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

June 1981
Engineering and Research Center

U.S. Department of the Interior
Bureau of Reclamation
Division of Research
Concrete and Structural Branch
Concrete Performance in Crystal Dam, Colorado: 1-Year Core Report

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Results of physical properties tests conducted on cores extracted from mass concrete in Crystal Dam for testing at 70 days', 6 months', and 1 year's age indicate good quality, uniform, well-consolidated concrete. This report contains test data through 1 year's age and is a part of a series of reports on long-time evaluations of strength and elastic properties of concrete in major Bureau of Reclamation dams. The average compressive strengths at 6 months and 1 year were 33.7 and 35.0 MPa (4890 and 5080 lb/in²), respectively, which represent an average strength gain of 3.9 percent. Paralleling the strength increase, the moduli of elasticity also increased slightly from 31.4 to 31.7 GPa (4.55 x 10⁶ to 4.60 x 10⁶ lb/in²). Tensile strengths for jointed and nonjointed cores were comparable at 6 months, but the nonjointed 1-year tensile strengths averaged 40 percent higher. Ratios of tensile to compressive strengths were high, indicating good paste-aggregate bond. Discussions of test results, variations, construction joint bond, and Poisson's ratio are also included in the report.

17. KEY WORDS AND DOCUMENT ANALYSIS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

* Numbers in brackets refer to entries in the Bibliography.
CORE EXTRACTION AND DRILLING PROGRAM

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

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

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

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

SHIPPING AND RECEIVING

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

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

CORE TESTING PROGRAM

General

Cores were extracted so that studies could be made of the concrete at 70 days, 6 months, and 1 year. The studies included tests to determine compressive strengths, elastic properties, densities, and tensile strengths.
The early tests were conducted to evaluate the mix proportions and construction procedures and to permit any needed adjustments before too much concrete was placed.

Core Preparation

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

Density

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

Elastic Properties

Elastic property tests were run on the same core specimens selected for the compressive strength tests. Modulus of elasticity and Poisson's ratio were
determined using an extensometer-compressometer frame, with dial gages mounted so that longitudinal and lateral deformations were monitored as the actual load was applied. All specimens underwent preloading to reduce testing error. Each specimen was preloaded to an axial compressive stress of approximately 6.9 MPa (1000 lb/in²).

**Compressive Strength**

Compressive strength tests were conducted on selected core segments to obtain apparent in-place strengths which could be compared to the 150- by 300-mm (6- by 12-in) control cylinder strengths and to determine the strength development of the concrete in the dam over a period of 1 year. In general, the cores selected for compression testing did not contain construction joints.

Compressive strength was determined by axially loading the specimens at a rate of 14 MPa (2000 lb/in²) per minute until failure. Several of the specimens were ruptured completely to permit visual observation of the fractures. No evidence of chemical attack of the concrete was observed.

**Tensile Strength**

Thirty-eight cores were used for tension tests. Twenty-three of these cores intersected horizontal construction joints. Steel plates, 50 mm (2 in) thick, were cemented with epoxy to the ends of each test specimen. Following a 24-hour cure of the epoxy at room temperature, the cores were placed in the testing machine with the end plates connected to the upper and lower platens through chain linkages. All specimens were loaded axially at a rate of 1.4 MPa (200 lb/in²) per minute until failure occurred (fig. 4).
Density

The computed densities are shown in tables 1 and 1A. The density averaged 2458 kg/m³ (153.4 lb/ft³) for all tests.

Elastic Properties

Results of elastic properties tests are summarized in tables 1, 1A, and 2. The moduli of elasticity averaged 31.7 GPa (4.60 x 10^6 lb/in²) at 1 year's age. As expected, there was some increase in the moduli from 70 days to 1 year (fig. 5).

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

Compressive Strength

The results of the individual tests are shown in tables 1 and 1A. Summaries of results are shown in table 2 and figures 6 and 7. The average compressive strength for the concrete was 33.7 MPa (4890 lb/in²) at 6 months' age and 35.0 MPa (5080 lb/in²) at 1 year's age. This shows a 3.9-percent increase in strength from 6 months' age to 1 year's age, which is slightly below average for typical strength development in mass concrete.

The compressive strengths of the cores ranged from 29.2 MPa (4230 lb/in²) to 39.0 MPa (5660 lb/in²) at 6 months' age and from 29.7 MPa (4300 lb/in²) to 40.4 MPa (5860 lb/in²) at 1 year's age. The corresponding coefficients
of variation at 6 months and 1 year were 8.6 and 8.9 percent, respectively, which are excellent for general construction field quality control.

**Tensile Strength**

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


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<th>Bending strength (psi)</th>
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**Comments:**
- Core 10-44-1 drilled in S1 face 0.21 rad (11°) off vertical. Broke below the joint at elevation 2159.
- Core 10-44-2 drilled in S1 face 0.03 rad (1°) off vertical. Broke below the joint at elevation 2282.
- Core 10-44-3 drilled in S1 face 0.21 rad (11°) off vertical. Broke above the joint at elevation 2282.
- Core 10-44-4 drilled in S1 face 0.03 rad (1°) off vertical. Broke above the joint at elevation 2282.
- Core 10-44-5 drilled in S1 face 0.21 rad (11°) off vertical. Broke above the joint at elevation 2282.
- Core 10-44-6 drilled in S1 face 0.03 rad (1°) off vertical. Broke above the joint at elevation 2282.
- Core 10-44-7 drilled in S1 face 0.21 rad (11°) off vertical. Broke above the joint at elevation 2282.
- Core 10-44-8 drilled in S1 face 0.03 rad (1°) off vertical. Broke above the joint at elevation 2282.
- Core 10-44-9 drilled in S1 face 0.21 rad (11°) off vertical. Broke above the joint at elevation 2282.
- Core 10-44-10 drilled in S1 face 0.03 rad (1°) off vertical. Broke above the joint at elevation 2282.

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- 10-44B | 10-16-74 | 3-79.5 | 3-79.5 | 9.18 | 237.5 | 237.5 | 9.18 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 |
- 10-44C | 10-16-74 | 3-79.5 | 3-79.5 | 9.18 | 237.5 | 237.5 | 9.18 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 | 1,845 |
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**Average Comments:**
- Average of concrete drilled vertically from foundation gallery floor, broke 50 in. above joint at elevation 2129.
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<td>5.9</td>
<td>No joint</td>
<td>Concrete drilled vertically from utility gallery floor, construction joints at elevations 2312 and 2318.</td>
</tr>
<tr>
<td>1-1975</td>
<td>16-180</td>
<td>100 psi</td>
<td>3-21</td>
<td>6.25</td>
<td>5.9</td>
<td>No joint</td>
<td>Concrete drilled vertically from utility gallery floor, construction joints at elevations 2312 and 2318.</td>
</tr>
<tr>
<td>1-1975</td>
<td>16-190</td>
<td>100 psi</td>
<td>3-21</td>
<td>6.25</td>
<td>5.9</td>
<td>No joint</td>
<td>Concrete drilled vertically from utility gallery floor, construction joints at elevations 2312 and 2318.</td>
</tr>
<tr>
<td>1-1975</td>
<td>16-200</td>
<td>100 psi</td>
<td>3-21</td>
<td>6.25</td>
<td>5.9</td>
<td>No joint</td>
<td>Concrete drilled vertically from utility gallery floor, construction joints at elevations 2312 and 2318.</td>
</tr>
</tbody>
</table>

*Design values other than actual yield values. | First number, block number; second, lift number; third, core specimen number. |
| Had joint break during construction? | Yes | No | | Yes | No | | Yes | No | |

**Table 1. Summary of results obtained from tests performed on 560-mm (10-in) diameter concrete cores - Crystal Loxx [SI METRIC UNITS] - Continued.**
<table>
<thead>
<tr>
<th>Elevatio n (ft)</th>
<th>Material properties of fresh concrete</th>
<th>Properties of hardened concrete</th>
<th>Joint Strength (psi)</th>
<th>Break Strength (psi)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age tested (days)</td>
<td>Water/cement (by wt)</td>
<td>Sand/cement (by wt)</td>
<td>Air voids (by vol)</td>
<td>Strength (28 days)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compressive (ksi)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tensile (ksi)</td>
</tr>
</tbody>
</table>

- **Table IA** - Summary of results obtained from tests performed on 80-mm (10-in) diameter concrete cores - Crystal Dam [1000-POUND UNITS]
<table>
<thead>
<tr>
<th>Table A - Summary of results obtained from tests performed on 250mm (10-in) diameter concrete cores -agliated from 34047-3 (1972) - continued</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core No.</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Note: The above table is a summary of results obtained from tests performed on 250mm (10-in) diameter concrete cores.
Table 2. - Summary of test data - Crystal Dam concrete cores

<table>
<thead>
<tr>
<th>Average age</th>
<th>Number of specimens</th>
<th>Average compressive strength (MPa)</th>
<th>Coefficient of variation (%)</th>
<th>Strength ratio * (%)</th>
<th>Modulus of elasticity (GPa)</th>
<th>Poisson's ratio (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 days</td>
<td>6</td>
<td>28.0</td>
<td>19.7</td>
<td>81</td>
<td>27.6</td>
<td>4.00 x 10^6</td>
</tr>
<tr>
<td>6 months</td>
<td>14</td>
<td>33.7</td>
<td>8.6</td>
<td>112</td>
<td>31.4</td>
<td>4.55 x 10^6</td>
</tr>
<tr>
<td>1 year</td>
<td>14</td>
<td>35.0</td>
<td>8.9</td>
<td>116</td>
<td>31.7</td>
<td>4.60 x 10^6</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Type of specimen</th>
<th>Average age</th>
<th>Number of specimens tested</th>
<th>Average tensile strength (MPa)</th>
<th>Average strength ratio tensile/compressive (%)</th>
<th>Number of failures at joints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jointed</td>
<td>76 days</td>
<td>3</td>
<td>1.17</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Nonjointed</td>
<td>69 days</td>
<td>1</td>
<td>1.17</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Jointed</td>
<td>6 months</td>
<td>11</td>
<td>1.38</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Nonjointed</td>
<td>6 months</td>
<td>7</td>
<td>1.24</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Jointed</td>
<td>1 year</td>
<td>9</td>
<td>1.31</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Nonjointed</td>
<td>1 year</td>
<td>7</td>
<td>1.79</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

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Figure 1. - Hole locations for 250-mm (10-in) diameter cores - Crystal Dam.
Figure 2. - Typical "as-received" condition of 250-mm (10-in) diameter cores - Crystal Dam. Photo Pb22C-427-7363.
Figure 3. - Typical 250-mm (10-in) diameter cores showing a construction joint - Crystal Dam. Photo C-8426-2.
Figure 4. - Typical 250-mm (10-in) diameter core after tensile strength test - Crystal Dam. Photo C-8448-1.
Figure 5. - Average moduli of elasticity of mass concrete in Crystal Dam.
Figure 6. - Average compressive strength of mass concrete in Crystal Dam.
Figure 7. - Ratio of core to companion 28-day cylinder strengths in Crystal Dam.
Figure 8. - Average tensile strength of mass concrete in Crystal Dam.
Figure 9. - Ratio of tensile strengths to companion compressive strengths in Crystal Dam.
A free pamphlet is available from the Bureau entitled, "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request to the Bureau of Reclamation, Engineering and Research Center, PO Box 25007, Denver Federal Center, Bldg. 67, Denver, CO 80225, Attn D-922.