R-89-03

EVALUATION OF CONCRETE CORES - ARROWROCK DAM IDAHO

May 1989

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Research and Laboratory Services Division
Concrete and Structural Branch

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
R-89-03

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
EVALUATION OF CONCRETE CORES -
ARROWROCK DAM, IDAHO

5. REPORT DATE
May 1989

6. PERFORMING ORGANIZATION CODE
D-3730

7. AUTHOR(S)
William F. Kepler

8. PERFORMING ORGANIZATION REPORT NO.
R-89-03

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Bureau of Reclamation
Denver Office
Denver CO 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Same

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
DIBR

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the Denver Office, Denver, Colorado.

16. ABSTRACT

Construction of Arrowrock Dam was completed in 1915. This structure is distinctive in that it is one of three dams constructed with what was called "sand-cement." In 1987 cores were taken to determine the integrity of the structure. Strength tests indicate a lessening of strength with depth in the structure.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- concretes/ cores/ compressive strength/ direct tensile strength/ splitting tensile strength/ tensile strength/ modulus of elasticity/ Poisson's ratio/ mass concrete/ petrographic investigation/ sand-cement/ concrete properties/ density/ thick-arch dam/

b. IDENTIFIERS-- Arrowrock Dam, Boise Project, Idaho, Pacific Northwest Region

c. COSATI Field/Group *COWRR:* *SRIM:*

18. DISTRIBUTION STATEMENT

19. SECURITY CLASS (THIS REPORT)
UNCLASSIFIED

20. SECURITY CLASS (THIS PAGE)
UNCLASSIFIED

21. NO. OF PAGES
32

22. PRICE

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise 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 promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Arrowrock Dam

CONTENTS

TABLES

CONTENTS - Continued

Page

FIGURES

Figure

APPENDIX

INTRODUCTION

Arrowrock Dam is located on the Boise River about 20 miles (32 km) east of the city of Boise, Idaho. The dam is a thick-arch, concrete gravity structure 348.6 feet (106 m) high with a base width of 238 feet (72.4 m), top width of 15.5 feet (4.7 m), and crest length of 1,100 feet (335 m). More than 585,000 yd^3 (455 000 m^3) of concrete were placed in the structure. The dam was built during three construction periods from 1912 to 1915; work was suspended during the winter months. From 1935 to 1937, the downstream face was resurfaced and the dam was raised 5 feet (1.5 m) to elevation 3220 (982 m). At maximum water surface elevation 3216 (980 m), the reservoir has a storage capacity of 286,500 acre-feet (353 400 000 m^3). Upon completion in 1915, Arrowrock Dam was the highest dam in the world (Bureau of Reclamation, 1980).

At the request of the Concrete Dams Branch, a concrete core study was performed to (1) determine the physical properties of the mass concrete, and (2) help determine the integrity of the structure.

In July 1987, 6-inch (150-mm) diameter cores were extracted from Arrowrock Dam to evaluate the strength and elastic properties of the concrete. This report presents the results and conclusions from the physical properties testing and the petrographic examination.

The cores were evaluated for:

- Compressive strength
- Modulus of elasticity
- Poisson's ratio
- Direct tensile strength
- Splitting tensile strength
- Density
- Petrographic examination.

Average age of the cores at testing was 62 years from the time of placement. Only the concrete placed during the original 1912 to 1915 construction period was tested.

For a typical plan and profile of Arrowrock Dam, see figures 1 through 4.

CONCLUSIONS

1. The compressive strength of the concrete is lower than expected for a mass concrete dam of this age. Direct tensile and splitting tensile strengths are also low, but are normal when compared to the compressive strength.

2. Compressive strength test results indicate a definite loss of strength with depth in the dam. Tests for direct tensile strength of the unjointed material and splitting tensile strength confirm these results. The loss of strength with depth could be due to a change of cement source after the first year of construction. The modulus of elasticity and Poisson's ratio do not change with depth and are normal for mass concrete (Bureau of Reclamation, 1961).

3. The direct tensile strength of the unjointed concrete decreases with depth, but the strength across the joints does not change significantly with depth. The strength across the joints averages 61 percent of the average strength of the unjointed concrete, which is normal for mass concrete.

4. The splitting tensile strength is lower than normal for mass concrete and decreases with depth.

5. The concrete density does not change significantly with depth and is normal for mass concrete.

6. Petrographic examination (see appendix) shows that the concrete examined is of fair physical quality with a poor-to-fair paste-aggregate bond. The aggregate is physically fair to satisfactory and is chemically innocuous except for a few isolated areas of silica gel associated with opal-coated basalt particles. Alkali-aggregate reaction was observed sporadically through the concrete, but no continuing deleterious effects due to alkali-aggregate reactions are expected. The paste is moderately consolidated and hard to moderately hard throughout the concrete, while less consolidated at the joints. Although the concrete has no entrained air, there was no evidence of freeze-thaw or chemical attack, even though water-soluble chloride and sulfate ions were detected. The concrete core examined was not exposed to freeze-thaw conditions.

ARROWROCK DAM CONCRETE

Arrowrock Dam was designed and built by the Bureau of Reclamation. There were no design strength requirements for the concrete; instead, the mix proportions were specified. The maximum allowable compressive stress in the original design was 417 lb/in^2 (2.88 MPa).

The cement used for dam construction was, for the most part, a blend of normal portland cement and finely ground granite. The granite, taken largely from the spillway channel excavation, was dried, crushed to about a 20-mesh (850-μm) size in ball mills, and then interground with the normal coarsely ground portland cement in tube mills. The charge of materials into the tube mills was proportioned to contain 45 percent granite and 55 percent cement by weight. The materials were interground until 90 percent of the mixture would pass a No. 200 (75 μm) screen.

All sand-cement, as the blend of portland cement and ground granite was named, was required to pass the tests for portland cement before being used in the dam. To ensure fulfillment of this requirement, hourly samples were taken from the tube mills and blended together to form composite daily samples that were tested for fineness, proportions of cement and granite, setting time, 7-day tensile strength, and soundness. It was deemed significant at the time that not a single sample of the sand-cement failed to pass the soundness test. The cost of dam construction and blending plant operation was $9.77 per ton ($10.77/metric ton) for sand-cement, as compared with $14.15 per ton ($15.60/metric ton) for portland cement (Savage, 1936).

Aggregates were obtained from the riverbed at the damsite for the first two sections of the dam and from 13 miles downstream for the third section. The maximum-size aggregate is 4-1/2 inches (115 mm), with up to 20 percent by volume of boulders added by hand when available. During the investigation, 6-inch (150-mm) rock was found in the cores.

Two types of concrete were placed in the dam: interior and exterior. The exterior concrete was placed on the exterior 5 to 6 feet (1.5 to 1.8 m) of each face and in the lower portion of the dam. The rest of the structure was made of interior concrete.

In the interior concrete, the proportions of sand-cement, river sand, river gravel [up to 2.5 in (63.5 mm)], and river cobbles (2.5 to 4.5 in) were 1.0:2.5:5.0:2.75 by volume. In the exterior concrete, the proportions were 1.0:2.0:4.5:2.5 by volume. The sand-cement content was 361 lb/yd^3 (214 kg/m^3) for interior concrete and 395 lb/yd^3 (234 kg/m^3) for exterior concrete. Cementitious materials for the exterior concrete consisted of 76 percent by volume of sand-cement and 24 percent of portland cement. This is equivalent to 66 percent portland cement and 34 percent granite. The water-to-cement ratio was 0.65; enough water was added to the concrete to make a dense, uniform plastic mix. Most of the batches were dry enough that there was no appreciable bleeding at the surface after spading and tamping.

There was no temperature control of the in-place concrete. The average temperature rise after placing, measured by four embedded thermometers located in various parts of the dam, was 30 °F (16 °C). The maximum temperature measured in the hydrating concrete was 95 °F (35 °C).

CONSTRUCTION

The concrete was mixed in three 1-yd^3 (0.75-m^3) mixers. The cement was weighed; all other materials were measured by volume. Mixing time, including dumping into the concrete skips, was 1 minute. Concrete was transported in 4-yd^3 (3.1-m^3) skips by cableways, deposited in hoppers, and then distributed by 40-foot (12.2-m) chutes. The concrete was placed in 2-foot (0.6-m) layers compacted by spading and tamping. Occasionally, large stones (plums) were spaded in (Paul, 1915).

The concrete was usually placed in 4-foot (1.2-m) high blocks, but there were blocks up to 8 feet (2.4 m) high. On the average, a 4-foot height of concrete was placed per day. Blocks were placed in alternate order to facilitate concrete cooling. Alternate blocks were kept about three blocks above adjacent blocks.

Before starting a concrete placement, the surface of the previous placement was cleaned using scrubbing brushes, steel brooms, and sponges. A layer of neat cement grout was then troweled onto the moist surface just before concrete placement.

When the concrete obtained sufficient strength, the forms were removed and the concrete was cured by sprinkling with water for at least 6 weeks.

The dam was built in three sections, one during each construction season. The first section, which was intended to protect subsequent work, extended along the upstream face to elevation 3150 (960 m). The second portion brought the entire dam up to this elevation. The third section completed the dam to elevation 3215 (980 m). The upper 65 feet (19.8 m) of the dam are reinforced with 1-inch (2.55-cm) square steel bars placed 40 inches (1 m) on center near the upstream face.

Each section extended the length of the dam, but was divided into 150-, 50-, or 25-foot (45.7-, 15.2-, or 7.6-m) lengths by vertical/radial contraction joints. Measured from the upstream face, these joints were located every 150 feet from the bottom of the dam up to elevation 3085 (940 m), every 50 feet from elevation 3085 to elevation 3150 (960 m), and every 25 feet from elevation 3150 to the top of the dam.

The vertical walls formed by the radial joints had vertical wells - three at the bottom, decreasing to one at the top. When construction was completed, these wells were filled with concrete placed in cold weather, thus providing a watertight seal at the construction joints. Annealed copper waterstops (Z shaped) were placed in the joints near the upstream face.

By 1936 the downstream face had disintegrated due to freeze-thaw action. The depth of disintegration varied from nothing at the top of the dam to 18 inches (460 mm) at the lower portions of the downstream face where snow collected during the winter months. This deterioration did not affect the strength or stability of the dam (McMillan and Lyse, 1957).

In the summer of 1936, the downstream face was repaired with an 18-inch layer of concrete up to within 22 feet (6.7 m) of the top of the dam. The concrete was placed in 25-foot (7.6-m) square panels to match the original joints in the upper part of the dam. The top 22 feet of the dam were covered with a 1-inch layer of shotcrete. The outer spillway wall was also covered with shotcrete. To increase storage capacity, the dam was raised 5 feet (1.5 m) and new parapet walls were added (Russell, 1938).

DRILLING AND HANDLING

Five 6-inch (150-mm) diameter cores were extracted from Arrowrock Dam during 1987 to furnish specimens for physical properties testing. The drill holes were spaced approximately equally across the top of the dam. Drill hole 2 was drilled down an existing contraction joint. Drill hole 2A was drilled next to hole 2 to provide core for testing. All cores were drilled vertically. Table 1 shows drill hole locations.

The moist cores were wrapped in plastic at the jobsite and then shipped in wooden crates packed with sawdust to the Bureau of Reclamation Denver laboratories. In Denver, the core specimens were logged and photographed, and test specimens were selected.

ASTM C 42, "Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete" (ASTM, 1987), specifies that the diameter of concrete core extracted for compressive strength testing "should preferably be at least three times the nominal maximum size of coarse aggregate used in the concrete, and must be at least twice the maximum nominal aggregate size of the coarse aggregate in the core sample." Therefore, since the mass concrete contains 6-inch maximum-size aggregate, by ASTM standards, the diameter of the core should preferably have been 18 inches (460 mm) and had to be at least 12 inches (305 mm). However, to obtain the maximum number of test specimens with funds available, 6-inch-diameter cores were extracted.

TESTING

Compressive Strength

Compressive strength testing was done according to ASTM C 39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" (ASTM, 1987). The 6-inch-diameter specimens were capped with a sulfur compound. Specimens were sealed in plastic to prevent moisture loss.

The modulus of elasticity (E) and Poisson's ratio (r) were determined using epoxied strain gauges with computer readout. Lines of strain gauges were placed around the cylinder, two along either side of the long axis and two around the middle. Each line consisted of two strain gauges connected in series. The manufacturer recommends that the total length of the strain gauges be between 2.5 and 3 times the size of the maximum-size aggregate. The maximum-size aggregate was 6 inches; therefore, the total length of the strain gauges should have been at least 15 inches (380 mm). However, the two 4-inch (100-mm) long strain gauges connected in series developed a total length of only 8 inches (200 mm). Subsequent testing to confirm the use of two rather than three strain gauges in series yielded comparable results.

Values for E and r were computed using ASTM C 469, "Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression" (ASTM, 1987), and the test method "Procedure for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression" (Bureau of Reclamation, in preparation) which uses a stress range between 100 and 1,000 lb/in^2 (689 and 6895 kPa). The compressive strength specimens were tested to failure. The compressive strength values were adjusted for the specimens with a length-to-diameter ratio not equal to 2.0 according to ASTM C 42 (ASTM, 1987).

Direct Tensile Strength

The core specimens for direct tension testing were sawcut to provide a length-to-diameter ratio equal to 2. Double end plates 4-1/2 inches (115 mm) thick and designed to minimize deformation were bonded to each end of the core with epoxy, which was then cured for 24 hours. The specimens were sealed to prevent moisture loss and were then placed in a hydraulic testing machine and loaded to failure in tension at 200 $lb/in^2/min$ (1380 kPa/min).

Splitting Tensile Strength

Splitting tensile strength testing was done in accordance with ASTM C 496, "Standard Tensile Strength of Cylindrical Concrete Specimens" (ASTM, 1987).

Density

The density of the concrete was determined by dividing the "as is" weight of the concrete specimen by the volume of water the specimen displaced.

TEST RESULTS

Test results are summarized in tables 2, 3, 4, and 5.

Compressive Strength

The compressive strength of the concrete was lower than expected for a mass concrete dam of this age. Test results also indicate a definite loss of strength with depth in the dam. The average strength for the top third of the dam was 3,470 lb/in^2 (23.9 MPa), for the middle third was 3,390 lb/in^2 (23.4 MPa), and for the bottom third was 3,010 lb/in^2 (20.8 MPa).

The modulus of elasticity and Poisson's ratio did not change with depth. The modulus of elasticity averaged 3.95 x 10^6 lb/in^2 (27.2 GPa), and Poisson's ratio averaged 0.20. These values are highly dependent on the aggregate.

Direct Tensile Strength

The direct tensile strength was lower than expected, but is normal when compared with the compressive strength. The direct tensile strength of the unjointed concrete decreased with depth, but the strength across the joints did not change significantly with depth. The strength across the joints averaged 61 percent of the average strength of the unjointed concrete.

Direct tensile strength of the unjointed concrete averaged 215 lb/in^2 (1480 kPa) for the top third of the dam, 185 lb/in^2 (1280 kPa) for the middle third, and 170 lb/in^2 (1170 kPa) for the bottom third. Direct tensile strength of the jointed material averaged 120 lb/in^2 (830 kPa) for the top and middle thirds, and 110 lb/in^2 (760 kPa) for the bottom third.

For mass concrete, the direct tensile strength should be between 4 and 6 percent of the compressive strength. At Arrowrock Dam, the direct tensile strength of the unjointed concrete averaged 5.8 percent of the compressive strength.

Despite the marked segregation due to method of placement and consolidation, the direct tensile strength across the joints is normal for mass concrete. This is probably due to the exceptional joint preparation during construction.

Splitting Tensile Strength

The splitting tensile strength test results showed a loss of strength with depth. The top third of the dam averaged 470 lb/in^2 (3240 kPa), the middle third averaged 400 lb/in^2 (2760 kPa), and the bottom third averaged 350 lb/in^2 (2410 kPa).

Density

The densities, shown in tables 2, 3, and 4, vary little from sample to sample and are normal for mass concrete. The average density of the mass concrete is 150.6 lb/ft^3 (2412 kg/m^3).

BIBLIOGRAPHY

ASTM, *Annual Book of ASTM Standards, Concrete and Mineral Aggregates*, vol. 04.02, American Society for Testing and Materials, 1987.

Bureau of Reclamation, *Arrowrock Dam, Safety of Dam and Appurtenant Works*, Denver, Colorado, September 1980.

Bureau of Reclamation, *Properties of Mass Concrete in Bureau of Reclamation Dams*, Concrete Laboratory Report No. C-1009, Denver, Colorado, December 1961.

Dunstan, E. R., *Evaluation of Concrete Cores, Arrowrock Dam, Idaho*, Report No. GR-82-6, Bureau of Reclamation, Denver, Colorado, March 1982.

McMillan, F. R., "Memorandum of Core Tests, Arrowrock Dam," Bureau of Reclamation, November 24, 1931.

McMillan, F. R., and I. Lyse, "Arrowrock Dam Inspection of June 1957 and Comparison with Previous Inspections," Bureau of Reclamation, June 1957.

Paul, C. H., "The Arrowrock Dam," The Boston Society of Civil Engineers, Papers and Discussions, November 1915.

Russell, F. M., Memorandum to R. F. Blanks, Subject: "Corrections and Additions to ACI Report of Arrowrock Dam," Bureau of Reclamation, January 8, 1938.

Savage, J. L., "Special Cements for Mass Concrete," Bureau of Reclamation, Denver, Colorado, Second Congress of the International Commission on Large Dams, World Power Conference, Washington, D.C., 1936.

Table 1. - Arrowrock Dam drill hole locations.

Drill hole	Station	Coordinates		Elevation From ft	Elevation From m	Elevation To ft	Elevation To m
1	1+25	N 702,671.27	E 454,465.98	3156.9	962.2	3156.0	962.0
2	2+25	N 702,738.30	E 454,538.53	3216.0	980.2	3149.5	960.0
2A	2+30	N 702,741.98	E 454,541.08	3216.0	980.2	3138.7	956.7
3	5+05	N 702,982.14	E 454,663.79	3216.0	980.2	3140.8	957.3
4	7+30	N 703,201.82	E 454,685.17	3216.0	980.2	3139.8	957.0
5	10+05	N 703,460.74	E 454,612.46	3216.0	980.2	3140.9	957.3

Note: All drill holes were located about 4 to 5 feet (1 to 1.5 m) from the upstream parapet wall.

Table 2. - Compressive strength, Arrowrock Dam concrete cores.

Drill hole	Elevation (ft)	Density (lb/ft^3)	Compressive strength (lb/in^2)	Reclamation Modulus of elasticity ($lb/in^2 \times 10^6$)	Reclamation Poisson's ratio	ASTM Modulus of elasticity ($lb/in^2 \times 10^6$)	ASTM Poisson's ratio
2A	3207.0	152.0	3,490	5.68	0.26	5.49	0.26
	3199.4	147.5	3,830	3.86	0.22	3.71	0.22
	3193.3	155.0	3,480				
3	3206.2	153.0	3,660	3.63	0.19	3.33	0.19
	3199.1	148.7	2,850	2.60	0.15	2.58	0.16
	3193.4	152.0	2,860	3.03	0.24	3.02	0.24
4	3206.5	152.4	3,800	4.57	0.16	4.38	0.16
	3199.8	151.4	3,230				
	3193.0	152.3	3,680	4.55		4.38	
5	3206.3	150.8	3,870	3.95	0.19	3.87	0.19
	3199.2	152.3	3,270	4.73	0.25	4.50	0.26
	3193.7	153.7	3,580	3.96	0.10	3.81	0.14
Averages		151.8	3,470	4.06	0.19	3.91	0.20
2A	3184.0	148.5	3,520	3.17	0.12	3.01	0.12
	3176.0	152.2	2,860	4.44	0.19	4.31	0.20
	3166.7		3,710	4.23	0.17	4.02	0.17
3	3186.6	150.7	3,340	4.41	0.34	4.18	0.35
	3173.0	145.1	3,800	3.28	0.15	3.19	0.16
	3167.2		2,830	3.61	0.20	3.53	0.21
4	3185.4	149.0	4,190	3.78	0.21	3.53	0.21
	3171.4		2,960	3.78	0.21	3.65	0.21
	3164.6		2,420	3.86	0.23	3.80	0.24
5	3186.6	150.3	3,400	3.83		3.75	
	3176.4	148.6	3,360	3.39	0.17	3.29	0.17
	3166.0		4,270	4.08	0.13	3.85	0.13
Averages		149.2	3,390	3.82	0.19	3.68	0.20
2A	3160.7		3,620	4.54	0.18	4.31	0.18
	3148.1		3,650	3.39	0.16	3.17	0.16
	3140.6		3,210	4.01	0.21	3.86	0.21
3	3160.6		2,760	3.89	0.13	3.71	0.13
	3150.5		2,350	3.36	0.19	3.33	0.19
	3143.5		2,980	3.81	0.19	3.62	0.19
4	3158.9		3,200	4.58	0.24	4.37	0.24
	3151.1		3,410	4.46		4.20	
	3140.6		2,640	4.04	0.24	3.93	0.25
5	3159.8		2,580	4.10	0.24	3.99	0.25
	3150.2		3,210	4.29	0.33	4.03	0.34
	3142.5		2,530	3.01	0.15	2.97	0.15
Averages			3,010	3.96	0.21	3.79	0.21

Table 2A. - Compressive strength, Arrowrock Dam concrete cores (SI metric units).

Drill hole	Elevation (m)	Density (kg/m^3)	Compressive strength (MPa)	Reclamation		ASTM	
				Modulus of elasticity (GPa)	Poisson's ratio	Modulus of elasticity (GPa)	Poisson's ratio
2A	977.5	24 344	24.07	39.17	0.26	37.86	0.26
	975.2	23 624	26.41	26.62	0.22	25.59	0.22
	973.3	24 825	24.00				
3	977.2	24 504	25.24	25.03	0.19	22.97	0.19
	975.1	23 816	19.66	17.93	0.15	17.79	0.16
	973.3	24 336	19.72	20.90	0.24	20.83	0.24
4	977.3	24 408	26.21	31.52	0.16	30.21	0.16
	975.3	24 248	22.28				
	973.2	24 397	25.38	31.38		30.21	
5	977.3	24 147	26.69	27.24	0.19	26.69	0.19
	975.1	24 399	22.55	32.62	0.25	31.03	0.26
	973.4	24 621	24.69	27.31	0.10	26.28	0.14
Averages		24 310	23.9	28.0	0.19	26.9	0.20
2A	959.5	23 784	24.28	24.28	0.12	20.76	0.12
	968.0	24 376	19.72	30.62	0.19	29.72	0.20
	965.2		25.59	29.17	0.17	27.72	0.17
3	971.3	24 141	23.03	30.41	0.34	28.83	0.35
	967.1	23 239	26.21	22.62	0.15	22.00	0.16
	965.4		19.52	24.90	0.20	24.34	0.21
4	970.9	23 856	28.90	28.90	0.21	24.34	0.21
	966.6		20.41	26.07	0.21	25.17	0.21
	964.6		16.69	26.62	0.23	26.21	0.24
5	971.3	24 078	23.45	26.41		25.86	
	968.2	23 792	23.17	23.38	0.17	22.69	0.17
	965.0		29.45	28.14	0.13	26.55	0.13
Averages		23 900	23.4	26.4	0.19	25.4	0.20
2A	963.4		24.97	31.31	0.18	29.72	0.18
	959.5		25.17	23.38	0.16	21.86	0.16
	957.3		22.14	27.66	0.21	26.62	0.21
3	963.4		19.03	26.83	0.13	25.59	0.13
	960.1		16.21	23.17	0.19	22.97	0.19
	958.1		20.55	26.28	0.19	24.97	0.19
4	962.8		22.07	31.59	0.24	30.14	0.24
	960.5		23.52	30.76		28.97	
	957.3		18.21	27.86	0.24	27.10	0.25
5	963.1		17.79	28.28	0.24	27.52	0.25
	960.2		22.14	29.59	0.33	27.79	0.34
	957.8		17.45	20.76	0.15	20.48	0.15
Averages			20.8	27.3	0.21	26.1	0.21

Table 3. - Direct tensile strength, Arrowrock Dam concrete cores.

Drill hole	Elevation (ft)	Density (lb/ft^3)	No construction joint, strength (lb/in^2)	Construction joint, strength (lb/in^2)
2A	3195.6	151.9		50
	3194.3	151.5	145	
3	3204.4	154.5	225	
	3203.4	151.1		105
4	3204.4	153.9	260	
	3203.4	149.6		120
5	3204.9	152.7	225	
	3203.9	150.6		205
Averages		152.0	215	120
2A	3173.6	148.4	190	
	3172.7	145.9		100
3	3181.0	150.2		110
	3180.0	149.8	115	
	3176.4	149.4	160	
	3175.4	150.8		160
4	3181.6	151.4	230	
	3180.8	147.5		115
5	3180.8	146.9		105
	3179.9	159.8	225	
Averages		150.0	185	120
2A	3151.4	150.4	105	
	3150.4	150.1		95
3	3155.9	148.5		130
	3154.0	150.8	195	
5	3156.0	148.0		100
	3153.7	147.8	205	
Averages		149.3	170	110

Table 3A. - Direct tensile strength, Arrowrock Dam concrete cores (SI metric units).

Drill hole	Elevation (m)	Density (kg/m^3)	No construction joint, strength (kPa)	Construction joint, strength (kPa)
2A	963.0	24 328		345
	973.6	24 264	1000	
3	976.7	24 745	1552	
	976.4	24 200		724
4	976.7	24 649	1793	
	976.4	23 960		828
5	976.9	24 456	1552	
	976.5	24 120		1414
Averages		24 340	1470	830
2A	967.3	23 768	1310	
	967.0	23 367		690
3	969.6	24 056		759
	969.3	23 992	793	
	968.2	23 928	1103	
	967.9	24 152		1103
4	969.8	24 248	1586	
	969.5	23 624		793
5	969.5	23 528		724
	969.2	25 594	1552	
Averages		24 030	1270	810
2A	960.5	24 088	274	
	960.2	24 040		655
3	961.9	23 784		897
	961.3	24 152	1345	
5	961.9	23 704		690
	961.2	23 672	1414	
Averages		23 910	1010	750

Table 4. - Splitting tensile strength, Arrowrock Dam concrete cores.

Drill hole	Elevation (ft)	Density (lb/ft^3)	Strength (lb/in^2)
2A	3208.0	149.6	430
	3200.4	152.1	490
	3192.3	156.9	570
3	3207.2	153.2	470
	3200.4	150.9	505
	3192.4	154.8	560
4	3207.5	154.0	500
	3200.8	151.3	420
	3192.0	144.9	390
5	3207.3	152.4	410
	3197.9	149.7	470
	3192.7	150.7	420
Averages		151.7	470
2A	3183.0	148.0	350
	3177.0	149.1	420
	3165.7	152.8	410
3	3184.1	148.7	380
	3174.0	150.5	400
	3166.2	148.6	385
4	3184.4	150.8	450
	3169.0	152.0	360
	3165.6	149.7	410
5	3185.6	148.7	395
	3175.1	148.5	390
	3167.0	151.9	410
Averages		149.9	400
2A	3159.7	152.1	400
	3146.2	150.1	330
	3141.6	148.3	350
3	3159.6	153.5	330
	3148.9	150.6	350
	3145.5	149.6	345
4	3157.9	148.9	330
	3149.8	149.1	430
	3142.3	153.8	350
5	3158.8	149.4	330
	3149.2	149.6	380
	3143.5	148.7	310
Averages		150.3	355

Table 4A. - Splitting tensile strength, Arrowrock Dam concrete cores (SI metric units).

Drill hole	Elevation (m)	Density (kg/m³)	Strength (kPa)
2A	977.8	23 960	2966
	975.5	24 352	3379
	973.0	25 129	3931
3	977.6	24 529	3241
	975.5	24 165	3483
	973.0	24 793	3862
4	977.6	24 665	3448
	975.6	24 237	2897
	972.9	23 207	2690
5	977.6	24 408	2828
	974.7	23 979	3241
	973.1	24 136	2897
Averages		24 300	3240
2A	970.2	23 697	2414
	968.3	23 872	2897
	964.9	24 466	2828
3	970.5	23 811	2621
	967.4	24 110	2759
	965.1	23 803	2655
4	970.6	24 147	3103
	965.9	24 346	2483
	964.9	23 979	2828
5	971.0	23 822	2724
	967.8	23 784	2690
	965.3	24 328	2828
Averages		24 010	2740
2A	963.1	24 356	2759
	959.0	24 032	2276
	957.6	23 747	2414
3	963.0	24 591	2276
	959.8	24 118	2414
	958.7	23 958	2379
4	962.5	23 851	2276
	960.1	23 873	2966
	957.8	24 629	2414
5	962.8	23 926	2276
	959.9	23 955	2621
	958.1	23 817	2138
Averages		24 070	2430

Table 5. - Comparison of compressive strength, Arrowrock Dam concrete cores.

1914: 6-inch (152-mm) cube strengths

	28 days		90 days		180 days	
	lb/in^2	MPa	lb/in^2	MPa	lb/in^2	MPa
Interior	1,010	6.97	1,310	9.03	1,530	10.55
Exterior	1,370	9.45	1,810	12.48	1,980	13.66

1930 core test: 4-3/4-inch (121-mm) diameter cores
(McMillan, 1931)

Average compressive strength = 1,990 lb/in^2 (13.72 MPa)

1982 and 1987: 6-inch-diameter core tests
(Dunstan, 1982)

		Compressive strength		Modulus of elasticity		Poisson's ratio	Density	
		lb/in^2	MPa	lb/in^2 x 10^6	GPa		lb/ft^3	kg/m^3
1982	Dry	2,090	14.41	1.62	11.17	0.39	142	22.7
	Wet	1,250	8.62	0.93	6.41	0.19	144	23.0
1987	Moist	3,290	22.7	3.95	27.2	0.20	151	24.2

DRAWING NO. 2

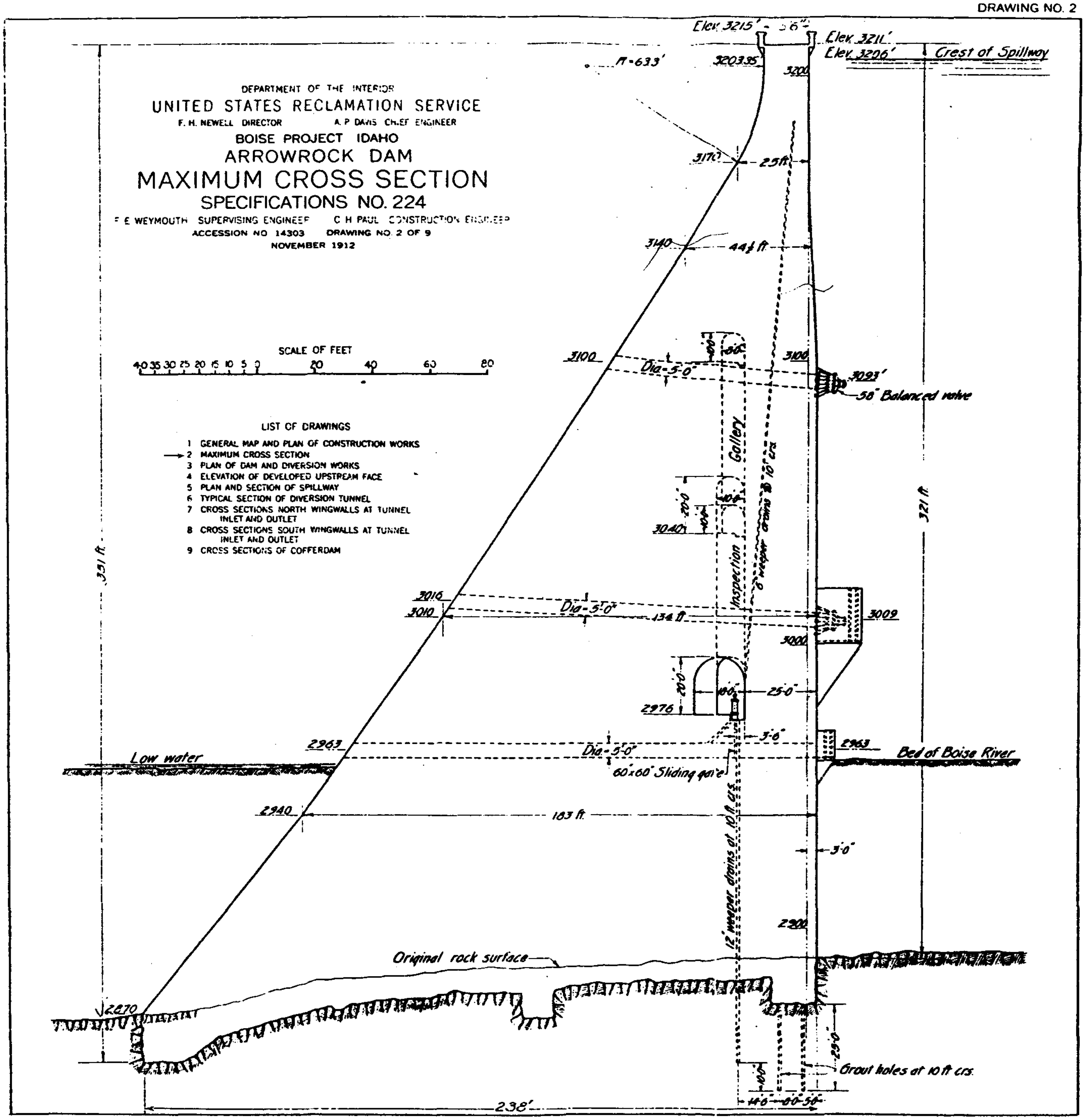

Figure 1. - Arrowrock Dam, maximum cross section.

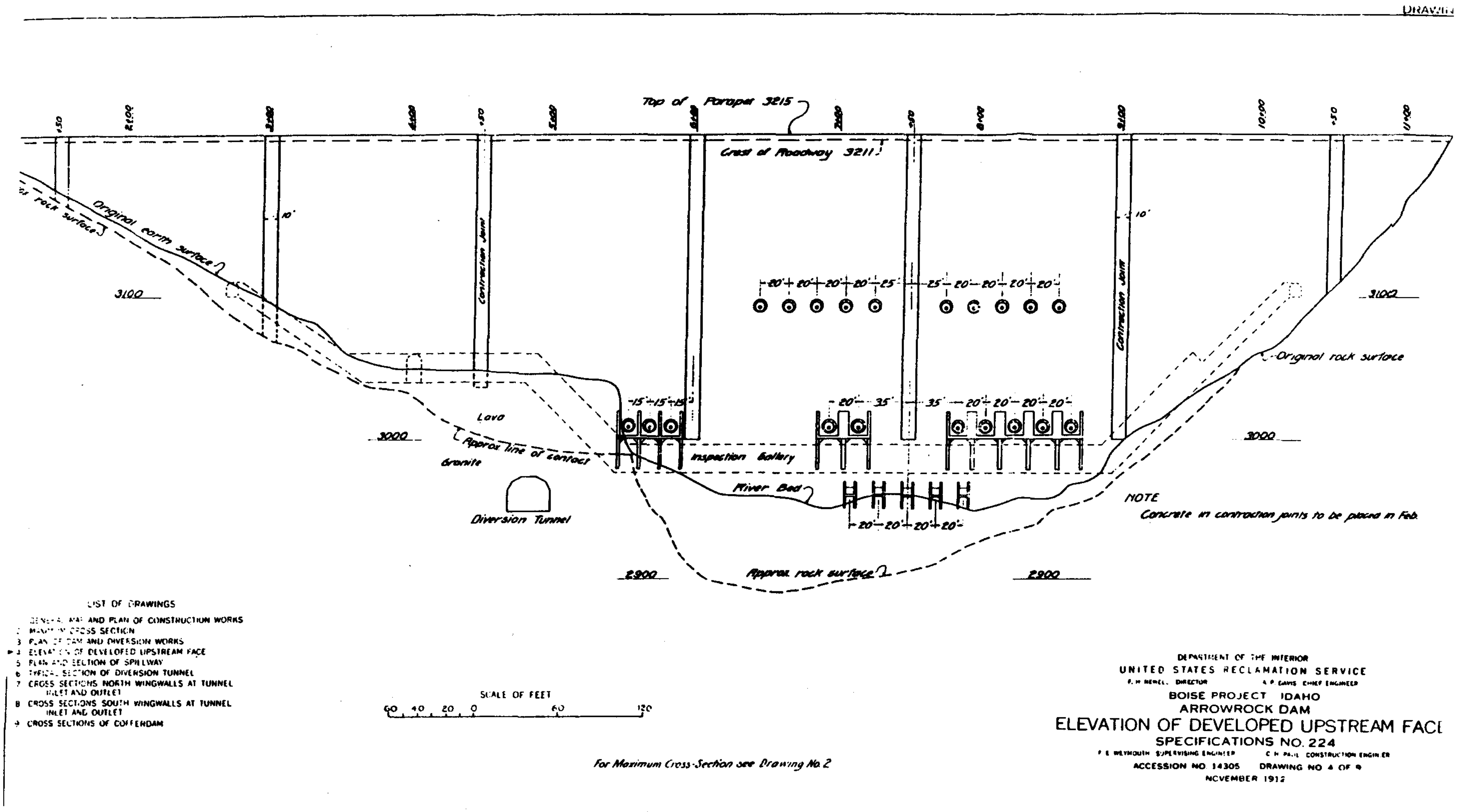

Figure 2. - Arrowrock Dam, elevation of developed upstream face.

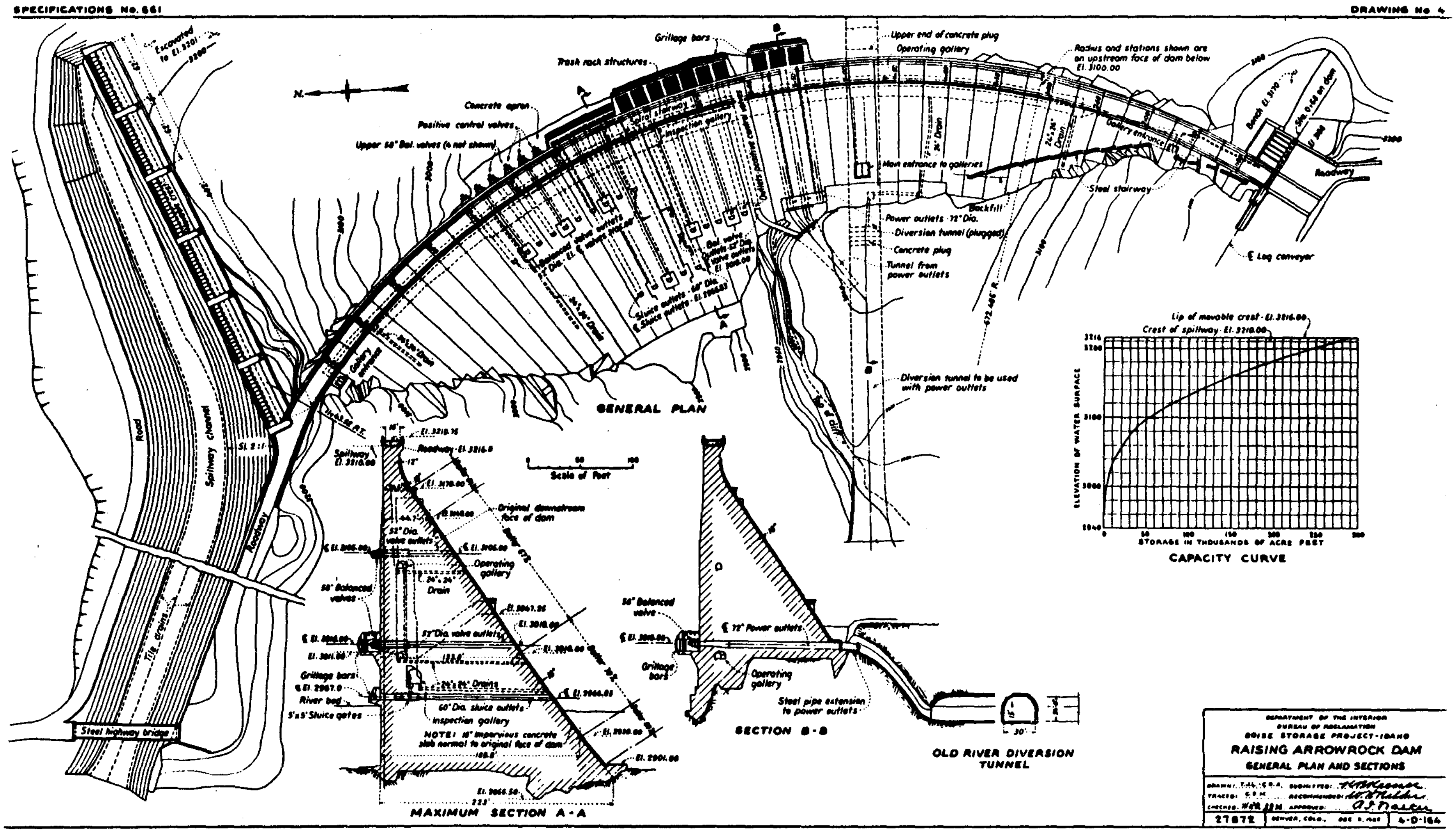

Figure 3. - Raising Arrowrock Dam, general plan and sections.

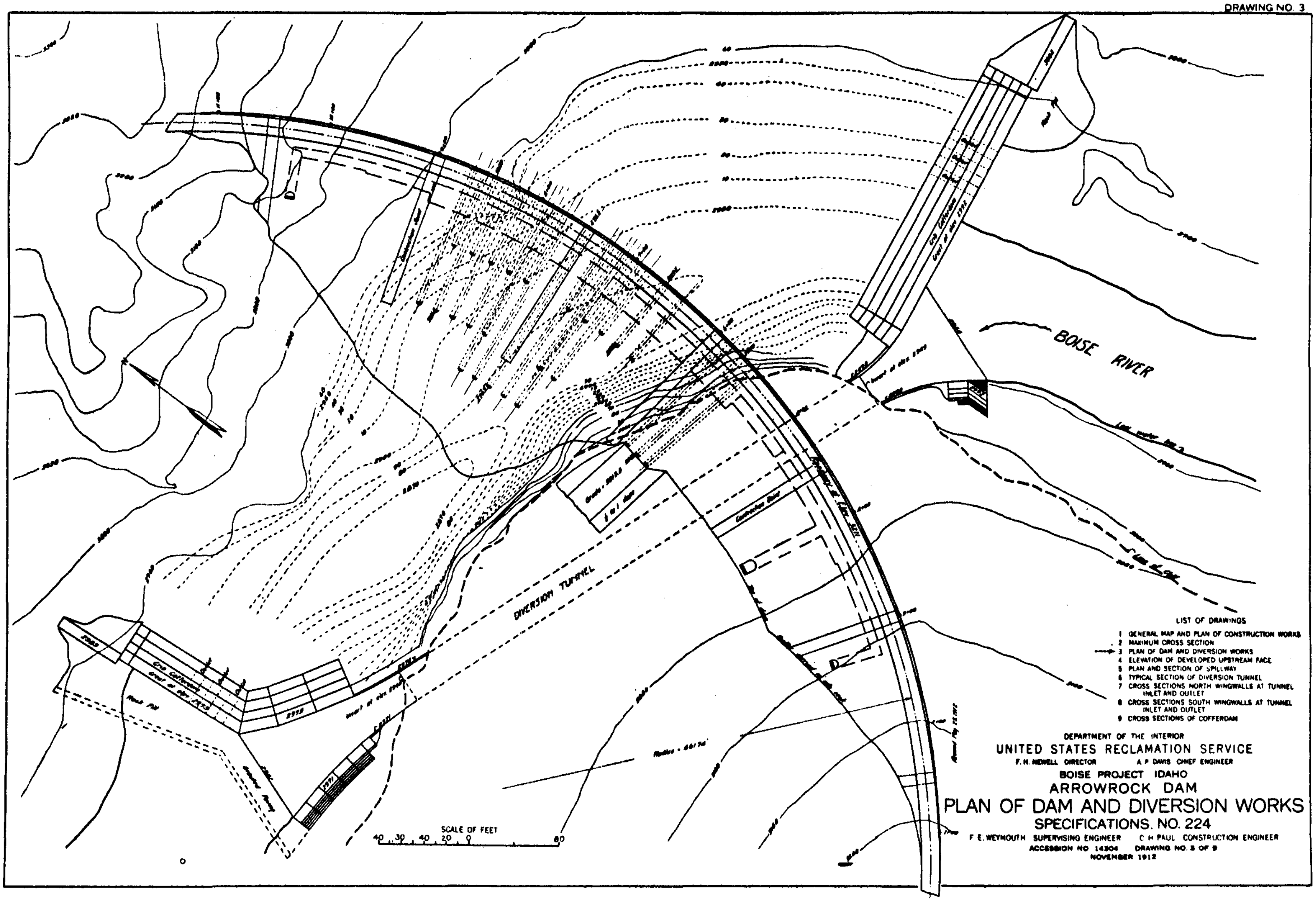

Figure 4. - Arrowrock Dam, plan of dam and diversion works.

APPENDIX

Petrographic examination

MS-884 (10-85)
Bureau of Reclamation

UNITED STATES GOVERNMENT

memorandum

Denver, Colorado
DATE: January 15, 1988

TO : Memorandum
Chief, Concrete and Structural Branch
Attention: W. F. Kepler

FROM : Head, Chemistry, Petrography, and Chemical Engineering Section

SUBJECT: Petrographic and Afterbreak Examinations of Selected Concrete Core Physical Properties Test Specimens - Arrowrock Dam - Boise Project, Idaho

Examined by: J. N. Hartwell

Petrographic referral code: 88-2

INTRODUCTION

A visual examination of 6-inch-diameter concrete core physical properties test specimens from Arrowrock Dam, Idaho, was performed in the Concrete Laboratory to select representative tested specimens for further examination in the Petrographic Laboratory. The specimens were visually selected from each drill hole as representative of lower and higher uniaxial compressive strength, splitting tensile strength, and direct tensile strength specimens tested to failure by the Concrete Section. The purposes of the examinations were to perform a complete petrographic analysis to determine the quality of the concrete and any types of deterioration and to perform an afterbreak examination of the selected physical properties test specimens.

PETROGRAPHIC EXAMINATION

The selected representative physical properties test specimens were examined megascopically, microscopically in thin section and polished surfaces, by X-ray diffraction, and by some qualitative physical and chemical techniques. A detailed "Petrographic Examination of Concrete" sheet is attached which includes visual observations and petrographic descriptions of aggregate, paste, voids, secondary and hydration products, fractures, and lift lines/construction joints. The examined representative lower and higher strength physical properties test specimens from drill holes DH-2A, -3, -4, and -5 were petrographically similar and, therefore, described together.

AFTERBREAK EXAMINATION AND RESULTS

The petrographic afterbreak examination consisted of visual and binocular microscope examinations of eight uniaxial compressive strength, eight splitting tensile strength, and nine direct tensile strength specimens tested to failure by the Concrete Section. The examination was performed to determine any apparent physical and/or structural features influencing the strengths of the selected representative lower and higher strength physical properties test specimens. The uniaxial compressive strengths for all the tested specimens ranged from about 2,350 to 4,270 lb/in^2, the splitting tensile strengths for all the tested specimens ranged from about 310 to 570 lb/in^2, and the direct tensile strengths for all the tested specimens ranged from about 50 to 260 lb/in^2.

The examined lower strength uniaxial compressive strength test specimens failed chiefly through the paste and around the aggregate and generally only occasionally through few aggregate. The examined higher strength specimens failed through the paste and generally around the aggregate and through few to occasionally somewhat numerous aggregate particles.

The examined lower strength splitting tensile strength test specimens failed chiefly through the paste and around the aggregate and generally only very occasionally through few aggregate. The examined higher strength specimens failed through the paste and generally through the aggregate and around only few to occasionally somewhat numerous aggregate particles.

The examined lower strength direct tensile strength test specimens failed through the paste and separated chiefly around the aggregate and/or within the poorly to moderately consolidated areas of the apparent lift lines/construction joints. The examined higher strength specimens generally failed through the paste and separated chiefly around and occasionally through few aggregate particles. It should be noted that examined higher strength specimen No. DH-3, 40.6 feet, which was the only examined higher strength specimen tested at a lift line/construction joint, failed through the paste and separated at the lift line/construction joint and around few aggregate particles. Several of the examined lower strength direct tensile strength test specimens exhibited a discontinuous layer of woody organic material which resembled sawdust and/or exhibited an irregular, globular shaped, apparent grout course or layer between the successive concrete placements of the lift lines/construction joints.

The strengths of the examined lower and higher strength physical properties test specimens were generally controlled by the poor paste-aggregate bond.

CONCLUSIONS

The examined concrete core from Arrowrock Dam, Idaho, is petrographically of fair physical quality primarily due to the poor to fair paste-aggregate bond and is considered chemically innocuous except for a few isolated areas of silica gel apparently associated with opal-coated basalt particles.

The examined concrete contains physically fair to satisfactory and apparently chemically innocuous aggregate. The paste is generally moderately consolidated and well distributed with aggregate, hard to moderately hard, generally poorly to moderately consolidated near lift lines/construction joints, and slightly to moderately absorptive and exhibits a poor to fair paste-aggregate bond. The examined concrete appears normally hydrated and contains no entrained air voids but somewhat numerous entrapped air voids as well as several to somewhat numerous water and channel voids and only few microfractures. Trace to minor amounts of silica gel are occasionally concentrated near some basalt particles and in microfractures.

There is no evidence for adverse climatic effects or chemical attack, although water-soluble chloride and sulfate ions were chemically detected. Alkali-aggregate reaction was observed sporadically throughout the concrete apparently associated with opal-coated basalt particles. No opal coatings were observed on the basalt particles; however, it appears that opal reacted with alkalis in the the cement very early in the life of the concrete. Therefore, no prolonged or continuing deleterious effects due to alkali-aggregate reactions involving opal-coated particles are expected in the examined concrete.

Loretta A. Haugseth (Acting)

Attachment

Copy to: D-220
D-825
D-1511 (Kepler)
D-1523B
D-3300
(with attachment to each)

PETROGRAPHIC EXAMINATION OF CONCRETE

Subject:	Arrowrock Dam Boise Project, Idaho	Thin Sections No. P-11,803 to P-11,806 Concrete cores No. DH-2A, -3, -4, and -5

Visual observations

Twenty-five about 6-inch-diameter concrete core physical properties test specimens; generally very light gray to yellowish gray paste; moderately hard to hard; slightly to moderately absorptive; generally moderately consolidated; generally poor to fair paste-aggregate bond; somewhat numerous entrapped air, water, and channel voids; minor to occasionally moderate amounts of secondary products; very few pretest fractures

Petrographic examination

Aggregate

Gravel: Generally subrounded to rounded in shape with somewhat numerous subangular to angular as well as flat and/or elongated particles; chiefly granite series, altered andesite, and basalt with lesser to minor amounts of schist, gneiss, and altered volcanic particles as well as occasional wood fragments and mud/clay balls, may include few glassy volcanic particles

Sand: Generally subangular to angular in shape with somewhat numerous subrounded to rounded particles; includes same rock types found in gravel as well as monomineralic grains of quartz, feldspar, magnetite, amphibole, and mica with a few, miscellaneous accessory minerals

Gravel and sand: Appears petrographically of fair to satisfactory physical quality and apparently not deleteriously reactive with high-alkali cement; very few to occasional silica-gel exudations observed on/near gravel-size basalt particles

Paste

Generally very light gray to yellowish gray; generally moderately consolidated and well distributed with aggregate; generally poorly to moderately consolidated near lift lines/construction joints; poor to fair paste-aggregate bond; slightly to moderately absorptive; generally only slightly to occasionally moderately effervescent with dilute hydrochloric acid; hard to moderately hard, breaks with moderate to heavy hammer blows chiefly through paste and only very occasionally through aggregate

Voids

Somewhat numerous, generally irregularly shaped, sized, and distributed entrapped air voids as well as several to somewhat numerous water and channel voids; several areas near lift lines/construction joints exhibit large void spaces; most voids exhibit individual crystals, tufts of crystals, and/or coatings of secondary deposits

Secondary deposits

Minor amounts of ettringite and calcite in paste and as individual crystals, tufts of crystals, and/or coatings in voids and on rock sockets; trace to minor amounts of silica gel occasionally concentrated near some basalt particles; trace amounts of gypsum in paste; no silica gel developed on fragments soaked 10 days in deionized water; water-soluble sulfate and chloride ions chemically detected

Hydration products

Calcium silicates, portland cement hydration products, and water of hydration appear normal; no unhydrated portland cement particles observed; generally none to occasional traces of portlandite observed in paste; minor amounts of ettringite in paste

Fractures

Only few microfractures observed in thin sections and polished sections; most lined to filled with trace to minor amounts of calcite, ettringite, silica gel, portlandite ?, and/or gypsum; most occur adjacent to and/or at paste-aggregate interface and very occasionally in paste near some basalt particles

Lift lines/construction joints

Generally poorly to moderately consolidated; numerous, large, entrapped air voids; several exhibit a discontinuous layer of woody organic material resembling sawdust; several exhibit an intermittent, irregularly globular shaped, apparent grout course or layer