CONCRETE PERFORMANCE IN YELLOWTAIL DAM, MONTANA 10-YEAR CORE REPORT

Concrete and Structural Branch
Division of General Research
Engineering and Research Center
Bureau of Reclamation

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16. ABSTRACT

Ten-inch (25-cm) diameter concrete cores were extracted from mass concrete in Yellowtail Dam, Montana, 6 months, 1 year, 5 years, and 10 years after the concrete was placed. These cores were tested to determine physical properties of the concrete and to monitor changes in such properties with age. Test results indicate a good quality, well consolidated, durable concrete. Average compressive strength at 10 years' age was 5,010 lb/in^2 (34.5 MPa) for typical interior concrete and 5,000 lb/in^2 (34.5 MPa) for exterior concrete. Average moduli of elasticity at 10 years' age of interior and exterior concretes were 6.35 x 10^6 lb/in^2 and 6.29 x 10^6 lb/in^2 (4.38 x 10^4 MPa and 4.34 x 10^4 MPa) respectively. Average tensile strengths of the interior and exterior concretes at 10 years' age were 256 lb/in^2 and 268 lb/in^2 (1.76 MPa and 1.85 MPa) respectively.

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Concrete and Structural Branch
Division of General Research
Engineering and Research Center
Denver, Colorado
July 1975

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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INTRODUCTION

Yellowtail Dam is a concrete arch structure approximately 520 feet (158 meters) high and 1,450 feet (442 meters) long at the crest. It is on the Bighorn River about 45 miles (72 kilometers) southwest of Hardin, Montana, within the Crow Indian Reservation in Bighorn County, Montana. Mass concrete was placed in the dam during 1963, 1964, and 1965. Construction specifications No. DC-5525 provided for the extraction of 10-inch (25-cm) diameter concrete cores for testing at 6 months' age to determine various physical properties of the concrete. Cores were also extracted at 1, 5, and 10 years' ages to determine the change of such properties with age. This report presents test results documenting the development of the compressive strength, modulus of elasticity, and Poisson's ratio of the concrete during the first 10 years after construction of the dam. Also presented are results of tensile-strength tests performed on five core specimens extracted at 10 years' age.

Report No. C-1321 [1]* contains results of tests performed on concrete cores extracted from Yellowtail Dam at 6 months', 1 year's, and 5 years' age. Included in that report are data and conclusions from a construction joint investigation conducted during construction of the dam to

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* Numbers in brackets designate references listed at end of this report.

evaluate the wet sandblast and water-jet methods of construction joint cleanup.

Core specimens are available for possible later testing to determine shear strength and dynamic tensile strength. Dynamic tension test results will be presented in a separate Bureau of Reclamation report tentatively entitled "Dynamic Properties of Concrete Under Alternating Tensile and Compressive Loadings."

Cores are tentatively scheduled to be extracted and tested when the concrete in Yellowtail Dam reaches 20 years' age to further evaluate its physical properties. This study is part of a series of Bureau of Reclamation longtime evaluations of concrete in various dams.

CONCLUSIONS

Based on the results of tests conducted in this investigation and described herein, the following conclusions are made:

1. The overall quality and properties of the concrete in the cores from Yellowtail Dam are indicative of a well-designed, properly placed and cured, durable concrete expected to have a long service life.

2. The compressive strength of concrete in Yellowtail Dam increased normally to 10 years' age.

3. Concrete in the vertically drilled cores exhibited higher compressive strength than that of the concrete in the horizontally drilled cores as might have been expected, based on previous test results.

4. The tensile strength of the concrete in Yellowtail Dam at 10 years' age is about average compared with other Bureau of Reclamation mass concrete.

5. Development of the elastic properties of the Yellowtail Dam concrete to 10 years' age appeared to follow normally expected increasing trends.

SUMMARY OF PHYSICAL PROPERTIES OF 6-INCH MSA[1]

MASS CONCRETE IN YELLOWTAIL DAM

(Detailed data are contained in tables 1 through 9 and figures 2 through 5)

Compressive strengths (averages):

	Interior concrete[2]	Exterior concrete
6 months' age	3,800 lb/in^2 (26.2 MPa)	4,170 lb/in^2 (28.8 MPa)
1 year's age	3,770 lb/in^2 (26.0 MPa)	4,290 lb/in^2 (29.6 MPa)
5 years' age	5,180 lb/in^2 (35.7 MPa)	5,120 lb/in^2 (35.3 MPa)
10 years' age	5,010 lb/in^2 (34.5 MPa)	5,000 lb/in^2 (34.5 MPa)

Moduli of elasticity (averages):

	Interior concrete[2]	Exterior concrete
6 months' age	5.14×10^6 lb/in^2 (3.54×10^4 MPa)	5.37×10^6 lb/in^2 (3.70×10^4 MPa)
1 year's age	5.46×10^6 lb/in^2 (3.76×10^4 MPa)	5.32×10^6 lb/in^2 (3.67×10^4 MPa)
5 years' age	5.62×10^6 lb/in^2 (3.87×10^4 MPa)	5.75×10^6 lb/in^2 (3.96×10^4 MPa)
10 years' age	6.35×10^6 lb/in^2 (4.38×10^4 MPa)	6.29×10^6 lb/in^2 (4.34×10^4 MPa)

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[1] Maximum-size aggregate.
[2] Does not include specimens from interior concrete placed before July 1963, which contained concrete with atypically high cement content.

Poisson's ratio (averages):

	Interior concrete[2]	Exterior concrete
6 months' age	0.21	0.22
1 year's age	0.23	0.23
5 years' age	0.21	0.22
10 years' age	0.27	0.24

Tensile strengths (static loading - average):

	Interior concrete[3]	Exterior concrete
10 years' age	256 lb/in^2 (1.76 MPa)	268 lb/in^2 (1.85 MPa)

CONCRETE CONSTRUCTION MATERIALS AND MIX DESIGN

Concrete placed in Yellowtail Dam contains type II, low-alkali cement; fly ash; and 6-inch (15-cm) maximum-size aggregate. A neutralized vinsol-resin air-entraining agent was used to entrain 3 percent air by volume of concrete. One percent calcium chloride, by weight of cement, was added to the mix water as a set accelerator during cold weather concrete placements. No water-reducing, set-controlling admixtures were used in mass concrete in Yellowtail Dam.

Concrete aggregate was processed from material in the J. J. Sullivan pit, a stream deposit on the bank of the Bighorn River 2 miles (3 kilometers) downstream from the damsite. The coarse aggregate obtained from

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[2] Loc. cit.
[3] Includes only one interior specimen.

this deposit was good quality, dense, subrounded aggregate. The sand was good quality, dense, subangular to angular material. The aggregate was classified as potentially alkali-reactive.

Exterior mass concrete was designed to have a water/[cement + fly ash] ratio no greater than 0.53 by weight. Interior mass concrete had a water/[cement + fly ash] ratio no greater than 0.60. Twenty-five percent fly ash, by weight of total cementious material (cement + fly ash), was used in exterior mass concrete, and 30 percent fly ash was used in interior mass concrete. Design strength for exterior mass concrete was 3,000 lb/in^2 (20.7 MPa) at 28 days' age; design strength for interior mass concrete was 3,000 lb/in^2 at 180 days' age.

The initial mix design for interior concrete required cement plus pozzolan quantities in excess of 330 pounds per cubic yard (196 kg/m^3) of concrete. However, it was determined after the earliest concrete placements that the quantity of cement plus pozzolan was excessive, and during July 1963, the design quantity was decreased to less than 270 pounds per cubic yard (160 kg/m^3).

The mix design for exterior concrete was also adjusted during the early construction period. However, the adjustment reduced the cement plus pozzolan content only 27 lb/yd^3 (16 kg/m^3), from 357 lb/yd^3 to 330 lb/yd^3 (212 kg/m^3 to 196 kg/m^3).

EXTRACTING AND SHIPPING CONCRETE CORES

ASTM (American Society for Testing and Materials) Designation C 42-68 specifies that the diameter of concrete cores extracted for compressive strength testing should be three times as large, and must be at least two times as large, as the maximum aggregate size. Since mass concrete in Yellowtail Dam contains 6-inch maximum-size aggregate, by ASTM standards, cores should have had a diameter of 18 inches (46 cm) or a minimum diameter of at least 12 inches (30 cm). The Bureau chose to extract 10-inch cores for the following reasons:

1. The cost of core extraction increases significantly as the diameter of the core increases. The smaller 10-inch core size was chosen to permit more specimens to be extracted with the funds available, thereby minimizing the combined inaccuracies caused by minimal core diameter and minimal number of core specimens tested.

2. Cores are often extracted from relatively small access adits in the interior of the dam where there may be insufficient space for the larger equipment required for drilling larger concrete cores.

Ten-year cores were extracted with 9-5/8-inch (24.5-cm) inside diameter bits advancing at a rate of about 32 inches (81 cm) per hour.

MAR - 8

Cores extracted for earlier testing were extracted with 10-inch (25.4-cm) inside diameter bits advancing at a rate of 36 inches (91 cm) per hour. Each core was extracted in two to five sections. After extraction, the cores were wrapped with a layer of heavy paper and packed in wooden crates with damp sawdust. These were then shipped to the Division of General Research in Denver, Colorado, for testing.

Twenty-five 10-inch (25.4-cm) diameter cores were extracted from Yellowtail Dam for testing at 6 months' age, 24 cores for testing at 1 year's age, 5 cores for testing at 5 years' age, and 6 cores for testing at 10 years' age. Forty-six cores were extracted from interior concrete adjacent to galleries and adits within the dam, and 14 cores were extracted from exterior concrete near the downstream face of the dam. Twenty-six interior concrete cores were drilled vertically, and 20 were drilled horizontally. Five exterior concrete cores were drilled vertically, and nine were drilled horizontally. (See fig. 1 for drilling locations.)

SPECIMEN PREPARATION

After the cores arrived at the Engineering and Research Center, Denver, Colorado, they were unpacked and inspected. All cores

arrived in a damp condition, and no shipping damage was evident. Two of the sixty cores contained rock pockets apparently due to inadequate consolidation during placement of the concrete. Cores were logged to record specimen locations, presence of construction joints, and unusual characteristics such as embedded reinforcing steel, rock pockets, and discoloration possibly caused by deleterious chemical reaction in the aggregates. All cores were photographed individually or in groups to provide a future visual reference shown in figure 6. Specimens to be used for elastic properties and compressive strength tests were sawed to 20-inch (51-cm) lengths, to conform to the standard ℓ/d (length/diameter) ratio of 2.0. The ends of the specimens were ground flat to provide a good bearing surface for testing in compression. Specimens for testing in tension (10-year cores only) were sawed to 30-inch (76-cm) lengths, after which 2-inch (5-cm) thick steel plates were cemented with epoxy to each end of each specimen. After sawing and grinding and prior to testing, all specimens except those extracted at 10 years' age were stored in a 100 percent relative humidity and 73° F (23° C) controlled atmosphere. Ten-year specimens were stored in a 50 percent relative humidity and 73° F controlled atmosphere for several weeks during the testing process.

Two of the 10-year cores were drilled vertically through horizontal construction joints so that the quality of the bond at the construction joints could be evaluated. However, the concrete adjacent to

the construction joint in one of the cores was poorly consolidated, and the other core was broken at the construction joint during handling and prior to testing.

The apparent specific gravity of each specimen to be tested in compression was determined prior to the strength and elastic properties testing. Unit weights of the specimens were computed and recorded. The approved method for determining specific gravity as found in chapter 3, paragraphs 3.17 through 3.22 of the Bureau of Reclamation Material Laboratories Procedures Manual was used, except that the specimens were not ovendried. The weights of the specimens at the time the specific gravity determinations were begun were used in place of the ovendried weights to compute the specific gravities. Ovendried weights of the specimens were not obtained because of concern that the specified 225° F (107° C) drying temperature could have some effect upon the physical behavior of the concrete during the subsequent testing process.

TESTING OF SPECIMENS

Elastic behavior of the 10- by 20-inch (25.4- by 50.8-cm) specimens were monitored with an extensometer-compressometer frame with dial deflection gages mounted in such a way that longitudinal and lateral deformations could be measured as axial load was applied. Each specimen was

preloaded to an axial compressive stress of about 1,070 lb/in^2 (7.38 MPa). Then the load was released and reapplied. As the specimen was loaded the second time, axial and lateral deflections were read and recorded at 0, 107, and 1,070 lb/in^2 loads. The modulus of elasticity and Poisson's ratio were computed on the basis of the net strain between the 107 and 1,070 lb/in^2 loads.

After being tested for elastic properties, compression test specimens were loaded axially at a rate of 2,000 lb/in^2 (13.8 MPa) per minute until obvious failure occurred. The maximum load was recorded. Several specimens were loaded after failure until breakdown of the specimen allowed thorough visual inspection of the failure pattern.

Steel plates, 2-inch-thick, were attached with epoxy to both ends of each tensile specimen to provide a means of applying a tensile load. Tension test specimens were loaded axially at a rate of 200 lb/in^2 per minute until failure occurred. The maximum load was recorded. One specimen failed at the epoxy-specimen interface and was retested after the plate was attached with epoxy a second time.

TEST RESULTS

Concrete placement data and core test results are listed in tables 1-7. Summaries of compressive strengths, moduli of elasticity, and Poisson's

ratios are found in tables 8-9. Comparative data found in tables 8-9 includes only data from tests of specimens containing 6-inch maximum size aggregate.

As very few specimens were tested for each elastic property at 5 years' and 10 years' ages, any apparent changes in physical properties, especially at 10 years' age, are of little statistical significance. Twenty-year tests will perhaps confirm the 10-year results.

Compressive Strength

Average compressive strengths of the concrete cores increased during the first 10 years after placement of the concrete in Yellowtail Dam, figures 2 and 3. Cores extracted horizontally from typical interior concrete (excluding interior concrete with atypically high cement plus pozzolan content) increased in compressive strength 16 percent from 6 months' age (3,660 lb/in^2 [25.2 MPa]) to 10 years' age (4,240 lb/in^2 [29.2 MPa]); cores extracted horizontally from typical exterior concrete increased in compressive strength 15 percent (4,330 to 5,000 lb/in^2 [29.9 to 34.5 MPa]) during the same period. Interior concrete specimens exhibited higher average strength at all ages in vertically drilled cores than in horizontally drilled cores. The average compressive strength, 3,660 lb/in^2 (25.2 MPa) at 6 months' age, of the interior, horizontally drilled cores, was adequate to

ensure (with 85 percent degree of confidence) that the design strength of 3,000 lb/in^2 [20.7 MPa] at 6 months' age was achieved. The coefficient of variation for compressive strengths of cores extracted horizontally from interior concrete at 6 months' age was 12 percent.

Modulus of Elasticity and Poisson's Ratio

Test results indicate that the average modulus of elasticity and Poisson's ratio of concrete in Yellowtail Dam changed very little during the first 5 years of testing. However, both the modulus of elasticity and Poisson's ratio are showing higher values at 10 years' age. From 5 to 10 years' ages, the average modulus of elasticity of the interior concrete apparently increased from 5.6×10^6 to 6.4×10^6 lb/in^2 (3.9×10^4 MPa to 4.4×10^4 MPa), and the average Poisson's ratio increased from 0.21 to 0.27. Figures 4 and 5 show the development of the modulus of elasticity over 10 years' time.

The modulus of elasticity and Poisson's ratio of the concrete did not exhibit dependence upon the direction of drilling as did the compressive strength of the specimens. The moduli of elasticity and Poisson's ratios of the core specimens tested are normal for good quality Bureau of Reclamation mass concrete.

Tensile Strength

The average tensile strength, 270 lb/in^2 (1.9 MPa), of specimens tested at 10 years' age is about 5 percent of the average compressive strength of 10-year specimens and is normal for Bureau of Reclamation mass concrete.

REFERENCE

1. Graham, James R., "Concrete Performance in Yellowtail Dam, Montana: 5-Year Core Report," USBR Laboratory Report No. C-1321, October 1969.

Table 1

CONCRETE CORE TEST RESULTS
Yellowtail Dam
6" MSA Interior Concrete - 6 Months' Age

1/ Core No.	Elevation above sea level	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Concrete	Temperatures °F: Air Maximum	Temperatures °F: Air Minimum	Properties of concrete when placed: W/c+P by wt	Cement content lb/yd³	Pozzolan content lb/yd³	Water content lb/yd³	2/ Sand, percent	Unit weight fresh concrete lb/ft³	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	Specific gravity	Unit weight lb/ft³	Remarks
5-3-1-H	3466.5	8-13-64	11-30-64	2- 9-65	57	90	61	0.53	190	81	142	24	152.2	1,360	2,160	-	4,000	5.36	0.21	2.44	152.0	
5-3-2-H	3466.5	8-13-64	11-30-64	2- 9-65	57	90	61	.53	190	81	142	24	152.2	1,360	2,160	-	2,830	5.08	.17	2.41	150.1	
5-4-1-V	3462.5	7-31-64	12- 1-64	1-27-65	54	95	57	.60	184	80	159	23	150.5	1,520	2,650	-	3,640	4.89	.24	2.34	145.8	Top 18" is 1-1/2" MSA
5-4-2-V		7-31-64	12- 1-64	1-27-65	54	95	57	.60	184	80	159	23	150.5	1,520	2,650	-	2,960	4.62	.21	2.45	152.6	concrete
9-1-1-H	3465.7	7-25-64	11-30-64	1-21-65	53	89	50	.56	186	79	149	22	150.4	2,050	3,620	-	4,570	5.74	.19	2.48	154.5	
9-1-2-H	3465.7	7-25-64	11-30-64	1-21-65	53	89	50	.56	186	79	149	22	150.4	2,050	3,620	-	3,680	5.33	.24	2.47	153.9	
9-2-1-V	3462.5	7-17-64	11-30-64	1-13-65	56	91	61	.57	188	83	154	23	151.2	2,410	4,000	-	3,250	4.42	.20	2.55	158.9	Top 12" is 3" MSA concrete
9-2-2-V		7-17-64	11-30-64	1-13-65	56	91	61	.57	188	83	154	23	151.2	2,410	4,000	-	3,300	4.72	.23	2.41	150.1	
10-1-1-H	3210.5	7-16-63	11-20-63	1-16-64	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	3,450	-	-	2.44	152.0	
10-1-2-H	3210.5	7-16-63	11-20-63	1-16-64	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	-	-	-	-	-	Tension specimen
10-1-3-H	3210.5	7-16-63	11-20-63	1-16-64	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	3,780	5.49	.23	2.43	151.4	
10-2-1-V	3207.5	7- 9-63	11-21-63	1- 9-64	-	90	67	.51	420	0	216	31	-	-	-	-	4,310	5.30	.23	2.41	150.1	1-1/2" MSA concrete
10-2-2-V	3205.0	7- 9-63	11-21-63	1- 9-64	60	90	67	.52	186	89	143	23	152.7	2,280	3,800	-	3,890	5.05	.18	2.47	153.9	
14-1-1-H	3465.7	8-12-64	11-24-64	2- 8-65	54	87	47	.59	184	78	155	24	151.0	1,340	2,280	-	3,660	5.39	.20	2.47	153.9	
14-1-2-H	3465.7	8-12-64	11-24-64	2- 8-65	54	87	47	.59	184	78	155	24	151.0	1,340	2,280	-	2,950	4.82	.23	2.42	150.8	
14-2-1-V	3462.5	8- 1-64	11-24-64	1-28-65	55	98	61	.52	184	79	138	23	150.4	2,000	3,240	-	4,070	4.74	.21	2.37	147.7	Some 1-1/2" MSA concrete
14-2-2-V		8- 1-64	11-24-64	1-28-65	55	98	61	.52	184	79	138	23	150.4	2,000	3,240	-	3,720	4.98	.20	2.45	152.6	at top of core
16-1-1-V	3185.0	5- 1-63	8- 5-63	11- 1-63	53	44	-	.52	211	93	159	23	151.1	2,230	4,140	-	3,840	6.17	.29	2.44	152.0	
16-1-2-V	3183.3	5- 1-63	8- 5-63	11- 1-63	53	44	-	.52	211	93	159	23	151.1	2,230	4,140	-	5,640	5.21	.26	2.43	151.4	
16-1-3-V	3180.4	5- 1-63	8- 5-63	11- 1-63	53	44	-	.52	211	93	159	23	151.1	2,230	4,140	-	4,720	5.78	.28	2.47	153.9	
16-3-1-V	3185.0	5- 8-63	8- 6-63	11- 6-63	55	48	-	.45	233	92	148	23	151.1	3,060	4,420	-	4,220	-	-	2.47	153.9	
16-3-2-V	3183.8	5- 8-63	8- 6-63	11- 6-63	55	48	-	.45	233	92	148	23	151.1	3,060	4,420	-	4,480	5.99	.22	2.46	153.2	
16-3-3-V	3182.0	5- 8-63	8- 6-63	11- 6-63	55	48	-	.45	233	92	148	23	151.1	3,060	4,420	-	4,900	5.70	.22	2.45	152.6	
17-1-1-V	3185.0	5-25-63	8- 7-63	11-26-63	54	60	-	.43	363	0	158	28	148.3	3,630	4,950	-	4,050	5.44	.24	2.46	153.2	3" MSA concrete
17-1-2-V	3182.8	5-25-63	8- 7-63	11-26-63	54	60	-	.43	363	0	158	28	148.3	3,630	4,950	-	6,140	5.48	.20	2.48	154.5	3" MSA concrete
17-1-3-V	3180.5	5-25-63	8- 7-63	11-26-63	54	60	-	.43	363	0	158	28	148.3	3,630	4,950	-	6,890	5.31	.22	2.44	152.0	3" MSA concrete
18-1-1-H	3188.0	5-18-63	11-14-63	12-12-63	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	4,740	-	-	2.47	153.9	3/
18-1-2-H	3188.0	5-18-63	11-14-63	12-12-63	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	-	-	-	2.51	156.4	3/
18-1-3-H	3188.0	5-18-63	11-14-63	12-12-63	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	3,570	6.04	.27	2.45	152.6	3/
18-1-4-H	3188.0	5-18-63	11-14-63	12-12-63	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	4,540	5.71	.22	2.43	151.4	3/
18-1-1-V	3185.0	5- 3-63	8- 7-63	12-12-63	58	60	-	.49	272	105	184	30	146.2	2,460	3,990	-	4,570	5.03	.08	2.40	149.5	3" MSA concrete
18-1-2-V	3182.8	5- 3-63	8- 7-63	12-12-63	58	60	-	.49	272	105	184	30	146.2	2,460	3,990	-	2,800	5.62	.14	2.47	153.9	3" MSA concrete
18-1-3-V	3180.6	5- 3-63	8- 7-63	12-12-63	58	60	-	.49	272	105	184	30	146.2	2,460	3,990	-	5,430	5.54	.24	2.48	154.5	3" MSA concrete
18-2-1-V	3185.0	5- 3-63	11-15-63	12-12-63	58	65	37	.49	272	105	184	30	146.2	2,460	3,990	-	4,230	5.58	.25	2.42	150.8	3" MSA concrete 4/
18-2-2-V	3182.5	5- 3-63	11-15-63	12-12-63	58	65	37	.47	234	91	153	23	151.3	2,420	4,120	-	4,460	5.66	.26	2.44	152.0	4/
18-7-1-H	3465.7	7-30-64	11-23-64	2- 3-65	59	96	65	.53	187	81	142	22	151.9	1,790	3,180	-	3,890	5.36	.22	2.45	152.6	
18-7-2-H	3465.7	7-30-64	11-23-64	2- 3-65	59	96	65	.53	187	81	142	22	151.9	1,790	3,180	-	3,340	5.23	.16	2.53	157.6	
18-8-1-V	3462.5	7-17-64	11-20-64	1-13-65	63	91	61	.46	300	135	198	34	148.5	2,720	4,190	5,700						Mix data for top 18" of 1-1/2" MSA concrete
					60	91	61	.56	185	79	148	23	150.1	1,750	2,930	4,210	4,770	4.74	.19	2.35	146.4	Mix data for top 18" of
18-8-2-V		7-17-64	11-20-64	1-13-65	60	91	61	.56	185	79	148	23	150.1	1,750	2,930	4,210	3,800	5.26	.24	2.36	147.0	1-1/2" MSA concrete
20-1-1-H	3465.7	7-16-64	11-17-64	1-12-65	60	92	58	.54	183	78	141	23	149.4	1,860	2,990	-	3,900	5.18	.20	2.48	154.5	
20-1-2-H	3465.7	7-16-64	11-17-64	1-12-65	60	92	58	.54	183	78	141	23	149.4	1,860	2,990	-	3,730	5.36	.22	2.44	152.0	
20-2-1-V	3462.5	7-10-64	11-17-64	1- 6-65	57	91	69	.46	185	79	122	24	149.6	2,440	3,690	-	5,120	5.58	.27	2.34	145.8	Some 1-1/2" MSA concrete
20-2-2-V		7-10-64	11-17-64	1- 6-65	57	91	69	.46	185	79	122	24	149.6	2,440	3,690	-	4,430	4.96	.19	2.43	151.4	at top of core
24-3-1-H	3466.0	8-12-64	11-10-64	2- 8-65	54	87	46	.59	184	78	155	24	151.0	1,340	2,280	-	4,020	5.05	.20	2.46	153.3	
24-3-2-H	3466.0	8-12-64	11-10-64	2- 8-65	54	87	46	.59	184	78	155	24	151.0	1,340	2,280	-	3,510	5.57	.23	2.42	150.8	
24-4-1-V	3462.5	8- 5-64	11-10-64	2- 1-65	58	103	70	.54	189	81	147	23	153.2	1,950	3,310	4,510	5,090	5.37	.22	2.36	147.0	Top 12" is 1-1/2" MSA
24-4-2-V		8- 5-64	11-10-64	2- 1-65	58	103	70	.54	189	81	147	23	153.2	1,950	3,310	4,510	3,710			2.38	148.3	concrete
24-5-1-V	3462.5	8- 5-64	11-11-64	2-11-65	58	103	70	.54	189	81	147	23	153.2	1,950	3,310	4,510	4,390	5.23	.23	2.42	150.8	
24-5-2-V		8- 5-64	11-11-64	2-11-65	58	103	70	.54	189	81	147	23	153.2	1,950	3,310	4,510	3,790	4.67	.18	2.50	155.8	
Average														2,160	3,550	4,590	4,140	5.30	.22	2.44	152.0	

1/ Core number denotes; Block number - Core number in that block - Specimen from that core - Direction drilled (Vertically/Horizontally)
2/ Sand percent expressed as percent of total absolute volume of concrete aggregate
3/ Core testing age is 7 months
4/ Core testing age is 7-1/2 months

Table 2

CONCRETE CORE TEST RESULTS
Yellowtail Dam
6" MSA Exterior Concrete - 6 Months' Age

1/ Core No.	Elevation above sea level	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Concrete	Temperatures °F: Air Maximum	Temperatures °F: Air Minimum	Properties of concrete when placed: W/c+P by wt	Cement content lb/yd³	Pozzolan content lb/yd³	Water content lb/yd³	2/ Sand, percent	Unit weight fresh concrete lb/ft³	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	Specific gravity	Unit weight lb/ft³	Remarks
5-1-1-H	3466.5	8-13-64	12- 1-64	2- 9-65	57	90	61	0.45	248	79	148	22	151.3	2,230	3,230	-	3,610	5.37	0.22	2.41	150.1	
5-1-2-H	3466.5	8-13-64	12- 1-64	2- 9-65	57	90	61	.45	248	79	148	22	151.3	2,230	3,230	-	3,610	5.53	.25	2.44	152.0	
5-2-1-V	3462.5	7-31-64	12- 1-64	1-27-65	57	95	57	.45	251	80	151	22	152.5	2,900	4,600	6,080	4,120	4.95	.24	2.44	152.0	Top 12" is 1-1/2" MSA concrete
5-2-2-V		7-31-64	12- 1-64	1-27-65	57	95	57	.45	251	80	151	22	152.5	2,900	4,600	6,080	4,690	5.07	.21	2.48	154.5	
18-3-1-H	3209.5	6-25-63	11-18-63	12-23-63	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	4,500	5.47	.26	2.48	154.5	
18-3-2-H	3209.5	6-25-63	11-18-63	12-23-63	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	5,900	6.21	.24	2.47	153.9	
24-1-1-H	3465.9	8-12-64	11- 9-64	2- 8-65	54	87	46	.44	251	82	147	22	151.	2,950	3,970	-	4,390	5.75	.21	2.45	152.6	
24-1-2-H	3465.9	8-12-64	11- 9-64	2- 8-65	54	87	46	.44	251	82	147	22	151.	2,950	3,970	-	3,980	5.05	.19	2.44	152.0	
24-2-1-V	3462.5	8- 5-64	11- 9-64	2- 1-65	60	103	70	.47	247	81	155	21	150.	2,710	4,230	-	4,180	5.32	.20	2.42	150.8	
24-2-2-V		8- 5-64	11- 9-64	2- 1-65	60	103	70	.47	247	81	155	21	150.	2,710	4,230	-	2,700	5.02	.18	2.39	148.9	
Average														2,930	4,220	6,080	4,170	5.37	.22	2.44	152.1	

1/ Core number denotes: Block number - Core number in that block - Specimen from that core - Direction drilled (Vertically/Horizontally)
2/ Sand percent expressed as percent of total absolute volume of concrete aggregate

Table 3

CONCRETE CORE TEST RESULTS
Yellowtail Dam
6" MSA Exterior Concrete - 1 Year's Age

1/ Core No.	Elevation above sea level	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Concrete	Temperatures °F: Air Maximum	Temperatures °F: Air Minimum	Properties of concrete when placed: W/c+P by wt	Cement content lb/yd³	Pozzolan content lb/yd³	Water content lb/yd³	2/ Sand, percent	Unit weight fresh concrete lb/ft³	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	Specific gravity	Unit weight lb/ft³	Remarks
5-7-1-H	3465.6	8-13-64	6-24-65	8-13-65	57	90	61	0.45	248	79	148	22	151.3	2,230	3,230	-	4,900	5.49	0.25	2.44	152.0	
5-7-2-H	3465.6	8-13-64	6-24-65	8-13-65	57	90	61	.45	248	79	148	22	151.3	2,230	3,230	-	3,910	6.04	.23	2.48	154.5	
5-8-1-V	3462.2	7-31-64	6-24-65	7-30-65	57	95	57	.45	251	80	151	22	152.5	2,900	4,600	6,080	5,130	5.04	.20	2.43	151.4	Top 12" is 1-1/2" MSA concrete
5-8-2-V	3459.7	7-31-64	6-24-65	7-30-65	57	95	57	.45	251	80	151	22	152.5	2,900	4,600	6,080	5,050	5.13	.20	2.50	155.8	
18-6-1-H	3210.5	6-25-63	6- 8-64	6-25-64	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	4,470	5.59	.20	2.46	153.2	
18-6-2-H	3210.5	6-25-63	6- 8-64	6-25-64	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	3,810	5.38	.25	2.41	150.1	
24-8-1-H	3465.6	8-12-64	7- 1-65	8-12-65	54	87	46	.44	251	82	147	22	151.4	2,950	3,970	-	4,440	5.36	.22	2.46	153.2	
24-8-2-H	3465.6	8-12-64	7- 1-65	8-12-65	54	87	46	.44	251	82	147	22	151.4	2,950	3,970	-	4,160	5.29	.29	2.48	154.5	
24-9-1-V	3462.2	8- 5-64	7- 1-65	8- 5-65	60	103	70	.47	247	81	155	21	150.1	2,710	4,220	-	4,130	4.99	.21	2.40	149.5	
24-9-2-V	3459.9	8- 5-64	7- 1-65	8- 5-65	60	103	70	.47	247	81	155	21	150.1	2,710	4,220	-	3,970	-	-	2.39	148.9	
24-9-3-V	3458.4	8- 5-64	7- 1-65	8- 5-65	60	103	70	.47	247	81	155	21	150.1	2,710	4,220	-	3,870	-	-	2.42	150.8	
24-9-4-V	3456.9	8- 5-64	7- 1-65	8- 5-65	60	103	70	.47	247	81	155	21	150.1	2,710	4,220	-	3,630	5.27	.25	2.47	153.9	
Average														2,890	4,220	6,080	4,290	5.36	.23	2.44	152.3	

1/ Core number denotes: Block number - Core number in that block - Specimen from that core - Direction drilled (Vertically/Horizontally)
2/ Sand percent expressed as percent of total absolute volume of concrete aggregate

Table 4

CONCRETE CORE TEST RESULTS
Yellowtail Dam
6" MSA Interior Concrete - 1 Year's Age

1/ Core No.	Elevation above sea level	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Concrete	Temperatures °F: Air Maximum	Temperatures °F: Air Minimum	Properties of concrete when placed: W/c+P by wt	Cement content lb/yd³	Pozzolan content lb/yd³	Water content lb/yd³	2/ Sand, percent	Unit weight fresh concrete lb/ft³	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	Specific gravity	Unit weight lb/ft³	Remarks
5-5-1-H	3466.5	8-13-64	6-25-65	8-13-65	57	90	61	0.53	190	81	142	24	152.2	1,360	2,160	-	2,970	5.01	0.20	2.46	153.2	
5-5-2-H	3466.5	8-13-64	6-25-65	8-13-65	57	90	61	.53	190	81	142	24	152.2	1,360	2,160	-	3,520	5.72	.30	2.44	152.0	
5-6-1-V	3462.2	7-30-64	6-25-65	7-30-65	54	85	57	.60	184	80	159	23	150.5	1,520	2,650	-	3,370	4.57		2.36	147.0	Top 18" is 1-1/2" MSA concrete
5-6-2-V	3459.6	7-30-64	6-25-65	7-30-65	54	85	57	.60	184	80	159	23	150.5	1,520	2,650	-	3,130	5.20	.24	2.45	152.6	
9-3-1-H	3465.7	7-25-64	6-26-65	7-26-65	53	89	50	.56	186	79	149	22	150.4	2,050	3,630	-	4,030	6.33	.25	2.50	155.8	
9-3-2-H	3465.7	7-25-64	6-26-65	7-26-65	53	89	50	.56	186	79	149	22	150.4	2,050	3,630	-	4,150	5.39	.25	2.47	153.9	
9-4-1-V	3462.3	7-17-64	6-25-65	7-16-65	54	91	61	.57	188	83	154	23	151.2	2,410	4,000	-	2,920	-	-	2.34	145.8	Top 12" is 3" MSA concrete
9-4-2-V	3460.8	7-17-64	6-25-65	7-16-65	54	91	61	.57	188	83	154	23	151.2	2,410	4,000	-	3,500	5.21	.23	2.38	148.4	
9-4-3A-V	3458.3	7-17-64	6-25-65	7-16-65	54	91	61	.57	188	83	154	23	151.2	2,410	4,000	-	4,050	5.21	.23	2.46	153.2	
10-4-1-H	3210.5	7-16-63	6- 5-64	7-16-64	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	4,310	5.90	.22	2.48	154.5	
10-4-2-H	3210.5	7-16-63	6- 5-64	7-16-64	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	4,150	5.30	.26	2.41	150.1	
10-3-1-V	3207.5	7- 9-63	6- 4-64	7- 9-64	60	90	67	.51	420	0	216	31	-	-	-	-	-	-	-	-	-	Mix data for top 8" of 1-1/2" MSA concrete
10-3-2-V		7- 9-63	6- 4-64	7- 9-64	60	90	67	.52	186	89	143	23	152.7	2,280	3,800	5,040	4,390	4.83	.24	2.42	150.8	Mix data for 6" MSA concrete
								.52	186	89	143	23	152.7	2,280	3,800	5,040	4,410	5.82	.24	2.50	155.8	
14-3-1-H	3465.7	8-12-64	6-28-65	8-12-65	54	87	47	.59	184	78	155	24	151.0	1,340	2,280	-	2,500	5.30	.21	2.46	153.2	
14-3-2-H	3465.7	8-12-64	6-28-65	8-12-65	54	87	47	.59	184	78	155	24	151.0	1,340	2,280	-	2,880	4.90	.20	2.47	153.9	
14-4-1-V	3462.2	8- 1-64	6-28-65	8- 2-65	55	98	61	.52	184	79	138	23	150.4	2,000	3,240	-	3,890	5.22	.23	2.40	149.5	Top of core was 1-1/2" MSA concrete
14-4-2-V	3459.6	8- 1-64	6-28-65	8- 2-65	55	98	61	.52	184	79	138	23	150.4	2,000	3,240	-	3,790	4.82	.20	2.46	153.2	
18-2-1-V	3185.0	5- 3-63	11-15-63	5- 4-64	57	65	37	.47	234	91	153	23	151.31	2,420	4,120	-	5,120	6.10	.26	2.42	150.8	
18-2-2-V	3182.7	5- 3-63	11-15-63	5- 4-64	57	65	37	.47	234	91	153	23	151.31	2,420	4,120	-	4,530	5.28	.29	2.45	152.6	
18-2-3-V	3180.4	5- 3-63	11-15-63	5- 4-64	57	65	37	.47	234	91	153	23	151.31	2,420	4,120	-	5,220	5.38	.22	2.47	153.9	
18-3-1-H	3209.5	6-25-63	11-18-63	5- 4-64	54	81	49	.41	261	96	145	23	154.27	3,840	5,080	-	4,200	5.43	.24	2.42	150.8	
18-3-2-H	3209.5	6-25-63	11-18-63	5- 4-64	54	81	49	.41	261	96	145	23	154.27	3,840	5,080	-	5,020	5.21	.24	2.46	153.2	
18-3-3-H	3209.5	6-25-63	11-18-63	5- 4-64	54	81	49	.41	261	96	145	23	154.27	3,840	5,080	-	4,910	5.30	.27	2.46	153.2	
18-5-1-H	3188.0	5-18-63	6- 5-64	6-23-64	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	5,470	5.92	.23	2.47	153.9	
18-5-2-H	3188.0	5-18-63	6- 5-64	6-23-64	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	5,280	5.09	.21	2.44	152.0	
18-4-1-V	3185.0	5- 3-63	6- 5-64	6-24-64	58	65	37	.49	272	105	184	30	146.2	2,460	3,990	-	-	-	-	-	-	Top 7" is 3" MSA concrete
								.47	234	91	153	23	151.3	2,420	4,120	-	5,940	5.80	.21	2.43	151.4	
18-4-2-V	3185.0	5- 3-63	6- 5-64	6-24-64	58	65	37	.47	234	91	153	23	151.3	2,420	4,120	-	6,310	6.07	.23	2.44	152.0	
18-9-1-H	3465.7	7-30-64	6-28-65	7-30-65	59	96	65	.53	187	81	142	22	151.9	1,790	3,180	-	3,730	6.12	.20	2.48	154.5	
18-9-2-H	3465.7	7-30-64	6-28-65	7-30-65	59	96	65	.53	187	81	142	22	151.9	1,790	3,180	-	3,440	5.48	.26	2.48	154.5	
18-10-1-V	3462.1	7-17-64	6-29-65	7-16-65	65	91	61	.46	300	135	198	34	148.5	2,720	-	5,700	5,710	5.65	.22	2.40	149.5	Top 18" is 1-1/2" MSA concrete
18-10-2-V	3459.3	7-17-64	6-29-65	7-16-65	60	91	61	.56	185	79	148	23	150.1	1,750	2,930	-	4,420	5.18	.21	2.48	154.5	
20-3-1-H	3465.7	7-16-64	6-29-65	7-16-65	60	92	58	.54	183	78	141	23	149.4	1,860	2,990	-	4,470	5.55	.20	2.49	155.1	
20-3-2-H	3465.7	7-16-64	6-29-65	7-16-65	60	92	58	.54	183	78	141	23	149.4	1,860	2,990	-	3,780	6.08	.25	2.46	153.2	
20-4-1-V	3462.2	7-10-64	6-29-65	7-14-65	57	91	69	.46	185	79	122	24	149.6	2,440	3,690	-	5,640	5.74	.21	2.44	152.0	Top of core was 1-1/2" MSA concrete
20-4-2-V	3459.6	7-10-64	6-29-65	7-14-65	57	91	69	.46	185	79	122	24	149.6	2,440	3,690	-	5,480	6.32	.25	2.50	155.8	
24-6-1-H	3466	8-12-64	7- 1-65	8-12-65	54	87	46	.59	184	78	155	24	151.0	1,340	2,280	-	4,240	5.39	.23	2.46	153.2	
24-6-2-H	3466	8-12-64	7- 1-65	8-12-65	54	87	46	.59	184	78	155	24	151.0	1,340	2,280	-	3,510	5.60	.24	2.45	152.6	
24-7-1-V	3462.2	8-15-64	6-30-65	8-16-65	58	103	70	.54	189	81	147	23	153.2	1,950	3,300	-	3,620	5.12	.23	2.40	149.5	
24-7-2-V	3459.7	8-15-64	6-30-65	8-16-65	58	103	70	.54	189	81	147	23	153.2	1,950	3,300	-	3,180	5.94	.30	2.44	152.0	
Average														2,140	3,480	5,260	4,240	5.49	.23	2.45	152.4	

1/ Core number denotes: Block number - Core number in that block - Specimen from that core - Direction drilled (Vertically/Horizontally)
2/ Sand percent expressed as percent of total absolute volume of concrete aggregate

Table 5

CONCRETE CORE TEST RESULTS
Yellowtail Dam
6" MSA Concrete - 5 Years' Age

1/ Core No.	Elevation above sea level	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Concrete	Temperatures °F: Air Maximum	Temperatures °F: Air Minimum	Properties of concrete when placed: W/c+P by wt	Cement content lb/yd³	Pozzolan content lb/yd³	Water content lb/yd³	2/ Sand, percent	Unit weight fresh concrete lb/ft³	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	Specific gravity	Unit weight lb/ft³	Remarks
												Interior Concrete										
18-7-1-V	3185.0	5- 3-63	7-31-68	8-19-68	58	65	37	0.49	272	105	184	30	146.2	2,460	3,990	-	5,590	5.88	0.23	2.41	150.1	Top 18" is 3" MSA concrete
18-7-2-V	3183.5	5- 3-63	7-31-68	8-19-68	57	65	37	.47	234	91	153	23	151.3	2,420	4,120	-	6,350	-	-	2.40	149.5	
18-7-3-V	3080.6	5- 3-63	7-31-68	8-19-68	57	65	37	.47	234	91	153	23	151.3	2,420	4,120	-	6,960	5.40	.20	2.44	151.8	
18-8-1-H	3188.0	5-18-63	8- 3-68	8-19-68	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	5,350	5.76	.23	2.48	154.5	3" MSA concrete
18-8-2-H	3186.0	5-18-63	8- 3-68	8-19-68	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	4,690	5.41	.21	2.44	152.3	
10-5-1-V	3207.5	7- 9-63	10- 3-68	10-24-68	-	90	67	.51	420	0	216	31	-	-	-	-	5,860	5.40	.20	2.43	151.2	Top 12" is 1-1/2" MSA
10-5-3-V	3203.8	7- 9-63	10- 3-68	10-24-68	60	90	67	.52	186	89	143	23	152.7	2,280	3,800	5,040	5,760	6.11	.21	2.46	153.4	concrete
10-6-1-H	3210.7	7-16-63	10- 3-68	10-24-68	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	4,890	5.77	.24	2.47	153.8	
10-6-2-H	3208.8	7-16-63	10- 3-68	10-24-68	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	4,230	5.18	.21	2.43	151.2	
Average														2,200	3,820	5,040	5,520	5.61	.22	2.44	152.0	
												Exterior Concrete										
18-9-1-H	3209	6-25-63	9-14-68	10- 8-68	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	4,630	6.02	.19	2.48	154.5	
18-9-2-H	3209	6-25-63	9-14-68	10- 8-68	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	5,610	5.49	.26	2.45	152.6	
Average														3,840	5,080	-	5,120	5.75	.22	2.46	153.5	

1/ Core number denotes; Block number - Core number in that block - Specimen from that core - Direction drilled (Vertically/Horizontally)

2/ Sand percent expressed as percent of total absolute volume of concrete aggregate

Table 6

CONCRETE CORE TEST RESULTS
Yellowtail Dam
6" MSA Concrete - 10 Years' Age

1/ Core No.	Elevation above sea level	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Concrete	Temperatures °F: Air Maximum	Temperatures °F: Air Minimum	Properties of concrete when placed: W/c+P by wt	Cement content lb/yd³	Pozzolan content lb/yd³	Water content lb/yd³	2/ Sand, percent	Unit weight fresh concrete lb/ft³	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	Specific gravity	Unit weight lb/ft³	Remarks
												Interior Concrete										
10-7-1-H	3210.5	7-16-63	3-22-74	6-13-74	54	90	55	0.55	187	90	151	23	152.3	1,890	3,130	-	4,180	6.37	0.26	2.44	151.9	
10-7-2-H	3210.5	7-16-63	3-22-74	6-13-74	54	90	55	.55	187	90	151	23	152.3	1,890	3,130	-	4,310	6.49	.29	2.49	155.0	
10-8-1-V	3207.5	7- 9-63	3-22-74	6-14-74	60	90	67	.51	420	0	216	31	-	-	-	-	-	-	-	-	-	Top 18" is 1-1/2" MSA
10-8-1-V	3206.0	7- 9-63	3-22-74	6-14-74	60	90	67	.52	186	89	143	23	152.7	2,280	3,640	-	6,550	6.27	.27	2.42	150.9	concrete
18-9-1-H	3188.0	5-18-63	3-11-74	6-10-74	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	5,420	6.80	.25	2.45	152.9	
18-9-3-H	3188.0	5-18-63	3-12-74	6-10-74	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	5,460	6.18	.28	2.42	151.0	
18-9-4-H	3188.0	5-18-63	3-13-74	6-13-74	50	77	48	.46	235	95	153	22	151.9	2,140	4,140	-	6,210	5.85	.19	2.44	152.0	
18-10-3-V	3179.6	5- 3-63	3- 9-74	6-10-74	57	65	37	.47	234	91	153	23	151.3	2,420	4,120	-	7,520	6.67	.25	2.52	156.8	
Average														2,130	3,780	-	5,660	6.38	.26	2.45	152.9	
												Exterior Concrete										
18-11-2-H	3209.5	6-25-63	3-16-74	6-14-74	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	5,120	6.31	.22	2.51	156.3	
18-11-3-H	3209.5	6-25-63	3-17-74	6-13-74	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	5,150	6.70	.26	2.43	151.5	
18-12-3-H	3209.5	6-25-63	3-19-74	6-10-74	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	5,280	6.05	.23	2.47	153.9	
18-12-4-H	3209.5	6-25-63	3-19-74	6-10-74	54	81	49	.41	261	96	145	23	154.3	3,840	5,080	-	4,470	6.11	.24	2.45	152.5	
Average														3,840	5,080	-	5,000	6.29	.24	2.46	153.6	

1/ Core number denotes: Block number - Core number in that block - Specimen from that core - Direction drilled (Vertically/Horizontally)
2/ Sand percent expressed as percent of total absolute volume of concrete aggregate

Table 7

CONCRETE CORE STATIC-TENSION TEST RESULTS
Yellowtail Dam
6" MSA Concrete - 10 Years' Age

1/ Core No.	Elevation above sea level	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Concrete	Temperatures °F: Air Maximum	Temperatures °F: Air Minimum	Properties of concrete when placed: W/c+P by wt	Cement content lb/yd³	Pozzolan content lb/yd³	Water content lb/yd³	2/ Sand, percent	Unit weight fresh concrete lb/ft³	10-Year static tensile strength lb/in²	Remarks
							Interior Concrete								
10-7-4-H	3210.5	7-16-63	3-22-74	6-18-74	54	90	55	0.55	187	90	151	23	152.3	256	
18-9-2-H	3188.0	5-18-63	3-13-74	6-18-74	50	77	48	.46	235	95	153		151.9	290	
Average														273	
							Exterior Concrete								
18-11-1-H	3209.5	6-25-63	3-16-74	6-18-74	54	81	49	.41	261	96	145	23	154.3	265	
18-11-4-H	3209.5	6-25-63	3-18-74	6-18-74	54	81	49	.41	261	96	145	23	154.3	304	
18-12-1-H	3209.5	6-25-63	3-18-74	6-18-74	54	81	49	.41	261	96	145	23	154.3	235	
Average														268	

1/ Core number denotes: Block number - Core number in that block - Specimen from that core - Direction drilled (Vertically/Horizontally)
2/ Sand percent expressed as percent of total absolute volume of concrete aggregate

Table 8

SUMMARY OF TEST RESULTS
Yellowtail Dam
10-inch-diameter Concrete Cores

Properties of concretes (6-inch maximum-size aggregate) with similar (cement + pozzolan)/yd^3 contents 1/

Test age	No. specimens	Average compressive strength (lb/in^2)	Average E (lb/in^2 x 10^{-6})	Average Poisson's ratio	Average cement + pozzolan (lb/yd^3)	Average W/(c + P) ratio
			Interior - Horizontal			
6 months	14	3,660	5.31	0.21	267	0.56
1 year	14	3,690	5.58	.23	267	.56
5 years	2	4,560	5.48	.22	277	.55
10 years	2	4,240	6.43	.27	277	.55
			Interior - Vertical			
6 months	14	3,950	4.96	.22	267	.54
1 year	13	3,850	5.32	.23	268	.54
5 years	2	5,810	5.76	.20	275	.52
10 years	1	6,550	6.27	.27	275	.52

1/ (Cement + pozzolan)/yd^3 range: 261 to 277 lb/yd^3 - Excludes interior concrete placed before July 1963, which contains atypically high cement and pozzolan quantities.

Table 9

SUMMARY OF TEST RESULTS
Yellowtail Dam
10-inch-diameter Concrete Cores

Properties of concretes (6-inch maximum-size aggregate) with similar (cement + pozzolan)/yd^3 contents 1/

Test age	No. specimens	Average compressive strength (lb/in^2)	Average E (lb/in^2 x 10^{-6})	Average Poisson's ratio	Average cement + pozzolan (lb/yd^3)	Average W/(c + P) ratio
			Interior - Horizontal			
6 months	3	4,280	5.88	0.24	330	0.46
1 year	5	4,980	5.39	.24	346	.43
5 years	2	5,020	5.58	.22	330	.46
10 years	3	5,700	6.28	.24	330	.46
			Interior - Vertical			
6 months	4	4,520	5.78	.23	325	.46
1 year	5	5,420	5.73	.24	325	.47
5 years	2	6,660	5.40	.20	325	.47
10 years	1	7,520	6.67	.25	325	.47
			Exterior - Horizontal			
6 months	6	4,330	5.56	.23	339	.44
1 year	6	4,280	5.52	.24	339	.44
5 years	2	5,120	5.75	.22	357	.41
10 years	4	5,000	6.29	.24	357	.41
			Exterior - Vertical			
6 months	4	3,920	5.09	.21	330	.46
1 year	6	4,300	5.11	.22	329	.46

1/ (Cement + pozzolan)/yd^3 range: 304 to 357 lb/yd^3

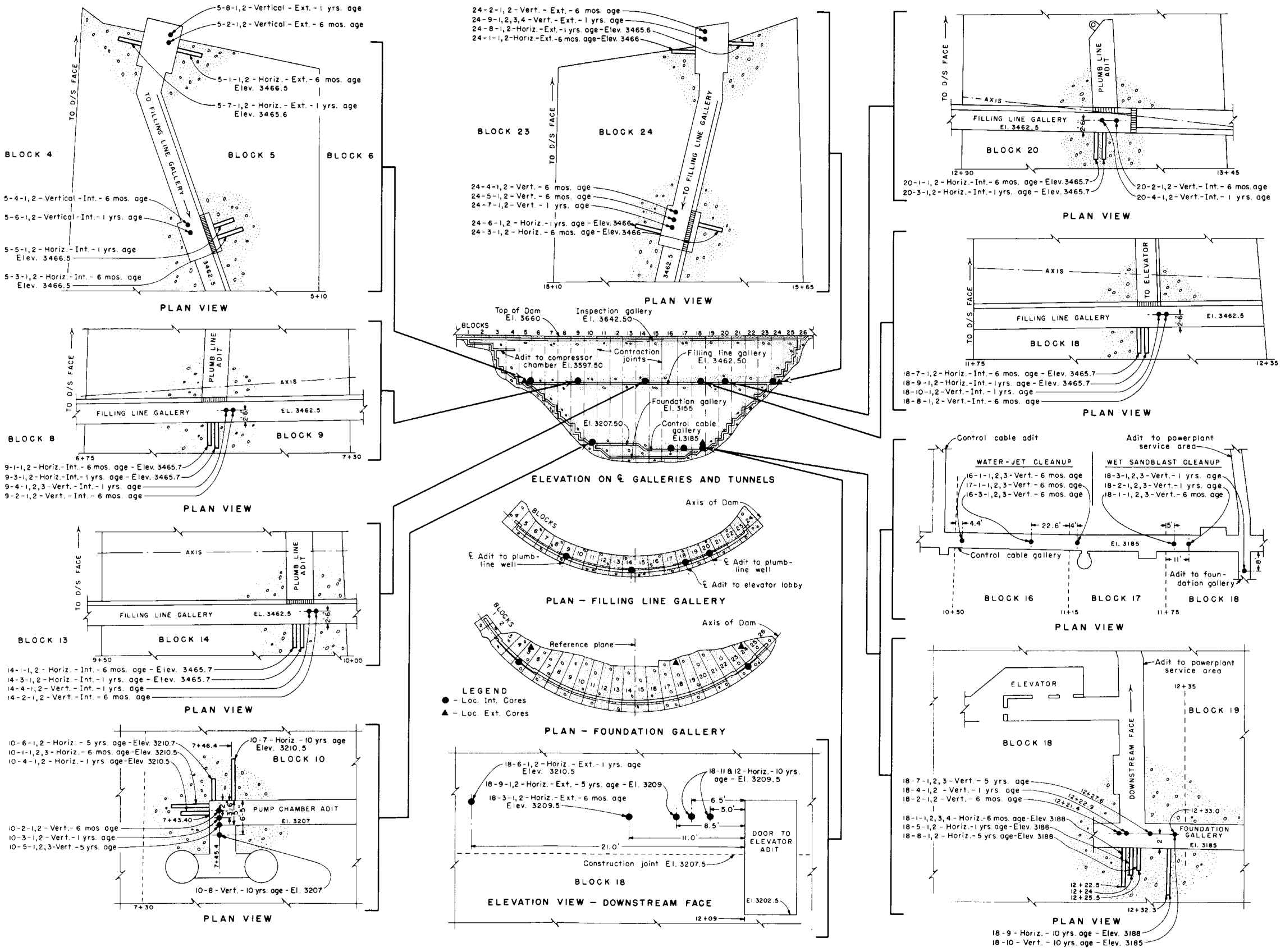

Figure 1 - Core drilling locations in Yellowtail Dam

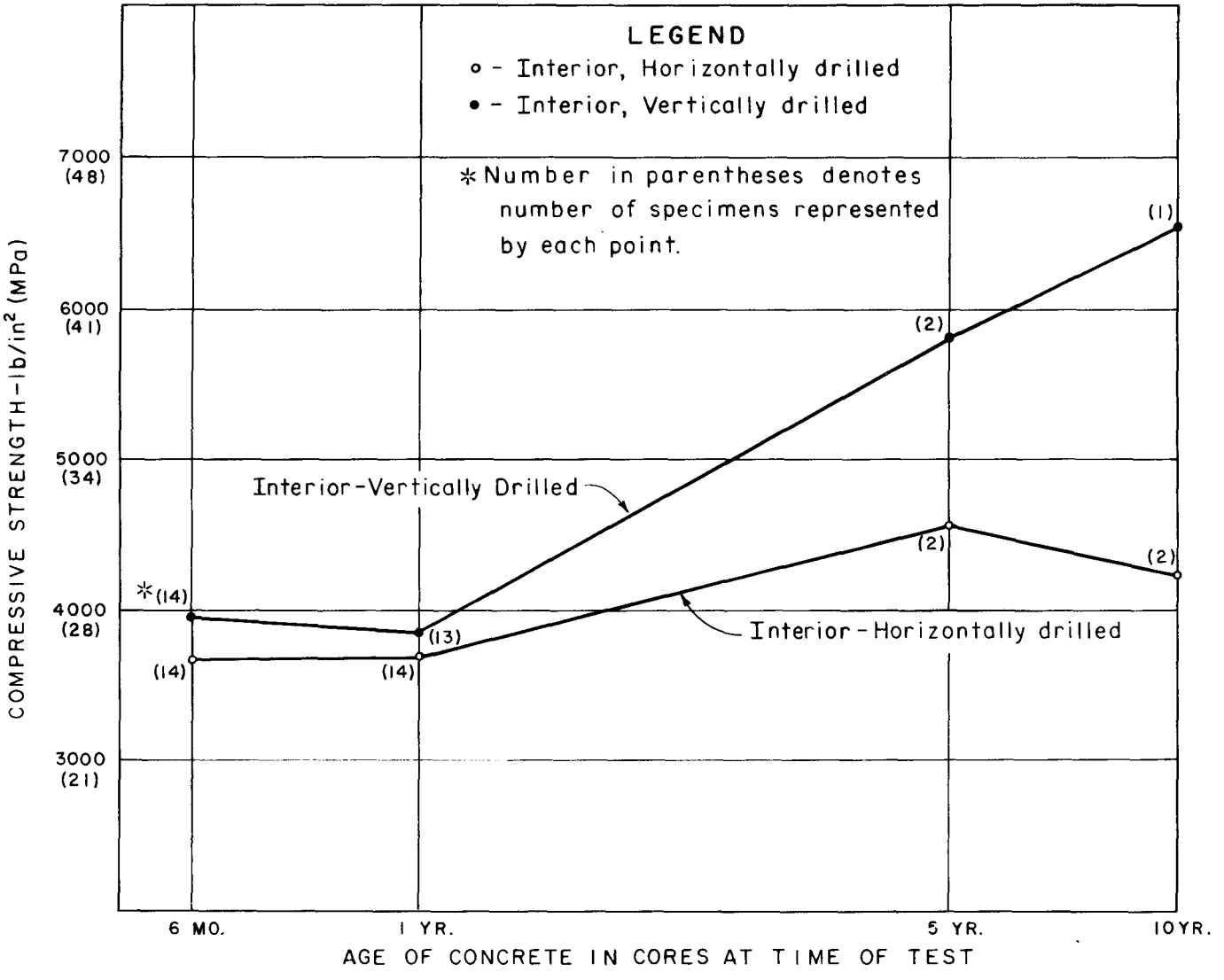

Figure 2 - Average compressive strengths of mass concrete containing 261 to 277 lb/yd^3 cement plus pozzolan concrete core investigation - Yellowtail Dam

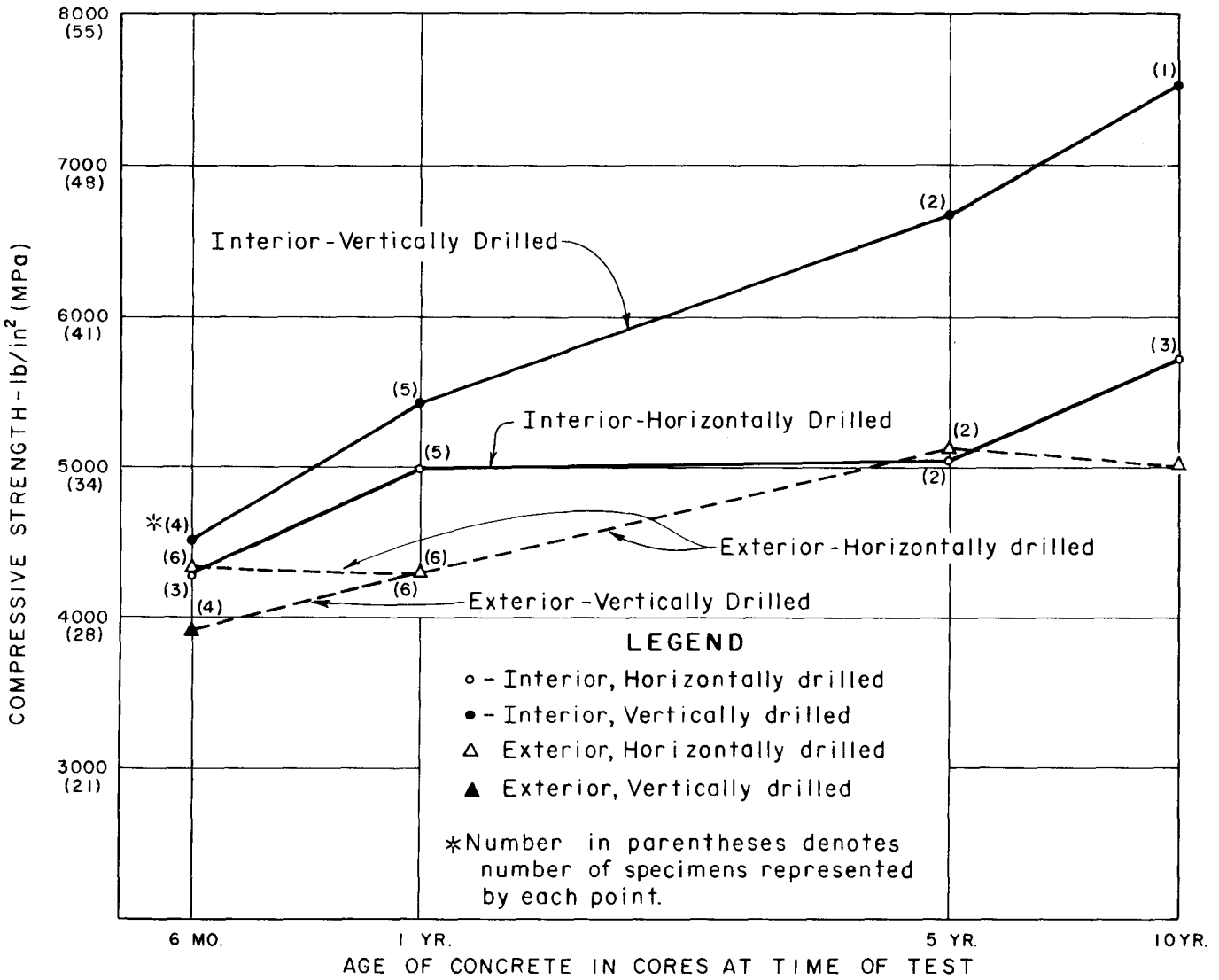

Figure 3 - Average compressive strengths of mass concrete containing 304 to 357 lb/yd^3 cement plus pozzolan concrete core investigation - Yellowtail Dam

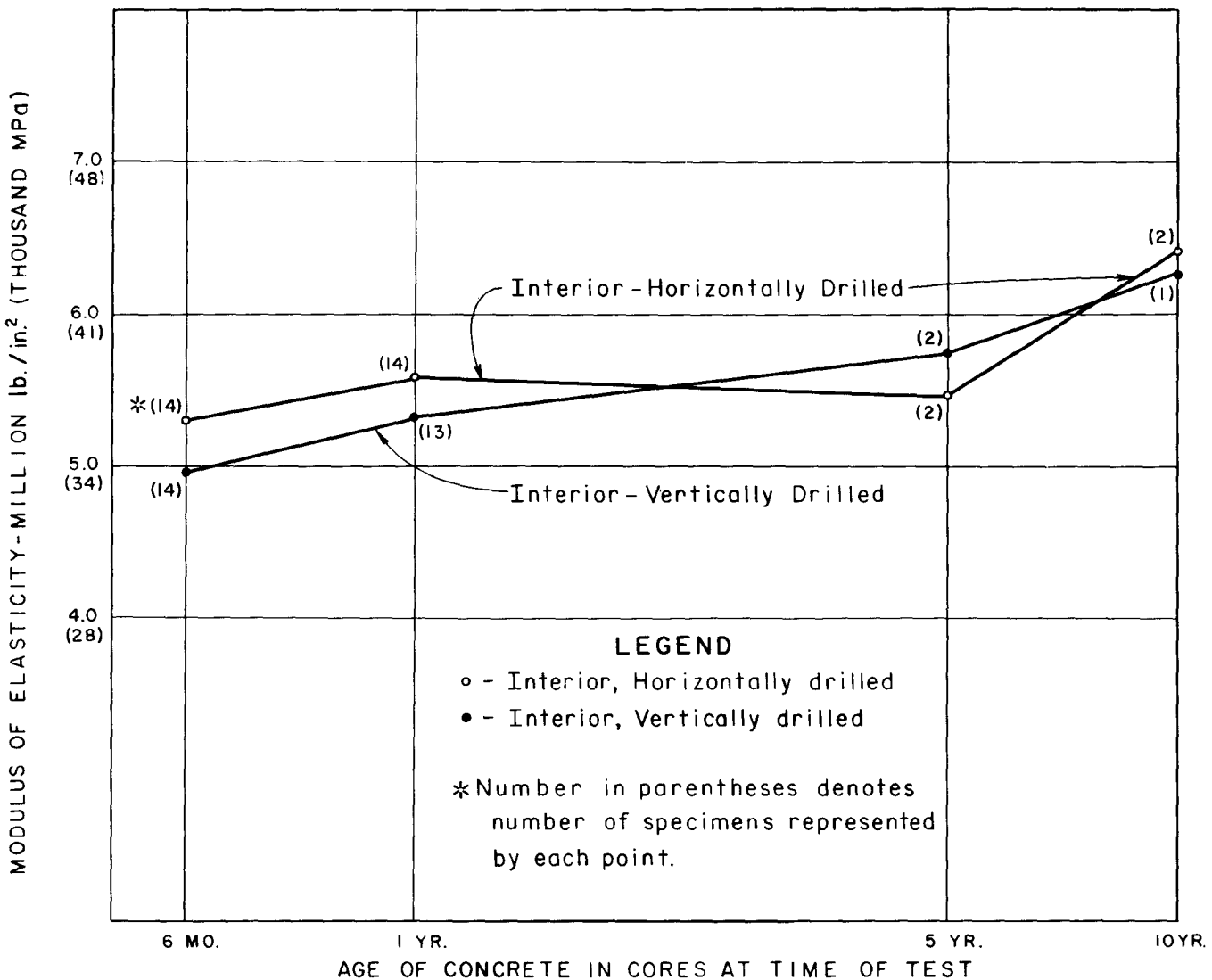

Figure 4 - Average moduli of elasticity of mass concrete containing 261 to 277 lb/yd^3 cement plus pozzolan concrete core investigation - Yellowtail Dam

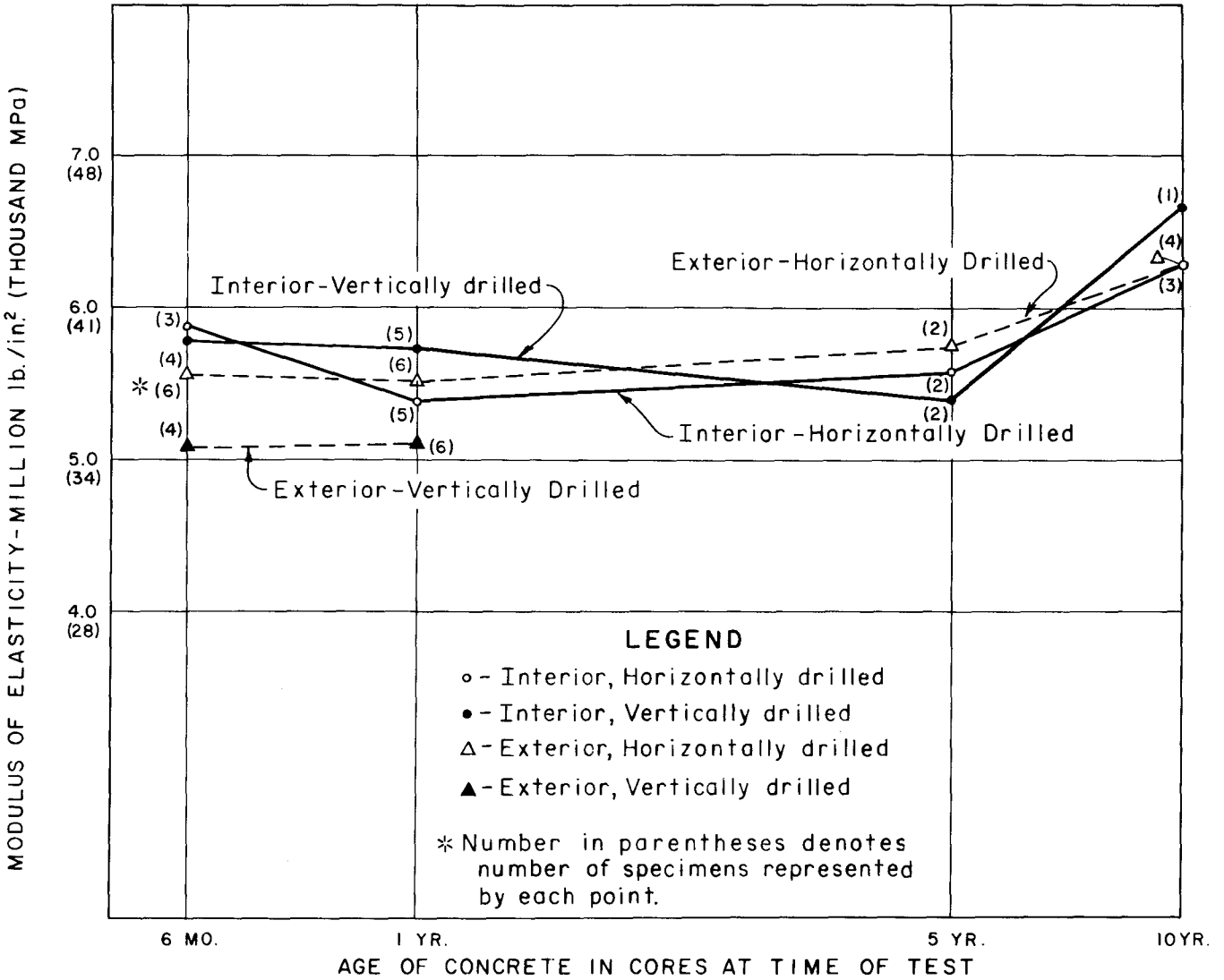

Figure 5 - Average moduli of elasticity of mass concrete containing 304 to 357 lb/yd^3 cement plus pozzolan concrete core investigation - Yellowtail Dam

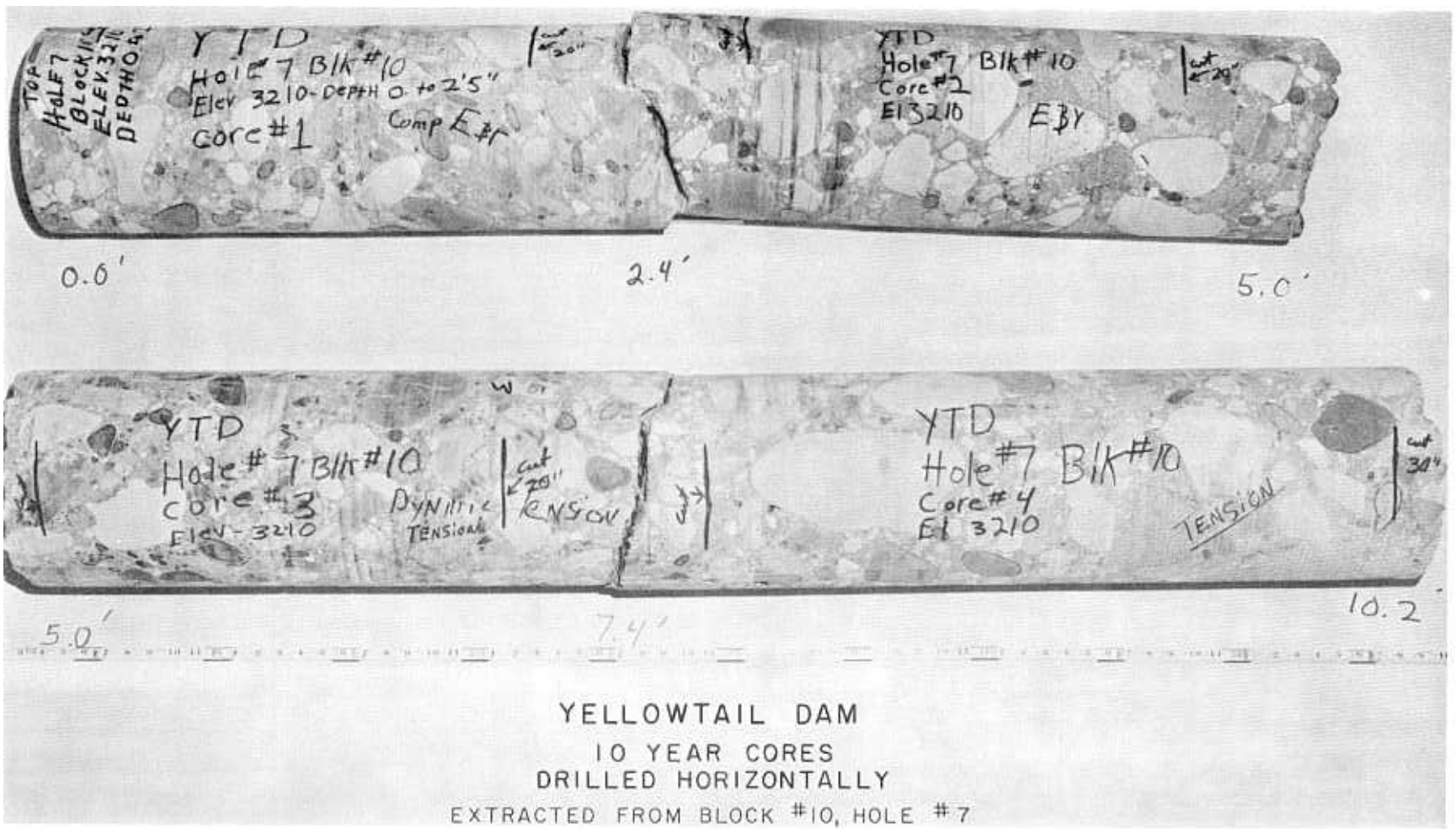

Figure 6 - Typical 10-inch Core as Marked for Cutting (Photo P459-D-75970)

7-1750 (12-74)
Bureau of Reclamation

CONVERSION FACTORS–BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-72) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, it gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron (μ)
Inches (in)	25.4 (exactly)	Millimeters (mm)
Inches	2.54 (exactly)*	Centimeters (cm)
Feet (ft)	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters (m)
Feet	0.0003048 (exactly)*	Kilometers (km)
Yards (yd)	0.9144 (exactly)	Meters (m)
Miles (statute) (mi)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers (km)
	AREA	
Square inches (in^2)	6.4516 (exactly)	Square centimeters (cm^2)
Square feet (ft^2)	*929.03	Square centimeters
Square feet	0.092903	Square meters (m^2)
Square yards (yd^2)	0.836127	Square meters
Acres	*0.40469	Hectares (ha)
Acres	*4,046.9	Square meters (m^2)
Acres	*0.0040469	Square kilometers (km^2)
Square miles (mi^2)	2.58999	Square kilometers
	VOLUME	
Cubic inches (in^3)	16.3871	Cubic centimeters (cm^3)
Cubic feet (ft^3)	0.0283168	Cubic meters (m^3)
Cubic yards (yd^3)	0.764555	Cubic meters (m^3)
	CAPACITY	
Fluid ounces (U.S.) (oz)	29.5737	Cubic centimeters (cm^3)
Fluid ounces (U.S.)	29.5729	Milliliters (ml)
Liquid pints (U.S.) (pt)	0.473179	Cubic decimeters (dm^3)
Liquid pints (U.S.)	0.473166	Liters (l)
Quarts (U.S.) (qt)	*946.358	Cubic centimeters (cm^3)
Quarts (U.S.)	*0.946331	Liters (l)
Gallons (U.S.) (gal)	*3,785.43	Cubic centimeters (cm^3)
Gallons (U.S.)	3.78543	Cubic decimeters (dm^3)
Gallons (U.S.)	3.78533	Liters (l)
Gallons (U.S.)	*0.00378543	Cubic meters (m^3)
Gallons (U.K.)	4.54609	Cubic decimeters (dm^3)
Gallons (U.K.)	4.54596	Liters (l)
Cubic feet (ft^3)	28.3160	Liters
Cubic yards (yd^3)	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters (m^3)
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb) (gr)	64.79891 (exactly)	Milligrams (mg)
Troy ounces (480 grains)	31.1035	Grams (g)
Ounces (avdp) (oz)	28.3495	Grams
Pounds (avdp) (lb)	0.45359237 (exactly)	Kilograms (kg)
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms (kg)
FORCE/AREA		
Pounds per square inch (lb/in^2)	0.070307	Kilograms per square centimeter (kg/cm^2)
Pounds per square inch	6894.76	Pascals (Pa), or Newtons per square meter (N/m^2)
Pounds per square foot (lb/ft^2)	4.88243	Kilograms per square meter (kg/m^2)
Pounds per square foot	47.8803	Pascals (Pa), or Newtons per square meter (N/m^2)
MASS/VOLUME (DENSITY)		
Ounces per cubic inch (oz/in^3)	1.72999	Grams per cubic centimeter (g/cm^3)
Pounds per cubic foot (lb/ft^3)	16.0185	Kilograms per cubic meter (kg/m^3)
Pounds per cubic foot	0.0160185	Grams per cubic centimeter (g/cm^3)
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.) (oz/gal)	7.4893	Grams per liter (g/l)
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.) (lb/gal)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds (in-lb)	0.011521	Meter-kilograms (m-kg)
Inch-pounds	1.12985×10^6	Centimeter-dynes (cm-dyn)
Foot-pounds (ft-lb)	0.138255	Meter-kilograms (m-kg)
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch (ft-lb/in)	5.4431	Centimeter-kilograms per centimeter (cm-kg/cm)
Ounce-inches (oz-in)	72.008	Gram-centimeters (g-cm)
VELOCITY		
Feet per second (ft/s)	30.48 (exactly)	Centimeters per second (cm/s)
Feet per second	0.3048 (exactly)*	Meters per second (m/s)
Feet per year (ft/yr)	$*0.965873 \times 10^{-6}$	Centimeters per second
Miles per hour (mi/h)	1.609344 (exactly)	Kilometers per hour (km/hr)
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2 (ft/s^2)	*0.3048	Meters per second^2 (m/s^2)
FLOW		
Cubic feet per second (second-feet) (ft^3/s)	*0.028317	Cubic meters per second (m^3/s)
Cubic feet per minute (ft^3/m)	0.4719	Liters per second (l/s)
Gallons (U.S.) per minute (gal/min)	0.06309	Liters per second
FORCE*		
Pounds (lb)	*0.453592	Kilograms (kg)
Pounds	*4.4482	Newtons (N)
Pounds	$*4.4482 \times 10^5$	Dynes (dyn)

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories (kg-cal)
British thermal units (Btu)	1,055.06	Joules (J)
Btu per pound	2.326 (exactly)	Joules per gram (J/g)
Foot-pounds (ft-lb)	*1.35582	Joules (J)
POWER		
Horsepower (hp)	745.700	Watts (w)
Btu per hour (Btu/hr)	0.293071	Watts
Foot-pounds per second (ft-lb/sec)	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor) transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9, then subtract 17.78	Celsius or Kelvin degrees
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

GPO 831-381

ABSTRACT

Ten-inch (25-cm) diameter concrete cores were extracted from mass concrete in Yellowtail Dam, Montana, 6 months, 1 year, 5 years, and 10 years after the concrete was placed. These cores were tested to determine physical properties of the concrete and to monitor changes in such properties with age. Test results indicate a good quality, well consolidated, durable concrete. Average compressive strength at 10 years' age was 5,010 lb/in^2 (34.5 MPa) for typical interior concrete and 5,000 lb/in^2 (34.5 MPa) for exterior concrete. Average moduli of elasticity at 10 years' age of interior and exterior concretes were 6.35×10^6 lb/in^2 and 6.29×10^6 lb/in^2 (4.38×10^4 MPa and 4.34×10^4 MPa) respectively. Average tensile strengths of the interior and exterior concretes at 10 years' age were 256 lb/in^2 and 268 lb/in^2 (1.76 MPa and 1.85 MPa) respectively.

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Bur Reclam Rep GR-9-75, Div Gen Res, July 1975. Bureau of Reclamation, Denver, 31 p.

DESCRIPTORS--/ concretes/ *compressive strength/ *tensile strength/ Poisson's ratio/ physical properties/ concrete testing/ concrete dams/ mass concrete/ *cores/ laboratory tests/ concrete mixes/ concrete technology/ concrete properties/ modulus of elasticity
IDENTIFIERS--/ Yellowtail Dam, Montana/ longtime tests
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