R-90-09

CONCRETE PERFORMANCE AT CRYSTAL DAM, COLORADO - 10-YEAR CORE REPORT

April 1990

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

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16. ABSTRACT

This report discusses the results of physical properties testing of cores extracted from the mass concrete in Crystal Dam, Colorado, approximately 10 years after placement. The properties tested were compressive strength, modulus of elasticity, Poisson's ratio, direct tensile strength, and density. This study is part of a series in the long-term evaluation of strength and elastic properties of concrete in various dams.

The overall evaluation of the concrete cores from Crystal Dam indicates a good quality, uniform, well-consolidated concrete. Results of the tests on the cores show the average compressive strength of the concrete is higher than normal for mass concrete of this age. The modulus of elasticity, density, and tensile strengths are within the ranges normally expected for mass concrete.

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a. *DESCRIPTORS*-- Concretes/ cores/ compressive strength/ tensile strength/ modulus of elasticity/ Poisson's ratio/ mass concrete/ concrete properties/ concrete dams

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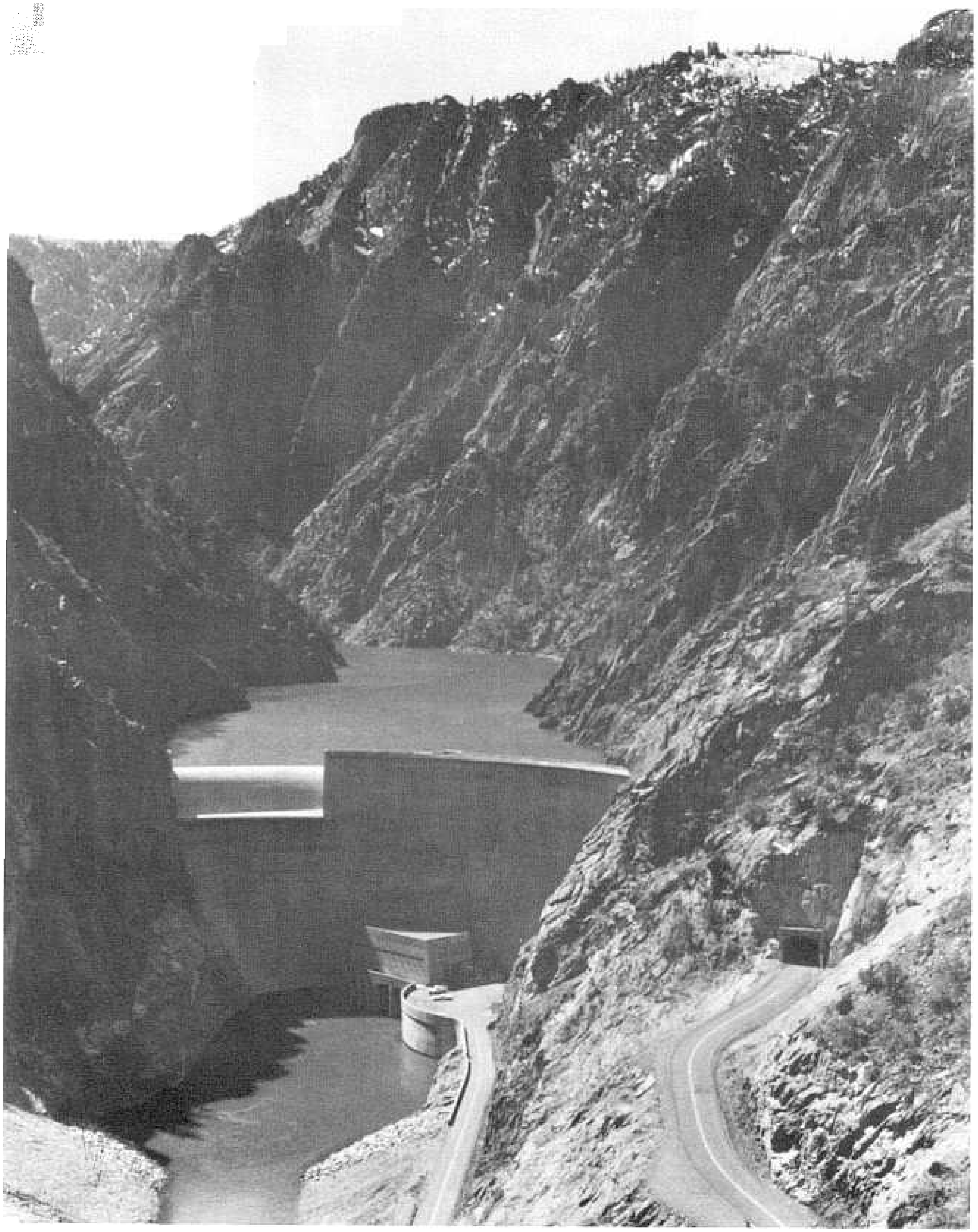

Crystal Dam. P622C-427-15976NA.

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by

William F. Kepler

Concrete and Structural Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

SI METRIC

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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

The research covered by this report was funded under the Bureau of Reclamation PRESS (Program Related Engineering and Scientific Studies) allocation No. DB-14, *Longtime Concrete Studies.*

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INTRODUCTION

Crystal Dam is located in the Black Canyon of the Gunnison River, about 25 miles (40 km) west of Gunnison, Colorado, in Montrose County (fig. 1). The dam is a double-curvature, thin-arch concrete dam 323 feet (98 m) high with a crest length of 635 feet (194 m), a top width of 10 feet (3 m), and a maximum base width of 29 feet (9 m). The spillway crest elevation is 6756 feet (2060 m), 1 foot (0.3 m) above normal high water surface; the parapet elevation is 6776 feet (2065 m). More than 147,000 yd^3 (112 390 m^3) of concrete were placed in the structure. Construction of the dam started in June 1974 and was completed in August 1976. At the normal high water surface, the reservoir has a capacity of 26,000 acre-feet (32 070 000 m^3).

Crystal Dam is part of the Curecanti Unit of the Colorado River Storage Project. The Curecanti Unit develops the water storage and hydroelectric power generating potential along a 40-mile (64-km) section of the Gunnison River in Colorado. The unit is composed of three dams and powerplants: Blue Mesa, Morrow Point, and Crystal (Bureau of Reclamation, 1981a).

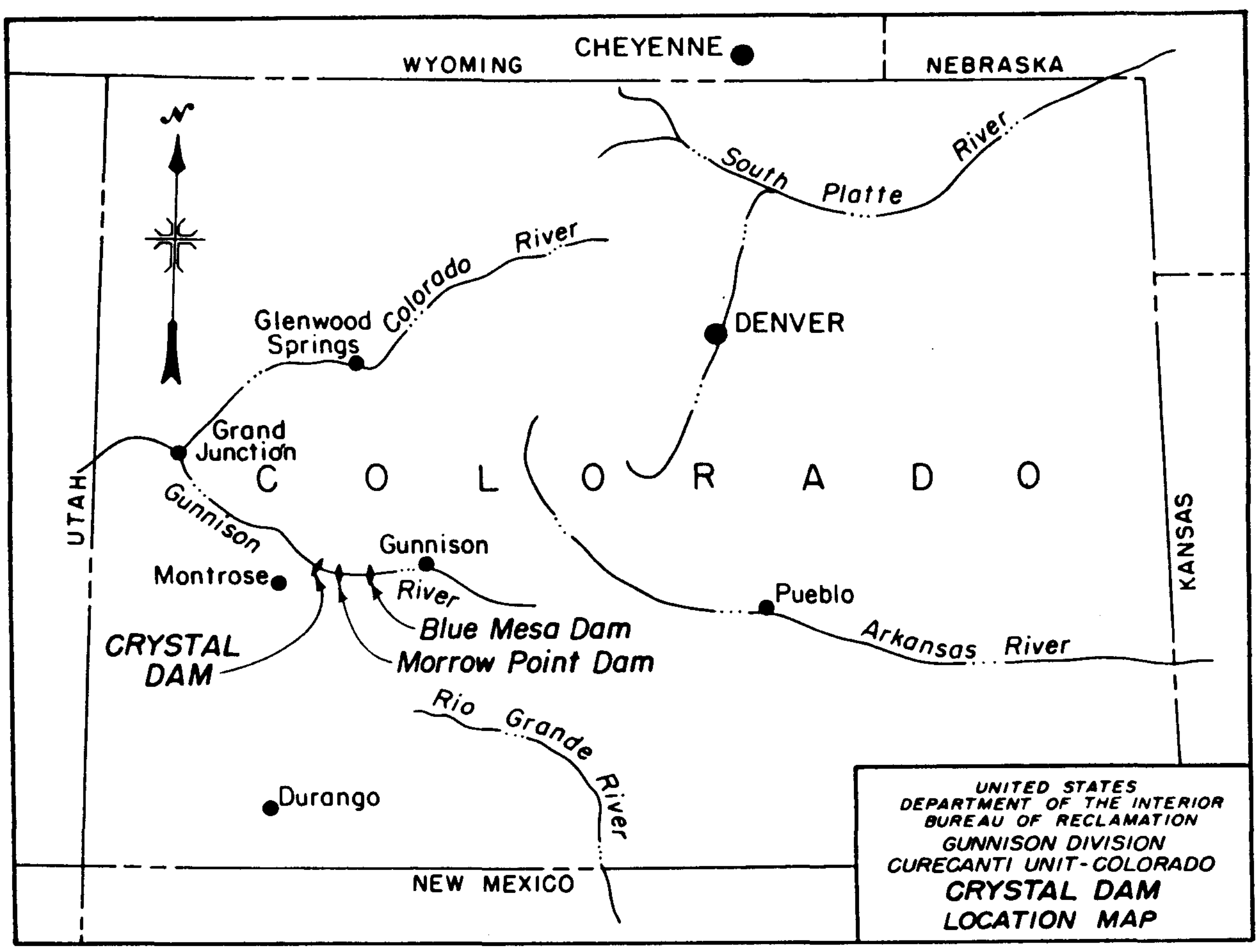

Figure 1. - Crystal Dam location map.

In April 1985, as part of the long-term concrete studies, 10-inch (250-mm) diameter cores were extracted to evaluate the strength and elastic properties of the concrete. These values are compared to those of earlier studies to evaluate the effects of aging and service on various physical properties of the concrete.

This report presents the results of the physical properties testing. At the time of testing, the average age of the cores was 11 years. The cores were evaluated for:

- Compressive strength
- Modulus of elasticity
- Poisson's ratio
- Direct tensile strength
- Density

CONCLUSIONS

1. The overall quality of the concrete cores from Crystal Dam indicates a durable concrete having a compressive strength exceeding the design requirements.

2. In comparison to the 6-month and 1-year cores, there is an increase in compressive strength and modulus of elasticity. These changes are normal for mass concrete at this age (Bureau of Reclamation, 1981b).

3. The compressive strength of the concrete is higher than most mass concrete. Direct tensile strengths are normal for the compressive strengths obtained.

4. The modulus of elasticity is normal for concrete of this strength and age. Poisson's ratio is low when compared to the 6-month and 1-year averages. These test data show a possible problem with the lateral strain measurement testing procedure and the results are questionable. See table 1 for a comparison of the compressive strength and the elastic properties results for 70 days, 6 months, 1 year, and 11 years.

5. The direct tensile strength is 4.3 percent of the compressive strength. The normal expected range for mass concrete is 4 to 6 percent of the compressive strength. The strength across construction joints averages 65 percent of the average strength of the unjointed concrete, which is normal for mass concrete (Bureau of Reclamation, 1961).

CRYSTAL DAM CONCRETE

Crystal Dam concrete contains type II, low-alkali cement; 3-inch (75-mm) maximum-size aggregate; an AEA (air-entraining admixture); and a WRA (water-reducing admixture). The specifications stated that the "Design of mass concrete is based on concrete having a minimum compressive strength of 4,000 lb/in^2 (27.6 MPa) at 365 days." A typical mass concrete mixture had 386 pounds of cement per cubic yard (134 kg/m^3), a water-to-cement ratio of 0.50, and 23 percent of the total aggregate was sand (Bureau of Reclamation, 1973). For typical yield quantities, see table 2.

The cement used was manufactured by Ideal Cement Company at Portland, Colorado. The aggregate for the concrete, obtained from the Gunnison River channel, was a natural sand and coarse aggregate, with the addition of some crushed oversize. See appendix A for the aggregate quality evaluation.

CONSTRUCTION

The batch plant was located just downstream of the Crystal damsite. The plant had four weigh hoppers, one each for cement, water and ice, sand, and coarse aggregate. The batched ingredients were mixed in an 8-1/2-yd^3 (6.5-m^3) stationary mixer. Concrete was mixed in 8-yd^3 (6.1-m^3) batches; the mixing time was 3 minutes. It was then dumped into a 16-yd^3 (12.2-m^3) "gob" hopper located directly below the mixer. The concrete was loaded from the "gob" hopper into 6-yd^3 (4.6-m^3) concrete buckets. The concrete buckets were then hauled two at a time to the damsite by trucks. Tower cranes were used to lift the concrete buckets from the trucks to the placement area (Bureau of Reclamation, 1983).

During the summer months, crushed ice was used as part of the mixing water to maintain the concrete temperature below 50 °F (10 °C). During the hottest part of the summer, as much as 97 percent of the mixing water was obtained from crushed ice. During the fall, when the air temperature was cooler, it was necessary to use hot water to maintain the concrete temperature above 40 °F (4 °C). The maximum water temperature used in the concrete was 105 °F (40.6 °C).

The dam mass concrete placements covered three concrete placing seasons and involved two winter shutdown periods. The first concrete placing season began July 31, 1974, and ran through November 21, 1974. During the first placing season, blocks 5 through 10 were placed from the foundation rock to elevation 6550 feet (1996.4 m), blocks 11 and 13 to elevation 6520 feet (1987.3 m), and blocks 12 and 14 to elevation 6540 feet (1993.4 m). Each block was placed in 10-foot (3.0-m) lifts with the exception of the foundation placements.

The specifications allowed the contractor the option of combining blocks thereby eliminating some contraction joints. The contractor elected to combine blocks 6 and 7, 14 and 15, and 16 and 17. The combined block placing started at elevation 6550 (1996.4 m) at the beginning of the 1975 season.

The bulk of mass concrete in the dam was placed in the 1975 construction season, when the contractor placed over 87,920 yd^3 (67 220 m^3) of mass concrete out of the total 147,000 yd^3 (112 390 m^3) in the dam. The second season extended from May 3 to October 21, 1975. By the end of the 1975 construction season the contractor had blocks 5, 8, 10, 12, and 14 and 15 at elevation 6710 feet (2045.2 m). Blocks 6 and 7, 9, 11, 13, and 16 and 17 were at elevation 6700 feet (2042.2 m).

The third and last construction season extended from May 5 to August 30, 1976. All mass concrete was completed to elevation 6768 feet (2062.9 m) by July 2, and the top of the dam completed on August 30, 1976.

Each 10-foot lift consisted of six layers, each individual layer was 20 inches (0.50 m) deep. After the concrete was deposited in a pile by the bucket, it was knocked down with a vibrator to a

20-inch-deep layer and then consolidated on 18-inch (0.45-m) centers across the entire layer. Placements began so that the first concrete layer would cover the downstream one-half of the block. Five more layers were then stairstepped to the top of the placement. The exposed area of mass concrete was minimized by placing the concrete in this stairstep fashion until the block was completed. The average placement rate for the three construction seasons was 70 yd^3 per hour (50 m^3 per hour).

DRILLING AND HANDLING

The 10-inch (250-mm) diameter cores were extracted from Crystal Dam during 1985 to furnish specimens for physical properties testing. The cores for this testing program were extracted from drill holes located near the drill holes of the 6-month and 1-year core testing program. The 6-month and 1-year cores were also 10 inches in diameter. All cores were drilled vertically. See table 3 and figure 2 for drill hole locations.

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

ASTM C 42, "Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete" (American Society for Testing and Materials, 1985), specifies that the diameter of concrete cores for compressive strength testing "should preferably be at least three times the nominal maximum size of coarse aggregate used in the concrete, and must be at least twice the maximum nominal aggregate size of the coarse aggregate in the core sample." Since the mass concrete contained 3-inch (75-mm) maximum-size aggregate, the 10-inch-diameter cores met the ASTM requirements.

TESTING

Compressive Strength and Elastic Properties

The compressive strength testing was done according to ASTM C 39 "Compressive Strength of Cylindrical Concrete Specimens." The ends of 10-inch (250-mm) diameter compressive strength specimens were lapped plane to a tolerance of 0.002 inch (0.05 mm). After removal from the fog room at 100 percent relative humidity and 73.3 °F (22.9 °C), specimens were sealed in plastic to prevent moisture loss (American Society for Testing and Materials, 1985).

USBR 4469, "Procedure for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression" (in preparation) was followed for the testing using the compressometer-extensometer to determine the modulus of elasticity (E), and Poisson's ratio (r). USBR 4469 computes E and r between the stress range of 100 and 1,000 lb/in^2 (689 and 6895 KPa).

On 15 of the 30 specimens, strain gauges with a computer readout were also used to determine the modulus of elasticity and Poisson's ratio. Lines of strain gauges were placed around the cylinder, two along either side of the long axis and two around the middle. Each line consisted of two strain

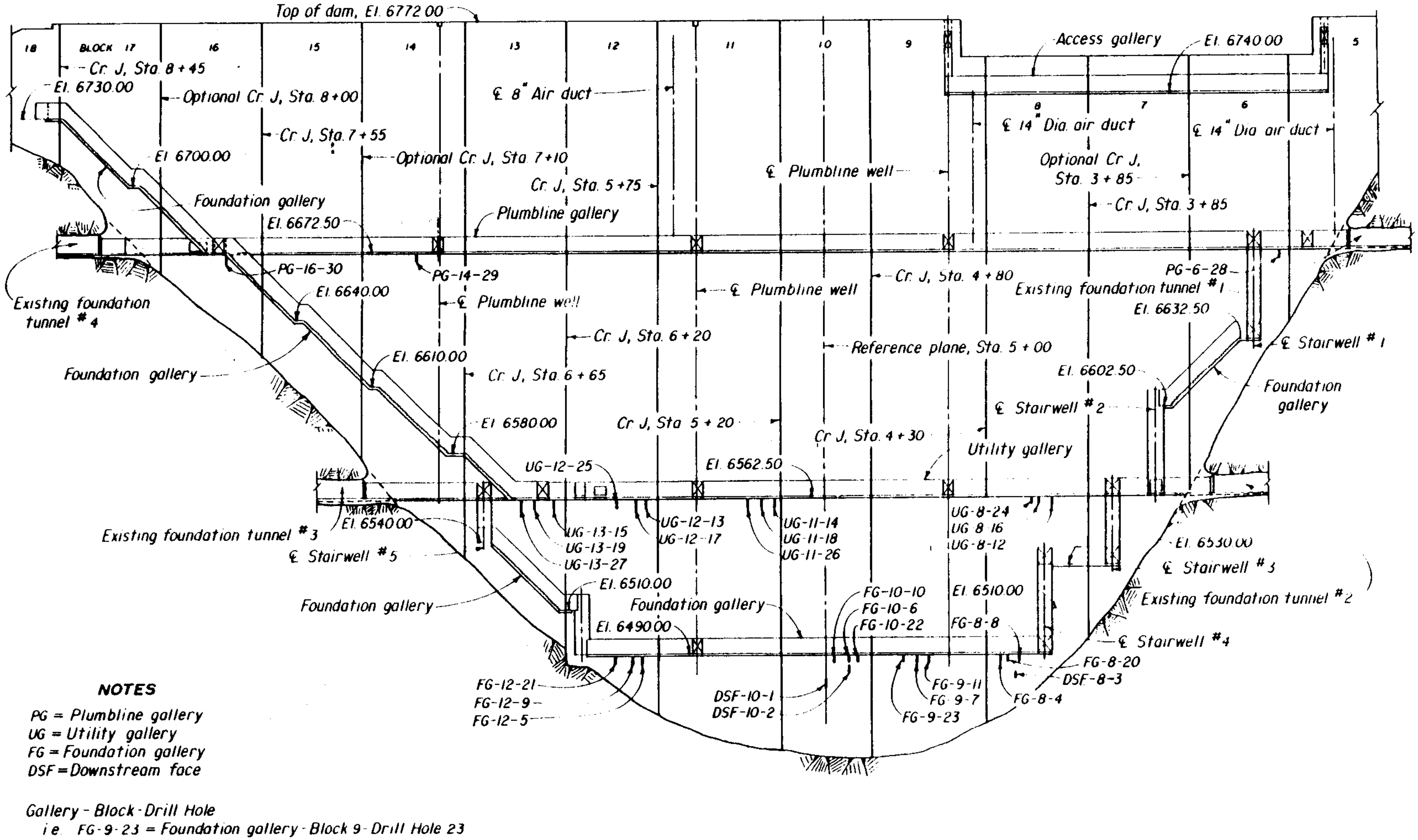

Figure 2. - Crystal Dam cross section and drill hole locations.

gauges connected in series. The manufacturer recommends that the total length of the strain gauges be between two and one-half and three times the size of the maximum-size aggregate. The maximum-size aggregate was 3 inches (75-mm); therefore, the total length of the strain gauges should have been at least 7.5 inches (190 mm). The two 4-inch (100-mm) long strain gauges connected in series developed a total length of 8 inches (200 mm).

Direct Tensile Strength

The direct tensile strength testing was done according to USBR 4914 "Direct Tensile Strength, Static Modulus of Elasticity, and Poisson's Ratio of Cylindrical Concrete Specimens in Tension" (in preparation). The core specimens for direct tension testing were sawcut to provide a length-to-diameter ratio equal to 2. Double-end plates 4-1/2 inches (115 mm) thick and designed to minimize deformation were bonded to each end of a core with epoxy, which was then cured for 24 hours. The specimens were sealed to prevent moisture loss and were then placed in a hydraulic testing machine and loaded to failure in tension at 200 lb/in^2/min (1380 KPa/min).

Density

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

TEST RESULTS

Compressive Strength and Elastic Properties

The average compressive strength for the 30 specimens tested at 11 years was significantly higher than the design strength of 4,000 lb/in^2 (27.6 MPa) at 1 year. The excess strength was due to the increased paste volume required to place the concrete and to ensure adequate bond at the construction joints. The average compressive strength was 6,320 lb/in^2 (43.5 MPa) and ranged from 4,740 to 7,590 lb/in^2 (32.7 to 52.3 MPa). The standard deviation for the compressive strength testing was 750 lb/in^2 (5.2 MPa). The average compressive strength at 6 months was 4,890 lb/in^2 (33.7 MPa), and at 1 year was 5,080 lb/in^2 (35.0 MPa). Test results for compressive strength can be found in tables 4 and 5.

The modulus of elasticity was normal for mass concrete of this strength and age, and was slightly higher than the 6-month and 1-year moduli. It averaged 4.79 x 10^6 lb/in^2 (33.0 GPa) and ranged from 3.86 to 5.62 x 10^6 lb/in^2 (26.6 to 38.7 GPa). The standard deviation for the modulus of elasticity testing was 0.41 x 10^6 lb/in^2 (2.7 GPa). The average modulus of elasticity at 6 months was 4.55 x 10^6 lb/in^2 (31.4 GPa); the average modulus of elasticity at 1 year was 4.60 x 10^6 lb/in^2 (31.7 GPa).

Poisson's ratio was low when compared to the 6-month and 1-year values. The test data indicate problems in accurately determining the lateral strain. Poisson's ratio averaged 0.14, and ranged from 0.08 to 0.20. The standard deviation for Poisson's ratio testing was 0.03. The average Poisson's ratio at 6 months was 0.21; the average Poisson's ratio at 1 year was 0.20. Therefore, the 11-year value would be expected to be 0.20.

Direct Tensile Strength

Direct tensile strengths are normal when compared to the compressive strength. The direct tensile strength of the unjointed mass concrete normally is between 4 and 6 percent of the compressive strength. The direct tensile strength of the unjointed concrete was 4.3 percent of the compressive strength. The direct tensile strength of the unjointed concrete averaged 270 lb/in^2 (1870 KPa), and ranged from 190 to 375 lb/in^2 (1310 to 2590 KPa). The standard deviation was 35 lb/in^2 (250 KPa). The average direct tensile strength of the unjointed concrete at 6 months was 180 lb/in^2 (1240 KPa); at 1 year it was 260 lb/in^2 (1290 KPa). The direct tensile strength specimens tested at 6 months and at 1 year had a length to diameter ratio equal to 3.0.

The direct tensile strength of the jointed concrete averaged 175 lb/in^2 (1220 KPa), and ranged from 100 to 265 lb/in^2 (690 to 1830 KPa). The standard deviation for the direct tensile strength of the jointed concrete was 65 lb/in^2 (460 KPa). The direct tensile strength of the jointed concrete was 65 percent of the direct tensile strength of the unjointed concrete. This is normal for mass concrete. The average direct tensile strength of the jointed concrete at 6 months was 200 lb/in^2 (1390 KPa); at 1 year it was 190 lb/in^2 (1310 KPa). Test results for the direct tensile strength are shown in tables 6 and 7.

Density

The densities, shown in tables 4 and 6, varied little from sample to sample and are normal for mass concrete. The average density of the mass concrete was 153.1 lb/ft^3 (2452 kg/m^3), and ranged from 147.2 to 158.4 lb/ft^3 (2358 to 2537 kg/m^3). The standard deviation for the density testing was 2.3 lb/ft^3 (37 kg/m^3). The average density of the mass concrete at 6 months was 154.2 lb/ft^3 (2470 kg/m^3); at 1 year it was 153.7 lb/ft^3 (2460 kg/m^3).

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Table 1. - Summary of compressive strength and elastic properties vs. age

Age	Compressive strength lb/in² (MPa)	Standard deviation lb/in² (MPa)	Modulus of elasticity x 10^6 lb/in² (GPa)	Poisson's ratio	Number of specimens
70 days	4,060 (28.0)	800 (5.7)	4.00 (27.6)	0.20	6
6 months	4,890 (33.7)	420 (2.9)	4.55 (31.4)	0.21	14
1 year	5,080 (35.0)	450 (3.1)	4.60 (31.7)	0.20	30
11 years	6,320 (43.5)	750 (5.2)	4.79 (33.0)	0.14	30

Note: All core tested had 10-inch diameter.

Table 2. - Crystal Dam mass concrete - typical yield quantities per yd³ (per m³)

Material	Weight	Source
Water	192 lb (67 kg)	
Cement	387 lb (135 kg)	Ideal, Portland CO
Sand	777 lb (269 kg)	Gunnison River channel
Coarse aggregate	2,725 lb (945 kg)	Gunnison River channel
AEA	5 oz (148 mL)	Protex Industries
WRA	1 oz (25 mL)	Protex Industries

Concrete temperature	=	48 °F (8.9 °C)
Slump	=	2.25 inches (55 mm)
Unit weight	=	151.1 lb/ft³ (2420 kg/m³)
Air content:		
Gravimetric	=	3.4 percent
Pressure meter	=	4.7 percent
W/C	=	0.50
Sand content	=	23 percent of total aggregate
Coarse aggregate content	=	30.0 percent No. 4 to 3/4-inch (4.75- to 19.0-mm) 35.0 percent 3/4- to 1-1/2-inch (19.0- to 37.5-mm) 35.0 percent 1-1/2- to 3-inch (37.5- to 75-mm)
Required compressive strength at 28 days	=	4,960 lb/in² (34.2 MPa)
Design strength at 1 year	=	4,000 lb/in² (27.6 MPa)

Note: From September 1975 L-29 Construction Progress Report for concrete placed on September 10, 1975.

Table 3. - Drill hole location, designation, and age tested

Drill hole	Designation	Location gallery/block	Age tested
1	DSF/10/1	Downstream face/10	70 days
2	DSF/10/2	Downstream face/10	70 days
3	DSF/8/3	Downstream face/8	70 days
4	FG/8/4	Foundation gallery/8	6 months
5	FG/12/5	Foundation gallery/12	6 months
6	FG/10/6	Foundation gallery/10	6 months
7	FG/9/7	Foundation gallery/9	6 months
8	FG/8/8	Foundation gallery/8	1 year
9	FG/12/9	Foundation gallery/12	1 year
10	FG/10/10	Foundation gallery/10	1 year
11	FG/9/11	Foundation gallery/9	1 year
12	UG/8/12	Utility gallery/8	6 months
13	UG/12/13	Utility gallery/12	6 months
14	UG/11/14	Utility gallery/11	6 months
15	UG/13/15	Utility gallery/13	6 months
16	UG/8/16	Utility gallery/8	1 year
17	UG/12/17	Utility gallery/12	1 year
18	UG/11/18	Utility gallery/11	1 year
19	UG/13/19	Utility gallery/13	1 year
20	FG/8/20	Foundation gallery/8	11 years
21	FG/12/21	Foundation gallery/12	11 years
22	FG/10/22	Foundation gallery/10	11 years
23	FG/9/23	Foundation gallery/9	11 years
24	UG/8/24	Foundation gallery/8	11 years
25	UG/12/25	Utility gallery/8	11 years
26	UG/11/26	Utility gallery/11	11 years
27	UG/13/27	Utility gallery/13	11 years
28	PG/6/28	Plumbline gallery/6	11 years
29	PG/14/29	Plumbline gallery/14	11 years
30	PG/16/30	Plumbline gallery/16	11 years

DSF = Downstream face
FG = Foundation gallery
UG = Utility gallery
PG = Plumbline gallery

Table 4a. - Compressive strength, density, and elastic properties - English units

Drill hole	Elevation (ft)	Density (lb/ft^3)	Compressive strength (lb/in^2)	Modulus of elasticity ($\times 10^6$ lb/in^2)	Poisson's ratio
FG/8/20	6488	151.1	5,560	4.70	0.15
	6486	151.2	4,750	4.51	0.16
	6478	151.9	5,290	4.54	0.16
FG/12/21	6489	151.9	5,290	4.54	0.16
	6486	148.9	6,940	4.77	0.09
	6483	149.7	6,530	4.52	0.16
FG/10/22	6486	153.0	6,670	5.04	0.16
	6483	153.8	6,460	5.05	0.16
	6478	152.3	5,680	4.59	0.17
FG/9/23	6488	152.0	6,420	4.76	0.14
	6486	153.7	5,370	4.64	0.15
	6478	151.2	4,740	4.16	0.14
UG/8/24	6561	156.2	7,590	5.29	0.17
	6556	155.3	6,440	5.29	0.17
UG/12/25	6559	153.6	7,130	4.75	0.14
	6556	151.9	7,360	4.77	0.08
	6553	156.1	6,690	5.08	0.15
UG/11/26	6561	154.4	6,920	3.86	0.10
	6558	155.4	5,550	4.86	0.14
	6552	152.6	7,080	4.19	0.09
UG/13/27	6561	156.2	6,120	4.93	0.09
	6556	152.8	5,620	4.33	0.10
	6553	154.1	6,390	5.15	0.20
PG/6/28	6671	158.4	6,750	5.06	0.11
	6669	152.3	7,270	5.42	0.20
	6663	156.2	6,920	5.11	0.15
PG/14/29	6666	154.8	6,940	5.62	0.15
	6664	157.2	5,450	4.85	0.15
PG/16/30	6666	153.4	6,560	4.56	0.11
	6663	156.4	6,060	4.92	0.14
Average		153.4	6,320	4.79	0.14
Standard deviation		2.5	750	0.41	0.03

Table 4b. - Compressive strength, density, and elastic properties - SI units

Drill hole	Elevation (m)	Density (kg/m^3)	Compressive strength (MPa)	Modulus of elasticity (GPa)	Poisson's ratio
FG/8/20	1977.5	2420	38.3	32.4	0.15
	1976.9	2422	32.8	31.1	0.16
	1974.5	2433	36.5	31.3	0.16
FG/12/21	1977.8	2358	42.7	30.3	0.16
	1976.9	2398	47.8	32.9	0.09
	1976.0	2398	45.0	31.2	0.16
FG/10/22	1976.9	2451	46.0	34.7	0.16
	1976.0	2464	39.2	31.6	0.16
	1974.5	2440	39.2	31.6	0.17
FG/9/23	1977.5	2435	44.3	32.8	0.14
	1976.9	2462	37.0	32.0	0.15
	1974.5	2422	32.7	28.7	0.14
UG/8/24	1999.8	2502	52.3	36.5	0.17
	1998.3	2488	44.4	36.5	0.17
UG/12/25	1999.2	2460	49.2	32.8	0.14
	1998.3	2433	50.7	32.9	0.08
	1997.4	2500	46.1	35.0	0.15
UG/11/26	1999.8	2473	47.7	26.6	0.10
	1998.9	2489	38.3	33.5	0.14
	1997.0	2444	48.8	28.9	0.09
UG/13/27	1999.8	2502	42.2	34.0	0.09
	1998.3	2448	38.7	29.9	0.10
	1997.4	2468	44.1	35.5	0.20
PG/6/28	2033.3	2537	46.5	34.9	0.11
	2032.7	2440	50.1	37.4	0.20
	2030.9	2502	48.0	35.2	0.15
PG/14/29	2031.8	2480	47.8	38.7	0.15
	2031.2	2518	37.6	33.4	0.15
PG/16/30	2031.8	2457	45.2	31.4	0.11
	2030.9	2505	41.8	33.9	0.14
Average		2458	43.5	33.0	0.14
Standard deviation		40	5.2	2.7	0.03

Table 5a. - Average compressive strength and modulus of elasticity for each drill hole location and age - English units

Location gallery/block	Average compressive strength (lb/in^2)/modulus of elasticity (x 10^6 lb/in^2) (number of specimens per average)		
	Age		
	6 months	1 year	11 years
Foundation gallery/8	4,790/4.82 (2)	4,580/4.03 (2)	5,200/4.58 (3)
Foundation gallery/12	5,000/4.51 (2)	4,850/4.06 (1)	6,550/4.56 (3)
Foundation gallery/10	4,950/4.66 (2)	4,740/4.61 (1)	6,270/4.89 (3)
Foundation gallery/9	4,560/4.21 (2)	4,500/4.23 (2)	5,510/4.52 (3)
Average	4,820/4.55 (8)	4,630/4.23 (6)	5,880/4.64 (12)
Utility gallery/8	4,670/4.79 (1)	5,490/5.02 (1)	7,020/5.29 (2)
Utility gallery/12	5,530/4.56 (1)	5,620/5.62 (2)	7,060/4.87 (3)
Utility gallery/11	4,850/4.66 (2)	5,600/4.79 (3)	6,520/4.30 (3)
Utility gallery/13	4,950/4.31 (2)	4,900/4.28 (2)	6,040/4.80 (3)
Average	4,970/4.58 (6)	5,410/4.90 (8)	6,630/4.77 (11)

Table 5b. - Average compressive strength and modulus of elasticity for each drill hole location and age - SI units

Location gallery/block	Average compressive strength (MPa)/modulus of elasticity (GPa) (number of specimens per average)		
	Age		
	6 months	1 year	11 years
Foundation gallery/8	33.0/33.2 (2)	31.6/27.8 (2)	35.9/31.6 (3)
Foundation gallery/12	34.5/31.1 (2)	33.4/28.0 (1)	45.2/31.4 (3)
Foundation gallery/10	34.1/32.1 (2)	32.7/31.8 (1)	43.2/33.7 (3)
Foundation gallery/9	31.4/29.0 (2)	31.0/29.2 (2)	38.0/31.2 (3)
Average	33.2/31.4 (8)	31.9/29.2 (6)	40.5/32.0 (12)
Utility gallery/8	32.2/33.0 (1)	37.9/34.6 (1)	48.4/36.5 (2)
Utility gallery/12	48.7/31.4 (1)	38.7/38.7 (2)	48.7/33.6 (3)
Utility gallery/11	33.4/32.1 (2)	38.6/33.0 (3)	45.0/29.6 (3)
Utility gallery/13	34.1/29.7 (2)	33.8/29.5 (2)	41.6/33.1 (3)
Average	34.3/31.6 (6)	37.3/33.8 (8)	45.7/32.9 (11)

Table 6a. - Direct tensile strength and density - English units

Drill hole	Elevation (ft)	Density (lb/ft^3)	Direct tensile strength Nonjointed (lb/in^2)	Direct tensile strength Jointed (lb/in^2)
FG/8/20	6483	150.0	260	
	6480	151.0		100
FG/12/21	6480	151.2	200	
	6478	150.8	190	
FG/10/22	6488	151.8	290	
	6480	150.9		125
FG/9/23	6483	153.8	210	
			250	
	6480			
UG/8/24	6558	152.9	295	
	6553	153.4	250	
	6550	153.4		265
UG/12/25	6562	152.7	280	
	6551	155.7	225	
UG/11/26	6550	152.4	320	
UG/13/27	6558	150.9	275	
	6550	151.6		215
PG/6/28	6666	152.7	275	
	6661	154.3	290	
PG/14/29	6671	155.4	290	
	6669	150.5	290	
	6661	154.9	375	
PG/16/30	6671	156.4	280	
	6669	151.5	265	
	6661	153.2	325	
Average		152.7	270	175
Standard deviation		1.7	35	65

Table 6b. - Direct tensile strength and density - SI units

Drill hole	Elevation (m)	Density (kg/m^3)	Direct tensile strength Nonjointed (kPa)	Direct tensile strength Jointed (kPa)
FG/8/20	1976.0	2403	1790	
	1975.1	2419		690
FG/12/21	1975.1	2422	1380	
	1974.5	2416	1310	
FG/10/22	1977.5	2432	2000	
	1975.1	2417		860
FG/9/23	1976.0	2464	1450	
	1975.1		1720	
UG/8/24	1998.9	2449	2030	
	1997.4	2457	1720	
	1996.4	2457		1830
UG/12/25	2000.1	2446	1930	
	1996.7	2494	1550	
UG/11/26	1996.4	2494	2210	
UG/13/27	1998.9	2417	1900	
	1996.4	2428		1480
PG/6/28	2031.8	2446	1900	
	2030.3	2472	2000	
PG/14/29	2033.3	2489	2000	
	2032.7	2411	2000	
	2030.3	2481	2590	
PG/16/30	2033.3	2505	1930	
	2032.7	2427	1830	
	2030.3	2454	2240	
Average		2446	1870	1220
Standard deviation		27	250	460

Table 7. - Summary of direct tensile strength vs. age

Type of specimen	Average age	Number of specimens	Average tensile strength (lb/in^2)	(KPa)
Jointed	70 days	3	170	1170
Nonjointed	70 days	1	170	1170
Jointed	6 months	11	200	1380
Nonjointed	6 months	7	180	1240
Jointed	1 year	9	190	1310
Nonjointed	1 year	7	260	1790
Jointed	11 years	4	175	1220
Nonjointed	11 years	20	270	1870

APPENDIX

Aggregate quality evaluation

EL 251
8-63

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

OFFICE OF CHIEF ENGINEER
DIVISION OF RESEARCH
CONCRETE AND STRUCTURAL BRANCH
DENVER, COLORADO 80225
DATE 9-2-66

AGGREGATE ~~XXXXX~~ QUALITY EVALUATION

REPORT NO. C-563B
COMPILED BY B. J. Brink
CHECKED BY H. E. Dickey
REVIEWED BY A. B. Crosby
SUBMITTED BY E. C. Higginson

STATE Colorado	REG. 4	SOURCE NO.	LAT. 38° N / LONG. 107° W
SAMPLE NO. M-5115	MATERIAL Sand and gravel		DATE REC'D. 2-11-65
DEPOSIT NAME River Channel Area, T.P. 623			OVERBURDEN Not Furnished
OWNERSHIP Not Furnished			VOLUME Not Furnished
LOCATION Gunnison River Channel Coordinates N 680,286.95 - E 1,391,908.73			
Approximately SEC. 14	T 49N	R 7W	MERIDIAN New Mexico Principal
FEATURE Crystal Dam and Powerplant			
PROJECT Colorado River Storage--Curecanti Unit			
REMARKS			
			DATE LTR. TRANS. 2-10-65

GRADING (DES. 4,5,6) CUM. % RETAINED

SIEVE	PIT RUN	3"-1½"	1½"-¾"	¾"-#4	FINE AGG.	WASHED FINE AGG.
6 IN						
3½ IN.						
3 IN.	0					
2½ IN	-					
1¾ IN	-					
1½ IN	31					
1¼ IN	-					
⅞ IN.	-					
¾ IN	59					
⅝ IN.	-					
⅜ IN	81					
5/16 IN.	-					
NO. 4	100				0	
NO. 5					-	
NO. 8					33	
NO. 16					54	
NO. 30					76	
NO. 50					90	
NO. 100					96	
PAN					100	
F.M.	7.71				3.49	
% SAND	28					

TEST RESULTS

	6"-3"	3"-1½"	1½"-¾"	¾"-⅜"	⅜"-#4	FINE AGG	WASHED FINE AGG
SP. GR., S.S.D. (DES. 9,10)		2.65	2.65	2.61	2.60	2.58	
ABSORPTION, % (DES. 9,10)		0.7	1.5	1.8	2.0	2.4	
ORGANIC IMPURITIES, (DES. 14)	—	—	—	—	—	Clear	
PERCENT SILT (DES. 16)						1.9	
% LIGHTER - SP. GR. (DES. 17,18,42)							
CLAY LUMPS, % (DES. 13)							
SAND EQUIVALENT	—	—	—	—	—	88	98
NA_2SO_4 LOSS, 5 CYC. WGT'D. % LOSS (DES. 19)			1.7			—	2.5

L.A. ABRASION (DES. 21) GRADING	"A"	"B"	"C"	"D"
% LOSS, 100 REV.	4.0			
% LOSS, 500 REV.	22.0			

FREEZING AND THAWING DATA

CONCRETE: W/C RATIO	SLUMP INCHES	% AIR METER	H_2O LBS./YD^3	28-DAY STRENGTH 3"x6" CYL'S.	WEIGHT LOSS, %	CYCLES	RIRRAP: WEIGHT LOSS, % 3 INCH CUBE	CYCLES
		Not tested						

ALKALI - AGGREGATE REACTIVITY DATA

MATERIALS	SAND				GRAVEL			
CEMENT NO.		Petro only				Petro only		
SODA EQUIVALENT								
TEST AGG. %	100	100	50	25	100	100	50	25
EXP % - 6 MO.								
EXP % - 12 MO.								

PETROGRAPHIC DESCRIPTION: MEMORANDUM NO. 65-33 DATE: 3-19-65 BY: L. D. Klein

The gravel is subangular to mostly subrounded and rounded streamworn in shape and is composed primarily of acidic and intermediate volcanics, schist and gneiss with decreasing amounts of granite, quartzite and basalt. About 2 percent of the gravel is physically unsound and about 64 percent is alkali-reactive. The sand is subangular to angular in shape and is composed primarily of the same rock types found in the gravel. About 2 percent of the sand is physically unsound and about 52 percent is alkali-reactive.

CONCLUSIONS: Aggregate comparable to Sample No. M-5115 is suitable for use in concrete, provided proper gradings are obtained and low-alkali cement is used.

FOR UNITED STATES GOVERNMENT USE ~~ONLY~~

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GPO 837-192

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

OFFICE OF CHIEF ENGINEER
DIVISION OF RESEARCH
CONCRETE AND STRUCTURAL BRANCH
DENVER, COLORADO 80225
DATE 9-2-66

AGGREGATE [redacted] QUALITY EVALUATION

REPORT NO. C-563B
COMPILED BY
CHECKED BY
REVIEWED BY
SUBMITTED BY

STATE Colorado	REG. 4	SOURCE NO.	LAT. 38° N — LONG. 107° W
SAMPLE NO. M-5116	MATERIAL Sand and gravel		DATE REC'D. 2-11-65
DEPOSIT NAME River Channel Area, T.P. 809			OVERBURDEN Not Furnished
OWNERSHIP Not Furnished			VOLUME Not Furnished
LOCATION Gunnison River Channel, Coordinates N 679,185.66 - E 1,392,237.11			
Approximately SEC. 14	T 49N	R 7W	MERIDIAN New Mexico Principal
FEATURE Crystal Dam and Powerplant			
PROJECT Colorado River Storage--Curecanti Unit			
REMARKS			
			DATE LTR. TRANS. 2-10-65

GRADING (DES. 4,5,6) CUM. % RETAINED

SIEVE	PIT RUN	3"-1½"	1½"-¾"	¾"-#4	FINE AGG	WASHED FINE AGG
6 IN						
3½ IN						
3 IN	0					
2½ IN	-					
1¾ IN	-					
1½ IN	17					
1¼ IN	-					
7/8 IN	-					
¾ IN	43					
5/8 IN	-					
3/8 IN	74					
5/16 IN	-					
NO. 4	100				0	0
NO. 5					-	-
NO. 8					31	32
NO. 16					50	51
NO. 30					69	71
NO. 50					86	88
NO. 100					94	97
PAN					100	100
F.M.	7.34	—	—	—	3.30	3.39
% SAND	38	—	—	—	—	—

TEST RESULTS

	6"-3"	3"-1½"	1½"-¾"	¾"-3/8"	3/8"-#4	FINE AGG	WASHED FINE AGG
SP. GR., S.S.D. (DES. 9,10)		2.58	2.62	2.61	2.61	2.60	2.60
ABSORPTION, % (DES. 9,10)		1.1	1.6	1.8	2.0	2.5	2.2
ORGANIC IMPURITIES, (DES. 14)	—	—	—	—	—	std.	
PERCENT SILT (DES. 16)						3.2	·
% LIGHTER - SP. GR. (DES. 17,18,42)							
CLAY LUMPS, % (DES. 13)							
SAND EQUIVALENT	—	—	—	—	—	82	96
NA_2SO_4 LOSS, 5 CYC. WGT'D. % LOSS (DES. 19)				2.4		—	4.5

L.A. ABRASION (DES. 21) GRADING	"A"	"B"	"C"	"D"
% LOSS, 100 REV.	4.3			
% LOSS, 500 REV.	23.0			

FREEZING AND THAWING DATA

CONCRETE: W/C RATIO	SLUMP INCHES	% AIR METER	H_2O LBS./YD³	28-DAY STRENGTH 3"x 6" CYLS.	WEIGHT LOSS, %	CYCLES	RIPRAP: WEIGHT LOSS, % 3 INCH CUBE	CYCLES
		Not tested						

ALKALI - AGGREGATE REACTIVITY DATA

MATERIALS	SAND				GRAVEL			
CEMENT NO.	Petro only				Petro only			
SODA EQUIVALENT								
TEST AGG. %	100	100	50	25	100	100	50	25
EXP % - 6 MO.								
EXP % - 12 MO.								

PETROGRAPHIC DESCRIPTION: MEMORANDUM NO. 65-33 DATE: 3-19-65 BY: L. T. Klein

The gravel is subangular to mostly subrounded and rounded streamworn in shape and is composed primarily of acidic and intermediate volcanics, schist and gneiss, with decreasing amounts of granite, quartzite and basalt. About 2 percent of the gravel is physically unsound and about 64 percent is alkali-reactive. The sand is subangular to angular in shape and is composed primarily of the same rock types found in the gravel. About 2 percent of the sand is physically unsound and about 49 percent is alkali-reactive.

CONCLUSIONS: Aggregate comparable to Sample No. M-5116 is suitable for use in concrete, provided proper gradings are obtained, the sand is washed to remove excess silt, and low-alkali cement is used.

★ U.S. GPO: 1990 773-182/20,000

GPO 837-192

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.