GR-85-12

PROPERTIES OF CONCRETE IN GLEN CANYON DAM— 20-Year Core Report

April 1986
Engineering and Research Center

U.S. Department of the Interior
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16. ABSTRACT

The physical properties of concrete cores extracted from mass concrete in Glen Canyon Dam were tested at various ages from 6 months to 20 years. The principal properties investigated were the compressive strength, the tensile strength and elastic properties.

This report discusses the results of tests on concrete cores extracted at 20 years' age. It includes the data from previous reports on cores tested at 6 months, 1 year, 2 years, 5 years, and 10 years. The cores extracted at 20 years' age show apparent decreases in compressive strength of 16 percent in interior concrete and 6 percent in exterior concrete during the preceding 10 years. However, these decreases are thought to be due to differences in the moisture conditions of the concrete cores tested, not from deterioration of the concrete.

Bond strength across horizontal construction joints was quite variable, as indicated by the direct tensile strength of cores with construction joints averaging 20 to 30 percent less than the tensile strength of companion cores without construction joints.

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by

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Prepared Under Contract No. 5-CA-81-05760

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

April 1986

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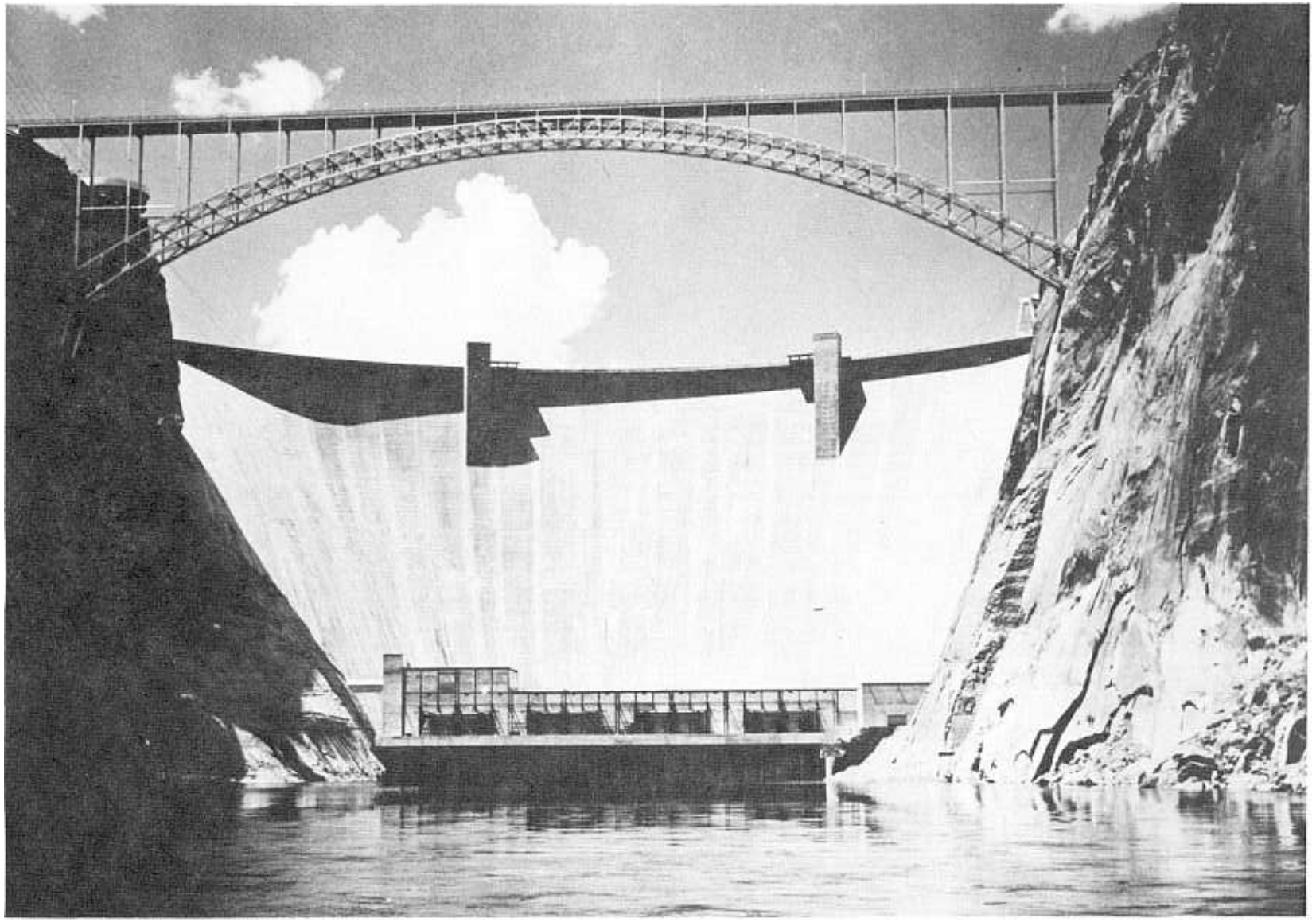

Frontispiece. – Glen Canyon Dam.

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INTRODUCTION

Glen Canyon Dam is a 710-ft (216-m) high concrete arch structure on the Colorado River in northern Arizona, about 15 miles (24 km) upstream of Lees Ferry. The dam was completed in 1964. It is a principal feature of the Colorado River Storage Project.

A concrete core testing program was included in the construction specifications to monitor the quality and uniformity of the concrete placed in the dam. This core testing program provided for 10-in (254-mm) diameter concrete cores to be extracted for testing at ages of 6 months, 1 year, 2 years, and 5 years. After the coring performed under the construction contract, additional cores were extracted at 10 years and 20 years to monitor the changes in concrete properties and to enhance the structural behavior studies being developed from the over 1000 stress and strain measuring instruments embedded in the structure. USBR (Bureau of Reclamation) laboratory reports No. C-1067 [1]*, C-1067A [2], and GR-22-76 [3] present data and conclusions on core tests through 10 years' age.

This report presents the results of tests performed on 10-in (254-mm) diameter cores extracted from Glen Canyon Dam at the age of 20 years. Tests were conducted to obtain values for compressive strength, tensile strength, modulus of elasticity, and Poisson's ratio. Pieces of cores were examined petrographically; a copy of the petrographic examination report is included as appendix A in this report. In addition, two specimens were tested in direct shear to obtain break bond and sliding friction values; a copy of the report of these tests is included as appendix B. Data from the earlier core tests [1, 2, 3] are included in this report for easy reference.

Two general types of mass concrete were placed in Glen Canyon Dam. The greater portion of the structure has an interior mix concrete with relatively low cement content and a pozzolan. The pozzolan was a natural pumice intended to be used in the amount of 30 percent by mass of the cement plus pozzolan. However, because the supplier could not provide the required amount of pozzolan, less than 30 percent was frequently used. The exterior concrete mix had about 50 lb/yd^3 (30 kg/m^3) more cement, but the same mass of pozzolan as the interior mix. The exterior mix was placed in the approximately 10 ft (3 m) of concrete adjacent to exposed surfaces. More cement was provided in the exterior concrete to give it durability for exposure in moderate to severe climatic conditions.

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* Numbers in brackets refer to entries in the bibliography.

A rounded natural aggregate from the Wahweep Creek deposit was used for the concrete. The maximum size aggregate was 6 in (152 mm), but the material available in the 3- to 6- in (76- to 152-mm) size fraction was deficient. Therefore, the amount used was less than normal. The general average gradation of the aggregate used was as follows:

Aggregate size		Percent
Sand		21
No. 4 to ¾ in	(4.8 to 19.0 mm)	20
¾ to 1½ in	(19.0 to 38.1 mm)	24
1½ to 3 in	(38.1 to 76.2 mm)	25
3 to 6 in	(76.2 to 152.0 mm)	10

The unprocessed aggregate contained variable amounts of lightweight, unsound, and deleterious rock. Most of the deleterious materials were in the size fractions from No. 8 to 1½ in (2.36 to 38.1 mm). Aggregate from these size fractions used in the exterior concrete were processed through a heavy-media treatment [4] to remove particles with a specific gravity less than 2.5.

The portland cement used in the concrete was a low-alkali type II cement. Pozzolan was supplied from a deposit of natural pumice ground to meet fineness requirements, but otherwise unprocessed. An AEA (air-entraining admixture) was used in all concrete, and starting in June 1961, a set-retarding WRA (water-reducing admixture) was added to the concrete mix. The portland cement content in the concrete was reduced about 10 percent with the use of the WRA.

CONCLUSIONS

1. Apparent decreases in the compressive strengths of cores tested at 20 years from similar cores tested at 10 years (6 percent for exterior concrete and 16 percent for interior concrete) were probably caused by changed test conditions, not by deterioration of the concrete.

2. Bond strength across horizontal construction joints was quite variable. The direct tensile strength of cores with construction joints averaged 20 to 30 percent less than the tensile strength of companion cores without construction joints.

3. The modulus of elasticity of the concrete has remained virtually unchanged since the 1- and 2-year tests were taken.

4. Cores extracted from concrete containing a water-reducing admixture continue to show higher compressive strengths than cores taken from concrete without a water-reducing admixture. This was true even when the concretes containing the admixture had a reduced cement content.

5. A petrographic examination of core samples showed that the quality of the concrete was satisfactory. It was hard, generally well-consolidated, and well-hydrated, with a generally strong paste-aggregate bond. There was no evidence of freeze-thaw damage, chemical attack, or reaction with aggregate particles.

DRILLING, HANDLING, AND TESTING PROCEDURES

Twenty-five 10-in (254-mm) diameter cores were extracted from Glen Canyon Dam during 1981 and 1982 to furnish test specimens of approximately 20-year-old concrete. Nine of the cores were drilled from exterior concrete, and 16 cores were drilled from interior concrete. Of the nine exterior cores, eight were drilled horizontally, one vertically. Four of the cores extracted from interior concrete were drilled horizontally, 12 vertically. Figure 1 shows the locations from which the 20-year cores and previous cores were drilled. A typical core is shown on figure 2.

Manpower restrictions and higher priority work precluded testing of the cores when they were received at the E&R Center laboratory. The cores were visually inspected and left in their shipping crates exposed to the laboratory environment. The relative humidity at the laboratory averaged less than 50 percent. Therefore, the cores were subject to drying for various periods, from 6 months to over 2 years. To bring the cores to a uniform moisture condition, they were saturated before testing and tested in a saturated condition.

Cores tested for compressive strength, modulus of elasticity, and Poisson's ratio were sawed to lengths of 20 in (508 mm). Their ends were then lapped flat to a tolerance of 0.002 in (0.05 mm). The modulus of elasticity and Poisson's ratio were determined in accordance with ASTM C 469, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression." An elasticity (compressometer-extensometer) frame with dial gauges for measuring longitudinal and lateral deformations was placed around the specimen. Before test measurements were taken, a preload of 1000 lb/in^2 (6.9 MPa) was applied to the specimen to check the operation of the gauges and to observe approximate elastic properties of the core. Then stress-strain values were recorded at zero load, 100 lb/in^2 (0.7 MPa), and 1000 lb/in^2 (6.9 MPa). The elasticity frame was then removed, and the core loaded to failure in compression.

Cores tested in direct tension were sawed to lengths of 20 in (508 mm). Cores containing a construction joint were sawed so the construction joint fell at approximately mid-length. Double end plates, 4½ in (114 mm) thick, designed to minimize deformation, were bonded to the ends of each specimen with epoxy adhesive. The epoxy was cured for 24 hours. Meanwhile, the test specimens were sealed with plastic to prevent moisture loss. After the epoxy curing period, the specimens were placed in a hydraulic testing machine with the end plates fastened to the upper and lower platens with clevis connectors. Figure 3 shows a core loaded in tension.

Selected fragments of the cores were examined petrographically. The concrete was examined megascopically, microscopically, by X-ray diffraction, by differential thermal analysis, and by qualitative physical and chemical tests (app. A).

Two cores, one with and one without a construction joint, were tested for direct shear strength. Although shear testing was not a scheduled part of the test program, a shear machine able to test 10-in (254-mm) specimens became available during the program. Two cores were made available for shear testing. Break bond data were obtained by subjecting each specimen to a constant normal load, while increasing the horizontal shearing load until the specimen failed or broke bond. The failed specimens were then subjected to a series of sliding friction tests in which increasing normal loads were applied and the shear stresses required to displace the surface were measured.

TEST RESULTS

Test results for the individual core specimens and other core data are given in tables 8 and 9. Test data from the previous core programs [1, 2, 3] are repeated in tables 1 through 7 for easy reference. A summary of the data is presented in tables 10 and 11.

Compressive Strength

The compressive strength data at 20 years' age (table 10 and fig. 4) indicate an apparent decrease in compressive strength of 16 percent in the interior concrete and 6 percent in the exterior concrete during the preceding 10 years. If these decreases in the core strengths are an accurate indication of loss of strength in the structure then the loss is significant. However, the reduced strength is believed to have resulted from a change in the moisture condition of the cores at the time of testing, not from a loss of strength of concrete in the structure.

ASTM Designation: C 42, "Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete," states that test specimens should be submerged in lime-saturated water for at least 40 hours immediately before testing. This is because dry concrete tests 20 to 30 percent higher in compressive strength than saturated concrete does [5]. Therefore, to compare concretes accurately, they should be at the same moisture condition or saturated.

The 20-year cores had been subjected to varying periods of drying in laboratory air before testing. Consequently, to bring these cores to a uniform moisture condition, they were placed in a fog room of 100 percent relative humidity for 4 months before testing. The 10-year cores had not been saturated and were tested in the moisture condition in which they were received [3]. Reports of 1-, 2-, and 5-year concrete [1, 2] do not identify the moisture condition of the cores when tested.

The apparent decrease in strength at 20 years is the result of comparing test data from concretes of different moisture conditions. The results of the modulus of elasticity tests and the petrographic examination support this opinion. Normally, a reduction in compressive strength from deterioration within concrete coincides with a reduction in elasticity. However, the 20-year cores had no reduction in their modulus of elasticity (fig. 5), and the petrographic report (app. A) shows no evidence of concrete deterioration. In a report on properties of concrete to 22 years' age, Higginson [6] indicated that cores extracted from structures over many years tend to plot as a sawtooth curve rather than as a smooth progression. Accordingly, the low results obtained at 2 and 20 years are not unusual.

Compressive strengths of vertically drilled cores from interior concrete continually tested higher than horizontally drilled cores. Nevertheless, the strengths of the 28-day control cylinders were about the same for the blocks where the horizontal and vertical cores were extracted. Consequently, the disparity in compressive strength is probably not the result of a difference in the concrete, but the result of the aggregate orientation, voids, and other factors related to the direction of loading. No comparison can be made for the exterior concrete because of the small number of vertically drilled cores.

Effect of Water-Reducing Admixtures

Cores extracted from concrete containing WRA show higher strengths than cores from concrete without WRA, even with a reduced cement content in the WRA concretes (fig. 7). The use of a WRA is advantageous in mass concrete not only because it yields higher strength, but also because less heat is generated (because of the lower cement content).

Cement Efficiency

In the earlier core test reports, [1, 2, 3], the "cement efficiency" was reported. This term is a misnomer; but, because it was used in the earlier reports, it is used for the 20-year tests in this report (table 10 and fig. 8). The cement efficiency, or more correctly the cement-pozzolan efficiency, indicates the compressive strength per unit mass of cementitious materials used. However, this value is affected not only by the quality of the cement and/or pozzolan, but also by aggregate properties, mixture proportions, use of WRA, consolidation of the concrete, curing, and other factors.

Coefficient of Variation

The coefficient of variation of the compressive strengths at 20 years is rather high: 21 percent for the interior concrete and 23 percent for the exterior concrete (table 10 and fig. 9). However, these coefficients of variation are considered acceptable because the compressive strength values are the averages of cores drilled horizontally and vertically with and without WRA, and with varying amounts of pozzolan. These values are also within the normal variations in core testing.

Modulus of Elasticity

Average 20-year modulus of elasticity values for both interior and exterior cores were higher than the 10-year values, but virtually unchanged from the 1- and 2-year values (table 10 and fig. 5). This supports the theory that the reduced compressive strength of the 20-year cores was caused by the change in moisture conditions during testing, not by deterioration of the concrete.

Tensile Strength

In the 10- and 20-year tests, a few cores were tested in direct tension. Approximately half of the cores tested from interior concrete contained a construction joint. The individual test results are given in tables 6, 7, 8 and 9, and the results are summarized in table 11.

Although the tensile strength program was too limited for other than qualified conclusions, it does appear that the full tensile strength of the concrete was not obtained across many of the horizontal construction joints. For the 10-year tests, the tensile strength of interior concrete cores containing construction joints averaged 77 percent of the tensile strength of the unjointed cores. For the 20-year tests, it averaged 71 percent.

The tensile strengths of unjointed cores were compared with the compressive strengths of cores taken from the same locations. For the interior concrete, the 10-year cores showed the tensile strength to be 5.2 percent of the compressive strength, and 20-year cores showed the tensile strength to be 6.7 percent. The tensile strength of the exterior concrete, which had a higher cement content than the interior concrete, was greater than that of the interior concrete. However, as a percentage of the compressive strength the tensile strength of exterior concrete was less: 4.8 percent for the 10-year cores and 5.5 percent for the 20-year cores. Figure 10 shows a typical broken surface of a core after failure in tension.

Petrographic Examination

The core samples examined petrographically indicated that the concrete was hard, generally well consolidated, well hydrated, and had a generally strong paste-aggregate bond. The concrete was generally uncarbonated and showed no evidence of freeze-thaw damage, chemical attack, or reaction with aggregate particles. Some flattened air voids were noted beneath large aggregate particles. This may have contributed to the difference in strength of horizontally and vertically drilled cores. The report of the petrographic examination is in appendix A.

Direct Shear Tests

Although direct shear tests were not part of the original test program, two cores were tested in direct shear. One core contained a construction joint and was positioned to fail at or near the joint. Results of the break bond and sliding friction tests and the calculated values for cohesion and tangent of the angle of friction (tangent Phi) are shown in table 12.

Although the direct tensile tests indicated a weakness in the bond strength at construction joints, the single-jointed specimen tested in shear had a higher break bond strength than the specimen tested without a joint. The complete report of the direct shear tests is in appendix B.

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Table 1. - *Compilation of core data for interior concrete at 6 months' and 1 year's age* (sheet 1 of 2)

6 MONTHS' AGE

Location No.6/	Core No.1/	Direction drilled5/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt4/ fresh conc, lb/cu ft	Properties of hardened concrete: Control cylinders: Compressive strength, lb/in² 28-day	Concrete cores: Compressive strength, lb/in²	Concrete cores: Elastic properties: E x 10⁻⁶ lb/in²	Concrete cores: Elastic properties: r	Concrete cores: Specific gravity	Concrete cores: Unit weight lb/cu ft	Strength ratio core 28-d cyl, percent
1.	7B-753-35	V	3090.0	11- 8-60	5- 3-61	6-16-61	45	64	45	0.60	195	94	172	21	148.3	2,100	3,680	7.10	0.22	2.42	150.8	175
2.	7B-755-34	H	3091.8	11- 9-60	5-11-61	6-14-61	45	49	32	0.61	199	94	178	21	150.7	2,390	3,640	6.07	0.19	2.42	150.8	152
3.	7B-750-34#1	H	3091.8	11- 9-60	5-10-61	6-13-61	45	49	32	0.61	199	94	178	21	150.7	2,390	3,770	6.19	0.16	2.43	151.4	158
	7B-750-34#2	H	3091.8	11-28-60	5- 9-61	6-14-61	45	49	32	0.61	199	94	178	21	150.7	2,390	3,960	6.18	0.20	2.42	150.8	166
4.	15B-750-24	H	3092.0	11-24-60	5-15-61	6-16-61	51	56	37	0.59	199	94	173	21	151.0	2,250	3,600	6.38	0.13	2.44	152.0	160
5.	15B-755-24	H	3092.0	11-24-60	5-15-61	6-16-61	51	56	37	0.59	199	94	173	21	151.0	2,250	3,310	7.46	0.18	2.45	152.6	147
6.	14A-874-5	V	3187.5	4-17-61	9-15-61	10-13-61	48	83	55	0.62	193	70	160	21	149.3	2,400	4,970	6.52	0.17	2.41	150.1	207
7.	14A-876-5	V	3187.5	4-17-61	9-26-61	10-13-61	48	83	55	0.62	193	70	160	21	149.3	2,400	4,480	5.82	0.22	2.40	149.5	187
8.	8A-874-4#1	V	3187.5	4-21-61	9-19-61	10-18-61	49	82	53	0.59	198	70	159	20	150.9	2,770	4,430	6.79	0.20	2.44	152.0	160
	8A-874-4#2	V	3184.9	4-21-61	9-16-61	10-18-61	49	82	53	0.59	198	70	159	20	150.9	2,770	4,680	6.40	0.18	2.44	152.0	169
9.	12A-874-5#1	V	3187.5	4-26-61	9-19-61	10-23-61	49	71	45	0.58	198	70	155	20	151.0	3,140	3,960	5.75	0.16	2.45	152.6	126
	12A-874-5#2	V	3185.1	4-26-61	9-19-61	10-23-61	49	71	45	0.58	198	70	155	20	151.0	3,140	3,930	5.64	0.22	2.41	150.1	125
10.	10A-874-10#1	V	3187.5	4-26-61	9-22-61	10-23-61	45	71	50	0.60	198	70	159	20	149.0	2,370	5,510	6.21	0.22	2.45	152.6	232
	10A-874-10#2	V	3185.2	4-26-61	9-22-61	10-24-61	45	71	50	0.60	198	70	159	20	149.0	2,370	4,080	4.65	0.17	2.36	147.0	172
11.	2/6A-850-5#1	V	3187.5	5- 3-61	9-23-61	10-30-61	--	94	61	0.59	253	94	205	26	147.5	2,680	3,960	5.46	0.22	2.38	148.3	148
	2/6A-850-5#2	V	3185.1	5- 3-61	9-23-61	10-30-61	--	94	61	0.59	253	94	205	26	147.5	2,680	4,500	5.91	0.19	2.41	150.1	168
12.	15A-874-5#1	V	3187.5	5-10-61	9-27-61	11- 6-61	48	92	68	0.54	220	70	159	20	150.5	3,280	3,830	6.11	0.21	2.36	147.0	117
	15A-874-5#2	V	3185.4	5-10-61	9-27-61	11- 6-61	48	92	68	0.54	220	70	159	20	150.5	3,280	3,510	5.91	0.18	2.42	150.8	107
13.	17A-874-13#1	V	3187.5	5-16-61	9-27-61	11-13-61	44	90	61	0.59	220	70	171	20	150.8	2,920	4,180	6.22	0.16	2.43	151.4	143
	17A-874-13#2	V	3185.0	5-16-61	9-27-61	11-13-61	44	90	61	0.59	220	70	171	20	150.8	2,920	4,220	5.90	0.18	2.39	148.9	144
14.	13A-874-18#1	V	3187.5	5-19-61	9-28-61	11-15-61	45	94	63	0.59	220	70	170	20	150.2	3,180	3,940	6.08	0.17	2.43	151.4	124
	13A-874-18#2	V	3185.6	5-19-61	9-28-61	11-15-61	45	94	63	0.59	220	70	170	20	150.2	3,180	4,860	5.76	0.21	2.34	145.8	153
15.	2/11A-874-7#1	V	3187.5	5-18-61	10- 2-61	11-14-61	--	94	63	0.59	253	94	205	26	147.5	2,680	3,910	6.30	0.19	2.43	151.4	146
	2/11A-874-7#2	V	3185.0	5-18-61	10- 2-61	11-14-61	--	94	63	0.59	253	94	205	26	147.5	2,680	4,260	6.08	0.22	2.44	152.0	159
16.	9A-874-16#1	V	3187.5	5-23-61	10- 2-61	11-17-61	48	96	66	0.54	207	80	156	21	152.5	2,970	4,450	5.76	0.18	2.37	147.7	150
	9A-874-16#2	V	3185.0	5-23-61	10- 2-61	11-17-61	48	96	66	0.54	207	80	156	21	152.5	2,970	5,480	7.01	0.25	2.43	151.4	185
17.	8A-893-21#1	V	3479.0	8- 4-62	1-17-63	2-26-63	49	67	40	0.54	188	7/ 80	145	21	149.9	2,870	4,700	6.26	0.17	2.46	153.3	164
	8A-893-21#2	V	3476.5	8- 4-62	1-17-63	2-26-63	49	67	40	0.54	188	7/ 80	145	21	149.9	2,870	4,560	5.35	0.24	2.40	149.5	159
18.	17-893-20#1	V	3478.7	10- 9-62	2-19-63	4- 9-63	47	85	57	0.53	242	7/ 80	170	26	--	3,260	4,410	6.13	0.16	2.44	152.0	135
	17-893-20#2	V	3476.2	10- 9-62	2-19-63	4- 9-63	47	85	57	0.53	242	7/ 80	170	26	--	3,030	4,790	6.28	0.18	2.45	152.6	158
19.	8-875-21#1	V	3585.0	12-27-62	6- 7-63	6-27-63	46	41	19	0.56	188	7/ 70	144	22	150.1	2,590	3,540	5.31	0.16	2.36	147.0	137
	8-875-21#2	V	3582.5	12-27-62	6- 7-63	6-27-63	46	41	19	0.56	188	7/ 70	144	22	150.1	2,590	5,680	6.47	0.18	2.44	152.0	219
20.	17-861-19#1	V	3585.0	2- 9-63	6-27-63	8- 9-63	51	66	41	0.57	188	7/ 72	148	22	149.6	2,640	4,330	5.57	0.15	2.39	148.9	164
	17-861-19#2	V	3582.5	2- 9-63	6-27-63	8- 9-63	51	66	41	0.57	188	7/ 72	148	22	149.6	2,640	4,920	5.20	0.15	2.41	150.1	186
21.	17-888-4#2	V	3695.0	6- 5-63	10-22-63	12- 5-63	46	86	61	0.52	190	7/ 70	135	22	149.6	2,420	3,850	6.81	0.17	2.44	152.0	159
					Average											2,730	3/4,280	6.09	0.19	2.42	150.5	159

1/Core numbers are coded to show location in the dam; example, 7B-750-34#2, shows this core as procured from Block 7B at a distance of 750 feet from the center of curvature of the axis of the dam, and 34 feet to the right of the 6/7 radial joint, #2 indicates the second or lower specimen from the core. Elevations are shown in a separate column.
2/Concrete represented by these cores contains 3-inch maximum-size aggregate.
3/Standard deviation 594 psi; coefficient of variation 13.9 percent. (Represents concrete with and without WRA.)
4/Based on unit weight can calibration made in June 1961.
5/H = Horizontal; V = Vertical.
6/Refers to numbers shown on Figure 1.
7/Mix also contains 0.37% water reducing agent (WRA) by weight of cement and pozzolan.

Table 1. - *Compilation of core data for interior concrete at 6 months' and 1 year's age* (sheet 2 of 2)

1 YEAR'S AGE

Location No.6/	Core No.1/	Direction drilled5/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt4/ fresh conc, lb/cu ft	Properties of hardened concrete: Control cylinders: Compressive strength, lb/in² 28-day	Control cylinders: 90-day	Concrete cores: Compressive strength, lb/in²	Concrete cores: Elastic properties: E x 10⁻⁶ lb/in²	Concrete cores: Elastic properties: r	Concrete cores: Specific gravity	Concrete cores: Unit weight lb/cu ft	Strength ratio core 28-d cyl, percent
22.	7B-753-30	V	3090.0	11- 8-60	10- 3-61	11- 8-61	45	64	45	0.60	195	94	172	21	148.3	2,100	--	3,780	7.22	0.20	2.42	150.8	180
23.	7B-755-33	H	3094.0	11- 8-60	10- 4-61	11- 8-61	45	64	45	0.60	195	94	172	21	148.3	2,100	--	3,800	5.98	0.18	2.41	150.1	181
24.	7B-750-33	H	3094.0	11- 8-60	10- 4-61	11- 8-61	45	64	45	0.60	195	94	172	21	148.3	2,100	--	3,690	5.88	0.19	2.41	150.1	176
25.	15B-755-26	H	3095.0	11-24-60	10- 9-61	11-24-61	51	56	37	0.59	199	94	173	21	151.0	2,250	--	4,540	7.01	0.24	2.42	150.8	202
26.	15B-750-24	H	3094.0	11-24-60	10- 5-61	11-24-61	51	56	37	0.59	199	94	173	21	151.0	2,250	--	4,780	7.28	0.20	2.45	152.6	212
27.	14A-876-17	V	3187.5	4-17-61	3-19-62	4-17-62	47	87	52	0.61	193	70	167	20	149.3	2,400	3,370	3,740	5.72	0.20	2.38	148.3	156
28.	8A-876-4	V	3187.5	4-21-61	3-20-62	4-30-62	48	82	53	0.60	198	70	163	20	151.3	2,700	--	4,050	6.41	0.16	2.45	152.6	150
29.	12A-874-59	V	3187.5	4-25-61	3-16-62	4-30-62	49	71	45	0.56	198	70	163	20	151.5	3,140	4,450	4,840	5.74	0.21	2.40	149.5	154
30.	10A-876-10	V	3187.5	4-26-61	3-20-62	4-30-62	47	74	47	0.61	198	70	163	21	149.3	2,380	--	4,710	6.06	0.20	2.37	147.7	198
31.	2/6A-852-5	V	3187.5	5- 3-61	3-23-62	5- 3-62	--	94	61	0.59	253	94	205	26	147.5	2,680	3,470	3,670	5.27	0.16	2.38	148.3	137
32.	15A-876-5	V	3187.5	5-10-61	3-19-62	5-10-62	48	93	63	0.56	220	70	164	20	150.5	2,870	--	3,780	5.14	0.20	2.31	143.9	132
33.	17A-876-13	V	3187.5	5-16-61	3-19-62	5-16-62	46	90	61	0.58	220	70	164	20	151.9	3,310	--	4,330	5.96	0.17	2.42	150.7	131
34.	2/11A-876-7	V	3187.5	5-18-61	3-23-62	5-21-62	--	94	63	0.59	253	94	205	26	147.5	2,680	--	4,760	5.78	0.24	2.41	150.1	178
35.	13A-876-18	V	3187.5	5-19-61	3-23-62	5-21-62	46	94	63	0.59	220	70	164	20	149.7	2,940	--	3,920	5.79	0.18	2.42	150.8	133
36.	9A-876-16	V	3187.5	5-23-61	3-22-62	5-21-62	48	95	66	0.55	210	80	163	21	151.8	2,900	--	4,550	6.01	0.19	2.38	148.3	157
37.	8A-910-15#1	V	3390.0	3-23-62	2-21-63	3-21-63	47	61	38	0.53	240	7/ 81	171	26	147.2	2,740	--	6,270	6.26	0.19	2.45	152.6	229
	8A-910-15#2	V	3388.0	3-23-62	2-21-63	3-21-63	47	61	38	0.53	240	7/ 81	171	26	147.2	2,740	--	5,180	6.23	0.19	2.44	152.0	189
38.	8A-898-20	V	3480.0	8- 4-62	6-28-63	8- 5-63	49	99	72	0.55	186	7/ 72	142	22	150.4	3,650	5,150	6,010	6.12	0.16	2.45	152.6	165
39.	8A-892-20	V	3480.0	8- 4-62	6-28-63	8- 5-63	49	99	72	0.55	186	7/ 72	142	22	150.4	3,650	5,150	5,750	6.28	0.18	2.46	153.2	158
40.	17A-891-21#1	V	3480.0	10- 9-62	8-21-63	10- 9-63	47	85	57	0.53	242	7/ 80	170	26	147.8	2,260	4,360	5,970	6.79	0.17	2.47	153.9	264
	17A-891-21#2	V	3477.6	10- 9-62	8-24-63	10- 9-63	49	85	57	0.54	194	7/ 70	143	22	150.0	2,950	4,260	4,860	7.28	0.18	2.48	154.5	165
41.	8-873-21#1	V	3585.0	12-27-62	11- 5-63	12-27-63	43	41	19	0.55	189	7/ 70	142	22	150.4	2,910	--	4,820	6.15	0.24	2.38	148.3	166
	8-873-21#2	V	3582.7	12-27-62	11- 5-63	12-27-63	43	41	19	0.55	189	7/ 70	142	22	150.4	2,910	--	5,780	6.67	0.20	2.44	152.0	199
42.	17-864-19#1	V	3585.0	2- 9-63	1- 9-64	2-10-64	51	66	41	0.57	188	7/ 72	148	22	149.6	2,640	--	4,860	6.39	0.19	2.41	150.1	184
	17-864-19#2	V	3582.7	2- 9-63	1- 9-64	2-10-64	51	66	41	0.57	188	7/ 72	148	22	149.6	2,640	--	5,450	6.24	0.19	2.41	150.1	206
43.	17-888-8#2	V	3695.0	6- 5-63	4- 7-64	6- 5-64	46	86	61	0.52	190	7/ 70	135	22	149.6	2,420	--	6,090	6.69	0.21	2.39	148.9	252
44.	22-883-43#1	H	3348.0	2-23-62	1-21-63	2-26-63	47	99	72	0.55	188	7/ 74	143	22	150.4	3,650	--	3,690	6.26	0.16	2.45	152.6	101
	22-883-43#2	H	3348.0	2-23-62	1-21-63	2-26-63	47	99	72	0.55	188	7/ 74	143	22	150.4	3,650	--	4,800	6.26	0.18	2.41	150.1	132
					Average					0.59						2,770	4,320	3/4,730	6.24	0.19	2.41	150.5	174

1/Core numbers are coded to show location in the dam; example, 7B-750-34#2, shows this core as procured from Block 7B at a distance of 750 feet from the center of curvature of the axis of the dam, and 34 feet to the right of the 6/7 radial joint, #2 indicates the second or lower specimen from the core. Elevations are shown in a separate column.
2/Concrete represented by these cores contains 3-inch maximum size aggregate.
3/Standard deviation 821 psi; coefficient of variation 17.4 percent. (Represents concrete with and without WRA.)
4/Based on unit weight can calibration made in June 1961.
5/H = Horizontal; V = Vertical.
6/Refers to numbers shown on Figure 1.
7/Mix also contains 0.37% water reducing agent (WRA) by weight of cement and pozzolan.

Table 2 - *Compilation of core data for exterior concrete at 6 months' and 1 year's age*

6 MONTHS' AGE

Location No.5/	Core No.1/	Direction drilled4/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt3/ fresh conc, lb/cu ft	Properties of hardened concrete: Control cylinders: Compressive strength, lb/in² 28-day	Concrete cores: Compressive strength, lb/in²	Elastic properties: E x 10⁻⁶ lb/in²	Elastic properties: r	Specific gravity	Unit weight lb/cu ft	Strength ratio core 28-d cyl, percent
45.	8B-708-16	H	3160	2-10-61	5-26-61	8-15-61	--	64	38	0.51	233	94	167	20	150.9	3,520	5,500	8.39	0.25	--	--	156
46.	17B-708-16	H	3160	3-23-61	5-18-61	9-19-61	--	82	50	0.51	233	94	167	20	150.9	3,340	6,290	6.72	0.22	2.46	150.2	188
47.	11B-708-16	H	3160	3-28-61	5-22-61	9-25-61	--	65	39	0.51	233	94	167	20	150.9	3,340	5,180	6.83	0.16	2.46	153.6	155
48.	14B-708-16	H	3160	3-31-61	5-19-61	9-27-61	--	68	42	0.51	233	94	167	20	150.9	3,340	5,710	6.84	0.20	2.44	152.0	171
49.	8-775-12#1	H	3483	9-21-62	2-26-63	3-21-63	47	90	63	0.47	254	6/ 72	153	21	149.9	--	4,320	6.57	0.19	2.50	155.8	--
	8-775-12#2	H	3481	9-21-62	2-26-63	3-21-63	47	90	63	0.47	254	6/ 72	153	21	149.9	--	5,310	6.53	0.17	2.48	154.5	--
50.	26-847-17#1	H	3550	3-15-63	8-17-63	9-16-63	46	58	30	0.46	254	6/ 72	150	21	150.4	--	5,210	7.18	0.20	2.46	153.2	--
	26-847-17#2	H	3550	3-15-63	8-17-63	9-16-63	46	58	30	0.46	254	6/ 72	150	21	150.4	--	5,730	6.46	0.19	2.44	152.0	--
51.	26-803-17#1	H	3633	5-16-63	10-18-63	--	45	91	61	0.46	254	6/ 72	150	21	150.3	--	7,540	6.78	0.14	2.48	154.5	--
	26-803-17#2	H	3633	5-16-63	10-18-63	--	45	91	61	0.46	254	6/ 72	150	21	150.3	--	6,320	6.56	0.15	2.47	153.9	--
52.	8-888-6#1	V	3697	4-20-63	9- 5-63	10-21-63	48	--	--	0.52	273	6/ 80	182	26	147.7	--	6,650	6.75	0.20	2.44	152.0	--
	8-888-6#2	V	3695	4-20-63	9- 5-63	10-21-63	47	--	--	0.46	254	6/ 72	150	21	150.3	--	6,520	6.69	0.19	2.44	152.0	--
53.	17-888-4#1	V	3697	6- 5-63	10-22-63	12- 5-63	46	86	61	0.52	273	6/ 80	182	26	147.7	--	5,680	6.29	0.19	2.40	149.5	--
					Average											3,390	2/5,840	6.81	0.19	2.46	152.8	168

1/Core numbers are coded to show location in the dam; example, 7B-750-34#2, shows this core as procured from Block 7B at a distance of 750 feet from the center of curvature of the axis of the dam, and 34 feet to the right of the 6/7 radial joint, #2 indicates the second or lower specimen from the core. Elevations are shown in a separate column.
2/Standard deviation 809 psi; coefficient of variation 13.8 percent. (Represents concrete with and without WRA.)
3/Based on unit weight can calibration made in June 1961.
4/H = Horizontal, V = Vertical.
5/Refers to numbers shown on Figure 1.
6/Mix also contains 0.37% water reducing agent (WRA) by weight of cement and pozzolan.

1 YEAR'S AGE

Location No.5/	Core No.1/	Direction drilled4/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt3/ fresh conc, lb/cu ft	Properties of hardened concrete: Control cylinders: Compressive strength, lb/in² 28-day	Concrete cores: Compressive strength, lb/in²	Elastic properties: E x 10⁻⁶ lb/in²	Elastic properties: r	Specific gravity	Unit weight lb/cu ft	Strength ratio core 28-d cyl, percent
54.	8B-708-14	H	3160	2-10-61	1-15-62	2- 9-62	--	64	38	0.51	233	94	167	20	150.9	3,520	5,220	6.29	0.22	2.41	150.1	148
55.	14B-708-14	H	3160	2-15-61	1- 8-62	2-15-62	--	68	42	0.51	233	94	167	20	150.9	3,340	5,480	6.45	0.20	2.39	148.9	164
56.	17B-708-14	H	3160	3-23-61	1- 9-62	3-23-62	--	82	50	0.51	233	94	167	20	150.9	3,340	5,760	6.39	0.27	2.44	152.0	172
57.	11B-708-14	H	3160	3-28-61	1- 8-62	3-28-62	--	65	39	0.51	233	94	167	20	150.9	3,340	5,610	6.73	0.21	2.42	150.8	168
58.	8B-804-8#1	H	3362	1-31-62	1-15-63	2-26-63	47	59	32	0.47	256	6/ 80	157	21	149.6	--	4,530	5.66	0.17	2.36	147.0	--
	8B-804-8#2	H	3362	1-31-62	1-15-63	2-26-63	47	59	32	0.47	256	6/ 80	157	21	149.6	--	4,330	5.96	0.21	2.40	149.5	--
59.	8-806-16#1	H	3486	9-21-62	8-16-63	9-20-63	47	90	63	0.47	254	6/ 72	153	21	149.9	--	5,780	6.34	0.16	2.47	153.9	--
	8-806-16#2	H	3486	9-21-62	8-16-63	9-20-63	47	90	63	0.47	254	6/ 72	153	21	149.9	--	4,050	6.72	0.17	2.45	152.6	--
60.	26-747-15#1	H	3550	3-15-63	1- 9-64	3-16-64	46	58	30	0.46	254	6/ 72	150	21	150.4	--	6,480	6.81	0.16	2.46	153.2	--
	26-747-15#2	H	3550	3-15-63	1- 9-64	3-16-64	46	58	30	0.46	254	6/ 72	150	21	150.4	--	6,570	6.69	0.20	2.46	153.2	--
61.	26-803-14#1	H	3633	5-16-63	4- 6-64	4-23-64	47	91	61	0.46	254	6/ 72	150	21	150.3	--	5,880	6.69	0.19	2.47	153.9	--
	26-803-14#2	H	3633	5-16-63	4- 6-64	4-23-64	47	91	61	0.46	254	6/ 72	150	21	150.3	--	6,260	6.64	0.17	2.46	153.3	--
62.	8-888-12#1	V	3697	4-20-63	3- 6-64	4-20-64	48	--	--	0.52	273	6/ 80	182	26	147.7	--	7,190	7.06	0.22	2.46	153.2	--
	8-888-12#2	V	3695	4-20-63	3- 6-64	4-20-64	47	--	--	0.46	254	6/ 72	150	21	150.3	--	3,310	7.27	0.23	2.42	150.8	--
63.	17-888-8#1	V	3697	6- 5-63	4- 7-64	6- 5-64	46	86	61	0.52	273	6/ 80	182	26	147.7	--	5,710	6.88	0.21	2.38	148.3	--
					Averages											3,390	2/5,480	6.57	0.20	2.43	151.4	163

1/Core numbers are coded to show location in the dam; example, 7B-750-34#2, shows this core as procured from Block 7B at a distance of 750 feet from the center of curvature of the axis of the dam, and 34 feet to the right of the 6/7 radial joint, #2 indicates the second or lower specimen from the core. Elevations are shown in a separate column.
2/Standard deviation 991 psi; coefficient of variation 18.1 percent. (Represents concrete with and without WRA.)
3/Based on unit weight can calibration made in June 1961.
4/H = Horizontal; V = Vertical.
5/Refers to numbers shown on Figure 1.
6/Mix also contains 0.37% water reducing agent (WRA) by weight of cement and pozzolan.

Table 3. - *Compilation of core data for interior and exterior concrete at 2 years' age*

INTERIOR CONCRETE

Location No.3/	Core No.1/	Direction drilled4/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt fresh conc, lb/cu ft	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/cu ft	Strength ratio core 28-d cyl, percent
64.	5B-632-40#1	V	3188.0	5-23-61	4-27-63	5-24-63	48	96	65	0.54	207	80	155	21	149.5	1,500	2,970	--	4,540	5.28	0.17	2.42	150.8	153
	5B-632-40#2	V	3188.0	5-23-61	4-27-63	5-24-63	48	96	65	0.54	207	80	155	21	149.5	1,420	2,840	--	4,590	4.76	0.17	2.36	147.0	162
65.	5B-750-40#1	H	3191.0	6- 2-61	4-25-63	6- 3-63	48	85	65	0.52	207	80	149	21	150.1	1,450	3,180	4,160	4,140	6.15	0.17	2.45	152.6	130
	5B-750-40#2	H	3191.0	6- 2-61	4-25-63	6- 3-63	48	85	65	0.52	207	80	149	21	150.1	1,520	3,180	4,240	4,440	5.76	0.13	2.42	150.8	140
66.	5B-754-41#1	V	3187.5	5-23-61	4-24-63	5-23-63	48	96	65	0.54	207	80	155	21	149.5	1,500	2,970	--	4,450	5.05	0.17	2.36	147.0	150
	5B-754-41#2	V	3187.5	5-23-61	4-24-63	5-23-63	48	96	65	0.54	207	80	155	21	149.5	1,420	2,840	--	3,210	4.77	0.18	2.36	147.0	113
67.	9A-872-24#1	H	3191.0	6- 2-61	4-22-63	6- 3-63	50	85	55	0.52	207	80	149	21	149.0	--	2,650	--	3,360	6.94	0.20	2.46	153.2	127
	9A-872-24#2	H	3191.0	6- 2-61	4-22-63	6- 3-63	50	85	55	0.52	207	80	149	21	149.0	--	2,800	--	4,270	5.94	0.18	2.41	150.1	152
68.	9A-876-25#1	V	3187.5	5-23-61	4-20-63	5-24-63	48	96	65	0.54	207	80	155	21	149.5	1,500	2,970	--	4,260	5.71	0.20	2.37	147.6	143
	9A-876-25#2	V	3187.5	5-23-61	4-20-63	5-24-63	48	96	65	0.54	207	80	155	21	149.5	1,420	2,840	--	3,180	4.90	0.15	2.38	148.3	112
69.	11A-872-12#1	H	3191.0	6- 2-61	4-19-63	6- 3-63	49	85	55	0.55	207	80	158	21	147.5	1,220	2,670	3,750	4,170	6.76	0.20	2.46	153.2	156
	11A-872-12#2	H	3191.0	6- 2-61	4-19-63	6- 3-63	49	85	55	0.55	207	80	158	21	147.5	1,180	2,620	3,800	4,370	6.28	0.18	2.43	151.4	167
70.	11A-876-13#1	V	3187.5	5-18-61	4-17-63	5-20-63	46	93	61	0.56	220	70	162	20	146.7	1,350	2,870	--	3,590	5.08	0.16	2.40	149.5	125
	11A-876-13#2	V	3187.5	5-18-61	4-17-63	5-20-63	46	93	61	0.56	220	70	162	20	146.7	1,420	3,020	--	3,430	5.47	0.14	2.43	151.4	114
71.	19B-754-4#1	V	3187.5	6- 8-61	5- 4-63	6-10-63	49	100	70	0.58	188	5/ 80	155	21	149.7	1,230	3,280	4,190	4,320	5.18	0.19	2.36	147.0	132
	19B-754-4#2	V	3187.5	6- 8-61	5- 4-63	6-10-63	49	100	70	0.58	188	5/ 80	155	21	149.7	1,420	2,710	4,300	4,340	5.26	0.20	2.39	148.9	160
72.	19B-755-5#1	H	3191.0	6-16-61	5- 4-63	6-17-63	46	100	73	0.59	188	5/ 80	158	21	149.6	1,000	2,690	--	4,830	5.93	0.17	2.42	150.8	180
	19B-755-5#2	H	3191.0	6-16-61	5- 4-63	6-17-63	46	100	73	0.59	188	5/ 80	158	21	149.6	1,530	3,180	--	4,650	6.32	0.17	2.44	152.0	146
73.	8A-849-2#1	V	3285.0	10- 9-61	9-11-63	10- 9-63	47	71	47	0.59	186	5/ 80	157	21	149.8	--	2,830	--	7,060	6.91	0.20	2.41	150.1	249
	8A-849-2#2	V	3282.5	10- 9-61	9-11-63	10- 9-63	47	71	47	0.59	186	5/ 80	157	21	149.8	--	2,830	--	5,370	6.73	0.19	2.43	151.4	190
	Average															1,380	2,900	4,070	2/4,330	5.76	0.18	2.41	150.0	150

1/See Table 1, footnote #1 for explanation of these core numbers.
2/Standard deviation 497 psi, coefficient of variation 11.5 percent. (Represents concrete with and without WRA.)
3/Refers to numbers shown on Figure 1.
4/H = horizontal: V = vertical
5/Mix also contains 0.37% water reducing agent (WRA) by weight of cement and pozzolan.

EXTERIOR CONCRETE

Location No.3/	Core No.1/	Direction drilled5/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt fresh conc, lb/cu ft	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/cu ft	Strength ratio core 28-d cyl, percent
74.	5B-627-11#1	H	3191.0	6- 2-61	4-27-63	6- 3-63	48	96	65	0.49	256	6/ 80	165	21	150.5	2,100	3,920	--	4,040	6.78	0.19	2.47	153.9	103
	5B-627-11#2	H	3191.0	6- 2-61	4-27-63	6- 3-63	48	96	65	0.49	256	6/ 80	165	21	150.5	2,200	3,910	--	4/2,880	6.68	0.14	2.45	152.6	74
75.	8B-704-12#1	H	3220.0	5-16-61	4-11-63	5-16-63	50	90	61	0.53	233	94	173	20	147.0	--	3,480	4,830	5,510	6.32	0.17	2.46	153.2	158
	8B-704-12#2	H	3220.0	5-16-61	4-11-63	5-16-63	50	90	61	0.53	233	94	173	20	147.0	--	3,450	4,790	5,460	6.54	0.16	2.47	153.9	158
76.	8B-708-15#1	H	3231.5	5-24-61	4-13-63	5-24-63	48	95	66	0.52	233	94	170	20	147.2	--	3,400	5,590	4,420	6.61	0.17	2.46	153.2	130
	8B-708-15#2	H	3231.5	5-24-61	4-13-63	5-24-63	48	95	66	0.52	233	94	170	20	147.2	--	3,400	5,130	4,840	6.16	0.17	2.46	153.2	142
77.	8B-714-10#1	H	3242.5	6-30-61	4-15-63	7-1-63	48	104	78	0.50	256	6/ 80	168	21	149.0	1,610	3,500	--	6,550	7.50	0.20	2.45	152.6	187
	8B-714-10#2	H	3242.5	6-30-61	4-15-63	7-1-63	48	104	78	0.50	256	6/ 80	168	21	149.0	1,620	3,430	--	6,540	6.63	0.16	2.44	152.0	191
	Averages															1,880	3,560	5,080	2/5,340	6.65	0.17	2.46	153.1	143

1/See Table 1, footnote #1, for explanation of these core numbers.
2/Standard deviation 888 psi, coefficient of variation 16.6 percent. (Represents concrete with and without WRA.)
3/Refers to numbers shown on Figure 1.
4/Low strength due to concentration of 3" - 6" cobbles. Not included in averages.
5/H = horizontal: V-vertical
6/Mix also contains 0.37% water reducing agent (WRA) by weight of cement and pozzolan.

Table 4. - *Compilation of core data for interior concrete at 5 year's age*

Location No.4/	Core No.	Direction drilled3/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt fresh conc, lb/cu ft	WRA5/	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/cu ft	Strength ratio core 28-d cyl, percent
78.	1/5B-750-36#1	H	3192.2	6- 2-61	5-27-66	7-18-66	48	85	55	0.52	207	80	149	21	150.1	0	1,480	3,180	4,200	4,280	6.44	0.17	2.47	153.9	134
	5B-750-36#2	H	3192.2	6- 2-61	5-27-66	7-18-66	48	85	55	0.52	207	80	149	21	150.1	0	1,480	3,180	4,200	3,200	5.76	0.17	2.45	152.6	101
79.	5B-751-41#1	V	3187.5	5-23-61	5-23-66	7-15-66	48	96	65	0.54	207	80	155	22	149.5	0	1,450	2,900	--	4,460	5.55	0.17	2.40	149.5	154
	5B-751-41#2	V	3185.0	5-23-61	5-23-66	7-15-66	48	96	65	0.54	207	80	155	22	149.5	0	1,450	2,900	--	3,610	--	--	2.42	150.7	124
80.	8A-849-4.5#1	V	3285.0	10-10-61	8- 1-66	10-10-66	47	71	47	0.59	186	80	157	21	149.8	0.37	--	2,830	--	8,120	6.27	0.19	2.42	150.7	287
	8A-849-4.5#2	V	3282.5	10-10-61	8- 1-66	10-10-66	47	71	47	0.59	186	80	157	21	149.8	0.37	--	2,830	--	7,130	6.35	0.15	2.43	151.3	252
81.	8A-887-20#1	V	3480.0	8- 4-62	2- 3-68	3- 1-68	49	99	72	0.55	186	72	142	22	150.4	0.37	--	3,650	5,150	6,270	5.81	0.18	2.39	148.9	172
	8A-887-20#2	V	3477.5	8- 4-62	2- 3-68	3- 1-68	49	99	72	0.55	186	72	142	22	150.4	0.37	--	3,650	5,150	6,260	5.89	0.18	2.36	147.0	172
82.	8A-870-19#1	V	3585.0	12-27-62	2- 5-68	3- 1-68	43	41	19	0.55	189	70	142	22	150.4	0.37	--	2,910	--	4,750	5.71	0.16	2.35	146.4	163
	8A-870-19#2	V	3582.5	12-27-62	2- 5-68	3- 1-68	43	41	19	0.55	189	70	142	22	150.4	0.37	--	2,910	--	6,220	6.65	0.16	2.43	151.4	214
83.	8A-910-4#1	V	3390.0	3-23-62	7- 8-66	3-23-67	46	61	38	0.54	188	80	144	21	149.1	0	1,260	2,730	--	6,450	6.73	0.19	2.42	150.8	236
	8A-910-4#2	V	3387.5	3-23-62	7- 8-66	3-23-67	46	61	38	0.54	188	80	144	21	149.1	0	1,260	2,730	--	5,960	6.29	0.20	2.41	150.8	218
84.	9A-873-26.5#1	H	3191.8	6- 2-61	6- 9-66	7-18-66	50	85	55	0.52	207	80	149	21	149.0	0	--	2,720	--	3,420	6.60	0.27	2.44	152.0	126
	9A-873-26.5#2	H	3191.8	6- 2-61	6- 9-66	7-18-66	50	85	55	0.52	207	80	149	21	149.0	0	--	2,720	--	3,760	6.12	0.18	2.43	151.4	138
85.	9A-874-25.3#1	V	3187.5	5-23-61	6- 2-66	7-15-66	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	--	4,800	5.34	0.19	2.37	147.6	166
	9A-874-25.3#2	V	3185.0	5-23-61	6- 2-66	7-15-66	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	--	4,160	5.37	0.18	2.47	153.4	143
86.	11A-873-16.5#1	H	3191.9	6- 1-61	6-16-66	7-18-66	49	85	55	0.55	207	80	158	21	147.5	0	1,200	2,640	3,780	4,140	6.36	0.18	2.46	158.2	157
	11A-873-16.5#2	H	3191.9	6- 1-61	6-16-66	7-18-66	49	85	55	0.55	207	80	158	21	147.5	0	1,200	2,640	3,780	4,580	6.17	0.20	2.44	152.0	173
87.	11A-874-13.6#1	V	3187.5	5-18-61	6-13-66	7-15-66	47	93	63	0.57	218	69	163	20	146.2	0	1,420	3,020	--	4,540	5.74	0.17	2.43	151.4	150
	11A-874-13.6#2	V	3185.0	5-18-61	6-13-66	7-15-66	47	93	63	0.57	218	69	163	20	146.2	0	1,420	3,020	--	4,830	6.34	0.21	2.46	153.2	160
88.	17A-897-20#1	V	3480.0	10- 9-62	1-21-68	2-12-68	49	85	57	0.54	194	70	143	22	150.0	0.37	--	2,950	4,260	6,390	6.06	0.18	2.41	150.1	217
	17A-897-20#2	V	3477.5	10- 9-62	1-21-68	2-12-68	47	85	57	0.53	242	80	170	26	147.8	0.37	--	3,260	4,360	5,920	6.05	0.16	2.45	152.6	182
89.	17A-888-12#1	V	3697.5	6- 5-63	2- 6-68	6- 5-68	46	86	61	0.52	190	70	135	22	149.6	0.37	--	2,420	--	6,290	6.68	0.12	2.40	149.5	260
	17A-888-12#2	V	3695.0	6- 5-63	2- 6-68	6- 5-68	46	86	61	0.52	273	80	182	26	147.7	0.37	--	2,420	--	6,900	7.03	0.18	2.42	150.8	285
90.	17A-852-19#1	V	3585.0	2- 9-63	2- 2-68	3- 1-68	51	66	41	0.57	188	72	148	22	149.6	0.37	--	2,640	--	6,260	6.35	0.17	2.42	150.8	237
	17A-852-19#2	V	3582.5	2- 9-63	2- 2-68	3- 1-68	51	66	41	0.57	188	72	148	22	149.6	0.37	--	2,640	--	5,940	6.40	0.23	2.37	147.7	225
91.	19B-752-5.7#1	V	3187.5	6- 8-61	6-30-66	7-19-66	49	100	70	0.58	188	80	155	21	149.7	0.37	1,320	2,990	4,240	4,220	5.68	0.20	2.40	149.5	141
	19B-752-5.7#2	V	3185.0	6- 8-61	6-30-66	7-19-66	49	100	70	0.58	188	80	155	21	149.7	0.37	1,320	2,990	4,240	4,630	5.59	0.18	2.43	151.4	155
92.	19B-755-9.5#1	H	3191.0	6-16-61	6-28-66	7-19-66	46	100	73	0.59	188	80	158	20	149.6	0.37	1,320	2,930	--	4,610	5.24	0.16	2.41	150.1	157
	19B-755-9.5#2	H	3191.0	6-16-61	6-28-66	7-19-66	46	100	73	0.59	188	80	158	20	149.6	0.37	1,320	2,930	--	3,930	5.68	0.20	2.41	150.1	134
93.	22A-883-40.5#1	H	3348.8	2-23-62	1-17-68	2-12-68	49	67	40	0.54	188	80	145	21	149.9	0.37	1,220	2,870	--	5,300	6.25	0.15	2.41	150.1	185
	22A-883-40.5#2	H	3348.8	2-23-62	1-17-68	2-12-68	49	67	40	0.54	188	80	145	21	149.9	0.37	1,220	2,870	--	5,660	5.72	0.17	2.40	149.5	197
	Averages																1,350	2,900	4,340	2/5,220	6.07	0.18	2.42	150.8	182

1/See Table 1, footnote #1 for explanation of these core numbers.
2/Standard deviation 1,186 psi, coefficient of variation 22.7 percent. (Represents concrete with and without WRA.)
3/H = Horizontal, V = Vertical.
4/Refers to numbers shown on Figure 1.
5/Water-reducing agent - percent by weight of cement plus pozzolan.

Table 5. - *Compilation of core data for exterior concrete at 5 years' age*

Location No.4/	Core No.	Direction drilled3/	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/cu yd	Pozzolan content, lb/cu yd	Water content, lb/cu yd	Sand %	Unit wt fresh conc, lb/cu ft	WRA5/	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/cu ft	Strength ratio core 28-d cyl, percent
94.	1/5B-630-14.5#1	H	3191.0	6- 2-61	6-21-66	7-19-66	48	85	55	0.49	256	80	165	21	150.5	0.37	2,150	3,920	--	4,070	6.28	0.19	2.45	152.6	104
	5B-630-14.5#2	H	3191.0	6- 2-61	6-21-66	7-19-66	48	85	55	0.49	256	80	165	21	150.5	0.37	2,150	3,920	--	3,870	6.09	0.19	2.46	153.2	99
95.	5B-635-36#1	V	3188.0	5-23-61	6-23-66	7-19-66	50	96	65	0.51	233	94	167	20	147.7	0	1,830	3,860	--	4,130	4.77	0.16	2.35	146.4	107
	5B-635-36#2	V	3188.0	5-23-61	6-23-66	7-19-66	50	96	65	0.51	233	94	167	20	147.7	0	1,830	3,860	--	4,140	5.21	0.17	2.38	148.0	107
96.	8A-882-20#1	V	3697.5	4-20-63	1-10-68	4-20-68	48	--	--	0.52	273	80	182	26	147.7	0.37	--	--	--	6,080	6.58	0.21	2.40	149.5	--
	8A-882-20#2	V	3695.0	4-20-63	1-10-68	4-20-68	47	--	--	0.46	254	72	150	21	150.3	0.37	--	--	--	6,180	7.18	0.20	2.41	150.1	--
97.	8A-804-8#1	H	3484.5	9-21-63	12- 6-67	2-12-68	47	90	63	0.47	254	72	153	21	149.9	0.37	--	--	--	7,920	6.48	0.17	2.44	152.0	--
	8A-804-8#2	H	3484.5	9-21-63	12- 6-67	2-12-68	47	90	63	0.47	254	72	153	21	149.9	0.37	--	--	--	7,300	6.47	0.16	2.43	151.4	--
98.	8B-696.5-14.5#1	H	3222.0	5-16-61	7-15-66	8- 3-66	50	90	61	0.53	233	94	173	20	147.0	0	--	3,470	--	5,030	6.19	0.21	2.46	153.2	145
	8B-696.5-14.5#2	H	3222.0	5-16-61	7-15-66	8- 3-66	50	90	61	0.53	233	94	173	20	147.0	0	--	3,470	--	4,090	6.46	0.20	2.45	152.6	118
99.	8B-700-18#1	H	3230.0	5-24-61	7-19-66	8- 3-66	48	95	66	0.52	233	94	170	20	147.2	0	--	3,400	--	5,080	6.13	0.16	2.44	152.0	149
	8B-700-18#2	H	3230.0	5-24-61	7-19-66	8- 3-66	48	95	66	0.52	233	94	170	20	147.2	0	--	3,400	--	3,480	4.91	0.20	2.60	161.9	102
100.	8B-706-12#1	H	3244.0	6-30-61	7-20-66	8- 3-66	48	104	78	0.50	256	80	168	21	149.0	0	1,620	3,460	--	6,490	6.16	0.17	2.42	150.7	188
	8B-706-12#2	H	3244.0	6-30-61	7-20-66	8- 3-66	48	104	78	0.50	256	80	168	21	149.0	0	1,620	3,460	--	5,290	6.54	0.19	2.42	150.7	153
101.	8B-756-11#1	H	3364.0	1-31-62	7-28-66	1-31-67	47	59	32	0.47	256	80	157	21	149.6	0.37	--	--	--	5,960	5.74	0.16	2.36	147.0	--
	8B-756-11#2	H	3364.0	1-31-62	7-28-66	1-31-67	47	59	32	0.47	256	80	157	21	149.6	0.37	--	--	--	5,540	5.97	0.19	2.41	150.1	--
102.	26-806-21#1	H	3635.0	5-16-63	1- 3-68	5-16-68	45	91	61	0.46	254	72	150	21	150.2	0.37	--	--	--	6,780	6.88	0.17	2.47	153.9	--
	26-806-21#2	H	3635.0	5-16-63	1- 3-68	5-16-68	45	91	61	0.46	254	72	150	21	150.2	0.37	--	--	--	6,680	7.04	0.18	2.47	153.9	--
103.	26-747-21#1	H	3552.0	3-15-63	1- 6-68	3-15-68	46	58	30	0.46	254	72	150	21	150.4	0.37	--	--	--	7,510	7.42	0.18	2.44	152.0	--
	26-747-21#2	H	3552.0	3-15-63	1- 6-68	3-15-68	46	58	30	0.46	254	72	150	21	150.4	0.37	--	--	--	7,170	7.35	0.20	2.46	153.3	--
	Averages																1,870	3,620	--	2/5,640	6.29	0.18	2.44	151.7	127

1/See Table 1, footnote #1 for explanation of these core numbers.
2/Standard deviation 1,330 psi, coefficient of variation 23.6 percent. (Represents concrete with and without WRA.)
3/H = Horizontal, V = Vertical.
4/Refers to numbers shown on Figure 1.
5/Water-reducing agent - percent by weight of cement plus pozzolan.

Table 6. - *Compilation of core data for interior concrete at 10 years' age*

Location No. 4/	Core No.	Direction drilled	Elevation above sea level 3/	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Fresh concrete	Temperatures °F: Air Max.	Temperatures °F: Air Min.	Properties of concrete when placed: W/c+p by wt.	Cement content lbs/cu yd	Pozzolan content lbs/cu yd	Water content lbs/cu yd	Sand percent	Unit wt. fresh conc. lbs/cu ft	WRA 5/	Control cylinders: Compressive strength lb/in² 7-day	28-day	90-day	Properties of hardened concrete: Concrete cores: Compressive strength lb/in²	E x 10^{-6} lb/in²	r	Tensile strength psi	Strength ratio tensile/comp. percent	Specific gravity	Unit weight lbs/cu ft	Compressive strength of core: 28-day cylinder strength (percent)
104	1/ 5B-750-22.5-1	Horizontal	3191.5	6- 2-61	2-24-72	3-28-72	48	85	55	0.52	207	80	149	21	150.1	0	1,480	3,180	4,200	4,730	5.56	0.16	-	-	2.43	151.4	148
	5B-750-22.5-2	Horizontal	3191.5	6- 2-61	2-24-72	3-28-72	48	85	55	0.52	207	80	149	21	150.1	0	1,480	3,180	4,200	4,700	6.11	0.24	-	-	2.41	150.1	148
	5B-750-22.5-3	Horizontal	3191.5	6- 2-61	2-24-72	3-28-72	48	85	55	0.52	207	80	149	21	150.1	0	1,480	3,180	4,200	-	-	-	337	7.1	-	-	-
105	9A-873-35-1	Horizontal	3192.0	6- 3-61	3-31-72	4-24-72	50	85	55	0.52	207	80	149	21	149.0	0	-	2,720	-	4,000	5.91	0.17	-	-	2.43	151.4	147
	9A-873-35-2	Horizontal	3192.0	6- 3-61	3-31-72	4-24-72	50	85	55	0.52	207	80	149	21	149.0	0	-	2,720	-	4,120	5.63	0.21	-	-	2.40	149.5	151
	9A-873-35-3	Horizontal	3192.0	6- 3-61	3-31-72	4-24-72	50	85	55	0.52	207	80	149	21	149.0	0	-	2,720	-	4,020	6.01	0.18	-	-	2.40	149.5	148
106	11A-873-20-1	Horizontal	3192.0	6- 2-61	4- 6-72	6- 1-72	49	85	55	0.55	207	80	158	21	147.5	0	1,200	2,640	3,780	4,510	6.00	0.17	-	-	2.41	150.8	170
	11A-873-20-2	Horizontal	3192.0	6- 2-61	4- 6-72	6- 1-72	49	85	55	0.55	207	80	158	21	147.5	0	1,200	2,640	3,780	4,130	5.58	0.14	-	-	2.42	150.8	156
	11A-873-20-3	Horizontal	3192.0	6- 2-61	4- 6-72	6- 1-72	49	85	55	0.55	207	80	158	21	147.5	0	1,200	2,640	3,780	-	-	-	305	7.1	-	-	-
107	19B-755-32.5-1	Horizontal	3191.5	6-17-61	4-16-72	5-31-72	46	100	73	0.59	188	80	158	20	149.6	0.37	1,320	2,930	-	5,440	5.16	0.13	-	-	2.38	148.3	186
	19B-755-32.5-2	Horizontal	3191.5	6-17-61	4-16-72	5-31-72	46	100	73	0.59	188	80	158	20	149.6	0.37	1,320	2,930	-	6,020	5.33	0.11	-	-	2.42	150.8	205
	19B-755-32.5-3	Horizontal	3191.5	6-17-61	4-16-72	5-31-72	46	100	73	0.59	188	80	158	20	149.6	0.37	1,320	2,930	-	-	-	-	328	5.7	-	-	-
108	22A-883-42-1	Horizontal	3350.0	2-24-62	4-12-72	5-31-72	49	67	40	0.54	188	80	145	21	149.9	0.37	1,280	2,880	-	5,380	5.50	0.14	-	-	2.38	148.2	187
	22A-883-42-2	Horizontal	3350.0	2-24-62	4-12-72	5-31-72	49	67	40	0.54	188	80	145	21	149.9	0.37	1,280	2,880	-	6,210	4.35	0.13	-	-	2.38	148.2	216
	22A-883-42-3	Horizontal	3350.0	2-24-62	4-12-72	5-31-72	49	67	40	0.54	188	80	145	21	149.9	0.37	1,280	2,880	-	-	-	-	300	5.2	-	-	-
109	5B-754-39-1	Vertical	3186.5	5-24-61	2-11-72	3-25-72	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	-	4,260	4.48	0.14	-	-	2.38	148.3	146
	5B-754-39-2	Vertical	3184.5	5-24-61	2-11-72	3-25-72	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	-	3,680	4.28	0.15	-	-	2.36	147.0	126
	7/ 5B-754-39-3	Vertical	3181.0	5-24-61	2-11-72	3-25-72	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	-	-	-	-	240	6.0	-	-	-
110	8A-849-6-1	Vertical	3284.0	10-10-61	4-21-72	6- 5-72	47	71	47	0.59	186	80	157	21	149.8	0.37	-	2,830	-	6,860	5.77	0.16	-	-	2.41	153.8	242
	8A-849-6-2	Vertical	3281.5	10-10-61	4-21-72	6- 5-72	47	71	47	0.59	186	80	157	21	149.8	0.37	-	2,830	-	5,780	5.75	0.15	-	-	2.40	149.6	204
	7/ 8A-849-6-3	Vertical	3278.5	10-10-61	4-21-72	6- 5-72	47	71	47	0.59	186	80	157	21	149.8	0.37	-	2,830	-	-	-	-	273	4.3	-	-	-
111	8A-868-19-1	Vertical	3584.0	12-27-62	1-12-73	2- 5-73	43	41	19	0.55	189	70	142	22	150.4	0.37	1,830	2,910	-	5,290	6.37	0.19	-	-	2.59	161.4	182
	8A-868-19-2	Vertical	3582.0	12-27-62	1-12-73	2- 5-73	43	41	19	0.55	189	70	142	22	150.4	0.37	1,830	2,910	-	-	-	-	224	4.2	-	-	-
112	8A-882-20-1	Vertical	3479.0	8- 4-62	1- 9-73	2- 5-73	49	99	72	0.55	186	72	142	22	150.4	0.37	-	3,650	5,150	7,450	6.47	0.17	-	-	2.45	152.6	204
	8A-882-20-2	Vertical	3477.0	8- 4-62	1- 9-73	2- 5-73	49	99	72	0.55	186	72	142	22	150.4	0.37	-	-	-	-	-	-	260	3.5	-	-	-
113	8A-888-32-1	Vertical	3696.0	4-20-63	2-12-73	3-19-73	48	-	-	0.52	273	80	182	26	147.7	0.37	-	-	-	6,110	6.46	0.20	-	-	2.36	147.0	-
	8A-888-32-2	Vertical	3694.5	4-20-63	2-12-73	3-19-73	48	-	-	0.52	273	80	182	26	147.7	0.37	-	-	-	-	-	-	275	4.5	-	-	-
	8A-888-32-3	Vertical	3693.0	4-20-63	2-12-73	3-19-73	48	-	-	0.52	273	80	182	26	147.7	0.37	-	-	-	6,110	5.57	0.12	-	-	2.39	148.9	-
114	8A-910-6-1	Vertical	3389.0	3-23-62	4-19-72	6- 5-72	46	61	38	0.54	188	80	144	21	149.1	0.37	1,260	2,730	-	7,420	6.69	0.15	-	-	2.40	149.6	272
	8A-910-6-2	Vertical	3386.5	3-23-62	4-19-72	6- 5-72	46	61	38	0.54	188	80	144	21	149.1	0.37	1,260	2,730	-	6,750	5.39	0.14	-	-	2.42	150.7	247
	7/ 8A-910-6-3	Vertical	3383.0	3-23-62	4-19-72	6- 5-72	46	61	38	0.54	188	80	144	21	149.1	0.37	1,260	2,730	-	-	-	-	231	3.3	-	-	-
115	9A-874-36-1	Vertical	3186.0	5-24-61	3-29-72	4-24-72	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	-	4,700	5.69	0.19	-	-	2.36	147.0	162
	9A-874-36-2	Vertical	3183.5	5-24-61	3-29-72	4-24-72	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	-	4,140	5.29	0.16	-	-	2.40	149.5	143
	9A-874-36-3	Vertical	3180.5	5-24-61	3-29-72	4-24-72	48	96	65	0.54	207	80	155	22	149.5	0	1,460	2,900	-	-	-	-	204	4.6	-	-	-
116	11A-874-19.4-1	Vertical	3186.5	5-19-61	3-23-72	6- 1-72	47	93	63	0.57	218	69	163	20	146.2	0	1,420	3,020	-	4,460	5.28	0.14	-	-	2.43	151.4	148
	11A-874-19.4-2	Vertical	3183.5	5-19-61	3-23-72	6- 1-72	47	93	63	0.57	218	69	163	20	146.2	0	1,420	3,020	-	4,950	4.11	0.12	-	-	2.42	150.8	164
	7/ 11A-874-19.4-3	Vertical	3180.5	5-19-61	3-23-72	6- 1-72	47	93	63	0.57	218	69	163	20	146.2	0	1,420	3,020	-	-	-	-	182	3.8	-	-	-
117	17A-857-19-1	Vertical	3584.0	2- 9-63	2-23-73	3-26-73	51	66	41	0.57	188	72	148	22	149.6	6/ 0.5	-	2,640	-	6,040	6.05	0.16	-	-	2.42	150.7	229
	7/ 17A-857-19-3	Vertical	3580.5	2- 9-63	2-23-73	3-26-73	51	66	41	0.57	188	72	148	22	149.6	0.5	-	2,640	-	-	-	-	149	2.5	-	-	-
118	17A-888-26.5-1	Vertical	3696.0	6- 6-63	2-15-73	3-19-73	46	86	61	0.52	190	70	135	-	149.6	0.37	-	2,420	-	5,330	6.63	0.14	-	-	2.41	150.1	220
	7/ 17A-888-26.5-3	Vertical	3689.5	6- 6-63	2-15-73	3-19-73	46	86	61	0.52	190	70	135	-	149.6	0.37	-	2,420	-	-	-	-	246	4.6	-	-	-
119	17A-895-20-1	Vertical	3479.0	10- 9-62	2-26-73	6- 5-73	47	85	57	0.53	242	80	170	26	147.8	0.37	-	3,260	4,360	5,270	6.03	0.18	-	-	2.41	150.1	162
	17A-895-20-2	Vertical	3477.0	10- 9-62	2-26-73	6- 5-73	47	85	57	0.53	242	80	170	26	147.8	0.37	-	3,260	4,360	-	-	-	273	5.2	-	-	-
120	19B-752.5-10-1	Vertical	3186.5	6- 9-61	4-14-72	5-31-72	49	100	70	0.58	188	80	155	21	149.7	0.37	1,320	2,990	4,240	4,860	4.69	0.13	-	-	2.39	148.9	162
	19B-752.5-10-2	Vertical	3184.5	6- 9-61	4-14-72	5-31-72	49	100	70	0.58	188	80	155	21	149.7	0.37	1,320	2,990	4,240	5,150	5.48	0.13	-	-	2.41	150.1	172
	7/ 19B-752.5-10-3	Vertical	3180.5	6- 9-61	4-14-72	5-31-72	49	100	70	0.58	188	80	155	21	149.7	0.37	1,320	2,990	4,240	-	-	-	180	3.6	-	-	-
Average																	1,390	2,890	4,210	2/ 5,260	5.59	0.16	250	4.7	2.41	150.2	180

1/ See Table No. 1 for explanation of these core numbers.
2/ Standard Deviation 1,015 psi; coefficient of variation 19.3 percent. (Represents concrete with and without WRA.)
3/ Elevation at midlength of core specimens drilled vertically.
4/ Refers to numbers shown on Figure 1.
5/ Water-reducing agent - percent by weight of cement plus pozzolan.
6/ 0.5 percent calcium chloride by weight of cement. (No WRA added.)
7/ Core contained a construction joint.

Table 7. - *Compilation of core data for exterior concrete at 10 years' age*

Location No. 4/	Core No.	Direction drilled	Elevation above sea level 3/	Dates: Concrete placed	Dates: Specimen drilled	Dates: Specimen tested	Temperatures °F: Fresh concrete	Temperatures °F: Air Max.	Temperatures °F: Air Min.	Properties of concrete when placed: W/c+p by wt.	Cement content lbs/cu yd	Pozzolan content lbs/cu yd	Water content lbs/cu yd	Sand percent	Unit wt. fresh conc. lbs/cu ft	WRA 5/	Control cylinders: Compressive strength lb/in² 7-day	28-day	90-day	Properties of hardened concrete: Concrete cores: Compressive strength lb/in²	E x 10^{-6} lb/in²	r	Tensile strength	Strength ratio tensile/comp. percent	Specific gravity	Unit weight lbs/cu ft	Compressive strength of core: 28-day cylinder strength (percent)
121	1/ 5B-625-9.5-1	Horizontal	3192.0	6- 2-61	1-11-72	2-11-72	48	85	55	0.49	256	80	165	21	150.5	0.37	2,150	3,920	-	5,130	6.80	0.17	-	-	2.43	151.4	131
	5B-625-9.5-2	Horizontal	3192.0	6- 2-61	1-11-72	2-11-72	48	85	55	0.49	256	80	165	21	150.5	0.37	2,150	3,920	-	-	-	-	250	5.8	-	-	-
	5B-625-9.5-3	Horizontal	3192.0	6- 2-61	1-11-72	2-11-72	48	85	55	0.49	256	80	165	21	150.5	0.37	2,150	3,920	-	3,500	6.88	0.16	-	-	2.41	150.1	89
122	8A-803-6-1	Horizontal	3485.5	9-21-62	3-28-73	6- 8-73	47	90	63	0.47	254	72	153	21	149.9	0.37	-	-	-	6,680	6.72	0.18	-	-	2.42	150.1	-
	8A-803-6-2	Horizontal	3485.5	9-21-62	3-28-73	6- 8-73	47	90	63	0.47	254	72	153	21	149.9	0.37	-	-	-	6,810	6.39	0.16	-	-	2.42	153.9	-
	8A-803-6-3	Horizontal	3485.5	9-21-62	3-28-73	6- 8-73	47	90	63	0.47	254	72	153	21	149.9	0.37	-	-	-	-	-	-	370	5.5	-	-	-
123	8B-699-15-1	Horizontal	3225.0	5-16-61	3-23-72	4-24-72	50	90	61	0.53	233	94	173	20	147.0	0	-	3,470	-	5,010	5.24	0.16	-	-	2.41	150.1	144
	8B-699-15-2	Horizontal	3225.0	5-16-61	3-23-72	4-24-72	50	90	61	0.53	233	94	173	20	147.0	0	-	3,470	-	5,940	5.95	0.16	-	-	2.42	150.8	171
	8B-699-15-3	Horizontal	3225.0	5-16-61	3-23-72	4-24-72	50	90	61	0.53	233	94	173	20	147.0	0	-	3,470	-	-	-	-	158	2.9	-	-	-
124	8B-700-16-1	Horizontal	3230.0	5-24-61	3-20-72	4-24-72	48	95	66	0.52	233	94	170	20	147.2	0	-	3,400	-	5,120	5.41	0.25	-	-	2.44	152.0	150
	8B-700-16-2	Horizontal	3230.0	5-24-61	3-20-72	4-24-72	48	95	66	0.52	233	94	170	20	147.2	0	-	3,400	-	-	-	-	240	5.2	-	-	-
	8B-700-16-3	Horizontal	3230.0	5-24-61	3-20-72	4-24-72	48	95	66	0.52	233	94	170	20	147.2	0	-	3,400	-	4,020	4.47	0.08	-	-	2.42	150.8	118
125	8B-706-10.5-1	Horizontal	3244.0	6-30-61	2-11-72	3-25-72	48	104	78	0.50	256	80	168	21	149.0	0	1,620	3,460	-	7,120	6.64	0.20	-	-	2.42	150.8	206
	8B-706-10.5-2	Horizontal	3244.0	6-30-61	2-11-72	3-25-72	48	104	78	0.50	256	80	168	21	149.0	0	1,620	3,460	-	5,650	5.94	0.12	-	-	2.39	148.9	163
	8B-706-10.5-3	Horizontal	3244.0	6-30-61	2-11-72	3-25-72	48	104	78	0.50	256	80	168	21	149.0	0	1,620	3,460	-	-	-	-	349	5.5	-	-	-
126	8B-757-9.5-1	Horizontal	3364.5	2- 1-62	2-11-72	3-25-72	47	59	32	0.47	256	80	157	21	149.6	0.37	-	-	-	6,030	5.68	0.16	-	-	2.30	143.3	-
	8B-757-9.5-2	Horizontal	3364.5	2- 1-62	2-11-72	3-25-72	47	59	32	0.47	256	80	157	21	149.6	0.37	-	-	-	6,420	6.30	0.17	-	-	2.37	147.6	-
	8B-757-9.5-3	Horizontal	3364.5	2- 1-62	2-11-72	3-30-72	47	59	32	0.47	256	80	157	21	149.6	0.37	-	-	-	-	-	-	291	4.7	-	-	-
127	26-747-18-1	Horizontal	3553.75	3-15-63	4-30-73	6- 8-73	46	58	30	0.46	254	72	150	21	150.4	0.37	-	-	-	6,520	6.92	0.21	-	-	2.41	150.1	-
	26-747-18-2	Horizontal	3553.75	3-15-63	4-30-73	6- 8-73	46	58	30	0.46	254	72	150	21	150.4	0.37	-	-	-	6,430	7.05	0.19	-	-	2.44	152.0	-
	26-747-18-3	Horizontal	3553.75	3-15-63	4-30-73	6- 8-73	46	58	30	0.46	254	72	150	21	150.4	0.37	-	-	-	-	-	-	256	4.0	-	-	-
128	26-805-19.5-1	Horizontal	3365.75	5-16-63	5- 4-73	6- 8-73	45	91	61	0.46	254	72	150	21	150.3	0.37	-	-	-	6,840	6.24	0.13	-	-	2.43	151.4	-
	26-805-19.5-2	Horizontal	3365.75	5-16-63	5- 4-73	6- 8-73	45	91	61	0.46	254	72	150	21	150.3	0.37	-	-	-	6,480	6.90	0.18	-	-	2.42	150.8	-
	26-805-19.5-3	Horizontal	3365.75	5-16-63	5- 4-73	6- 8-73	45	91	61	0.46	254	72	150	21	150.3	0.37	-	-	-	-	-	-	344	5.2	-	-	-
129	5B-634-41-1	Vertical	3187.0	5-24-61	1-17-72	2-11-72	50	96	65	0.51	233	94	167	20	147.7	0	1,830	3,810	-	4,420	5.61	0.20	-	-	2.37	147.6	116
	5B-634-41-2	Vertical	3184.5	5-24-61	1-17-72	2-15-72	50	96	65	0.51	233	94	167	20	147.7	0	1,830	3,810	-	4,710	4.97	0.19		-	2.36	147.1	124
	6/ 5B-634-41-3	Vertical	3181.5	5-24-61	1-17-72	2-15-72	50	96	65	0.51	233	94	167	20	147.7	0	1,830	3,810	-	-	-	-	6/ 129	2.8	-	-	-
Average																	1,870	3,610	0	2/ 5,710	6.12	0.17	265	4.6	2.40	149.9	141

1/ See Table No. 1 for explanation of these core numbers.
2/ Standard deviation 1,038 psi; coefficient of variation 18.2 percent. (Represents concrete with and without WRA.)
3/ Elevation at midlength of core specimens that were drilled vertically.
4/ Refers to number shown on Figure 1
5/ Water-reducing agent - percent by weight of cement plus pozzolan.
6/ Core contained a construction joint; tensile specimen broke at construction joint when tested.

Table 8. – Core data for interior concrete at 20 years' age.

Location No.[1]	Core No.[2]	Direction drilled[7]	Elevation above sea level, ft[3]	Date: Concrete placed	Date: Specimen drilled	Date: Specimen tested	Temperature, °F: Concrete	Temperature, °F: Air Max.	Temperature, °F: Air Min.	Properties of concrete when placed: W/c+p by wt	Cement content, lb/yd³	Pozzolan content, lb/yd³	Water content, lb/yd³	Sand, %	Unit weight fresh conc., lb/ft³	WRA[4]	Properties of hardened concrete: Control cylinders: Compressive strength, lb/in²: 7-d	28-d	90-d	Concrete cores: Compressive strength, lb/in²	Elastic properties: E × 10⁻⁶, lb/in²	Elastic properties: r	Tensile strength, lb/in²	Strength ratio tensile/comp., %	Specific gravity	Unit wt, lb/ft³	Compressive strength of core: 28-d cylinder strength, %
130	5B-21.8-1	H	3189.7	06-02-61	03-24-81	09-02-83	48	85	55	0.52	207	80	149	21	150.1	0	1480	3180	4200	4130	5.80	0.16	–	–	2.42	151	130
	5B-21.8-2	H	3189.7	06-02-61	03-24-81	09-02-83	48	85	55	.52	207	80	149	21	150.1	0	1480	3180	4200	–	–	–	290	8.3	–	–	–
	5B-21.8-3	H	3189.7	06-02-61	03-24-81	09-02-83	48	85	55	.52	207	80	149	21	150.1	0	1480	3180	4200	3080	5.40	0.14	–	–	2.45	153	97
	5B-21.8-4	H	3189.7	06-02-61	03-24-81	09-02-83	48	85	55	.52	207	80	149	21	150.1	0	1480	3180	4200	3330	5.60	0.17	–	–	2.44	152	105
131	9A-42-1	H	3192.0	06-03-61	05-18-81	09-02-83	50	85	55	.52	207	80	149	21	149.0	0	–	2720	–	3390	5.10	0.12	–	–	2.43	151	125
	9A-42-2	H	3192.0	06-03-61	05-18-81	09-02-83	50	85	55	.52	207	80	149	21	149.0	0	–	2720	–	–	–	–	260	7.8	–	–	–
	9A-42-3	H	3192.0	06-03-61	05-18-81	09-02-83	50	85	55	.52	207	80	149	21	149.0	0	–	2720	–	3290	4.80	0.14	–	–	2.42	151	121
	9A-42-4	H	3192.0	06-03-61	05-18-81	09-02-83	50	85	55	.52	207	80	149	21	i49.0	0	–	2720	–	3340	5.20	0.12	–	–	2.38	148	123
132	11A-27-1B	H	3192.0	06-02-61	06-24-81	09-01-83	49	85	55	.55	207	80	158	21	147.5	0	1200	2640	3780	3180	6.30	0.14	–	–	2.48	154	120
	11A-27-2B	H	3192.0	06-02-61	06-24-81	09-01-83	49	85	55	.55	207	80	158	21	147.5	0	1200	2640	3780	–	–	–	290	8.3	–	–	–
	11A-27-3B	H	3192.0	06-02-61	06-24-81	09-01-83	49	85	55	.55	207	80	158	21	147.5	0	1200	2640	3780	3550	5.70	0.17	–	–	2.41	150	134
	11A-27-4B	H	3192.0	06-02-61	06-24-81	09-01-83	49	85	55	.55	207	80	158	21	147.5	0	1200	2640	3780	3720	5.60	0.16	–	–	2.43	151	141
133	19B-15-1	H	3191.5	06-17-61	12-10-81	09-07-83	46	100	73	.59	188	80	158	20	149.6	0.37	1320	2930	–	3930	6.50	0.16	–	–	2.42	151	134
	19B-15-2	H	3191.5	06-17-61	12-10-81	09-07-83	46	100	73	.59	188	80	158	20	149.6	.37	1320	2930	–	–	–	–	320	8.0	–	–	–
	19B-15-3	H	3191.5	06-17-61	12-10-81	09-07-83	46	100	73	.59	188	80	158	20	149.6	.37	1320	2930	–	3830	6.40	0.21	–	–	2.45	153	131
	19B-15-4	H	3191.5	06-17-61	12-10-81	09-07-83	46	100	73	.59	188	80	158	20	149.6	.37	1320	2930	–	4290	6.90	0.14	–	–	2.44	152	148
134	5B-40.3-3	V	3180.0	05-24-61	03-27-81	–	48	96	65	.54	207	80	155	22	149.5	0	1460	2900	–	–	–	–	210	7.2	–	–	–
135	8A-6-3	V	3277.5	10-10-61	07-02-81	08-30-83	47	71	47	.59	186	80	157	21	149.8	0.37	–	2830	–	4750	5.30	0.16	–	–	2.46	153	168
136	8A-19-1	V	3584.0	12-27-62	06-18-82	09-02-83	43	41	19	.55	189	70	142	22	150.4	.37	1830	2910	–	4040	6.20	0.17	–	–	2.36	147	139
137	8A-20-1	V	3479.0	08-04-62	07-09-81	08-30-83	49	99	72	.55	186	72	142	22	150.4	.37	–	3650	5150	5830	6.80	0.13	–	–	2.48	154	160
	8A-20-2	V	3477.0	08-04-62	07-09-81	08-30-83	49	99	72	.55	186	72	142	22	150.4	.37	–	3650	5150	4590	4.00	0.13	–	–	2.40	149	126
	8A-20-3	V	3475.0	08-04-62	07-09-81	08-30-83	49	99	72	.55	186	72	142	22	150.4	.37	–	3650	5150	–	–	–	40	0.8	–	–	–
138	8A-14-1	V	3696.0	04-20-63	06-16-82	09-01-83	48	–	–	.52	273	80	182	26	147.7	.37	–	–	–	4820	7.10	0.18	–	–	2.43	152	–
	8A-14-2	V	3693.0	04-20-63	06-16-82	09-01-83	48	–	–	.52	273	80	182	26	147.7	.37	–	–	–	5590	7.00	0.17	–	–	2.63	164	–
	[5]8A-14-3	V	3690.5	04-20-63	06-16-82	09-01-83	48	–	–	.52	273	80	182	26	147.7	.37	–	–	–	–	–	–	180	3.5	–	–	–
139	8A-2-1	V	3388.0	03-23-62	07-07-81	09-01-83	46	61	38	.54	188	80	144	21	149.1	.37	1260	2730	–	5110	6.50	0.14	–	–	2.43	151	187
	8A-2-2	V	3386.0	03-23-62	07-07-81	09-01-83	46	61	38	.54	188	80	144	21	149.1	.37	1260	2730	–	5330	5.50	0.17	–	–	2.38	148	195
140	9A-44.5-1	V	3186.0	05-24-61	05-21-81	08-30-83	48	96	65	.54	207	80	155	22	149.5	0	1460	2900	–	4720	5.10	0.13	–	–	2.51	156	163
	9A-44.5-2	V	3183.0	05-24-61	05-21-81	08-30-83	48	96	65	.54	207	80	155	22	149.5	0	1460	2900	–	2670	5.40	0.15	–	–	2.40	150	161
	9A-44.5-3	V	3180.0	05-24-61	05-21-81	08-30-83	48	96	65	.54	207	80	155	22	149.5	0	1460	2900	–	–	–	–	210	4.5	–	–	–
141	11A-27-2A	V	3183.0	05-19-61	06-19-81	09-06-83	47	93	63	.57	218	69	163	20	146.2	0	1420	3020	–	4560	5.20	0.10	–	–	2.45	153	151
	[5]11A-27-3A	V	3180.2	05-19-61	06-19-81	09-06-83	47	93	63	.57	218	69	163	20	146.2	0	1420	3020	–	–	–	–	70	1.5	–	–	–
142	17A-19-1	V	3583.5	02-09-63	06-25-82	09-03-83	51	66	41	.57	188	72	148	22	149.6	0.37	–	2640	–	4790	6.50	0.17	–	–	2.41	150	181
	[5]17A-19-3	V	3577.5	02-09-63	06-25-82	09-03-83	51	66	41	.57	188	72	148	22	149.6	.37	–	2640	–	–	–	–	[6]	–	–	–	–
143	17A-17.6-1	V	3696.0	06-06-63	06-24-82	09-02-83	46	86	61	.52	190	70	135	–	149.6	.37	–	2420	–	6450	6.80	0.15	–	–	2.45	153	266
	17A-17.6-2	V	3693.0	06-06-63	06-24-82	09-02-83	46	86	61	.52	190	70	135	–	149.6	.37	–	2420	–	4940	6.40	0.15	–	–	2.45	153	204
	[5]17A-17.6-3	V	3690.0	06-06-63	06-24-82	09-02-83	46	86	61	.52	190	70	135	–	149.6	.37	–	2420	–	–	–	–	190	3.3	–	–	–
144	17A-20-1	V	3478.8	10-09-62	07-02-82	09-06-83	47	85	57	.53	242	80	170	26	147.8	.37	–	3260	4360	6050	1.02	0.24	–	–	2.41	150	186
	17A-20-2	V	3476.0	10-09-62	07-02-82	09-06-83	47	85	57	.53	242	80	170	26	147.8	.37	–	3260	4360	4220	6.20	0.18	–	–	2.44	152	129
145	19B-13-1	V	3186.0	06-09-61	07-14-81	09-06-83	49	100	70	.58	188	80	155	21	149.7	.37	1320	2990	4240	3840	5.40	0.15	–	–	2.43	151	128
	[5]19B-13-3	V	3180.3	06-09-61	07-14-81	09-06-83	49	100	70	.58	188	80	155	21	149.7	.37	1320	2990	4240	–	–	–	200	5.2	–	–	–
	Average																1380	2910	4300	4390	5.71	0.16	210	5.3	2.44	152	150

Metric conversions: 1 ft = 0.3048 m; 1 lb/yd³ = 0.593 kg/m³; 1 lb/ft³ = 16.02 kg/m³; 1 lb/in² = 6.894 × 10⁻³ MPa; 1 lb/ft² = 4.79 × 10⁻² MPa.

[1] Refers to numbers shown on fig. 1.
[2] See table 1 for explanation of these core numbers.
[3] Elevation at midlength of core specimens drilled vertically.
[4] Water-reducing admixture = percent by weight of cement plus pozzolan.
[5] Core contained a construction joint.
[6] Broke in construction joint during handling.
[7] H = horizontal; V = vertical.

Table 9. – Core data for exterior concrete at 20 years' age.

Location No.[1]	Core No.[2]	Direction drilled	Elevation above sea level, ft[3]	Date: Concrete placed	Date: Specimen drilled	Date: Specimen tested	Temperature, °F: Fresh Concrete	Temperature, °F: Air Max.	Temperature, °F: Air Min.	Properties of concrete when placed: W/c+p by wt	Cement content, lb/yd³	Pozzolan content, lb/yd³	Water content, lb/yd³	Sand, %	Unit weight fresh conc., lb/ft³	WRA[4]	Properties of hardened concrete: Control cylinders: Compressive strength, lb/in²: 7-d	28-d	90-d	Concrete cores: Compressive strength, lb/in²	Elastic properties: E × 10⁻⁶, lb/in²	Elastic properties: r	Tensile strength, lb/in²	Strength ratio tensile/comp., %	Specific gravity	Unit wt, lb/ft³	Compressive strength of core: 28-d cylinder strength, %
146	5B-6.6-1	H	3191.0	06-02-61	03-10-81	09-02-83	48	85	55	0.49	256	80	165	21	150.5	0.37	2150	3920	–	5040	–	–	–	–	2.47	154	128
	5B-6.6-2	H	3191.0	06-02-61	03-10-81	09-02-83	48	85	55	.49	256	80	165	21	150.5	.37	2150	3920	–	–	–	–	270	5.8	–	–	–
	5B-6.6-4	H	3191.0	06-02-61	03-10-81	09-02-83	48	85	55	.49	256	80	165	21	150.5	.37	2150	3920	–	4260	6.10	0.15	–	–	2.27	141	109
147	8A-4-1	H	3484.5	09-21-62	11-02-82	08-30-83	47	90	63	.47	254	72	153	21	149.9	.37	–	–	–	7200	7.10	0.18	–	–	2.45	153	–
	8A-4-2	H	3484.5	09-21-62	11-02-82	08-30-83	47	90	63	.47	254	72	153	21	149.9	.37	–	–	–	–	–	–	440	6.4	–	–	–
	8A-4-3	H	3484.5	09-21-62	11-02-82	08-30-83	47	90	63	.47	254	72	153	21	149.9	.37	–	–	–	7650	6.80	0.16	–	–	2.44	152	–
	8A-4-4	H	3484.5	09-21-62	11-02-82	08-30-83	47	90	63	.47	254	72	153	21	149.9	.37	–	–	–	5900	7.00	0.20	–	–	2.44	152	–
148	8B-11-1	H	3222.0	05-16-61	03-20-81	08-30-83	50	90	61	.53	233	94	173	20	147.0	0	–	3470	–	4850	6.80	0.20	–	–	2.46	153	140
	8B-11-2	H	3222.0	05-16-61	03-20-81	08-30-83	50	90	61	.53	233	94	173	20	147.0	0	–	3470	–	3840	6.00	0.17	–	–	2.46	153	110
	8B-11-3	H	3222.0	05-16-61	03-20-81	08-30-83	50	90	61	.53	233	94	173	20	147.0	0	–	3470	–	–	–	–	210	5.2	–	–	–
	8B-11-4	H	3222.0	05-16-61	03-20-81	08-30-83	50	90	61	.53	233	94	173	20	147.0	0	–	3470	–	3420	5.30	0.20	–	–	2.47	154	99
149	8B-14-1	H	3229.5	05-24-61	10-05-82	08-30-83	48	95	66	.52	233	94	170	20	147.2	0	–	3400	–	4880	6.60	0.18	–	–	2.45	153	144
	8B-14-2	H	3229.5	05-24-61	10-05-82	08-30-83	48	95	66	.52	233	94	170	20	147.2	0	–	3400	–	–	–	–	230	5.7	–	–	–
	8B-14-3	H	3229.5	05-24-61	10-05-82	08-30-83	48	95	66	.52	233	94	170	20	147.2	0	–	3400	–	3480	4.60	0.12	–	–	2.42	151	102
	8B-14-4	H	3229.5	05-24-61	10-05-82	08-30-83	48	95	66	.52	233	94	170	20	147.2	0	–	3400	–	3710	6.00	0.17	–	–	2.41	150	109
150	8B-8.5-1	H	3244.0	06-30-61	10-08-82	08-30-83	48	104	78	.50	256	80	168	21	149.0	0	1620	3460	–	6130	8.10	–	–	–	2.31	144	185
	8B-8.5-2	H	3244.0	06-30-61	10-08-82	08-30-83	48	104	78	.50	256	80	168	21	149.0	0	1620	3460	–	–	–	–	380	6.7	–	–	–
	8B-8.5-3	H	3244.0	06-30-61	10-08-82	08-30-83	48	104	78	.50	256	80	168	21	149.0	0	1620	3460	–	5080	6.90	0.17	–	–	2.45	152	147
	8B-8.5-4	H	3244.0	06-30-61	10-08-82	08-30-83	48	104	78	.50	256	80	168	21	149.0	0	1620	3460	–	5770	7.40	0.19	–	–	2.45	152	167
151	8B-7-1	H	3364.0	02-01-62	10-27-82	08-30-83	47	59	32	.47	256	80	157	21	149.6	0.37	–	–	–	6320	7.20	0.22	–	–	2.38	148	–
	8B-7-2	H	3364.0	02-01-62	10-27-82	08-30-83	47	59	32	.47	256	80	157	21	149.6	.37	–	–	–	–	–	–	330	5.7	–	–	–
	8B-7-3	H	3364.0	02-01-62	10-27-82	08-30-83	47	59	32	.47	256	80	157	21	149.6	.37	–	–	–	5580	6.80	0.15	–	–	2.40	149	–
	8B-7-4	H	3364.0	02-01-62	10-27-82	08-30-83	47	59	32	.47	256	80	157	21	149.6	.37	–	–	–	5460	6.70	0.18	–	–	2.41	150	–
152	26A-15-1	H	3552.5	03-15-63	11-22-82	09-06-83	46	58	30	.46	254	72	150	21	150.4	.37	–	–	–	6560	7.00	0.17	–	–	2.41	150	–
	26A-15-2	H	3552.5	03-15-63	11-22-82	09-06-83	46	58	30	.46	254	72	150	21	150.4	.37	–	–	–	–	–	–	270	3.8	–	–	–
	26A-15-4	H	3552.5	03-15-63	11-22-82	09-06-83	46	58	30	.46	254	72	150	21	150.4	.37	–	–	–	7520	7.20	0.16	–	–	2.45	153	–
153	26A-24.5-1	H	3634.5	05-16-63	11-16-82	09-07-83	45	91	61	.46	254	72	150	21	150.3	.37	–	–	–	6050	8.60	0.16	–	–	2.48	155	–
	26A-24.5-2	H	3634.5	05-16-63	11-16-82	09-07-83	45	91	61	.46	254	72	150	21	150.3	.37	–	–	–	–	–	–	380	6.4	–	–	–
	26A-24.5-3	H	3634.5	05-16-63	11-16-82	09-07-83	45	91	61	.46	254	72	150	21	150.3	.37	–	–	–	5780	7.90	0.20	–	–	2.46	153	–
154	5B-32-1	V	3186.5	05-24-61	03-12-81	09-02-83	50	96	65	.51	233	94	167	20	147.7	0	1830	3810	–	3690	–	–	–	–	–	–	97
	5B-32-2	V	3184.5	05-24-61	03-12-81	09-02-83	50	96	65	.51	233	94	167	20	147.7	0	1830	3810	–	–	–	–	160	4.2	–	–	–
	Average																1840	3570	–	5370	6.81	0.18	300	5.5	2.43	151	128

Metric conversions: 1 ft = 0.3048 m; 1 lb/yd³ = 0.593 kg/m³; 1lb/ft³ = 16.02 kg/m³; 1 lb/in² = 6.894 × 10⁻³ MPa.

[1] Refers to numbers shown on fig. 1.

[2] See table 1 for explanation of these core numbers.

[3] Elevation at midlength of core specimens drilled vertically.

[4] Water-reducing admixture = percent by weight of cement plus pozzolan.

Table 10. – Summary of concrete core data.

Test age	No. of specimens	Average compressive strength, lb/in²	Cement efficiency, [1]lb/in²	Coefficient of variation, %[2]	Core strength-28-d cylinder, %	Average *E*, 10^6 lb/in²	Average Poisson's ratio
			Interior – Averages of All Specimens				
6 mo	35	4280	14.9	13.9	159	6.06	0.19
1 yr	28	4730	16.6	17.4	174	6.24	0.19
2 yr	20	4330	15.3	11.5	150	5.76	0.18
5 yr	32	5220	19.0	22.7	182	6.07	0.18
10 yr	30	5260	18.9	19.3	180	5.59	0.16
20 yr	29	4390	15.5	20.9	150	5.71	0.16
			Interior – Horizontally Drilled				
6 mo	5	3660	12.7	–	157	6.46	0.17
1 yr	6	4220	14.8	–	167	6.44	0.19
2 yr	8	4280	15.1	–	150	6.26	0.18
5 yr	10	4290	15.6	–	150	6.03	0.18
10 yr	11	4840	17.6	–	169	5.56	0.16
20 yr	12	3590	12.7	–	126	5.78	0.15
			Interior – Vertically Drilled				
6 mo	30	4390	15.2	–	159	6.02	0.19
1 yr	22	4870	17.1	–	176	6.19	0.19
2 yr	12	4360	15.4	–	150	5.42	0.18
5 yr	22	5640	20.5	–	196	6.09	0.18
10 yr	18	5510	19.6	–	187	5.60	0.15
20 yr	17	4960	17.5	–	170	5.67	0.16
			Exterior – Averages of All Specimens				
6 mo	13	5840	17.7	13.8	168	6.81	0.19
1 yr	15	5480	16.6	18.1	163	6.13	0.20
2 yr	8	5340	16.1	16.6	143	6.65	0.17
5 yr	20	5640	17.0	23.6	127	6.29	0.18
10 yr	18	5710	16.9	18.2	141	6.12	0.17
20 yr	22	5370	16.3	23.3	128	6.81	0.18
			Exterior – Horizontally Drilled				
6 mo	10	5710	17.3	–	168	6.89	0.19
1 yr	12	5500	16.6	–	163	6.45	0.19
2 yr	8	5340	16.1	–	143	6.65	0.17
5 yr	16	5770	17.4	–	132	6.38	0.18
10 yr	16	5860	17.2	–	146	6.22	0.17
20 yr	21	5450	16.5	–	131	6.81	0.18
			Exterior – Vertically Drilled				
6 mo	3	6280	19.0	–	–	6.57	0.19
1 yr	3	5400	16.3	–	–	7.07	0.22
2 yr	–	–	–	–	–	–	–
5 yr	4	5130	15.5	–	107	5.94	0.18
10 yr	2	4560	14.0	–	120	5.29	0.20
20 yr	1	3690	11.2	–	97	–	–

Metric conversion: 1 lb/in² = 6.894×10^{-3} MPa.
[1] Refers to cement-pozzolan efficiency.
[2] Represents concrete with and without WRA.

Table 11. – Average tensile strengths of cores with and without construction joints, 10-in-diameter cores.

Test age	Type of concrete	Type of specimen	No. of specimens	Tensile strength: Average, lb/in²	Tensile strength: Coefficient of variation, %	Average strength ratio tensile/comp., %
10 yr	Interior	Jointed	7	214	19.2	4.0
10 yr	Interior	Unjointed*	9	278	15.1	5.2
10 yr	Exterior	Jointed	1	129	–	2.8
10 yr	Exterior	Unjointed*	8	282	23.4	4.8
20 yr	Interior	Jointed	5	170	30	3.6
20 yr	Interior	Unjointed*	6	240	40	6.7
20 yr	Exterior	Jointed	–	–	–	–
20 yr	Exterior	Unjointed*	9	300	29	5.5

Metric conversion: 1 lb/in² = 6.894 × 10^{-3} MPa.
* Includes horizontal and vertical.

Table 12. – Direct shear tests.

Core No.	Normal Stress (N): lb/in²	Normal Stress (N): MPa	Shear Stress: lb/in²	Shear Stress: MPa	Linear regression: Equation, lb/in² [MPa]	Linear regression: Phi cohesion: degrees	Linear regression: Phi cohesion: lb/in²	Linear regression: Phi cohesion: MPa	Remarks*
17A-19-2 (no joint)	49	0.3	355	2.4					BB
	50	.3	139	1.0					SF
	100	.7	208	1.4					SF
	150	1.0	260	1.8	S = 81.2 + 1.212(N) [S = 0.56 + 1.212(N)]	50	81	0.6	SF
8A-2-3 (joint)	50	0.3	523	3.6					BB
	50	.3	190	1.3					SF
	100	.7	211	1.5					SF
	150	1.0	259	1.8	S = 150.5 + 0.694(N) [S = 1.038 + 0.694(N)]	35	151	1.0	SF

* BB = Break bond; SF = Sliding friction.

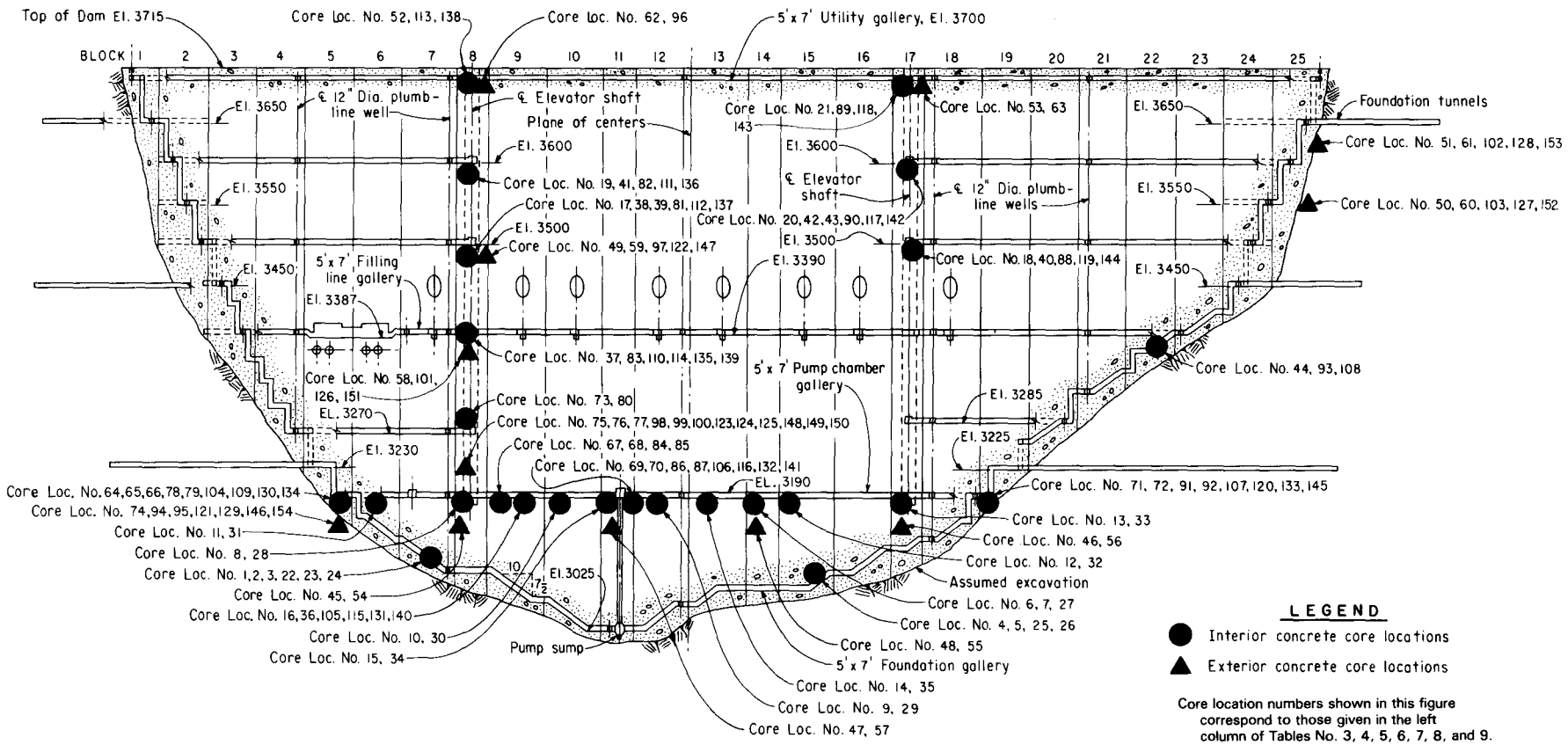

Figure 1. – Locations of core extractions in Glen Canyon Dam.

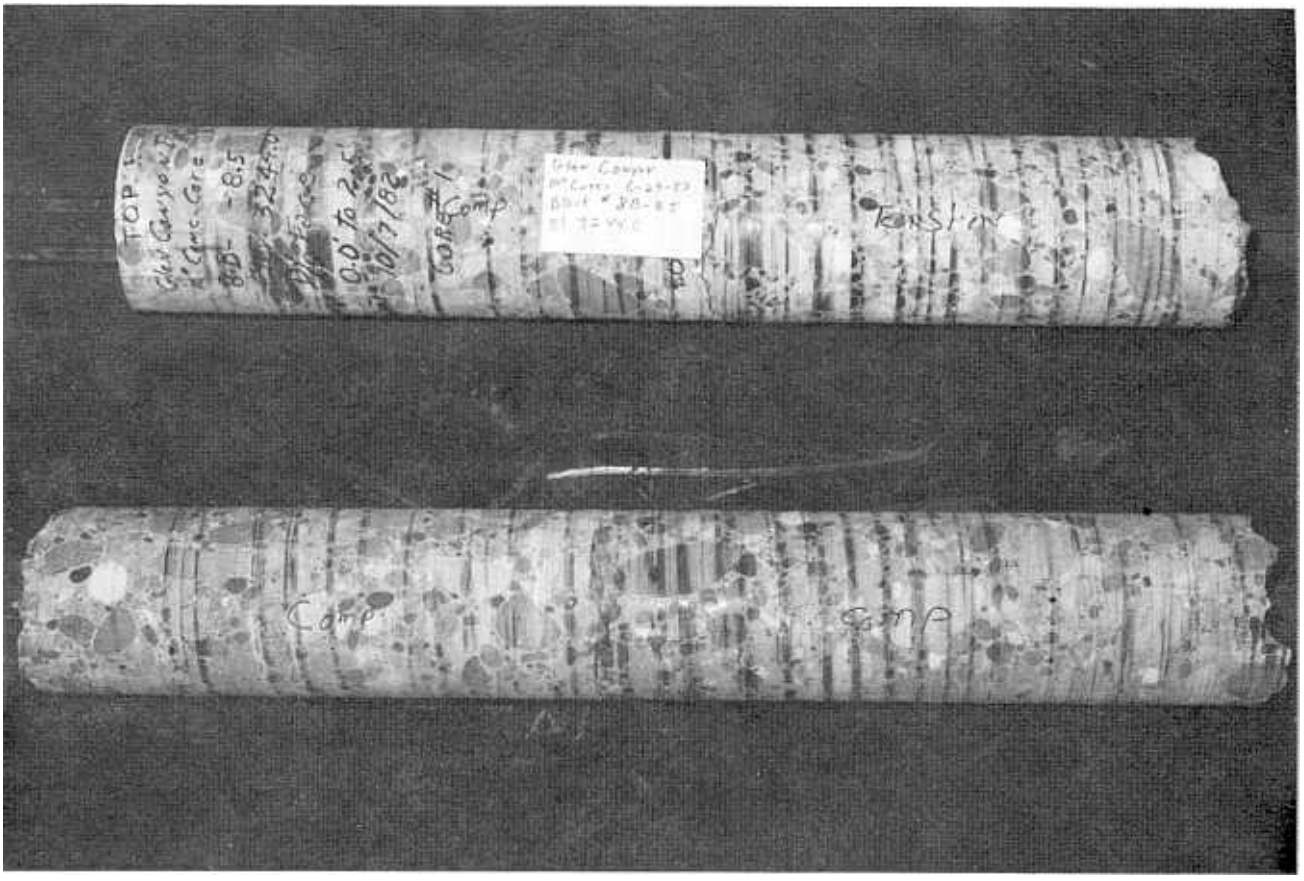

Figure 2. – Typical 10-in (254-mm) diameter concrete cores.

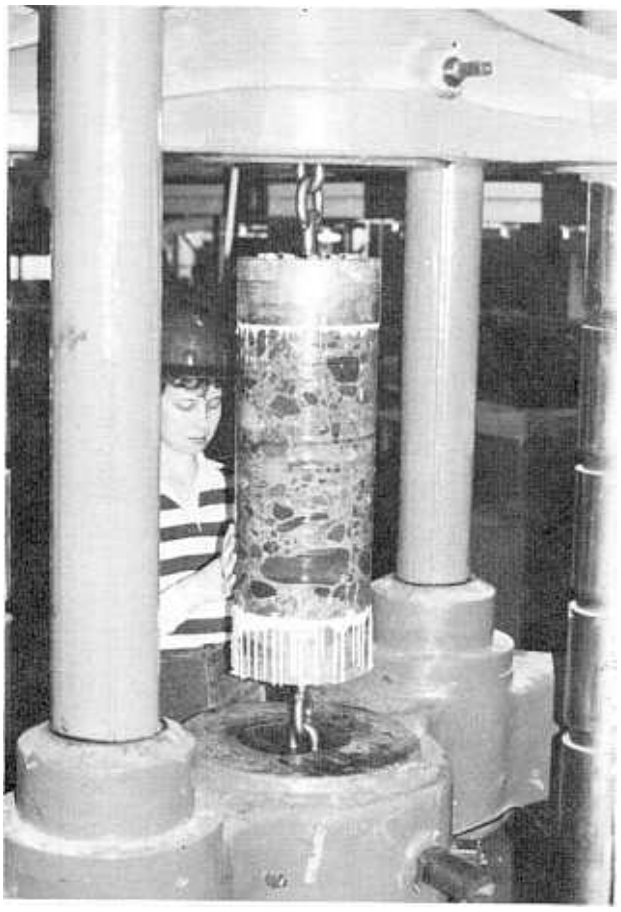

Figure 3. – Typical tension test of a 10-in diameter concrete core.

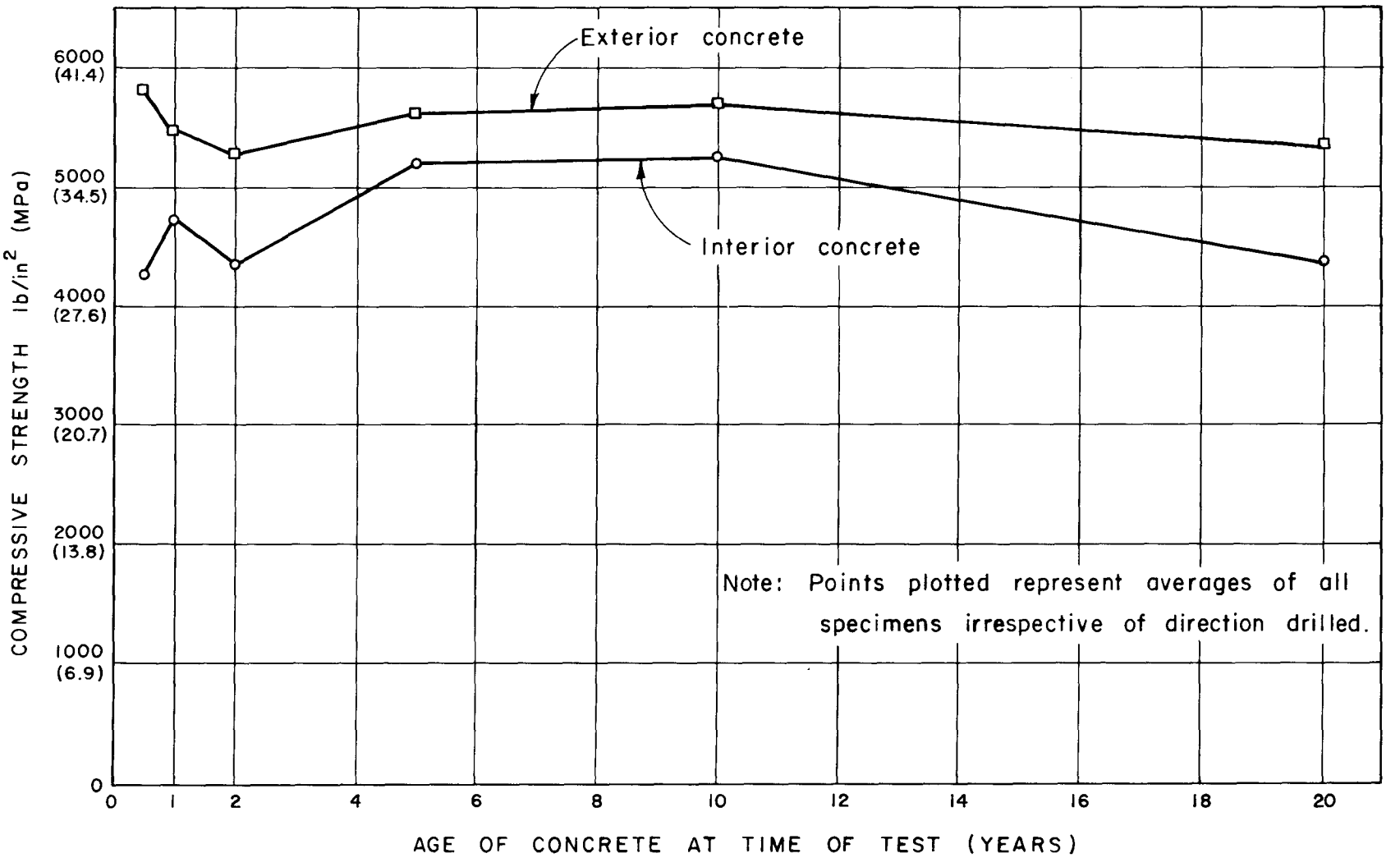

Figure 4. – Compressive strengths of concrete during first 20 years.

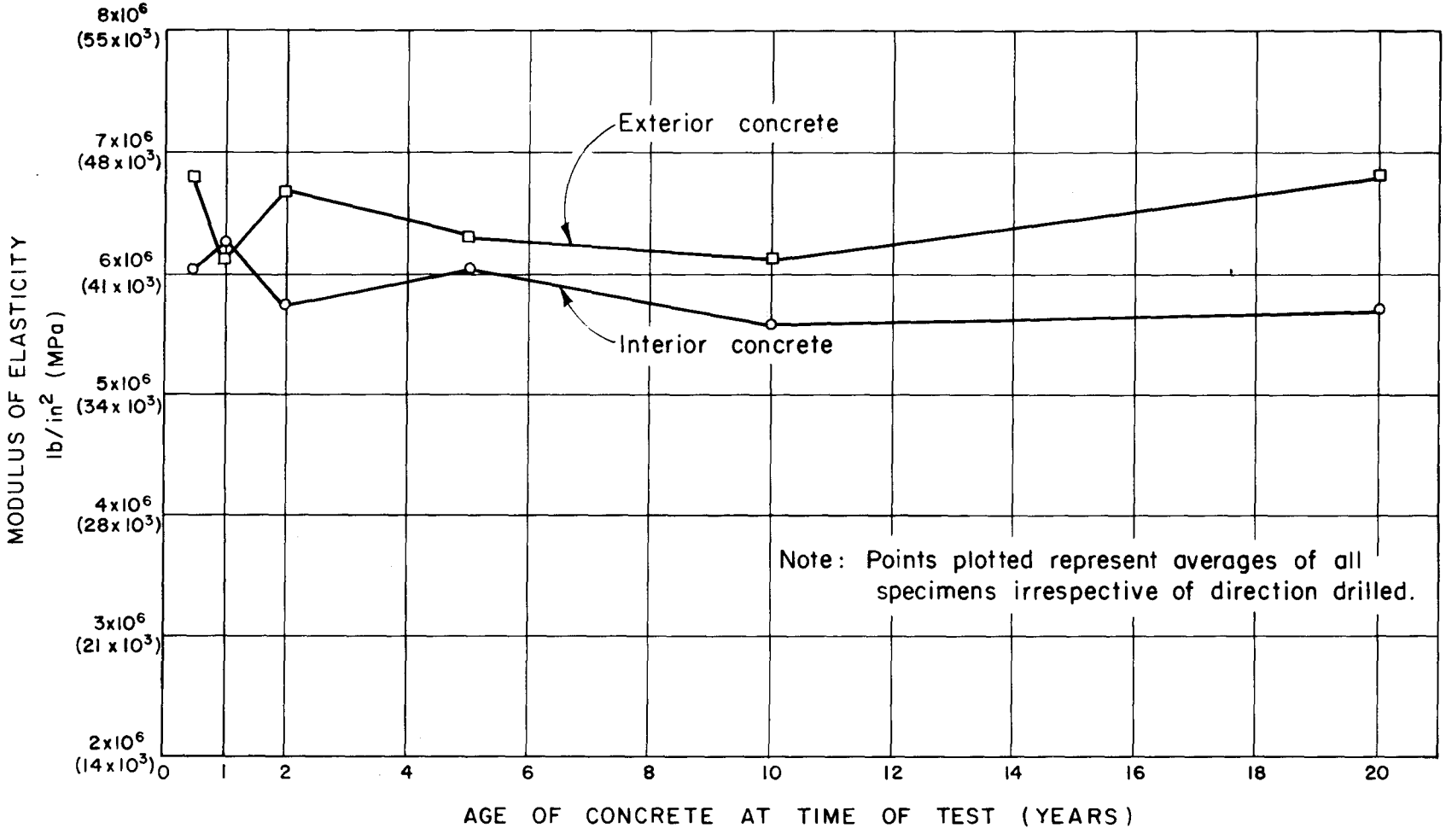

Figure 5. – Modulus of elasticity of the concrete.

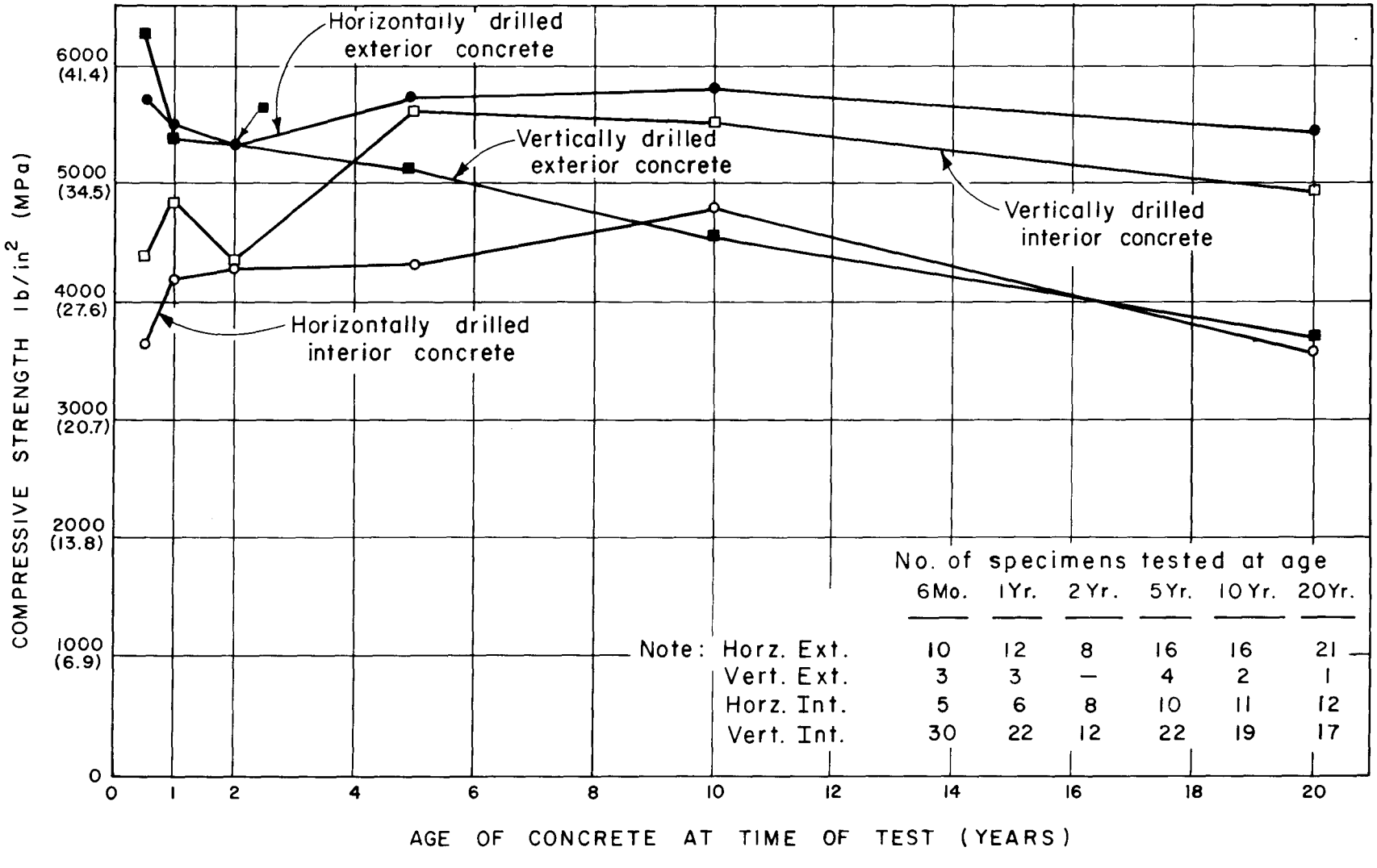

Figure 6. – Compressive strengths of concrete as affected by drilling direction.

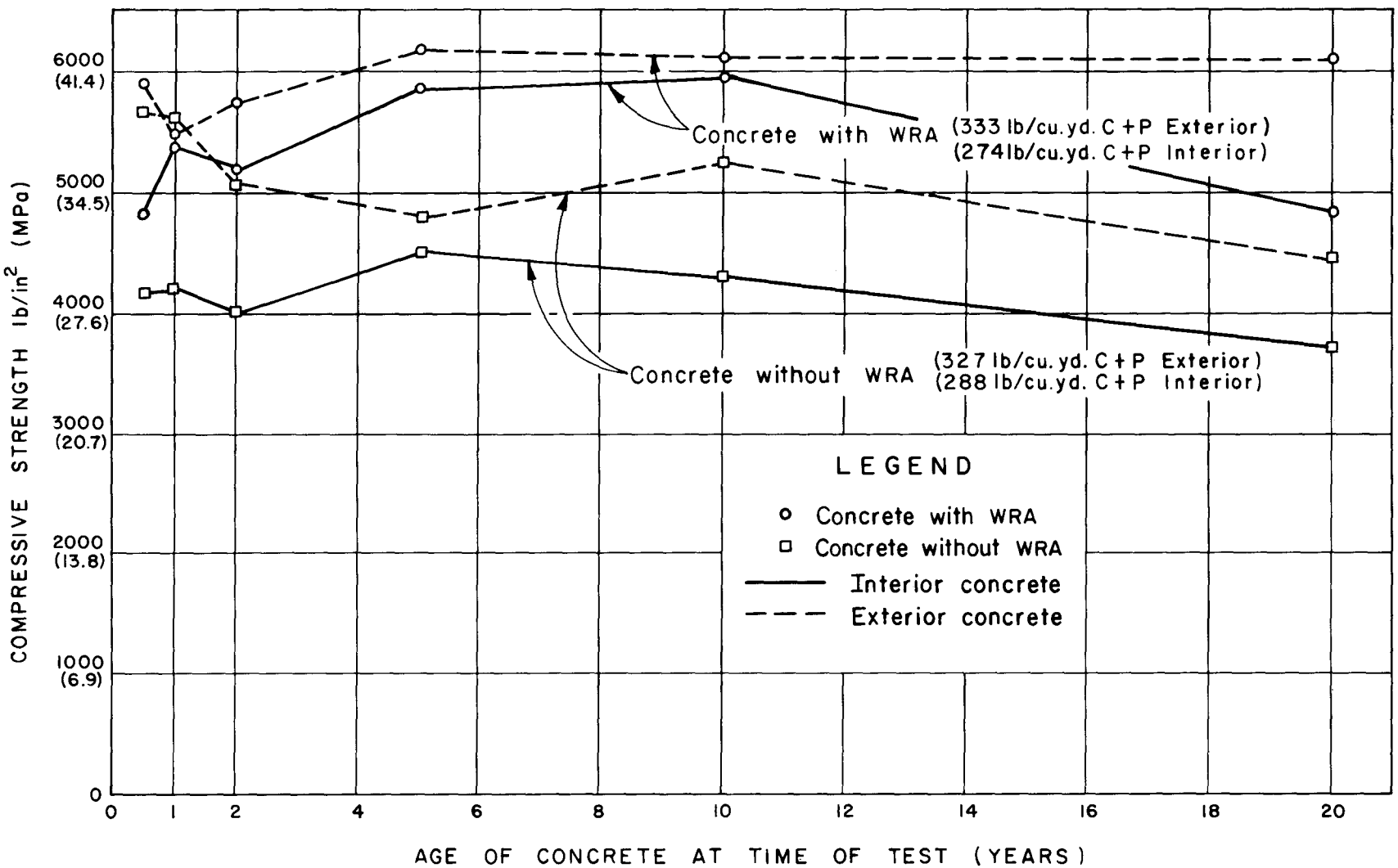

Figure 7. – Compressive strengths of concrete as affected by water-reducing admixtures.

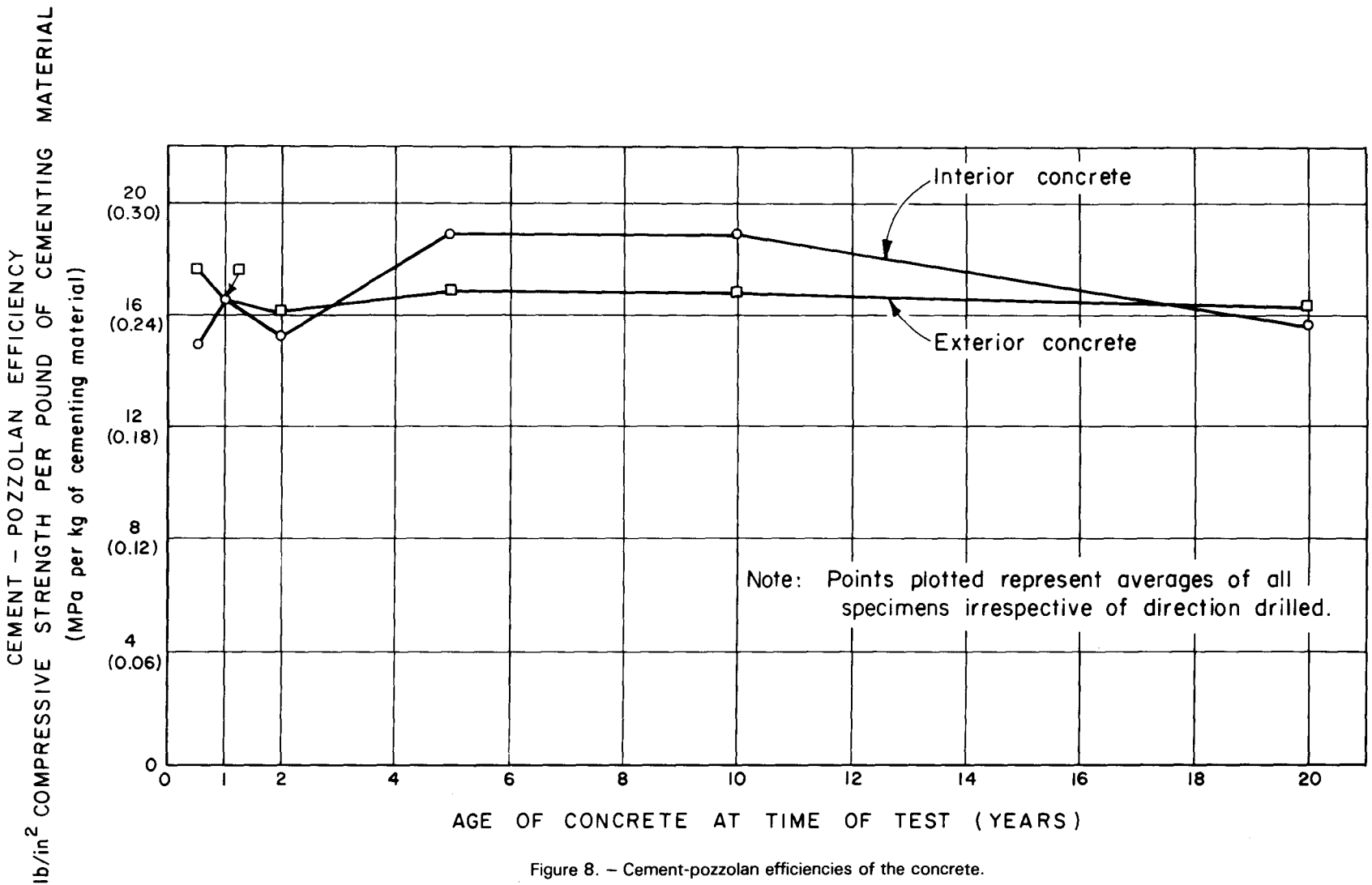

Figure 8. – Cement-pozzolan efficiencies of the concrete.

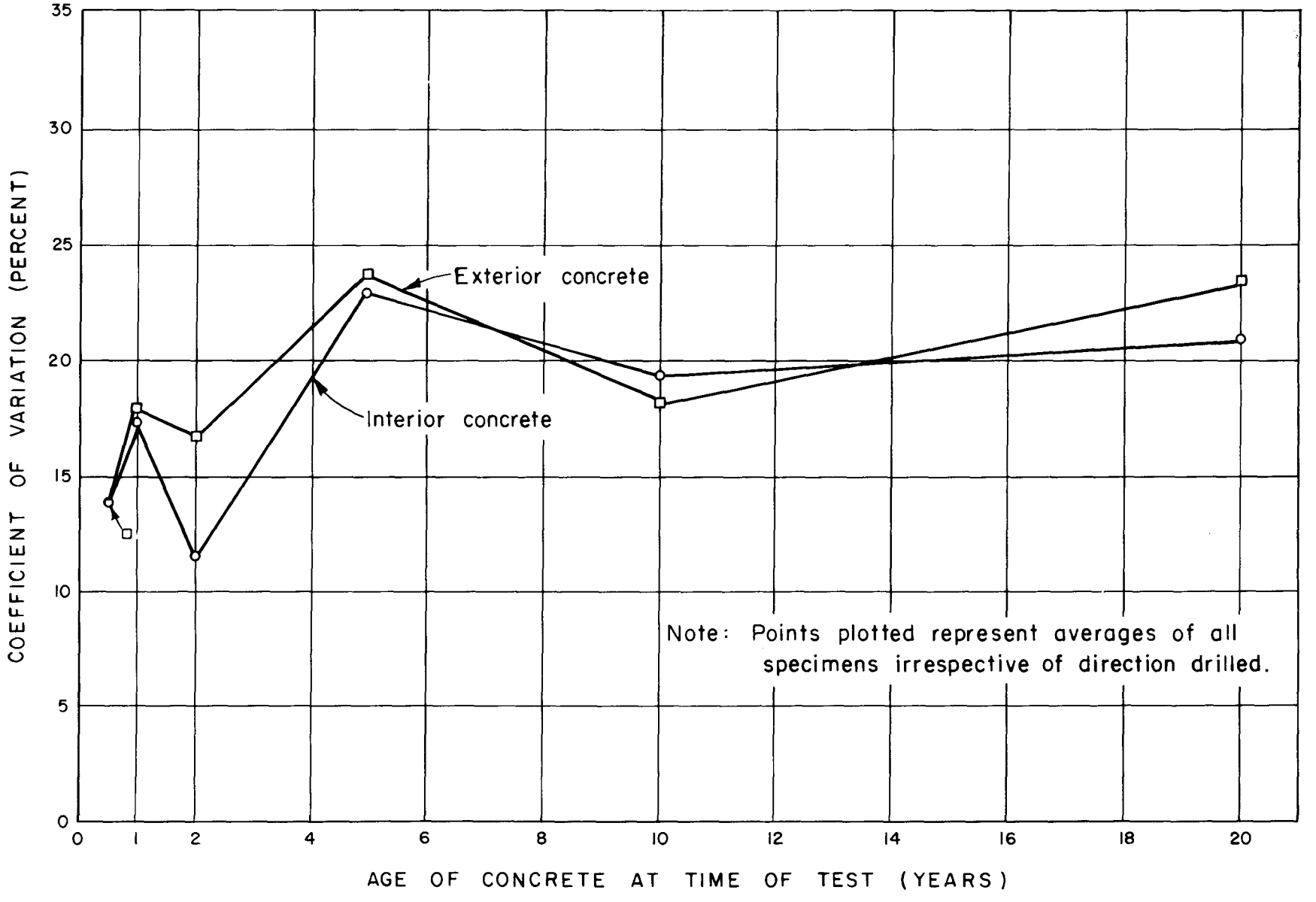

Figure 9. – Coefficients of variation of the concrete specimen strengths.

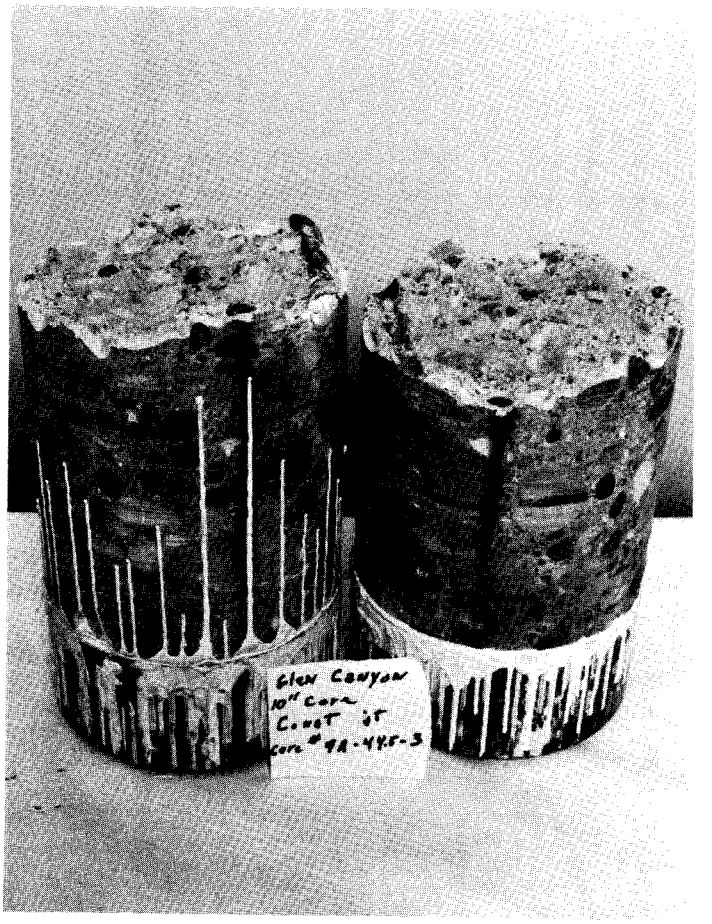

Figure 10. – Typical broken face of a core after failure in tension.

APPENDIX A

PETROGRAPHIC EXAMINATION OF CONCRETE CORES

OPTIONAL FORM NO. 10
JULY 1973 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Memorandum

Denver, Colorado

TO : Chief, Concrete and Structural Branch

DATE: April 18, 1984

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

SUBJECT: Petrographic Examination of Concrete Core - Glen Canyon Dam - DB-14
Longtime Concrete Studies - Colorado River Storage Project, Arizona

Examined by: C. A. Bechtold

Petrographic referral code: 84-26

INTRODUCTION

Concrete core samples (250 mm in diameter) were given a cursory examination in the Concrete Laboratory to select representative fragments to be further examined and tested in the Petrographic Laboratory. The examination was requested to determine the petrographic quality of the concrete as a part of a 20-year study program.

It should be noted that the near-surface, exterior concrete was fabricated with about 50 lb/yd^3 more cement than the interior concrete, and all plus No. 8 and minus 1-1/2-inch exterior concrete aggregate was subjected to heavy media beneficiation. Also, the 20-year interior concrete compressive strengths are typically lower for the horizontally drilled core and higher for the vertically drilled core.

PETROGRAPHIC EXAMINATION

The cores were examined megascopically, microscopically, by X-ray diffraction and differential thermal analyses, and by some qualitative physical and chemical tests.

A detailed "Petrographic Examination of Concrete" sheet is attached which includes the cursory observations and petrographic descriptions of the aggregate, paste, voids, secondary and hydration products, and fractures.

CONCLUSIONS

The examined core samples from the Glen Canyon Dam are petrographically of satisfactory quality as indicated by hard, generally well consolidated, well hydrated concrete with a generally strong paste-aggregate bond. There is no evidence of freeze-thaw damage, chemical attack, or reaction with aggregate particles.

5010-110

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Aggregate in both interior and near-surface concrete appeared generally similar in composition even though the aggregate used in near-surface concrete had been subjected to heavy-media beneficiation.

The paste in both the near-surface and interior concrete is generally uncarbonated with only a thin layer of calcium carbonate on the outer surfaces of core. However, slightly less calcium hydroxide and calcium silicates were detected in the near-surface concrete even though the near-surface concrete was fabricated with more cement than the interior concrete. This suggests that the near-surface concrete may be in the initial stages of aging. All compressive strength results are satisfactory, although typically somewhat lower than the 10-year compressive strengths.

The air voids which are flattened and lying beneath large aggregate particles can concentrate stresses similar to alined flat particles and probably account for the difference observed in interior concrete compressive strength specimens from the vertical and horizontal drill holes.

Howard A. Salman

Attachment

Copy to: D-220
D-915
D-1511
D-1523B
D-3300

PETROGRAPHIC EXAMINATION OF CONCRETE

Appendix A

Subject:	Glen Canyon Dam - DB-14 Longtime Concrete Studies - Colorado River Storage Project, Arizona	Thin Sections No. P-11,337 and P-11,338 Field No. DH-5B, 8A and B, 9A, 11A, 17A, 19B, and 26A

Cursory observations: 250-mm-diameter core; generally well consolidated; gray paste; no secondary deposits in voids or along rock sockets, thin layer of calcium carbonate observed on outer surfaces; paste, aggregate, and voids generally well distributed; no freeze-thaw damage observed

Petrographic examination:

Aggregate - appears similar in both near-surface and interior concrete

- Gravel: subrounded to rounded in shape; consists of chert, cherty sandstone and limestone, limestone, quartzite, quartzose sandstone, and altered volcanics

- Sand: subangular to angular in shape; includes same rock types found in the gravel as well as monomineralic grains of quartz, feldspar, amphibole, magnetite, mica, and a few ferruginous particles and miscellaneous detrital minerals

- Gravel and sand: petrographically of satisfactory physical quality and potentially deleteriously reactive with high-alkali cement

Paste - appears similar in both near-surface and interior concrete; gray; vitreous; moderately to slightly absorptive; breaks with a hard hammer blow generally through to around aggregate particles indicating a generally strong paste-aggregate bond; generally well distributed with aggregate and voids; generally well consolidated; slight to no effervescence with dilute hydrochloric acid

Voids - numerous small entrained air voids; concentrations of large entrapped air voids in a few local areas; a few flattened, large entrapped air voids beneath large aggregate particles; generally unfilled

Secondary products - some calcium carbonate on outer surfaces of core; voids and rock sockets generally free of secondary deposits; no silica gel developed in concrete soaked in Denver tapwater for several weeks

Hydration products - normal amounts of calcium silicates, slightly more in interior concrete than in near-surface concrete; only minor calcium hydroxide but slightly more in interior concrete than in near-surface concrete; adequate water of hydration

Fractures - generally unfractured

APPENDIX B

DIRECT SHEAR TESTS

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

UNITED STATES GOVERNMENT

Memorandum

Memorandum
TO : Head, Concrete Section

Denver, Colorado
DATE: MAR 21 1985

THROUGH: Chief, Concrete and Structural Branch jjp 3/22/85
Chief, Geotechncial Branch PCK 3-21-85

FROM : Head, Rock Mechanics Section

SUBJECT : Direct Shear Tests of Concrete Specimens from Glen Canyon Dam

Geotechnical Branch Reference No.: 85-33

Investigated by: R. L. Brammer, A. V. Scott, B. Harper, and M. J. Romansky

Written by: R. Kelsic and M. J. Romansky

Date of D-1511 requesting memorandum: July 25, 1984

Purpose of testing (Analyses): To evaluate concrete shear strength parameters at Glen Canyon Dam.

Date testing completed: September 4, 1984

Preliminary transmittal of test results: September 12, 1984

INTRODUCTION

Direct shear tests, as requested by Concrete and Structural Branch Memorandum dated July 25, 1984, were performed on two specimens from Glen Canyon Dam. Both cores were approximately 10 inches in diameter.

SPECIMEN CONDITION

The specimens, approximately 20 years in age, were intact and tested dry for break bond and sliding friction analysis. Specimen 8A-2-3 was a construction joint while 17A-19-2 was intact material with voids in the concrete on either side of the test horizon as shown on page 1 of the appendix. There was no water staining or deterioration of aggregate or cement in either specimen.

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LABORATORY TESTING

A linear regression analysis of test data from each specimen is summarized in table 1. Before and after testing photographs of the specimens, shear stress versus displacement plots, and a linear regression analysis summary sheet and plot for each specimen are shown in the appendix. A combined analysis using data from both specimens is summarized in table 2 and a linear regression analysis of the sliding friction data from both specimens is shown graphically on figure 1.

With just two specimens tested, the combined break bond data have no statistical correlation. Peak shearing stresses developed at failure for specimens 8A-2-3 and 17A-19-2 were 523 and 355 lb/in^2, respectively, at an approximate normal stress of 50 lb/in^2. The angle of sliding friction was 35° for specimen 8A-2-3 and 50° for specimen 17A-19-2. Shearing stress of 190 lb/in^2 for specimen 8A-2-3 developed at the second application of 50-lb/in^2 normal stress with 0.0579 inch horizontal displacement. Specimen 17A-19-2 developed 139-lb/in^2 shearing stress at the second application of 50 lb/in^2 normal stress with 0.0788-inch horizontal displacement.

A combined linear regression analysis of break bond data from both specimens was not used to determine shear strength parameters because both breaks were conducted at the same normal stress. However, combined sliding friction test results yielded a cohesion of 116 lb/in^2 and a sliding friction angle of 44°.

CONCLUSIONS

Test results should be used with discretion because of the limited number of test specimens (two) and succeeding small number of sliding friction runs employed in this test program. Before applying these test results, a thorough review of available drill logs and construction reports should be conducted to locate areas of joint contact similar to those found in these laboratory test specimens. This is considered essential to identify areas where these shear strength parameters might be applicable. Only construction joints similar to the samples submitted for break bond evaluation should be used to approximate joint strength.

W. G. Austin

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D-1542
D-1543 (2)

Table 1. - Direct shear test results - Summary

Specimen No.	Feature	Area (in^2)	Shear[1] stress (lb/in^2)	Cohesion (lb/in^2)	Friction angle (degrees)	Comments[2]
8A-2-3	Construction joint	80.99	523	151	35	50, 50, 100, 150
17A-19-2	Intact	81.33	355	81	50	49, 50, 100, 150

[1] Peak shearing stress developed at the first applied normal stress.
[2] Loading sequence (normal stress in lb/in^2).

Table 2. - Combined test data summary

Feature	Break bond Linear regression results		Sliding friction Linear regression results	
	Angle of internal friction (degrees)	Cohesion (lb/in^2)	Angle of sliding friction (degrees)	Cohesion (lb/in^2)
Intact joints	1/	1/	44°	116

1/ Insufficient number of specimens for statical analysis.

Sheet 1 of 1
Project: CRSP
Feature: Glen Canyon Dam

Tables 1 and 2

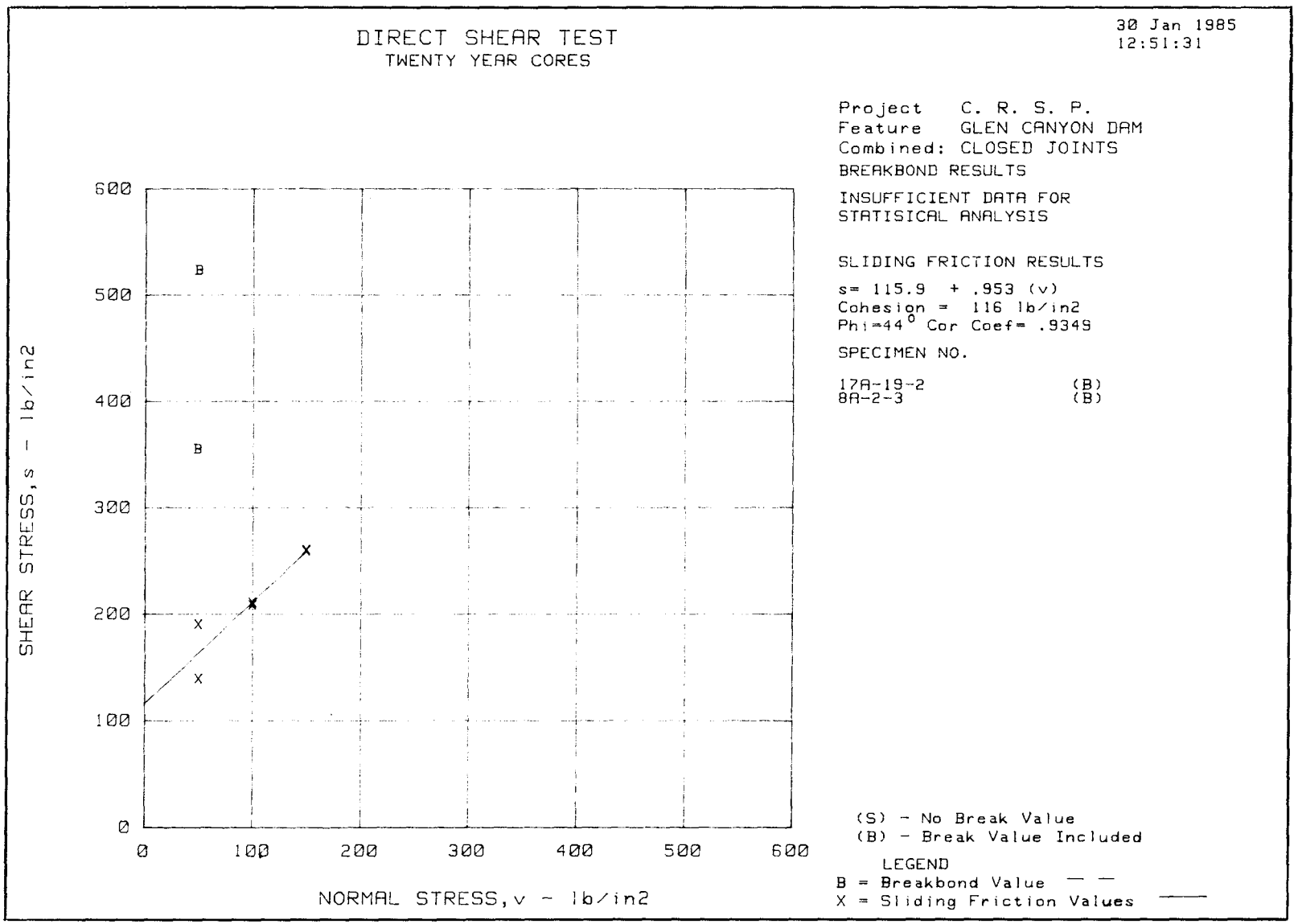
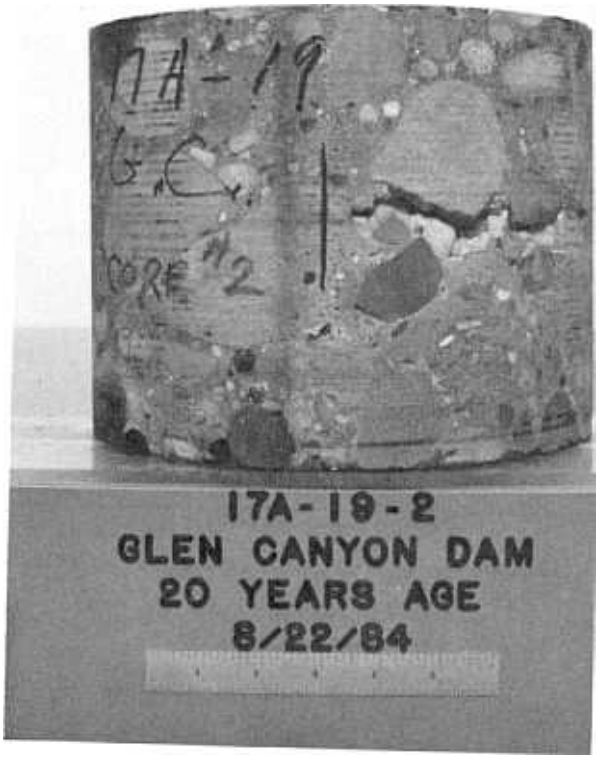
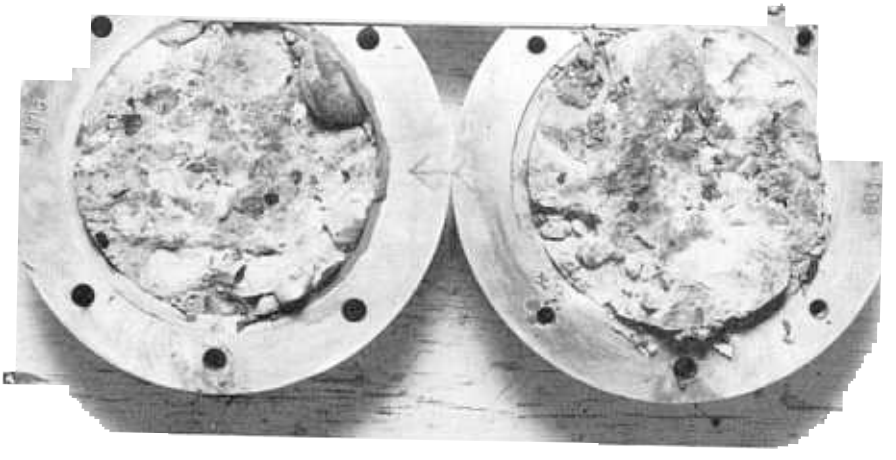

DIRECT SHEAR TEST
TWENTY YEAR CORES
30 Jan 1985
12:51:31
Project C. R. S. P.
Feature GLEN CANYON DAM
Combined: CLOSED JOINTS
BREAKBOND RESULTS
INSUFFICIENT DATA FOR
STATISICAL ANALYSIS
SLIDING FRICTION RESULTS
s= 115.9 + .953 (v)
Cohesion = 116 lb/in2
Phi=44° Cor Coef= .9349
SPECIMEN NO.
17A-19-2 (B)
8A-2-3 (B)
SHEAR STRESS, s - lb/in2
NORMAL STRESS, v - lb/in2
0
100
200
300
400
500
600
B
X
(S) - No Break Value
(B) - Break Value Included
LEGEND
B = Breakbond Value
X = Sliding Friction Values

Figure 1



Specimen before testing
(Parallel to sliding direction

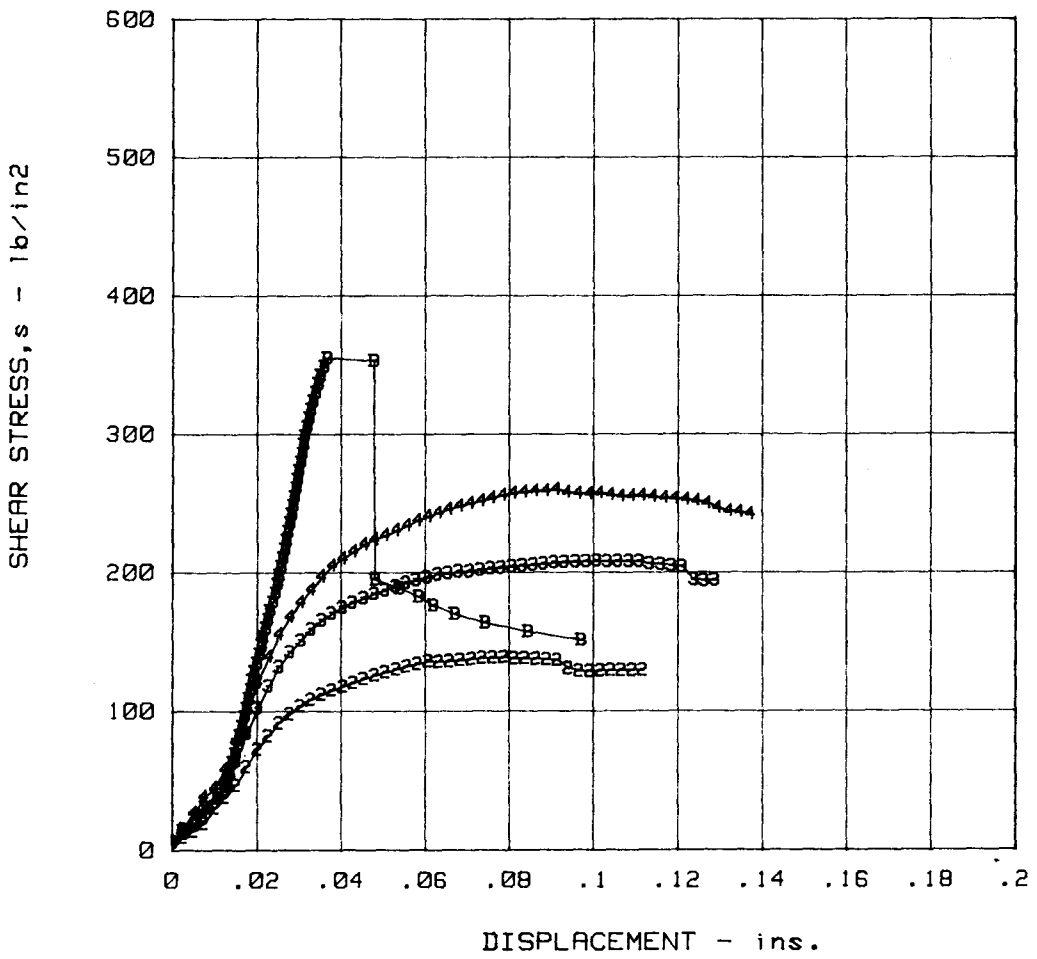
17A-19-2
GLEN CANYON DAM
20 YEAR AGE
9/20/84



Specimen after testing

DIRECT SHEAR TEST

9 Feb 1985
15:09:41



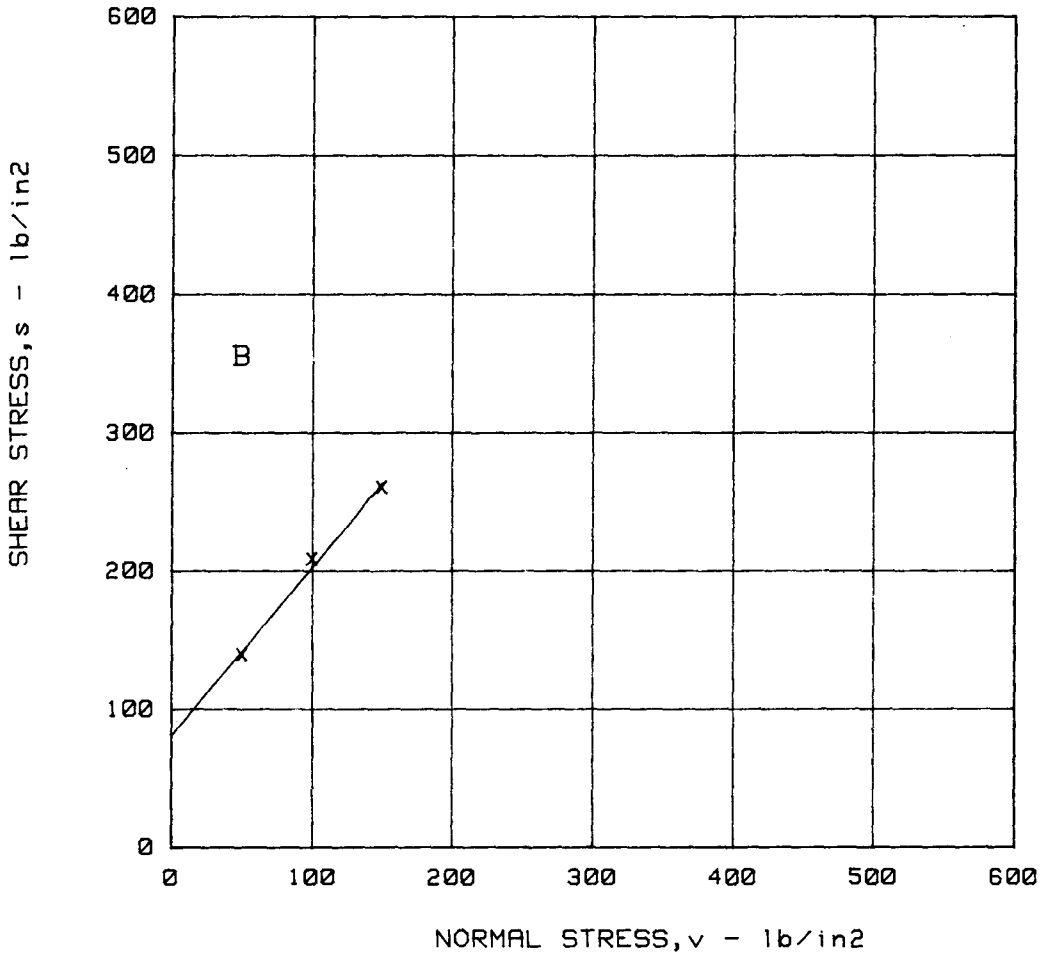
Project	C. R. S. P.
Feature	GLEN CANYON DAM
Type	CLOSED JOINT-20 YEAR
Spec no.	17A-19-2
Tested By:	R.L.B.
Date Tested	08/24/84
Area	81.329 Sq. in.

LEGEND

NORMAL lb/in2	SYMBOL
49	B
50	2
100	3
150	4

DIRECT SHEAR TEST

9 Feb 1985
15:12:18



Project	C. R. S. P.
Feature	GLEN CANYON DAM
Type	CLOSED JOINT-20 YEAR
Spec no.	17A-19-2
Tested By:	R.L.B.
Date Tested	08/24/84
Area	81.329 Sq. in.

v lb/in2	s lb/in2
49	355
50	139
100	208
150	260

SLIDING FRICTION RESULTS

s= 81.2 +1.212 (v)

COHESION = 81 lb/in2

PHI= 50° COR COEF= .9964

LEGEND

B = BREAKBOND VALUE

X = SLIDING FRICTION VALUES

9 Feb 1985
15:14:16

DATA SUMMARY

Project C. R. S. P.
Feature GLEN CANYON DAM
Type CLOSED JOINT-20 YEAR
Spec no. 17A-19-2
Tested By: R.L.B.
Date Tested 08/24/84
Area 81.329 Sq. in.

NORMAL LOAD (lbs)	SHEAR LOAD (lbs)	DISPLACEMENT (ins)	NORMAL STRESS (lb/in2)	SHEAR STRESS (lb/in2)
3985	28850	.0366	49	355
4066	11292	.0788	50	139
8133	16950	.1009	100	208
12199	21150	.0914	150	260

SUM X*X = 35000
SUM Y*Y = 130342
SUM X*Y = 66792
SUM X = 300
SUM Y = 607

SLIDING FRICTION RESULTS
s= 81.2 +1.212 (v)
COHESION = 81 lb/in2
PHI= 50° COR COEF= .9964

30 Jan 1985 08:47:49

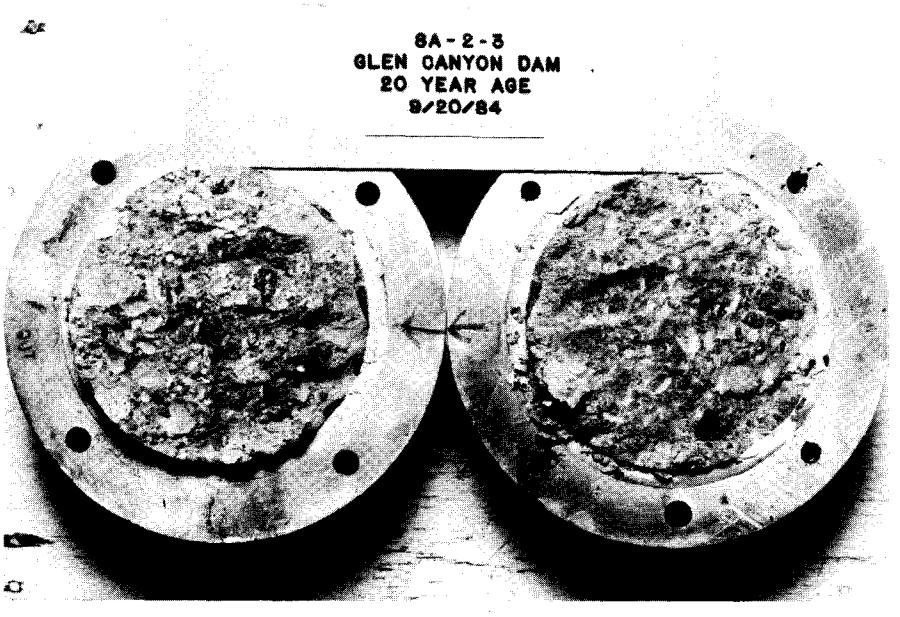
FINAL DATA

Project C. R. S. P.
Feature GLEN CANYON DAM
Type CLOSED JOINT-20 YEAR
Spec no. 17A-19-2
Tested By: R.L.B.
Date Tested 08/24/84
Area 81.329 Sq. in.

NORMAL STRESS lb/in2	SHEAR STRESS lb/in2	DISPLACEMENT inches
50	6	0.0000
49	12	.0027
50	18	.0054
50	25	.0069
50	31	.0080
50	37	.0106
50	44	.0123
51	50	.0131
51	56	.0137
51	63	.0143
51	69	.0149
51	76	.0155
50	82	.0160
50	89	.0165
50	96	.0170
50	102	.0175
50	109	.0180
50	115	.0185
50	122	.0189
50	128	.0194
50	135	.0200
50	141	.0205
50	147	.0210
50	153	.0214
50	160	.0220
50	166	.0225
50	172	.0230
50	178	.0238
50	185	.0243
50	191	.0247
50	197	.0252
50	204	.0257
50	210	.0261
50	217	.0265
50	223	.0269
50	229	.0273
50	236	.0277
50	242	.0281
50	248	.0285
50	254	.0288
50	261	.0292
50	267	.0295
50	273	.0299
50	280	.0303
50	286	.0306
50	292	.0310
50	299	.0313
50	305	.0318
50	311	.0323
50	317	.0328
50	323	.0333
50	330	.0339
50	336	.0345
50	342	.0351
49	348	.0359
49	355	.0366
49	353	.0477
50	195	.0480
49	188	.0538
50	182	.0584
50	176	.0619
50	170	.0670
50	164	.0742
50	157	.0844
-50	151	.0970
50	3	0.0000
50	9	.0025
50	14	.0050
51	19	.0075
50	30	.0101
50	38	.0126
51	47	.0151
50	60	.0176
50	73	.0201
50	82	.0227
50	91	.0252
50	98	.0277
50	104	.0303
50	108	.0328
50	112	.0354
50	115	.0379
50	118	.0405
50	120	.0430
50	123	.0455
50	126	.0481
50	128	.0506
51	130	.0532
51	132	.0557
51	134	.0583
51	136	.0608
50	135	.0633
50	136	.0659
50	137	.0685
50	137	.0711
50	138	.0736
50	139	.0762
50	139	.0788
50	138	.0813
50	138	.0838
50	138	.0864
50	137	.0890
50	137	.0916
50	131	.0942
50	129	.0967
50	129	.0993
50	129	.1018
50	129	.1043
50	129	.1068
50	129	.1094
-50	129	.1119
100	7	0.0000
100	15	.0026
101	23	.0051
101	32	.0076
100	38	.0102
100	47	.0127
101	64	.0152

100	84	.0177
100	102	.0202
100	118	.0228
100	132	.0253
100	143	.0278
100	151	.0304
101	159	.0329
101	166	.0354
101	171	.0379
100	175	.0404
100	178	.0429
100	182	.0455
100	185	.0480
100	187	.0505
100	190	.0530
100	193	.0555
100	195	.0580
100	197	.0605
100	199	.0631
101	199	.0656
101	201	.0681
100	201	.0707
100	202	.0732
100	203	.0757
100	203	.0782
100	204	.0808
100	205	.0833
100	206	.0858
100	206	.0883
100	207	.0908
100	207	.0933
100	208	.0959
100	208	.0984
100	208	.1009
100	208	.1034
100	208	.1059
100	208	.1085
100	208	.1110
100	206	.1135
100	206	.1161
100	205	.1186
100	204	.1211
100	195	.1239
100	194	.1264
-100	194	.1289
150	6	0.0000
150	15	.0025
150	27	.0051
150	39	.0076
151	45	.0101
151	59	.0127
150	78	.0152
151	99	.0178
151	121	.0203
150	139	.0229
150	155	.0254
150	168	.0279
150	179	.0305
150	188	.0330
151	197	.0355
151	205	.0381
150	210	.0406
150	215	.0431
150	220	.0457
150	224	.0482
149	227	.0507
150	231	.0533
150	234	.0559
150	238	.0584
150	241	.0609
150	243	.0634
150	246	.0659
150	248	.0685
150	250	.0710
150	252	.0736
150	254	.0761
150	256	.0787
150	257	.0812
150	258	.0837
150	259	.0863
150	259	.0889
150	260	.0914
150	258	.0940
149	257	.0966
149	257	.0992
150	257	.1017
150	256	.1043
149	255	.1068
149	255	.1093
151	255	.1118
150	255	.1144
150	254	.1170
150	253	.1195
150	253	.1221
150	252	.1246
150	250	.1272
150	246	.1297
150	244	.1323
150	243	.1348
-150	242	.1373

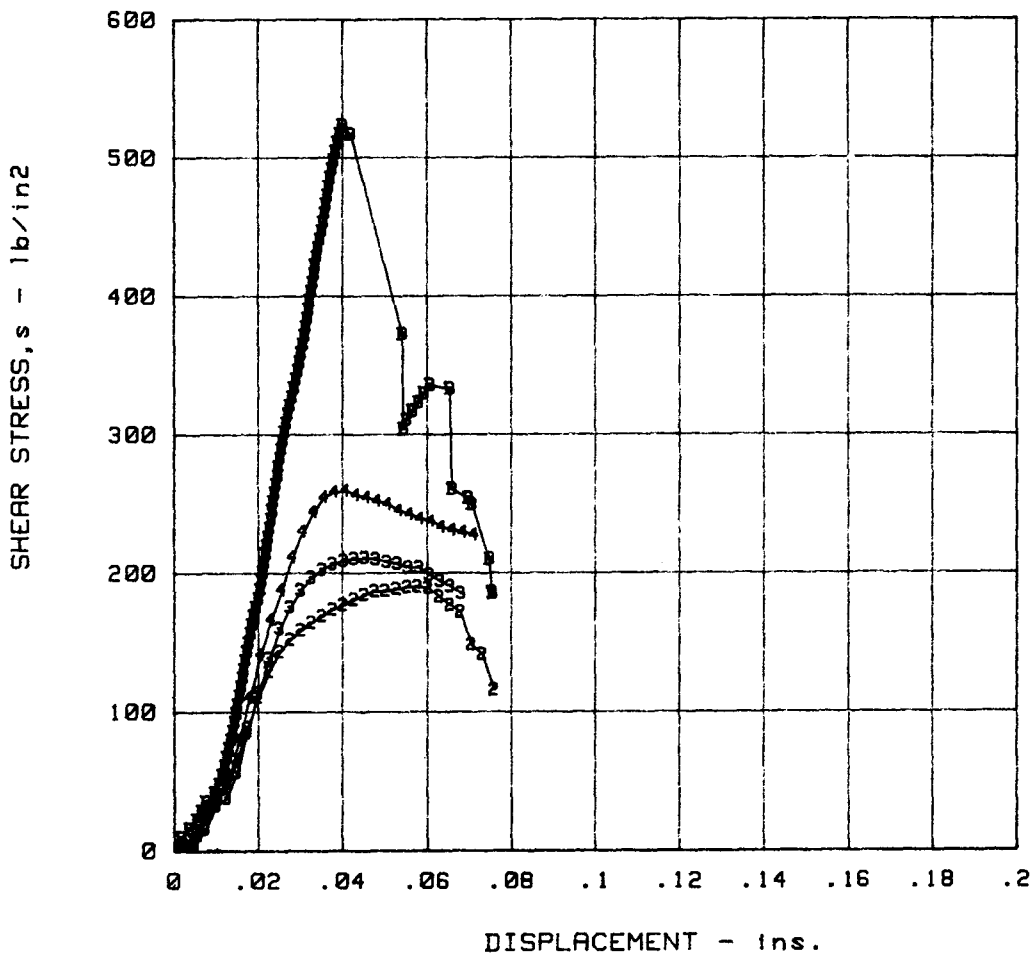
Specimen before testing
(Parallel to sliding direction)



Specimen after testing

DIRECT SHEAR TEST

30 Jan 1985
08:55:28



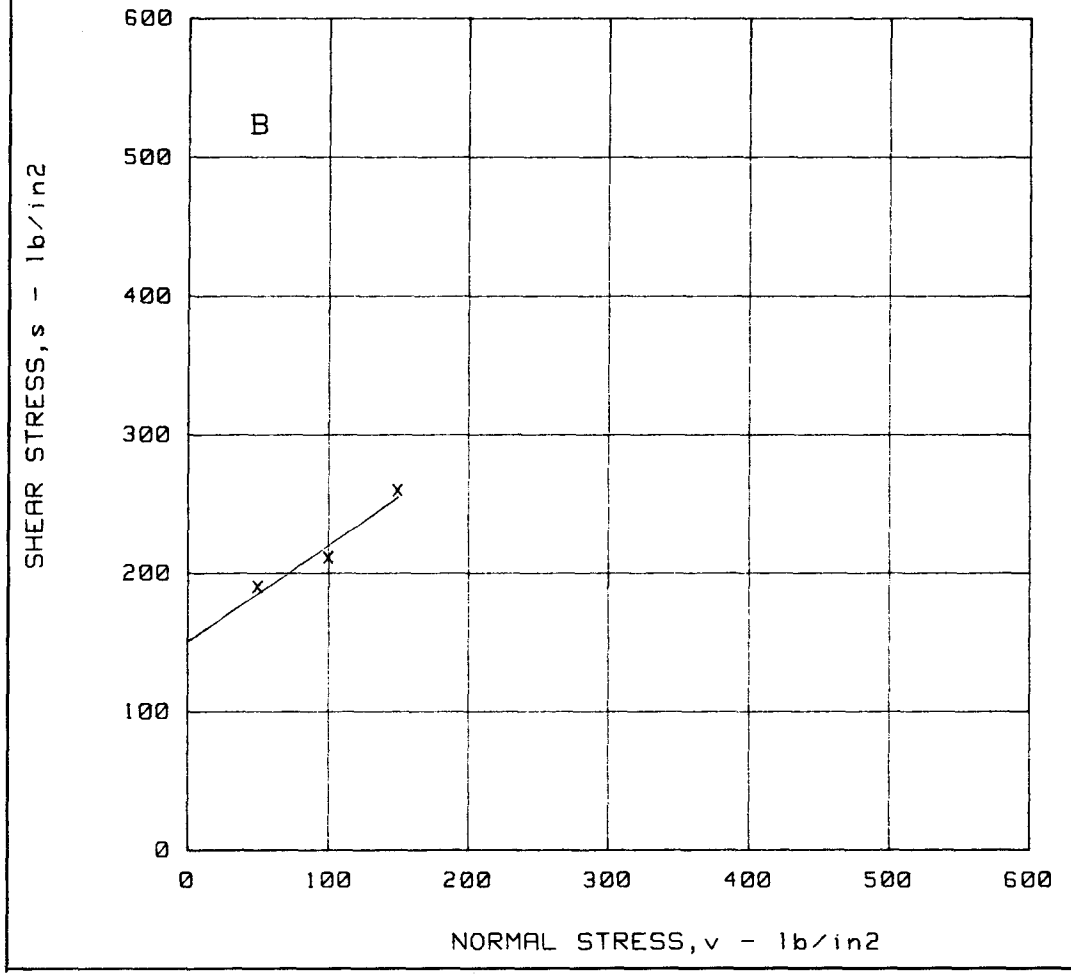
Project	C. R. S. P.
Feature	GLEN CANYON DAM
Type	CLOSED JOINT-20 YEAR
Spec no.	8A-2-3
Tested By:	R.L.B.
Date Tested	08/24/84
Area	80.994 Sq. in.

LEGEND

NORMAL lb/in2	SYMBOL
50	B
50	2
100	3
150	4

DIRECT SHEAR TEST

30 Jan 1985
08:58:49



Project	C. R. S. P.
Feature	GLEN CANYON DAM
Type	CLOSED JOINT-20 YEAR
Spec no.	8A-2-3
Tested By:	R.L.B.
Date Tested	08/24/84
Area	80.994 Sq. in.

v lb/in2	s lb/in2
50	523
50	190
100	211
150	259

SLIDING FRICTION RESULTS

s= 150.5 + .694 (v)

COHESION = 151 lb/in2

PHI= 35° COR COEF= .9749

LEGEND

B = BREAKBOND VALUE

X = SLIDING FRICTION VALUES

30 Jan 1985
09:01:07

DATA SUMMARY

Project C. R. S. P.
Feature GLEN CANYON DAM
Type CLOSED JOINT-20 YEAR
Spec no. 8A-2-3
Tested By: R.L.B.
Date Tested 08/24/84
Area 80.994 Sq. in.

NORMAL LOAD (lbs)	SHEAR LOAD (lbs)	DISPLACEMENT (ins)	NORMAL STRESS (lb/in2)	SHEAR STRESS (lb/in2)
4050	42375	.0400	50	523
4050	15375	.0579	50	190
8099	17075	.0454	100	211
12149	21000	.0409	150	259

SUM X*X = 35000
SUM Y*Y = 147705
SUM X*Y = 69465
SUM X = 300
SUM Y = 660

SLIDING FRICTION RESULTS
s= 150.5 + .694 (v)
COHESION = 151 lb/in2
PHI= 35^{0} COR COEF= .9749

30 Jan 1985 08:49:51

FINAL DATA

Project C. R. S. P.
Feature GLEN CANYON DAM
Type CLOSED JOINT-20 YEAR
Spec no. 8A-2-3
Tested By: R.L.B.
Date Tested 08/24/84
Area 80.994 Sq. in.

NORMAL STRESS lb/in2	SHEAR STRESS lb/in2	DISPLACEMENT inches
50	3	0.0000
50	9	.0018
50	16	.0036
50	22	.0054
50	29	.0065
50	35	.0075
50	41	.0096
50	48	.0107
50	54	.0114
50	61	.0120
50	67	.0125
50	73	.0130
50	80	.0135
50	86	.0139
50	92	.0143
50	98	.0148
50	105	.0151
50	111	.0155
50	118	.0159
50	124	.0163
50	130	.0166
50	137	.0170
50	143	.0174
50	149	.0177
50	156	.0182
50	162	.0186
50	169	.0190
50	175	.0194
50	181	.0200
50	188	.0205
50	194	.0208
50	200	.0211
50	207	.0214
50	213	.0218
50	219	.0221
50	226	.0224
50	232	.0227
50	238	.0230
50	245	.0233
50	251	.0236
50	257	.0239
50	264	.0242
50	270	.0246
50	276	.0248
50	283	.0252
50	289	.0255
49	295	.0258
50	301	.0262
50	308	.0267
50	314	.0271
49	320	.0275
49	327	.0280
50	333	.0285
50	339	.0290
49	346	.0295
50	352	.0298
50	358	.0301
49	365	.0306
49	371	.0310
49	377	.0313
50	384	.0316
50	390	.0319
50	396	.0322
49	403	.0326
49	409	.0329
50	416	.0332
50	422	.0334
49	428	.0339
50	434	.0342
50	441	.0346
50	447	.0350
50	453	.0354
50	460	.0358
50	466	.0361
50	472	.0364
50	478	.0367
50	485	.0371
50	491	.0375
50	498	.0379
50	504	.0383
50	511	.0388
50	517	.0394
50	523	.0400
50	517	.0419
49	372	.0541
49	304	.0543
50	310	.0551
50	316	.0565
50	323	.0579
50	329	.0591
50	336	.0607
50	333	.0654
50	260	.0659
50	254	.0698
50	249	.0706
49	210	.0747
48	186	.0754
-48	185	.0754
50	2	0.0000
50	4	.0025
50	13	.0050
50	24	.0075
50	37	.0101
51	45	.0126
51	65	.0151
49	88	.0176
50	110	.0201
50	129	.0227
50	143	.0252
50	152	.0277
50	159	.0303
50	164	.0328
50	169	.0353
50	173	.0378
50	177	.0403
50	181	.0428
50	184	.0453
50	187	.0478
50	187	.0503
50	188	.0529

50	190	.0554
50	190	.0579
50	189	.0604
50	183	.0630
50	176	.0655
50	172	.0680
48	148	.0706
48	141	.0732
-47	115	.0759
100	1	0.0000
100	3	.0025
100	5	.0050
100	16	.0076
100	32	.0101
100	38	.0126
100	57	.0151
101	85	.0176
102	113	.0201
99	138	.0227
99	160	.0252
100	175	.0277
100	188	.0302
101	197	.0328
100	202	.0353
100	206	.0378
100	209	.0404
100	210	.0429
100	211	.0454
100	210	.0480
100	208	.0506
100	206	.0531
100	204	.0556
99	204	.0582
100	198	.0607

100	194	.0632
100	190	.0657
-100	185	.0682
150	1	0.0000
150	2	.0020
150	3	.0040
150	11	.0060
150	26	.0080
150	38	.0106
150	52	.0131
151	80	.0156
150	110	.0181
151	141	.0207
150	166	.0232
150	188	.0257
150	211	.0282
150	230	.0307
151	244	.0333
151	255	.0358
150	258	.0383
150	259	.0409
150	256	.0434
150	254	.0459
150	252	.0484
150	249	.0509
150	245	.0535
151	242	.0560
150	239	.0585
150	237	.0611
150	233	.0636
150	230	.0662
149	229	.0687
-150	227	.0713

GPO 850-376

Mission of the Bureau of Reclamation

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

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

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

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.