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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE BARTLETT DAM SPILLWAY SALT RIVER PROJECT, ARIZONA

Report No. Hyd-576

HYDRAULICS BRANCH
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

OCTOBER 2, 1967

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

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by

G. L. Beichley

October 2, 1967

HYDRAULICS BRANCH
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Office of Chief Engineer . Denver, Colorado

ACKNOWLEDGEMENTS

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CONTENTS

ABSTRACT

Studies using a 1:100 scale model of Bartlett Dam spillway showed that erosion in the discharge channel was caused by impact of the spillway flow. Remedial work performed thus far has been beneficial, but additional paving protection and concrete fill should be installed along the left bank and at the base of the steep slope. These channel protection measures will prevent undermining the concrete-lined chute for all discharges up to the design flow of 175,000 cfs (4,952.5 cms). At flows of about 50,000 cfs (1,415 cms) or more, erosion is expected in the discharge channel remote from the concrete-lined chute. Excavation of protruding ridges to straighten the channel would do more harm than good. The studies proved that all 3 gates should be opened for best flow distribution at the flip bucket.

DESCRIPTORS-- *spillways/ dams/ jets/ slope protection/ *flood damages/ spillway gates/ hydraulic models/ hydraulic structures/ chutes/ pavements/ *erosion control/ *channel improvements/ flood protection/ erosion/ gate control
IDENTIFIERS-- Salt River Project, Ariz/ Arizona/ Bartlett Dam, Arizona

PURPOSE

The studies were conducted to determine corrective measures needed to prevent additional erosion damage in the discharge channel near the existing concrete-lined spillway chute.

RESULTS

1. The model confirmed that the erosion damage in the discharge channel was almost entirely due to the impact of the flow impinging on the badly fractured rock rather than to the churning of loose rock in the turbulent flow (Figure 9).

2. Repairs made after the 1965-66 floods appear to be well located for protection of the channel against further erosion, but the paving should be extended a little higher and farther downstream along the left bank (Figures 4, 9, and 11).

3. The deep erosion hole at the base of the steep slope should be filled with concrete (Figures 4, 7, and 11). This concrete fill should extend from the existing concrete on the upstream side of the hole to sound rock on the downstream side and should slope downward to the left in the direction of flow to flush loose rock from the channel.

4. At flows greater than about 50,000 cfs (1,415 cms) part of the jet will impinge in the downstream portion of the channel beyond the paved area (Figure 12); however, erosion damage will be sufficiently remote that the foundation of the spillway should not be endangered.

5. The spillway gates should be equally opened for best flow distribution at the flip bucket (Figure 8).

6. The two ridges partially blocking the downstream end of the channel should not be removed (Figure 13).

7. The upstream ridge and the existing weir in the left branch of the channel help form a shallow pool at the base of the paved slope for flows up to 50,000 cfs (1,415 cms) (Figure 14). This pool aids in absorbing some of the energy in the jet and in reducing erosion.

INTRODUCTION

Bartlett Dam is part of the Salt River Project near Phoenix, Arizona (Figure 1). The spillway in the right abutment is gate-controlled and discharges into a 170-foot-wide (51.82-meter-wide), concrete-lined chute. The chute is superelevated, curves to the left, and terminates in a flip bucket. The design discharge capacity of the spillway is 175,000 cfs (4,952.5 cms).

Originally, flow from the flip bucket fell in an excavated channel leading to the river channel. The drop from the end of the excavated channel to the riverbed is about 100 feet (30.48 meters). The rock in this area is composed of two types of granite. One is a coarse-grained granite severely weathered to irregular depths.

This weathered rock is weak and easily eroded, but the underlying rock is hard and sound. The other type of granite is fine-grained, competent, and resistant to erosion. Three dominant systems of joints affect both rock types--two near-vertical systems and one irregularly developed horizontal system.

Floods in 1942 and 1965-66 severely eroded the excavated channel. Prior to the 1965-66 flood, the channel was repaired by placing mass concrete in retaining walls and blocks in the badly eroded portion of the channel near the downstream end of the chute (Figure 2). The 1965-66 spillway flows, estimated at 28,500 cfs (806.55 cms) from near-maximum reservoir elevation, washed out or undermined these concrete slabs and blocks in several areas (Figure 3). Erosion of the rock was quite rapid where the concrete had overlain the weak, weathered granite. At the base of the steep portion of the eroded channel, about 100 feet (30.48 meters) downstream from the concrete chute, one hole was eroded in the weathered rock to a depth of about 15 feet (4.57 meters).

Remedial work in the channel after the 1956-66 flood consisted of repairing damaged concrete blocks and protecting rock surfaces with formed or pneumatically placed concrete anchored to the rock (Figures 4 and 5). The hydraulic model studies described in this report were performed to determine channel improvement or additional protection necessary to prevent further erosion near the spillway chute and to determine the combination of operating gates that will provide the best flow distribution.

THE MODEL

The 1:100 scale model of the spillway (Figure 6) included the approach channel, crest, control gates and piers, superelevated concrete-lined chute, and the discharge channel from the chute downstream to the natural stream channel. The spillway and discharge channel were of concrete construction; the piers were formed in wood and the control gates were made of sheet metal. Two portions of the right bank near the downstream end of the discharge channel were made removable in anticipation that additional excavation in this area might improve prototype operation.

The discharge channel topography was initially constructed of three parts sand to one part pozzolan, 3/4-inch (1.9 cm) thick on wire mesh. This produced a firm but erodible topography which helped in evaluating the type and location of the severest erosion to be expected.

THE INVESTIGATION

The model was operated at discharges up to 50,000 cfs (1,415 cms) to determine flow conditions that might have caused the erosion. At discharges of 10,000, 20,000, and 50,000 cfs (283, 566, and 1,415 cms) flow from the spillway impinged on the areas that had been badly damaged in the prototype channel (Figure 8). The severest damage appeared to have occurred where the impact forces of the jet had apparently loosened and eroded the rock at the weathered joints. Initial tests made with the erodible channel indicated that the erosion began at the left downstream corner of the concrete-lined chute and progressed downstream as the discharge increased (Figure 9). This test confirmed the belief that the major portion of the erosion was due to flow impact rather than to rocks churning in the turbulent flow.

Gate Operation

Various combinations of operating gates were tested (Figure 10) to determine the combination that would provide optimum flow distribution in the chute. These tests showed that closing the right gate reduced the flow impingement on the right bank along the edge of the paved area and increased the impingement along the left bank. With the left gate closed, the reverse was true. These flow conditions were more pronounced when either the left or right gate was operated singly. The tests showed that all three gates should be opened equally for best flow distribution from the chute.

Channel Protection

Even with all three gates equally opened, portions of the flow impinged on the left and right sides of the discharge channel beyond the limits of the paved area. These areas of impingement are subject to erosion during future spillway discharges (Figures 4, 5, and 8). Erosion on the right side will occur far enough downstream that it is not likely to endanger the structure or undermine the paved area (Figure 5). Erosion may occur adjacent to the left concrete wall of the spillway chute and farther downstream along the left bank (Figure 4). The paving should be extended to prevent this erosion (Figures 9 and 11).

Spillway discharges have eroded a 15-foot (4.57-meter)-deep hole at the base of the steep slope in the prototype discharge channel

(Figure 4). Further spillway operation possibly will increase the size of this hole and undermine the concrete paving on the steep slope. This hole should be filled with concrete extending from the existing concrete on the upstream side to the rock on the downstream side of the pool (Figures 7 and 11). Sloping this concrete fill downward from approximately elevation 1635 to elevation 1615 in the direction of flow along the existing channel (Figure 7) will flush loose rock downstream during spillway operation.

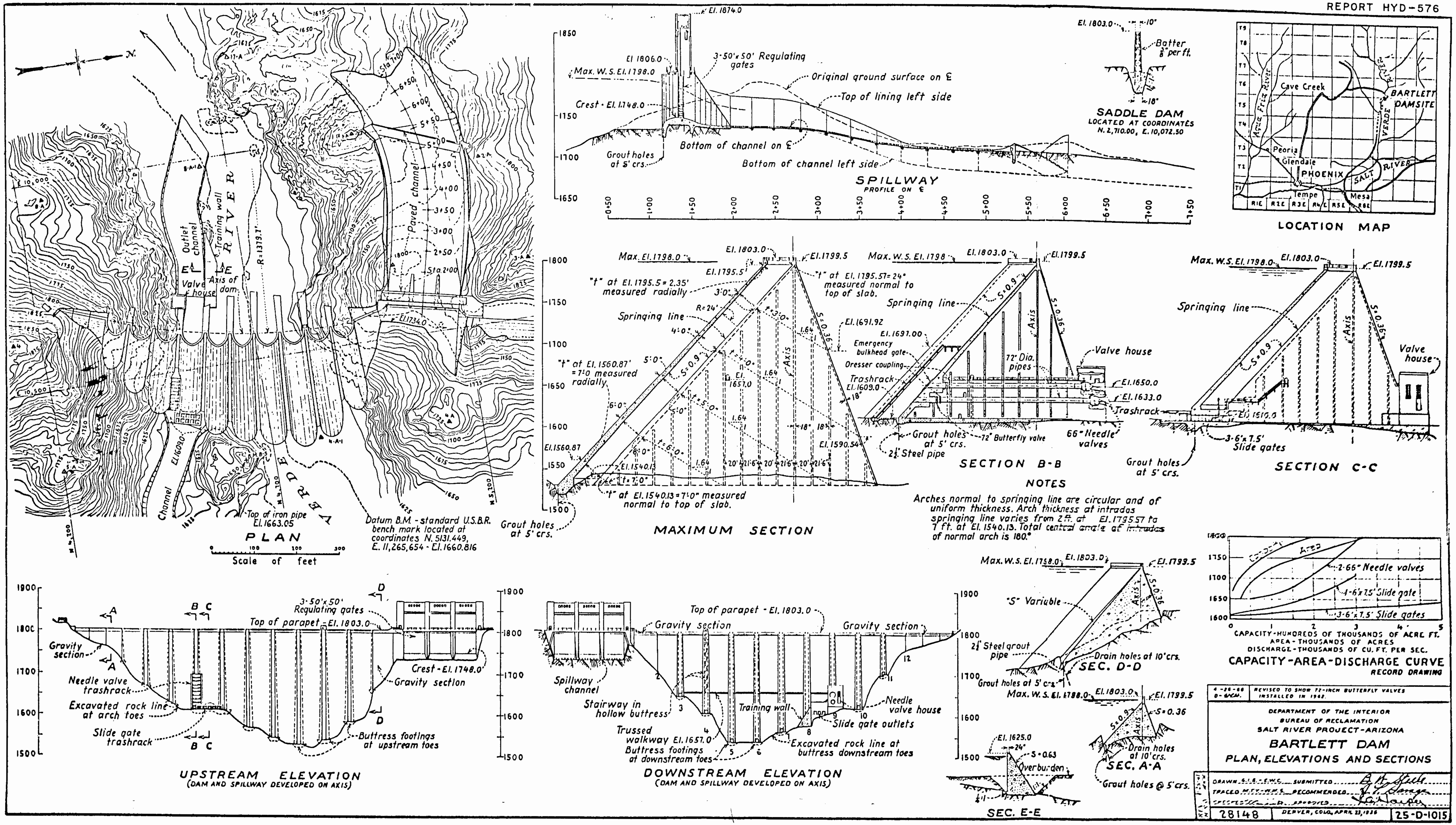
At flows of 100,000 (2,830) and 175,000 cfs (4,952.50 cms) (Figure 12) part of the jet impinged near the first ridge in the downstream portion of the discharge channel beyond the paved area. Discharges of these magnitudes will probably cause considerable erosion in the prototype channel remote from the spillway chute.

Channel Improvement

A high ridge of rock extends partly across the discharge channel about 100 feet (30.48 meters) downstream from the base of the steep slope; about 250 feet (76.20 meters) farther downstream, a second confining ridge protrudes into the channel. It was first thought that these ridges might be trapping loose rock in the channel and causing a "ball mill" type of erosion damage.

The two ridges were constructed in the model so that they could easily be removed and the channel could be tested with and without the ridges in place (Figure 13). Tests were run at discharges of 20,000 cfs (566 cms) and 50,000 cfs (1,415 cms) to determine the effect of removing either or both ridges. The tests showed that any loose rock that might fall into the channel will flush from the area, with or without the ridges in place.

Actually, the upstream ridge and the existing weir at approximately elevation 1640 in the left branch of the discharge channel (Figure 14) maintain a pool for flows up to 50,000 cfs (1,415 cms). This pool appeared to absorb part of the energy of the falling jet which would reduce the erosion damage (Figure 14); and, therefore should not be removed.


PLAN
Scale of feet
Datum B.M. - standard U.S.B.R. bench mark located at coordinates N. 5131.449, E. 11,265,654 - El. 1660.816
Top of iron pipe El. 1663.05
VERDE RIVER
Outlet channel
Training wall
Valve house
Axis of dam
R=1319.1'
Paved channel
Channel
SPILLWAY
PROFILE ON ℄
El. 1874.0
El 1806.0
3-50'x50' Regulating gates
Max. W.S. El. 1798.0
Crest - El. 1748.0
Original ground surface on ℄
Top of lining left side
Bottom of channel on ℄
Bottom of channel left side
Grout holes at 5' crs.
SADDLE DAM
LOCATED AT COORDINATES N. 2,710.00, E. 10,072.50
El. 1803.0
Batter 1/8" per ft.
LOCATION MAP
Cave Creek
BARTLETT DAMSITE
Peoria
Glendale
PHOENIX
SALT RIVER
Tempe
Mesa
MAXIMUM SECTION
Max. El. 1798.0
El. 1803.0
El. 1799.5
Springing line
"t" at El. 1795.5 = 2.35' measured radially
"t" at El. 1560.87' = 7'0 measured radially
"t" at El. 1540.13 = 7'0" measured normal to top of slab.
Grout holes at 5' crs.
SECTION B-B
Max. W.S. El. 1798
El. 1691.92
El. 1697.00
Emergency bulkhead gate
Dresser coupling
Trashrack
72" Dia. pipes
Valve house
El. 1650.0
El. 1633.0
Grout holes at 5' crs.
72" Butterfly valve
66" Needle valves
2 1/2" Steel pipe
SECTION C-C
3-6'x7.5' Slide gates
NOTES
Arches normal to springing line are circular and of uniform thickness. Arch thickness at intrados springing line varies from 2 ft. at El. 1795.57 to 7 ft. at El. 1540.13. Total central angle at intrados of normal arch is 180°.
CAPACITY-AREA-DISCHARGE CURVE
RECORD DRAWING
Capacity
Area
2-66" Needle valves
1-6'x7.5' Slide gate
3-6'x7.5' Slide gates
CAPACITY-HUNDREDS OF THOUSANDS OF ACRE FT.
AREA-THOUSANDS OF ACRES
DISCHARGE-THOUSANDS OF CU. FT. PER SEC.
SEC. D-D
"S" Variable
2 1/2" Steel grout pipe
Drain holes at 10' crs.
Grout holes at 5' crs.
SEC. A-A
Drain holes at 10' crs.
Grout holes @ 5' crs.
SEC. E-E
El. 1625.0
Overburden
UPSTREAM ELEVATION
(DAM AND SPILLWAY DEVELOPED ON AXIS)
Gravity section
Needle valve trashrack
Excavated rock line at arch toes
Slide gate trashrack
Top of parapet - El. 1803.0
Crest - El. 1748.0
Buttress footings at upstream toes
DOWNSTREAM ELEVATION
(DAM AND SPILLWAY DEVELOPED ON AXIS)
Top of parapet - El. 1803.0
Spillway channel
Stairway in hollow buttress
Trussed walkway El. 1657.0
Buttress footings at downstream toes
Training wall
Needle valve house
Slide gate outlets
Excavated rock line at buttress downstream toes
REVISED TO SHOW 72-INCH BUTTERFLY VALVES INSTALLED IN 1942.
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT-ARIZONA
BARTLETT DAM
PLAN, ELEVATIONS AND SECTIONS
28148
DENVER, COLO., APRIL 23, 1936
25-D-1015

BARTLETT DAM SPILLWAY
DISCHARGE CHANNEL EROSION AND REPAIRS
PRIOR TO THE 1965-66 FLOOD

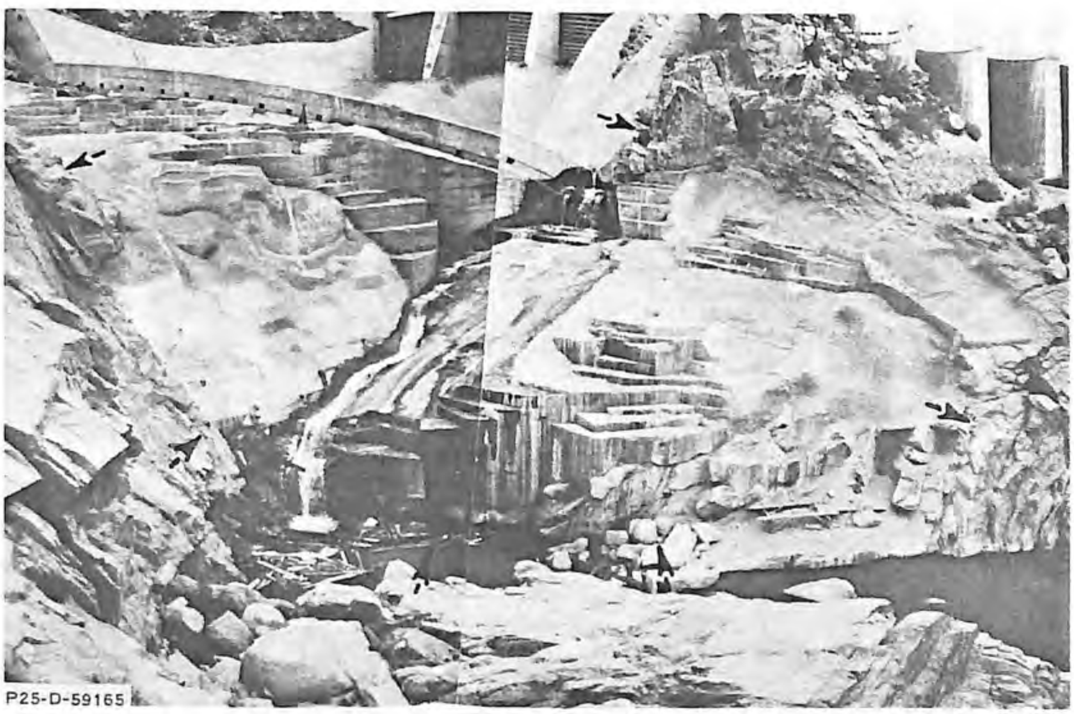
A. Note the undermining of previous channel repairs.

B. View looking towards right bank.

C. Note both vertical and horizontal joints in the weathered rock.

BARTLETT DAM SPILLWAY
DISCHARGE CHANNEL EROSION
Caused by 1965-66 Flood

P25-D-59164



P25-D-59165

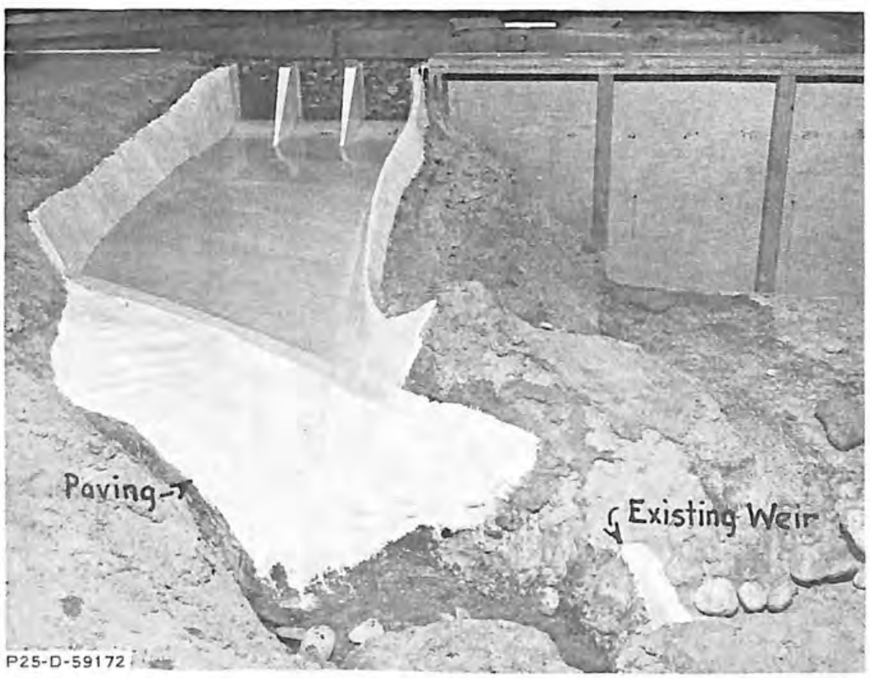
Water stands in a 15-foot (4.57-meter)-deep hole eroded at the base of the steep slope. Areas subject to future erosion are indicated by the arrows.

BARTLETT DAM SPILLWAY
Repairs to Discharge Channel Following
the 1965-66 Flood

Areas subject to future erosion are indicated by the arrows.

BARTLETT DAM SPILLWAY
Repairs to the Discharge Channel Following
the 1965-66 Flood

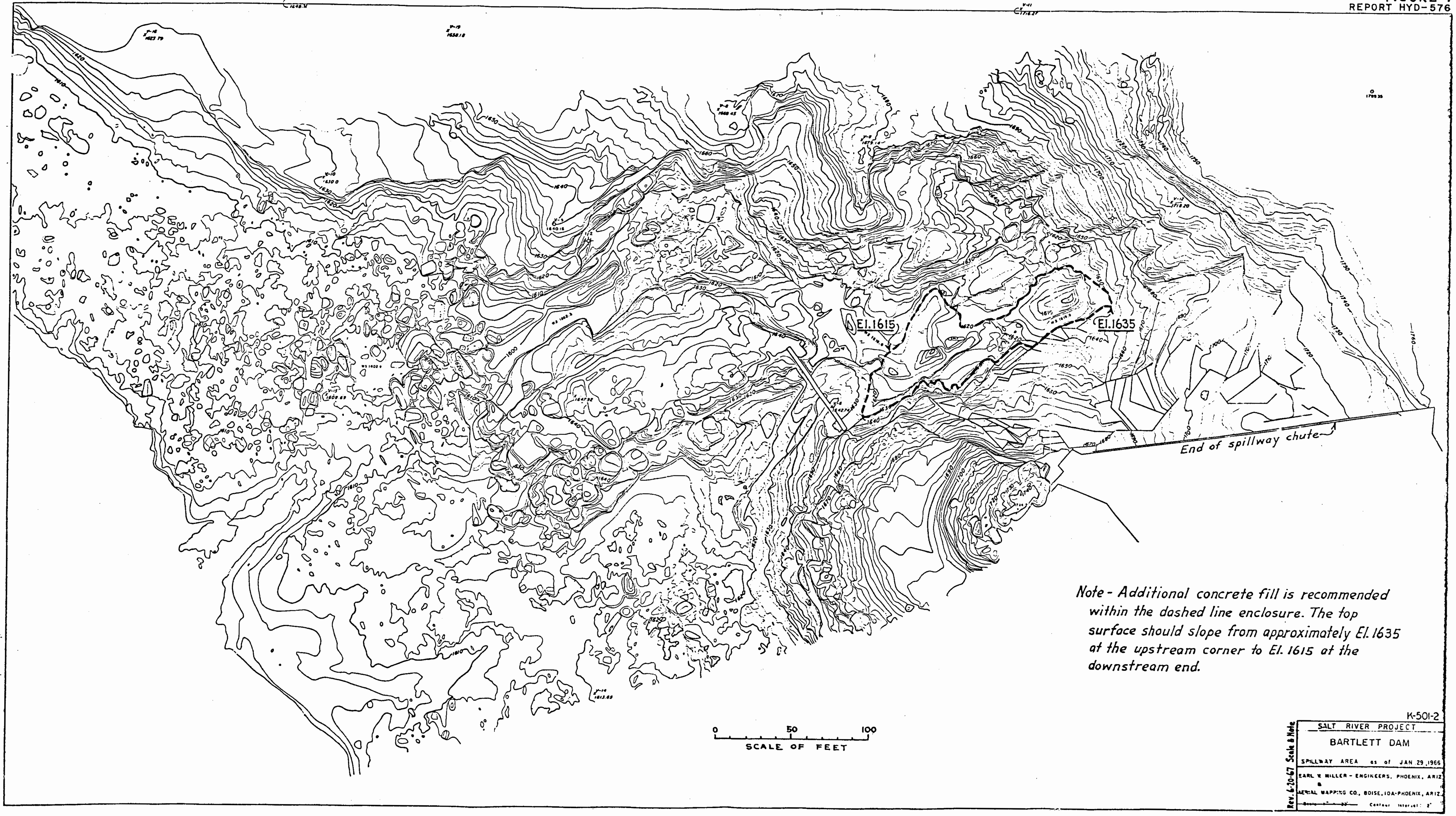

P25-D-59171



P25-D-59172

The extent of concrete paving placed in discharge channel following the 1965-66 flood is painted white.

BARTLETT DAM SPILLWAY
The 1:100 scale model


El. 1615
El. 1635
End of spillway chute
Note - Additional concrete fill is recommended within the dashed line enclosure. The top surface should slope from approximately El. 1635 at the upstream corner to El. 1615 at the downstream end.
0 50 100
SCALE OF FEET
K-501-2
SALT RIVER PROJECT
BARTLETT DAM
SPILLWAY AREA as of JAN. 29, 1966
EARL V. MILLER - ENGINEERS, PHOENIX, ARIZ.
&
AERIAL MAPPING CO., BOISE, IDA-PHOENIX, ARIZ.
Contour interval: 2'
Rev. 6-20-67 Scale & Note

A. 10,000 cfs (283 cms)

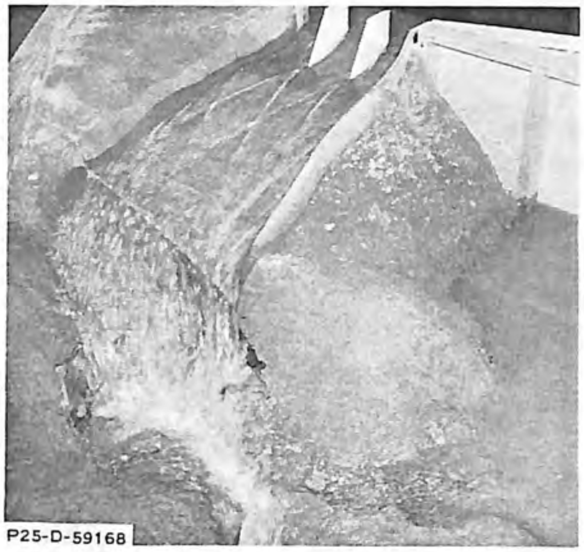
B. 20,000 cfs (566 cms)

C. 50,000 cfs (1,415 cms)

All flow through three gates equally open at Reservoir elevation 1803

The areas of flow impingement on the left and right banks beyond the white paved area are indicated by the arrows.

BARTLETT DAM SPILLWAY
Flow in Discharge Channel
1:100 scale model



A. 30,000 cfs (849 cms)

B. 175,000 cfs (4,952.5 cms)

C. Erosion resulting from flows of 30,000 and 175,000 cfs (849 and 4,952.5 cms)

Areas requiring additional concrete protection are indicated by the arrows.

BARTLETT DAM SPILLWAY
Erosion Test
1:100 scale model

A. Left gate closed

B. Right gate closed

14,000 cfs (396.2 cms) at reservoir elevation 1803

C. Left and center gates closed

D. Right and center gates closed

7,000 cfs (198.1 cms) at reservoir elevation 1803

The areas of flow impingment on the left and right banks beyond the white paved area are are indicated by the arrows.

BARTLETT DAM SPILLWAY
Flow with unsymmetrical gate operation
1:100 scale model

A. Recommended additional concrete paving is indicated by the arrows

B. Recommended additional concrete fill is indicated by the arrow

BARTLETT DAM SPILLWAY
Recommended Channel Protection
1:100 scale model

A. 100,000 cfs (2,830 cms)

B. 175,000 cfs (4,952.5 cms)

BARTLETT DAM SPILLWAY
Flow Conditions with Channel Protection

1:100 scale model

A. First and second ridges are removed to the elevation shown. Ridge locations are indicated by the arrows.

B. First ridge only is removed.

BARTLETT DAM SPILLWAY
Channel Alterations Tested
1:100 scale model

A. Recommended concrete fill

B. Concrete fill with first ridge removed is not recommended

20,000 cfs (566 cms) at reservoir elevation 1803

C. Same as A

D. Same as B

50,000 cfs (1,415 cms) at reservoir elevation 1803

BARTLETT DAM SPILLWAY
Flow conditions with and without First Ridge

1:100 scale model

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
	MASS	
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
	FORCE/AREA	
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
	MASS/VOLUME (DENSITY)	
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
	MASS/CAPACITY	
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
	BENDING MOMENT OR TORQUE	
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
	VELOCITY	
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
	ACCELERATION*	
Feet per second^2	0.3048*	Meters per second^2
	FLOW	
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
	FORCE*	
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
	WORK AND ENERGY*	
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
	POWER	
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
	HEAT TRANSFER	
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
	WATER VAPOR TRANSMISSION	
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 835-159