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**KEY WORDS AND DOCUMENT ANALYSIS**

a. **DESCRIPTIONS**— concretes/cores/compressive strength/modulus of elasticity/Poisson's ratio/mass concrete/petrographic investigation/concrete properties/absorption/density/shear strength

b. **IDENTIFIERS**— Black Canyon Dam/Boise Project/Idaho/gravity dam/PN Region

c. **COSATI Field/Group** 13M  COWRR: 1313  SRM:

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EVALUATION OF CONCRETE CORES
BLACK CANYON DAM, IDAHO

by

Peter O. Castaneda

Concrete and Structural Branch
Division of Research
Engineering and Research Center
Denver, Colorado
June 1983
Frontispiece.—Black Canyon Dam, Payette Division, Boise Project, Idaho. Photo P3-100-847-I
ACKNOWLEDGMENTS

This study was conducted by members of the Concrete and Structural Branch. Significant contributions to the report were made by J. N. Hartwell, Applied Sciences Branch, who performed the petrographic examination; and by members of the Geotechnical Branch, who performed the shear and sliding friction tests.
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Conclusions</td>
<td>1</td>
</tr>
<tr>
<td>Core extraction and drilling</td>
<td>2</td>
</tr>
<tr>
<td>Shipping and receiving</td>
<td>2</td>
</tr>
<tr>
<td>Core testing</td>
<td>2</td>
</tr>
<tr>
<td>Appendix A – Petrographic examination</td>
<td>9</td>
</tr>
<tr>
<td>Appendix B – Break bond and sliding friction test results</td>
<td>15</td>
</tr>
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</table>

## TABLES

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1</td>
<td>4</td>
</tr>
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<td></td>
<td>Summary of Black Canyon Dam core testing</td>
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</table>

## FIGURES

<table>
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</thead>
<tbody>
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<tr>
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<td>7</td>
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<td>Drill hole locations – Black Canyon Dam</td>
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INTRODUCTION

The Black Canyon Dam, on the Payette River near Emmett, Idaho, is a concrete, gravity-type dam with an ogee overflow spillway. Built by the Bureau of Reclamation in 1924, the dam has a structural height of 183 feet and serves to divert water to the Payette Division through the Black Canyon Canal. The dam heads the gravity distribution system in the 114,000-acre Payette Division. The Bureau continues to operate and maintain the dam. A general location map is shown on figure 1.

In June and August 1977, 6- and 10-inch-diameter cores, respectively, were extracted from the dam. These cores were tested to evaluate the condition of concrete in the dam. These data and analyses were provided for use in evaluating the structural integrity of the existing structure and for design modifications required to withstand the redefined maximum inflow design flood and maximum credible earthquake.

CONCLUSIONS

1. Though only a limited number of specimens were tested, compressive strength and density results indicate that the concrete in Black Canyon Dam is of good quality, when compared to the concrete design strength of 2,000 pounds per square inch required in the original specifications. The average compressive strength was 4,500 pounds per square inch, and the average density was 155.4 pounds per cubic foot. Considering the age of the concrete and construction methods available at the time of construction, the test results were favorable.

2. The petrographic examination (app. A) indicates that the concrete is of satisfactory physical and chemical quality. No evidence of alkali-aggregate reaction, sulfate or chloride attack, or freeze-thaw deterioration was observed in the examined interior concrete.

3. Direct shear test results, analyzed by linear regression, are comparable to results obtained on other Bureau projects, with the cohesion on sliding friction tests averaging 215.5 pounds per square inch, and the average angle of friction (φ) was 39°. Sliding friction results indicate
similar behavior in both unbonded and bonded joints. Statistical variances prevented any conclusions on the break bond tests.

4. From visual inspection and the testing, the concrete is of good quality and is serviceable, with only surface deterioration occurring on the downstream face.

CORE EXTRACTION AND DRILLING

About 78 feet of 6-inch-diameter cores and 86 feet of 10-inch-diameter cores were extracted from the dam in June and August 1977, respectively. Two galleries run throughout the length of the overflow section, one 25 feet and another 50 feet below the top of the section. Core drilling occurred in these galleries, with drill hole 76-1 drilled in the left one-third of the upper gallery, and drill hole 76-2 drilled in the middle one-third of the upper gallery. In the lower gallery, drill holes 76-3 and 76-4 were in the left one-third, and drill holes 76-5, 76-6, 76-6A, and 76-6B in the middle one-third. Locations of the drill holes are shown on figure 2.

SHIPPING AND RECEIVING

Cores were marked appropriately for location and elevation, packed in damp sawdust, and shipped to the Engineering and Research Center in Denver, Colorado, for testing and examination. When the cores arrived in Denver, they were unpacked, logged, and inspected. Lift lines were identified and marked; however, the locations of two of the lift lines were later questioned by the Rock Mechanics Section after erratic results were found during direct shear testing (app. B). All cores were damp and undamaged when received; however, they were then subjected to an extended drying period of about 4 years in the laboratory before testing. Just prior to testing, all cores were placed in a vacuum for at least 30 minutes, and submerged for vacuum-saturation for 72 hours.

CORE TESTING

Compression tests were performed on the 6-inch cores, and direct shear tests on the 10-inch cores. Compressive strength tests were run in accordance with ASTM designation: C 42 (Obtaining and
Testing Drilled Cores and Sawed Beams of Concrete). Prior to testing, the 6-inch-diameter cores were sawed to 12-inch lengths to conform to the standard length-diameter ratio of 2:1. The density of each specimen was determined in accordance with ASTM designation: C 642 (Specific Gravity, Absorption, and Voids in Hardened Concrete), except that specimens were saturated by vacuum saturation rather than by soaking in boiling water.

The direct shear tests were performed as described in appendix B, and analyzed in accordance with Bureau Report No. GR-15-76. The 10-inch-diameter cores were cut to a height of about 8 to 10 inches, with an identified lift line located at midpoint, and oriented perpendicular to the axis of the cylinder. The specimens were then embedded in 4-inch steel load rings, and shear loads were applied to the joints. Sliding friction and break bond tests were run on intact (bonded) joints; only sliding friction tests were run on unbonded joints. The purpose of these shear tests was to aid the designer in selecting the angle of friction (φ) and the cohesion to predict structural performance.

Representative fragments of the cores were selected for petrographic examination to determine the petrographic quality of the concrete and evaluate leaching at the lift lines. The selected fragments were examined megascopically, microscopically, by x-ray diffraction and differential thermal analysis, and by some qualitative physical and chemical tests.

A summary of results from data for density, compressive strength, and shear strength tests is given in table 1. Detailed petrographic evaluations are given in appendix A, and details on the shear testing are given in appendix B.

---

Table 1.—Summary of Black Canyon Dam core testing

| Drill hole No. | Specimen depth (ft) | Compressive strength (lb/in²) | Modulus of elasticity (lb/in² x 10⁶) | Poisson's ratio | Density (lb/ft³) | Break bond Normal load Break value (lb/in²) (lb/in²) Sliding friction Cohesion (lb/in²) Tan φ |
|----------------|---------------------|-----------------------------|-----------------------------------|----------------|----------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 76-1           | 4.9                 | 3,260                       | 3.34                              | 0.30           | 147.1          | –                               | –                               | –                               | –                               | 265                             | 0.94                            |
| 76-1           | 8.9                 | 5,470                       | 3.46                              | 0.18           | 155.9          | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-1           | 9.4                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-2           | 1.0                 | 4,750                       | 3.68                              | 0.16           | 153.7          | –                               | –                               | 542                             | 100                             | 227                             | 0.60                            |
| 76-2           | 6.8                 | 3,460                       | 2.84                              | 0.19           | 153.2          | –                               | –                               | 595                             | 96                              | 200                             | 0.78                            |
| 76-2           | 11.0                | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-3           | 3.0                 | –                           | –                                 | –              | –              | –                               | –                               | 721                             | 114                             | 227                             | 0.71                            |
| 76-3           | 3.5                 | –                           | –                                 | –              | –              | –                               | –                               | 827                             | 50                              | 354                             | 0.83                            |
| 76-3           | 5.5                 | 5,100                       | 4.17                              | 0.20           | 157.8          | –                               | –                               | 945                             | 198                             | 177                             | 0.83                            |
| 76-3           | 8.2                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-3           | 10.0                | 4,350                       | 3.13                              | 0.15           | 165.4          | –                               | –                               | 945                             | 198                             | 177                             | 0.83                            |
| 76-3           | 8.2                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-4           | 2.4                 | 4,320                       | 4.69                              | 0.22           | 155.8          | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-4           | 3.0                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-4           | 4.8                 | 4,050                       | 2.78                              | 0.19           | 154.7          | –                               | –                               | 187                             | 1.17                            | –                               | –                               |
| 76-5           | 2.8                 | 3,430                       | 2.87                              | 0.28           | 156.3          | –                               | –                               | –                               | –                               | 131                             | 0.84                            |
| 76-5           | 4.8                 | 4,260                       | 3.20                              | 0.16           | 155.1          | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-5           | 6.5                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-5           | 8.0                 | 4,350                       | 3.81                              | 0.19           | 155.4          | –                               | –                               | –                               | –                               | 152                             | 0.74                            |
| 76-6           | 2.7                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-6           | 10.8                | 7,180                       | 4.20                              | 0.21           | 154.4          | –                               | –                               | 414                             | 106                             | 181                             | 0.89                            |
| 76-6A          | 4.0                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-6B          | 2.6                 | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| 76-6B          | 12.4                | –                           | –                                 | –              | –              | –                               | –                               | –                               | –                               | –                               | –                               |
| Average        |                     | 4,500                       | 3.51                              | 0.20           | 155.4          | 206                             | 0.87                            |

1 Compressive strength testing used 6-inch cores, and 10-inch cores were used for direct shear testing.
2 Sliding friction results are by linear regression analysis.
3 Lift line may not have been precisely marked.
Figure 1.—General location map.
NOTE
All stations measured along axis of dam.
APPENDIX A

PETROGRAPHIC EXAMINATION
Memorandum

TO: Chief, Concrete and Structural Branch

FROM: Chief, Applied Sciences Branch

DATE: April 14, 1982

SUBJECT: Petrographic Examination of Concrete Core - Black Canyon Dam - Boise Project, Idaho

Examined by: J. N. Hartwell

Petrographic referral code: 82-21

INTRODUCTION

A cursory examination of Black Canyon Dam 6- and 10-inch-diameter concrete core from drill holes 76-1 through -6, -6A, and 6-B was performed in the Concrete Laboratory to select representative fragments for further testing and examination in the Petrographic Laboratory. All holes were drilled from galleries within the dam.

The purposes of the examination were to determine the petrographic quality of the concrete, including deterioration due to alkali-aggregate reaction, and investigate leaching at the lift lines. In addition, comparative observations were made between lower and higher strength concrete.

PETROGRAPHIC EXAMINATION

The selected concrete fragments were examined megascopically, microscopically, by XRD (X-ray diffraction) and DTA (differential thermal analysis), 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 aggregate, paste, air voids, secondary and hydration products, microfractures, and other observations. Fragments from the various drill holes are petrographically similar and, therefore, are described together.

CONCLUSION-DISCUSSION

Concrete

The examined concrete from Black Canyon Dam is petrographically of satisfactory physical and chemical quality and, therefore, is considered serviceable.
concrete. No evidence of alkali-aggregate reaction, sulfate or chloride attack, or freeze-thaw deterioration was observed in the examined concrete.

The aggregate is physically satisfactory and chemically innocuous. The concrete is generally gray to tan and slightly to moderately absorptive. The distribution of the paste and aggregate is variable but generally satisfactory and the paste-aggregate bond is moderately strong. The examined concrete contains few entrapped air voids which are generally unfilled to very few lined with calcium carbonate, calcium hydroxide, and occasionally ettringite. The presence of calcium hydroxide and calcium silicates as cement products and the absence of unhydrated cement particles indicate the examined concrete is well hydrated. The presence of calcium carbonate and ettringite indicates somewhat old, carbonated concrete.

Compressive strength values of concrete core tested by the Concrete Section ranged from approximately 3,200 to 7,200 lb/in² with an average of approximately 4,500 lb/in². Comparative observations of higher and lower strength concrete indicate the lower strength specimens contained more larger gravel particles (+3 in) and/or appeared to be less well consolidated than higher strength specimens.

Lift Lines

The examined lift lines or suspected lift lines from Black Canyon Dam are petrographically of variable physical quality and do not appear to have deteriorated significantly since emplacement.

The examined lift lines are quite variable in appearance. Well-consolidated areas are generally slightly absorptive, carbonated, comprised chiefly of paste and sand, and contain few entrapped air voids. Poorly consolidated areas are generally moderately absorptive, carbonated, comprised of paste and sand and gravel, and contain numerous entrapped air voids.

Areas which exhibit poor consolidation and contain numerous entrapped air voids may be sufficiently porous, if interconnected, to allow water to percolate very slowly through the structure, therefore, some leaching at lift lines may be expected. However, only a few examined areas exhibited minor amounts of secondarily deposited calcium carbonate and/or iron oxides.

Ice crystal impressions in rock sockets at or near several examined lift lines indicate freezing prior to initial set of the concrete. Although no weakening of the concrete was apparent in the affected areas, the ice crystal impressions may contribute to leaching at lift lines.

L. D. Tindall Jr.

Attachment

Copy to: D-220 D-1511 (Guy)
D-915 D-1523
Petrographic Examination of Concrete

Subject: Black Canyon Dam Boise Project, Idaho
Field No.: DH 76-1 through -6A, and -6B

Cursory Observations: Concrete - 6-in (0.15-m) and 10-in (0.25-m) diameter core; moderately to well consolidated; few to moderate amounts of entrapped air voids; tan to gray paste; very slightly fractured to nonfractured; no reaction rims around aggregate particles; slight to moderate effervescence with cold dilute HCl (hydrochloric acid); chiefly slightly to moderately absorptive. Lift lines - well to poorly consolidated; few to numerous amounts of entrapped air voids; tan to gray paste; moderate to high effervescence with cold dilute HCl; moderately absorptive; ice crystal impressions in rock sockets at or near lift lines

Petrographic Examination

Aggregate (concrete and lift lines)

Gravel: Generally rounded to subrounded in shape; consists of granite-diorite series rocks, altered volcanics, basalt, quartzite, few woody fragments (sticks, roots, etc.) especially at or near lift lines, obsidian, and a few glassy volcanic rock types

Sand: Generally subrounded to subangular in shape; consists of same rock types found in the gravel as well as monomineralic grains of quartz, feldspar, mica, amphibole, olivine, and a few miscellaneous detrital minerals

Gravel and sand: Petrographically of satisfactory physical quality and not considered potentially deleteriously reactive with high-alkali cement

Paste

Concrete - Generally gray to tan; generally slightly to moderately absorptive; breaks with moderate to hard hammer blows generally around and through very few aggregate particles; variably distributed with sand and gravel; moderately strong paste-aggregate bond; generally moderately well to poorly consolidated; exterior paste moderately effervescent and interior paste only slightly effervescent with cold dilute HCl

Lift lines - Generally tan to gray; variable, but generally moderately to slightly absorptive; variable, chiefly paste and sand with very few visible coarse gravel particles to well distributed paste and aggregate; moderately strong paste-aggregate bond; variable, poorly to well consolidated; generally moderately effervescent with cold dilute HCl

Voids (concrete and lift lines)

Chiefly few to numerous entrapped air voids generally at or near lift lines or occasionally concentrated beneath larger gravel particles; irregularly shaped; and generally unfilled to very few lined with calcium carbonate, calcium hydroxide, and occasionally ettringite
Secondary Products (concrete and lift lines)

Moderate amounts of calcium carbonate in paste and lining few voids and rock sockets; lift lines contain more calcium carbonate in paste and occasionally thinly coated with calcium carbonate and/or iron oxides; minor amounts of ettringite lining few voids; no silica gel developed in fragments soaked 3 to 4 weeks in Denver tapwater; only minor amounts of soluble chloride ions and no sulfate ions chemically detected.

Hydration Products (concrete and lift lines)

Moderate amounts of portlandite (calcium hydroxide) and calcium silicates; no unhydrated cement particles; water of hydration appears adequate.

Microfractures (concrete and lift lines)

Generally nonfractured; few unfilled discontinuous microfractures generally in paste and around aggregate particles.

Other Observations

Ice crystal impressions in rock sockets generally at or near several lift lines; cloth fibers on few lift line surfaces apparently from material used during curing.
APPENDIX B

BREAK BOND AND SLIDING FRICTION TEST RESULTS
Memorandum

TO: Head, Concrete Section

THROUGH: Chief, Concrete and Structural Branch
Chief, Geotechnical Branch "Acting"

FROM: Head, Rock Mechanics Section

DATE: May 12, 1982

Denver, Colorado

SUBJECT: Break Bond and Sliding Friction Test Results on Black Canyon Dam - 10-inch-diameter Concrete Core

Direct shear tests were performed on 12 concrete specimens from Black Canyon Dam as requested in memorandum from Chief Design Engineer dated November 3, 1981, to Chief, Division of Research. The specimens were obtained from drill holes 76-1 through 76-6, 76-6A, and 76-6B, all of which yielded core approximately 10 inches in diameter. Seven specimens had both break bond and sliding friction tests performed, while the remaining five specimens had open joints and only the sliding friction tests were run.

The break bond tests were run using approximately 50-, 100-, and 200-lb/in² normal stress. All the sliding friction tests were performed under approximately the following repeated normal stress:

- 50 lb/in²
- 100 lb/in²
- 200 lb/in²
- 500 lb/in²

A direct shear test is where an intact specimen is subjected to a biaxial stress field until shear failure occurs in a predetermined location. This predetermined location is termed the "d" distance which is defined as the distance between the two holding devices to which shear and normal loads are applied. In this case, the normal load is applied perpendicular to the "lift lines" in the concrete specimens. The shear zone for these specimens was restricted to the material located within the "d" distance of 1 inch which is the standard distance for 10-inch-diameter specimens on the large shear machine.

Failure analysis for all sliding friction data has been defined by the linear regression method. The results of all of the tests are shown in the appendix. A linear regression analysis for all of the specimens is shown in figure 1. This includes both break bond and sliding friction results. The regression results for the break bond points are suspect. It is felt this condition was a result of the "lift line" of some specimens were not precisely located. The two most questionable specimens are DH-76-3 2.0 and 8.2. Not only does
the high break value appear suspicious, table 1, but examination of these specimens after the test shows that large aggregate was also broken in the sheared zone. See afterbreak photographs in the appendix.

As seen in table 1, the overall, the results for sliding friction tests ranged from 131.1 to 354.1 lb/in² for cohesion and from 0.604 to 1.172 for tan φ. The regression analysis yielded a cohesion of 205.4 lb/in² and a tan φ of 0.87 for the combined results of both break-induced slides and open joint slides as shown in figure 1. It can be noted that the results for the open joint slides have a lower cohesion value than the break-induced slides. This comparison is shown graphically on figures 2 and 3. The open joint slides, figure 3, result in a cohesion of 191.7 lb/in² and a tan φ of 0.95. This is compared to the break-induced slides, figure 2, of 215.5 lb/in² and a tan φ of 0.81. This can be explained by the fact that the open joints are cleaner and less rough than the freshly broken break-induced joints.
Table 1.—Summary of Black Canyon direct shear tests

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<th>Sliding friction</th>
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1 "Lift line" may not have been precisely marked.
Figure 1.

DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON  COMBINED

LEGEND
O = BREAK BOND RESULTS
X = SLIDING FRICTION RESULTS

BREAK BOND RESULTS
\[ \tau = 629.4 \pm 0.14 \] (e)
COHESION = 629.4 lb/in²
\[ \phi = 7.8^\circ \quad r^2 = 0.0017 \]

SLIDING FRICTION RESULTS
\[ \tau = 205.4 \pm 0.87 \] (e)
COHESION = 205.4 lb/in²
\[ \phi = 41.0^\circ \quad r^2 = 0.8097 \]
Figure 2.

DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS
BLACK CANYON BREAKS

![Graph showing shear stress vs normal stress with regression lines and data points.]

**LEGEND**
- O = Break bond results
- X = Sliding friction results

**BREAK BOND RESULTS**
- $\tau = 629.4 + 0.14(\sigma)$
- Cohesion = 629.4 lb/ft$^2$
- $\phi = 7.8^\circ$, $r^2 = 0.0017$

**SLIDING FRICTION RESULTS**
- $\tau = 215.5 + 0.81(\sigma)$
- Cohesion = 215.5 lb/ft$^2$
- $\phi = 39.0^\circ$, $r^2 = 0.8018$
Figure 3.

DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS
BLACK CANYON SLIDES

Sliding Friction Results:
- \( \tau = 191.7 + 0.95(\sigma) \)
- Cohesion = 191.7 lb/in²
- \( \phi = 43.4^\circ \)
- \( r^2 = 0.8283 \)

No Breaks

Break Bond Results:
- No Breaks

Shear Stress, \( \tau \) - Lb/in²
Normal Stress, \( \sigma \) - Lb/in²

Figure 3.
APPENDIX
TO
APPENDIX B
Direct shear testing, 10-inch core, DH-76-1
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
### Sliding Friction Test Analysis

#### Linear Regression Results

**Black Canyon**

**Specimen Number**: DH 76-1 9.4  
**Area**: 70.32 sq in

<table>
<thead>
<tr>
<th>Run Number</th>
<th>N</th>
<th>S</th>
<th>Maximum Vertical Displacement</th>
<th>LVDT Other</th>
<th>INCHES</th>
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<td>512</td>
<td>762</td>
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<td>NO DATA</td>
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</tr>
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</table>

*Linear Regression Results*

\[ S = 265.0 + 0.93908(N) \]

Correlation = 0.9600

\[ \Phi = 43.2 \text{ Degrees} \]

Cohesion = 265.0 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON DH 76-1 9.4

SLIDING FRICTION RESULTS
\[ \tau = 265.0 + 0.94 (\sigma) \]
COHESION = 265.0 lb/in^2
\( \theta = 43.2^\circ \)  \( r^2 = 0.9600 \)

Shear Stress, \( \tau - \text{lb/in}^2 \)

Normal Stress, \( \sigma - \text{lb/in}^2 \)
Direct shear testing, 10-inch core, DH-76-2
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
BREAK BOND AND SLIDING FRICTION TEST ANALYSIS  
ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS  
BLACK CANYON  
SPECIMEN NUMBER DH76-2 7.2  AREA = 65.63 SQ IN  

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MAXIMUM VERTICAL DISPLACEMENT - CENTERLINE - LEFT - RIGHT - AVERAGE  
LVDT OTHER INCHES  

--- PSI -----  

NO DATA  

* LINEAR REGRESSION RESULTS *  
S = 226.8 + .60354(N)  
CORRELATION = .8641  
PHI = 31.1 DEGREES  
COHESION (THROUGH BREAK BOND VALUE) = 482.2 PSI  
COHESION (SLIDING) = 226.8 PSI  

* ANGLE-ENVELOPE RESULTS *  
PHI MAX = 81.1 DEGREES (6.35308)  
PHI MIN = 47.4 DEGREES (1.08657)  
PHI AVG = 70.8 DEGREES (2.86963)  
COHESION (MAX PHI) = 0.00 PSI  
COHESION (MIN PHI) = 484.05 PSI  
COHESION (AVG PHI) = 256.14 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS
BLACK CANYON   DH76-2 7.2

SLIDING FRICTION RESULTS
\[ \tau = 226.8 \times 0.60 \cdot \theta \]
COHESION = 226.8 lb/in\(^2\)
\[ \phi = 31.1^\circ \quad r^2 = 0.8641 \]

LEGEND
\( \oplus \) = BREAK BOND VALUE
\( \times \) = SLIDING FRICTION VALUES
Direct shear testing, 10-inch core, DH-76-2
Black Canyon Dam

View 3.—Concrete surface after testing.
BREAK BOND AND SLIDING FRICTION TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER DH 76-2 11.0 AREA = 65.24 SQ IN

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<th>N</th>
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</table>

*LINEAR REGRESSION RESULTS*

\[ S = 200.1 + 0.77723(N) \]

CORRELATION = 0.9482

\[ \Phi = 37.9 \text{ DEGREES} \]

COHESION (THROUGH BREAK BOND VALUE) = 520.3 PSI

COHESION (SLIDING) = 200.1 PSI

*ANGLE-ENVELOPE RESULTS*

\[ \Phi_{\text{MAX}} = 78.2 \text{ DEGREES} \]

\[ \Phi_{\text{MIN}} = 50.1 \text{ DEGREES} \]

\[ \Phi_{\text{AVG}} = 68.4 \text{ DEGREES} \]

COHESION (MAX PHI) = 134.89 PSI

COHESION (MIN PHI) = 480.07 PSI

COHESION (AVG PHI) = 352.72 PSI

34
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON

DH 76-2 11.0

SLIDING FRICTION RESULTS

\[ \tau = 200.1 + 0.78 \sigma \]

COHESION = 200.1 lb/in²

\( \theta = 37.9^\circ \)

\[ r^2 = 0.9482 \]

LEGEND

\( \Theta \) = BREAK BOND VALUE

\( \times \) = SLIDING FRICTION VALUES
View 1

View 2

View 3.—Concrete surface after testing.
BREAK BOND AND SLIDING FRICTION TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER DH76-3 2.0 AREA = 69.66 SQ IN

<table>
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<th>N</th>
<th>S</th>
<th>MAXIMUM VERTICAL DISPLACEMENT</th>
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<tbody>
<tr>
<td></td>
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<td>CENTERLINE - LEFT RIGHT AVERAGE</td>
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<td>LVDT OTHER INCHES</td>
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* LINEAR REGRESSION RESULTS *

S = 354.1 + .83257(N) CORRELATION = .9970

PHI = 39.8 DEGREES COHESION(THROUGH BREAK BOND VALUE) = 785.2 PSI

COHESION(SLIDING) = 354.1 PSI

* ANGLE-ENVELOPE RESULTS *

PHI MAX = 82.9 DEGREES (8.03443)

PHI MIN = 57.0 DEGREES (1.53846)

PHI AVG = 76.3 DEGREES (4.11489)

COHESION (MAX PHI) = 424.90 PSI

COHESION (MIN PHI) = 749.87 PSI

COHESION (AVG PHI) = 620.98 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON

LEGEND

- BREAK BOND VALUE
× - SLIDING FRICTION VALUES

SLIDING FRICTION RESULTS

\[ \tau = 354.1 \times 0.83 (\sigma) \]

COHESION = 354.1 lb/in^2
\[ \phi = 39.8^\circ, r^2 = 0.9970 \]

BLACK DIRECT SHEAR TEST RESULTS

CANYON DH76-3 2.0
Direct shear testing, 10-inch core, DH-76-3
Black Canyon Dam

View 3.—Concrete surface after testing.
BREAK BOND AND SLIDING FRICTION TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER DH 76-3 3.5 AREA = 65.48 SQ IN

<table>
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<th>N</th>
<th>S</th>
<th>MAXIMUM VERTICAL DISPLACEMENT</th>
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<td>- CENTERLINE - LEFT RIGHT AVERAGE</td>
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<td>LVDT OTHER OTHER INCHES</td>
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<td>2</td>
<td>62</td>
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<td>257</td>
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<tr>
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<td>217</td>
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<td>5</td>
<td>524</td>
<td>617</td>
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* LINEAR REGRESSION RESULTS *

\[ S = 227.2 + 0.70818(N) \]  \( \text{CORRELATION} = 0.8720 \)

\[ \text{PHI} = 35.3 \text{ DEGREES} \]

\[ \text{COHESION(THROUGH BREAK BOND VALUE)} = 639.9 \text{ PSI} \]

\[ \text{COHESION(SLIDING)} = 227.2 \text{ PSI} \]

* ANGLE-ENVELOPE RESULTS *

\[ \text{PHI MAX} = 79.7 \text{ DEGREES} (5.51724) \]

\[ \text{PHI MIN} = 49.7 \text{ DEGREES} (1.17740) \]

\[ \text{PHI AVG} = 69.2 \text{ DEGREES} (2.63532) \]

\[ \text{COHESION (MAX PHI)} = 90.74 \text{ PSI} \]

\[ \text{COHESION (MIN PHI)} = 586.35 \text{ PSI} \]

\[ \text{COHESION (AVG PHI)} = 419.85 \text{ PSI} \]
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON

DH 76-3 3.5

SLIDING FRICTION RESULTS

\[ \tau = 227.2 + 0.71 \cdot \sigma \]

COHESION = 227.2 Lb/in^2

\[ \phi = 35.3^\circ \]

\[ r^2 = 0.8720 \]

LEGEND

@ - BREAK BOND VALUE

X - SLIDING FRICTION VALUES

NORMAL STRESS, \( \sigma \) - Lb/in^2

SHEAR STRESS, \( \tau \) - Lb/in^2
Direct shear testing, 10-inch core, DH-76-3
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
BREAK BOND AND SLIDING FRICTION TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER DH 76-3 8.2 AREA = 65.37 SQ IN

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<td>LVDT OTHER INCHES</td>
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* LINEAR REGRESSION RESULTS *

S = 176.5 + .83310(N) CORRELATION = .9948

PHI = 39.8 DEGREES COHESION(THROUGH BREAK BOND VALUE) = 780.4 PSI

COHESION(SLIDING) = 176.5 PSI

* ANGLE-ENVELOPE RESULTS *

PHI MAX = 76.7 DEGREES (4.24337)
PHI MIN = 49.6 DEGREES (1.17485)
PHI AVG = 67.8 DEGREES (2.44800)

COHESION (MAX PHI) = 105.09 PSI
COHESION (MIN PHI) = 712.76 PSI
COHESION (AVG PHI) = 460.63 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON

DH 76-3 8.2

LEGEND

● - BREAK BOND VALUE
× - SLIDING FRICTION VALUES

SLIDING FRICTION RESULTS

\[ \tau = 176.5 + 0.83 \sigma \]

COHESION = 176.5 lb/in²

\[ \phi = 39.8^\circ \quad r^2 = 0.9946 \]

NORMAL STRESS, \( \sigma \) - lb/in²

SHEAR STRESS, \( \tau \) - lb/in²

1100
1000
900
800
700
600
500
400
300
200
100
0
0 100 200 300 400 500 600 700 800

NORMAL STRESS, \( \sigma \) - lb/in²
Direct shear testing, 10-inch core, DH-76-4
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
SLIDING FRICTION TEST ANALYSIS
LINEAR REGRESSION RESULTS

BLACK CANYON
SPECIMEN NUMBER DH 76-4 3.0 AREA = 69.72 SQ IN

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<td>513.</td>
<td>792.</td>
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</table>

* LINEAR REGRESSION RESULTS *

\[ S = 186.6 + 1.17164(N) \] CORRELATION = .9886

\[ \Phi = 49.5 \text{ DEGREES} \] COHESION = 186.6 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS
BLACK CANYON DH 76-43.0

<table>
<thead>
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<th>σ (Lb/in²)</th>
<th>τ (Lb/in²)</th>
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<td>204.</td>
<td>425.</td>
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<tr>
<td>513.</td>
<td>792.</td>
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</tbody>
</table>

SLIDING FRICTION RESULTS
φ = 186.6 + 1.17 (σ)
COHESION = 186.6 Lb/in²
φ = 49.5°, r² = 0.9886

NORMA STRESS, σ - Lb/in²
SHEAR STRESS, τ - Lb/in²
Direct shear testing, 10-inch core, DH-76-5
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
SLIDING FRICTION TEST ANALYSIS
LINEAR REGRESSION RESULTS
BLACK CANYON

SPECIMEN NUMBER DH 76-5 6.5 AREA = 64.17 SQ IN

<table>
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<th>RUN NUMBER</th>
<th>N</th>
<th>S</th>
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<td>CENTERLINE - LEFT RIGHT AVERAGE</td>
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<td>INCHES</td>
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<td>500.</td>
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</table>

* LINEAR REGRESSION RESULTS *

$S = 131.1 + 0.83519(N)$ CORRELATION = .9999

PHI = 39.9 DEGREES COHESION = 131.1 PSI
**DIRECT SHEAR TEST**

**LINEAR REGRESSION RESULTS**

**BLACK CANYON**

<table>
<thead>
<tr>
<th>Normal Stress, ( \sigma ) - lb/in(^2)</th>
<th>Shear Stress, ( \tau ) - lb/in(^2)</th>
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<td>99.</td>
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<td>299.</td>
</tr>
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<td>500.</td>
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</tr>
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</table>

**SLIDING FRICTION RESULTS**

\[ \tau = 131.1 + 0.84 \theta \]

**COHESION**

\[ \text{Cohesion} = 131.1 \text{ lb/in}^2 \]

\[ \theta = 39.9^\circ \]

\[ r^2 = 0.9999 \]
Direct shear testing, 10-inch core, DH-76-6
Black Canyon Dam

View 1
View 2

View 3.—Concrete surface after testing.
SLIDING FRICTION TEST ANALYSIS
LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER DH 76-6 2.7 AREA = 81.70 SQ IN

<table>
<thead>
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<th>N</th>
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<th>MAXIMUM VERTICAL DISPLACEMENT</th>
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<th>RIGHT</th>
<th>AVERAGE</th>
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<td></td>
<td>LVDT</td>
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* LINEAR REGRESSION RESULTS *

$S = 152.3 + 0.74401(N)$ CORRELATION = 0.9917

$\phi = 36.6$ DEGREES COHESION = 152.3 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON DH 76-6 2.7

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<tr>
<th>σ (lb/in²)</th>
<th>τ (lb/in²)</th>
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</thead>
<tbody>
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<td>50</td>
<td>206</td>
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<td>205</td>
<td>289</td>
</tr>
<tr>
<td>511</td>
<td>539</td>
</tr>
</tbody>
</table>

SLIDING FRICTION RESULTS

τ = 152.3 + 0.74 (σ)
COHESION = 152.3 lb/in²
φ = 36.6° r² = 0.9917
Direct shear testing, 10-inch core, DH-76-6A
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
BREAK BOND AND SLIDING FRICTION TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER DH76-6A 4.0 AREA = 65.74 SQ IN

<table>
<thead>
<tr>
<th>RUN NUMBER</th>
<th>N</th>
<th>S</th>
<th>MAXIMUM VERTICAL DISPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CENTERLINE</td>
</tr>
<tr>
<td></td>
<td>----</td>
<td>----</td>
<td>----------</td>
</tr>
<tr>
<td></td>
<td>PSI</td>
<td>-----</td>
<td>---------</td>
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<tr>
<td>1</td>
<td>106</td>
<td>414</td>
<td>NO DATA</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>176</td>
<td>NO DATA</td>
</tr>
<tr>
<td>3</td>
<td>106</td>
<td>350</td>
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</tr>
<tr>
<td>4</td>
<td>207</td>
<td>344</td>
<td>NO DATA</td>
</tr>
<tr>
<td>5</td>
<td>513</td>
<td>639</td>
<td>NO DATA</td>
</tr>
</tbody>
</table>

*LINEAR REGRESSION RESULTS*

\[
S = 181.2 + 0.89386(N) \quad \text{CORRELATION} = 0.9244
\]

PHI = 41.8 DEGREES

COHESION (THROUGH BREAK BOND VALUE) = 319.4 PSI

COHESION (SLIDING) = 181.2 PSI

*ANGLE-ENVELOPE RESULTS*

PHI MAX = 74.2 DEGREES (3.52584)

PHI MIN = 51.2 DEGREES (1.24444)

PHI AVG = 67.6 DEGREES (2.42868)

COHESION (MAX PHI) = 41.54 PSI

COHESION (MIN PHI) = 282.37 PSI

COHESION (AVG PHI) = 157.36 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON DH76-6A 4.0

LEGEND

\( \ast \) = BREAK BOND VALUE
\( \times \) = SLIDING FRICTION VALUES

SLIDING FRICTION RESULTS

\[ \tau = 181.2 + 0.89 (\sigma) \]

COHESION = 181.2 lb/in²

\( \varphi = 41.8° \) \( r^2 = 0.9244 \)

NORMAL STRESS, \( \sigma \) - lb/in²

SHEAR STRESS, \( \tau \) - lb/in²

<table>
<thead>
<tr>
<th>( \sigma )</th>
<th>( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>106.00</td>
<td>414.00</td>
</tr>
<tr>
<td>50.00</td>
<td>176.00</td>
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<tr>
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<td>350.00</td>
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<tr>
<td>207.00</td>
<td>344.00</td>
</tr>
<tr>
<td>513.00</td>
<td>639.00</td>
</tr>
</tbody>
</table>

NORM.

100 200 300 400 500
0 100 200 300 400 500

63
Direct shear testing, 10-inch core, DH-76-6B
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
SLIDING FRICTION TEST ANALYSIS
LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER: DH 76-6B 2.6
AREA = 65.30 SQ IN

<table>
<thead>
<tr>
<th>RUN NUMBER</th>
<th>N</th>
<th>S</th>
<th>MAXIMUM VERTICAL DISPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CENTERLINE - LEFT RIGHT AVERAGE</td>
</tr>
<tr>
<td></td>
<td>PSI</td>
<td>INCHES</td>
<td></td>
</tr>
<tr>
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<td>50</td>
<td>306.</td>
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<tr>
<td>2</td>
<td>100</td>
<td>306.</td>
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</tr>
<tr>
<td>3</td>
<td>202</td>
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</tr>
<tr>
<td>4</td>
<td>513</td>
<td>760.</td>
<td>NO DATA</td>
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</table>

* LINEAR REGRESSION RESULTS *

\[ S = 226.7 + 1.02654(N) \]
CORRELATION = .9891

PHI = 45.8 DEG  
COHESION = 226.7 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS

BLACK CANYON DH 76-6B 2.6

<table>
<thead>
<tr>
<th>Normal Stress, ( \sigma ) (lb/in(^2))</th>
<th>Shear Stress, ( \tau ) (lb/in(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.</td>
<td>306.</td>
</tr>
<tr>
<td>100.</td>
<td>306.</td>
</tr>
<tr>
<td>202.</td>
<td>423.</td>
</tr>
<tr>
<td>513.</td>
<td>760.</td>
</tr>
</tbody>
</table>

SLIDING FRICITION RESULTS

\[ \tau = 226.7 + 1.03 \sigma \]  
COHESION = 226.7 lb/in\(^2\)  
\[ \phi = 45.8^\circ \]  
\[ r^2 = 0.9991 \]
Direct shear testing, 10-inch core, DH-76-6B
Black Canyon Dam

View 1

View 2

View 3.—Concrete surface after testing.
BREAK BOND AND SLIDING FRICTION TEST ANALYSIS

ANGLE-ENVELOPE AND LINEAR REGRESSION RESULTS

BLACK CANYON

SPECIMEN NUMBER DH76-68 12.4 AREA = 68.97 SQ IN

<table>
<thead>
<tr>
<th>RUN NUMBER</th>
<th>N</th>
<th>S</th>
<th>MAXIMUM VERTICAL DISPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PSI</td>
<td>CENTERLINE -</td>
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<tr>
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<td></td>
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<td>RIGHT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AVERAGE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INCHES</td>
</tr>
<tr>
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<td>207</td>
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<tr>
<td>2</td>
<td>50</td>
<td>186</td>
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<tr>
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<td>105</td>
<td>244</td>
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<td>207</td>
<td>371</td>
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</tr>
<tr>
<td>5</td>
<td>515</td>
<td>673</td>
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</table>

* LINEAR REGRESSION RESULTS *

\[ S = 139.1 + 1.04608(N) \]

CORRELATION = .9976

\( \phi = 46.3 \text{ DEGREES} \)

COHESION (THROUGH BREAK BOND VALUE) = 265.2 PSI

COHESION (SLIDING) = 139.1 PSI

* ANGLE-ENVELOPE RESULTS *

\( \phi_{\text{MAX}} = 74.9 \text{ DEGREES} (\ 3.71014) \)

\( \phi_{\text{MIN}} = 52.6 \text{ DEGREES} (\ 1.30704) \)

\( \phi_{\text{AVG}} = 66.3 \text{ DEGREES} (\ 2.28273) \)

COHESION (MAX PHI) = 0.00 PSI

COHESION (MIN PHI) = 211.32 PSI

COHESION (AVG PHI) = 9.73 PSI
DIRECT SHEAR TEST
LINEAR REGRESSION RESULTS
BLACK CANYON  DH76-6B 12.4

SLIDING FRICTION RESULTS
\[ \tau = 139.1 + 1.05 \phi \]
COHESION = 139.1 lb/in²
\( \phi = 46.3^\circ \)  \( r^2 = 0.9976 \)

LEGEND
\( \Theta \) = BREAK BOND VALUE
\( \times \) = SLIDING FRICTION VALUES

NORMAL STRESS, \( \sigma \) - lb/in²
SHEAR STRESS, \( \tau \) - lb/in²

\[ \text{Lb/in}^2 \quad \text{Lb/in}^2 \]
207.  481.
50.  186.
105.  244.
207.  371.
515.  673.

0  100  200  300  400  500  600
0  100  200  300  400  500  600

GPO 840-692
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.