam. Photo P622C-427-7363.

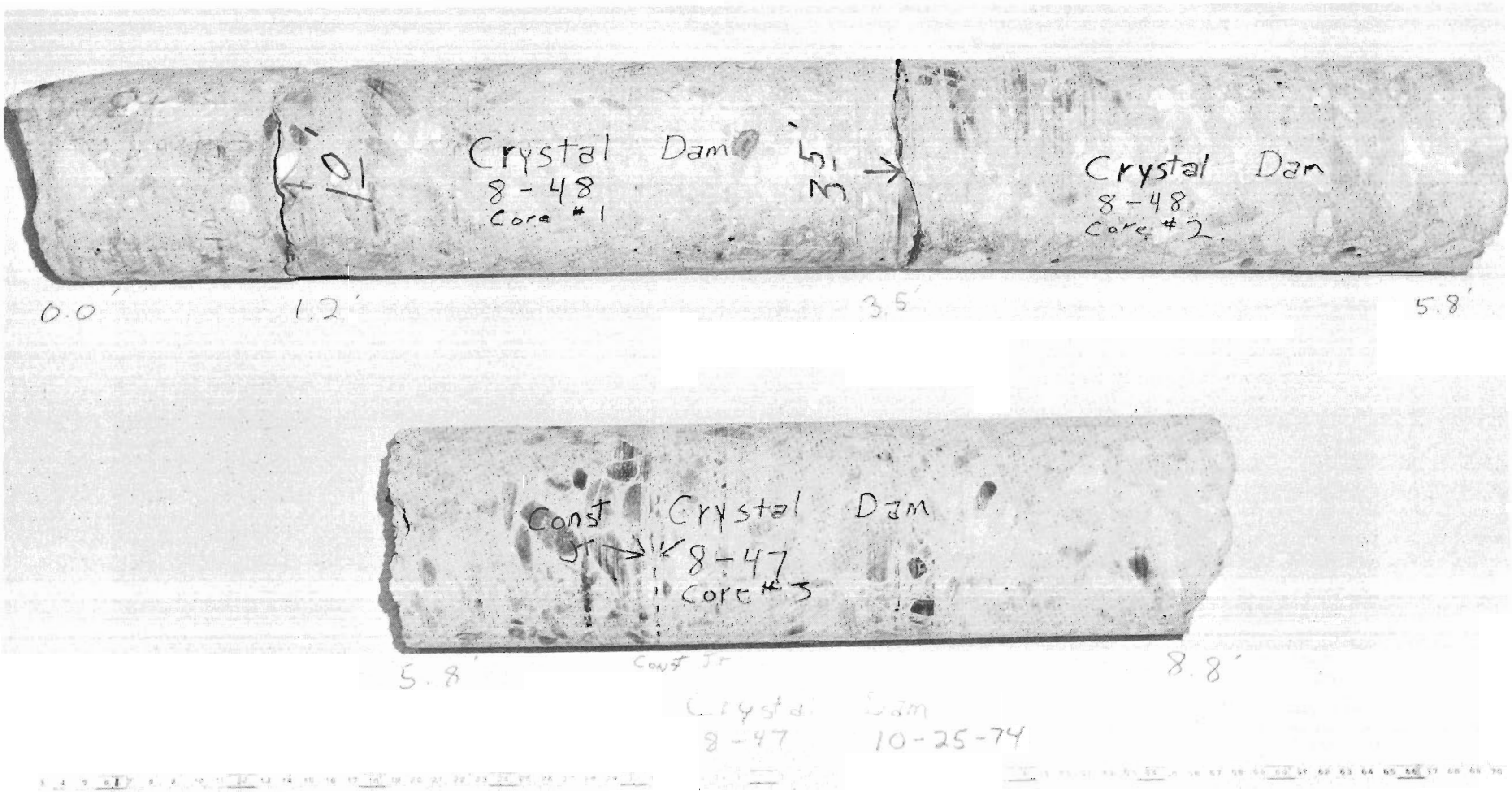


Figure 3. - Typical 250-mm (10-in) diameter cores showing a construction joint - Crystal Dam. Photo C-8426-2.

Figure 4. - Typical 250-mm (10-in) diameter core after tensile strength test - Crystal Dam. Photo C-8448-1.

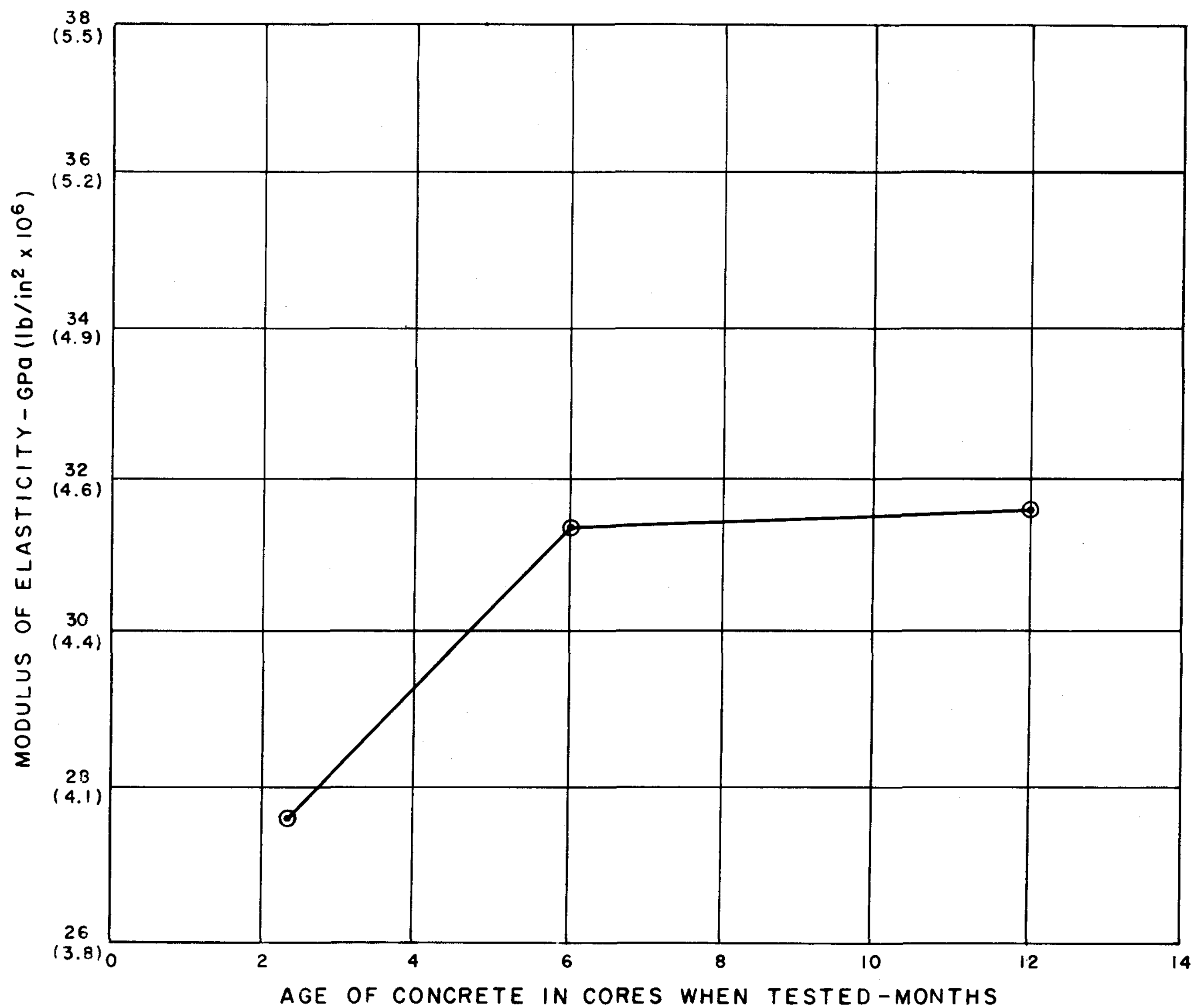


Figure 5. - Average moduli of elasticity of mass concrete in Crystal Dam.

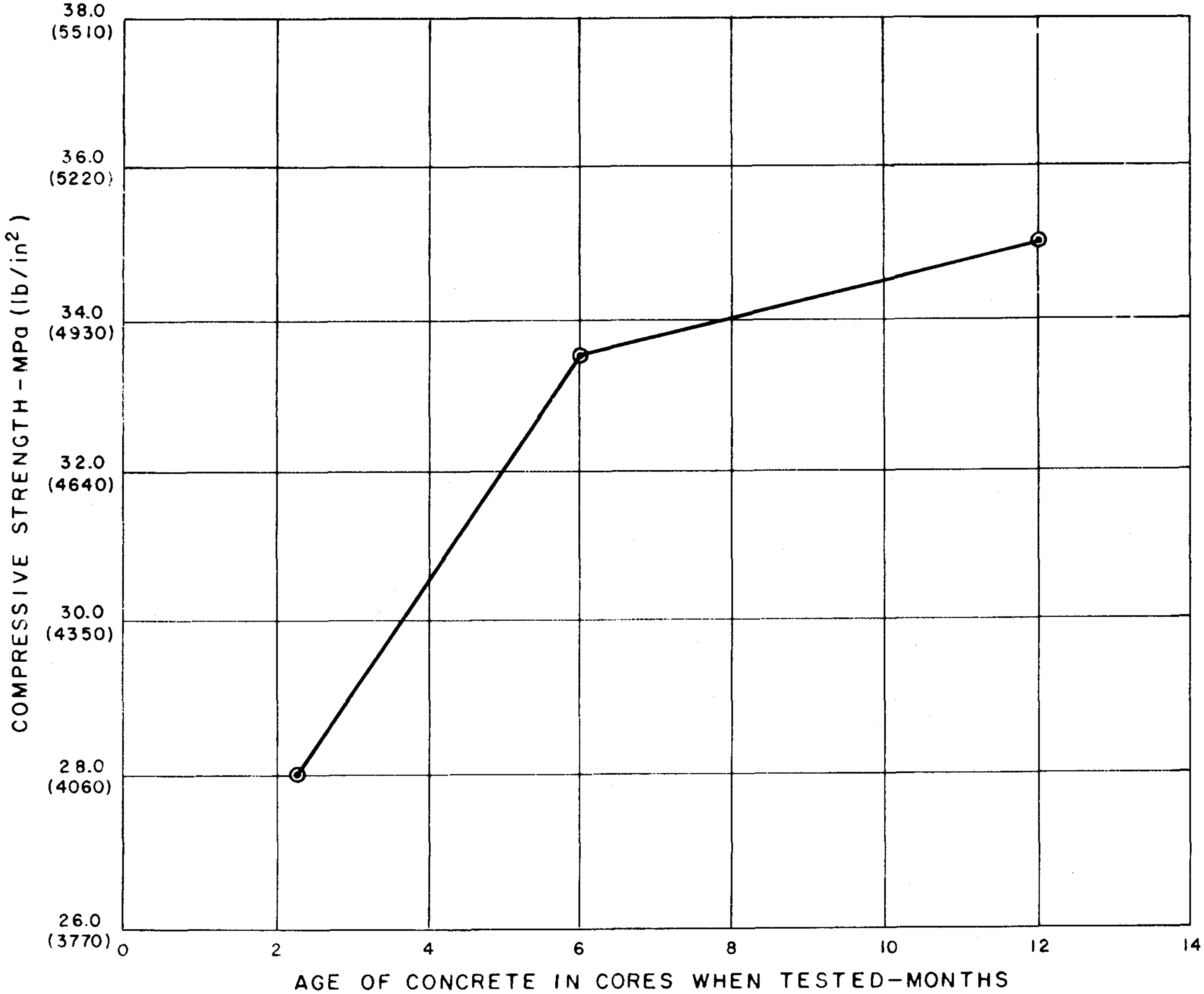


Figure 6. - Average compressive strength of mass concrete in Crystal Dam.

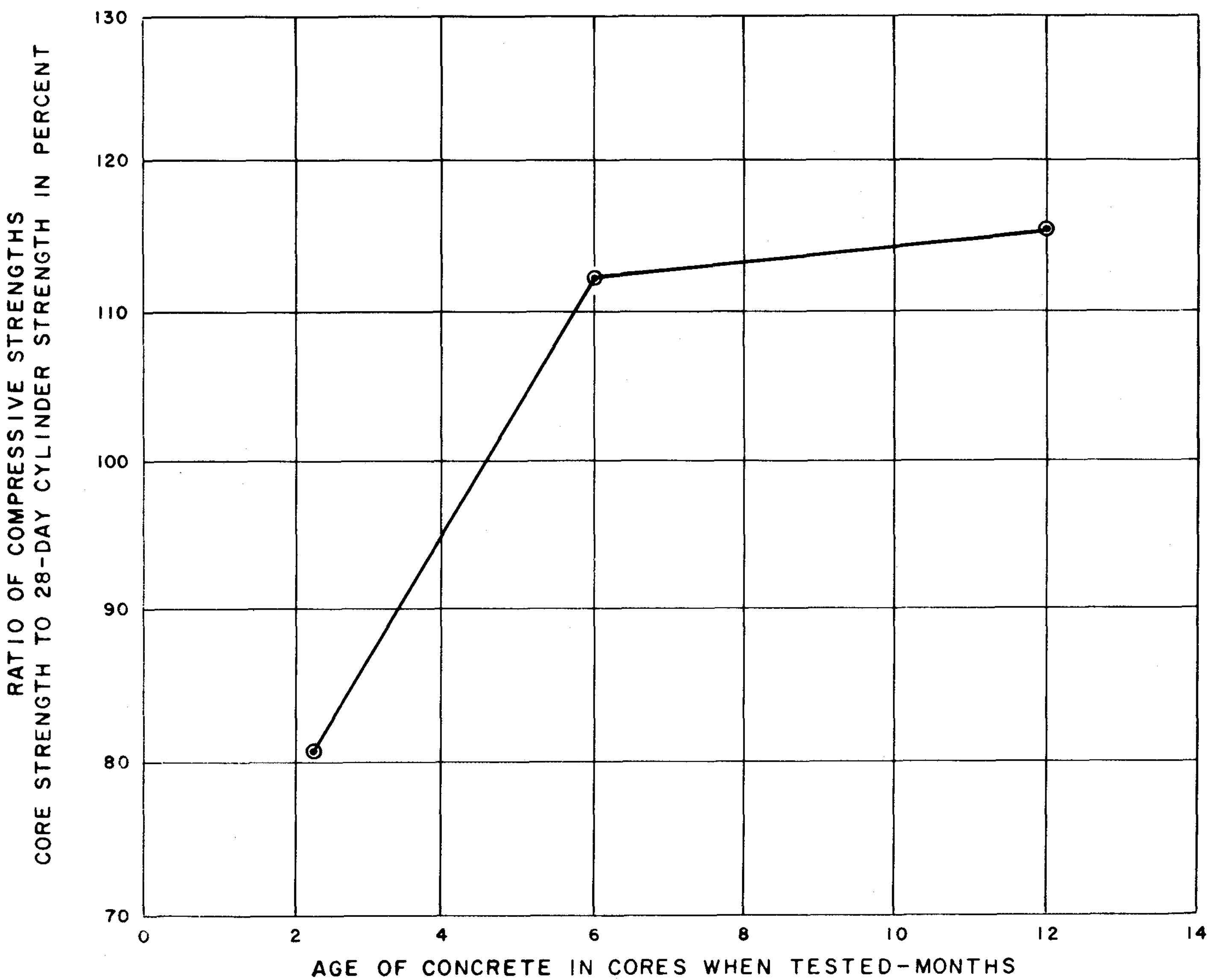


Figure 7. - Ratio of core to companion 28-day cylinder strengths in Crystal Dam.

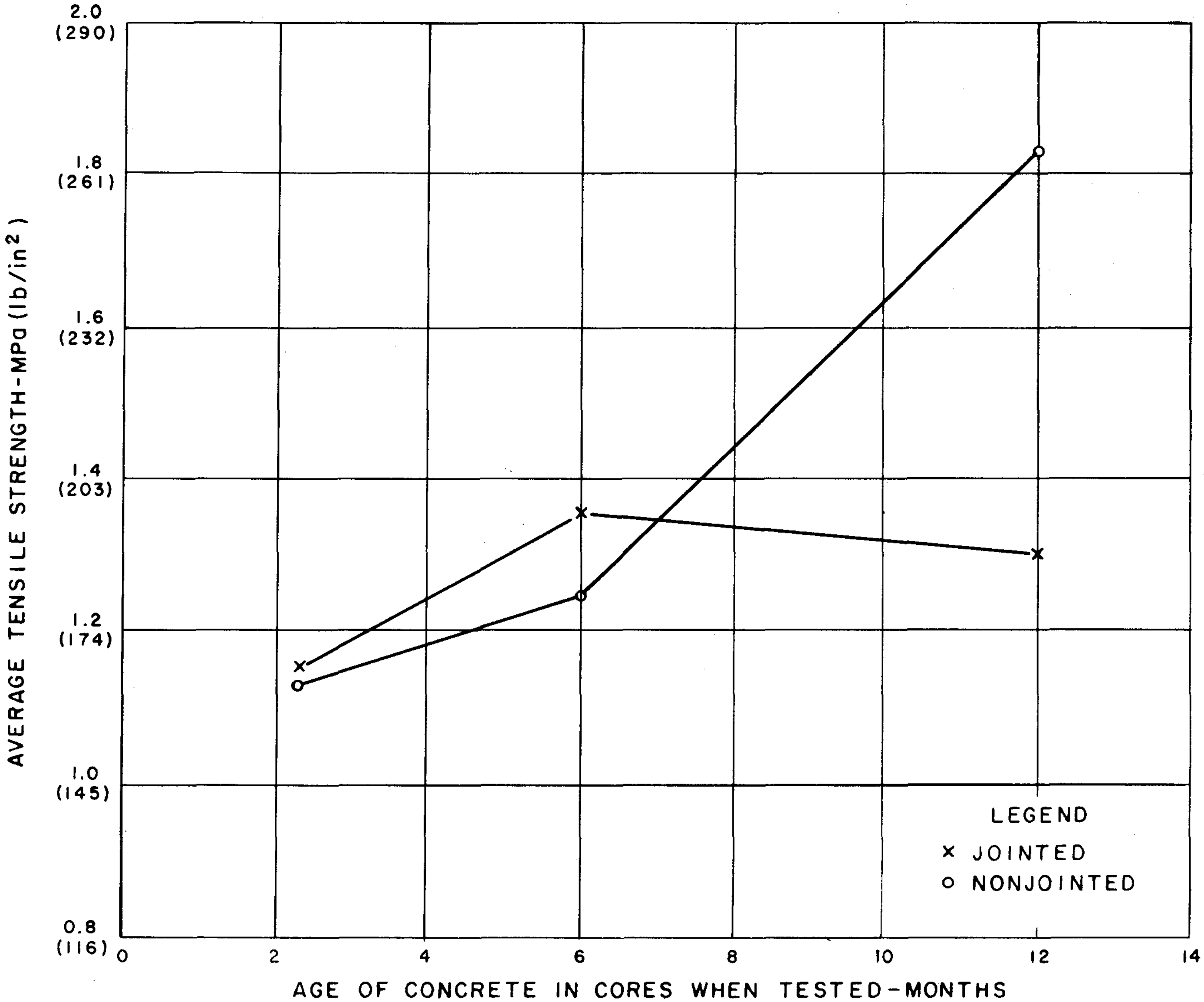


Figure 8. - Average tensile strength of mass concrete in Crystal Dam.

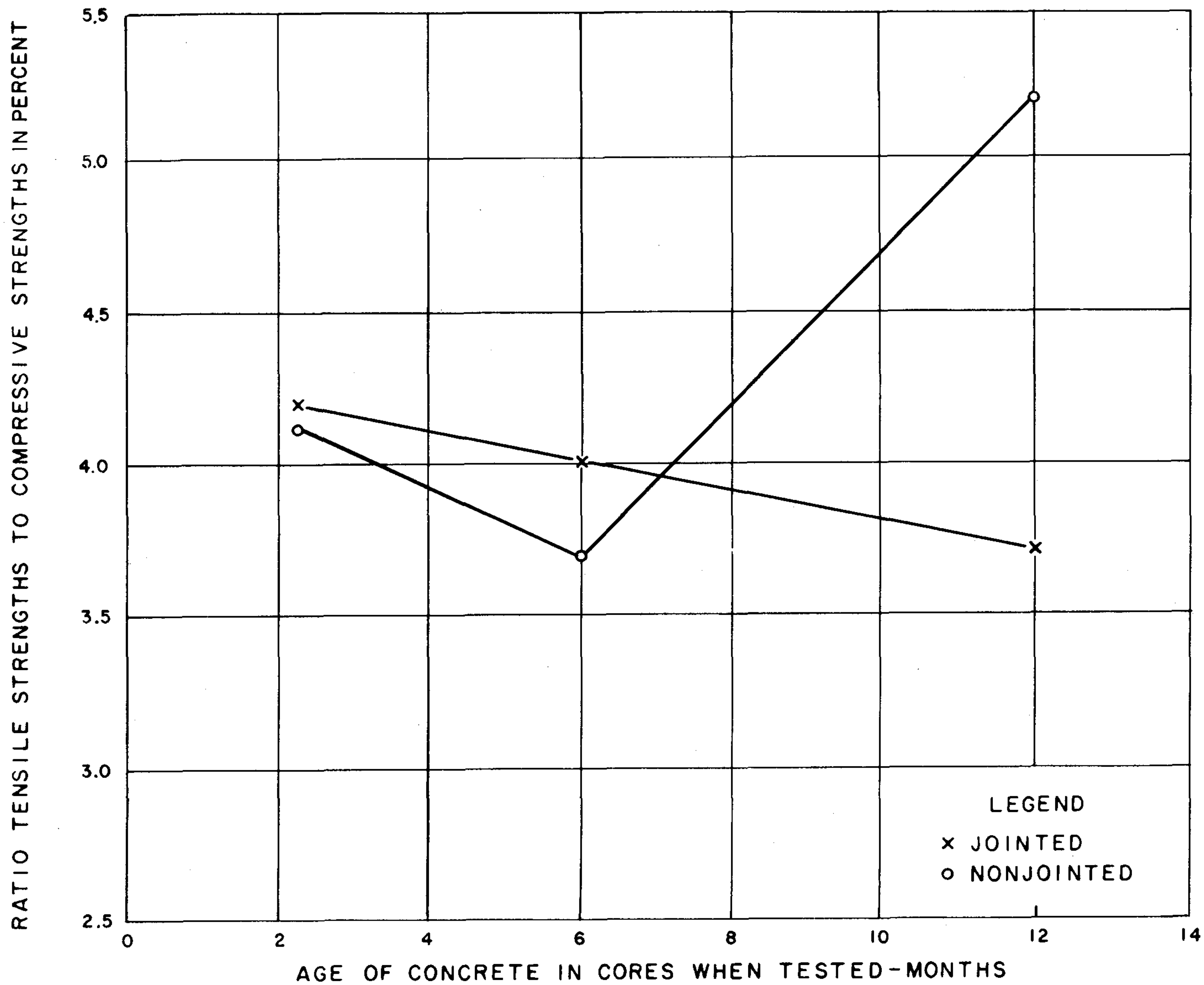


Figure 9. - Ratio of tensile strengths to companion compressive strengths in Crystal Dam.

A free pamphlet is available from the Bureau entitled, "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request to the Bureau of Reclamation, Engineering and Research Center, PO Box 25007, Denver Federal Center, Bldg. 67, Denver, CO 80225, Attn D-922.