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R-89-01

CONCRETE CORE TESTING BRANTLEY DAM, NEW MEXICO

February 1989

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
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 Brantley Dam 3 to 7 months after placement. The properties tested were the compressive strength, modulus of elasticity, Poisson's ratio, direct tensile strength, direct shear strength, splitting tensile strength, and density.

The overall quality of the concrete cores in Brantley Dam indicates a durable concrete having a compressive strength exceeding the design requirements. The elastic properties of the concrete are significantly higher than normal for mass concrete of this strength and age. The direct tensile strength is within the normal range for mass concrete. The direct shear strength of the intact joints is 60 percent of the parent material. The splitting tensile strength is within the range normally expected for mass concrete.

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CONCRETE CORE TESTING
BRANTLEY DAM
NEW MEXICO

by

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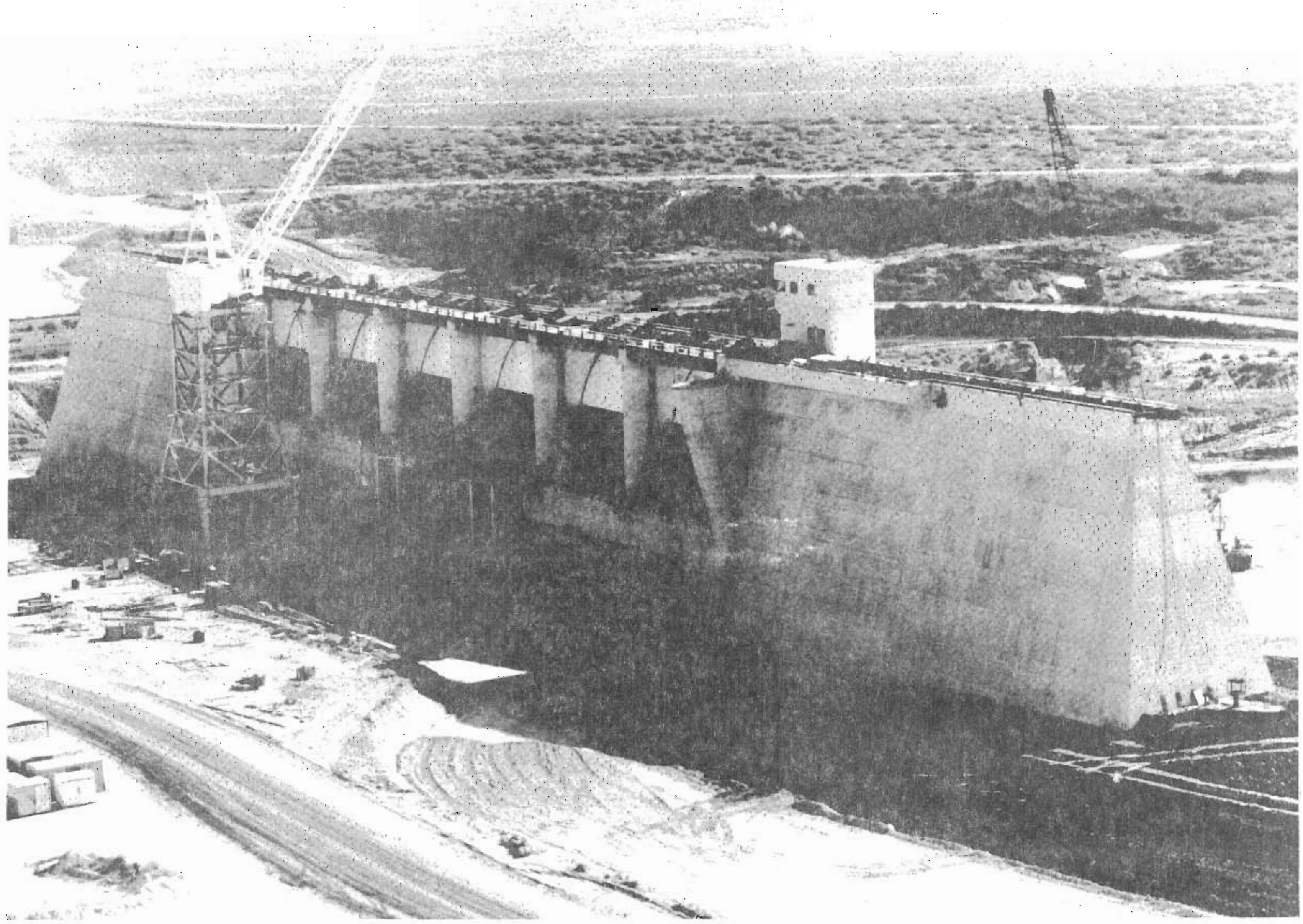
Concrete and Structural Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

SI METRIC

February 1989

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION



Brantley Dam, New Mexico - Spillway Section

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INTRODUCTION

Brantley Dam is located on the Pecos River, in Eddy County of southeastern New Mexico, about midway between the cities of Carlsbad and Artesia. It is an earthen and concrete gravity dam, 140 feet (43 m) high and 4 miles (6.4 km) long. The dam has a 700-foot (213-m) long concrete spillway flanked by nearly 2 miles (3.2 km) of earthfill on each side. Over 159,000 yd^3 (122 000 m^3) of concrete were placed in the structure between 1985 and 1987.

The concrete structure contains 28,500 tons (25 855 metric tons) of cement and pozzolan, and over 2.2 million pounds (1 million kg) of reinforcing steel. The 99,785 yd^3 (72 290 m^3) of mass concrete required over 52,000 feet (15 850 m) of 1-inch (25-mm) outside-diameter cooling coil to ensure proper temperature control.

The overflow spillway in the concrete section is controlled by six radial gates measuring 50 by 25 feet (15.2 by 7.6 m). The gates have a maximum discharge capacity of 350,000 ft^3/s (9910 m^3/s).

For a typical cross section and profile of the Brantley Dam spillway, see figures 1 and 2.

In August 1986, as part of the quality control program included in the specifications, 10-inch (250-mm) diameter cores were extracted from the partially completed mass concrete structure. While drilling in block 6, there was a significant loss of drill water indicating large voids in the mass concrete.

It was determined that more core sampling was necessary. Cores tested were taken from blocks 3, 4, 5, and 9, the right retaining wall, and the stilling basin. The cores were taken to determine the physical properties of the in-place concrete and to look for other void areas. More voids were found between elevations 3215 and 3235 (980 and 986 m) in block 6. These voids were attributed to some consolidation problems that occurred in concrete placed before August 1986. The drilling program included grouting all of the void areas found.

This report presents the results from the physical properties testing. The age of the cores at testing was between 4 and 10 months from the time of placement.

The cores were evaluated for:

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

The compressive strength requirement cited in the specifications for the mass concrete was that 80 percent of the 1-year strength tests exceed 3,500 lb/in^2 (24.1 MPa). The mass concrete contains type II portland cement, class F fly ash, 4-inch (100-mm) maximum-size aggregate, and a water-reducing, set-controlling admixture. An air-entraining admixture was used to entrain 3.5 percent air by volume of concrete. Aggregate for the concrete was obtained from borrow "H," upstream of the dam, near the right abutment. The aggregate was a natural gravel composed chiefly of limestone and dolomitic limestone. See table 1 for typical yield quantities for mass concrete.

See appendix I for the aggregate evaluation.

DRILLING AND HANDLING

Six randomly located 10-inch (250-mm) diameter cores and two 6-inch (150-mm) diameter cores were extracted from Brantley Dam during 1986 to furnish specimens for physical properties testing. The 10-inch cores tested were extracted from blocks 3 and 5, the right retaining wall, and the stilling basin. The 6-inch cores tested were extracted from blocks 4 and 9. All cores were drilled vertically. The initial cores extracted had rock pockets at the joints, and there was a significant loss of drill water indicating large voids in the mass concrete. Additional 10-inch, 6-inch, and NX-size cores were drilled throughout the dam to locate areas of poor consolidation. (See appendix II for locations of other cores.)

The moist cores were wrapped in plastic at the jobsite and then shipped in wooden crates packed with sawdust to the Bureau of Reclamation's Denver laboratories. In Denver, the core specimens were logged in and photographed, and test specimens were selected. The 10-inch-diameter specimens were sawed to 20-inch (500-mm) lengths to maintain a length-to-diameter ratio of 2.0. Specimens for direct shear testing were sawed to 4-inch (100-mm) lengths. The 6-inch-diameter specimens were used only for direct shear testing.

ASTM C 42, "Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete" (ASTM, 1986) specifies that the diameter of concrete core extracted 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." Therefore, since the mass concrete contains 4-inch maximum-size aggregate, the diameter of the core by ASTM standards should preferably have been 12 inches (300 mm); however, a 10-inch diameter was selected because it exceeded the minimum diameter permitted. Reclamation has a significant data base of concrete properties based on this diameter, and it was more economical than a 12-inch diameter.

TESTING

Compressive Strength and Elastic Properties

The compressive strength testing was done according to ASTM C 39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" (ASTM, 1986). The ends of compressive strength specimens were lapped plane to a tolerance of 0.002 inch (0.05 mm). Specimens were sealed in plastic to prevent moisture loss.

The modulus of elasticity (E) and Poisson's ratio (r) were determined using epoxied strain gauges with computer readout.

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 gauges connected in series. The manufacturer recommends that the total length of the strain gauges be between 2.5 and 3 times the size of the maximum-size aggregate. The maximum-size aggregate was 4 inches; therefore, the total length of the strain gauges should have been at least 10 inches (250 mm). However, the two 4-inch (100-mm) long strain gauges connected in series developed a total length of only 8 inches (200 mm). Subsequent testing to confirm the use of two rather than three strain gauges in series yielded comparable results.

Values for E and r were computed using the test method, "Procedure for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression" (Bureau of Reclamation, in preparation) which uses a stress range between 100 and 1,000 lb/in^2 (689 to 6895 kPa). The compressive strength specimens were tested to failure. The compressive strength values were adjusted for the specimens with a length-to-diameter ratio not equal to 2.0 according to ASTM C 42.

Direct Tensile Strength

The core specimens for direct tension testing were 10 inches in diameter and were sawcut to 20-inch lengths. The specimens were sealed in plastic to prevent moisture loss. Double end plates, 4-1/2 inches (114 mm) thick and designed to minimize deformation, were bonded to each end of the core with epoxy, which was then cured for 24 hours. The test specimens were then placed in a hydraulic testing machine and loaded to failure in tension at 200 lb/in^2/min (1379 kPa/min).

Splitting Tensile Strength

Splitting tensile strength testing of 10-inch-diameter specimens was done in accordance with ASTM C 496 "Standard Tensile Strength of Cylindrical Concrete Specimens" (ASTM, 1986).

Shear Strength

Currently in the Bureau of Reclamation, the direct shear (break bond) test is used to determine residual shear strength for integral concrete specimens and specimens with intact construction joints, while the sliding friction test is used for specimens with disbonded construction joints and for tests subsequent to the direct shear test. To determine the shear strength, data from these tests were analyzed by the linear regression method.

Eighteen concrete core specimens were tested by direct shear. Five tests were through unjointed material, four were on disbonded joints, and nine were along intact construction joints. Three specimens were 6 inches in diameter, and the remainder were 10 inches in diameter. The 6-inch-diameter specimens were tested in the 10,000-lbf (44.5-kN) normal, 20,000-lbf (89-kN) shear capacity machine, and the 10-inch specimens were tested in the 100,000-lbf (445-kN) normal, 240,000-lbf (1068-kN) shear capacity machine.

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 eight specimens tested is significantly higher than the design strength. The average strength of 5,200 lb/in^2 (35.8 MPa) was determined at an average age of 132 days. The specifications require that 80 percent of the compressive strength tests exceed 3,500 lb/in^2 (24.1 MPa) at 1 year. The results ranged between 3,360 and 6,870 lb/in^2 (23.2 and 47.4 MPa). Only one of the eight compressive strength tests was below 3,500 lb/in^2. Test results for compressive strength are shown in table 2. Due to the hardness of the limestone aggregate, the average modulus of elasticity and Poisson's ratio are significantly higher than normal for mass concrete of this strength and age. The modulus of elasticity averaged 6.61 x 10^6 lb/in^2 (45.6 GPa), ranging from 5.88 to 7.56 x 10^6 lb/in^2 (40.5 to 52.1 GPa). The Poisson's ratio for the concrete averaged 0.24.

Direct Tensile Strength

Although the direct tensile strength program was too limited for other than qualified conclusions, it appears that the full tensile strength of the concrete was obtained across many of the construction joints. The average direct tensile strength for four specimens was 265 lb/in^2 (1840 kPa), with values ranging from 220 to 330 lb/in^2 (1525 to 2290 kPa). Test results for the direct tensile strength are shown in table 2.

Splitting Tensile Strength

Results of the two splitting tensile strength tests were: 900 lb/in^2 (6200 kPa) and 555 lb/in^2 (3830 kPa). Both specimens were from stilling basin block 39A. Since the concrete represented by the splitting tensile specimens is different from that of the direct tensile specimens, there is no correlation between the two tests.

Shear Strength

The direct shear strength of the intact joints tested is 60 percent of the parent material. The angle of internal friction, ϕ , for the parent material is 76°, which is nearly the same as that of the intact construction joints, 78°. The cohesion, c, for the parent material is 575 lb/in^2 (3950 kPa), which is considerably higher than the 360 lb/in^2 (2475 kPa), for the intact joints. Once the sliding plane has been established, the angle of internal friction, ϕ , and the cohesion, c_a , are similar for the parent material [45°, 90 lb/in^2 (625 kPa)], the intact joints [44°, 50 lb/in^2 (345 kPa)], and the open joints [46°, 50 lb/in^2 (345 kPa)]. Table 3 summarizes direct shear strength testing. The complete testing data are in appendix III.

Density

The densities, shown in table 2, vary little from sample to sample and are higher than normal for mass concrete. This is due to the high specific gravity of the aggregate. The average density for 14 core specimens was 158.0 lb/ft^3 (771 kg/m^3), ranging from 155.0 to 160.3 lb/ft^3 (757 to 783 kg/m^3).

CONCLUSIONS

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

2. The modulus of elasticity of the concrete is almost 50 percent higher than normal for mass concrete of this strength and age.

3. The direct tensile strength of the concrete is 5 percent of the compressive strength. The normal expected range for mass concrete is 4 to 6 percent of the compressive strength.

4. The splitting tensile strength is 6 percent of the compressive strength, similar to that of mass concrete in other Bureau of Reclamation projects.

5. The direct shear strength of the intact joints is 60 percent of that of unjointed material.

BIBLIOGRAPHY

ASTM, *Annual Book of ASTM Standards, Concrete and Mineral Aggregates*, vol. 04.02, American Society for Testing and Materials, 1986.

Bureau of Reclamation, *Concrete Manual*, 9th ed., vol. 2, Denver, Colorado, in preparation.

Table 1. - Mass concrete, typical yield quantities per cubic yard (per cubic meter).

Material	Weight	Source
Water	170 lb (101 kg)	
Cement	256 lb (152 kg)	Lonestar Cement
Pozzolan	60 lb (36 kg)	Rocky Mountain Ash Company
Sand	1,131 lb (671 kg)	Borrow "H"
Coarse aggregate	2,561 lb (1519 kg)	Borrow "H"
Air entraining admixture	4 oz (118 mL)	Monier Air
Chemical admixture	12 oz (355 mL)	Monier LR

Concrete temperature = 45 °F (7.2 °C)

Slump = .2.0 inches (51 mm)

Unit weight = 153.9 lb/ft^3 (2465.2 kg/m^3)

W/C+P = 0.53

Air content: Gravimetric = 4.5 percent
Pressure meter = 3.3 percent

Sand content: 30 percent of total aggregate

Coarse aggregate content: 34 percent No. 4 to 3/4 inch (4.75 to 19 mm)
33 percent 3/4 to 1-1/2 inches (19.0 to 38.1 mm)
33 percent 1-1/2 to 4 inches (37.5 to 100 mm)

Compressive strength at 28 days = 5,375 lb/in^2 (37.06 MPa)

Required average strength = 3,343 lb/in^2 (23.05 MPa)

From January 1987 L-29 construction report for concrete placed on January 29, 1986.

Table 2. - Concrete properties.

Location (Block No.)	Elevation ft (m)	Date placed	Test age (days)	Density lb/ft^3 (kg/m^3)	Compressive strength lb/in^2 (MPa)	Modulus of elasticity lb/in^2 x 10^6 (GPa)	Poisson's ratio
COMPRESSIVE STRENGTH							
12- by 24-inch (305- by 610-mm) cast cylinders							
3		3/7/86	90	156.2 (2502.1)	4290 (29.6)	6.44 (44.4)	0.26
4		3/7/86	90	153.8 (2463.6)	4470 (30.8)	7.56 (52.1)	0.31
Averages			90	155.0 (2482.9)	4380 (30.2)	7.00 (48.3)	0.29
10- by 20-inch (254- by 508-mm) core specimens							
3-6N	3223.3 (982.5)	2/20/86	120	160.3 (2567.8)	5840 (40.3)	7.48 (51.6)	0.24
3-6N	3217.8 (980.8)	2/20/86	120	156.8 (2511.7)	5630 (38.8)	6.70 (46.2)	0.24
3-6N	3218.9 (981.1)	2/20/86	120	158.6 (2540.5)	4400 (30.3)	6.39 (44.0)	0.24
5-4S	3200.6 (975.5)	4/30/86	140	158.6 (2540.5)	6630 (45.7)	5.88 (40.5)	0.22
SB-35A*	3166.3 (965.1)	4/15/86	153	158.9 (2545.3)	6870 (47.4)	***	***
SB-37A	3172.5 (967.0)	4/24/86	141	155.0 (2482.9)	3360 (23.2)	***	***
SB-39A	3169.8 (966.2)	4/15/86	150	158.7 (2542.1)	4690 (32.3)	***	***
RRW-6T**	3216.2 (980.3)	5/22/86	113	159.3 (2551.7)	4220 (29.1)	***	***
Averages			132	158.3 (2535.7)	5210 (35.9)	6.61 (45.6)	0.24

Table 2. - Concrete properties (continued).

Location (Block No.)	Elevation ft (m)	Date placed	Age (days)	Density lb/ft^3 (kg/m^3)	Tensile strength lb/in^2 (kPa)
DIRECT TENSILE STRENGTH					
10- by 20-inch (254- by 508-mm) core specimens					
3-1	3221.0 (981.8)	2/20/86	210	158.4 (2537.3)	330 (2275)
3-1	3213.7 (979.5)	2/20/86	210	157.2 (2518.1)	255 (1758)
5-4S	3198.4 (974.9)	4/30/86	140	159.0 (2546.9)	260 (1793)
RRW-6T	3219.0 (981.2)	5/22/86	117	155.8 (2495.7)	220 (1517)
Averages			169	157.6 (2524.5)	265 (1827)
SPLITTING TENSILE STRENGTH					
10- by 20-inch (254- by 508-mm) core specimens					
SB-39A	3172.4 (966.9)	4/15/86	314	157.5 (2522.9)	900 (6205)
SB-39A	3168.1 (965.6)	4/15/86	314	157.9 (2529.3)	555 (3826)
Averages			314	157.7 (2526.1)	730 (5033)

*SB = stilling basin
**RRW = right retaining wall
***Not tested for modulus of elasticity or Poisson's ratio

Table 3. - Summary of shear strength test results.

	Direct shear		Sliding friction	
	ϕ, deg.	c, lb/in^2 (kPa)	ϕ, deg.	c_a, lb/in^2 (kPa)
Parent	76	575 (3950)	45	90 (625)
Intact joints	78	360 (2475)	44	50 (330)
Open joints	-	-	46	50 (345)

ϕ = angle of internal friction
c = cohesion in direct shear
c_a = cohesion in sliding friction

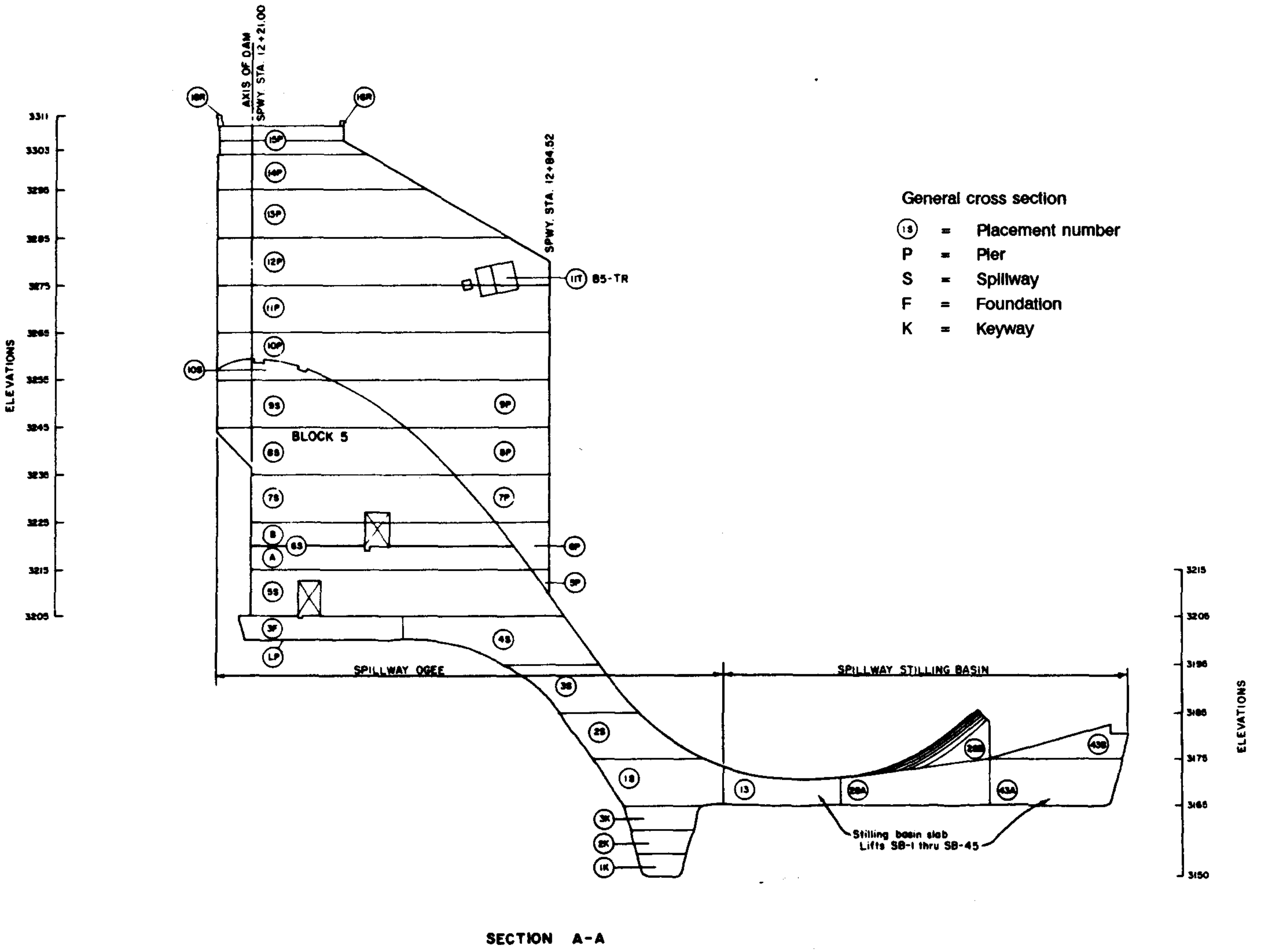
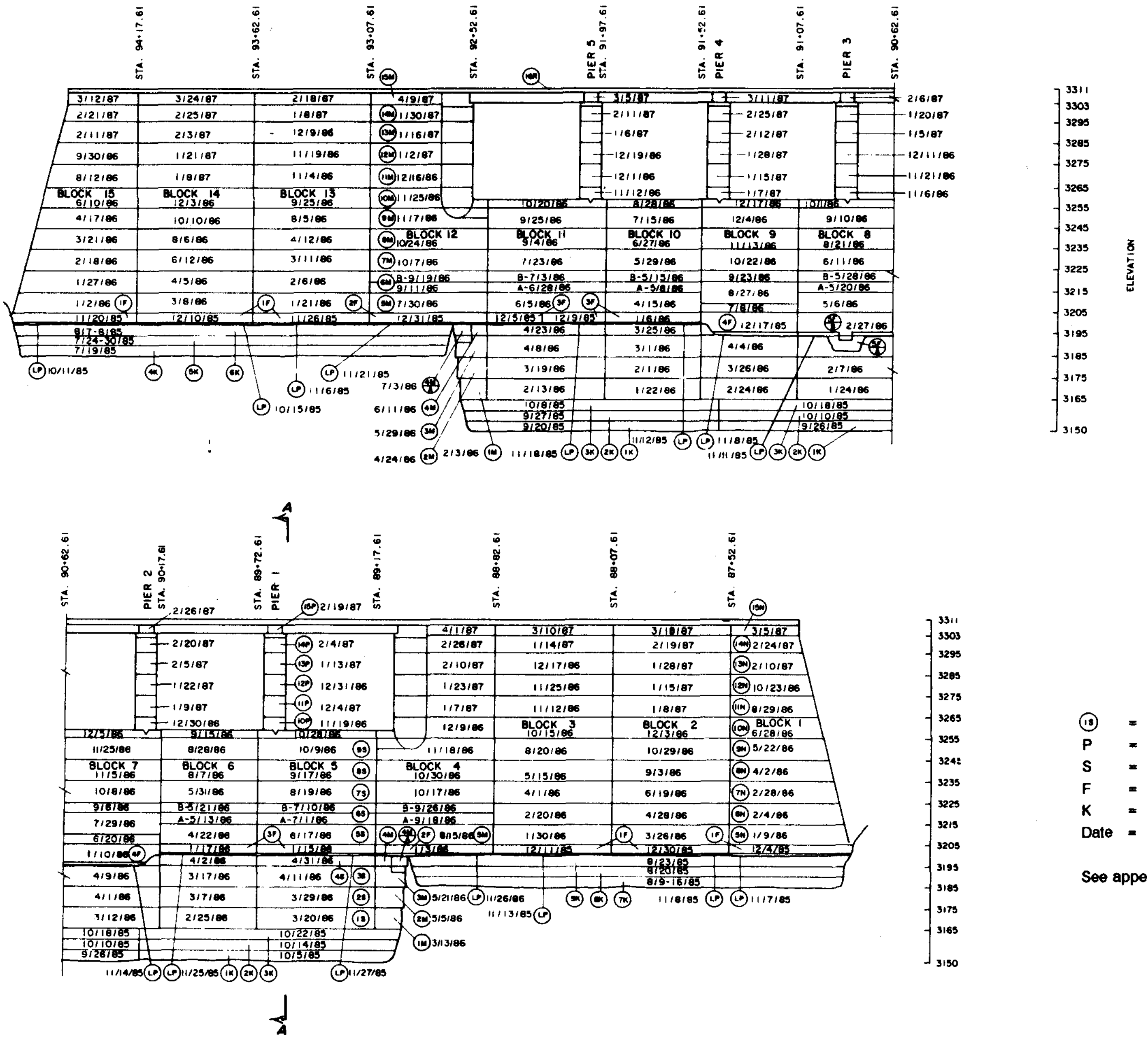


Figure 1. - Brantley Dam cross section.



⓵	=	Placement number
P	=	Pier
S	=	Spillway
F	=	Foundation
K	=	Keyway
Date	=	Date concrete was placed

See appendix II for locations of cores used in testing.

Figure 2. - Brantley Dam upstream elevations.

APPENDIX I

Aggregate Evaluation

EL-251 (8-71)
Bureau of Reclamation

SHEET NO. 1 OF 1

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

CONCRETE AND STRUCTURAL BRANCH
DIVISION OF GENERAL RESEARCH
ENGINEERING AND RESEARCH CENTER
DENVER, COLORADO 80225
DATE February 1973

AGGREGATE ~~XXXXXXXX~~ QUALITY EVALUATION

BRANCH FILE NO. C-1404
COMPILED BY R. N. Hess
CHECKED BY C. D. Prusia
REVIEWED BY J. S. Pierce
SUBMITTED BY J. R. Graham

IMPORTANT NOTICE
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STATE New Mexico **REG.** SW **SOURCE NO.** **LAT.** 32°N **LONG.** 104°W
SAMPLE NO. M-6786 **MATERIAL** Sand and gravel **DATE REC'D.** 11-17-76
DEPOSIT NAME Borrow Area "H" **OVERBURDEN** 0-3m (0-10 feet)
OWNERSHIP Bureau of Reclamation and private **VOLUME** Plus 2 486 250m³
LOCATION Along Rocky Arroyo to its confluence with Pecos River (3,250,000 yd³)
SEC. 1 & 2 **T** 21 S **R** 25 E **MERIDIAN** New Mexico Principal
FEATURE Brantley Dam
PROJECT Brantley
REMARKS
DATE LTR. TRANS. 11-8-76

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.	Field processed -					
2½ IN.		gravel grading				
1¾ IN.		not performed.				
1½ IN.						
1¼ IN.						
⅞ IN.						
¾ IN.						
⅝ IN.						
⅜ IN.						
5/16 IN.						
NO. 4					0	0
NO. 5					-	-
NO. 8					15	19
NO. 16					30	36
NO. 30					49	56
NO. 50					64	73
NO. 100					75	83
PAN					100	100
F.M		——			2.33	2.67
% SAND		——				

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)		2.75	2.78	2.78	2.77		2.64
ABSORPTION, % (DES. 9,10)		0.9	1.6	1.0	1.3		2.7
ORGANIC IMPURITIES, (DES. 14)	——	——	——	——	——	No. 4	No. 2
PERCENT SILT (DES. 16)						24.8	
% LIGHTER - SP. GR. (DES. 17,18,42)							
CLAY LUMPS, % (DES. 13)							
SAND EQUIVALENT	——	——	——	——	——		
NA$_2$SO$_4$ LOSS, 5 CYC. WGT'D. % LOSS (DES. 19)				3		——	7.

L.A. ABRASION (DES. 21) GRADING	"A"	"B"	"C"	"D"
% LOSS, 100 REV.	4			
% LOSS, 500 REV.	24			

FREEZING AND THAWING DATA

CONCRETE							RIRRAP	
W/C RATIO	SLUMP INCHES	% AIR METER	H$_2$O LBS./YD³	28-DAY STRENGTH 3"x 6" CYL'S.	WEIGHT LOSS, %	CYCLES	WEIGHT LOSS, % 3 INCH CUBE	CYCLES
0.51	3.0	5.7	248	5,040	25	850		

ALKALI - AGGREGATE REACTIVITY DATA

MATERIALS	SAND				GRAVEL			
CEMENT NO.		Not tested				Not tested		
SODA EQUIVALENT								
TEST AGG. %	100	100	50	25	100	100	50	25
EXP % - 6 MO.								
EXP % - 12 MO.								

PETROGRAPHIC DESCRIPTION: MEMORANDUM NO. 77-48 DATE: 8-5-77 BY: L. D. Klein

The gravel, subangular to mostly subrounded to rounded with about 8 percent flat and/or elongated particles and many particles covered with a calcium carbonate coating which is well bonded to the particle surface, is composed chiefly of limestone and dolomitic limestone with minor amounts of quartz pebbles, quartzite, quartzose sandstone, chert, and ferruginous particles. About 3 percent physically unsound and 0.3 percent alkali-reactive chert are present. The sand, mostly angular to rounded in shape, is composed of the same rock types found in the gravel and increasing amounts of monomineralic grains of calcite, dolomite, quartz, feldspar, ferruginous particles, mica, magnetite, chert, gypsum, and a few miscellaneous detrital minerals in the finer sizes. About 5 percent physically unsound and 1 percent potentially alkali-reactive chert are present in the coarse sand.

Conclusions: Aggregate comparable to sample No. M-6786 is suitable for use in concrete provided the sand is washed to remove excess silt and organic impurities and proper gradings are obtained.

GPO 837-497

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

UNITED STATES GOVERNMENT

Branch File No. C-1404 Appendix A

Memorandum

Memorandum
Denver, Colorado

TO : Head, Concrete Section

DATE: August 5, 1977

FROM : Head, Physical Sciences and Chemical Engineering Section

SUBJECT: Petrographic Examination of Concrete Aggregate - Brantley Dam - Brantley Project, New Mexico

Petrographic examination by: L.D. Klein

Petrographic referral code: 77-48

Material: Processed sand and gravel

Sample No. M-6786

Source: Borrow area H located in sec 1 and 2, T 21 S, R 25 E, New Mexico principal meridian

CONCLUSIONS

The examined gravel and sand, M-6786, are petrographically of satisfactory physical quality for use as concrete aggregate. The coarse gravel contains about 17 percent and 3 percent physically fair and poor quality particles, respectively. The coarse sand contains about 5 percent undesirable particles of poor physical quality.

The analyzed gravel and sand are not considered to be deleteriously reactive with high-alkali cement due to the presence of only about 1 percent chert.

SUMMARY

The gravel, subangular to mostly subrounded to rounded with about 8 percent flat and/or elongated particles and many particles covered with a calcium carbonate coating which is well bonded to the particle surface, is composed chiefly of limestone and dolomitic limestone with minor amounts of quartz pebbles, quartzite, quartzose sandstone, chert, and ferruginous particles. About 3 percent physically unsound and 0.3 percent alkali-reactive chert are present.

The sand, mostly angular to rounded in shape, is composed of the same rock types found in the gravel and increasing amounts of monomineralic grains of calcite, dolomite, quartz, feldspar, ferruginous particles, mica, magnetite, chert, gypsum, and a few miscellaneous detrital minerals in the finer sizes. About 5 percent physically unsound and 1 percent potentially alkali-reactive chert are present in the coarse sand.

J. E. Backstrom

Enclosure

Copy to: 1523

Table 1. - Petrographic examination of coarse aggregate
Sample No. M-6786

Rock types	Description of rock types	Physical quality	Percentage by particle count	
			38 mm to 19 mm	19 mm to 9.5 mm
Limestone and dolomitic limestone	Hard, dense to slightly vuggy, very finely crystalline, light to dark gray to buff to brownish to yellowish, somewhat absorptive and weathered surfaces, generally unfractured to slightly fractured, massive to somewhat bedded, includes minor arenaceous, fossiliferous and argillaceous limestone	Satisfactory	82.0	77.4
	Hard, slightly to moderately vuggy, moderately absorptive and weathered, somewhat fractured	Fair	14.5	19.0
	Hard to firm to friable to soft, highly absorptive, deeply weathered, somewhat fractured, slakes somewhat in water, can cause popouts in concrete	Poor	1.9	2.6
Quartz pebbles, quartzite and quartzose sandstone	Hard, dense, pebbles to fine grained, massive to bedded, somewhat absorptive, weathered and fractured	Satisfactory	1.0	-
	Firm to friable, highly absorptive, deeply weathered somewhat clayey	Poor	0.3	-
Chert*	Hard, dense, dark gray, angular	Satisfactory	0.3	0.3
Ferruginous particles	Firm, highly absorptive, deeply weathered, can cause staining and popouts in concrete	Poor	-	0.7

*Alkali-reactive rock types.

Table 2. - Summary of quality of coarse aggregate
Sample No. M-6786

		Percentage by particle count	
		38 mm to 19 mm	19 mm to 9.5 mm
Physical quality	Satisfactory	83.3	77.7
	Fair	14.5	19.0
	Poor	2.2	3.3
Chemical quality	Alkali reactive	0.3	0.3

Remarks: The coarse gravel consists of subangular to mostly subrounded to rounded stream worn particles with a few angular, broken particles. Flat and/or elongated particles constitute about 10 percent and 5 percent of the 38-19-mm and 19-9.5-mm size aggregate, respectively.

Many particles contain a thin calcium carbonate coating which is well bonded to the particle surface and is generally in optical continuity with the carbonate rocks.

The 4.75-mm size aggregate appears similar to the 19- to 9.5-mm size aggregate in composition, is angular to mostly subangular to rounded in shape, slightly poorer in physical quality, contains more alkali-reactive chert (about 2.4 percent) and contains a trace of clay balls. No opal or opaline particles were observed.

Table 3. - Petrographic examination of coarse sand
Sample No. M-6786

Rock and mineral types	Percentage by particle count		
	2.36 mm	1.18 mm	600μm
Limestone and dolomitic limestone	95	96	95
Quartz grains and quartzose sandstone	3	2	3
Chert	2	1	1
Ferruginous particles	Tr	1	1
Percent unsound	5	5	5
Percent alkali reactive	2	1	1
Percent flat	8	*	*
Percent calcium carbonate coated noncarbonates	1	*	*

*Not determined

Remarks: The coarse sand is mostly angular and subangular to rounded in shape. The fine sand is mostly angular to almost rounded in shape and consists of decreasing amounts of the fine-grained rock types found in the coarse sand and increasing amounts of monomineralic grains of calcite, dolomite, quartz, feldspar, ferruginous particles, magnetite, chert, gypsum, mica, and a few miscellaneous detrital minerals.

About 9 percent physically unsound and 1 percent alkali-reactive chert are present in the fine sand sizes.

The material removed by washing, about 19 percent by weight, consists of the same material as found in the fine sand sizes, in addition to some organic debris and clay. No chloride (salt) but significant sulfate (gypsum) was detected chemically.

APPENDIX II

Locations of Cores Used in Testing

LOCATIONS OF CORES USED IN TESTING

Block/Lift No.	Core diameter, inches (mm)	Dam station	Dam offset, feet (m)	Elevation (top) feet, (m)	Core depth, feet (m)	Date placed
3-6N	10 (254)	88 + 22	11.45 D/S* (3.49)	3225 (983.0)	12.4 (3.8)	2/86
3-6N	10 (254)	88 + 47	20.08 D/S (6.12)	3225 (983.0)	12.1 (3.7)	2/86
4-1M	6 (151)	89 + 13	85.07 D/S (25.93)	3174 (967.4)	12.4 (3.8)	3/86
5-4S	10 (254)	89 + 23	58.84 D/S (17.93)	3205 (976.9)	12.3 (3.7)	4/86
9-3S	6 (151)	91 + 25	67.80 D/S (20.66)	3195 (973.8)	12.2 (3.7)	4/86
**SB-35A	10 (254)	91 + 73	172.30 D/S (52.52)	3175 (967.7)	12.1 (3.7)	4/86
SB-37A	10 (254)	91 + 18	170.71 D/S (52.03)	3175 (967.7)	12.2 (3.7)	4/86
SB-39A	10 (254	90 + 52	170.74 D/S (52.04)	3175 (967.7)	12.3 (3.7)	4/86
***RRW-6T	10 (254)	88 + 38	230.70 D/S (70.32)	3225 (983.0)	12.0 (3.6)	5/86

Note: All locations are by dam stationing, not by spillway stationing.

*D/S = downstream
**SB = stilling basin
***RRW = right retaining wall

APPENDIX III

Shear Strength Testing Data

MS-884 (10-85)
Bureau of Reclamation

UNITED STATES GOVERNMENT

memorandum

DATE: Denver, Colorado
MAR 2 0 1987

TO : Memorandum
Chief, Concrete and Structural Branch 3/20/87

FROM Acting Chief, Geotechnical Branch

SUBJECT: Laboratory Test Results on Concrete - Direct Shear Tests - Brantley Dam - Brantley Project, New Mexico

Geotechnical Branch Memorandum Reference No. 87-13

Investigated by: R. Coco, S. Coman, B. Harper, R. Hough, R. Kelsic, J. Montgomery, B. Scavuzzo, and A. Scott

Written by: J. C. Bowen

INTRODUCTION

This memorandum reports results from direct shear tests of concrete core from Brantley Dam and appurtenant structures. These tests were used to evaluate the shear strengths of (1) parent material, (2) construction joints, and (3) open joints.

Brantley damsite is located on the Pecos River about 15 miles northwest (upstream) of Carlsbad, New Mexico. Brantley Dam will be a combination concrete and earthfill structure with a crest length of over 4 miles and a maximum structural height of 140 feet. The total initial reservoir capacity will be 348,500 acre-feet.

Eighteen concrete core specimens were submitted for direct shear testing by personnel from D-1511 [1, 2].[1] Five tests were through intact parent material, four were on open joints, and nine were along intact construction joints. Three specimens (4-3165.0, 4-3165.5, 9-3185.0) were 6 inches in diameter, and the remainder were 10 inches. The 6-inch-diameter specimens were tested in the 10,000-lbf normal, 20,000-lbf shear capacity machine, and the 10-inch specimens were tested in the 100,000-lbf normal, 240,000-lbf shear capacity machine. The direct shear test procedure is described in appendix A. All specimens were submerged in water overnight prior to testing.

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[1] Numbers in brackets refer to entries in the bibliography.

DISCUSSION

Individual direct shear test results for all 18 tests are listed in table 1. Plots of shear stress versus relative shear displacement, and peak shear stress versus normal stress for each of these tests are shown on figures 1 through 18. Photographs of each specimen before and after testing are provided in appendix B (figs. B1 through B18). The following abbreviations were used for specimen identification (Spec. No.) on figures 1 through 18:

Grouping	D-1511 specimen identification	Figure specimen identification
Parent (no construction joints)	B5-4S 3195.7	B5-3195.7
	B5-4S 3196.4	B5-3196.4
	3-1 3219.8	3-1-3219.8
	3-2 3222.2	3-2-3222.2
	BRRW-6T 3222.7	BRW-3222.7
Intact construction joints	SB-35LM/found. 3163.0	SB-3163.0
	SB-35A/L.Mat 3165.1	SB-3165.1
	SB-39A/L.Mat 3165.2	SB-3165.2
	B5-4S/3S 3195.0	B5-3195.0
	BRRW-6T/5T 3214.9	BRW-3214.9
	3-2 3215.2	3-2-3215.2
	4 3165.0	4-3165.0
	4 3165.5	4-3165.5
	9 3185.0	9-3185.0
Open joints	3-1 3218.9	3-1-3218.9
	3-1 3214.9	3-1-3214.9
	3-2 3220.0	3-2-3220.0
	3-2 3217.2	3-2-3217.2

Test results were grouped and analyzed as described below.

Parent Material (no construction joints)

Five concrete specimens were tested through intact parent material. These specimens were broken during the first test cycle and then tested for sliding friction at various normal stresses ranging from 25 to 300 lbf/in^2. Combined results for these five tests are summarized in table 2 and plotted on figure 19. Best-fit regression lines were calculated and drawn for both intact and sliding results.

All specimens slid to some extent on their encapsulating material, but specimen 3-2-3222.2 broke so deeply into it (fig. B4) that the sliding results were considered inaccurate and were deleted from the combined plot.

Construction Joints

Nine concrete specimens were sheared along intact construction joints. After the break cycle, these specimens were slid under normal stresses ranging from 25 to 300 lbf/in^2. Combined results for these tests are listed in table 2 and plotted on figure 20. The break bond failure envelope has a friction angle of 78° and a cohesion of 359 lbf/in^2, and the sliding failure envelope has a friction angle of 44° and a cohesion of 48 lbf/in^2. All specimens broke along their construction joints. Several may have slid to a small extent on their encapsulating material as they were displaced.

Open Joints

Four concrete specimens were sheared along open joints. Each specimen was slid under approximate normal stresses of 25, 50, 75, 100 and 150 lbf/in^2. Specimen 3-2-3220.0 was slid twice at a normal stress of approximately 150 lbf/in^2 because of breakage through intact material during the first slide. Results for this first slide/break are shown in table 1 and on figure 17, but were not included in the linear regression analysis for figure 17, and also were not used in the plot of the combined open joints (fig. 21). Except for this run, all other data were combined to yield a sliding failure envelope with a friction angle of 46° and a cohesion of 50 lbf/in^2. Combined results are listed in table 2 and plotted on figure 21.

SUMMARY AND CONCLUSION

Individual direct shear test results for the 18 concrete specimens are presented in table 1. Plots of shear stress versus relative displacement, and peak shear stress versus normal stress for each test are shown on figures 1 through 18. Combined test results for parent material, construction joints, and open joints are listed in table 2, and plots of peak shear stress versus normal stress for these three groups are shown on figures 19 through 21. Sliding results for specimen 3-2-3222.2 were deleted from the combined plot for parent material because this specimen broke deeply into the encapsulating material. The first slide cycle for specimen 3-2-3220.0 was deleted from the combined plot of open joints because of breakage through intact material. The five subsequent slide cycles were used.

The combined test results are summarized below:

	Intact		Sliding	
	ϕ (deg.)	c (lbf/in^2)	ϕ (deg.)	c (lbf/in^2)
Parent	76	573	45	91
Intact construction joints	78	359	44	48
Open joints	--	--	46	50

BIBLIOGRAPHY

[1] Drahushak-Crow, Roselle, Two-Way Memorandum to D-1542, Subject: "Direct Shear Testing of Brantley Dam Cores," Bureau of Reclamation, Denver, Colorado, September 15, 1986.

[2] Drahushak-Crow, Roselle, Two-Way Memorandum to D-1542, Subject: "Direct Shear Testing of Brantley Dam Concrete Cores," Bureau of Reclamation, Denver, Colorado, May 30, 1986.

CONTENTS

Brantley Dam

Geotechnical Branch Memeorandum Reference No. 87-13

TABLES

FIGURES

APPENDIX

EL- 633 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
DIRECT SHEAR TEST - LINEAR SOLUTION

Designation:____:_____-__

PROJECT: Brantley
FEATURE: Brantley Dam
TABLE: 1
PREPARED BY: J. Bowen
CHECKED BY: RHK 3-4-87
SHEET: 1 OF 6

SPECIMEN IDENTIFICATION			TEST ZONE DESCRIPTION								TEST VALUES DETERMINED AT Peak				SLIDING FRICTION FAILURE ENVELOPE 4/			
DRILL HOLE	DEPTH ☒ft ☐m	ROCK CLASSIFICATION 1/	TYPE OF FILL MATERIAL	THICKNESS OF FILL MATERIAL ☐(in) ☐(mm)	MOISTURE CONDITION WHEN TESTED 2/	ISRM JOINT ROUGHNESS COEFFICIENT	ORIENTATION OF TEST SURFACE FROM CORE AXIS (degrees)	TYPE OF TEST 3/	NOMINAL AREA ☒(in²) ☐(cm²)	NOMINAL DIAMETER ☒(in) ☐(mm)	NORMAL STRESS ☒(lbf/in²) ☐(kPa)	SHEAR STRESS ☒(lbf/in²) ☐(kPa)	HORIZONTAL DISPLACEMENT ☒(in) ☐(mm)	VERTICAL DISPLACEMENT ☐(in) ☐(mm)	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒ (lbf/in²) ☐(kPa)	CORRELATION COEFFICIENT	
B5-4S	3195.7				S		90	BB	68.68	9.351	49	825	.0550		46	110	.9576	
											26	94	.1332					
											51	164	.0714					
											102	256	.0469					
											201	342	.0534					
											302	391	.0371					
35-4S	3196.4				S		90	BB	68.31	9.326	04	998	.0714		41	23	.9960	
											25	49	.0506					
											49	75	.0398					
											103	111	.0321					
											103	100	.0219					
											200	196	.1149					
											302	294	.0779					
(Block) 3-1	3219.8				S		90	BB	68.82	9.361	25	698	.0412		50	117	.6145	
											50	231	.1097					
											74	297	.1449					
											26	65	.0706					
											149	274	.1418					

1/ CLASSIFICATION BY D-1511 personnel.
2/ S=SOAKED 12 HOURS PRIOR TO TESTING; W=WET, M=MOIST, AD=AIR DRY, OD=OVEN DRY.
3/ BB=BREAKBOND OR INTACT SHEAR STRENGTH; SF=SLIDING FRICTION.
4/ Mohr-Coulomb CRITERION.

EL- 633 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
DIRECT SHEAR TEST - LINEAR SOLUTION

Designation: ____ : ____ - __

PROJECT: Brantley
FEATURE: Brantley Dam
TABLE: 1

PREPARED BY: J. Bowen
CHECKED BY: RHK 3-4-87
SHEET: 2 OF 6

SPECIMEN IDENTIFICATION			TEST ZONE DESCRIPTION								TEST VALUES DETERMINED AT Peak				SLIDING FRICTION FAILURE ENVELOPE 4/			
DRILL HOLE	DEPTH ☒ ft ☐ m	ROCK CLASSIFICATION 1/	TYPE OF FILL MATERIAL	THICKNESS OF FILL MATERIAL ☐ (in) ☐ (mm)	MOISTURE CONDITION WHEN TESTED 2/	ISRM JOINT ROUGHNESS COEFFICIENT	ORIENTATION OF TEST SURFACE FROM CORE AXIS (degrees)	TYPE OF TEST 3/	NOMINAL AREA ☒ (in²) ☐ (cm²)	NOMINAL DIAMETER ☒ (in) ☐ (mm)	NORMAL STRESS ☒ (lbf/in2) ☐ (kPa)	SHEAR STRESS ☒ (lbf/in²) ☐ (kPa)	HORIZONTAL DISPLACEMENT ☒ (in) ☐ (mm)	VERTICAL DISPLACEMENT ☐ (in) ☐ (mm)	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒ (lbf/in²) ☐ (kPa)	CORRELATION COEFFICIENT	
(Block) 3-1 (cont.)											100	189	.0890					
(Block) 3-2	3222.2				S		90	BB	68.41	9.333	50	758	.0525		5/			
BRRW-6T	3222.7				S		90	BB	68.79	9.359	50	688	.0748		51	99	.9691	
											28	109	.0556					
											50	143	.0816					
											102	255	.0595					
											199	386	.0416					
											304	435	.0387					
SB-35LM	3163.0				S		90	BB	69.26	9.280	50	554	.1334		40	38	.9872	
											26	48	.0197					
											50	73	.0152					
											101	137	.0188					
											201	223	.0328					
											307	277	.1190					

1/ CLASSIFICATION BY D-1511 personnel.
2/ S=SOAKED 12 HOURS PRIOR TO TESTING; W=WET, M=MOIST, AD=AIR DRY, OD=OVEN DRY.
3/ BB=BREAKBOND OR INTACT SHEAR STRENGTH; SF=SLIDING FRICTION.
4/ Mohr-Coulomb CRITERION.
5/ Sliding results are not valid because specimen broke too deeply into its encapsulating material.

EL- 633 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
DIRECT SHEAR TEST - LINEAR SOLUTION

Designation: ____ : ____ - __

PROJECT: Brantley

FEATURE: Brantley Dam

TABLE: 1

PREPARED BY: J. Bowen

CHECKED BY: RHK 3-4-87

SHEET: 3 OF 6

SPECIMEN IDENTIFICATION			TEST ZONE DESCRIPTION							TEST VALUES DETERMINED AT Peak				SLIDING FRICTION FAILURE ENVELOPE 4/			
DRILL HOLE	DEPTH ☒ ft ☐ m	ROCK CLASSIFICATION 1/	TYPE OF FILL MATERIAL	THICKNESS OF FILL MATERIAL ☐ (in) ☐ (mm)	MOISTURE CONDITION WHEN TESTED 2/	ISRM JOINT ROUGHNESS COEFFICIENT	ORIENTATION OF TEST SURFACE FROM CORE AXIS (degrees)	TYPE OF TEST 3/	NOMINAL AREA ☒ (in^2) ☐ (cm^2) / NOMINAL DIAMETER ☐ (in) ☐ (mm)	NORMAL STRESS ☒ (lbf/in^2) ☐ (kPa)	SHEAR STRESS ☒ (lbf/in^2) ☐ (kPa)	HORIZONTAL DISPLACEMENT ☒ (in) ☐ (mm)	VERTICAL DISPLACEMENT ☒ (in) ☐ (mm)	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒ (lbf/in^2) ☐ (kPa)	CORRELATION COEFFICIENT	
SB-35A	3165.1				S		90	BB	9.283 67.68	99	812	.0397		42	40	.9982	
										31	61	.0217					
										56	94	.0141					
										101	136	.0207					
										200	229	.0245					
										303	310	.0215					
SB-39A	3165.2				S		90	BB	9.288 67.75	28	429	.0351		45	54	.9877	
										28	56	.0202					
										50	124	.0211					
										100	156	.0335					
										211	278	.0319					
										303	346	.0218					
B5-4S/3S	3195.0				S		90	BB	9.300 67.93	53	833	.0447		38	55	.9717	
										22	60	.0385					
										51	116	.0445					
										76	106	.0423					
										101	131	.0257					
										201	211	.0333					

1/ CLASSIFICATION BY D-1511 personnel.

2/ S=SOAKED 12 HOURS PRIOR TO TESTING; W=WET, M=MOIST, AD=AIR DRY, OD=OVEN DRY.

3/ BB=BREAKBOND OR INTACT SHEAR STRENGTH; SF=SLIDING FRICTION.

4/ Mohr-Coulomb CRITERION.

GPO 849-820

TABLE: 1 SHEET: 3 OF 6

EL- 633 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
DIRECT SHEAR TEST - LINEAR SOLUTION

Designation: _____:_____-__

PROJECT: Brantley
FEATURE: Brantley Dam
TABLE: 1
PREPARED BY: J. Bowen
CHECKED BY: RHK 3-4-87
SHEET: 4 OF 6

SPECIMEN IDENTIFICATION			TEST ZONE DESCRIPTION							TEST VALUES DETERMINED AT Peak				SLIDING FRICTION FAILURE ENVELOPE 4/			
DRILL HOLE	DEPTH ☒ ft ☐ m	ROCK CLASSIFICATION 1/	TYPE OF FILL MATERIAL	THICKNESS OF FILL MATERIAL ☐ (in) ☐ (mm)	MOISTURE CONDITION WHEN TESTED 2/	ISRM JOINT ROUGHNESS COEFFICIENT	ORIENTATION OF TEST SURFACE FROM CORE AXIS (degrees)	TYPE OF TEST 3/	NOMINAL AREA ☒ (in²) ☐ (cm²) / NOMINAL DIAMETER ☒ (in) ☐ (mm)	NORMAL STRESS ☒ (lbf/in²) ☐ (kPa)	SHEAR STRESS ☒ (lbf/in²) ☐ (kPa)	HORIZONTAL DISPLACEMENT ☒ (in) ☐ (mm)	VERTICAL DISPLACEMENT ☒ (in) ☐ (mm)	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒ (lbf/in²) ☐ (kPa)	CORRELATION COEFFICIENT	
BRRW-6T/5T	3214.9				S		90	BB	9.334 68.43	49	634	.0470		47	62	.9908	
										27	77	.0177					
										49	116	.0277					
										101	180	.0397					
										205	308	.0278					
										300	370	.0254					
(Block) 3-2	3215.2				S		90	BB	9.382 69.13	76	584	.0358		37	65	.6866	
										76	172	.0236					
										50	121	.0261					
										100	143	.0256					
										26	39	.0128					
										149	151	.0313					
(Block) 4	3165.0				S		90	BB	6.024 28.50	25	374	.0411	-.0967	51	19	.9978	
										100	149	.0200	-.0033				
										50	82	.0096	-.0045				
										150	203	.0175	-.0022				
										25	49	.0083	-.0063				
										75	108	.0297	-.0093				

1/ CLASSIFICATION BY D-1511 personnel.
2/ S=SOAKED 12 HOURS PRIOR TO TESTING; W=WET, M=MOIST, AD=AIR DRY, OD=OVEN DRY.
3/ BB=BREAKBOND OR INTACT SHEAR STRENGTH; SF=SLIDING FRICTION.
4/ Mohr-Coulomb CRITERION.

EL- 633 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
DIRECT SHEAR TEST - LINEAR SOLUTION

Designation: ____:_____-__

PROJECT: Brantley FEATURE: Brantley Dam TABLE: 1

PREPARED BY: J. Bowen CHECKED BY: RHK 3-4-87 SHEET: 5 OF 6

SPECIMEN IDENTIFICATION			TEST ZONE DESCRIPTION								TEST VALUES DETERMINED AT Peak				SLIDING FRICTION FAILURE ENVELOPE 4/			
DRILL HOLE	DEPTH ☒ft ☐m	ROCK CLASSIFICATION 1/	TYPE OF FILL MATERIAL	THICKNESS OF FILL MATERIAL ☐(in) ☐(mm)	MOISTURE CONDITION WHEN TESTED 2/	ISRM JOINT ROUGHNESS COEFFICIENT	ORIENTATION OF TEST SURFACE FROM CORE AXIS (degrees)	TYPE OF TEST 3/	NOMINAL DIAMETER ☒(in) ☐(mm)	NOMINAL AREA ☒(in²) ☐(cm²)	NORMAL STRESS ☒(lbf/in²) ☐(kPa)	SHEAR STRESS ☒(lbf/in²) ☐(kPa)	HORIZONTAL DISPLACEMENT ☒(in) ☐(mm)	VERTICAL DISPLACEMENT ☒(in) ☐(mm)	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒(lbf/in²) ☐(kPa)	CORRELATION COEFFICIENT	
(Block) 4	3165.5				S		90	BB	6.014	28.41	50	700	.0643	-.1226	54	14	.9934	
											100	157	.0394	-.0082				
											151	213	.0346	-.0078				
											75	126	.0244	-.0083				
											50	82	.0145	-.0053				
											25	41	.0103	-.0050				
(Block) 9	3185.0				S		90	BB	6.014	28.41	101	836	.0723	-.0686	48	57	.9875	
											25	79	.0255	-.0155				
											75	153	.0299	-.0075				
											50	108	.0150	-.0061				
											100	172	.0180	-.0046				
											150	216	.0202	-.0041				
(Block) 3-1	3218.9				S		74	SF	9.366	71.68	24	139	.0237		48	73	.8349	
											75	170	.0859					
											150	260	.0467					
											102	162	.0256					
											51	81	.0159					

1/ CLASSIFICATION BY D-1511 personnel.
2/ S=SOAKED 12 HOURS PRIOR TO TESTING; W=WET, M=MOIST, AD=AIR DRY, OD=OVEN DRY.
3/ BB=BREAKBOND OR INTACT SHEAR STRENGTH; SF=SLIDING FRICTION.
4/ Mohr-Coulomb CRITERION.

GPO 849-820

TABLE: 1 SHEET: 5 OF 6

EL- 633 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
DIRECT SHEAR TEST - LINEAR SOLUTION

Designation: ____:_____-__

PROJECT: Brantley
FEATURE: Brantley Dam
TABLE: 1
PREPARED BY: J. Bowen
CHECKED BY: RHK 3-4-87
SHEET: 6 OF 6

SPECIMEN IDENTIFICATION			TEST ZONE DESCRIPTION								TEST VALUES DETERMINED AT Peak				SLIDING FRICTION FAILURE ENVELOPE 4/		
DRILL HOLE	DEPTH ☒ft ☐m	ROCK CLASSIFICATION 1/	TYPE OF FILL MATERIAL	THICKNESS OF FILL MATERIAL ☐(in) ☐(mm)	MOISTURE CONDITION WHEN TESTED 2/	ISRM JOINT ROUGHNESS COEFFICIENT	ORIENTATION OF TEST SURFACE FROM CORE AXIS (degrees)	TYPE OF TEST 3/	NOMINAL DIAMETER ☒(in) ☐(mm)	NOMINAL AREA ☒(in²) ☐(cm²)	NORMAL STRESS ☒(lbf/in2) ☐(kPa)	SHEAR STRESS ☒(lbf/in²) ☐(kPa)	HORIZONTAL DISPLACEMENT ☒(in) ☐(mm)	VERTICAL DISPLACEMENT ☐(in) ☐(mm)	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒(lbf/in²) ☐(kPa)	CORRELATION COEFFICIENT
(Block) 3-1	3214.9				S		90	SF	9.362	68.84	50	186	.0457		23	80	.3483
											75	124	.0160				
											26	29	.0078				
											150	142	.0242				
											100	93	.0130				
(Block) 3-2	3220.0				S		90	SF	9.355	68.74	5/151	562	.0428		49	0	.9988
											150	173	.0230				
											101	122	.0159				
											77	90	.0151				
											51	62	.0152				
											31	33	.0179				
(Block) 3-2	3217.2				S		90	SF	9.366	68.90	101	301	.0356		55	47	.7295
											28	66	.0146				
											76	166	.0227				
											50	80	.0153				
											156	210	.0365				

1/ CLASSIFICATION BY D-1511 personnel.

2/ S=SOAKED 12 HOURS PRIOR TO TESTING; W=WET, M=MOIST, AD=AIR DRY, OD=OVEN DRY.

3/ BB=BREAKBOND OR INTACT SHEAR STRENGTH; SF=SLIDING FRICTION.

4/ D-1511 personnel CRITERION.

5/ specimen broke through some intact material during this first cycle.

TABLE: 1 SHEET: 6 OF 6

GPO 849 - 820

EL-634 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
COMBINED DIRECT SHEAR RESULTS - LINEAR SOLUTIONS

Designation: ____ :____-__

PROJECT: Brantley

FEATURE: Brantley Dam

TABLE: 2

PREPARED BY: J. Bowen

CHECKED BY: RHK 3-4-87

SHEET: 1 OF 2

SPECIMEN TEST SUITES			DIRECT SHEAR RESULTS					
			INTACT SHEAR STRENGTH			SLIDING FRICTION SHEAR STRENGTH		
			SOLUTION BY Mohr-Coulomb CRITERION			SOLUTION BY Mohr-Coulomb CRITERION		
ROCK GROUPING 1/	SPECIMEN IDENTIFICATION		ANGLE OF INTERNAL FRICTION (degrees)	COHESION ☒ (lbf/in^2) ☐ (kPa)	CORRELATION COEFFICIENT	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒ (lbf/in^2) ☐ (kPa)	CORRELATION COEFFICIENT
	DRILL HOLE	DEPTH ☒ ft ☐ m						
Parent (no construction joint)	B5-4S	3195.7	76	573	.9081	45	91	.8079
	B5-4S	3196.4						
	3-1	3219.8						
	2/ 3-2	3222.2						
	BRRW-6T	3222.7						
Intact Construction Joints	SB-35LM	3163.0	78	359	.7649	44	48	.9509
	SB-35A	3165.1						
	SB-39A	3165.2						
	B5-4s/3s	3195.0						
	BRRW-6T/5T	3214.9						
	3-2	3215.2						
	4	3165.0						
	4	3165.5						
	9	3185.0						

1/ GROUPING BY D-1511 personnel

2/ sliding results for this specimen were not used.

GPO 849-821

EL-634 (12-85)
Bureau of Reclamation

ROCK LABORATORY TEST DATA
COMBINED DIRECT SHEAR RESULTS - LINEAR SOLUTIONS

Designation: ____ : ____-__

PROJECT: Brantley
FEATURE: Brantley Dam
TABLE: 2
PREPARED BY: J. Bowen
CHECKED BY: RHK 3-4-87
SHEET: 2 OF 2

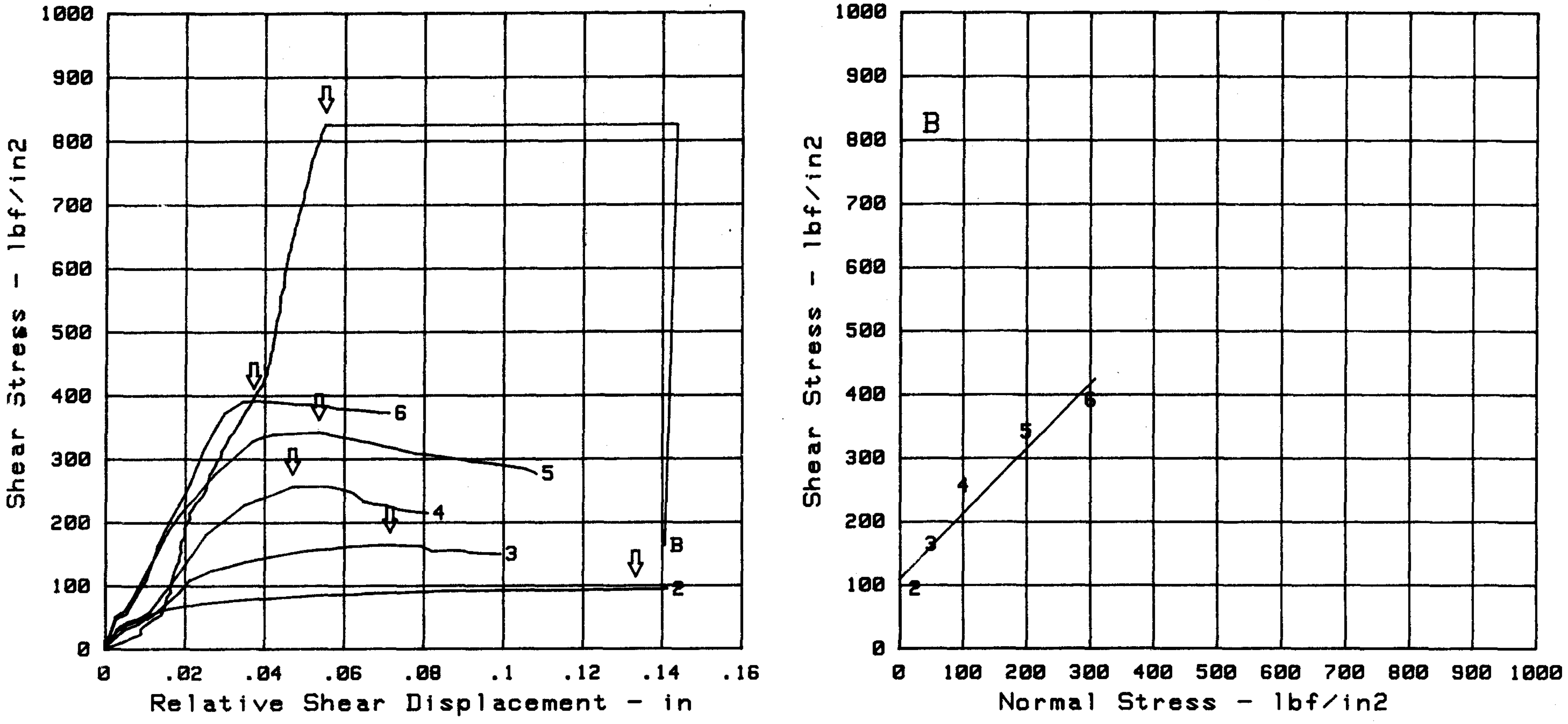
SPECIMEN TEST SUITES			DIRECT SHEAR RESULTS					
			INTACT SHEAR STRENGTH			SLIDING FRICTION SHEAR STRENGTH		
			SOLUTION BY Mohr-Coulomb CRITERION			SOLUTION BY Mohr-Coulomb CRITERION		
ROCK GROUPING 1/	SPECIMEN IDENTIFICATION		ANGLE OF INTERNAL FRICTION (degrees)	COHESION ☐(lbf/in²) ☐(kPa)	CORRELATION COEFFICIENT	ANGLE OF SLIDING FRICTION (degrees)	COHESION ☒(lbf/in²) ☐(kPa)	CORRELATION COEFFICIENT
	DRILL HOLE	DEPTH ☒ft ☐m						
Open Joints	3-1	3218.9				46	50	.6391
	3-1	3214.9						
	2/ 3-2	3220.0						
	3-2	3217.2						

1/ GROUPING BY D-1511 personnel

2/ The first cycle of this test was not included inthe combined results because of breakage through intact material.

GPO 849-821

Figure 1
DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	PARENT
Spec no.	B5-3195.7
Tested By	AS&BS&RH
Date Tested	10/14/86
Nominal Area	68.68 Sq. in.

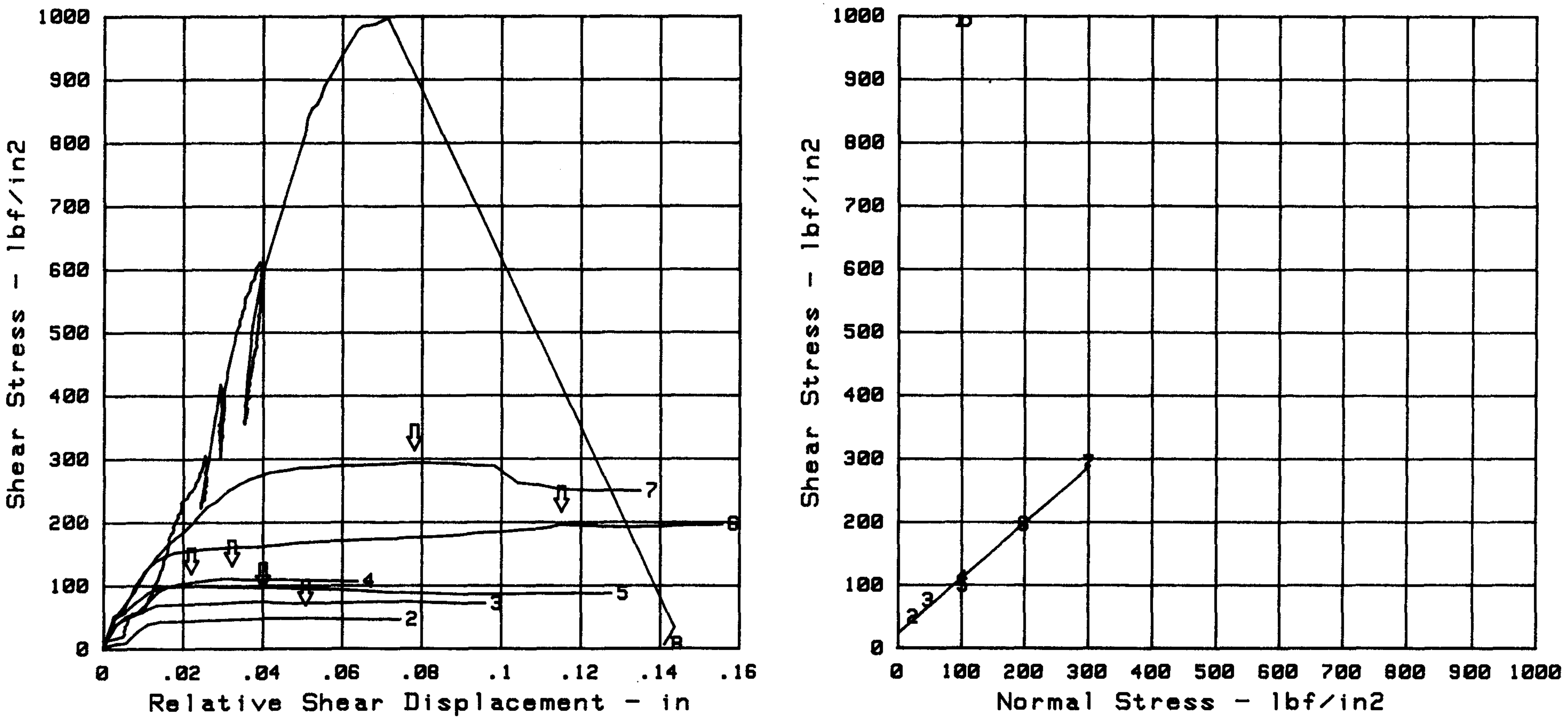
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
49	825	.0550	B
26	94	.1332	2
51	164	.0714	3
102	256	.0469	4
201	342	.0534	5
302	391	.0371	6

SLIDING FRICTION RESULTS
S= 109.7 +1.026 (N)
COHESION = 110 lbf/in2
PHI= 46 deg COR COEF= .9576

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 2

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	PARENT MATERIAL
Spec no.	B5-3196.4
Tested By	AS&KS
Date Tested	10/06/86
Nominal Area	68.31 Sq. in.

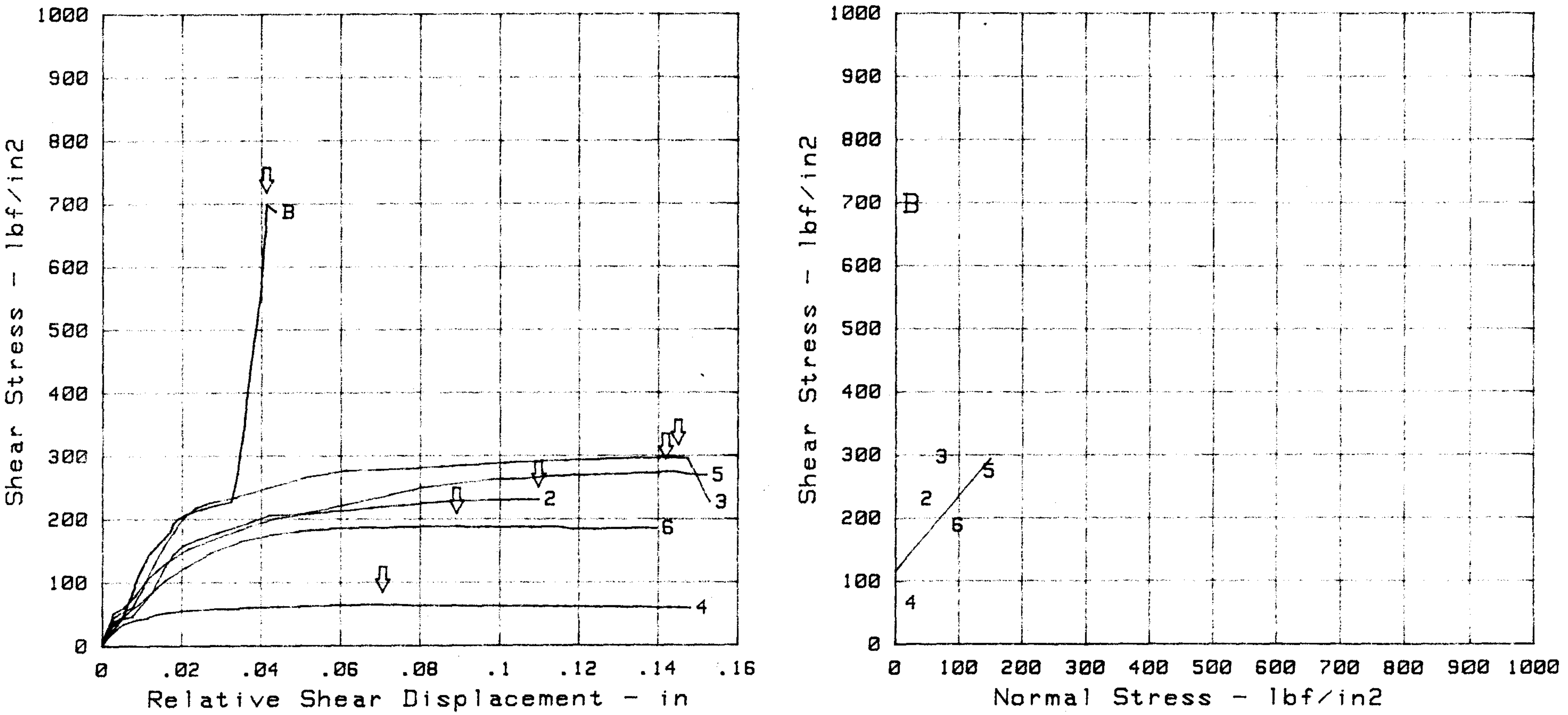
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
104	998	.0714	B
25	49	.0506	2
49	75	.0398	3
103	111	.0321	4
103	100	.0219	5
200	196	.1149	6
302	294	.0779	7

SLIDING FRICTION RESULTS
S= 22.9 + .879 (N)
COHESION = 23 lbf/in2
PHI= 41 deg COR COEF= .9960

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 3

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	PARENT MATERIAL
Spec no.	3-1-3219.8
Tested By	BH&RK
Date Tested	06/04/86
Nominal Area	68.82 Sq. in.

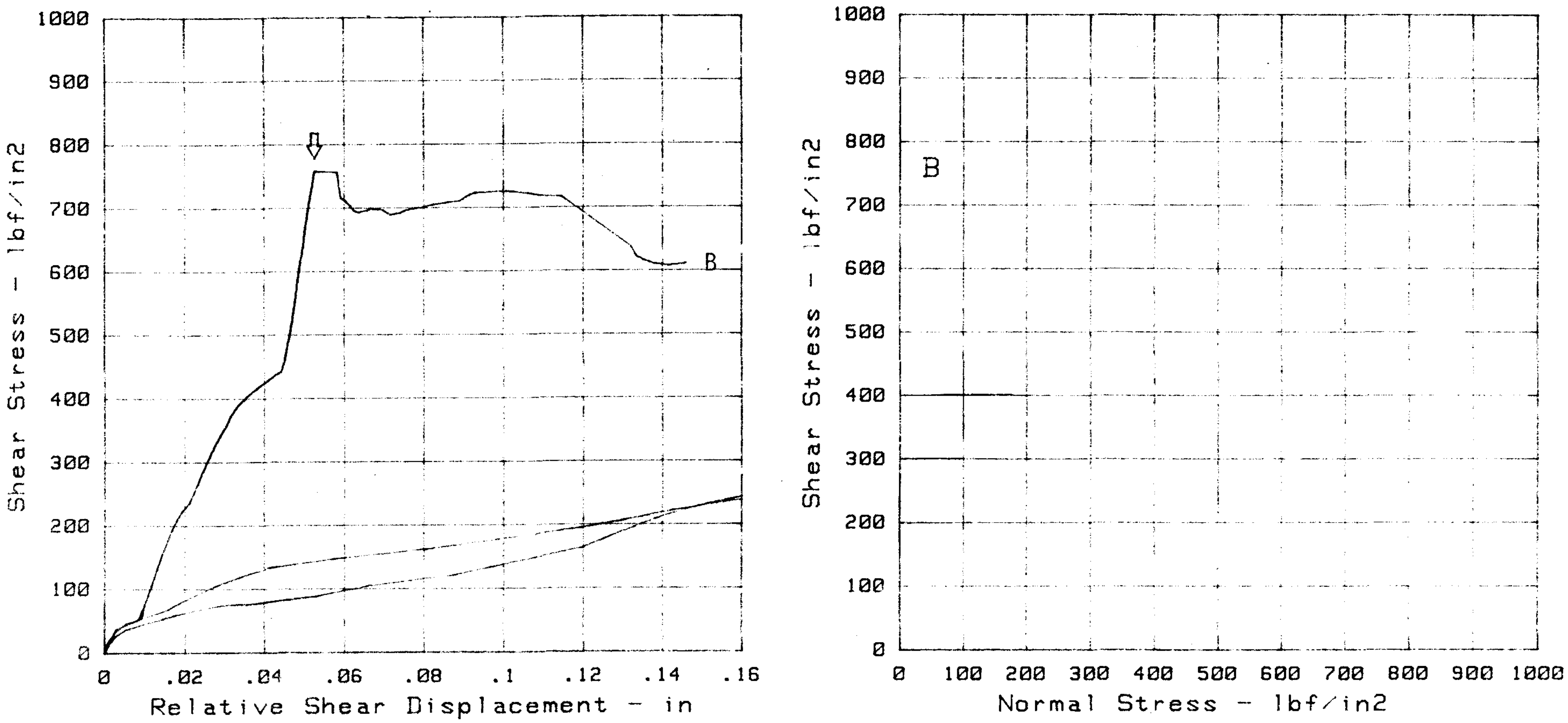
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
25	698	.0412	B
50	231	.1097	2
74	297	.1449	3
26	65	.0706	4
149	274	.1418	5
100	189	.0890	6

SLIDING FRICTION RESULTS
S= 116.6 +1.186 (N)
COHESION = 117 lbf/in2
PHI= 50 deg COR COEF= .6145

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 4

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	PARENT MATERIAL
Spec no.	3-2-3222.2
Tested By	BH
Date Tested	06/06/86
Nominal Area	68.41 Sq. in.

NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
50	758	.0525	B

SLIDING FRICTION RESULTS

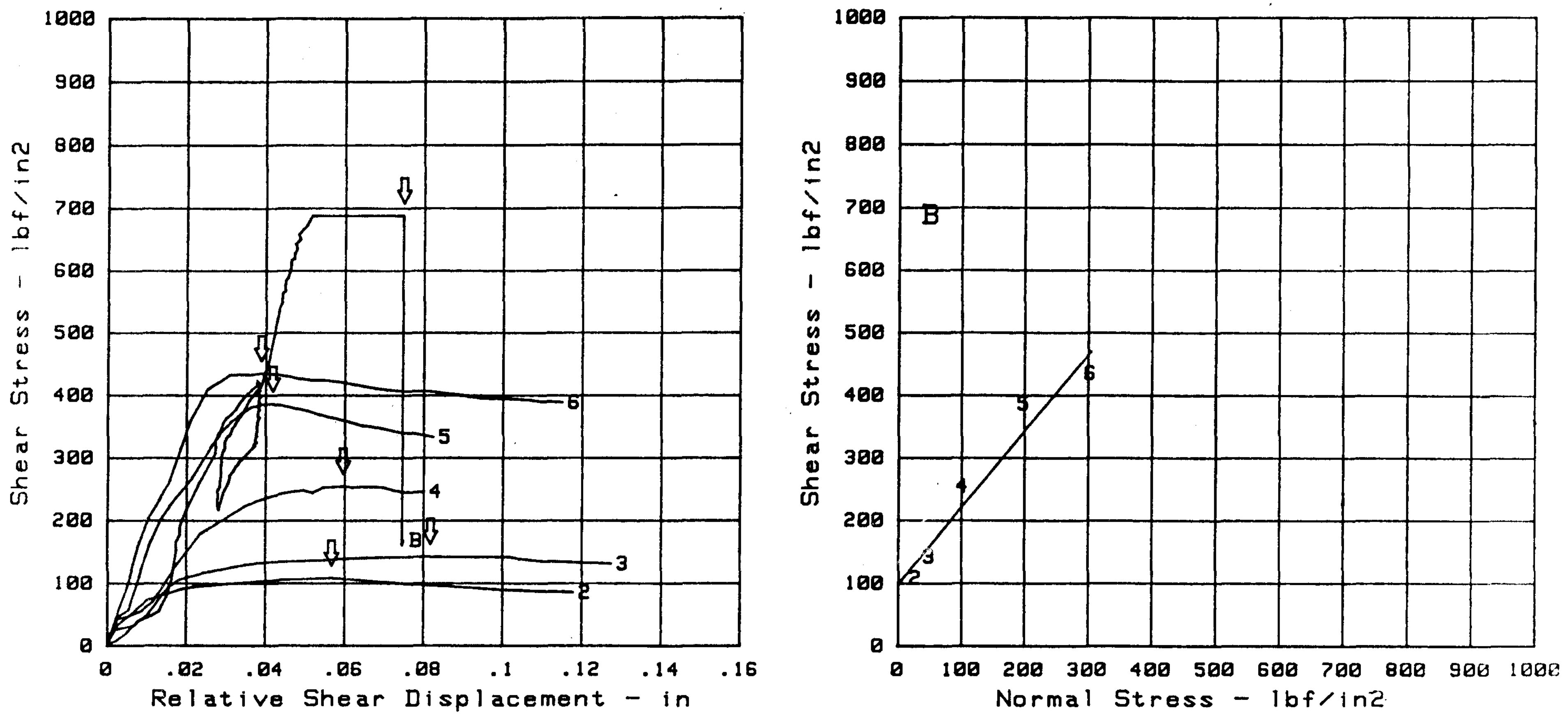
Results are not valid because specimen broke deeply into encapsulating material.

LEGEND

B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 5

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	PARENT
Spec no.	BRW-3222.7
Tested By	AS&BS&RH
Date Tested	10/14/86
Nominal Area	68.79 Sq. in.

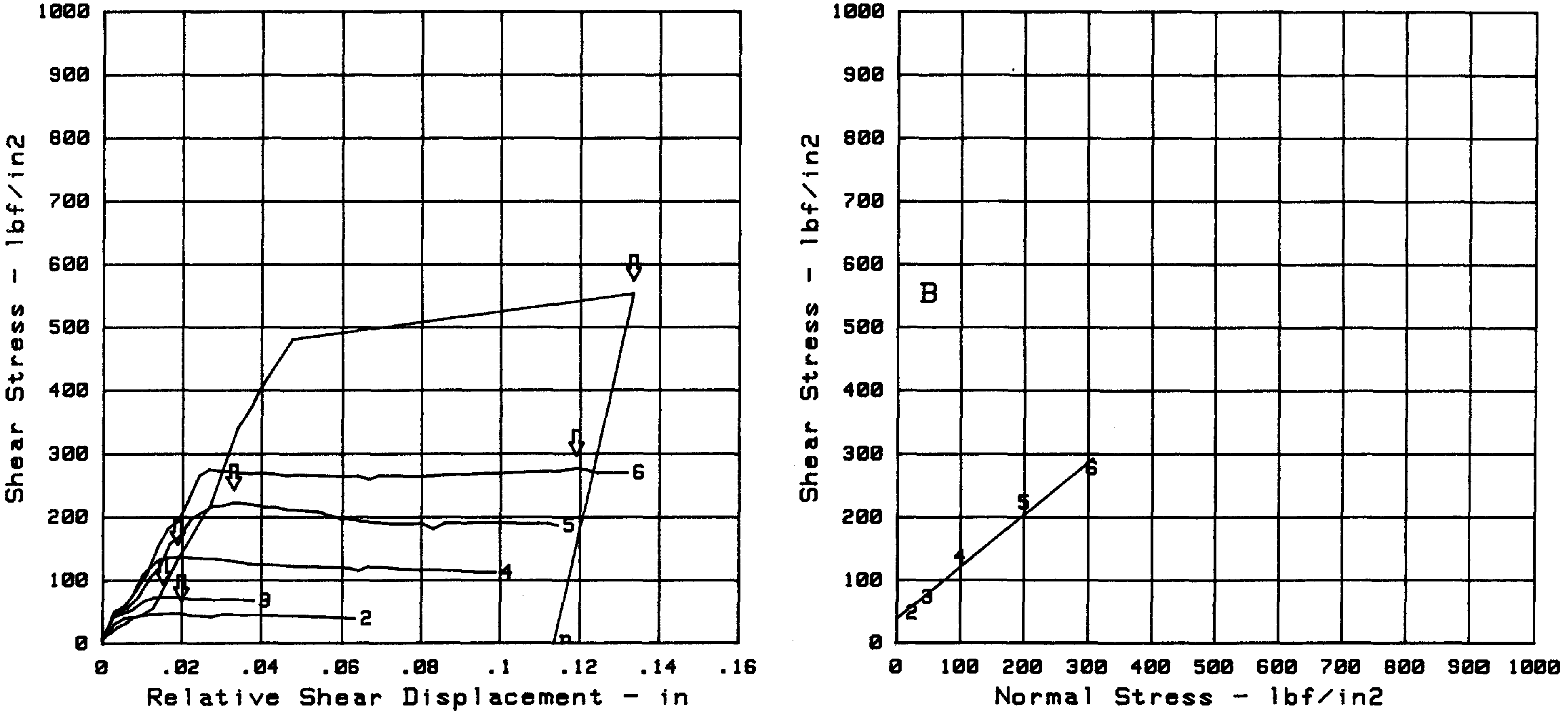
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
50	688	.0748	B
28	109	.0566	2
50	143	.0816	3
102	255	.0595	4
199	386	.0416	5
304	435	.0387	6

SLIDING FRICTION RESULTS
S= 98.9 +1.220 (N)
COHESION = 99 lbf/in2
PHI= 51 deg COR COEF= .9691

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 6

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	CONSTRUCTION JOINT
Spec no.	SB-3163.0
Tested By	AS&BS
Date Tested	10/17/86
Nominal Area	69.26 Sq. in.

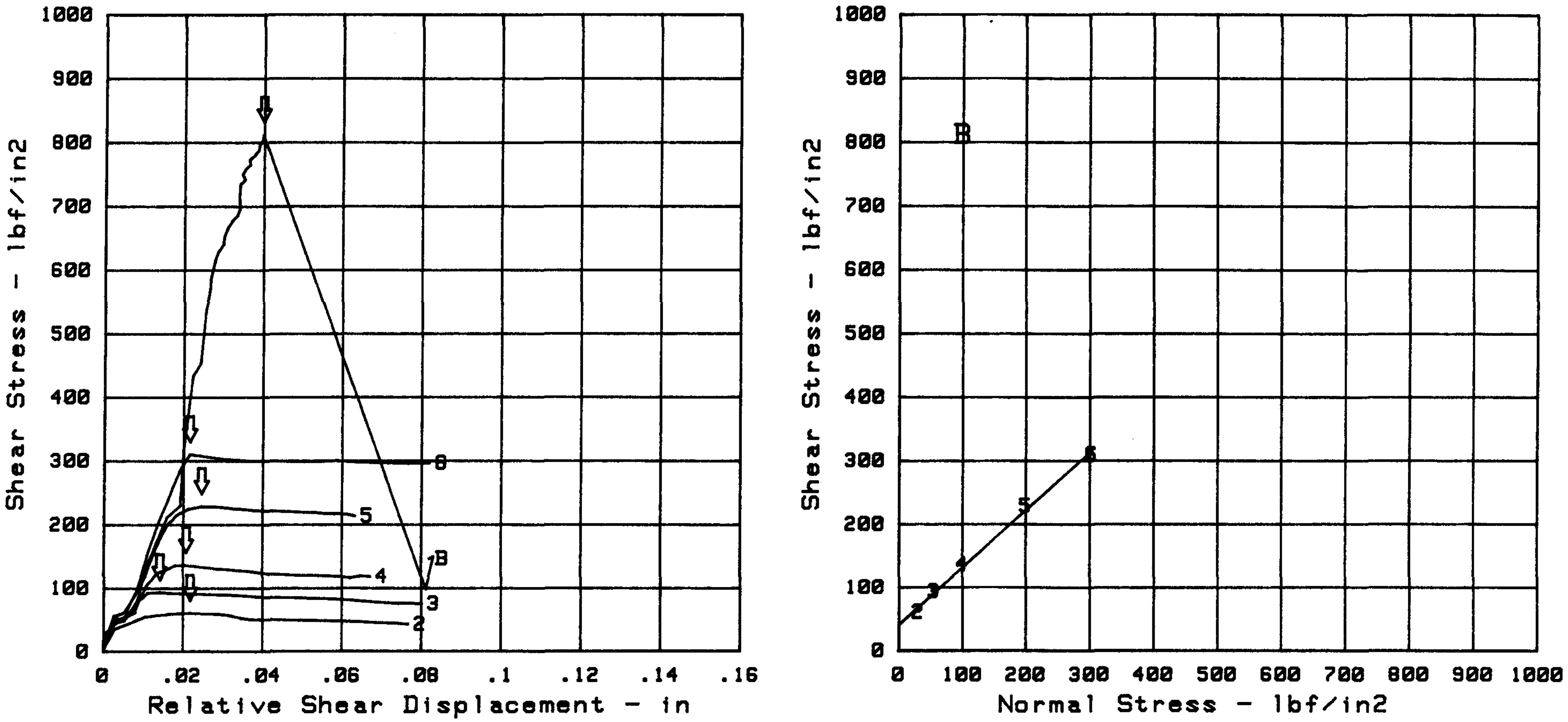
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
50	554	.1334	B
26	48	.0197	2
50	73	.0152	3
101	137	.0188	4
201	223	.0328	5
307	277	.1190	6

SLIDING FRICTION RESULTS
S= 38.2 + .826 (N)
COHESION = 38 lbf/in2
PHI= 40 deg COR COEF= .9872

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 7

DIRECT SHEAR TEST



Project BRANTLEY
Feature BRANTLEY DAM
Type CONSTRUCTION JOINT
Spec no. SB-3165.1
Tested By AS&BS
Date Tested 10/10/86
Nominal Area 67.68 Sq. in.

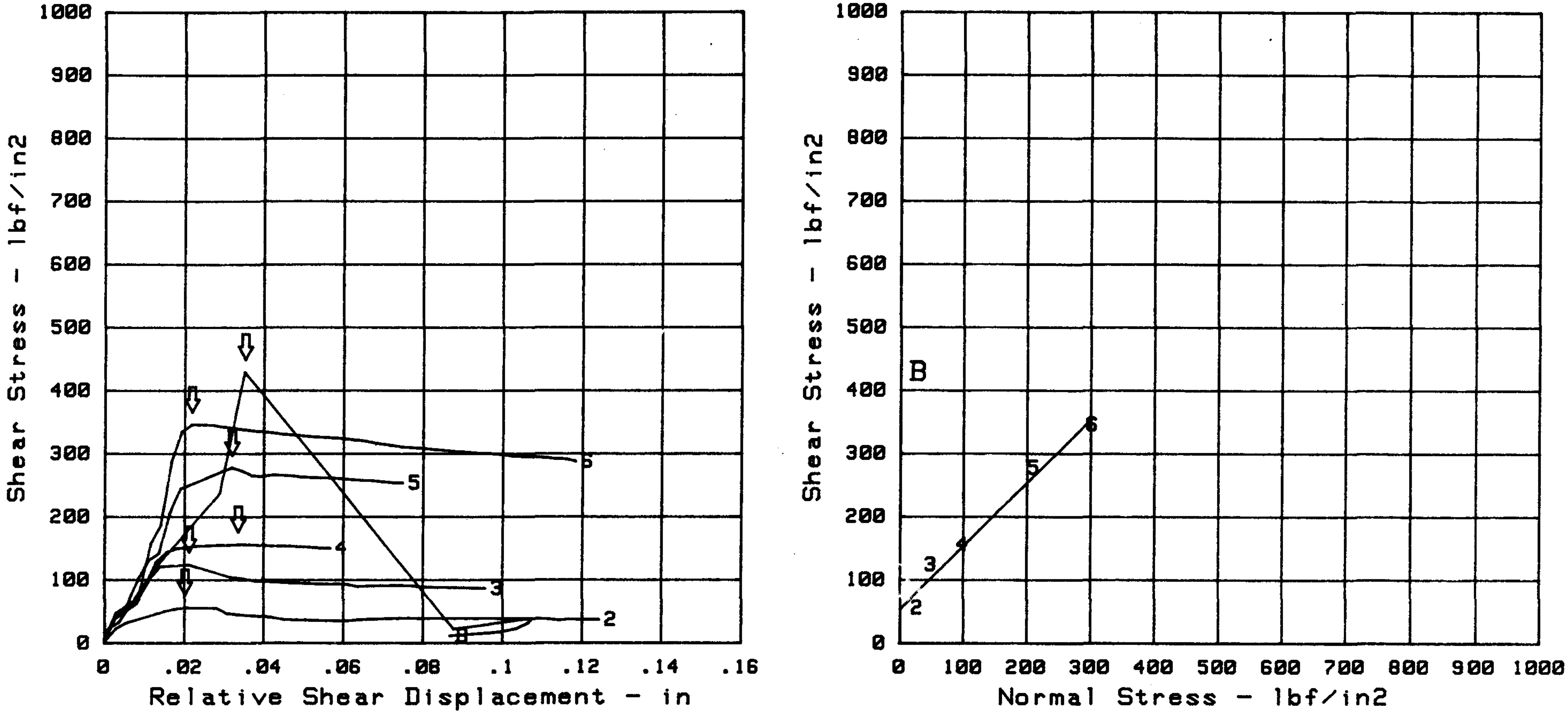
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
99	812	.0397	B
31	61	.0217	2
56	94	.0141	3
101	136	.0207	4
200	229	.0245	5
303	310	.0215	6

SLIDING FRICTION RESULTS
S= 40.5 + .908 (N)
COHESION = 40 lbf/in2
PHI= 42 deg COR COEF= .9982

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 8

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	CONSTRUCTION JOINT
Spec no.	SB-3165.2
Tested By	AS&RH
Date Tested	10/06/86
Nominal Area	67.75 Sq. in.

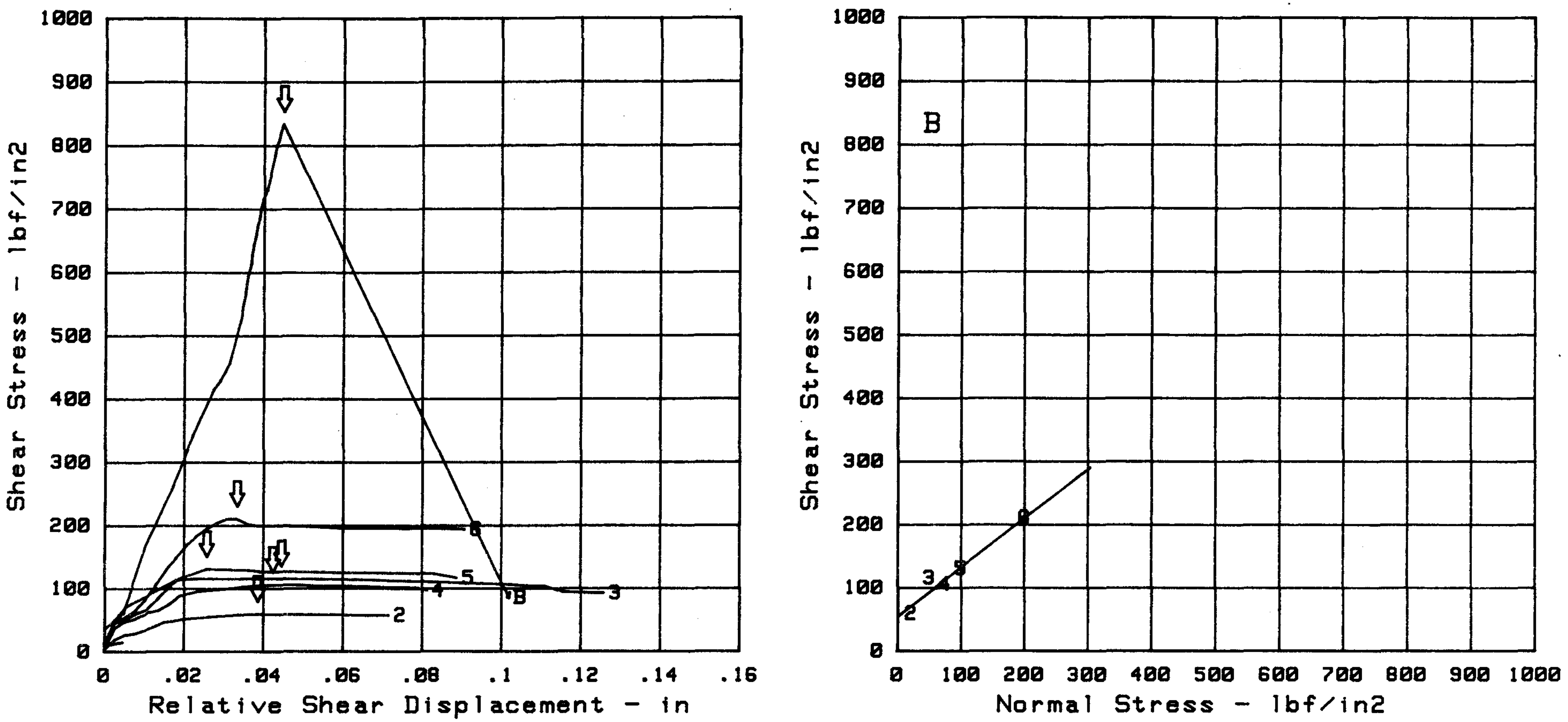
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
28	429	.0351	B
28	56	.0202	2
50	124	.0211	3
100	156	.0335	4
211	278	.0319	5
303	346	.0218	6

SLIDING FRICTION RESULTS
S= 53.6 +1.000 (N)
COHESION = 54 lbf/in2
PHI= 45 deg COR COEF= .9877

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 9

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	CONSTRUCTION JOINT
Spec no.	B5-3195.0
Tested By	AS&RH
Date Tested	10/06/86
Nominal Area	67.93 Sq. in.

NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
53	833	.0447	B
22	60	.0385	2
51	116	.0445	3
76	106	.0423	4
101	131	.0257	5
201	211	.0333	6

SLIDING FRICTION RESULTS

S= 54.5 + .778 (N)

COHESION = 55 lbf/in2

PHI= 38 deg COR COEF= .9717

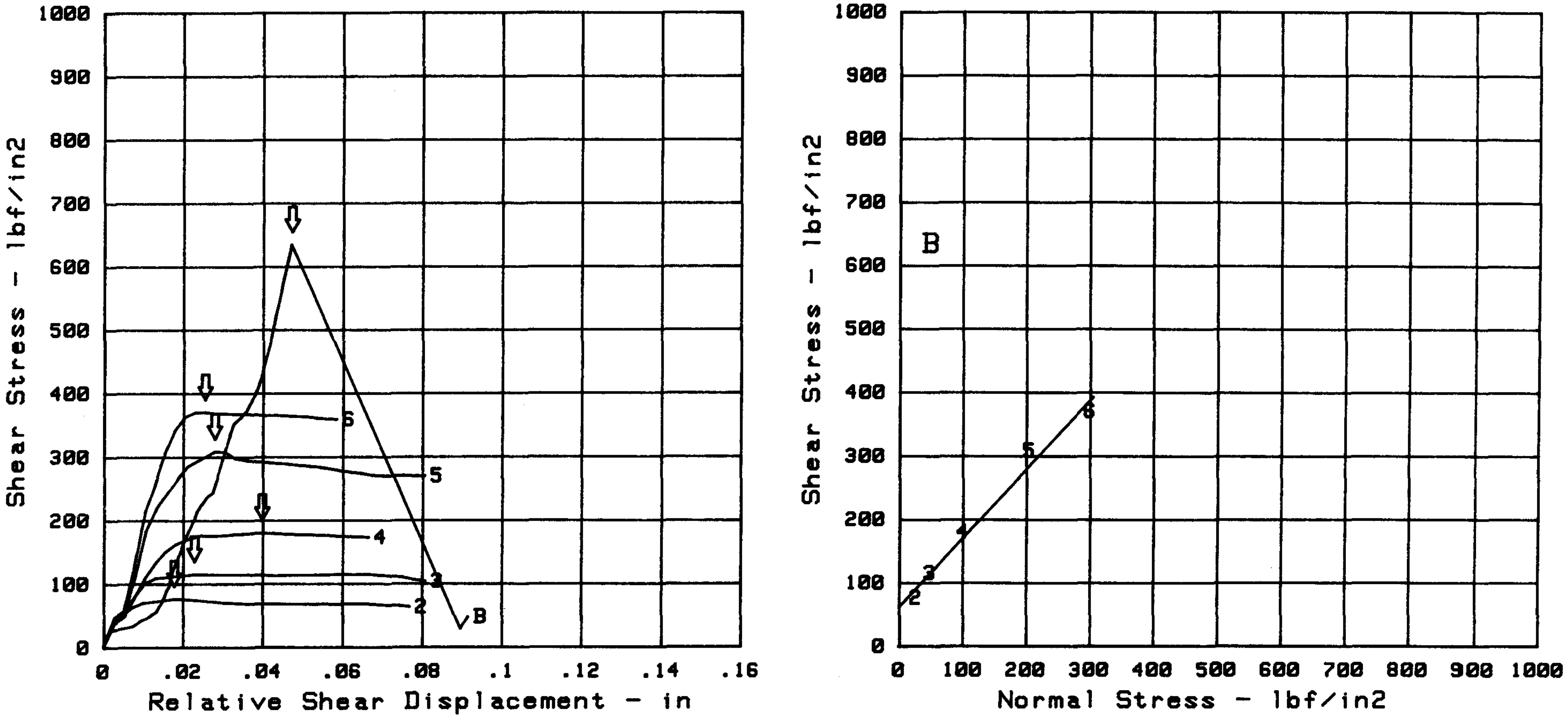
LEGEND

B = INTACT SHEAR STRENGTH

No. = SLIDING FRICTION TEST

Figure 10

DIRECT SHEAR TEST



Project BRANTLEY
Feature BRANTLEY DAM
Type CONSTRUCTION JOINT
Spec no. BRW-3214.9
Tested By AS&BS
Date Tested 10/16/86
Nominal Area 68.43 Sq. in.

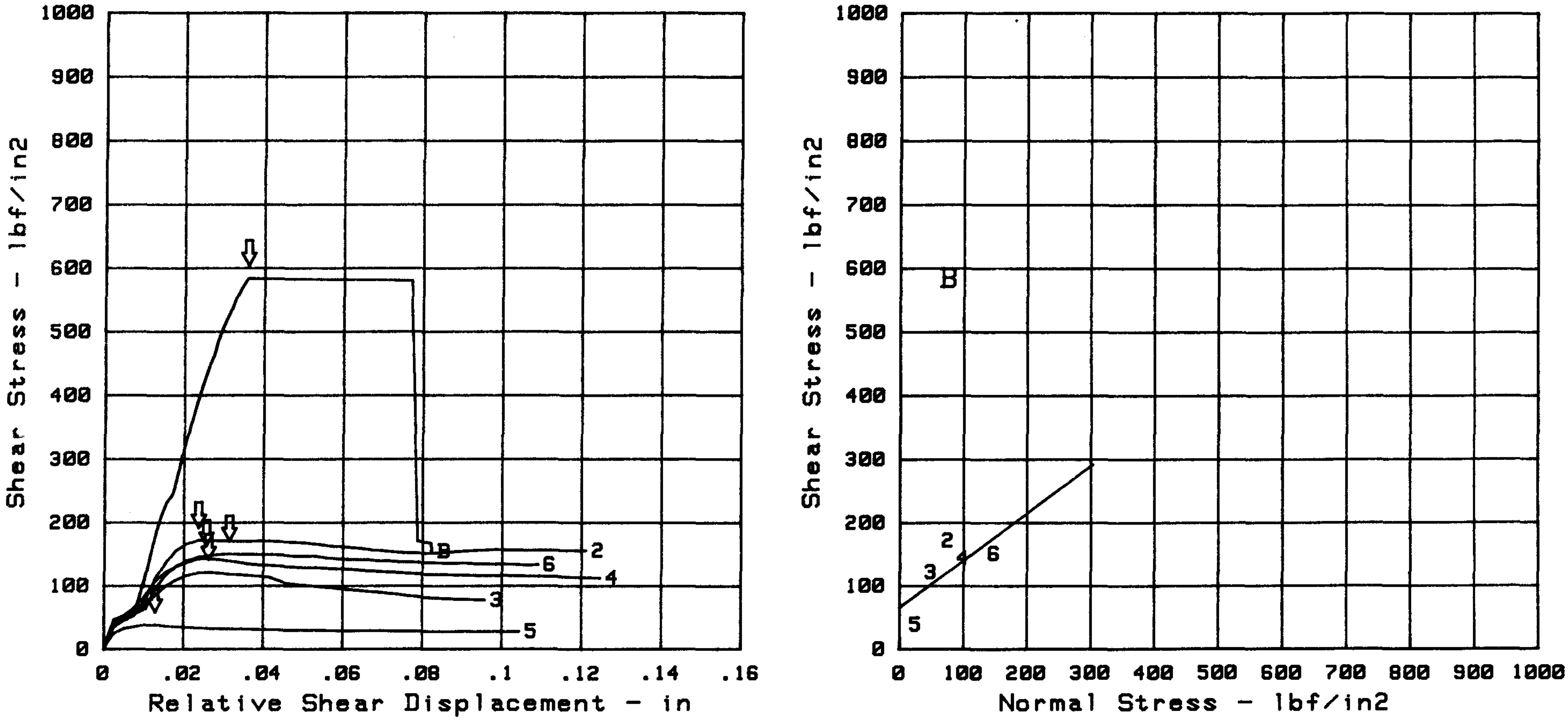
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
49	634	.0470	B
27	77	.0177	2
49	116	.0227	3
101	180	.0397	4
205	308	.0278	5
300	370	.0254	6

SLIDING FRICTION RESULTS
S= 62.0 +1.086 (N)
COHESION = 62 lbf/in2
PHI= 47 deg COR COEF= .9908

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 11

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	CONSTRUCTION JOINT
Spec no.	3-2-3215.2
Tested By	BH&RK
Date Tested	06/05/86
Nominal Area	69.13 Sq. in.

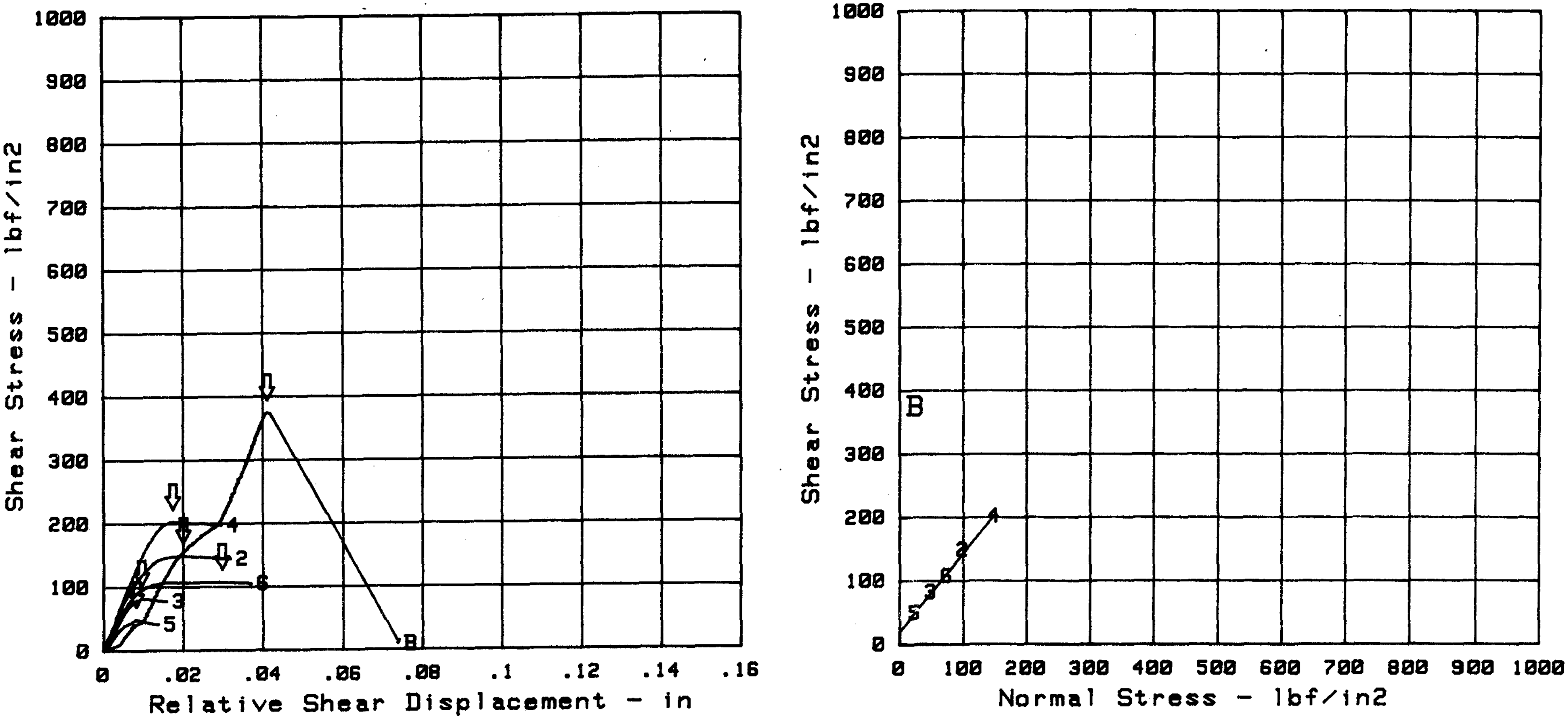
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
76	584	.0358	B
76	172	.0236	2
50	121	.0261	3
100	143	.0256	4
26	39	.0128	5
149	151	.0313	6

SLIDING FRICTION RESULTS
S= 65.4 + .746 (N)
COHESION = 65 lbf/in2
PHI= 37 deg COR COEF= .6866

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 12

DIRECT SHEAR TEST



Project C.U.P.
Feature BRANTLEY DAM
Type CONSTR. JOINT MUDMAT/KEYWAY
Spec no. 4-3165.0
Tested By B.HARPER
Date Tested 06/04/86
Nominal Area 28.50 Sq. in.

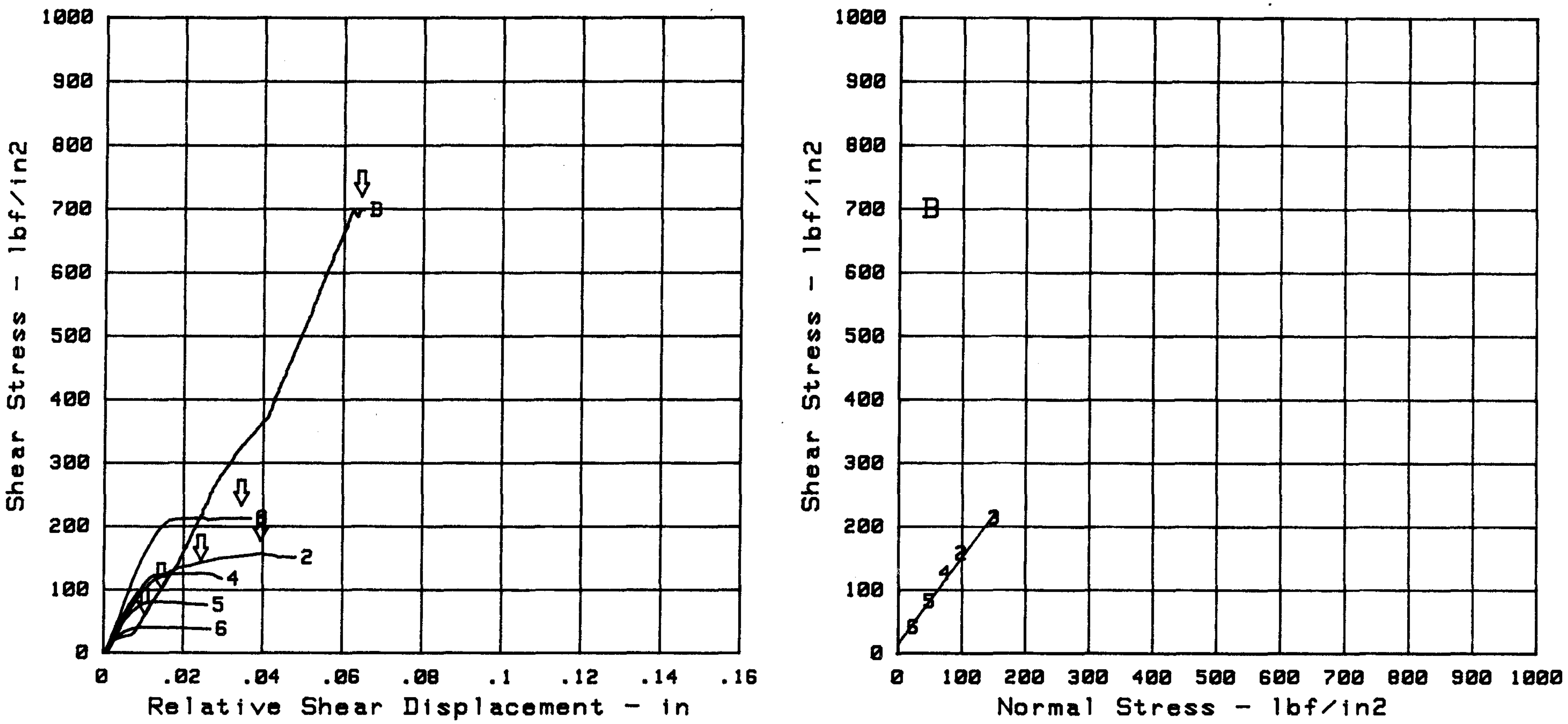
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
25	374	.0411	B
100	149	.0200	2
50	82	.0096	3
150	203	.0175	4
25	49	.0083	5
75	108	.0297	6

SLIDING FRICTION RESULTS
S= 19.1 +1.238 (N)
COHESION = 19 lbf/in2
PHI= 51 deg COR COEF= .9978

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 13

DIRECT SHEAR TEST



Project	C.U.P.
Feature	BRANTLEY DAM
Type	CONSTR. JOINT 1-M/MUDMAT
Spec no.	4-3165.5
Tested By	B.HARPER
Date Tested	06/27/86
Nominal Area	28.41 Sq. in.

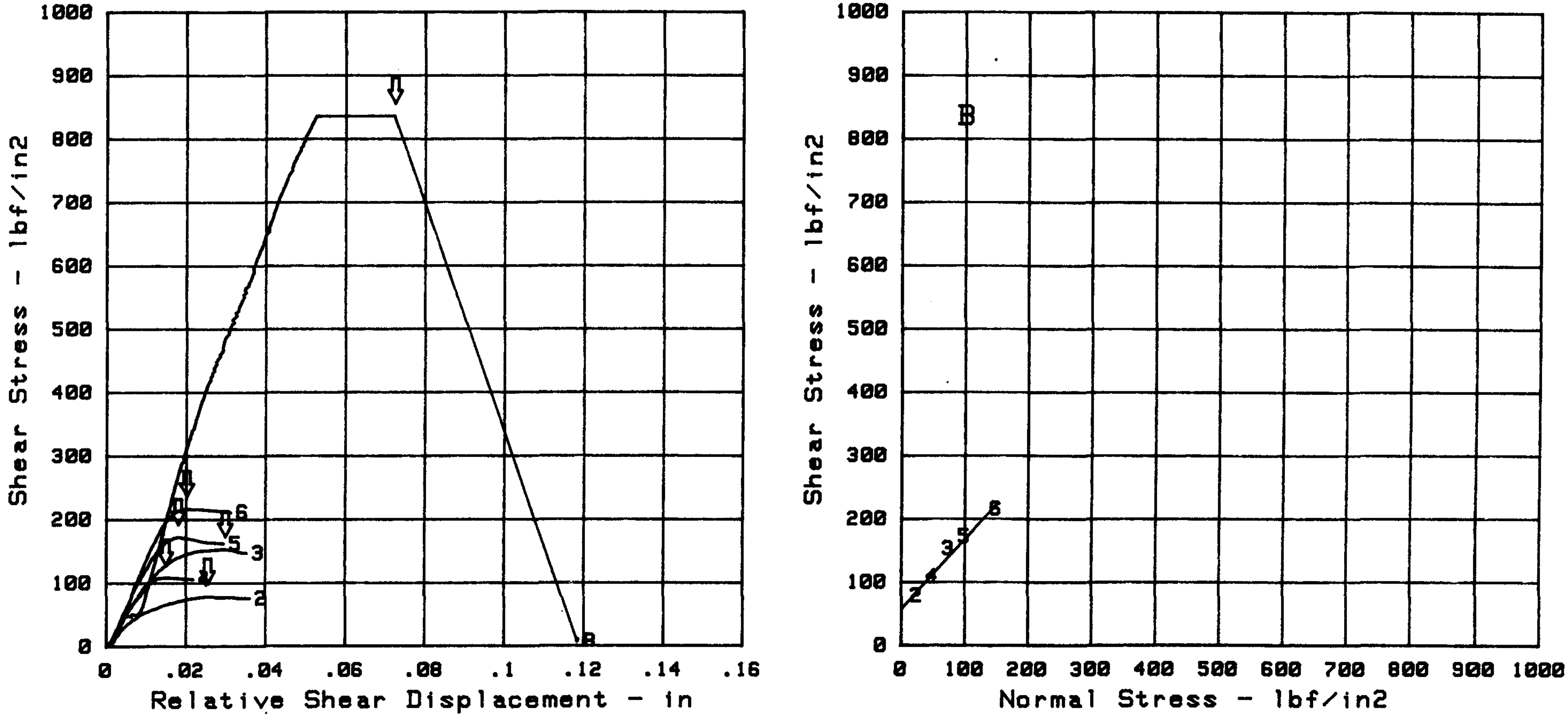
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
50	700	.0643	B
100	157	.0394	2
151	213	.0346	3
75	126	.0244	4
50	82	.0145	5
25	41	.0103	6

SLIDING FRICTION RESULTS
S= 14.3 +1.368 (N)
COHESION = 14 lbf/in2
PHI= 54 deg COR COEF= .9934

LEGEND
B = INTACT SHEAR STRENGTH
No. = SLIDING FRICTION TEST

Figure 14

DIRECT SHEAR TEST



Project	C.U.P.
Feature	BRANTLEY DAM
Type	CONSTR. JOINT 3-S/2-S
Spec no.	9-3185.0
Tested By	B.HARPER
Date Tested	08/06/86
Nominal Area	28.41 Sq. in.

NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
101	836	.0723	B
25	79	.0255	2
75	153	.0299	3
50	108	.0150	4
100	172	.0180	5
150	216	.0202	6

SLIDING FRICTION RESULTS

S= 57.0 +1.107 (N)

COHESION = 57 lbf/in2

PHI= 48 deg COR COEF= .9875

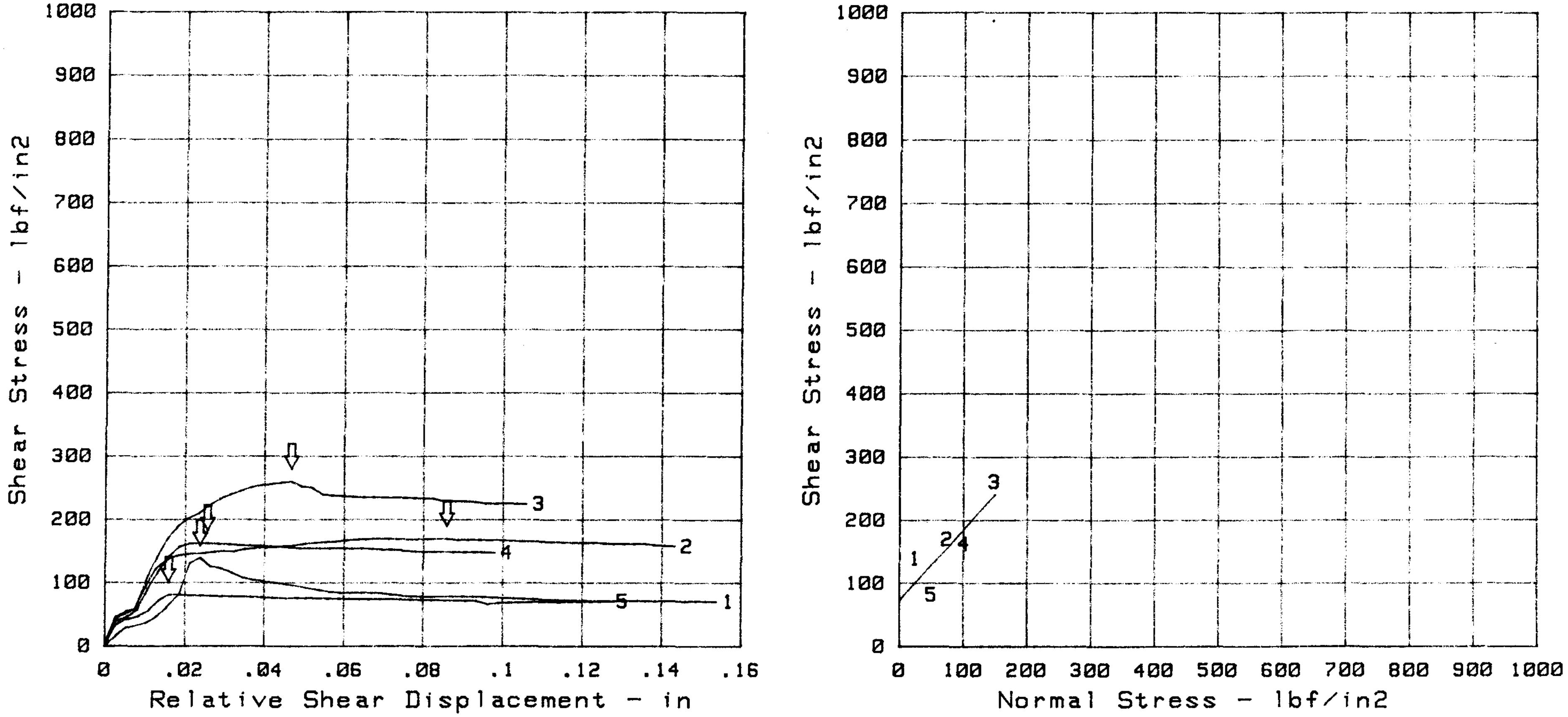
LEGEND

B = INTACT SHEAR STRENGTH

No. = SLIDING FRICTION TEST

Figure 15

DIRECT SHEAR TEST



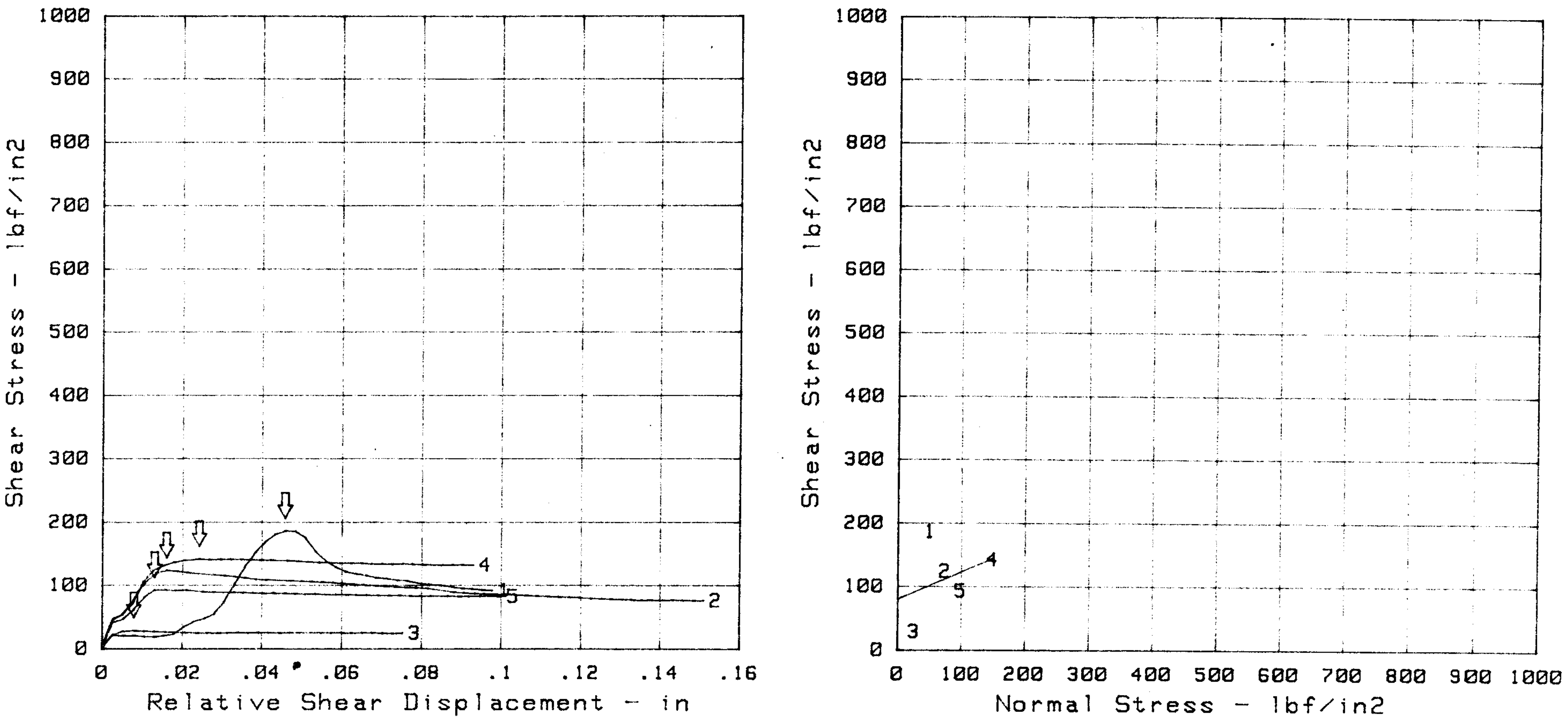
Project	BRANTLEY
Feature	BRANTLEY DAM
Type	OPEN JOINT
Spec no.	3-1-3218.9
Tested By	BH&RK
Date Tested	06/04/86
Nominal Area	71.68 Sq. in.

NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
24	139	.0237	1
75	170	.0859	2
150	260	.0467	3
102	162	.0256	4
51	81	.0159	5

SLIDING FRICTION RESULTS
S= 72.9 +1.116 (N)
COHESION = 73 lbf/in2
PHI= 48 deg COR COEF= .8349

Figure 16

DIRECT SHEAR TEST



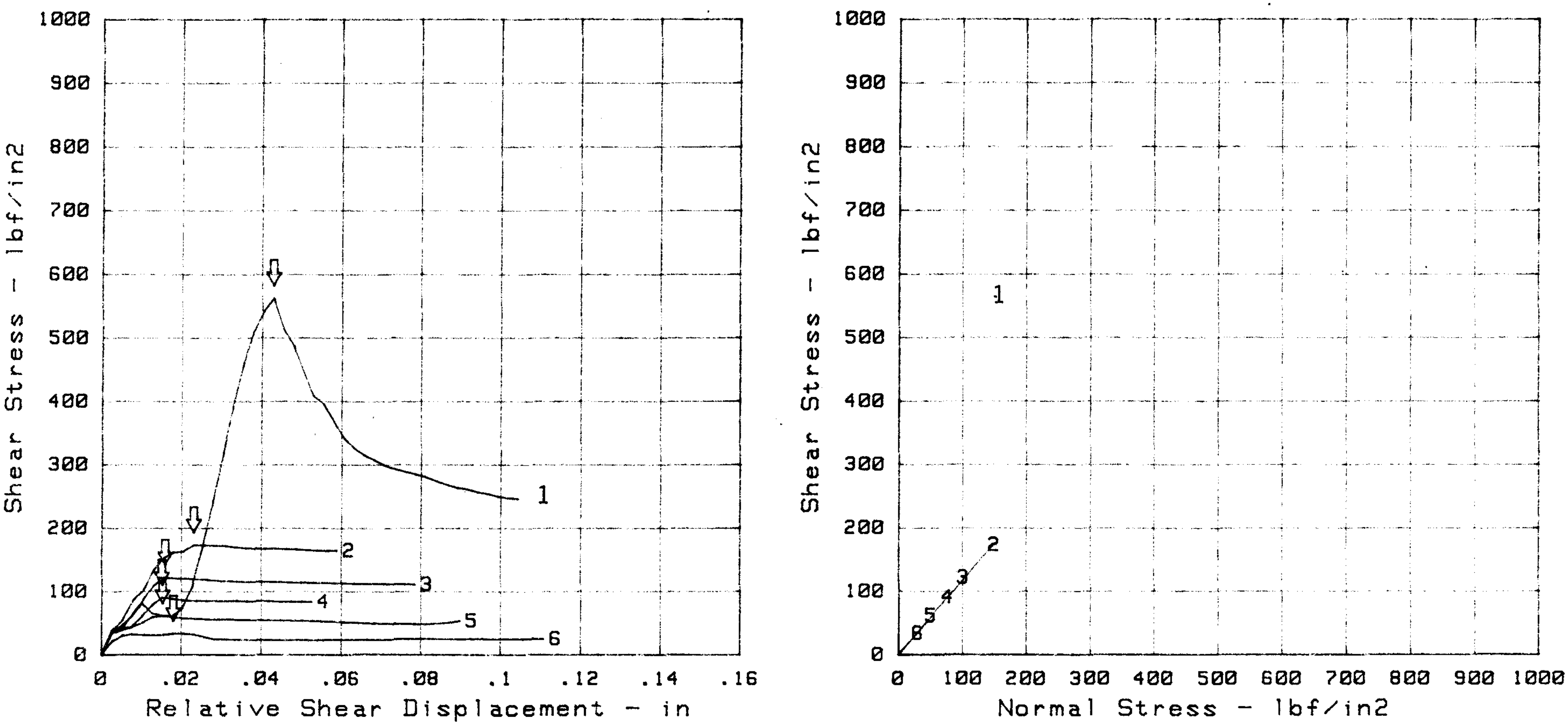
Project	BRANTLEY
Feature	BRANTLEY DAM
Type	OPEN JOINT
Spec no.	3-1-3214.9
Tested By	BH&RK&RC
Date Tested	06/04/86
Nominal Area	68.84 Sq. in.

NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
50	186	.0457	1
75	124	.0160	2
26	29	.0078	3
150	142	.0242	4
100	93	.0130	5

SLIDING FRICTION RESULTS
S= 80.3 + .428 (N)
COHESION = 80 lbf/in2
PHI= 23 deg COR COEF= .3483

Figure 17

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	OPEN JOINT
Spec no.	3-2-3220.0
Tested By	BH&RC
Date Tested	06/06/86
Nominal Area	68.74 Sq. in.

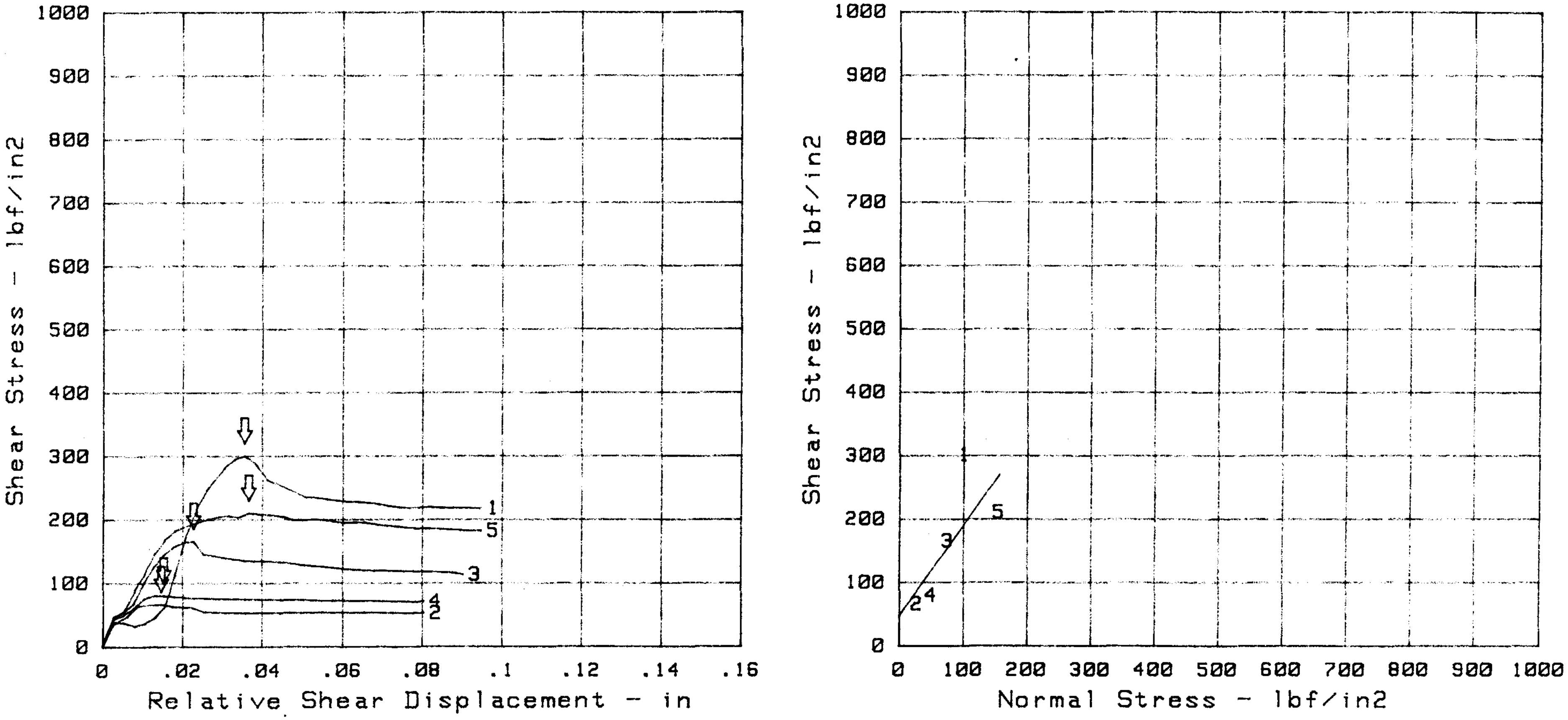
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
151	562	.0428	1
150	173	.0230	2
101	122	.0159	3
77	90	.0151	4
51	62	.0152	5
31	33	.0179	6

SLIDING FRICTION RESULTS
S= .2 +1.168 (N)
COHESION = 0 lbf/in2
PHI= 49 deg COR COEF= .9988

Note: Cycle 1 results were not included in this equation.

Figure 18

DIRECT SHEAR TEST



Project	BRANTLEY
Feature	BRANTLEY DAM
Type	OPEN JOINT
Spec no.	3-2-3217.2
Tested By	BH&JM&SC
Date Tested	06/06/86
Nominal Area	68.90 Sq. in.

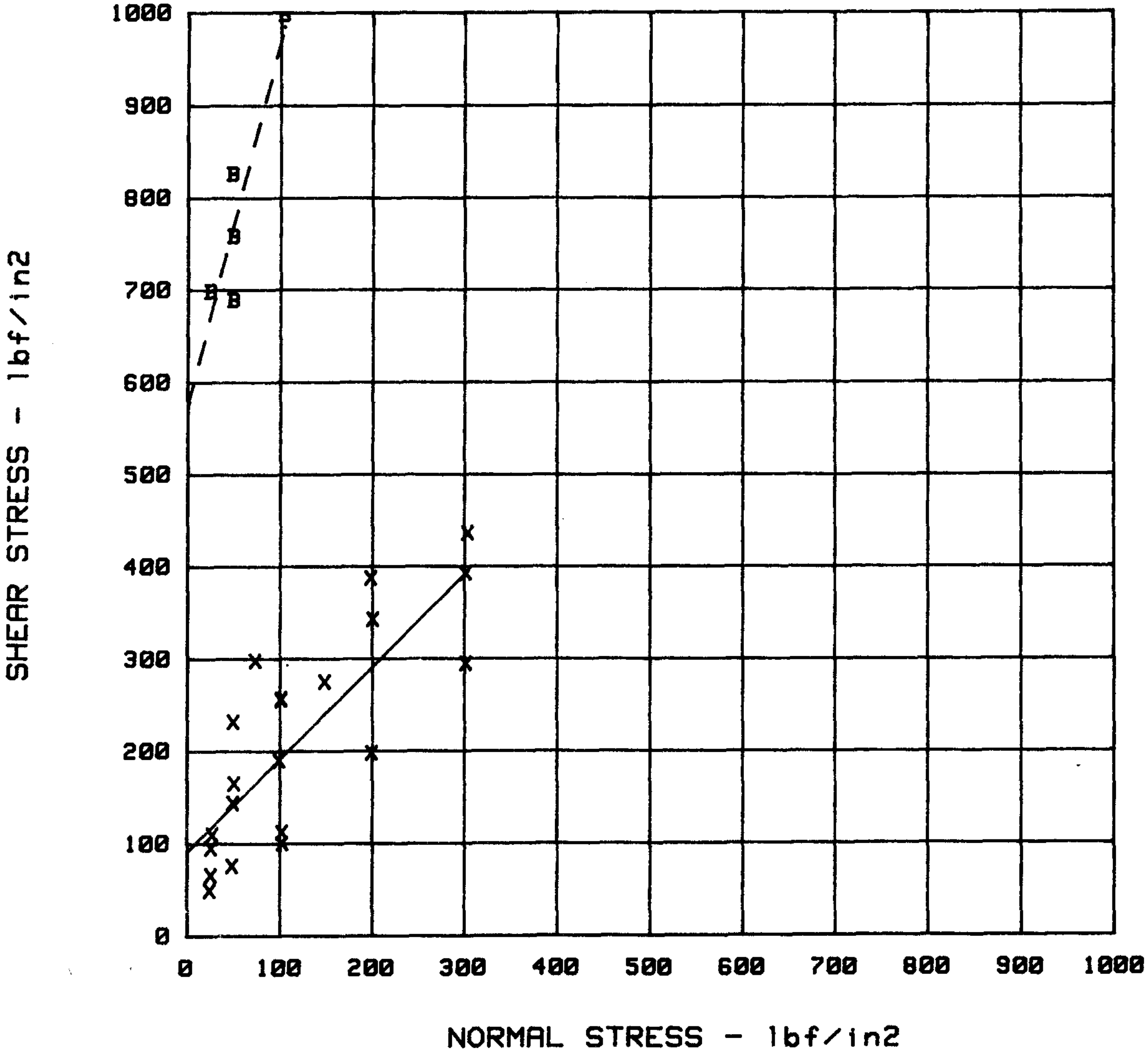
NORMAL STRESS lbf/in2	SHEAR STRESS lbf/in2	DISP in.	CYCLE NO.
101	301	.0356	1
28	66	.0146	2
76	166	.0227	3
50	80	.0153	4
156	210	.0365	5

SLIDING FRICTION RESULTS
S= 47.4 +1.424 (N)
COHESION = 47 lbf/in2
PHI= 55 deg COR COEF= .7295

Figure 19

DIRECT SHEAR TEST

CONCRETE - PARENT



Project: BRANTLEY
Feature: BRANTLEY DAM
Combined: ALL PARENT MATERIAL

INTACT SHEAR STRENGTH
S= 573.5 + 3.954 (N)
Cohesion = 573 lbf/in2
Phi= 76 deg Corr Coef= .9081

SLIDING FRICTION RESULTS
S= 91.2 + .999 (N)
Cohesion = 91 lbf/in2
Phi= 45 deg Corr Coef= .8079

SPECIMEN NO.		Normal Stress lbf/in2	Shear Stress lbf/in2
B5-3195.7	(B)	49	825
B5-3196.4	(B)	104	998
3-1-3219.8	(B)	25	698
3-2-3222.2	(B)	50	758
BRW-3222.7	(B)	50	688

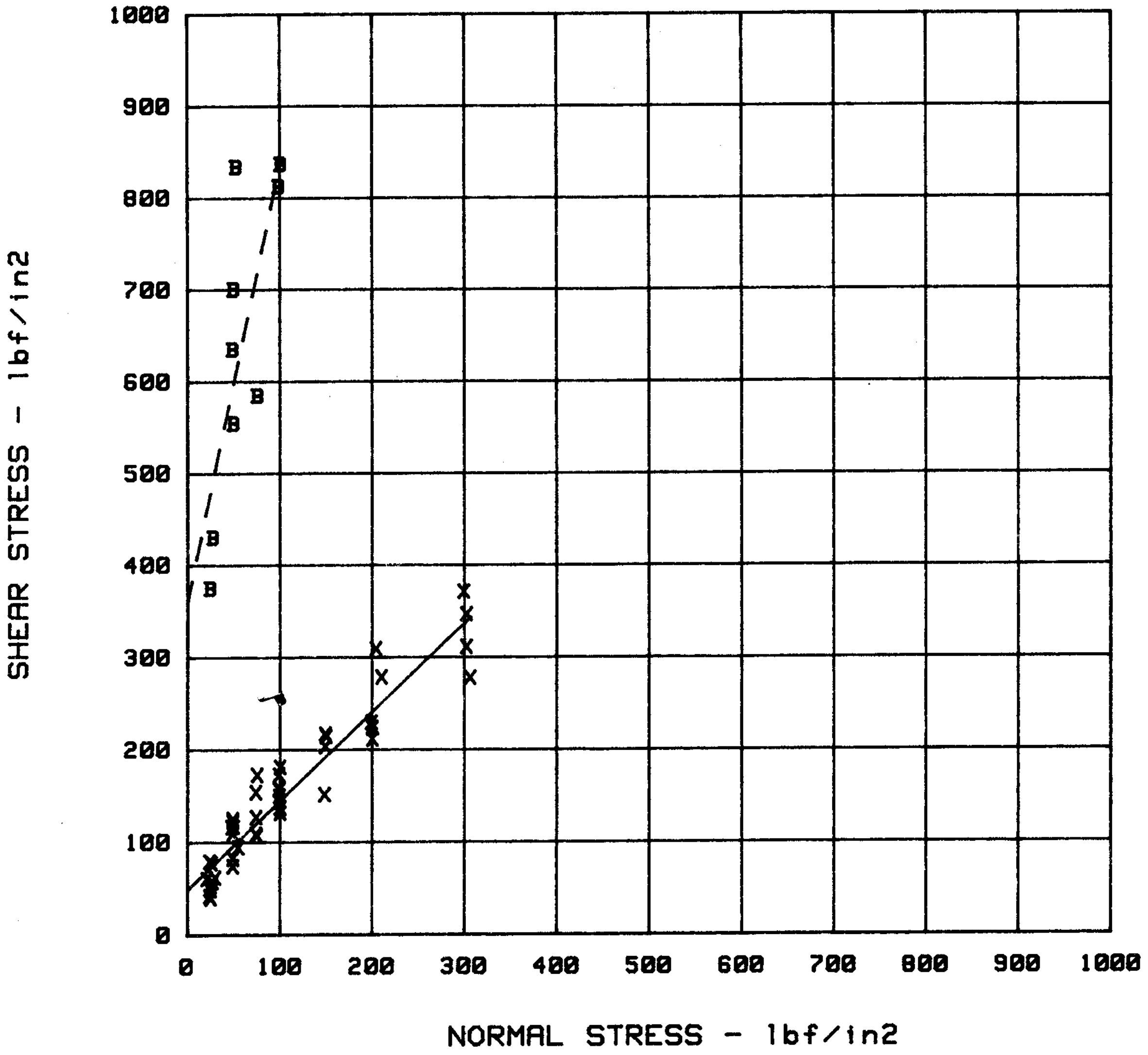
LEGEND
(S) - No Intact Value
(B) - Intact Shear Determined

Sliding Frict. Values(X) ————
B - Intact Shear Strength — — —

Figure 20

DIRECT SHEAR TEST

CONCRETE – CONSTRUCTION JOINTS



Project: BRANTLEY
Feature: BRANTLEY DAM
Combined: ALL CONSTRUCTION JOINTS

INTACT SHEAR STRENGTH
S= 359.0 + 4.754 (N)
Cohesion = 359 lbf/in2
Phi= 78 deg Corr Coef= .7649

SLIDING FRICTION RESULTS
S= 48.3 + .960 (N)
Cohesion = 48 lbf/in2
Phi= 44 deg Corr Coef= .9509

SPECIMEN NO.		Normal Stress lbf/in2	Shear Stress lbf/in2
SB-3163.0	(B)	50	554
SB-3165.1	(B)	99	812
SB-3165.2	(B)	28	429
B5-3195.0	(B)	53	833
BRW-3214.9	(B)	49	634
3-2-3215.2	(B)	76	584
4-3165.0	(B)	25	374
4-3165.5	(B)	50	700
9-3185.0	(B)	101	836

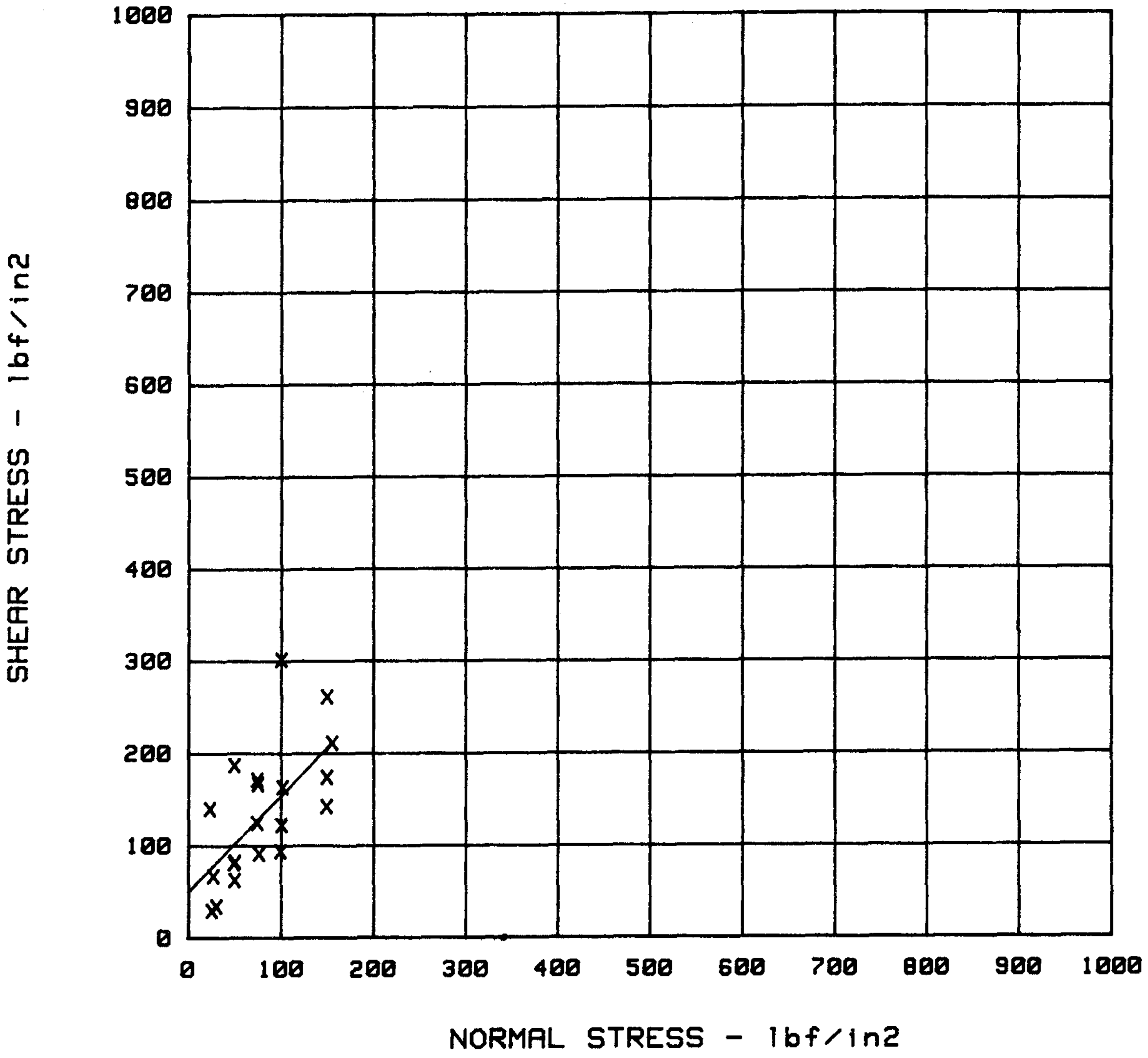
LEGEND
(S) - No Intact Value
(B) - Intact Shear Determined

Sliding Frict. Values(X) ———
B = Intact Shear Strength — — —

Figure 21

DIRECT SHEAR TEST

CONCRETE - OPEN JOINTS



Project: BRANTLEY
Feature: BRANTLEY DAM
Combined: ALL OPEN JOINTS

SLIDING FRICTION RESULTS
S= 50.1 + 1.039 (N)
Cohesion = 50 lbf/in2
Phi= 46 deg Corr Coef= .6391

SPECIMEN NO.

3-1-3218.9	(S)
3-1-3214.9	(S)
3-2-3220.0	(S)
3-2-3217.2	(S)

LEGEND
(S) - No Intact Value
(B) - Intact Shear Determined

Sliding Frict. Values(X) ————

Appendix A

Direct Shear Test Procedure

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ROCK AND CONCRETE DIRECT SHEAR TEST

The direct shear test is usually performed to determine shear strength along a preexisting surface in an intact specimen. Intact specimens typically contain some feature such as a healed joint, a bedding plane or foliation, a rock contact, or a concrete construction joint. Sliding friction tests can be performed following determination of intact shear strength. Other types of features tested for sliding friction are open rock joints or bedding planes, weak planes broken during drilling, or presawn shear surfaces.

Two laboratory direct shear machines are available for testing rock or concrete specimens. The small machine has 10,000-lbf normal and 20,000-lbf shear capacity and is used for specimens of approximately 2 to 6 inches in diameter. The standard gap or "d" distance between the upper and lower halves of the shear box is 1/4 inch. The large direct shear machine has 100,000-lbf normal and 240,000-lbf shear capacity. It can accommodate specimen sizes of 4 to 10 inches in diameter. The distance between the upper and lower halves of the shear box can be varied from 1/2 to 1 inch.

To perform the direct shear test in the laboratory, normal force and shear force are applied to the specimen using either pneumatic or hydraulic control. Forces are measured with dual-bridge load cells.

Shear (horizontal) displacement is measured using a single LVDT (linear variable differential transformer). This displacement is determined by measuring movement of the lower half of the shear box while the upper half is held stationary. Normal (vertical) displacement is currently measured only on the small machine using four LVDT's which register movement of the upper half of the shear box.

The same automatic data acquisition system is used with both laboratory machines. It provides a printout and plot of data as the test proceeds and also records the data for additional analyses following testing. Shear force, normal force, and displacements are measured and recorded simultaneously at preselected load or displacement increments. Loads are manually controlled, and small variations can occur in normal force and in shear force rate during testing.

Both intact shear strength and sliding friction tests are performed similarly. Data are recorded at predefined shear force intervals during the intact shear strength test and at given shear displacement intervals during sliding friction tests.

The following is a description of the testing sequence:

1. A specimen is encapsulated in gypsum cement in upper and lower holding rings such that the specimen test feature is centered and aligned within the gap between the rings.

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2. The encapsulated specimen is inserted into the test machine by slipping the bottom holding ring into the lower half of the shear box.

3. The upper half of the shear box is lowered over the top holding ring.

4. The shear box is moved until the upper half of the shear box comes into contact with rollers fixed to the direct shear apparatus, after which the two shear box halves are backed off slightly to ensure that no shear force is being applied to the specimen.

5. Bolts used to minimize specimen disturbance during handling are removed from the holding rings.

6. Normal force necessary to provide required normal stress is applied to the upper half of the shear box.

7. The upper half of the shear box is held in place in the horizontal direction while shear force is applied to the lower half of the shear box until a peak shear force is reached or until significant displacement occurs with no change in shear force.

8. The lower half of the shear box is backed off until the upper half of the shear box just moves away from the rollers.

9. The specimen is inspected in the test machine to determine if subsequent testing may proceed. If an intact specimen has been sheared, the shear profile is examined to determine if sliding friction tests can proceed without interference from the encapsulating material. Sliding friction test specimens must be inspected to determine if excessive shear displacement has occurred. If it is deemed necessary to rotate or realign the specimen, the specimen must be removed and the procedure continued beginning at step 2.

10. Normal force is adjusted to the next required normal stress, and the shear box is moved until the upper half of the shear box makes contact with the rollers.

11. Steps 7 through 10 are repeated for all required normal stresses.

A Mohr-Coulomb failure envelope is determined for each sliding friction test specimen. A visual best-fit line may be drawn through the data points, or a linear regression calculation may be performed to obtain a best-fit line. If several intact shear tests are performed on similar specimens at various normal stresses, an intact shear strength failure envelope can be determined using the combined data. Sliding friction test results may also be combined for similar specimens to provide a sliding friction failure envelope for multiple specimens.

Appendix B

Before and After Photographs of Direct Shear Test Specimens

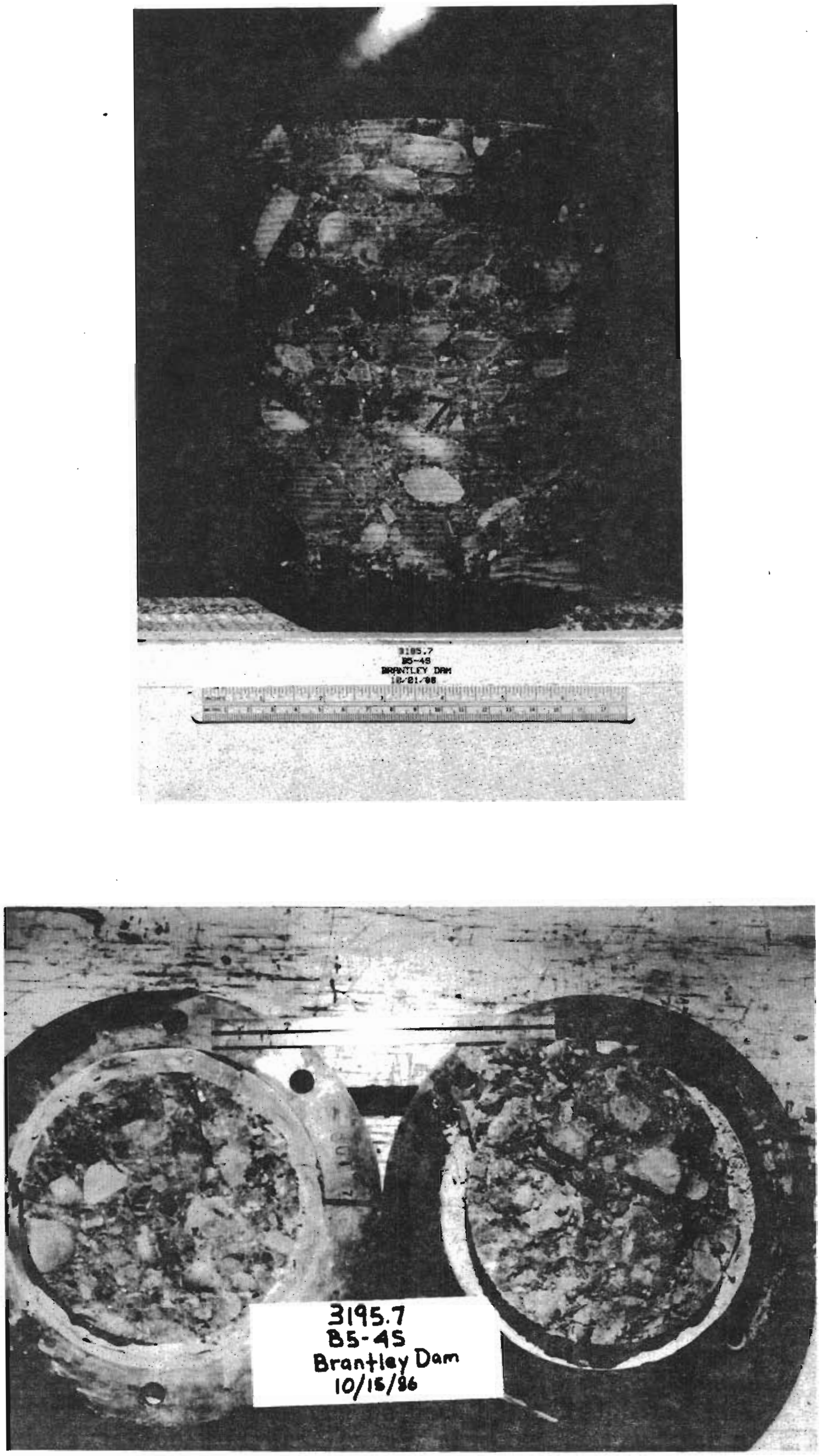


Figure B1. - Photographs of specimens before and after testing.

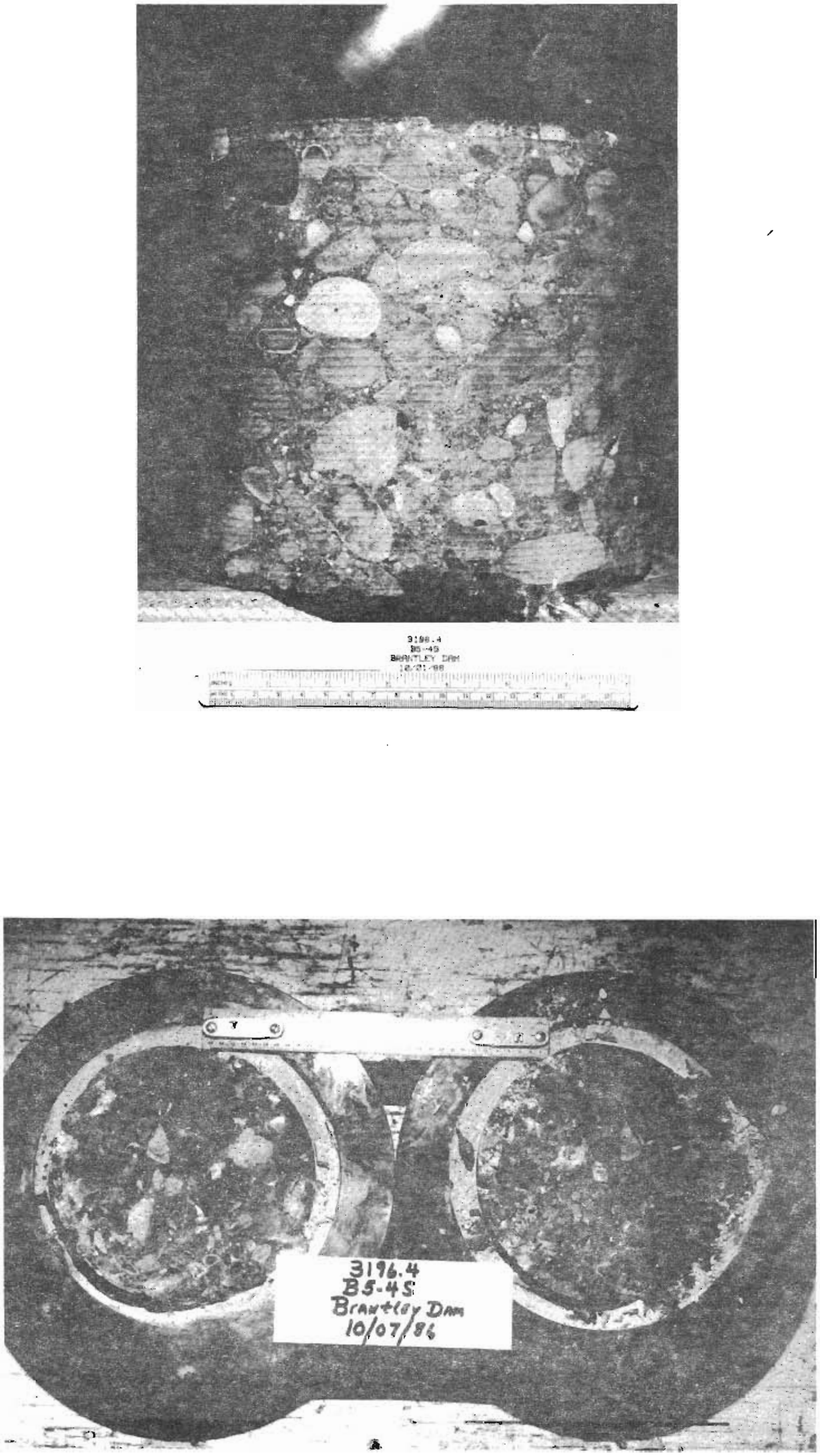


Figure B2. - Photographs of specimens before and after testing.

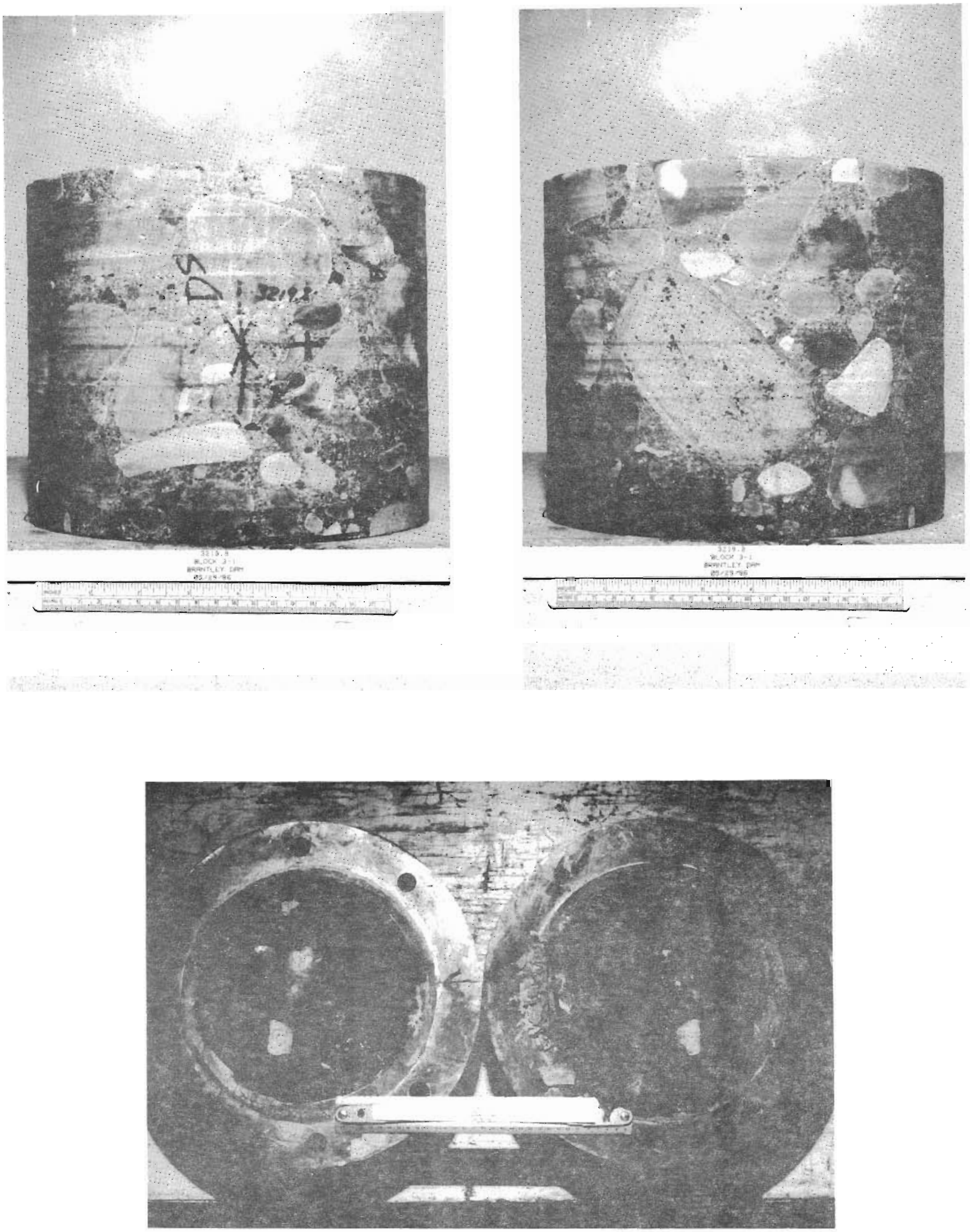


Figure B3. - Photographs of specimens before and after testing.

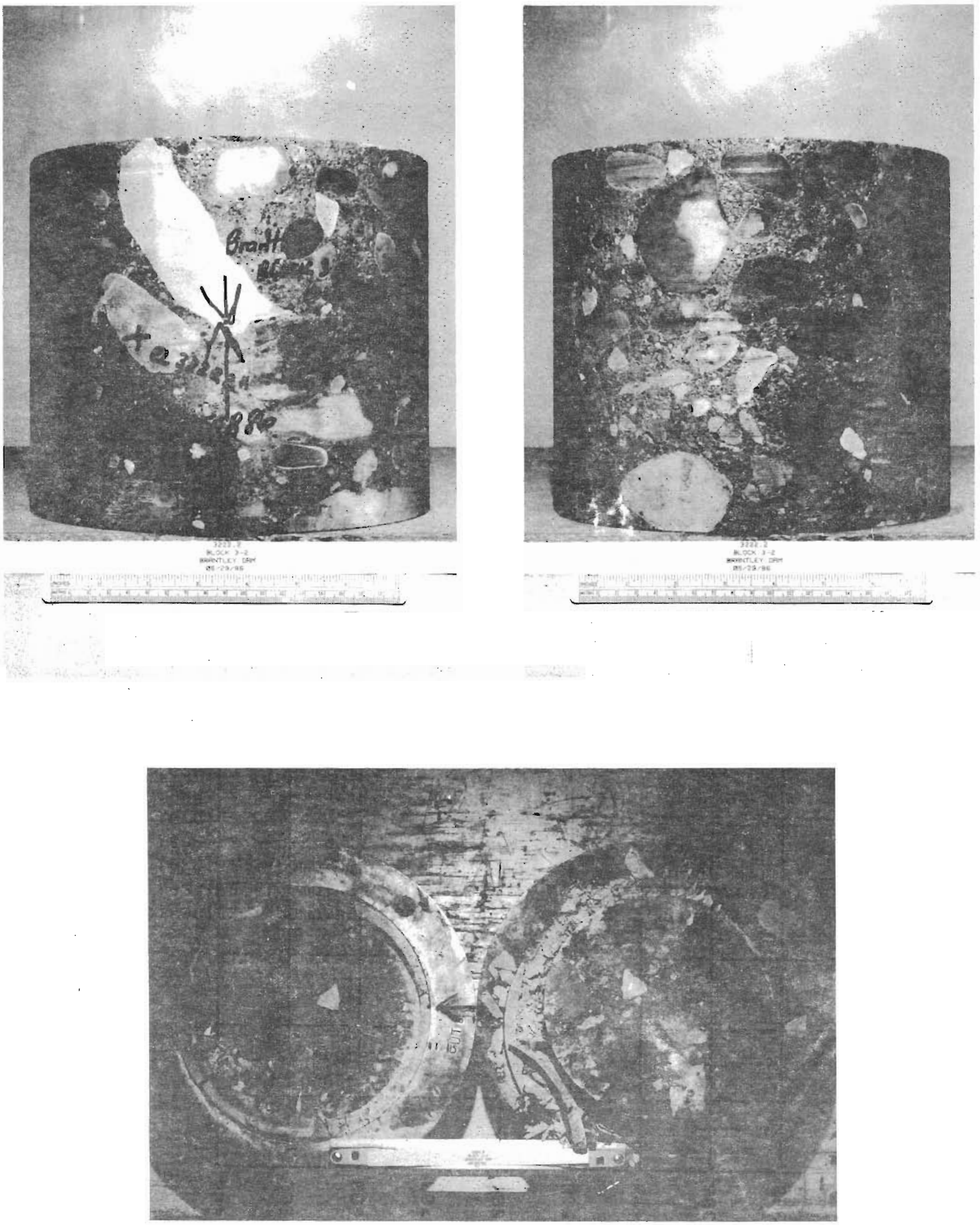


Figure B4. - Photographs of specimens before and after testing.

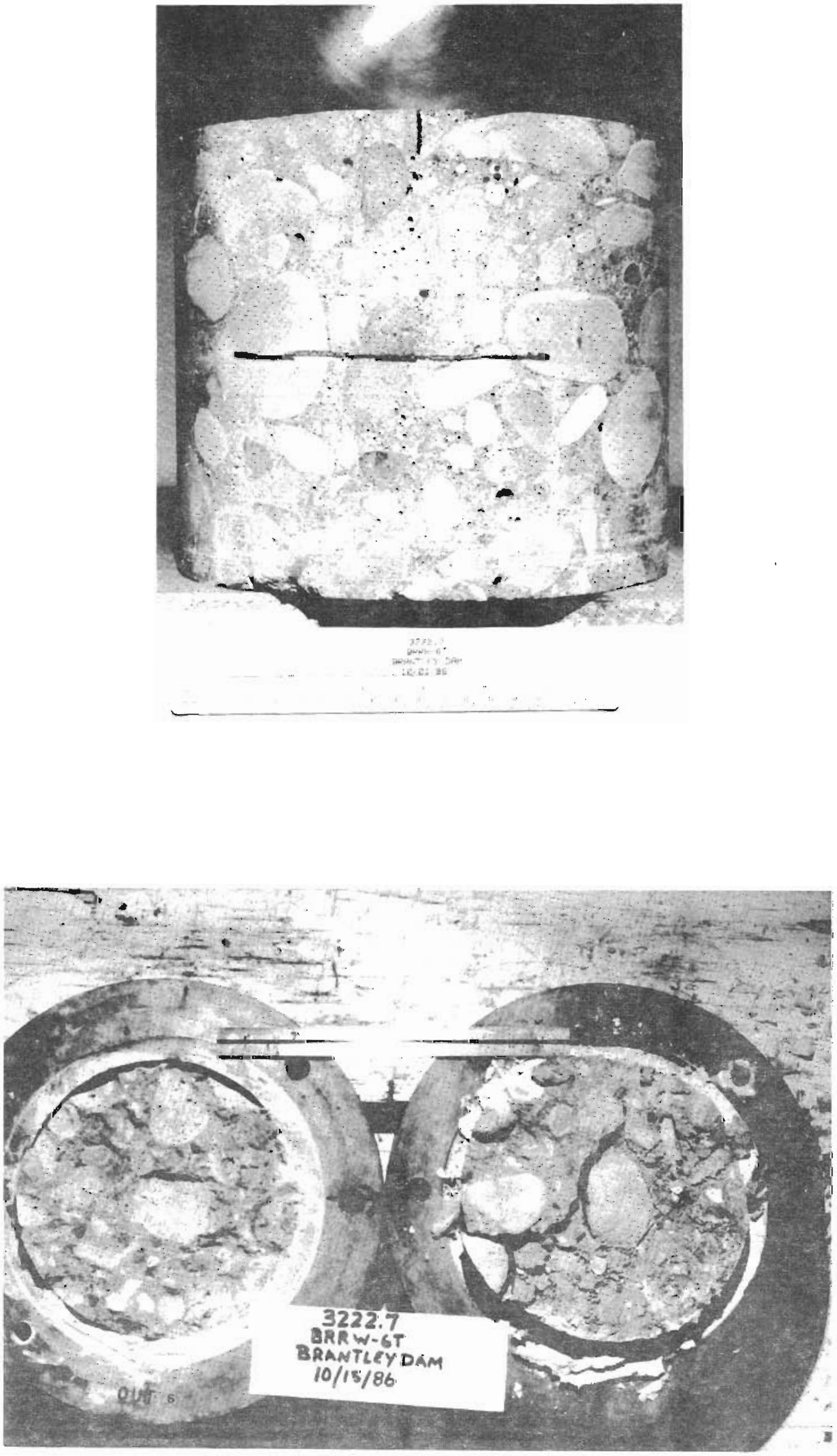


Figure B5. - Photographs of specimens before and after testing.

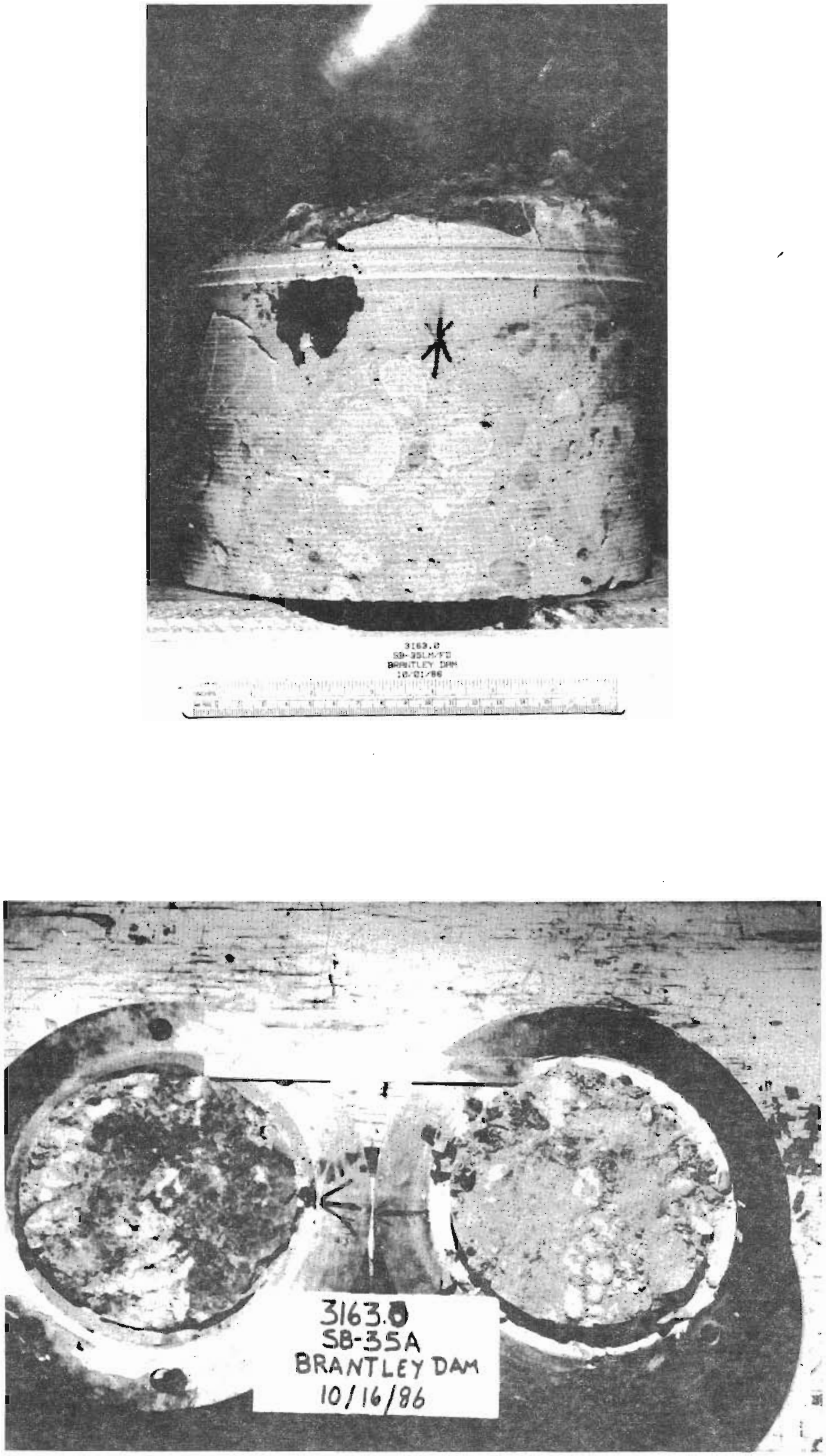


Figure B6. - Photographs of specimens before and after testing.

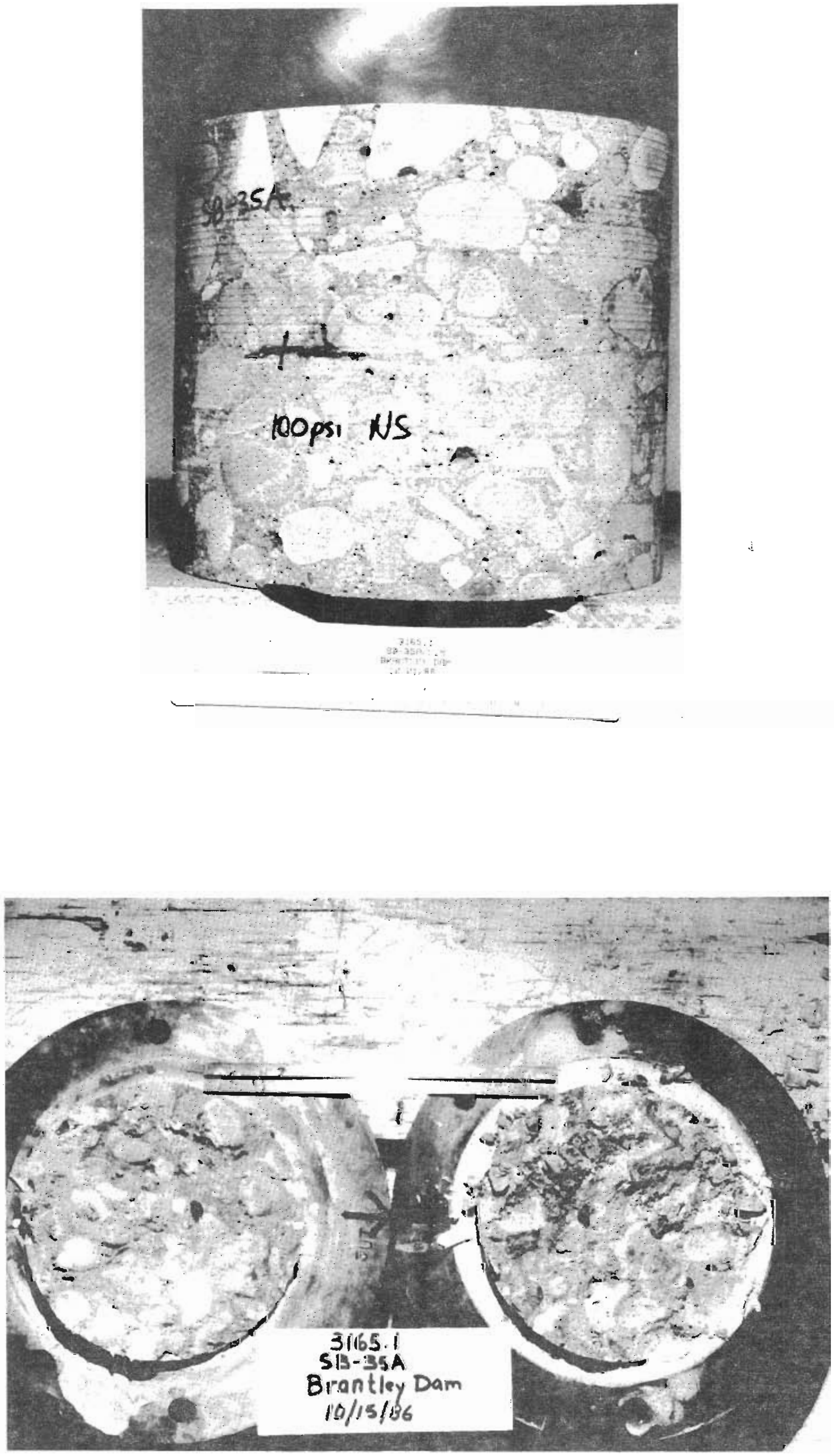
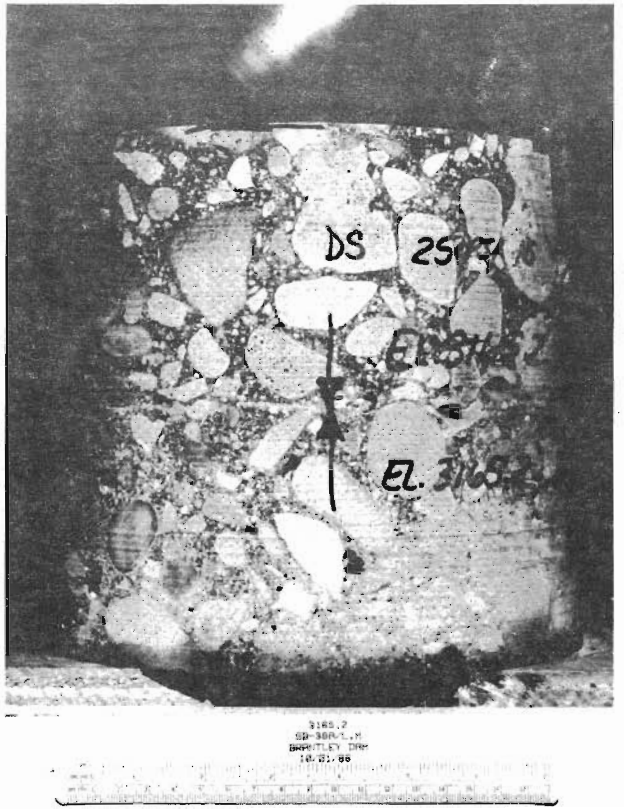


Figure B7. - Photographs of specimens before and after testing.



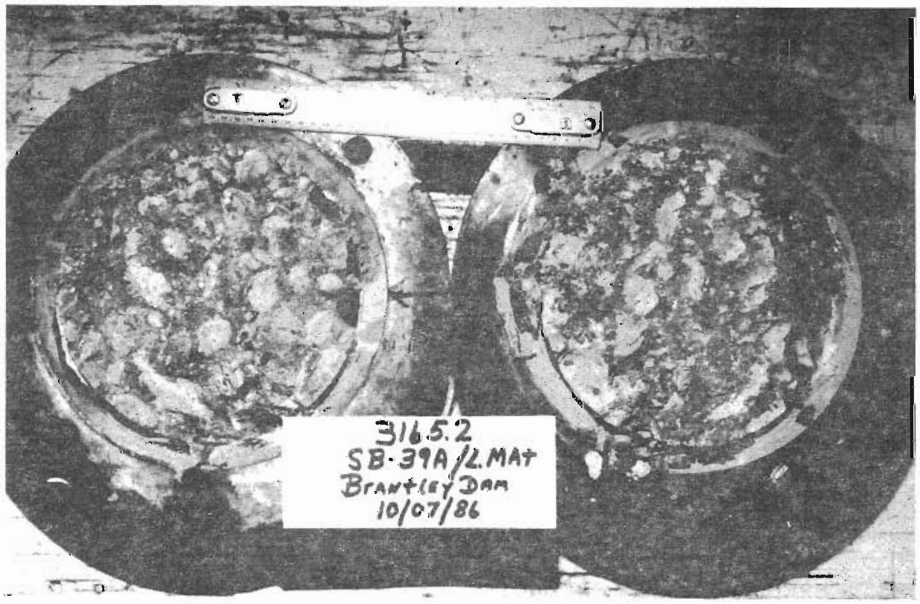


Figure B8. - Photographs of specimens before and after testing.

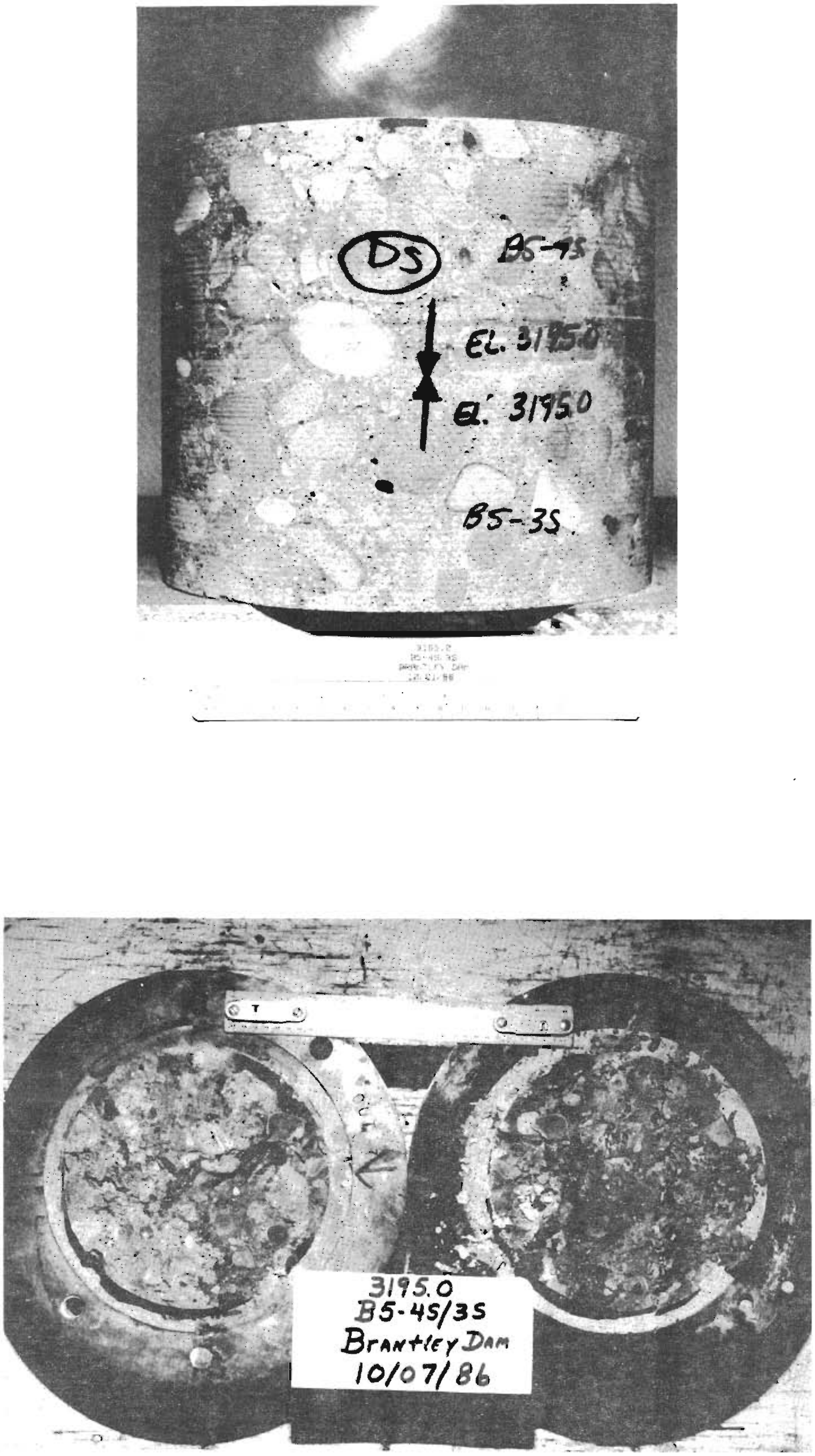


Figure B9. - Photographs of specimens before and after testing.

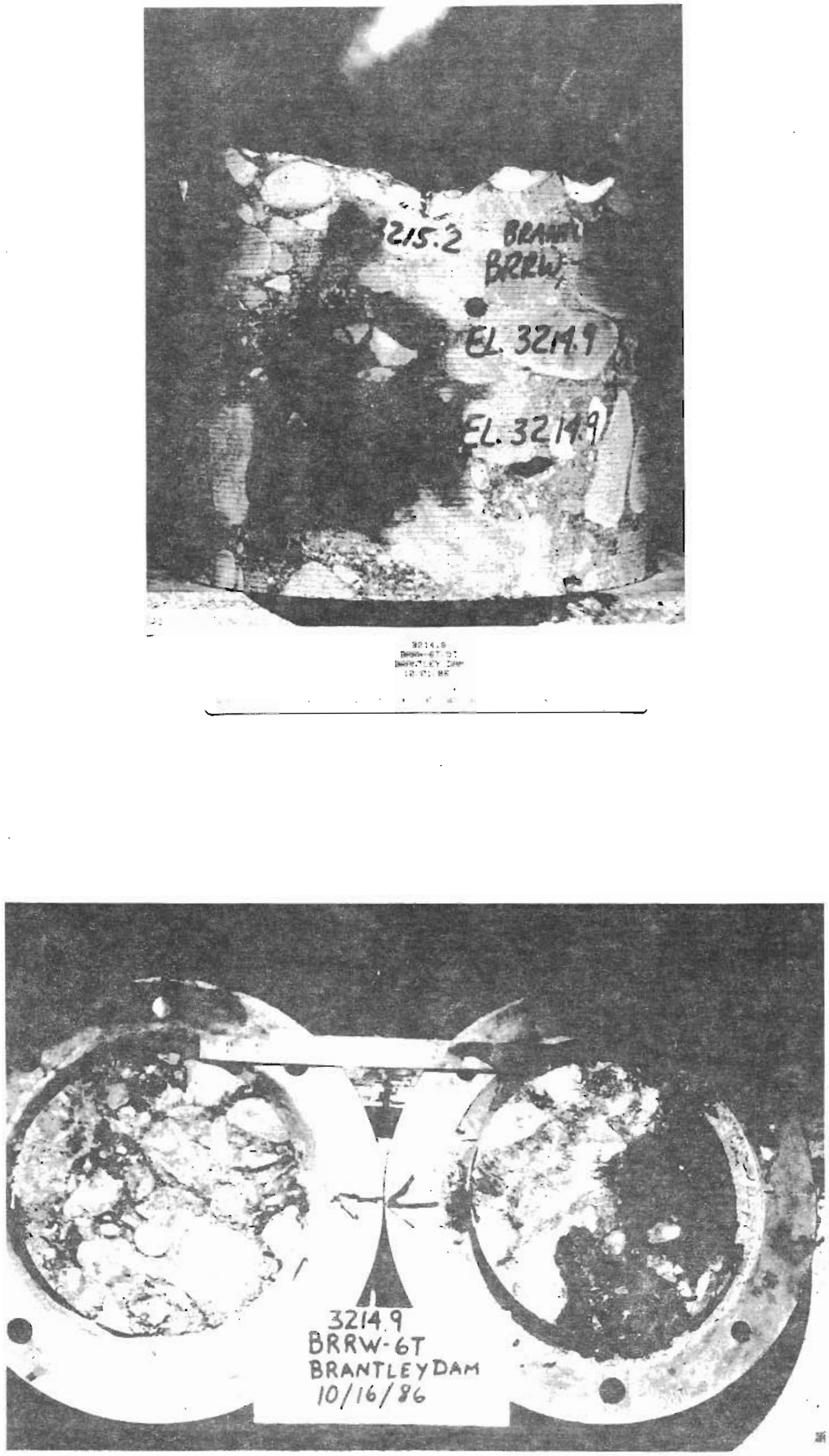


Figure B10. - Photographs of specimens before and after testing.

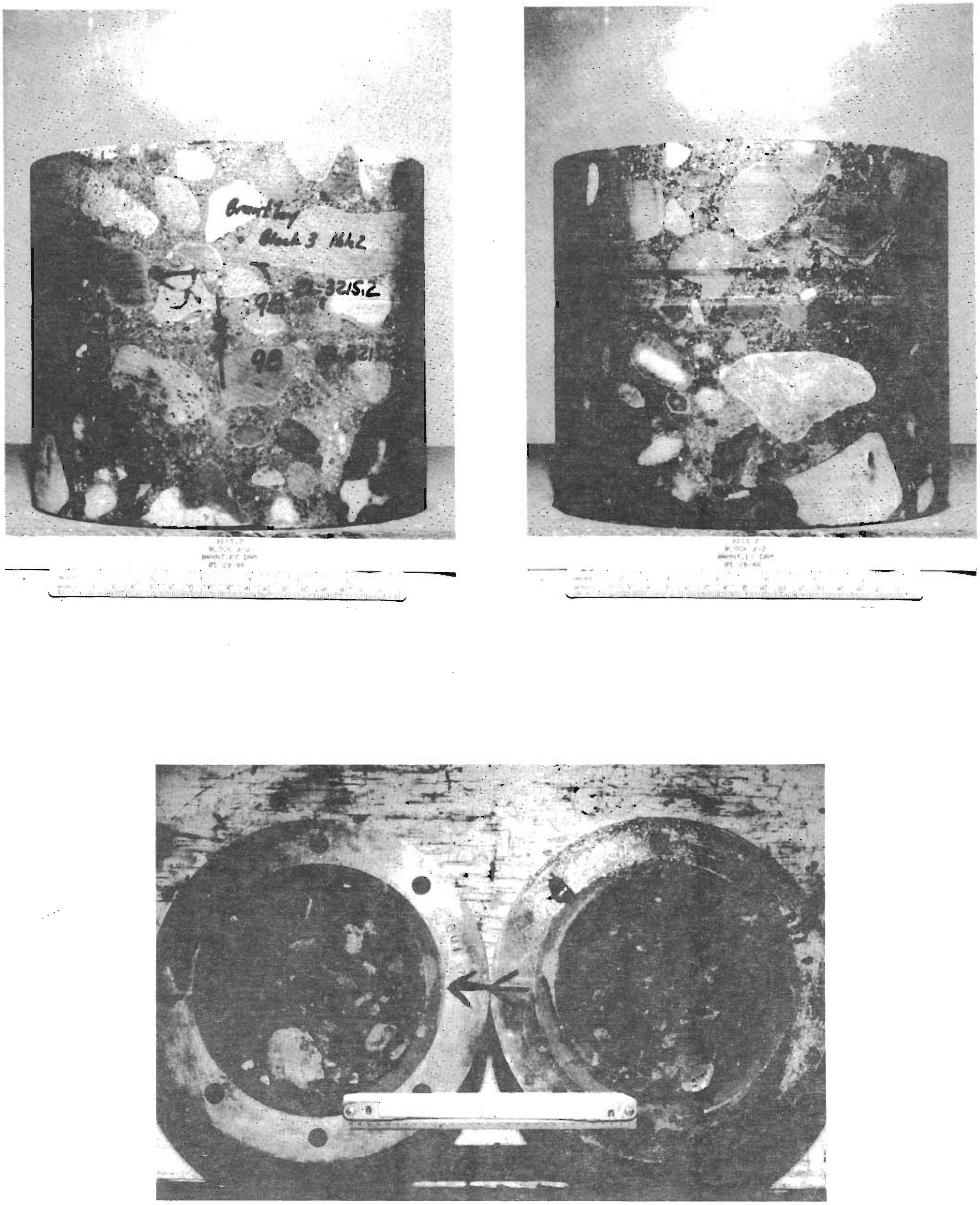


Figure B11. - Photographs of specimens before and after testing.

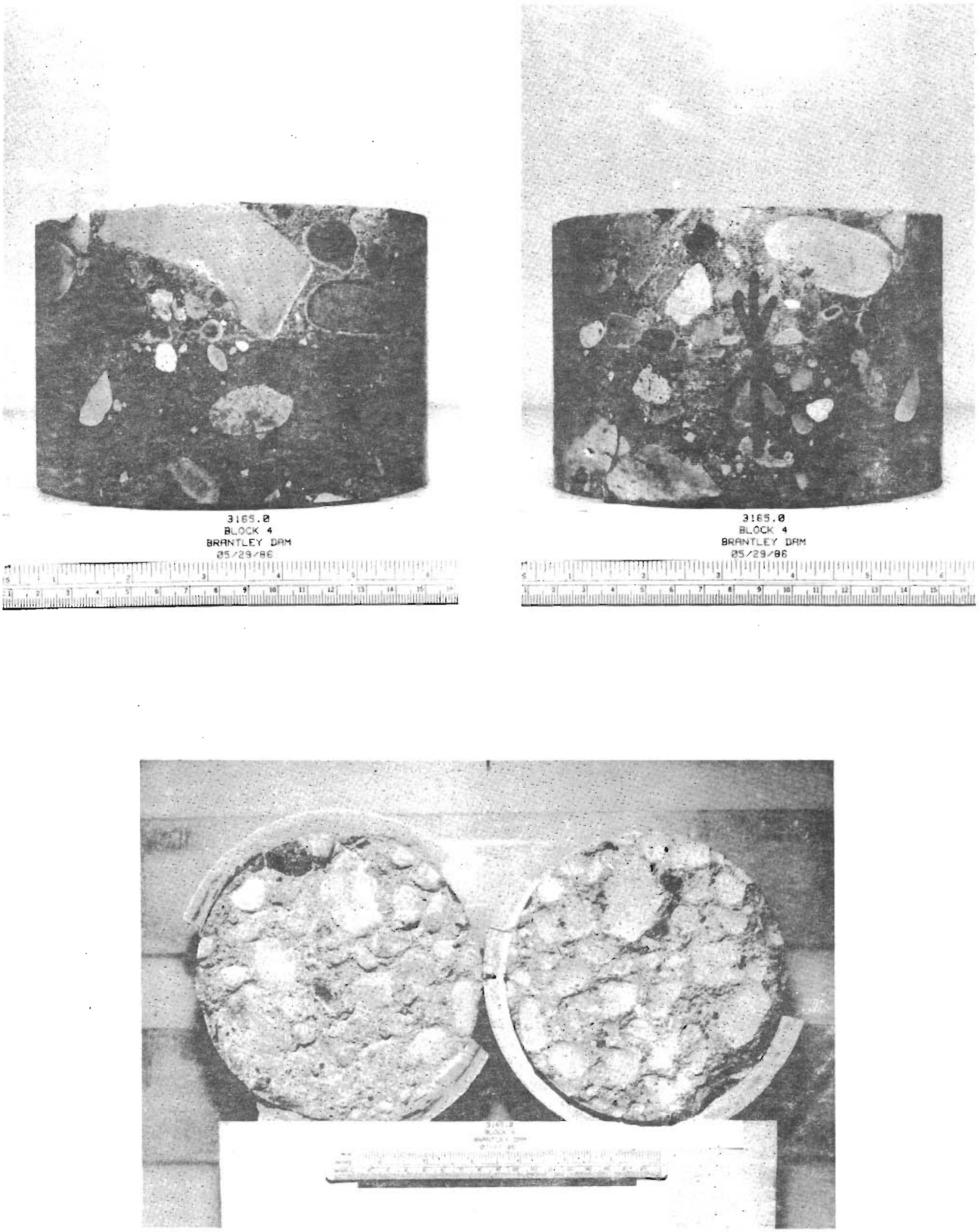


Figure B12. - Photographs of specimens before and after testing.

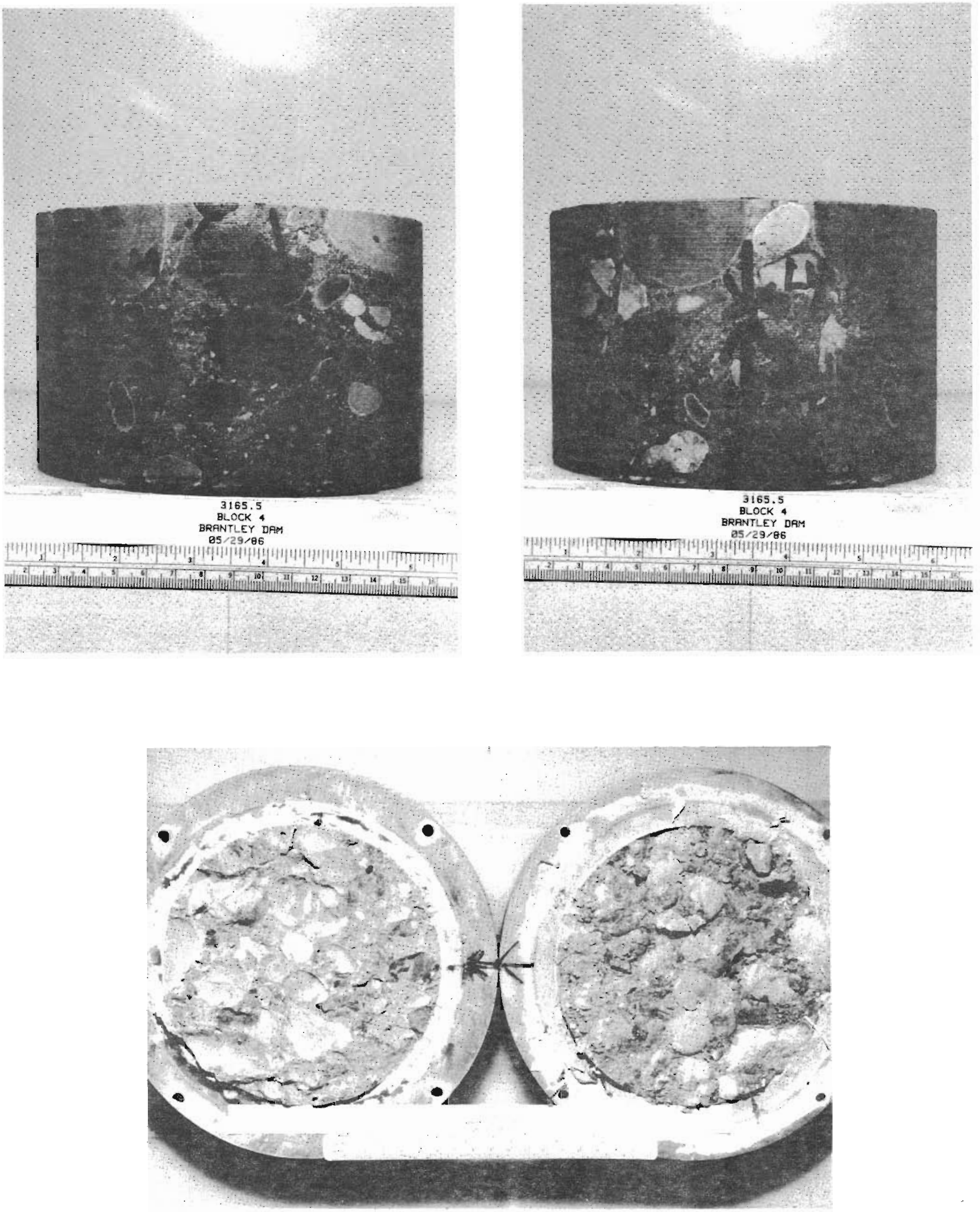


Figure B13. - Photographs of specimens before and after testing.

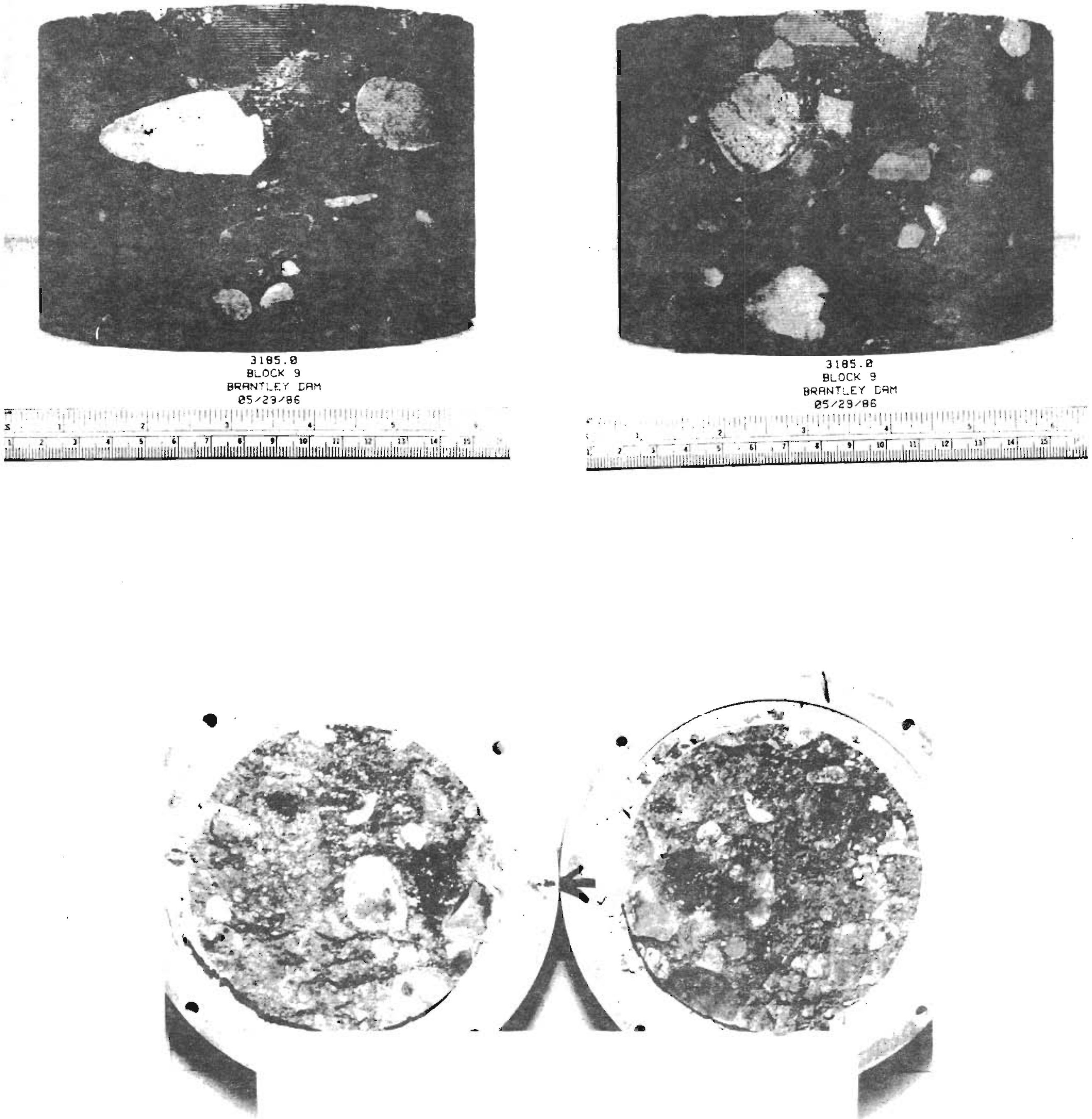


Figure B14. - Photographs of specimens before and after testing.

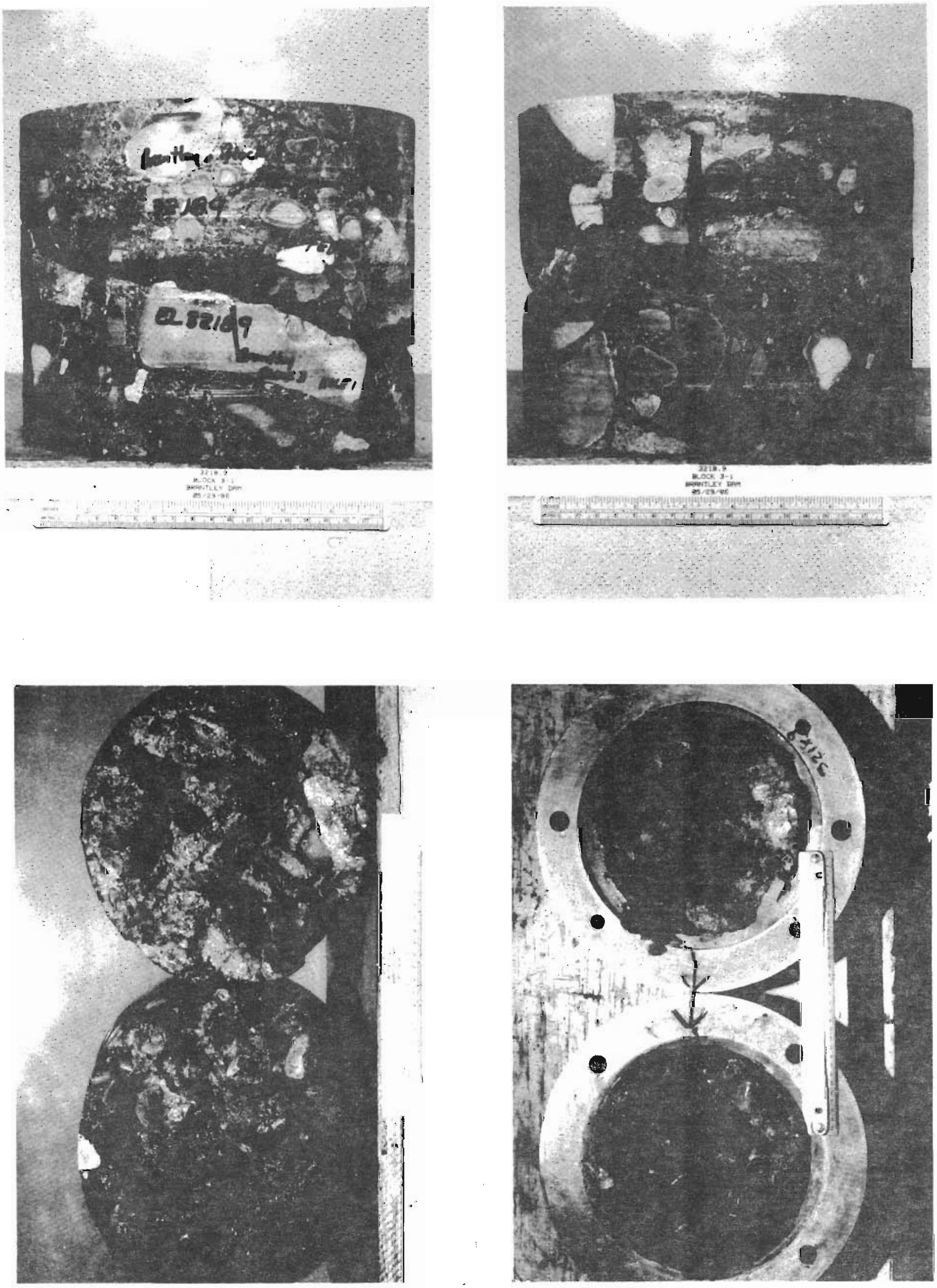


Figure B15. - Photographs of specimens before and after testing.

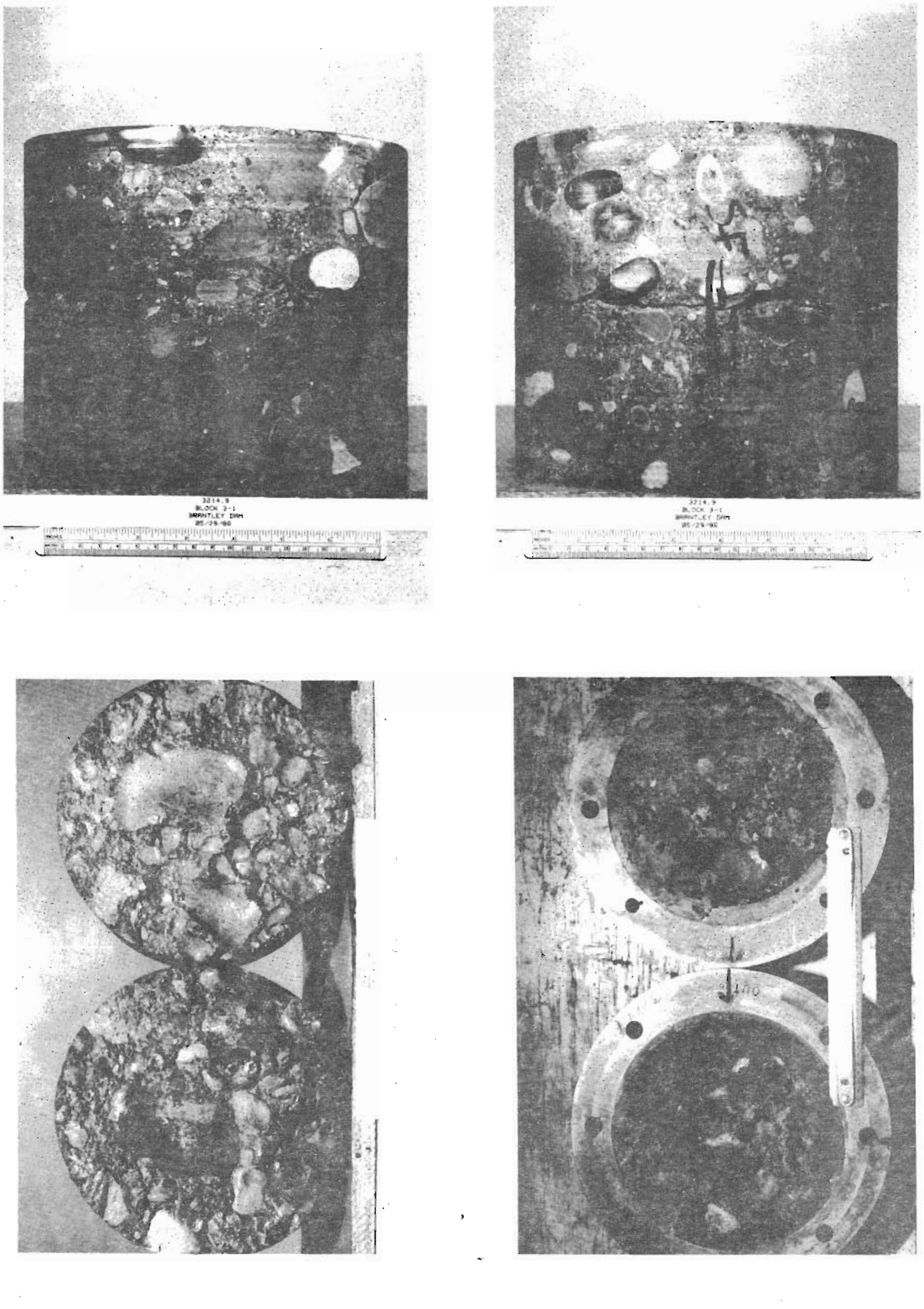


Figure B16. - Photographs of specimens before and after testing.

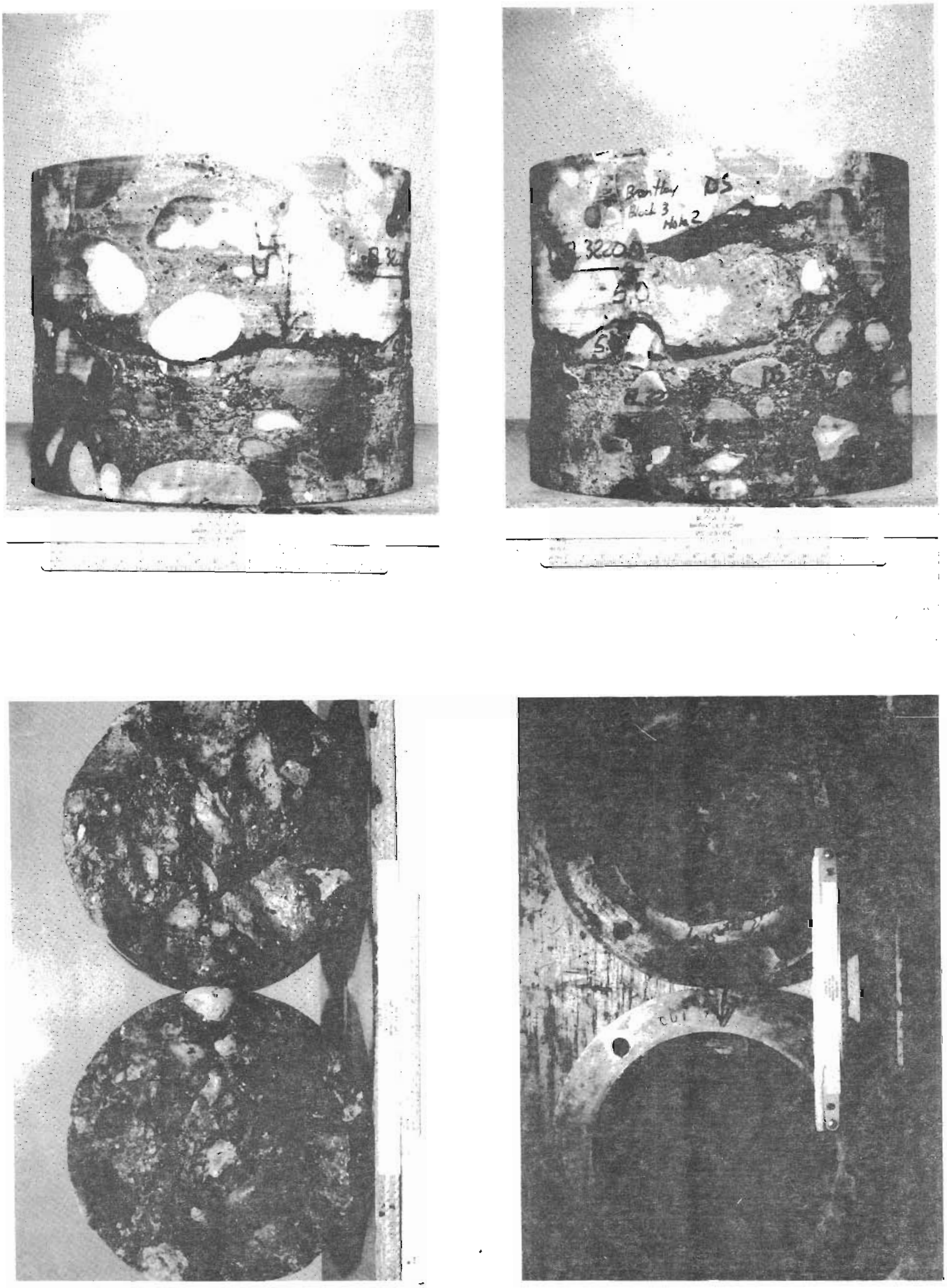


Figure B17. - Photographs of specimens before and after testing.

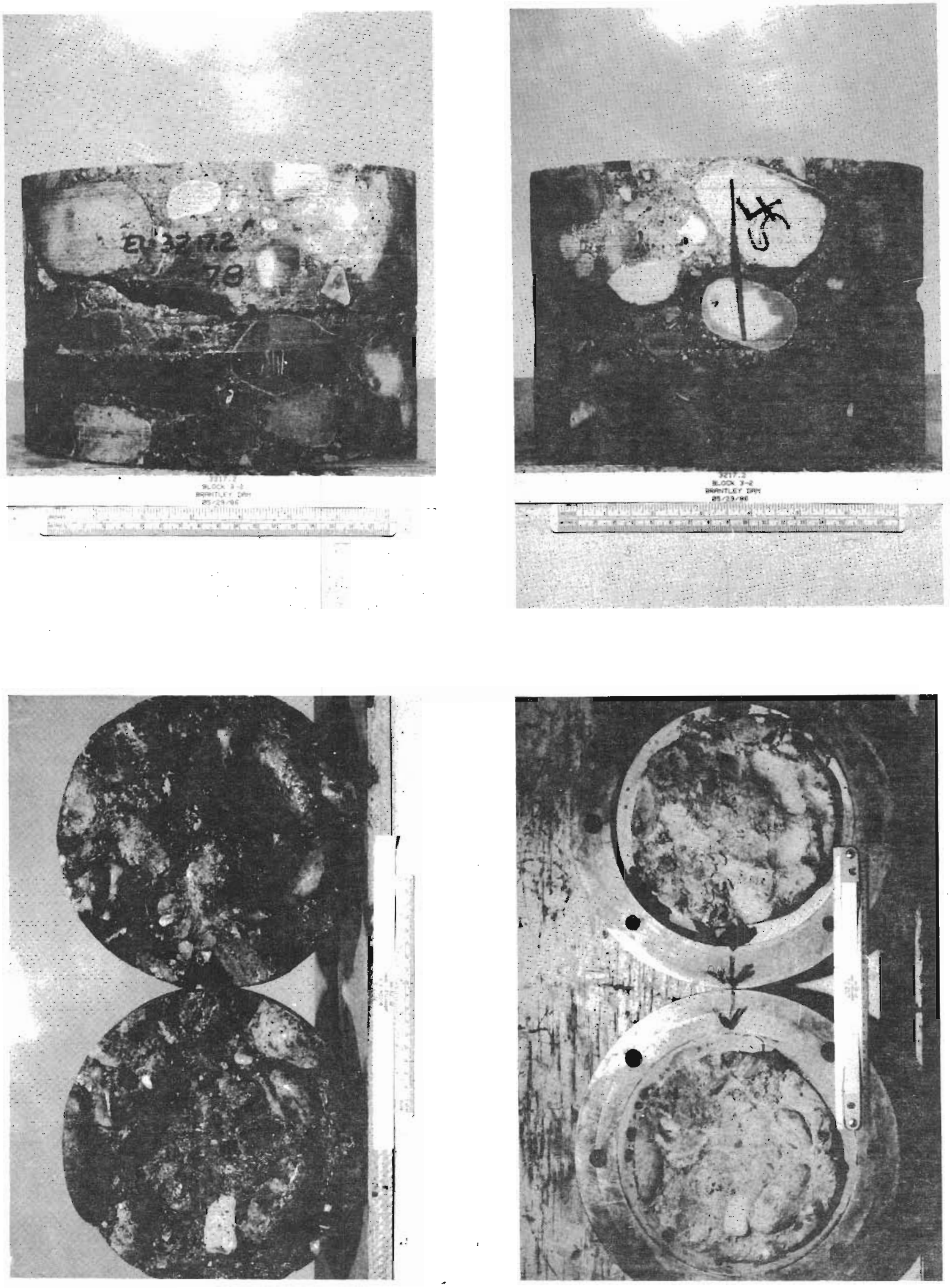


Figure B18. - Photographs of specimens before and after testing.

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-use 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-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.