UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 133

- - -

HYDRAULIC MODEL STUDIES FOR NEEDLE AND TUBE VALVES FOR FRIANT DAM AND CALIBRATION OF NEEDLE-VALVE AND SLUICE OUTLETS AT BARTLETT DAM

By

F. C. LOWE

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Denver, Colorado
July 15, 1943

HYD 133

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FOREWORD

In 1937 the Salt River Water Users' Association at Phoenix, Arizona, requested provision for measurement of discharge from the outlet works at Bartlett Dam in the Verde River. These outlets, consisting of two 66-inch needle valves and three 6- by 7-foot 6-inch slide gates, were calibrated by obtaining discharge data from hydraulic models. The results, included in this report, were transferred to the prototype structure according to the laws of hydraulic similitude and the Association was furnished tables and diagrams showing the relation between head, discharge, and gate or valve opening.

During the calibration of the model of one of the 66-inch needle valves, pressure gradients through the passages of the valve were obtained, which furnished another link in the study of the relation between the cavitating pressures and the destruction of metal in certain regions of prototype needle valves which had required excessive maintenance. Pilot tests on a 5-inch needle valve under heads up to 500 feet had demonstrated that the cavitating pressures and the erosion or pitting could be eliminated by changing the profile of the outlet passages. However, in changing the profile of the passage, the discharge capacity had been reduced. Furthermore, the pressure-discharge data were not sufficiently complete to design a specific valve.

With the detailed pressure and discharge measurements on the model of the Bartlett valve as a basis of comparison, a series of 15 tests was made using the information from the 5-inch valve. A design for the needle valves at Friant Dam was thus obtained in which the pressures would no longer cause cavitation and pitting and in which the discharge capacities were comparable to the original design of the needle valves. Those tests are described in detail in this report.

Concurrently a modification of the needle valve, known as the tube valve, was studied to obtain detailed pressure and discharge data.

The designs of the various valves tested were prepared in the mechanical section of the Bureau by B. H. Staats, engineer, under the supervision of P. A. Kinzie and W. C. Beatty, senior engineers. The testing of the models was performed by the personnel of the hydraulic laboratory.

All laboratories of the Bureau of Reclamation in Denver, Colorado, are in the Materials, Testing, and Control Division. All design work is under the supervision of J. L. Savage, Chief Designing Engineer, and all work of the Bureau is directed by S. O. Harper, Chief Engineer. The activities of the Bureau are directed by John C. Page, Commissioner.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
July 15, 1943

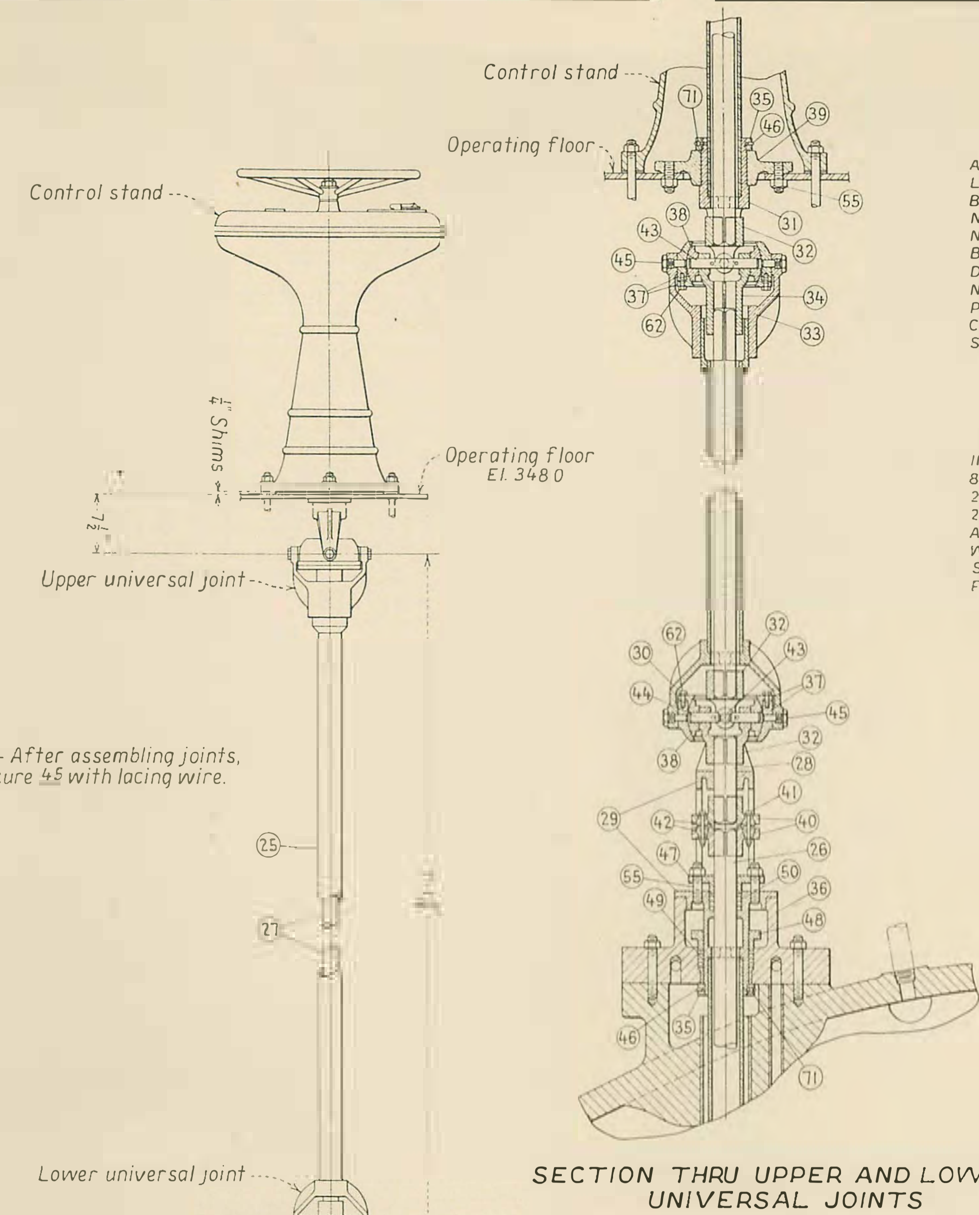
Laboratory Report No. 133.
Hydraulic Laboratory
Compiled by: F. C. Lowe

Reviewed by: J. E. Warnock.

Subject: Hydraulic model studieson needle and tube valves for Friant Dam and calibration of needle valve and sluice outlets at Bartlett Dam.

CHAPTER I - INTRODUCTION

1. Introduction. Three outlet works were constructed at Friant Dam: (1) the river outlet, consisting of four 110-inch diameter conduits; (2) the Friant-Kern Canal outlet, also consisting of four 110-inch diameter conduits; and (3) the Friant-Madera Canal outlet consisting of two 91-inch diameter conduits. Discharge through these conduits will be regulated by valves placed at their exits. Two 110- by 105-inch needle valves and two 110- by 102-inch tube valves will be used at the river outlet; two 110- by 105-inch needle valves and two 110- by 102-inch tube valves at the Friant-Kern Canal outlet; and two 91- by 87-inch needle valves at the Friant-Madera Canal outlet. The needle valves will be of the interior differential type, hydraulically operated (figure 1), while the tube valves will be the internal tube type, mechanically operated (figure 2). The needle valves will be used for regulation of small discharges because the jets issuing from those valves are smooth at any opening, while the jets from the tube valves will be unstable at openings less than 30 percent and will form considerable spray. At openings greater than 30 percent the jets of the needle and tube valves will be nearly identical. It is anticipated that under a maximum head of 248 feet a discharge of 5,900 second-feet can be obtained through each of the needle valves at the river outlet and a discharge of 5,200 second-feet through each of the tube valves. These estimates were obtained from a coefficient of discharge of 0.59 for the needle valves and 0.52 for the tube valves which was based upon the area of the conduit and the energy head measured one diameter upstream from the valve.



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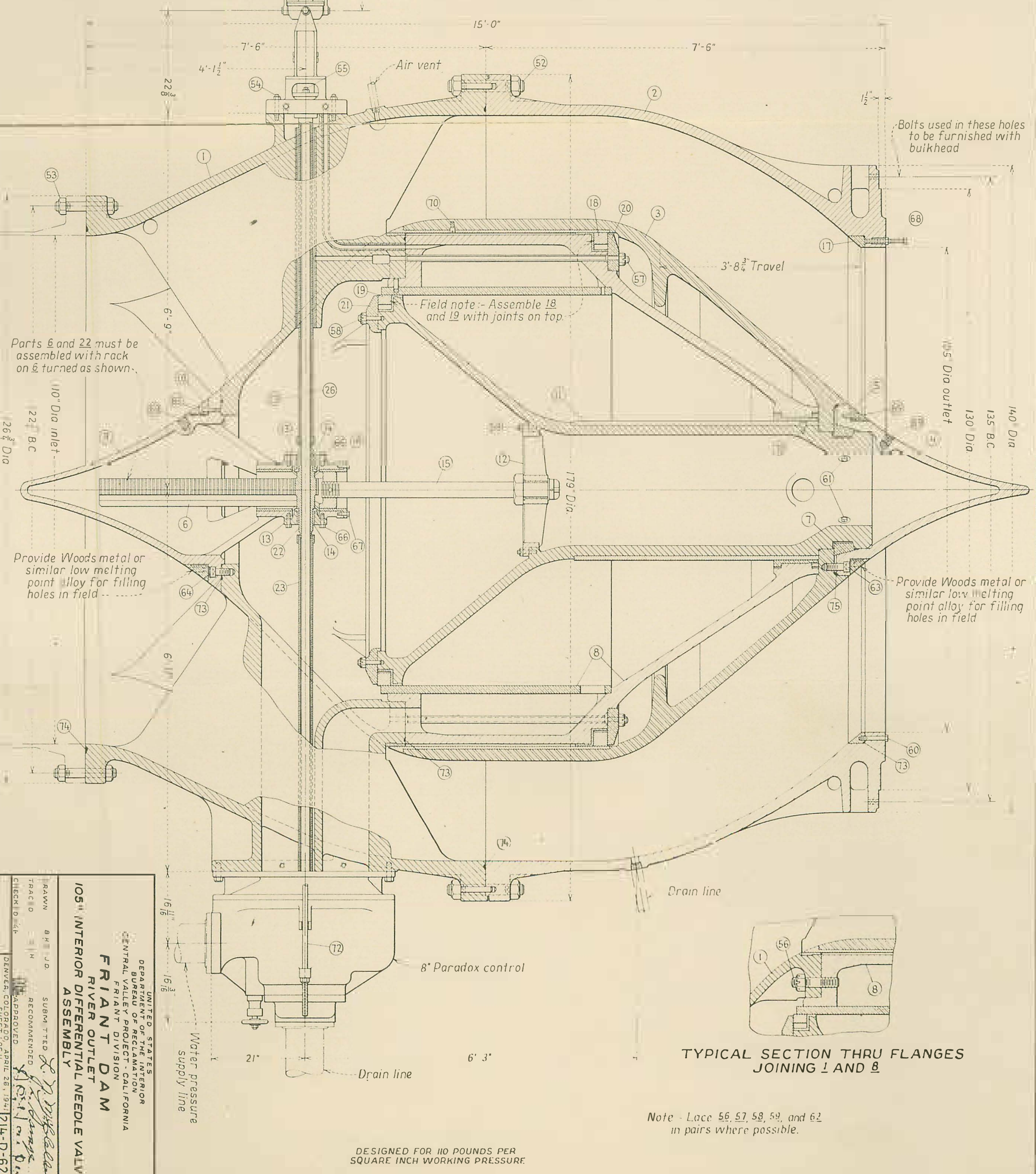


TYPICAL SECTION THRU FLANGES JOINING 1 AND 8

Note:- Lace 56, 57, 58, 59, and 62 in pairs where possible.

DESIGNED FOR 110 POUNDS PER SQUARE INCH WORKING PRESSURE

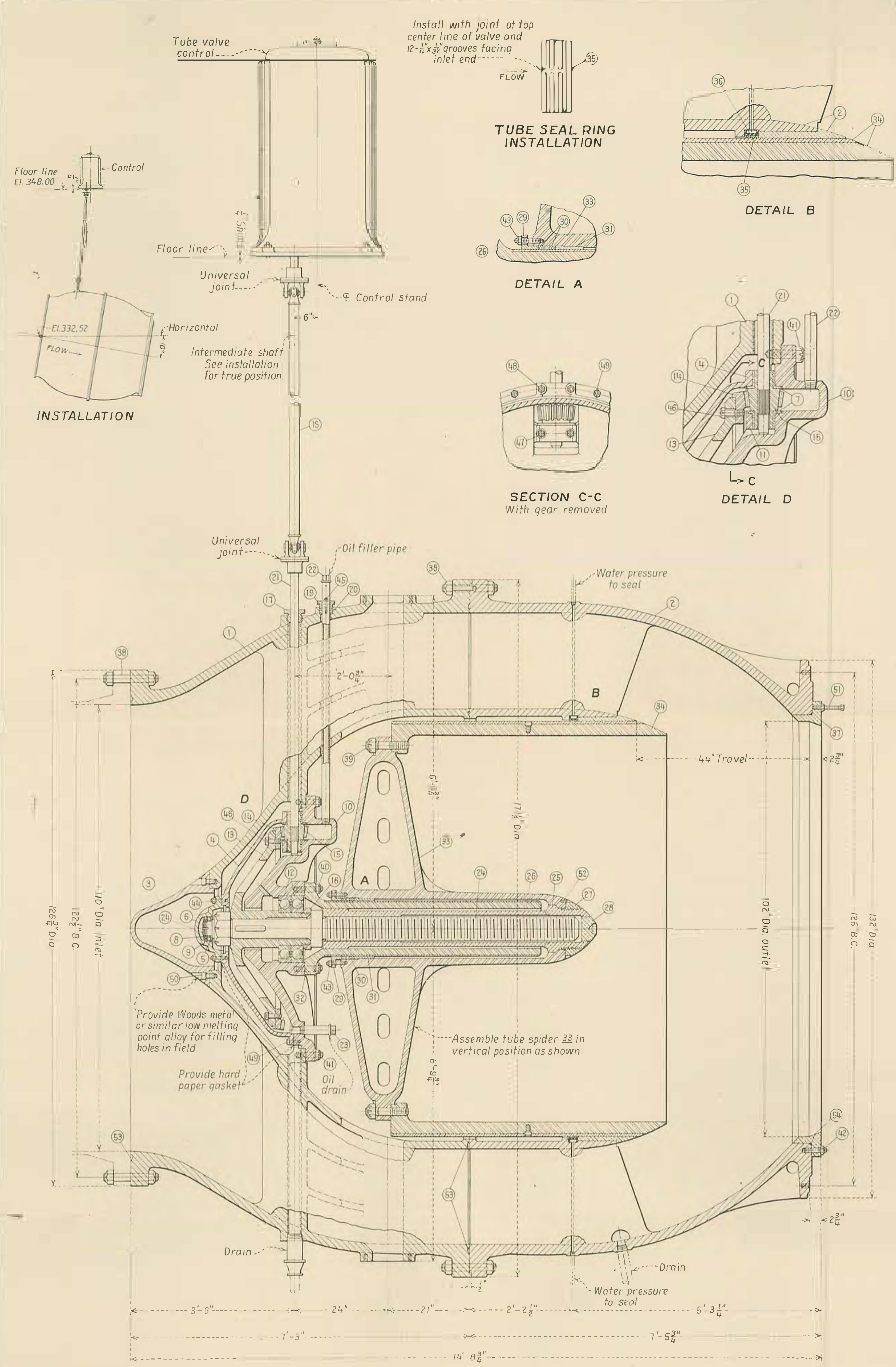
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
FRIANT DIVISION

FRIANT DAM
RIVER OUTLET
105" INTERIOR DIFFERENTIAL NEEDLE VALVE ASSEMBLY

DRAWN B.H.S. J.D. SUBMITTED L. N. McClellan
TRACED [illegible] RECOMMENDED J. L. Savage
CHECKED [illegible] APPROVED [illegible]

DENVER, COLORADO, APRIL 26, 1941
SHEET 1 OF 11

214-D-6265



DESIGNED FOR 110 POUNDS PER SQUARE INCH WORKING PRESSURE

NOTE

Provide brass lacing wire for parts 39, 40, 41, 46, 47, 48 and 49. Lace in pairs where possible.

REFERENCE DRAWINGS

102" REGULATING TUBE VALVE CONTROL-ASSEMBLY	214-D-6296
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UNITED STATES
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CENTRAL VALLEY PROJECT - CALIFORNIA
FRIANT DIVISION

FRIANT DAM
RIVER OUTLET
102" REGULATING TUBE VALVE ASSEMBLY

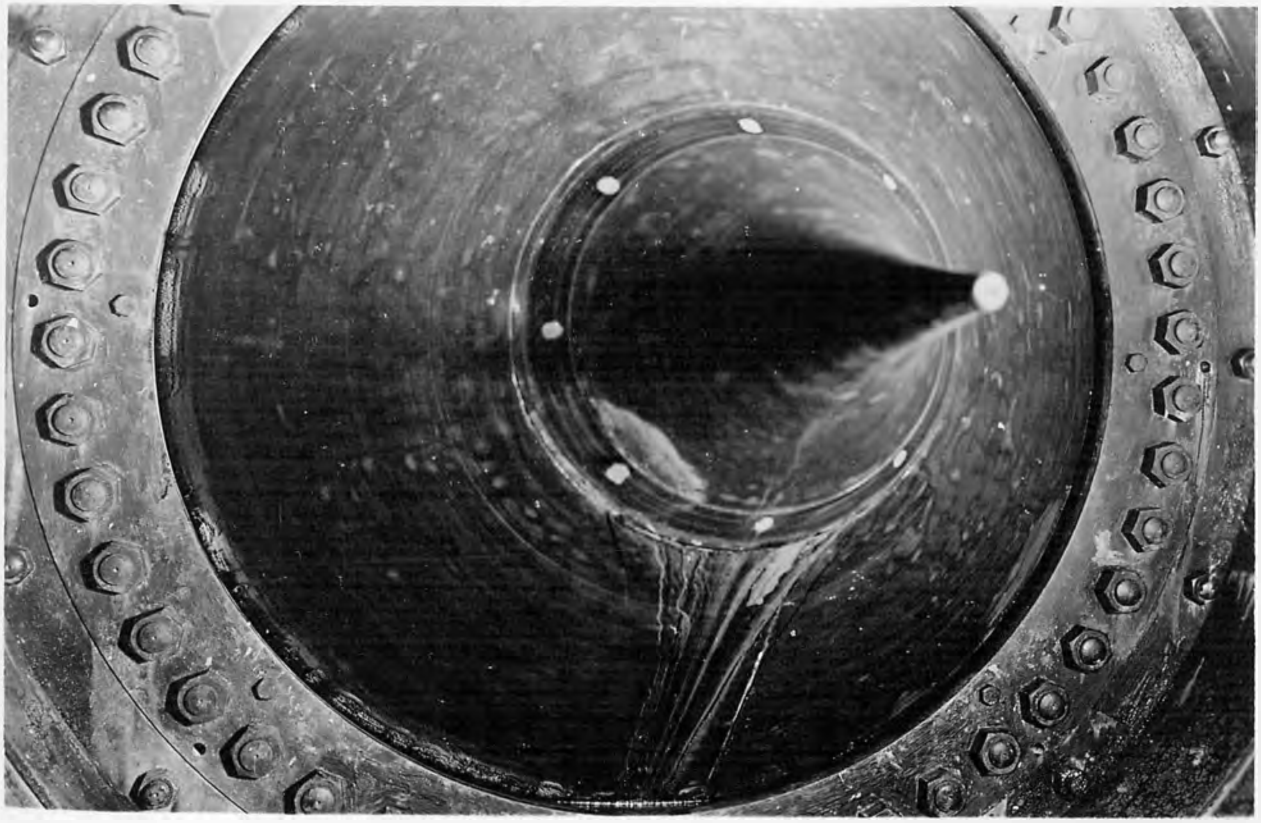
DRAWN B.H.S.-J.D. SUBMITTED
TRACED J.E.V. RECOMMENDED
CHECKED [illegible] APPROVED
DENVER, COLORADO, [illegible] 194[illegible] SHEET 1 OF 11
214-D-6284

FIGURE 2

The outlet section of the needle valves for Friant Dam will be different from that of many needle valves used in previous installations. The Friant needle valve will have a 39-degree needle and a 40-degree sharp-edged nozzle, while the previous needle valves, such as those at Bartlett Dam, had a 42-degree needle and a 36-degree 22-minute round-edged nozzle. This new design, developed with the aid of hydraulic model studies, was necessary because valves in the field were being damaged by pitting due to cavitation.

In his memorandum, "Report on inspection trip to study operation of outlet works, Alcova Dam, Kendrick Project, Wyoming," dated November 16, 1938, Associate Engineer C. W. Thomas included, as figures 3, 4, and 5 of his report, photographs of one of the needle valves in the Alcova outlet, showing the extent of pitting from cavitation on that valve (figure 3). Photographs of damage by cavitation were also included in the report "Tests to determine operating characteristics of tunnel-plug outlet works at Boulder Dam, Boulder Canyon Project," by the Board of Engineers, dated February 3, 1939. Later, field reports were received from several projects describing the performance of needle valves designed by the Bureau of Reclamation. Concerning cavitation, these reports were similar. When the valves were operated from 5 to 30 percent open, the effects of cavitation were severe, but when operated 100 percent open, the effects of cavitation were negligible. Pitting occurred on an annular section of the needle six to eight inches wide, located immediately downstream from the seat. Some pitting occurred on the outlet section of the nozzle.

Causes of this cavitation were studied originally on a 5-inch model of an Alcova Dam needle valve designed so that the outlet section could be revised easily. This model was tested in the laboratory under heads up to 70 feet and at Boulder Dam under heads as large as 500 feet. The tests are described in detail in the report, "Hydraulic Model Studies for the Design of Valves for Outlet Works," dated August 1941, by N. G. Noonan, H. M. Martin, and D. J. Hebert, associate engineers. Cavitation occurred in the original design, and pitting of the valve resulted. Since cavitation occurred in regions of extreme negative pressure, three principles of design were recommended to insure positive pressures throughout



General View

Close-up of Pitted Area
84-INCH CASPER ALCOVA VALVE

the valve passage:

"(1) The angle between the needle and nozzle must not be divergent in the direction of the flow. If the needle and the nozzle profiles are parallel, the pressures are maintained. However, a convergence from one to three degrees will give an increased factor of safety.

(2) The valve nozzle should have no point of inflection and should have a sharp edge. This keeps the minimum section at the outlet edge of the valve nozzle, and allows free access of air to the jet.

(3) The sealing point of the needle must be on the cone portion; that is, the base diameter of the cone must be slightly larger than the outlet diameter of the nozzle."

The needle valves for Friant Dam were not designed directly from the results of those recommendations because the coefficient of discharge was lowered by the changes. Therefore, a series of 15 tests was made to study more completely the pressure and discharge characteristics of needle valves to obtain through a step-by-step approach the desirable design.

The initial tests of this series were made on a 1:8 model of a Bartlett Dam 66-inch needle valve which was the same design as those being damaged in the field. These initial tests served two purposes; first, to complete an existing assignment involving the calibration of the Bartlett Dam needle valve and slide-gate outlets and secondly, to provide pressure-discharge measurements as a basis for subsequent tests on the Friant needle valves.

Since needle valves were expensive, due to the intricacy of the operating mechanism, tube valves were introduced. The tube valve differs from the needle valve in that a cylindrical tube replaces the needle, resulting in an appreciable saving of material. The performance of this valve design was also studied in the tests on a 5-inch model at Boulder Dam where it was found that the jet was unstable at small openings. Additional tests were necessary to find the range of regulation giving a stable jet, to make sure that no cavitation occurred and to determine the coefficient of discharge.

2. Summary of tests. The needle valve and the slide-gate outlets at

Bartlett Dam were first studied. A 1:8 model of the 66-inch needle valves, a 1:15 model of the three slide-gate outlets, and a 1:10 model of a single slide gate were calibrated to furnish discharge tables and diagrams for use in the field. Pressure gradients were also obtained on the needle-valve model to serve as initial tests on the Friant Dam needle-valve studies.

Subatmospheric pressures were observed in the 1:8 needle-valve model at the same location and for the same openings that pitting by cavitation was occurring in similar prototype valves. This suggested that if a model were designed with positive pressures, it would be certain that no cavitation would occur in the prototype. Therefore, the 1:8 Bartlett model was revised according to recommendations obtained from previous tests on the 5-inch needle valve as described in section 1. The angle between the needle and the nozzle converged 3 degrees, and the nozzle exit had a sharp edge. Positive pressures were obtained, but the discharge was reduced approximately 15 percent.

Since the outlet diameter and the profile were variables in subsequent tests, the coefficient of discharge based on the outlet diameter could no longer be used as a basis of comparison. It was decided to base the discharge coefficient of needle valves, and other valves, upon the area of the intake conduit and upon the energy head measured one diameter upstream from the valve. The 1:8 Bartlett model had an expanding entrance section not suitable for evaluation of the discharge coefficient. Losses in this expanding section were also questioned. Therefore, the early tests were repeated with a constant diameter conduit. The coefficient of the original Bartlett valve, 0.51, was favorable, while the coefficient of the revised valve, 0.42, was too low. Twelve additional tests were made on this revised valve to increase the coefficient as much as possible but still maintain positive pressures.

From these tests a valve having a coefficient of 0.48 was selected as a basis for the Friant design. This valve was not similar to the proposed Friant design because the intake diameter, in prototype, was 121-1/2 inches instead of 110 inches. Therefore, a model of the proposed Friant valve was constructed to a scale of 1:18.33. Pressures on this 1:18.33 model were, for all practical purposes, the same as those on the selected valve, but the discharge coefficient, based on 110 inches instead of 121-1/2 inches, was 0.59. However, the actual discharge through the two valves was proportionately the same, demonstrating that discharge through the valve was independent of the intake diameter within reasonable limitations. It became apparent that a coefficient of discharge based upon the intake diameter could be misleading unless more information about the valves were available. To avoid this, the nominal size of the valves is described by including both inlet and exit diameters, and it is believed that different types of valves may be compared more fairly if their intake and exit diameters are the same.

To expedite the testing program on tube valves, a preliminary test was made by revising a model tube valve which had been previously tested in studies of the Shasta Dam outlets. Although the valves were similar, the results of the Shasta tests could not be applied to the Friant studies, for the Shasta valves are to be placed in the conduit near the entrance, while the Friant valves are to be placed at the end of the outlet so as to discharge freely into the atmosphere. Thus different problems had to be considered for each type of installation.

This preliminary test demonstrated that a tube valve may not be suitable for regulation at small openings because of a disintegration of the jet and accompanying spray. This design was also unsatisfactory because negative pressures occurred on the lip of the tube when the valve was less than 50 percent open.

After the preliminary test the new model was built to a design which was based on knowledge gained from the preliminary test. The principal dimensions of this new model were made similar to those of the Friant needle valves which had been previously tested. This new design proved to be adequate and was considered as a final design for the Friant Dam outlets. As was also demonstrated in the preliminary test, satisfactory regulation at small openings, less than 30 percent, was not attained. However, all negative pressures were eliminated and the coefficient of discharge was 0.51.

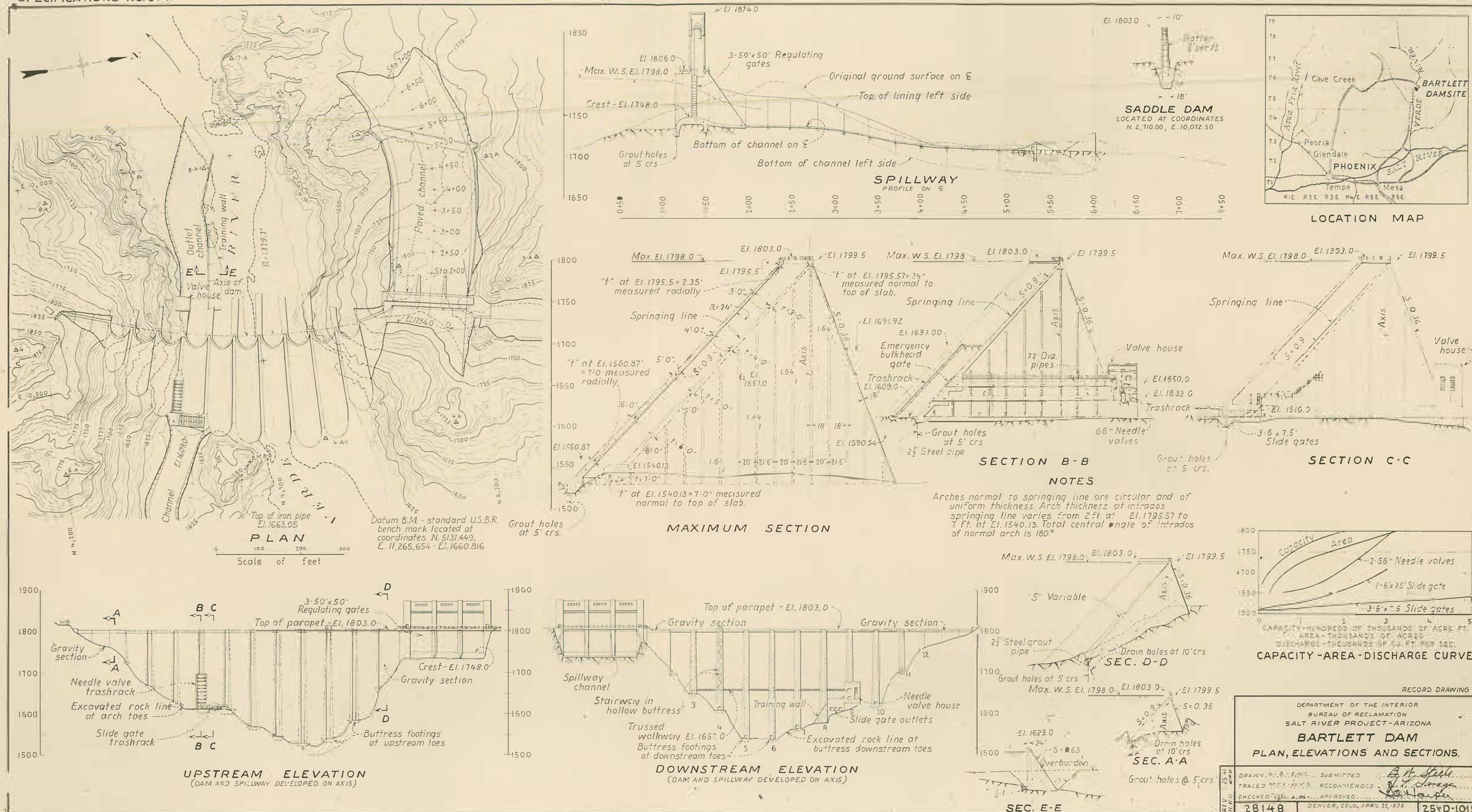
3. Conclusions. The pressure-discharge measurement on the needle valves confirmed the conclusions of previous tests on the 5-inch needle valve that to maintain positive pressures in the valve three considerations are necessary: (1) the angle between the needle and the nozzle must not be diverging; (2) the nozzle should have a sharp-edged exit; and (3) the seating point of the needle must be on the cone portion.

To have a maximum coefficient of discharge and still maintain positive pressures according to the criteria above, the exit diameter and the needle travel should be as large as possible. Once the exit diameter and the needle travel are established by the size of the valve, the outlet section of the valve controls the discharge.

This outlet section is the short section of the nozzle upstream from its exit forming the frustrum of a cone and the similar conical section on the needle downstream from its seat. The discharge can be increased by diverging this section, that is, by making the angle of the conical section of the needle greater than the angle of the conical section of the nozzle. However, negative pressures will result. A parallel outlet section - the same angle on the needle and the nozzle - will give the largest discharge coefficient and still maintain positive pressures. The tests were insufficient to determine the angles of the needle and the nozzle which would give the maximum coefficient. On the Friant Dam needle valve the angle of the needle was 39 degrees and the angle of the nozzle 40 degrees. It was indicated, however, that the coefficient would be larger if these angles were about 45 degrees. Additional needle-valve tests would be required to confirm this indication.

Since the outlet section of the valve controls both pressures and discharge, it is believed that the body of the valve upstream from the outlet section can be designed from a structural viewpoint, providing the area of passage is greater than the area of passage at the outlet section. Frictional losses, even in a crude valve, will be negligible.

Another feature that is unimportant hydraulically is the downstream


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
Grout holes at 5' crs.
Outlet channel
Training wall
Valve house
Axis of dam
Paved channel
R = 1319.7'
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
LOCATION MAP
Cave Creek
Agua Fria River
Verde
BARTLETT DAMSITE
Peoria
Glendale
PHOENIX
SALT RIVER
Tempe
Mesa
MAXIMUM SECTION
Max. El. 1798.0
El. 1803.0
El. 1799.5
El. 1795.5'
"t" at El. 1795.5 = 2.35' measured radially
"t" at El. 1795.57 = 24" measured normal to top of slab.
"t" at El. 1560.87' = 7'-0" measured radially
"t" at El. 1540.13 = 7'-0" measured normal to top of slab.
Springing line
El. 1691.92
El. 1590.54
El. 1560.87
El. 1540.13
SECTION B-B
Max. W.S. El. 1798
Emergency bulkhead gate
Trashrack
72" Dia. pipes
Valve house
El. 1650.0
El. 1633.0
El. 1609.0
Grout holes at 5' crs
2½" Steel pipe
66" Needle valves
SECTION C-C
3-6'x7.5' Slide gates
El. 1610.0
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 of intrados of normal arch is 180°.
CAPACITY-AREA-DISCHARGE CURVE
Capacity
Area
2-66" Needle valves
1-6'x7.5' Slide gate
3-6'x7.5 Slide gates
SEC. D-D
"S" Variable
2½" 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
Overburden
UPSTREAM ELEVATION
(DAM AND SPILLWAY DEVELOPED ON AXIS)
Gravity section
Needle valve trashrack
Excavated rock line at arch toes
Slide gate trashrack
3-50'x50' Regulating gates
Top of parapet - El. 1803.0
Crest - El. 1748.0
Gravity section
Buttress footings at upstream toes
DOWNSTREAM ELEVATION
(DAM AND SPILLWAY DEVELOPED ON AXIS)
Top of parapet - El. 1803.0
Gravity section
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
RECORD DRAWING
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT - ARIZONA
BARTLETT DAM
PLAN, ELEVATIONS AND SECTIONS.
DRAWN / TRACED / CHECKED / SUBMITTED / RECOMMENDED / APPROVED
28148
DENVER, COLO., APRIL 23, 1936
25-D-1015

LIST OF DRAWINGS

VALVE
- GENERAL ASSEMBLY - LIST OF PARTS 40-D-2420
- LAYOUT DIAGRAM 40-D-2421
- BODY 40-D-2422
- BODY SECTIONS 40-D-2423
- BODY EXTENSION - BODY TIP 40-D-2424
- NEEDLE - CONTROL RACK - CLAMP RING 40-D-2425
- DIAPHRAGM TUBE 40-D-2426
- PISTON RINGS - NOZZLE SEAT - RETAINERS 40-D-2427
- OUTLET FLANGE - RING RETAINER - BODY CAP 40-D-2428
- BOLTS - STUDS - MISCELLANEOUS PARTS 40-D-2429

5" PARADOX CONTROL
- ASSEMBLY - LIST OF PARTS 40-D-2430
- CONTROL BODY 40-D-2431
- CONTROL BASE - COVER - LINER - PISTON 40-D-2432

$1\frac{1}{2}$" CONTROL STAND - DIRECT OR EXTENDED
- ASSEMBLY - GEARS - LIST OF PARTS 40-D-2433
- PEDESTAL AND COVER - SHAFT - STEM - COUPLINGS 40-D-2434

$1\frac{1}{4}$" AIR VENT MANIFOLD
- ASSEMBLY - BODY - LIST OF PARTS 40-D-1029

WRENCHES AND EQUIPMENT 40-D-2435

ERECTION GUIDES 40-D-2436

SHOP TESTING SET UP AND INSTRUCTIONS 40-D-964

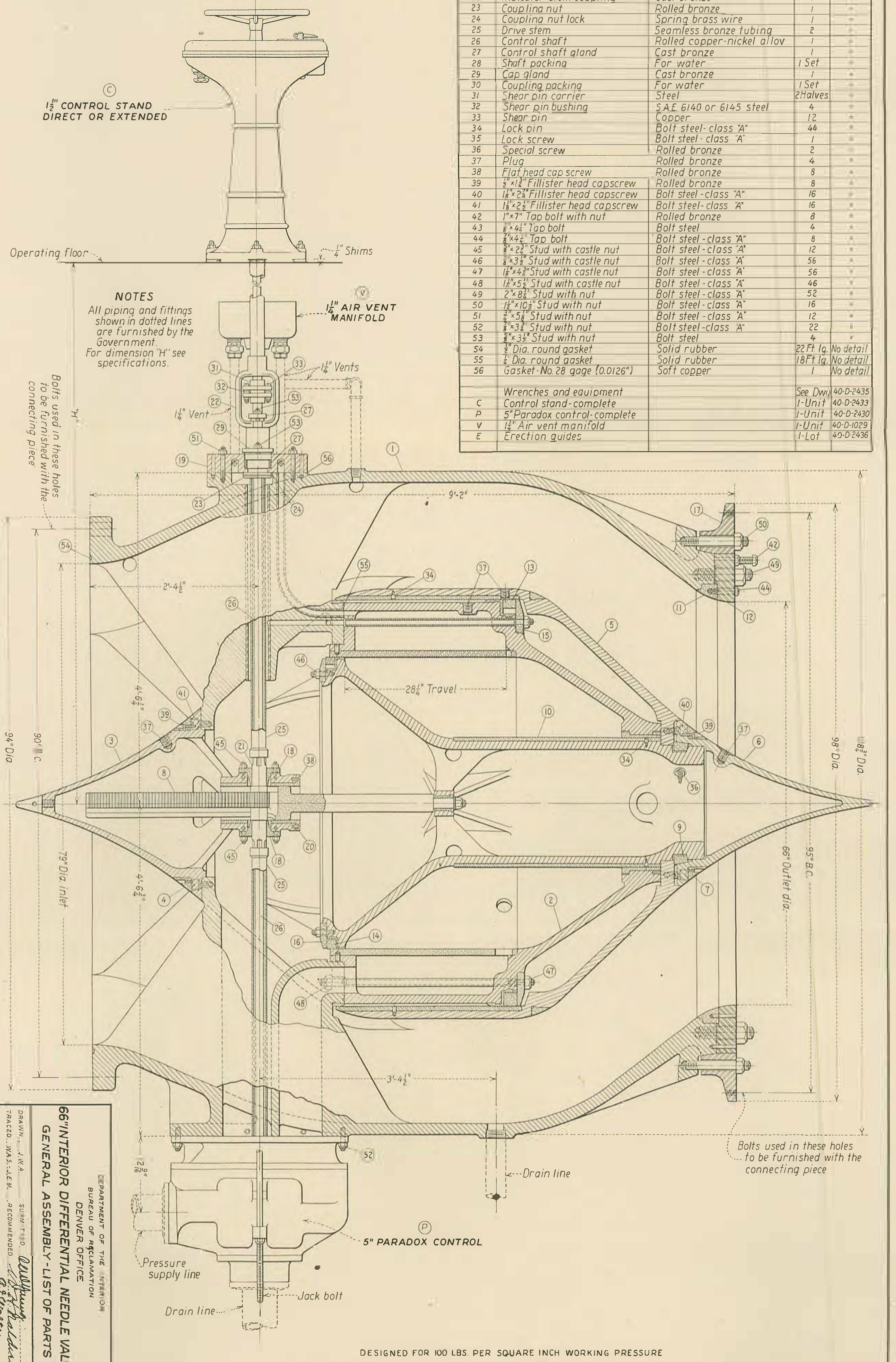
OPERATING INSTRUCTIONS (TO FIT EACH INSTALLATION)

LIST OF PARTS - ONE VALVE

PART NUMBER	DESCRIPTION	MATERIAL	NUMBER REQ'D	DRAWING NUMBER
1	Body	Semisteel	1	40-D-2422-3
2	Body extension	Semisteel	1	40-D-2424
3	Body tip	Semisteel	1	"
4	Body tip ring	Cast bronze	1	"
5	Needle body	Semisteel	1	40-D-2425
6	Needle tip	Nickel cast iron	1	"
7	Needle tip ring	Cast bronze	1	"
8	Control rack	High tensile cast bronze	1	"
9	Clamp ring	High tensile cast bronze	1	"
10	Diaphragm tube	Nickel cast iron	1	40-D-2426
11	Nozzle seat	Cast bronze	1	40-D-2427
12	Seat retainer	Cast steel	1	"
13	Piston ring	Cast manganese bronze	1	"
14	Piston ring	Cast manganese bronze	1	"
15	Ring retainer	Cast manganese bronze	1	"
16	Ring retainer	Cast manganese bronze	1	40-D-2428
17	Outlet flange	Cast steel	1	"
18	Rack pinion bearing	Rolled bronze	2	"
19	Body cap	Semisteel	1	"
20	Body tip bushing	Cast bronze	1	"
21	Control rack pinion	Rolled copper-nickel alloy	1	40-D-2429
22	Indicator stem coupling	Cast bronze	1	"
23	Coupling nut	Rolled bronze	1	"
24	Coupling nut lock	Spring brass wire	1	"
25	Drive stem	Seamless bronze tubing	2	"
26	Control shaft	Rolled copper-nickel alloy	1	"
27	Control shaft gland	Cast bronze	1	"
28	Shaft packing	For water	1 Set	"
29	Cap gland	Cast bronze	1	"
30	Coupling packing	For water	1 Set	"
31	Shear pin carrier	Steel	2 Halves	"
32	Shear pin bushing	S.A.E. 6140 or 6145 steel	4	"
33	Shear pin	Copper	12	"
34	Lock pin	Bolt steel - class "A"	44	"
35	Lock screw	Bolt steel - class "A"	1	"
36	Special screw	Rolled bronze	2	"
37	Plug	Rolled bronze	4	"
38	Flat head cap screw	Rolled bronze	8	"
39	$\frac{1}{2}$"×$1\frac{3}{4}$" Fillister head capscrew	Rolled bronze	8	"
40	$1\frac{1}{8}$"×$2\frac{7}{8}$" Fillister head capscrew	Bolt steel - class "A"	16	"
41	$1\frac{1}{8}$"×$2\frac{1}{2}$" Fillister head capscrew	Bolt steel - class "A"	16	"
42	1"×7" Tap bolt with nut	Rolled bronze	8	"
43	$\frac{7}{8}$"×$4\frac{1}{2}$" Tap bolt	Bolt steel	4	"
44	$\frac{7}{8}$"×$4\frac{1}{4}$" Tap bolt	Bolt steel - class "A"	8	"
45	$\frac{5}{8}$"×$2\frac{3}{4}$" Stud with castle nut	Bolt steel - class "A"	12	"
46	$\frac{7}{8}$"×$3\frac{1}{2}$" Stud with castle nut	Bolt steel - class "A"	56	"
47	$1\frac{1}{4}$"×$4\frac{3}{4}$" Stud with castle nut	Bolt steel - class "A"	56	"
48	$1\frac{1}{2}$"×$5\frac{1}{2}$" Stud with castle nut	Bolt steel - class "A"	46	"
49	2"×$8\frac{1}{4}$" Stud with nut	Bolt steel - class "A"	52	"
50	$1\frac{1}{2}$"×$10\frac{1}{2}$" Stud with nut	Bolt steel - class "A"	16	"
51	$\frac{3}{4}$"×$5\frac{5}{8}$" Stud with nut	Bolt steel - class "A"	12	"
52	$\frac{7}{8}$"×$3\frac{3}{4}$" Stud with nut	Bolt steel - class "A"	22	"
53	$\frac{5}{8}$"×$3\frac{1}{2}$" Stud with nut	Bolt steel	4	"
54	$\frac{1}{2}$" Dia. round gasket	Solid rubber	22 Ft. lg.	No detail
55	$\frac{1}{4}$" Dia. round gasket	Solid rubber	18 Ft. lg.	No detail
56	Gasket - No. 28 gage (0.0126")	Soft copper	1	No detail
	Wrenches and equipment		See Dwg.	40-D-2435
C	Control stand - complete		1-Unit	40-D-2433
P	5" Paradox control - complete		1-Unit	40-D-2430
V	$1\frac{1}{4}$" Air vent manifold		1-Unit	40-D-1029
E	Erection guides		1-Lot	40-D-2436

NOTES

All piping and fittings shown in dotted lines are furnished by the Government.
For dimension "H" see specifications.



DESIGNED FOR 100 LBS. PER SQUARE INCH WORKING PRESSURE

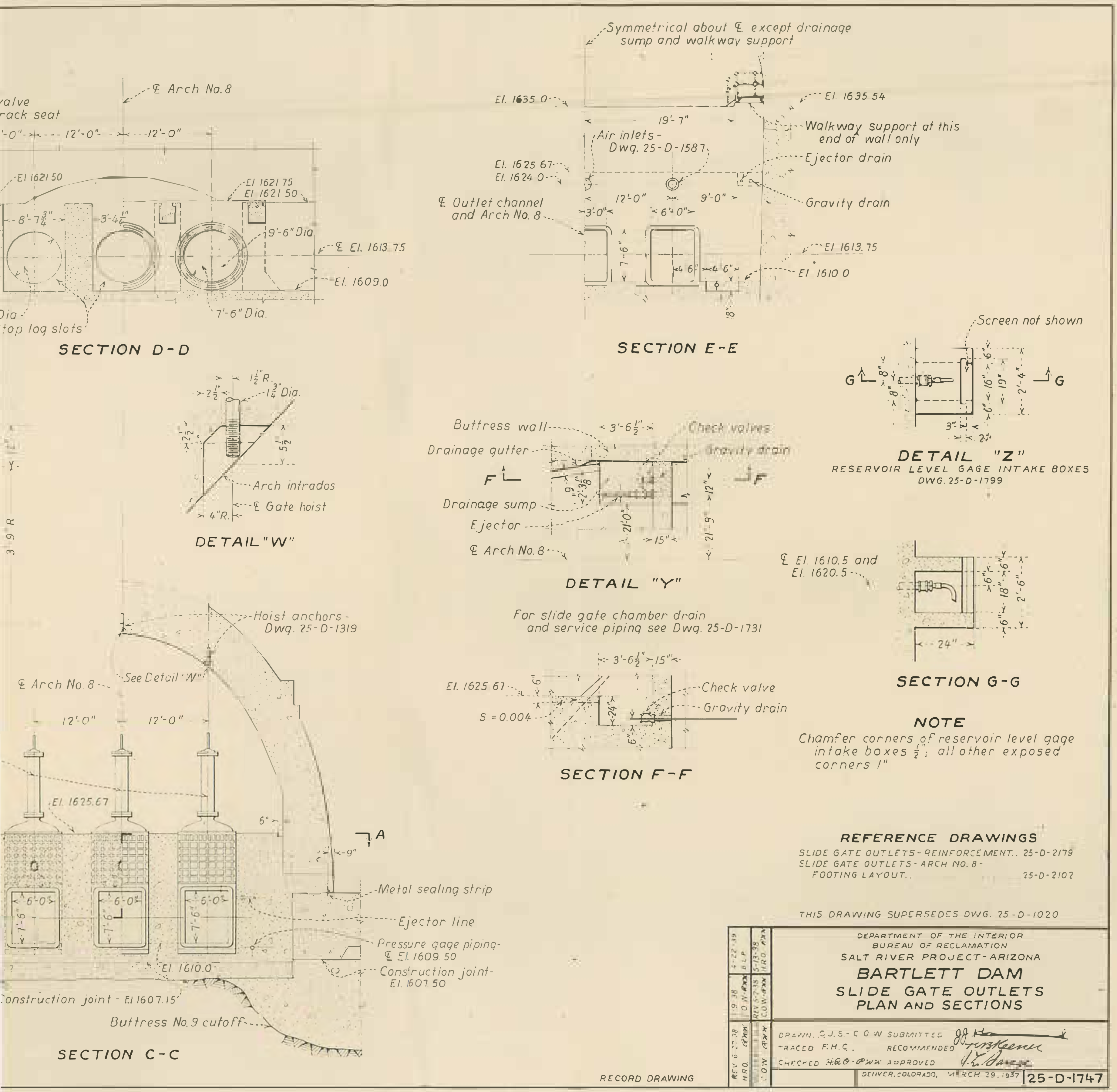
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

66" INTERIOR DIFFERENTIAL NEEDLE VALVE
GENERAL ASSEMBLY - LIST OF PARTS

DRAWN J.W.A. SUBMITTED [signature]
TRACED W.A.S. - J.E.M. RECOMMENDED [signature]
CHECKED M.E.N. APPROVED [signature]

28768 DENVER, COLORADO, OCT. 15, 1936 SHEET 1 OF 10 40-D-2420

FIGURE 6



SECTION D-D
℄ Arch No. 8
El 1621.50
El 1621.75
El 1621.50
9'-6" Dia.
℄ El. 1613.75
El. 1609.0
7'-6" Dia.
stop log slots
SECTION E-E
Symmetrical about ℄ except drainage sump and walkway support
El. 1635.0
El. 1635.54
Walkway support at this end of wall only
Air inlets - Dwg. 25-D-1587
El. 1625.67
El. 1624.0
Ejector drain
Gravity drain
℄ Outlet channel and Arch No. 8
El. 1613.75
El. 1610.0
DETAIL "W"
Arch intrados
℄ Gate hoist
DETAIL "Y"
Buttress wall
Drainage gutter
Check valves
Gravity drain
Drainage sump
Ejector
℄ Arch No. 8
For slide gate chamber drain and service piping see Dwg. 25-D-1731
SECTION F-F
El. 1625.67
S = 0.004
Check valve
Gravity drain
DETAIL "Z"
RESERVOIR LEVEL GAGE INTAKE BOXES
DWG. 25-D-1799
Screen not shown
SECTION G-G
℄ El. 1610.5 and El. 1620.5
NOTE
Chamfer corners of reservoir level gage intake boxes 1/2"; all other exposed corners 1"
SECTION C-C
Hoist anchors - Dwg. 25-D-1319
See Detail "W"
℄ Arch No. 8
El. 1625.67
Metal sealing strip
Ejector line
Pressure gage piping - ℄ El. 1609.50
Construction joint - El. 1607.50
El 1610.0
Construction joint - El 1607.15
Buttress No. 9 cutoff
REFERENCE DRAWINGS
SLIDE GATE OUTLETS - REINFORCEMENT .. 25-D-2179
SLIDE GATE OUTLETS - ARCH NO. 8 - FOOTING LAYOUT .. 25-D-2102
THIS DRAWING SUPERSEDES DWG. 25-D-1020
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT - ARIZONA
BARTLETT DAM
SLIDE GATE OUTLETS
PLAN AND SECTIONS
DRAWN C.J.S.-C.O.W. SUBMITTED
TRACED F.H.C. RECOMMENDED
CHECKED H.R.G.-P.W.W. APPROVED
DENVER, COLORADO, MARCH 29, 1937
25-D-1747
RECORD DRAWING

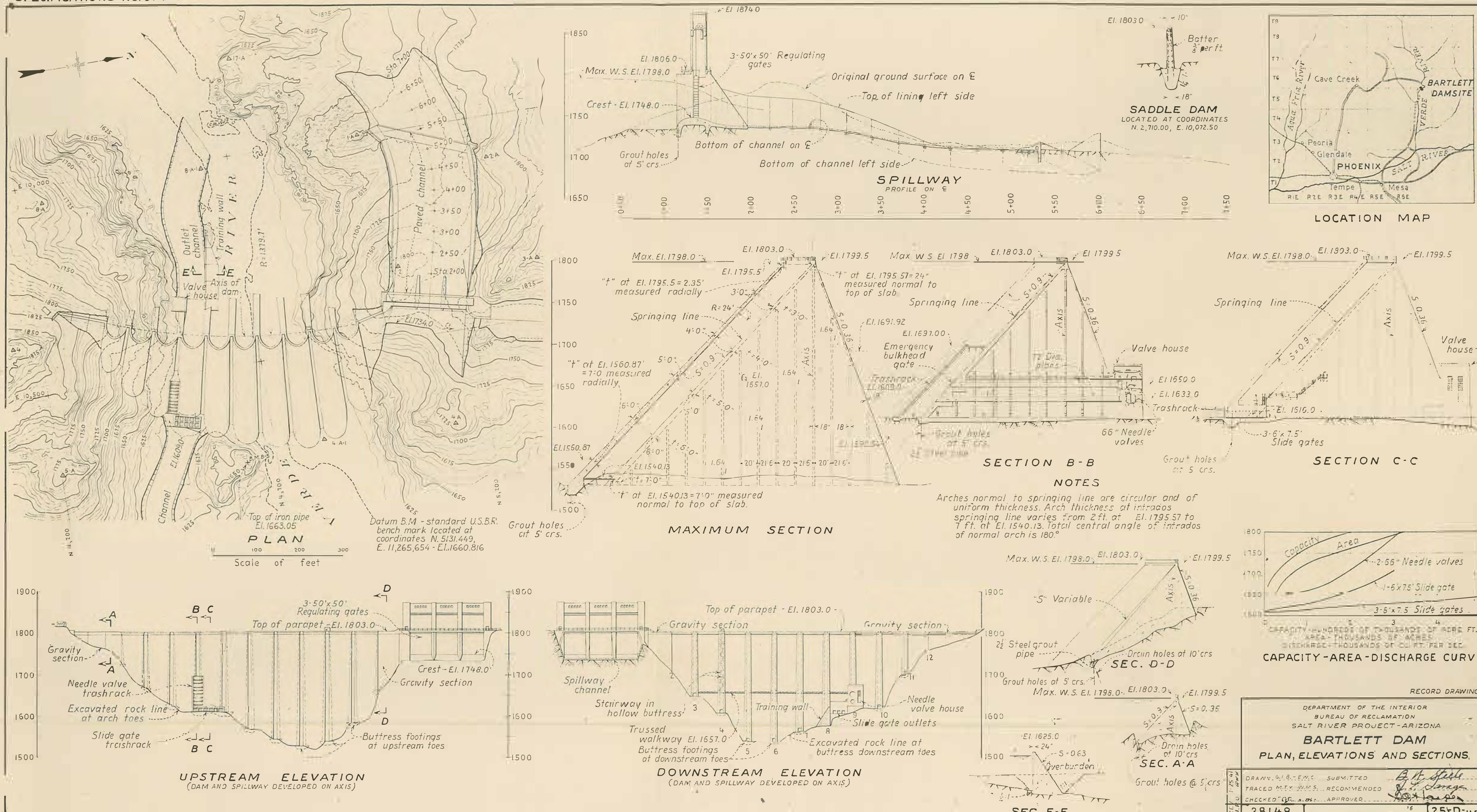
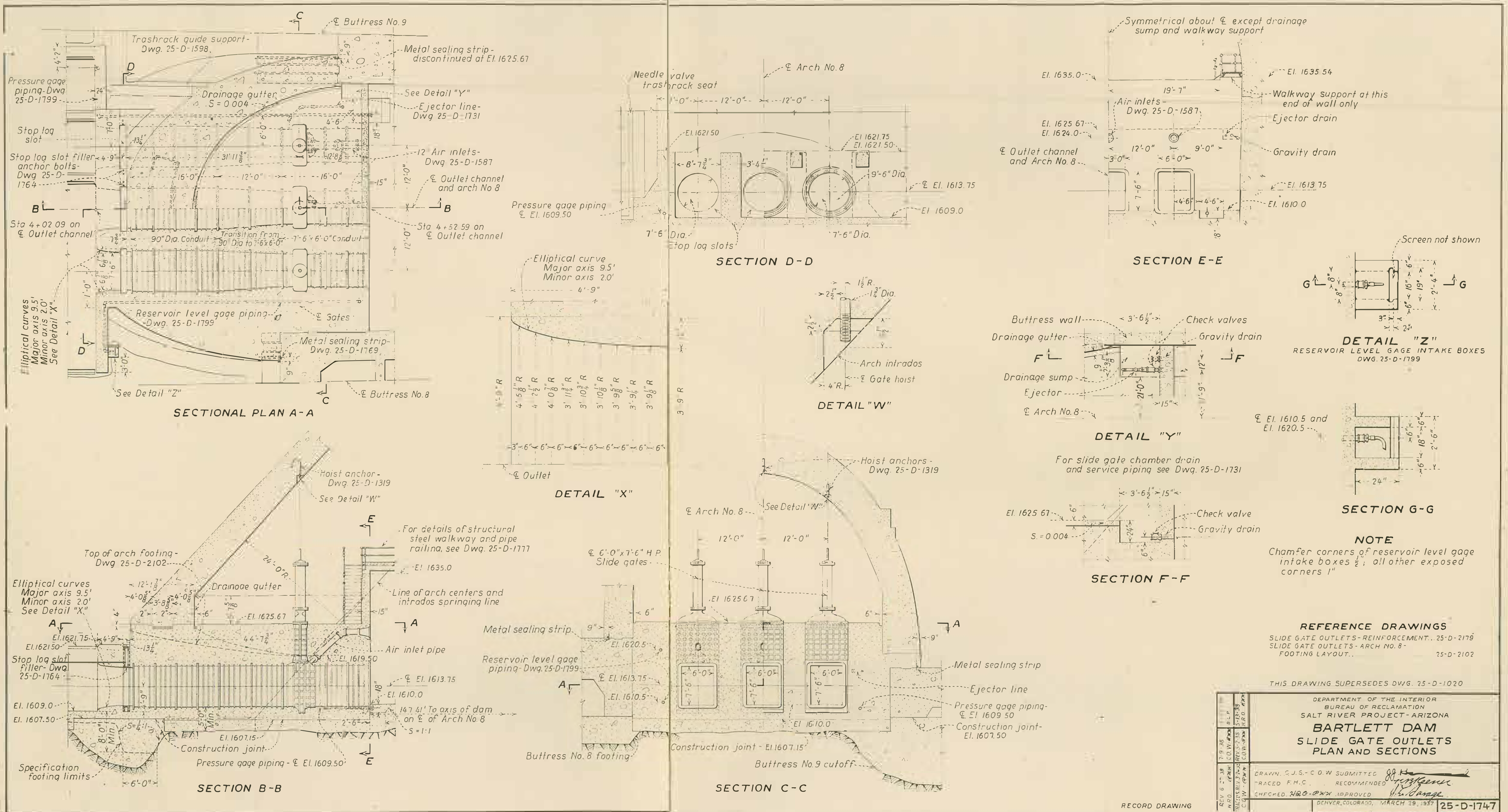

PLAN
Scale of feet
Outlet channel
Training wall
RIVER
Valve house
Axis of dam
Paved channel
Channel
Top of iron pipe El. 1663.05
Datum B.M. - standard U.S.B.R. bench mark located at coordinates N. 5131.449, E. 11,265.654 - El. 1660.816
Grout holes at 5' crs.
SPILLWAY
PROFILE ON ℄
El. 1874.0
El. 1806.0
Max. W.S. El. 1798.0
Crest - El. 1748.0
3-50'x50' Regulating gates
Original ground surface on ℄
Top of lining left side
Bottom of channel on ℄
Bottom of channel left side
Grout holes of 5' crs.
SADDLE DAM
LOCATED AT COORDINATES N. 2,710.00, E. 10,072.50
El. 1803.0
Batter
LOCATION MAP
Cave Creek
BARTLETT DAMSITE
VERDE RIVER
Agua Fria River
Peoria
Glendale
PHOENIX
SALT RIVER
Tempe
Mesa
MAXIMUM SECTION
Max. El. 1798.0
El. 1803.0
El. 1799.5
El. 1795.5
"t" at El. 1795.5 = 2.35' measured radially
"t" at El. 1795.57 = 2'4" measured normal to top of slab
Springing line
"t" at El. 1560.87' = 7'0" measured radially
"t" at El. 1540.13 = 7'0" measured normal to top of slab.
El. 1691.92
SECTION B-B
Max W.S. El. 1798
Emergency bulkhead gate
Trashrack
Valve house
El. 1650.0
El. 1633.0
66" Needle valves
Grout holes at 5' crs.
SECTION C-C
Max. W.S. El. 1798.0
El. 1803.0
El. 1799.5
Springing line
Valve house
Trashrack
El. 1516.0
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 of intrados of normal arch is 180°.
CAPACITY-AREA-DISCHARGE CURVE
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.
Max. W.S. El. 1798.0
El. 1803.0
El. 1799.5
"S" Variable
2½" Steel grout pipe
Drain holes at 10' crs.
Grout holes at 5' crs.
SEC. D-D
SEC. A-A
Drain holes at 10' crs.
Grout holes @ 5' crs.
El. 1625.0
Overburden
SEC. E-E
UPSTREAM ELEVATION
(DAM AND SPILLWAY DEVELOPED ON AXIS)
Gravity section
Needle valve trashrack
Excavated rock line at arch toes
Slide gate trashrack
3-50'x50' Regulating gates
Top of parapet - El. 1803.0
Crest - El. 1748.0
Gravity section
Buttress footings at upstream toes
DOWNSTREAM ELEVATION
(DAM AND SPILLWAY DEVELOPED ON AXIS)
Top of parapet - El. 1803.0
Gravity section
Spillway channel
Stairway in hollow buttress
Trussed walkway El. 1657.0
Buttress footings at downstream toes
Training wall
Slide gate outlets
Excavated rock line at buttress downstream toes
Needle valve house
RECORD DRAWING
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT - ARIZONA
BARTLETT DAM
PLAN, ELEVATIONS AND SECTIONS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
28148
25-D-1015

FIGURE 6


SECTIONAL PLAN A-A
Trashrack guide support-Dwg. 25-D-1598
℄ Buttress No. 9
Metal sealing strip-discontinued at El. 1625.67
Pressure gage piping-Dwg. 25-D-1799
Drainage gutter S = 0.004
See Detail "Y"
Ejector line-Dwg. 25-D-1731
Stop log slot
Stop log slot filler anchor bolts-Dwg. 25-D-1764
12 Air inlets-Dwg. 25-D-1587
℄ Outlet channel and arch No. 8
Sta. 4+02.09 on ℄ Outlet channel
Sta. 4+52.59 on ℄ Outlet channel
90" Dia. Conduit
Transition from 90" Dia. to 7'-6"x6'-0"
7'-6"x6'-0" Conduit
Elliptical curves Major axis 9.5' Minor axis 2.0' See Detail "X"
Reservoir level gage piping-Dwg. 25-D-1799
℄ Gates
Metal sealing strip-Dwg. 25-D-1769
See Detail "Z"
℄ Buttress No. 8
SECTION B-B
Hoist anchor-Dwg. 25-D-1319
See Detail "W"
For details of structural steel walkway and pipe railing, see Dwg. 25-D-1777
Top of arch footing-Dwg. 25-D-2102
Drainage gutter
El. 1635.0
Line of arch centers and intrados springing line
El. 1625.67
Air inlet pipe
El. 1621.75
El. 1621.50
El. 1619.50
Stop log slot filler-Dwg. 25-D-1764
℄ El. 1613.75
El. 1610.0
El. 1609.0
El. 1607.50
147.41' To axis of dam on ℄ of Arch No. 8
S = 1:1
El. 1607.15
Construction joint
Pressure gage piping-℄ El. 1609.50
Specification footing limits
DETAIL "X"
Elliptical curve Major axis 9.5' Minor axis 2.0'
℄ Outlet
SECTION D-D
Needle valve trashrack seat
℄ Arch No. 8
El. 1621.50
El. 1621.75
9'-6" Dia.
℄ El. 1613.75
El. 1609.0
Pressure gage piping ℄ El. 1609.50
7'-6" Dia.
Stop log slots
DETAIL "W"
Arch intrados
℄ Gate hoist
SECTION C-C
Hoist anchors-Dwg. 25-D-1319
℄ Arch No. 8
See Detail "W"
℄ 6'-0"x7'-6" H.P. Slide gates
El. 1625.67
Metal sealing strip
El. 1620.5
Reservoir level gage piping-Dwg. 25-D-1799
℄ El. 1613.75
El. 1610.5
El. 1610.0
Ejector line
Pressure gage piping-℄ El. 1609.50
Construction joint-El. 1607.50
Construction joint-El. 1607.15
Buttress No. 8 footing
Buttress No. 9 cutoff
SECTION E-E
Symmetrical about ℄ except drainage sump and walkway support
El. 1635.0
El. 1635.54
Walkway support at this end of wall only
Air inlets-Dwg. 25-D-1587
Ejector drain
El. 1625.67
El. 1624.0
Gravity drain
℄ Outlet channel and Arch No. 8
El. 1613.75
El. 1610.0
DETAIL "Y"
Buttress wall
Check valves
Drainage gutter
Gravity drain
Drainage sump
Ejector
℄ Arch No. 8
For slide gate chamber drain and service piping see Dwg. 25-D-1731
SECTION F-F
El. 1625.67
S = 0.004
Check valve
Gravity drain
DETAIL "Z"
RESERVOIR LEVEL GAGE INTAKE BOXES
DWG. 25-D-1799
Screen not shown
SECTION G-G
℄ El. 1610.5 and El. 1620.5
NOTE
Chamfer corners of reservoir level gage intake boxes 1/2"; all other exposed corners 1"
REFERENCE DRAWINGS
SLIDE GATE OUTLETS-REINFORCEMENT... 25-D-2179
SLIDE GATE OUTLETS-ARCH NO. 8-FOOTING LAYOUT... 25-D-2102
THIS DRAWING SUPERSEDES DWG. 25-D-1020
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT-ARIZONA
BARTLETT DAM
SLIDE GATE OUTLETS
PLAN AND SECTIONS
DRAWN C.J.S.-C.O.W. SUBMITTED
TRACED F.H.C. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO, MARCH 29, 1937
25-D-1747
RECORD DRAWING

LIST OF DRAWINGS

VALVE
- GENERAL ASSEMBLY - LIST OF PARTS 40-D-2420
- LAYOUT DIAGRAM 40-D-2421
- BODY 40-D-2422
- BODY SECTIONS 40-D-2423
- BODY EXTENSION - BODY TIP 40-D-2424
- NEEDLE - CONTROL RACK - CLAMP RING 40-D-2425
- DIAPHRAGM TUBE 40-D-2426
- PISTON RINGS - NOZZLE SEAT - RETAINERS 40-D-2427
- OUTLET FLANGE - RING RETAINER - BODY CAP 40-D-2428
- BOLTS - STUDS - MISCELLANEOUS PARTS 40-D-2429

5" PARADOX CONTROL
- ASSEMBLY - LIST OF PARTS 40-D-2430
- CONTROL BODY 40-D-2431
- CONTROL BASE - COVER - LINER - PISTON 40-D-2432

1½" CONTROL STAND - DIRECT OR EXTENDED
- ASSEMBLY - GEARS - LIST OF PARTS 40-D-2433
- PEDESTAL AND COVER - SHAFT - STEM - COUPLINGS 40-D-2434

1¼" AIR VENT MANIFOLD
- ASSEMBLY - BODY - LIST OF PARTS 40-D-1029

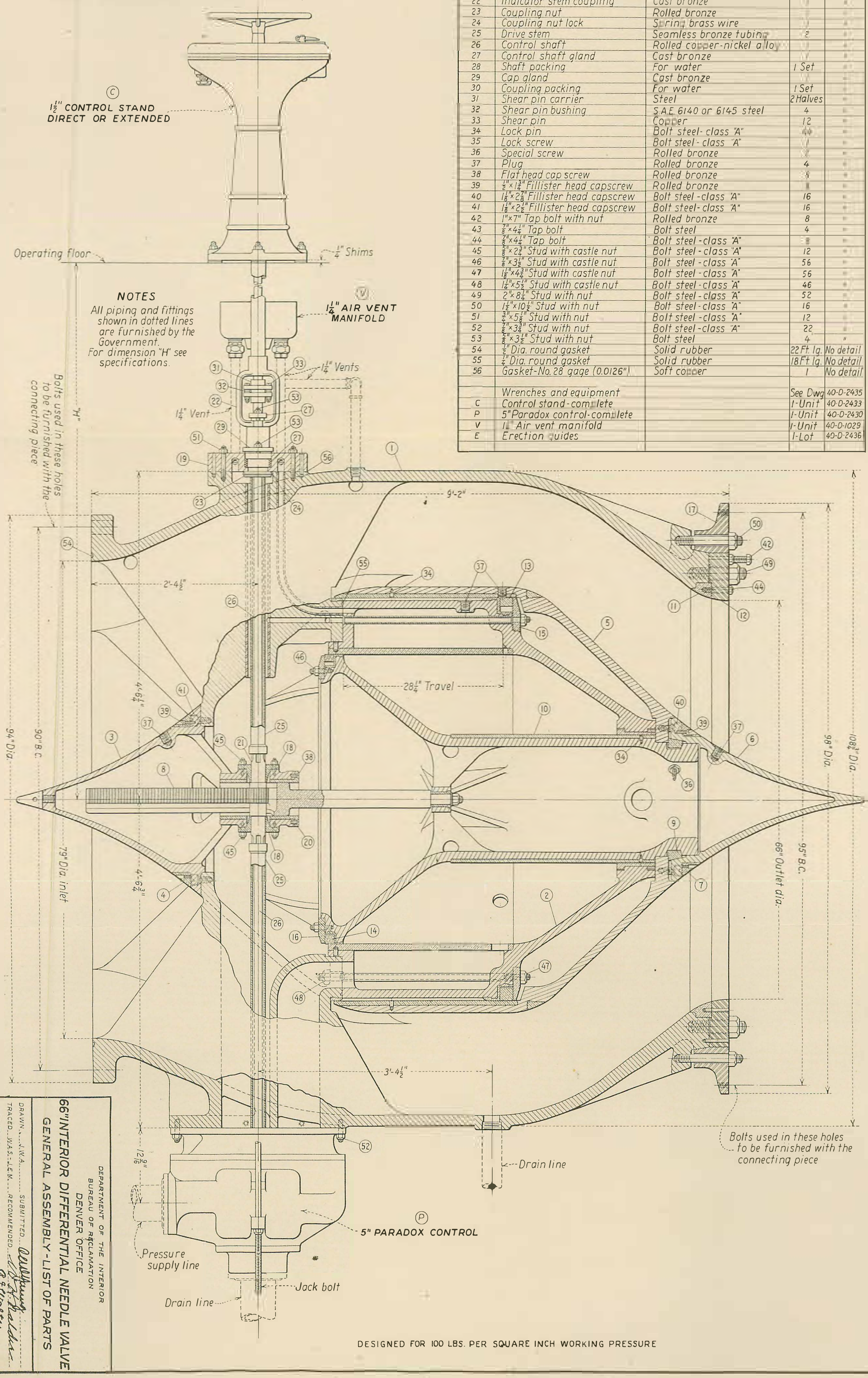
WRENCHES AND EQUIPMENT 40-D-2435
ERECTION GUIDES 40-D-2436
SHOP TESTING SET UP AND INSTRUCTIONS 40-D-964
OPERATING INSTRUCTIONS (TO FIT EACH INSTALLATION)

LIST OF PARTS - ONE VALVE

PART NUMBER	DESCRIPTION	MATERIAL	NUMBER REQ'D	DRAWING NUMBER
1	Body	Semisteel	1	40-D-2422 3
2	Body extension	Semisteel	1	40-D-2424
3	Body tip	Semisteel	1	"
4	Body tip ring	Cast bronze	1	"
5	Needle body	Semisteel	1	40-D-2425
6	Needle tip	Nickel cast iron	1	"
7	Needle tip ring	Cast bronze	1	"
8	Control rack	High tensile cast bronze	1	"
9	Clamp ring	High tensile cast bronze	1	"
10	Diaphragm tube	Nickel cast iron	1	40-D-2426
11	Nozzle seat	Cast bronze	1	40-D-2427
12	Seat retainer	Cast steel	1	"
13	Piston ring	Cast manganese bronze	1	"
14	Piston ring	Cast manganese bronze	1	"
15	Ring retainer	Cast manganese bronze	1	"
16	Ring retainer	Cast manganese bronze	1	40-D-2428
17	Outlet flange	Cast steel	1	"
18	Rack pinion bearing	Rolled bronze	2	"
19	Body cap	Semisteel	1	"
20	Body tip bushing	Cast bronze	1	"
21	Control rack pinion	Rolled copper-nickel alloy	1	40-D-2429
22	Indicator stem coupling	Cast bronze	1	"
23	Coupling nut	Rolled bronze	1	"
24	Coupling nut lock	Spring brass wire	1	"
25	Drive stem	Seamless bronze tubing	2	"
26	Control shaft	Rolled copper-nickel alloy	1	"
27	Control shaft gland	Cast bronze	1	"
28	Shaft packing	For water	1 Set	"
29	Cap gland	Cast bronze	1	"
30	Coupling packing	For water	1 Set	"
31	Shear pin carrier	Steel	2 Halves	"
32	Shear pin bushing	S.A.E. 6140 or 6145 steel	4	"
33	Shear pin	Copper	12	"
34	Lock pin	Bolt steel - class "A"	[illegible]	"
35	Lock screw	Bolt steel - class "A"	1	"
36	Special screw	Rolled bronze	[illegible]	"
37	Plug	Rolled bronze	4	"
38	Flat head cap screw	Rolled bronze	[illegible]	"
39	½"×1¾" Fillister head capscrew	Rolled bronze	[illegible]	"
40	1⅛"×2⅞" Fillister head capscrew	Bolt steel - class "A"	16	"
41	1⅛"×2½" Fillister head capscrew	Bolt steel - class "A"	16	"
42	1"×7" Tap bolt with nut	Rolled bronze	8	"
43	⅞"×4¼" Tap bolt	Bolt steel	4	"
44	⅞"×4¼" Tap bolt	Bolt steel - class "A"	[illegible]	"
45	⅝"×2¾" Stud with castle nut	Bolt steel - class "A"	12	"
46	⅞"×3½" Stud with castle nut	Bolt steel - class "A"	56	"
47	1⅛"×4¾" Stud with castle nut	Bolt steel - class "A"	56	"
48	1¼"×5½" Stud with castle nut	Bolt steel - class "A"	46	"
49	2"×8¼" Stud with nut	Bolt steel - class "A"	52	"
50	1½"×10½" Stud with nut	Bolt steel - class "A"	16	"
51	¾"×5⅛" Stud with nut	Bolt steel - class "A"	12	"
52	⅞"×3¾" Stud with nut	Bolt steel - class "A"	22	"
53	⅝"×3½" Stud with nut	Bolt steel	4	"
54	½" Dia. round gasket	Solid rubber	22 Ft. lg.	No detail
55	¼" Dia. round gasket	Solid rubber	18 Ft. lg.	No detail
56	Gasket - No. 28 gage (0.0126")	Soft copper	1	No detail
	Wrenches and equipment		See Dwg	40-D-2435
C	Control stand - complete		1-Unit	40-D-2433
P	5" Paradox control - complete		1-Unit	40-D-2430
V	1¼" Air vent manifold		1-Unit	40-D-1029
E	Erection guides		1-Lot	40-D-2436

NOTES

All piping and fittings shown in dotted lines are furnished by the Government.
For dimension "H" see specifications.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

66" INTERIOR DIFFERENTIAL NEEDLE VALVE
GENERAL ASSEMBLY - LIST OF PARTS

DRAWN J.W.A. SUBMITTED [signature]
TRACED W.A.S. - J.E.M. RECOMMENDED [signature]
CHECKED M.E.N. APPROVED [signature]

28768 | DENVER, COLORADO, OCT. 15, 1936 SHEET 1 OF 10 | 40-D-2420 tip of the needle. In previous tests on the 5-inch valve at Boulder Dam it was demonstrated that the shape of the tip had a negligible effect upon the discharge and little effect upon the jet except at very small openings.

The tests on the tube valves confirmed the previous conclusions that the jet was unstable at small openings and similar to the needle valve at larger openings. These tests were insufficient to state any other general conclusions.

CHAPTER II - CALIBRATION OF NEEDLE-VALVE AND SLIDE-GATE OUTLETS AT BARTLETT DAM

4. Proposed measurement of discharge at needle valve and slide-gate outlets. The normal flow through the Bartlett Dam is controlled by two outlet works. One consists of two 66-inch needle-valve outlets placed 23 feet and 40 feet, respectively, above the river bed (figures 4 and 5). The other, consisting of three 6-foot by 7-foot 6-inch slide gates, was placed near the river level for utilizing the bottom storage of the dam (figures 4 and 6). As the flow through the outlets is for irrigation, some means of measuring the discharge quantity was necessary.

In a letter to the Chief Engineer dated February 18, 1937, the Construction Engineer at Phoenix, Arizona, transmitted a letter from H. J. Lawson, General Superintendent and Chief Engineer of the Salt River Valley Water Users' Association, requesting that provision be made in the construction of Bartlett Dam for a discharge measurement station immediately downstream from the outlet works. The Association was concerned from a standpoint of accuracy and convenience of location so that the operator at the dam could quickly determine the discharge from the reservoir. In discussing the reply to this letter it was suggested that the outlets be rated and used to measure the outflow of water. This was covered in a memorandum by J. E. Warnock to K. B. Keener on March 4, 1937:

> "A relatively simple method of measuring the outflow of water from Bartlett Dam with a reasonable degree of accuracy would be to install pressure gages in the conduits of both the needle-valve outlets and the slide-gate outlets. A model of one needle valve and conduit and a model of one slide-gate out-

outlet can be constructed and operated to obtain a family of curves with three variables - pressure head vs. gate or valve openings vs. discharge quantity. The results of these two models can then be transferred to the actual outlets. It is believed that the result by this method will be more accurate than the control established in the river downstream and it will certainly be more convenient and cheaper. In installing the gages, a ring piezometer should be installed in each conduit to which the gages would be attached. A recording gage can be used which would give a continuous record of the pressure. The gate or valve opening can be recorded each time the operator changes the setting. By integration, the total flow can be computed over a given period.

The piezometer ring should be installed before the concrete around the conduits is poured. I have indicated the probable location of the piezometers on the drawing 25-D-1019 and 25-D-1020, in your copy of the specifications. These should be brought to the surface separately and then connected into a manifold so that each piezometer can be flushed occasionally."

This proposal was outlined in a letter from the Chief Engineer to the Construction Engineer on March 6, 1937, and was transmitted to the General Superintendent and Chief Engineer of the Salt River Valley Water Users' Association by a letter dated March 11, 1937. The approval of this plan by the Association was indicated in a letter dated April 10, 1937, from the Construction Engineer.

5. Calibration of outlets by models. Three models were built and calibrated by the hydraulic laboratory in the following order: (1) the three slide-gate outlets on a scale ratio of 1:15; (2) one slide-gate outlet to a scale ratio of 1:10; and (3) a model of one of the 66-inch needle valves on a scale ratio of 1:8.

A rating (table 1) based on a sluiceway gate being operated at the completely open position was obtained from tests on the 1:15 model of the three sluiceway outlets. This table was sent to the Construction Engineer at Phoenix, Arizona, by a letter dated February 1, 1938, which included instructions as follows:

TABLE I

BARTLETT DAM SLUICEWAY OUTLETS
RATING TABLE
ONE OUTLET - GATE FULLY OPEN

Water-surface elevation	Discharge second-feet	Water-surface elevation	Discharge second-feet	Water-surface elevation	Discharge second-feet
1610.0	0	1630.5	1,350	1650.5	2,043
1610.5	14	1631.0	1,372	1651.0	2,058
1611.0	27	1631.5	1,393	1651.5	2,072
1611.5	42	1632.0	1,415	1652.0	2,085
1612.0	57	1632.5	1,435	1652.5	2,098
1612.5	73	1633.0	1,456	1653.0	2,112
1613.0	91	1633.5	1,477	1653.5	2,125
1613.5	109	1634.0	1,496	1654.0	2,137
1614.0	129	1634.5	1,517	1654.5	2,150
1614.5	151	1635.0	1,536	1655.0	2,162
1615.0	176	1635.5	1,555	1655.5	2,174
1615.5	202	1636.0	1,574	1656.0	2,186
1616.0	231	1636.5	1,592	1656.5	2,197
1616.5	262	1637.0	1,610	1657.0	2,208
1617.0	298	1637.5	1,627	1657.5	2,221
1617.5	337	1638.0	1,645	1658.0	2,233
1618.0	385	1638.5	1,663	1658.5	2,244
1618.5	441	1639.0	1,680	1659.0	2,256
1619.0	517	1639.5	1,698	1659.5	2,267
1619.5	612	1640.0	1,716	1660.0	2,280
1620.0	680	1640.5	1,733	1660.5	2,292
1620.5	738	1641.0	1,750	1661.0	2,303
1621.0	788	1641.5	1,767	1661.5	2,315
1621.5	835	1642.0	1,783	1662.0	2,326
1622.0	881	1642.5	1,800	1662.5	2,337
1622.5	922	1643.0	1,816	1663.0	2,349
1623.0	960	1643.5	1,832	1663.5	2,361
1623.5	995	1644.0	1,849	1664.0	2,372
1624.0	1,027	1644.5	1,865	1664.5	2,383
1624.5	1,057	1645.0	1,880	1665.0	2,394
1625.0	1,085	1645.5	1,896	1665.5	2,407
1625.5	1,111	1646.0	1,912	1666.0	2,417
1626.0	1,136	1646.5	1,927	1666.5	2,429
1626.5	1,161	1647.0	1,942	1667.0	2,440
1627.0	1,187	1647.5	1,958	1667.5	2,452
1627.5	1,212	1648.0	1,973	1668.0	2,463
1628.0	1,236	1648.5	1,987	1668.5	2,474
1628.5	1,260	1649.0	2,001	1669.0	2,485
1629.0	1,284	1649.5	2,016	1669.5	2,495
1629.5	1,307	1650.0	2,030	1670.0	2,507
1630.0	1,328				

This table applicable only to gates completely open.

Discharge for more than one outlet may be obtained by multiplying values in this table by the number in operation.

". . . . This table is for a single sluiceway operating but the model studies indicated that the flow through two or three sluiceways can be computed by multiplying the discharge from one gate by the number in operation. The water surface elevation in this table is that which will be indicated on the continuous recording gage at the downstream end of the sluiceways."

Soon after the 1:15 model was built, it was anticipated that the gates would be operated at other positions than wide open. The 1:15 model was too small to accurately measure the discharge of a single gate partially open; so the 1:10 model of a single sluiceway was used. The rating (table 2) was prepared from data obtained from the 1:10 model and sent to the Construction Engineer by letter dated April 29, 1939, with instructions as follows:

"The discharge relationship is shown for each one-half foot between elevation 1615.5 and 1670.0 and for each one foot increment of gate opening. Discharges for intermediate heads and gate openings may be obtained by interpolation. The water surface elevation in this table is that indicated on the continuous recording gage at the downstream end of the outlet for low heads and on the reservoir gage on the downstream abutment for high heads.

In the studies of the 1 to 15 model of the three outlets and the 1:10 model of the single outlet, a region of unstable flow was found which it will be well to avoid in the operation of the outlets. This region is the increment of gate opening between seven feet and full open. The behavior of the stream in this region is uncertain for purposes of measurement. Furthermore, the outlets should not be operated at partial gate openings where discharge values are omitted in the accompanying tables.

When a choice is feasible, it will be more satisfactory for the purposes of flow measurements to operate at partial gate openings. This condition is due to the much more positive control formed by the gates than by the bell-mouth entrances. This also avoids the unstable region where the change occurs between orifice flow and open channel flow."

The 1:8 model of the needle valve outlet included the needle valve and a suitable length of approach conduit to insure proper velocity distribution at the valve and at the piezometers which measured the pressure head 15-3/16 inches upstream from the upstream flange of the valve (figure 7). From the data obtained on the model, a family of curves was de-

TABLE II

BARTLETT DAM SLUICEWAY OUTLETS

RATING TABLE

ONE OUTLET GATE PARTLY OPEN

Reservoir elev. in feet	Discharge in second-feet Gate opening 1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet
1615.5	82	-	-	-	-	-	-
1616.0	85	-	-	-	-	-	-
6.5	88	151	-	-	-	-	-
7.0	92	157	-	-	-	-	-
7.5	95	163	225	-	-	-	-
8.0	97	169	235	-	-	-	-
8.5	100	175	245	307	-	-	-
9.0	102	180	255	320	-	-	-
9.5	105	185	264	332	398	-	-
1620.0	108	190	272	345	415	-	-
0.5	110	195	282	357	433	504	-
1.0	113	201	290	370	450	527	-
1.5	115	206	299	381	467	549	-
2.0	117	210	307	392	483	571	-
2.5	120	216	315	404	499	593	736
3.0	122	220	323	415	515	614	762
3.5	125	225	330	425	529	633	787
4.0	127	230	338	436	545	654	812
4.5	129	235	345	446	558	672	836
1625.0	132	240	351	456	572	692	860
5.5	134	245	359	466	585	710	881
6.0	136	250	365	476	598	728	903
6.5	138	254	372	485	610	745	923
7.0	140	258	378	495	623	762	943
7.5	143	262	384	504	635	778	963
8.0	145	267	391	513	647	795	983
8.5	147	271	396	521	658	810	1,002
9.0	150	275	402	531	670	825	1,022
9.5	152	280	408	538	680	838	1,040
1630.0	154	284	414	547	690	855	1,061
0.5	156	288	419	556	703	867	1,080
1.0	158	292	425	564	714	880	1,100
1.5	160	296	431	573	724	893	1,119
2.0	162	300	436	580	736	905	1,138
2.5	164	304	441	588	745	918	1,157
3.0	166	308	447	595	756	930	1,175
3.5	167	312	452	603	766	943	1,193
4.0	169	316	458	610	776	955	1,212
4.5	171	320	464	617	785	967	1,229
1635.0	173	324	469	624	796	980	1,248
5.5	175	327	475	632	805	992	1,267
6.0	177	330	480	638	814	1,003	1,284
6.5	178	334	485	645	823	1,015	1,302
7.0	180	337	490	653	832	1,027	1,319

TABLE II

BARTLETT DAM SLUICEWAY OUTLETS

RATING TABLE

ONE OUTLET GATE PARTLY OPEN

Reservoir elev. in feet	Discharge in second-feet Gate opening 1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet
1637.5	182	340	495	660	841	1,038	1,337
8.0	184	344	500	667	850	1,050	1,354
8.5	185	348	505	674	858	1,062	1,370
9.0	187	351	510	681	866	1,074	1,386
9.5	190	354	515	688	875	1,085	1,402
1640.0	192	358	520	695	883	1,096	1,418
0.5	193	361	525	702	892	1,108	1,433
1.0	195	364	530	708	900	1,120	1,449
1.5	197	367	534	715	908	1,132	1,464
2.0	199	370	539	723	915	1,143	1,479
2.5	200	373	543	729	922	1,154	1,493
3.0	202	377	548	736	931	1,165	1,508
3.5	204	380	553	742	939	1,176	1,523
4.0	205	383	557	749	947	1,187	1,536
4.5	207	385	562	755	955	1,199	1,550
1645.0	208	388	565	762	963	1,210	1,564
5.5	210	391	570	768	971	1,220	1,578
6.0	212	393	574	774	978	1,231	1,590
6.5	213	396	578	780	987	1,242	1,604
7.0	215	398	583	787	995	1,252	1,618
7.5	216	401	587	793	1,003	1,262	1,632
8.0	218	403	592	798	1,011	1,272	1,645
8.5	220	406	596	803	1,018	1,282	1,658
9.0	221	408	600	808	1,026	1,292	1,670
9.5	223	411	604	813	1,033	1,303	1,683
1650.0	224	413	608	819	1,040	1,313	1,696
0.5	225	415	613	824	1,049	1,323	1,710
1.0	227	418	617	829	1,056	1,333	1,722
1.5	228	420	621	834	1,063	1,342	1,735
2.0	230	423	625	839	1,071	1,352	1,748
2.5	231	425	630	844	1,078	1,362	1,761
3.0	233	428	635	850	1,086	1,371	1,774
3.5	234	430	639	855	1,093	1,381	1,786
4.0	235	433	643	859	1,101	1,391	1,799
4.5	236	435	646	863	1,108	1,400	1,812
1655.0	237	437	651	868	1,115	1,410	1,824
5.5	239	440	655	873	1,123	1,420	1,836
6.0	240	442	659	878	1,130	1,429	1,849
6.5	242	445	663	883	1,137	1,438	1,861
7.0	243	447	667	888	1,144	1,448	1,874
7.5	244	450	671	892	1,151	1,458	1,887
8.0	245	452	675	897	1,158	1,466	1,898
8.5	247	454	678	902	1,165	1,476	1,911
9.0	249	456	683	907	1,172	1,485	1,923
1659.5	250	459	686	912	1,178	1,494	1,935

TABLE II

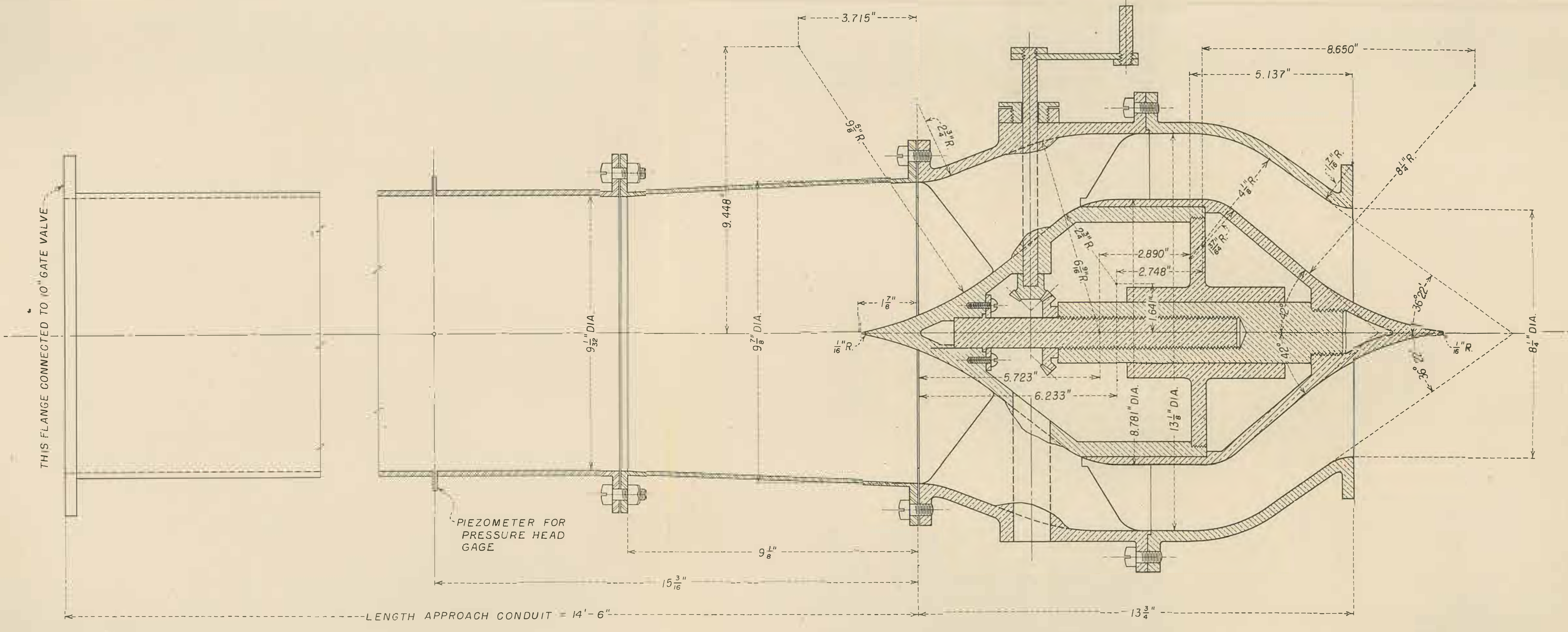
BARTLETT DAM SLUICEWAY OUTLETS

RATING TABLE

ONE OUTLET GATE PARTLY OPEN

Reservoir elev. in feet	Discharge in second-feet						
	Gate opening						
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet
1660.0	251	462	690	917	1,186	1,504	1,947
0.5	253	464	693	922	1,192	1,513	1,960
1.0	254	466	697	926	1,200	1,522	1,971
1.5	255	468	701	930	1,207	1,532	1,983
2.0	256	471	705	935	1,213	1,540	1,995
2.5	258	473	708	940	1,219	1,549	2,007
3.0	259	475	712	944	1,226	1,558	2,018
3.5	260	478	715	948	1,233	1,567	2,029
4.0	262	480	718	953	1,239	1,575	2,040
4.5	263	483	722	957	1,245	1,584	2,052
1665.0	264	485	725	962	1,252	1,592	2,063
5.5	265	487	728	967	1,258	1,600	2,075
6.0	266	490	731	972	1,263	1,608	2,085
6.5	268	492	735	976	1,270	1,617	2,097
7.0	269	494	738	980	1,276	1,625	2,108
7.5	270	497	742	985	1,282	1,632	2,118
8.0	272	499	745	990	1,287	1,639	2,130
8.5	273	501	749	994	1,293	1,647	2,141
9.0	275	504	752	998	1,298	1,655	2,152
9.5	276	506	756	1,003	1,304	1,662	2,163
1670.0	277	508	759	1,007	1,310	1,668	2,174

Discharge for more than one outlet may be obtained by multiplying values in this table by the number in operation.



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT - ARIZONA

BARTLETT DAM

1:8 SCALE MODEL 66-INCH NEEDLE VALVE FOR CALIBRATION TESTS

DRAWN..... F.C.L. ..... SUBMITTED..........
TRACED. P.L.H.-M.E.K. .. RECOMMENDED..........
CHECKED. ..... JEW .. APPROVED.......

DENVER, COLO. - NOV. 29, 1940

veloped with three variables, pressure head vs. valve openings vs. discharge quantity (figure 8). These results were transmitted to the field by a letter dated March 23, 1940, with the following instructions:

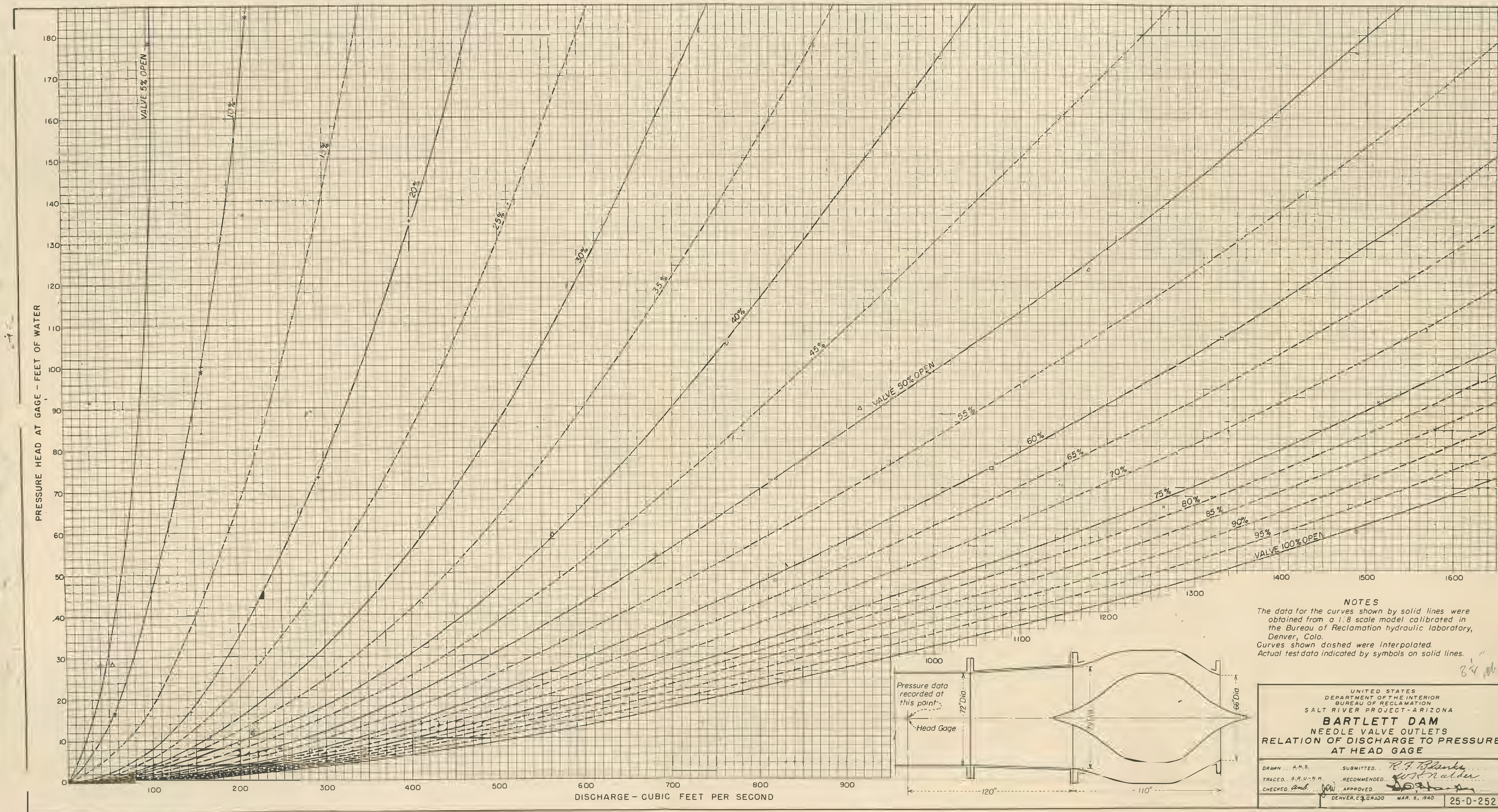
> "By installing a recording pressure gage on the piezometer outlets from the needle valve conduits, a continuous record of the pressure will be obtained. The valve opening can be recorded each time the operator changes the setting. By integration, the total flow can be computed over a given period."

The determination of discharge through measurement of pressure head a short distance upstream from the valve may seem unorthodox to the operator accustomed to obtaining discharge through outlets from the water surface elevation in the reservoir. However, discharge curves based upon the water surface elevation would not be accurate because frictional losses in the conduit of the prototype can not be duplicated in the model with any degree of precision. Even if this were done, the results would be uncertain because the friction of the prototype conduit will change with time, due to rust accumulations, and growths may appear gradually in the conduit. By measuring the pressure head near the valve all uncertainties can be eliminated inasmuch as losses by friction through the valves are negligible.

CHAPTER III - NEEDLE-VALVE TESTS

6. Use of 1:8 Bartlett Dam model for initial Friant Dam needle-valve tests. As can be seen in the difference between the dates of the first letter requesting means of measuring flow at Bartlett Dam, February 18, 1937, and the final transmittal of the rating curves for needle valves March 23, 1940, considerable time elapsed. This was due to the problem of the calibration of the model needle valve being subject to postponement in the face of more urgent work. However, when the problem of improving the design of the Friant Dam needle valves was assigned to the hydraulic laboratory, the 1:8 Bartlett model was used for initial tests since this model was similar to other prototype valves in which adverse effects of cavitation were observed. These studies included a detailed

FIGURE 8


PRESSURE HEAD AT GAGE - FEET OF WATER
DISCHARGE - CUBIC FEET PER SECOND
VALVE 5% OPEN
10%
15%
20%
25%
30%
35%
40%
45%
VALVE 50% OPEN
55%
60%
65%
70%
75%
80%
85%
90%
95%
VALVE 100% OPEN
NOTES
The data for the curves shown by solid lines were obtained from a 1:8 scale model calibrated in the Bureau of Reclamation hydraulic laboratory, Denver, Colo.
Curves shown dashed were interpolated.
Actual test data indicated by symbols on solid lines.
Pressure data recorded at this point
Head Gage
72" Dia.
66" Dia.
120"
110"
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT - ARIZONA
BARTLETT DAM
NEEDLE VALVE OUTLETS
RELATION OF DISCHARGE TO PRESSURE
AT HEAD GAGE
DRAWN A.N.S.
SUBMITTED R. F. Blanks
TRACED A.R.U.-N.H.
RECOMMENDED W. H. Nalder
CHECKED
APPROVED
DENVER, COLORADO MAR. 6, 1940
25-D-2527

pressure-discharge study covering the entire range of head and valve openings. In this way it was possible to complete the calibration requested by the field, chapter II, and at the same time make the initial Friant test.

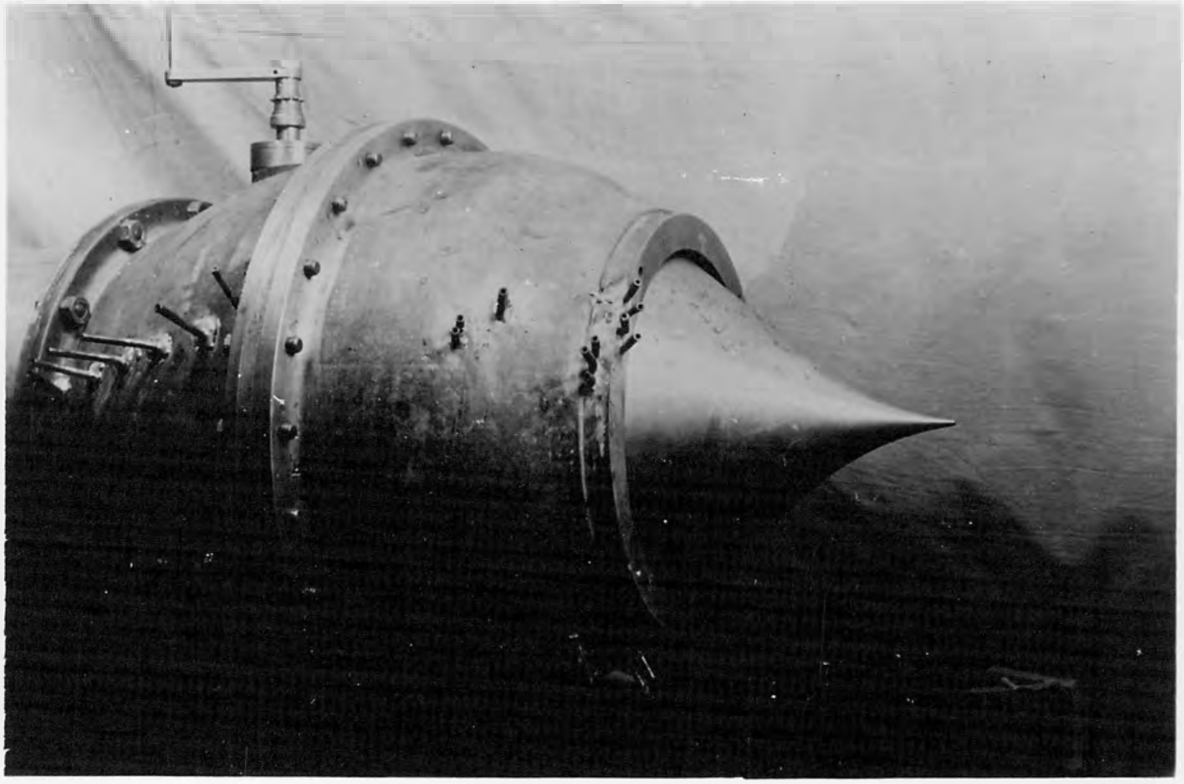
Negative pressures in the model paralleled cavitation in similar prototype structures. The model pressure gradients indicated a region of negative pressures on the needle immediately below the seat at valve openings up to 30 percent, and also on the curved portion of the nozzle downstream from its seat. Reports on prototype structures indicated that the region of cavitation on needles was immediately downstream from the seat and that it was severe up to openings of 30 percent but negligible when the valve was wide open. Cavitation also occurred on the curved portion of prototype nozzles downstream from the seat.

To eliminate negative pressures, the needle and the nozzle of this 1:8 Bartlett model were revised according to recommendations from previous tests on the 5-inch needle valve, described in the report, "Hydraulic Model Studies for the Design of Valves for Outlet Works," (Hyd.-98) by N. G. Noonan, H. M. Martin, and D. J. Hebert, August 1941. The angle between the needle and the nozzle was made to converge three degrees, a sharp-edged exit was used, and the seat was on the cone portion of the needle.

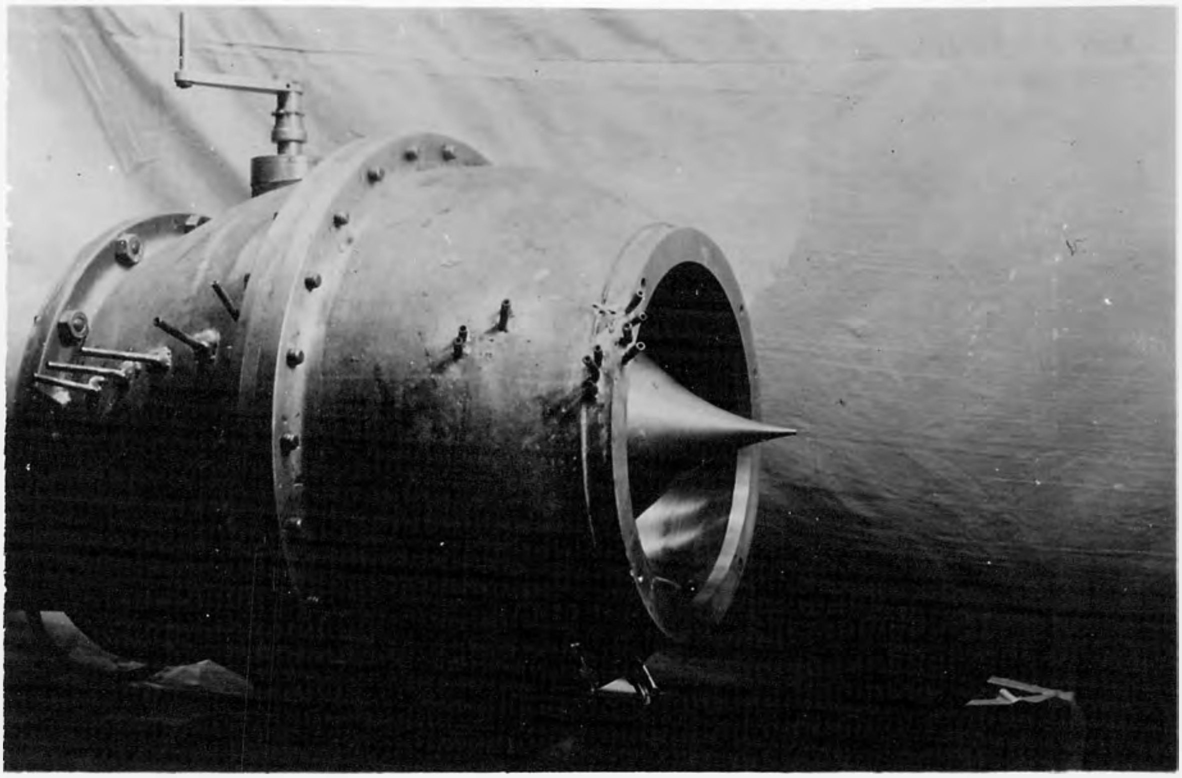
Pressure-discharge measurements on this revised valve were compared with the original Bartlett Dam model. The pressure gradients of the revised valve showed no negative pressures, but the discharge was only 85 percent of that of the original Bartlett Dam model. These two tests were considered as the initial tests for the design of the Friant Dam needle valves and were designated as tests 1 and 2. Their results seemed to define two limitations, for their pressure-discharge characteristics were opposite. The original 1:8 Bartlett valve, test 1, had a favorable discharge but developed negative pressures, while the valve of test 2 had positive pressures but the discharge was reduced. Tests on the Friant Dam needle valves could start by using a valve similar to the one used in test 2. Changes could be made to the nozzle and the needle so that positive pressures obtained in test 2 would be maintained but the discharge increased. These changes might be continued until a point was reached where a further increase of discharge would cause negative pressures. Such a valve would ostensibly be the ideal design.

Although this general method for conducting the preliminary studies was clear, two factors had to be decided before the testing could proceed. First, it was necessary to design a model of the Friant Dam needle valve to include the desirable features of the needle valve used in test 2; and secondly, it was necessary to determine a testing procedure and decide upon a point at which the area and the head would be measured for determining the coefficient of discharge.

7. The model. Since the Bartlett Dam needle-valve model was used in the initial tests for the Friant Dam needle valve, it was suggested that this model be adapted for use in the tests which were to follow (figures 9 and 10). Accordingly, a scale ratio of 1 to 12.3 was established for the Friant model by comparing the equatorial diameter of the body of the 1:8 Bartlett model to that of the tentative design of the Friant valves. Upstream from the equator of the adapted 1 to 12.3 Friant model, similarity between this model and the tentative design for the Friant Dam needle valves did not exist. For example, the 9-7/8-inch entrance diameter of the 1 to 12.3 model was equivalent to an entrance diameter of 121-1/2 inches in the prototype, while the actual entrance diameter for the Friant Dam needle valves will be 110 inches. This is not considered a serious departure in the tests since the primary function of the tests was to study the effect of different conditions of the needle and the nozzle, and it was contemplated that the design with the most favorable pressure-discharge conditions would be duplicated later in a model having the proper approach conditions. This later model was constructed to a scale ratio of 1 to 18.33, and duplication tests to check the effect of dissimilar entrance conditions between the 1 to 12.3 scale model and the 1 to 18.33 model concluded the needle-valve tests.

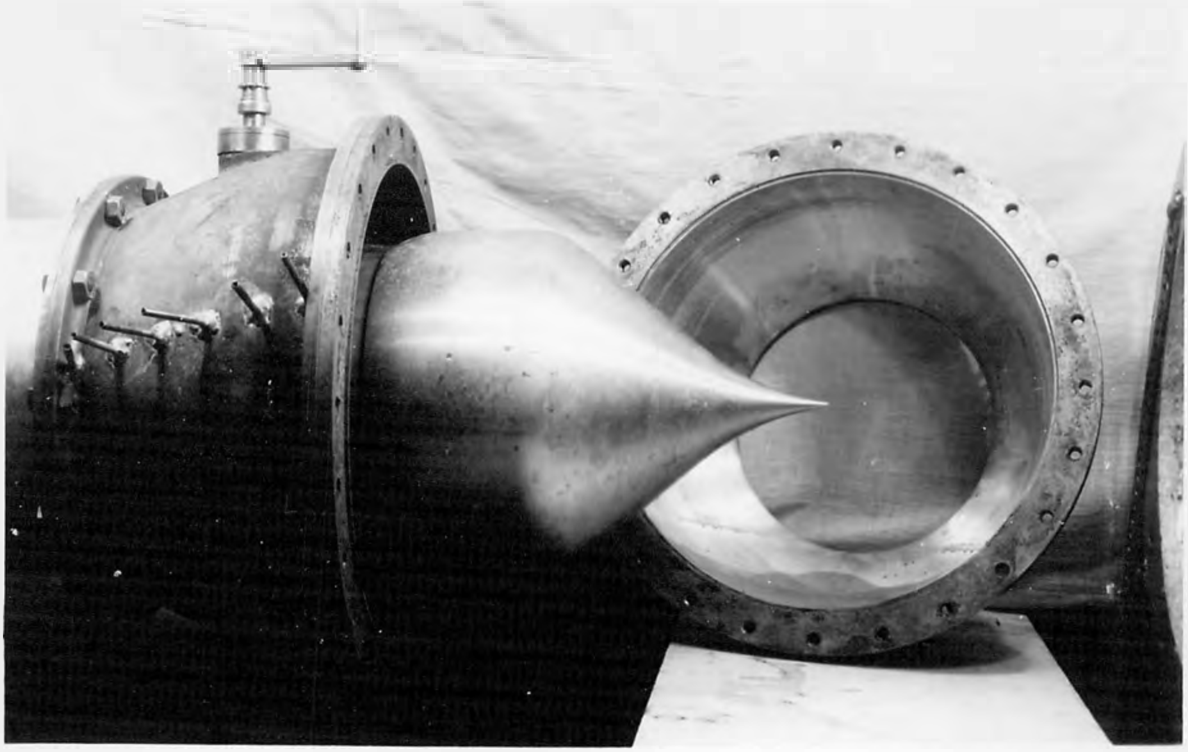


NEEDLE IN CLOSED POSITION

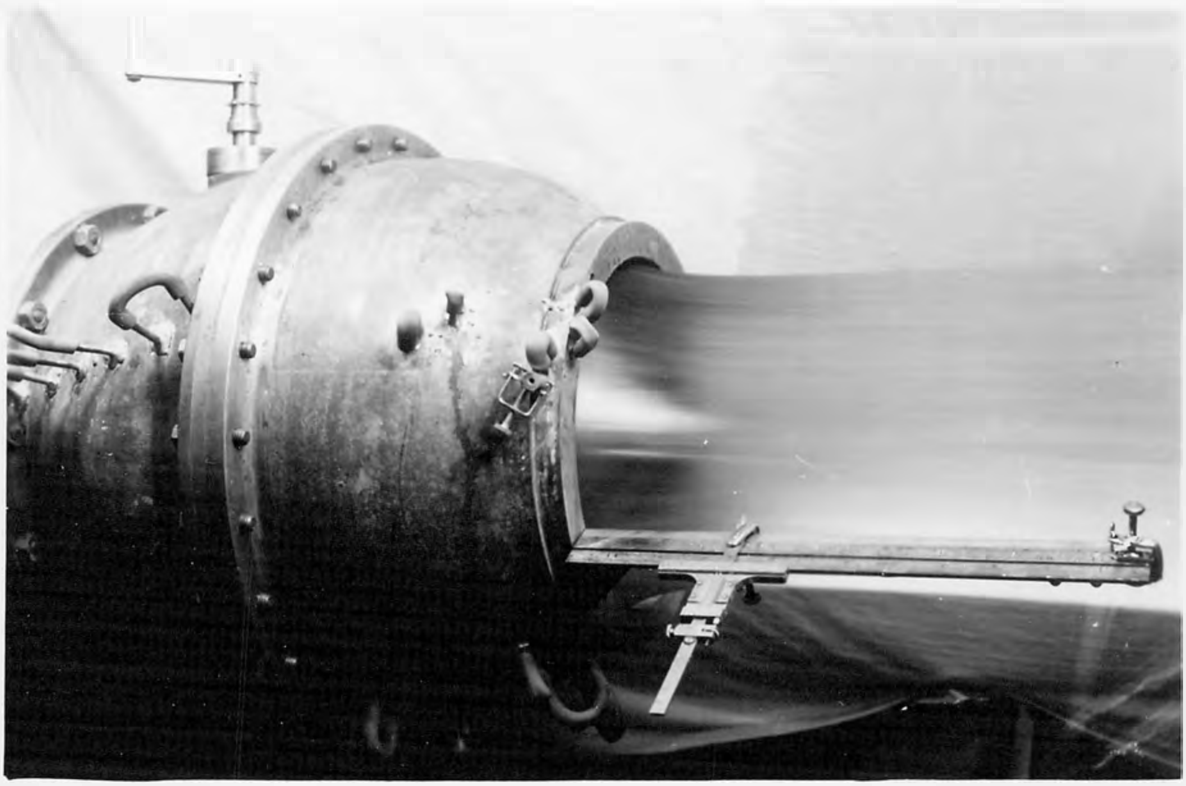


NEEDLE IN OPEN POSITION

1:12.3 NEEDLE VALVE MODEL



NOZZLE REMOVED SHOWING NEEDLE



VALVE DISCHARGING, 100 PERCENT OPEN,
SHOWING ATTACHMENT FOR MEASURING JET PROFILE

1:12.3 NEEDLE VALVE MODEL

In adapting the Bartlett Dam model needle valve to be used as a model for the Friant Dam needle valves, B. A. Halliday, in a memorandum to Senior Engineer W. C. Beatty, questioned the loss in the expanding entrance section which was part of the Bartlett Dam needle-valve model (figure 7). In a memorandum to Senior Engineer W. C. Beatty dated March 14, 1940, J. E. Warnock states this loss to be negligible:

> "In my opinion too much emphasis has been placed on this factor. To satisfy all interested persons, including ourselves, the conduit with the expanding section is being replaced by a constant-diameter conduit, and key tests will be repeated to give comparable data directly applicable to the Friant problem."

After the constant-diameter conduit was installed and the key tests were made, it was shown that the entrance losses in the expanding entrance section were negligible. These tests, reruns of the original and the revised Bartlett model valve, were designated as tests 1-R and 2-R. The 1 to 12.3 model used in the preliminary tests thus consisted of a constant-diameter entrance conduit to which was attached the body of the valve of the original Bartlett Dam model. A 3/8-inch sleeve was constructed to lengthen the body of the valve to study the effect of increasing the travel of the needle. An attachment was also constructed to measure the jets in the different tests (figure 10).

The 1 to 16.33 scale model needle valve had no special attachments besides piezometer connections for the measurement of pressure gradients.

8. <u>Testing procedure and measurement of coefficient of discharge.</u> As the pressure gradients and discharge coefficients were the important objectives, the testing was mainly to determine these factors for a complete range of heads and valve openings. The pressure gradients were measured by piezometers located along the critical sections of the needle and the nozzle. For each test, valve openings of 5, 20, 30, 50, 75, and 100 percent were studied. When the valve was 100 percent open, four runs were made by setting heads ranging from 2 to 22 feet of water. For all other valve openings only two runs were made, at heads of approximately

8 and 22 feet of water. The steps in making each run were to measure the valve opening and to set a discharge that gave the desired head. This discharge was then measured over a 90-degree V-notch weir while pressures on the needle and the nozzle were recorded.

In addition to these data, jet profiles were measured with the valves 100 percent open and the condition of the jet was noted at all other openings.

The coefficient of discharge C is the ratio of the actual discharge of a valve Q to a theoretical discharge $A\sqrt{2gH}$ in the formula $C = \frac{Q}{A\sqrt{2gH}}$ where A represents an area through which the water passes and H the head. While the area A is not based upon any fixed point in a valve, it may be that of the vena contracta of the jet, or the outlet diameter of the valve, or the diameter of the conduit to which the valve is attached. Some differences in opinion existed as to which point was best suited for these studies, but it was finally decided to base the area A upon the diameter of the conduit to which the valve was attached.

Questions also arose as to the best point for measuring the head, H. The best head to use would be the water surface elevation of the reservoir, but it was not convenient to do this in the model studies. Also, losses would not be the same in different conduits upstream from the valves. Therefore, the head was first measured at the upstream flange of the valve and defined as the pressure head plus the velocity head. Pressure gradients indicated a disturbance at this point, and, to avoid this disturbance, the head was finally measured one diameter upstream from the upstream flange of the valve. This definition excluded the use of an expanding entrance, such as was on the original model of the Bartlett Dam needle valve (figure 7), but demanded the constant-diameter approach conduit which was placed in the model to eliminate any possible losses due to the expanding entrance section.

9. Description of tests. After the first two tests were made, the expanding entrance section was replaced by the constant-diameter conduit and reruns of these tests, 1-R and 2-R, were considered as the first tests

of the Friant program (figure 11). As the test program was to involve changes in the outlet section of the revised valve, test 2-R, these changes were outlined and the following 15 tests made (figures 11, 12, and 13).

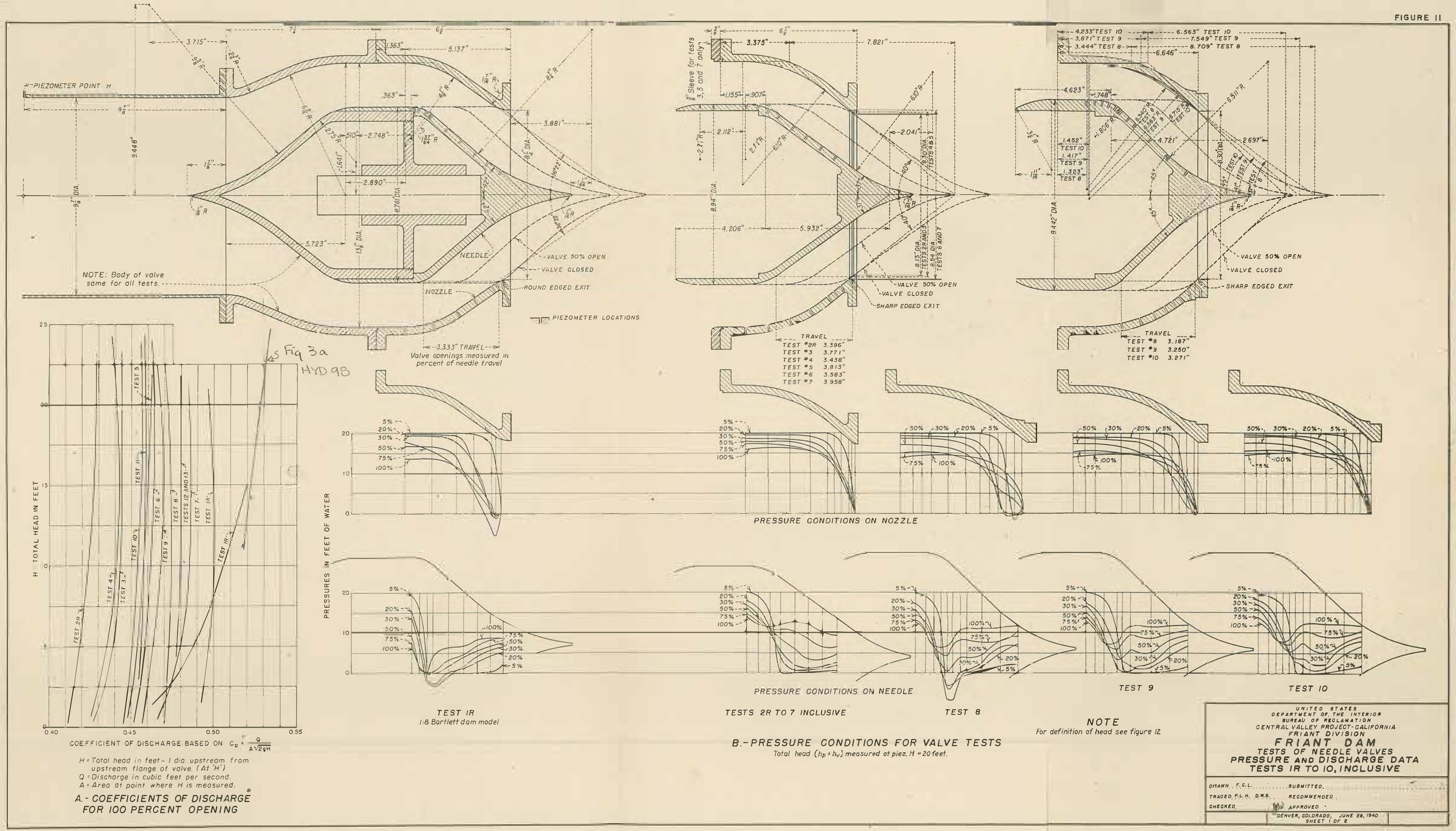
Test	
1-R	Rerun of test 1 on adapted Bartlett Dam needle valve to eliminate the effect of expanding entrance section (figure 11 B).
2-R	Rerun of test 2 on adapted Bartlett Dam needle valve to eliminate the effect of expanding entrance section.
3	Similar to test 2-R, except body of valve lengthened 3/8 inch to study effect of increased travel of needle.
4	Similar to test 2-R, except outlet diameter increased from 8.13 inches to 8.30 inches to study effect of increasing outlet diameter.
5	Similar to test 4, except body of valve increased 3/8 inch.
6	Similar to test 4, except outlet diameter increased to 8.54 inches.
7	Similar to test 6, except body of valve increased 3/8 inch.
8	Trial 1 - Mechanical section.
9	Trial 2 - Mechanical section.
10	Trial 3 - Mechanical section.
11	Trial 4 - Mechanical section (figure 12).
12	Trial 5 - Mechanical section.
13	Trial 6 - Mechanical section.
14	Similar to test 13, except body of valve increased 3/8 inch to study effect of travel of needle.
15	Duplication test on the 1:18.33 scale model to eliminate the effect of the difference in entrance conditions between the 1 to 12.3 scale model and the tentative Friant Dam needle-valve design (figure 13).

Test 1-R was similar to the original 1:8 Bartlett Dam needle valve, while tests 2-R through 7 studied variations in the revised valve of test 2, as noted above. Tests 8, 9, and 10, submitted by the mechanical section, studied changes in the contour of the nozzle of a needle valve similar to test 2-R. Tests 11 and 12 simulated the design for the Friant Dam needle valves. In this design, outlet diameters of 102 and 105 inches were proposed; thus test 11 had an outlet diameter equivalent to 102 inches and test 12 had an outlet diameter equivalent to 105 inches. As the nozzle of test 12 was formed with a compound curve, test 13 was similar to test 12 except the nozzle was made with a simple curve.

10. Selection of a valve for Friant Dam. The tests outlined in section 9 served two purposes: (1) to select a valve to be used for the design of the needle valves at Friant Dam, which was urgent; and (2) later, when time permitted, to study a few characteristics of needle valves from a general analysis of the test data.

To select a valve to be used for the design of the needle valves at Friant Dam, the results of tests 1 through 14, shown in figures 5 and 6, were compiled as follows:

Test	Pressures	Discharge coefficient	Remarks
1-R	Negative	0.51	Not satisfactory because of negative pressures.
2-R	Positive	0.425	Not satisfactory because of low discharge.
3	Positive	0.440	Not satisfactory because of low discharge.
4	Positive	0.438	Not satisfactory because of low discharge.
5	Positive	0.460	Not satisfactory because of low discharge.
6	Positive	0.462	Valve did not seat.
7	Positive	0.482	Valve did not seat.
8	Negative	0.474	Not satisfactory because of negative pressures.
9	Slight negative	0.470	Surface irregularities in prototype might cause cavitation.
10	Positive	0.456	Not satisfactory because of low discharge.
11	Positive	0.458	Not satisfactory because of low discharge.
12	Positive	0.480	Valve selected for further tests.


PIEZOMETER POINT H
NOTE: Body of valve same for all tests.
NEEDLE
NOZZLE
VALVE 50% OPEN
VALVE CLOSED
ROUND EDGED EXIT
SHARP EDGED EXIT
PIEZOMETER LOCATIONS
3.333" TRAVEL
Valve openings measured in percent of needle travel
1/8" Sleeve for tests 3, 5 and 7 only
TRAVEL
TEST #2R 3.396"
TEST #3 3.771"
TEST #4 3.438"
TEST #5 3.813"
TEST #6 3.583"
TEST #7 3.958"
TRAVEL
TEST #8 3.187"
TEST #9 3.250"
TEST #10 3.271"
4.233" TEST 10
3.871" TEST 9
3.444" TEST 8
6.563" TEST 10
7.549" TEST 9
8.709" TEST 8
Fig 3a
HYD 98
H - TOTAL HEAD IN FEET
COEFFICIENT OF DISCHARGE BASED ON $C_D = \frac{Q}{A\sqrt{2gH}}$
H = Total head in feet - 1 dia. upstream from upstream flange of valve. (At 'H')
Q = Discharge in cubic feet per second.
A = Area at point where H is measured.
A.- COEFFICIENTS OF DISCHARGE FOR 100 PERCENT OPENING
PRESSURES IN FEET OF WATER
PRESSURE CONDITIONS ON NOZZLE
PRESSURE CONDITIONS ON NEEDLE
TEST 1R
1:8 Bartlett dam model
TESTS 2R TO 7 INCLUSIVE
TEST 8
TEST 9
TEST 10
NOTE
For definition of head see figure 12
B.- PRESSURE CONDITIONS FOR VALVE TESTS
Total head $(h_p + h_v)$ measured at piez. H = 20 feet.
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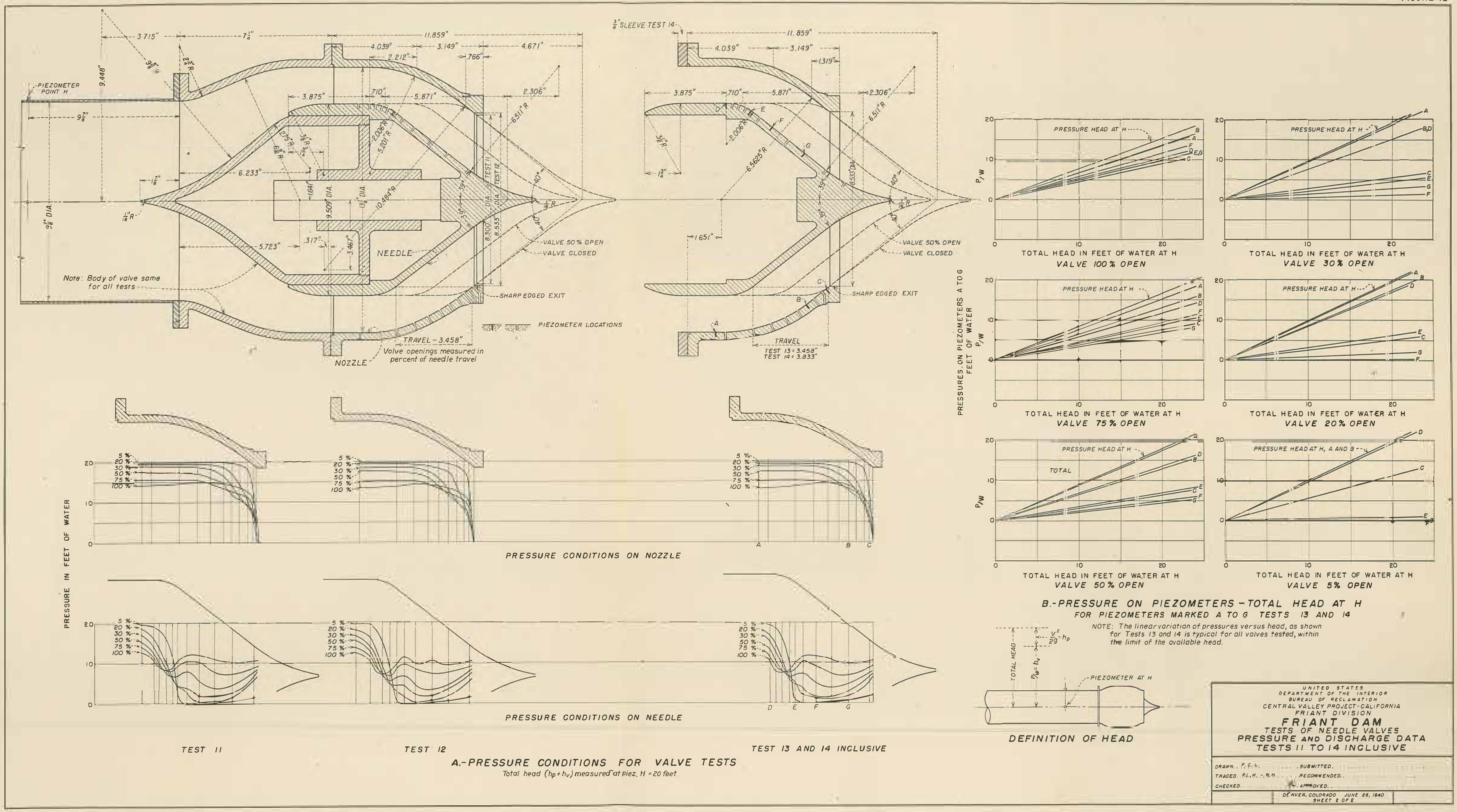
FRIANT DIVISION
FRIANT DAM
TESTS OF NEEDLE VALVES
PRESSURE AND DISCHARGE DATA
TESTS 1R TO 10, INCLUSIVE
DRAWN F.C.L. SUBMITTED
TRACED P.L.H. D.W.S. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO, JUNE 28, 1940
SHEET 1 OF 2
FIGURE 11

FIGURE 12



PIEZOMETER POINT H
Note: Body of valve same for all tests
NEEDLE
NOZZLE
TRAVEL - 3.458"
Valve openings measured in percent of needle travel
VALVE 50% OPEN
VALVE CLOSED
SHARP EDGED EXIT
PIEZOMETER LOCATIONS
TEST 11
TEST 12
3/8" SLEEVE TEST 14
TRAVEL
TEST 13 = 3.458"
TEST 14 = 3.833"
PRESSURE IN FEET OF WATER
PRESSURE CONDITIONS ON NOZZLE
PRESSURE CONDITIONS ON NEEDLE
TEST 11
TEST 12
TEST 13 AND 14 INCLUSIVE
A.-PRESSURE CONDITIONS FOR VALVE TESTS
Total head ($h_p + h_v$) measured at piez. H = 20 feet
PRESSURES ON PIEZOMETERS A TO G FEET OF WATER
P/W
PRESSURE HEAD AT H
TOTAL HEAD IN FEET OF WATER AT H
VALVE 100% OPEN
VALVE 30% OPEN
VALVE 75% OPEN
VALVE 20% OPEN
VALVE 50% OPEN
VALVE 5% OPEN
PRESSURE HEAD AT H, A AND B
TOTAL
B.-PRESSURE ON PIEZOMETERS - TOTAL HEAD AT H
FOR PIEZOMETERS MARKED A TO G TESTS 13 AND 14
NOTE: The linear variation of pressures versus head, as shown for Tests 13 and 14 is typical for all valves tested, within the limit of the available head.
TOTAL HEAD
$\frac{V^2}{2g} = h_v$
$P/W = h_p$
PIEZOMETER AT H
DEFINITION OF HEAD
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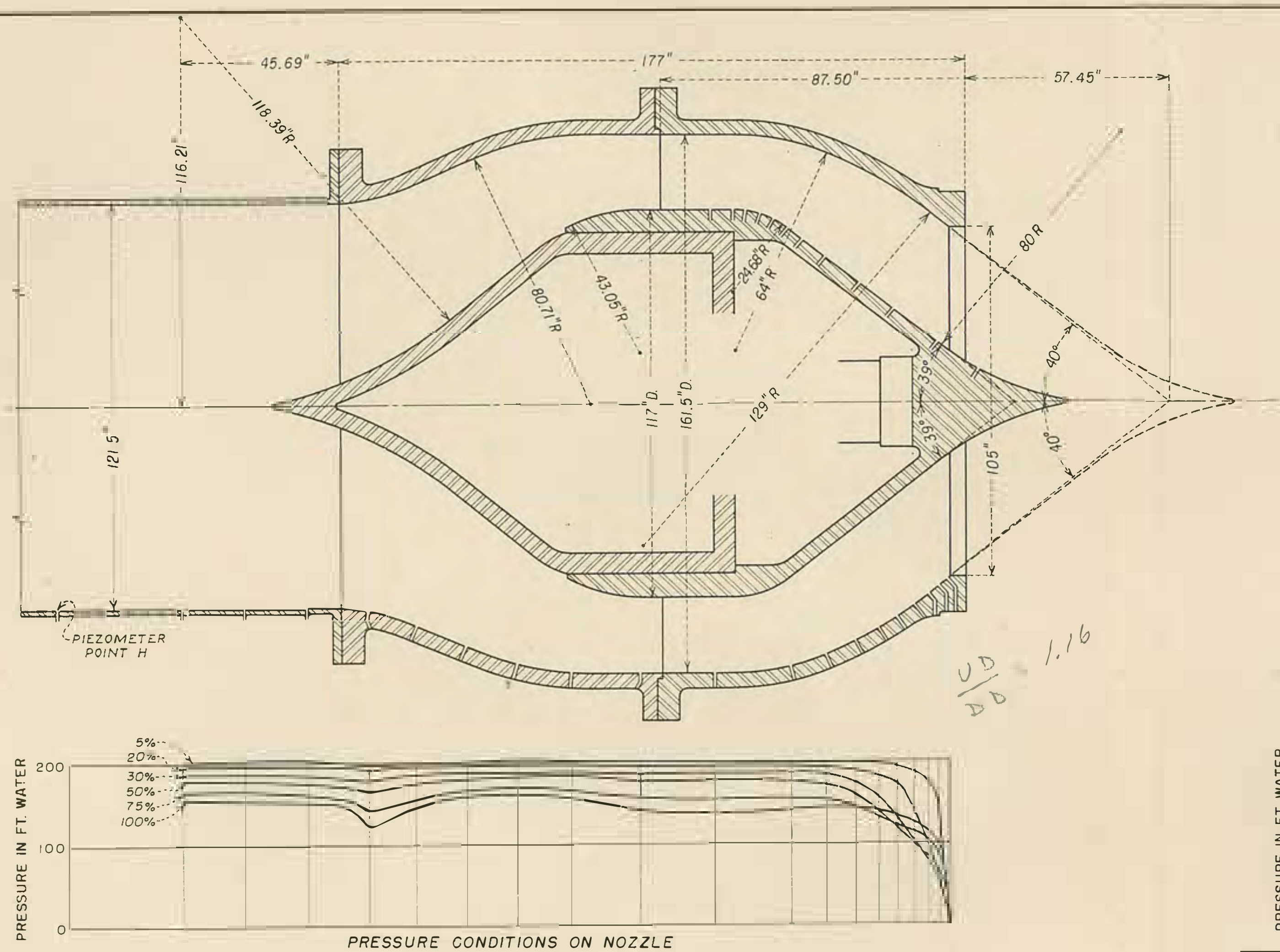
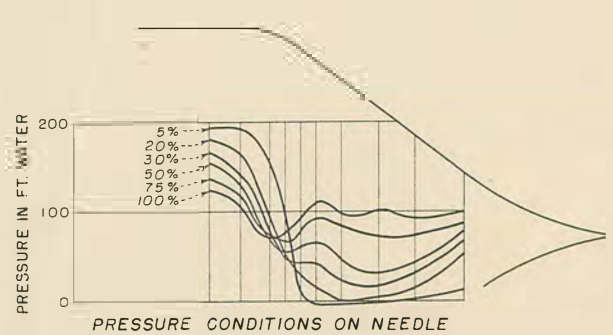
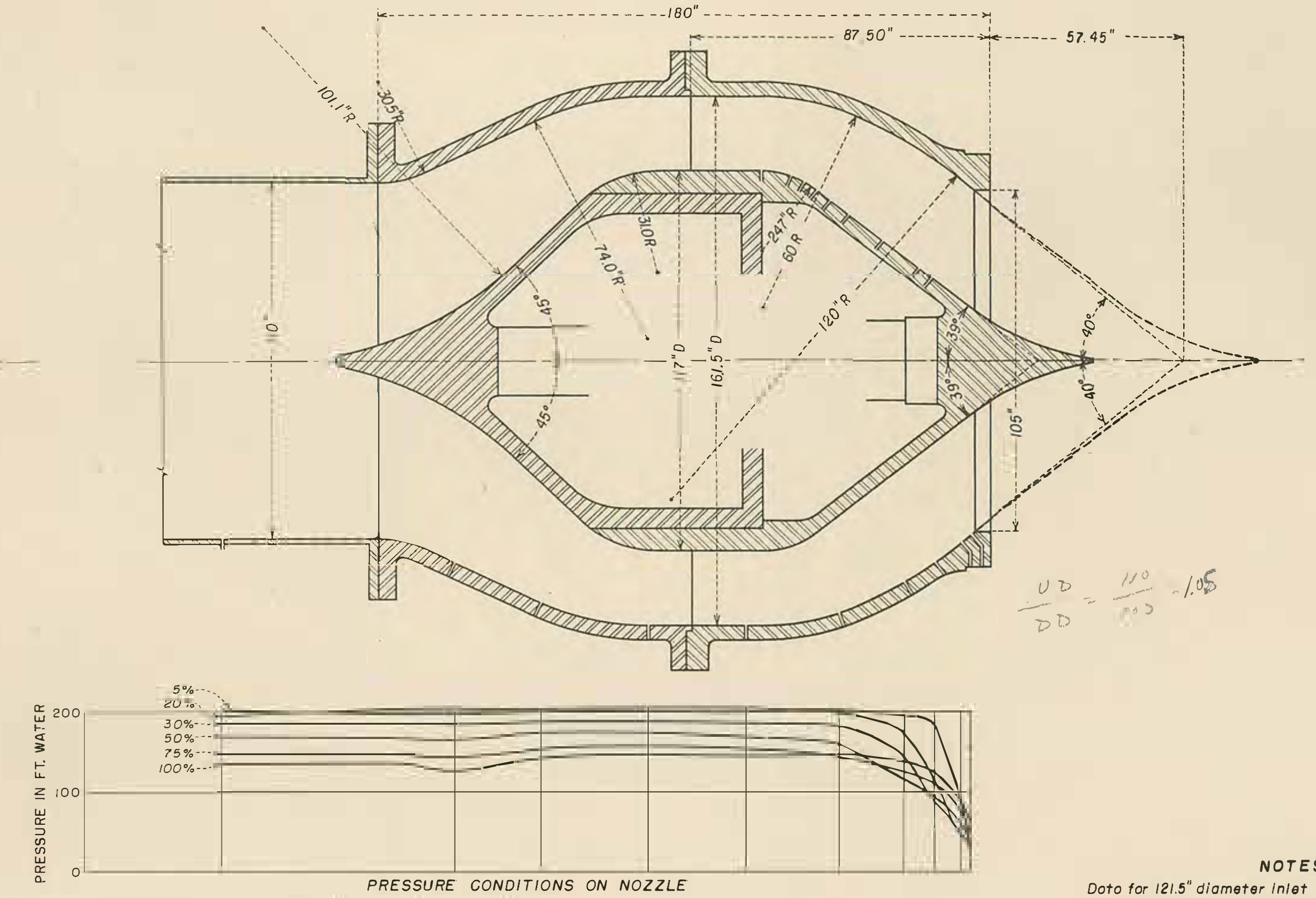
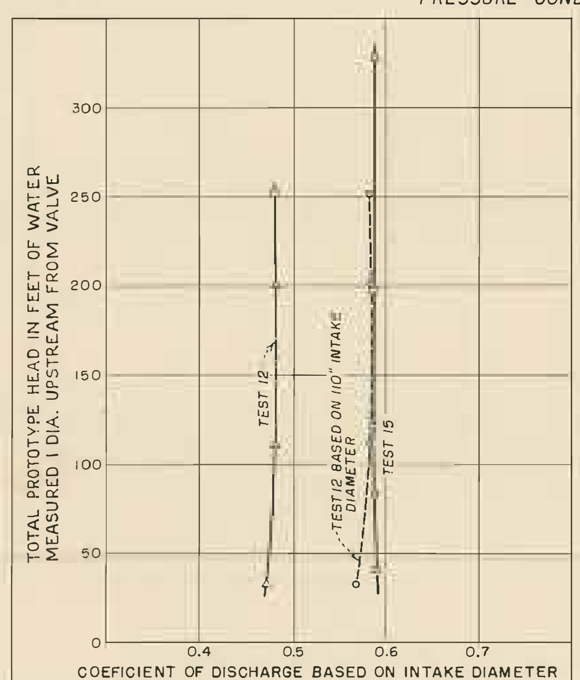
FRIANT DIVISION
FRIANT DAM
TESTS OF NEEDLE VALVES
PRESSURE AND DISCHARGE DATA
TESTS 11 TO 14 INCLUSIVE
DRAWN.. F.C.L. SUBMITTED
TRACED. R.L.H. - R.H. RECOMMENDED
CHECKED. APPROVED
DENVER, COLORADO JUNE 26, 1940
SHEET 2 OF 2

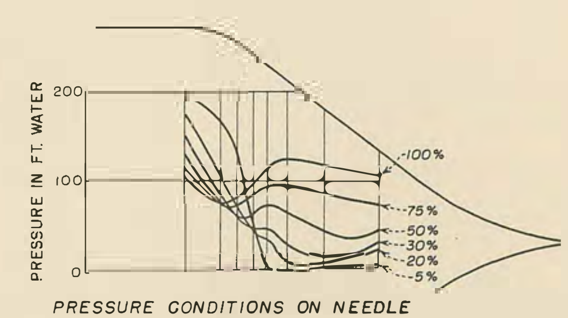




TEST 12







TEST 15

$\left(\frac{1.16}{1.05}\right)^2 = 1.22$

NOTES

Data for 121.5" diameter inlet (Test 12) was obtained from 1:12.3 scale model.
Data for 110" diameter inlet (Test 15) was obtained from 1:18.33 scale model.
Pressures for head = 200 feet prototype

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FRIANT DAM
TESTS OF NEEDLE VALVES
EFFECT OF INLET DIAMETER ON PRESSURES AND COEFFICIENTS TESTS 12 AND 15

DRAWN.. F.C.L. ..SUBMITTED.
TRACED. P.L.H. - M.E.K. .RECOMMENDED.
CHECKED. . JEW .APPROVED.
DENVER, COLORADO — OCT. 17, 1940

Test	Pressures	Discharge coefficient	Remarks
13	Positive	0.480	Performance as good as test 12.
14	Positive	0.500	Increased length of valve not economical.

The contour of the valve of test 12 was selected as that for the final design of the Friant Dam needle valve, and the 1 to 18.33 model of the final design of the Friant needle valve was constructed to produce the proper approach conditions. Pressures on this valve were, for all practical purposes, the same as those of the valve of test 12, and the coefficient of discharge was 0.584. .585

Although the coefficient of the 1 to 18.33 model is larger than the coefficient of the 1 to 12.3 model, it was shown that the relative quantity of water through both valves was the same. Figure 13 shows both valves in prototype dimensions. The principal difference is the 121-1/2-inch intake diameter for the valve of test 12 and the 110-inch intake diameter for the valve of test 15. If the energy head at both of these valves were the same, it can be shown that the discharge $Q = CA\sqrt{2gh}$ will be the same for all practical purposes, since the product $C \times A$ is the same for both valves. This must be true since the control is at the exit end of the valve and losses through the valve are negligible.

11. Measurement of jet profiles. Throughout the tests the shape and the condition of the jets were observed and the jets of tests 2-R through 14 were profiled up to their vena contracta with the valves 100 percent open (table 3). Observations of jets were made in the previous tests of the 5-inch valve and included as photographs in the report, "Hydraulic Model Studies for the Design of Valves for Outlet Works." HYD 78 In those tests and in tests 1-R to 15, inclusive, it was observed that the jets were more solid and had a better general appearance in valves having a sharp-edged nozzle exit than in valves having a curved nozzle exit. However, this difference should not be important in a prototype outlet although the sharp-edged exit might be preferable because it should cause less spray.

The jets of tests 2-R to 14, inclusive, were profiled by the coordinometer shown in figure 10. The procedure was to place the depth gage at a given position on the bar which was parallel to the axis of the valve and to move the point of the depth gage into the jet until it touched a solid wall of water. A white streak then appeared downstream from the depth-gage point. Near the valve exit the water surface was clear so that precise measurements could be obtained, but several inches downstream a spray began to form which concealed the actual boundary of the jet, making the above procedure necessary. At about six inches downstream from the nozzle exit the position of the jet boundary began to fluctuate, so no further measurements could be made. Apparently the vena contracta of the jets was about six inches from the nozzle exit. However, it was impossible to find the actual location. Since the vena contract was in a region difficult to measure, table 3 which gives the jet diameter at various distances from the valve exit should not be applied where a precise determination of the vena contracta is required.

12. Pressure-discharge study. In addition to evolving a valve design for Friant Dam, these tests were sufficient to study some pressure-discharge characteristics of needle valves having a sharp-edged nozzle exit. The object of this discussion is to state a criterion for maintaining positive pressures at all points in the valve at any valve opening and then to show how a maximum discharge coefficient may be obtained within this pressure criterion. For clarity, several terms are defined, as follows:

(a) Control.--The minimum area of passage through the valve, where velocities are a maximum and pressures a minimum, is the control. To maintain positive pressures through the valve, the control should always be at the exit of the outlet section of the valve.

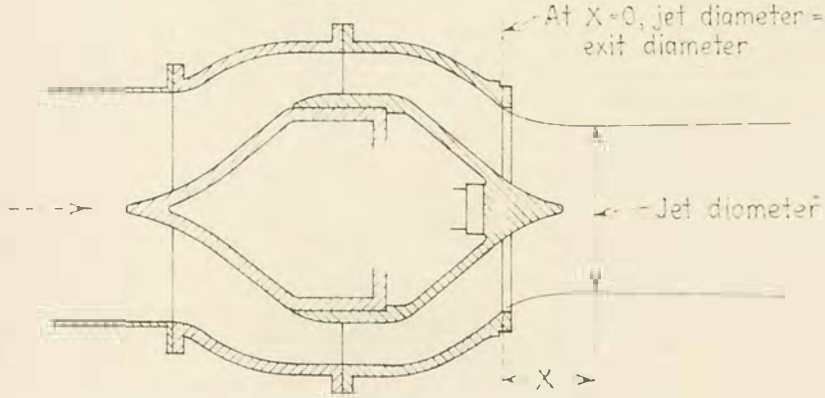
(b) Outlet section of the valve.--Before the water discharges from the valve into the atmosphere, it flows between two conical surfaces because a short section of the nozzle immediately upstream from its exit forms the frustrum of a cone, and opposite, a section of the needle downstream from its seat also forms the frustrum of a cone (figure 14). These

TABLE 3

FRIANT DAM NEEDLE-VALVE TESTS

MEASUREMENT OF JET PROFILES - VALVES 100 PERCENT OPEN

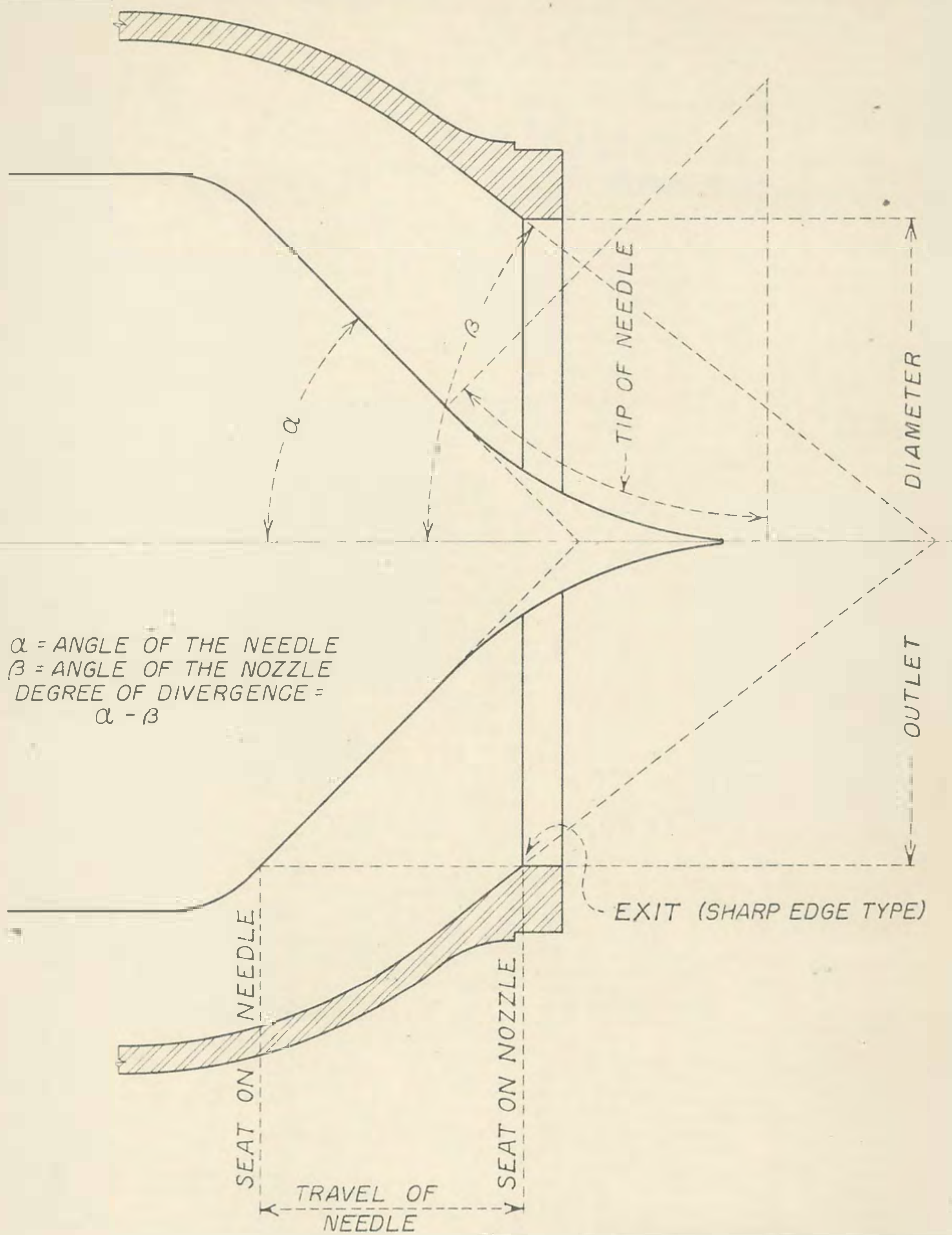
TESTS 2-R TO 14



Model data - All dimensions in inches

Test No.	2-R	3	4	5	6	7	8	9	10	11	12	13	14
X						Jet diameter at X							
0	8.130	8.13	8.30	8.30	8.54	8.54	8.30	8.30	8.30	8.30	8.533	8.533	8.533
0.25	7.89	7.89	8.03	8.03	8.21	8.22	8.03	8.03	8.03	8.10	8.27	8.27	8.27
0.50	7.66	7.68	7.81	7.81	7.98	8.01	7.84	7.82	7.82	7.90	8.08	8.08	8.08
0.75	7.48	7.51	7.63	7.64	7.81	7.85	7.67	7.65	7.65	7.72	7.90	7.90	7.92
1.00	7.32	7.36	7.48	7.49	7.66	7.72	7.54	7.51	7.51	7.57	7.75	7.75	7.79
1.25	7.20	7.25	7.35	7.37	7.54	7.59	7.42	7.40	7.37	7.44	7.61	7.61	7.67
1.50	7.10	7.15	7.24	7.27	7.43	7.49	7.32	7.30	7.27	7.33	7.50	7.50	7.57
1.75	7.02	7.06	7.15	7.18	7.33	7.39	7.24	7.22	7.18	7.24	7.41	7.41	7.47
2.00	6.95	6.98	7.07	7.11	7.24	7.31	7.17	7.14	7.11	7.16	7.33	7.32	7.38
2.50	6.84	6.87	6.96	6.99	7.10	7.19	7.07	7.04	7.00	7.04	7.20	7.18	7.25
3.00	6.76	6.78	6.87	6.91	7.00	7.10	6.99	6.96	6.93	6.95	7.10	7.07	7.18
3.50	6.71	6.73	6.81	6.85	6.92	7.04	6.93	6.91	6.87	6.88	7.02	7.01	7.13
4.00	6.67	6.68	6.77	6.80	6.86	7.01	6.90	6.87	6.83	6.84	6.97	6.98	7.09
4.50	6.64	6.65	6.73	6.76	6.82	6.98	6.88	6.84	6.80	6.82	6.93	6.96	7.07
5.00	6.62	6.62	6.71	6.73	6.80	6.97	6.87	6.81	6.79	6.81	6.91	6.95	7.06
5.50	6.60	6.61	6.69	6.71	6.78	6.96	6.86	6.80	6.78	6.80	6.90	6.94	7.05
6.00	6.60	6.61	6.68	6.70	6.77	6.96	6.86	6.80	6.78	6.80	6.90	6.94	7.04

FIGURE 14



α = ANGLE OF THE NEEDLE
β = ANGLE OF THE NOZZLE
DEGREE OF DIVERGENCE = $\alpha - \beta$

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FRIANT DAM
TESTS OF NEEDLE VALVES
DESCRIPTION OF
OUTLET SECTION OF NEEDLE VALVE

DRAWN. F.C.L. SUBMITTED
TRACED. P.L.H.-N.H. RECOMMENDED
CHECKED. F.W. APPROVED
DENVER, COLO. 10-16-40

cones, forming the outlet section, are described by their angle with the axis of the valve.

(c) <u>Angle of the needle, or α</u>.

(d) <u>Angle of the nozzle, or β</u>.

(e) <u>Converging outlet section.--Where</u> α is less than β, the outlet section is converging.

(f) <u>Parallel outlet section.--Where</u> α is equal to β, the outlet section appears to be parallel. Actually, the area of passage is converging because the direction of flow is towards the apex of the cones forming the outlet section.

(g) <u>Diverging outlet section.--Where</u> α is greater than β the outlet section appears to diverge, and $\alpha - \beta$ is called the degree of divergence. Actually, divergence of passage indicated by $\alpha - \beta$ may not exist. Since the direction of flow between the cones forming the outlet section is toward their apex, it is possible that the passage area be converging although $\alpha - \beta$ appears to be diverging. Divergence or convergence of passage will depend upon the valve opening.

13. <u>Pressure studies.--To</u> maintain positive pressures in the valve, the outlet section must be designed to keep the control at the exit. It was with this object in view that recommendations for valve design were made after studies on the 5-inch valve at Boulder Dam were completed. These were, briefly, to have a converging outlet section, a sharp-edged nozzle exit, and the seat of the needle on the cone portion. With a converging outlet section, pressures were positive at all valve openings (tests 2-R to 7 and 11 to 14, inclusive). With a parallel outlet section, pressures were also positive (test 10). With a diverging outlet section they were negative at openings less than 50 percent (test 8). With a divergence of 4 degrees, pressures were negative at openings less than 10 percent (test 9).

It was apparent that the control would be at the exit of a converging outlet section and at the exit of a parallel section. However, with a diverging section the control was at the exit at wide valve openings but upstream from the exit at small valve openings, with resulting negative pressures. If a valve were not to be operated at small openings, a diverging outlet section could be used. To approximate the critical opening where pressures change from positive to negative with further closure of the valve, it is only necessary to compare the area at the exit with an area a short distance upstream. The factors involved will be α, β, the needle travel, and the outlet diameter. With 8 degrees divergence, test 8, this critical opening was calculated to be 43 percent, which agrees with the test data. With 4 degrees divergence, test 9, the critical opening was approximately 10 percent. However, at such a small opening the outlet passage was so short that the difference of areas was slight. Accordingly, negative pressures were not severe.

In addition to the outlet section, as described, the curvature of the needle upstream from the seat also caused a reduction in pressure and may cause adverse effects if no factor of safety is used in selecting the difference between angles α and β. No tests were made to study the effects of this curvature. As long as the seat of the needle is on the cone portion and the curvature is similar to the valves tested, it should not be the cause of trouble.

In connection with pressure studies it is well to note the relation of pressure to head. Figure 12 B shows this relation to be linear. Tests of the 5-inch valve at Boulder Dam under heads of 500 feet show a linear relation of pressure to head if all pressures in the valve are positive. However, if negative pressures are present it is difficult to determine the exact pressure-head relationship.

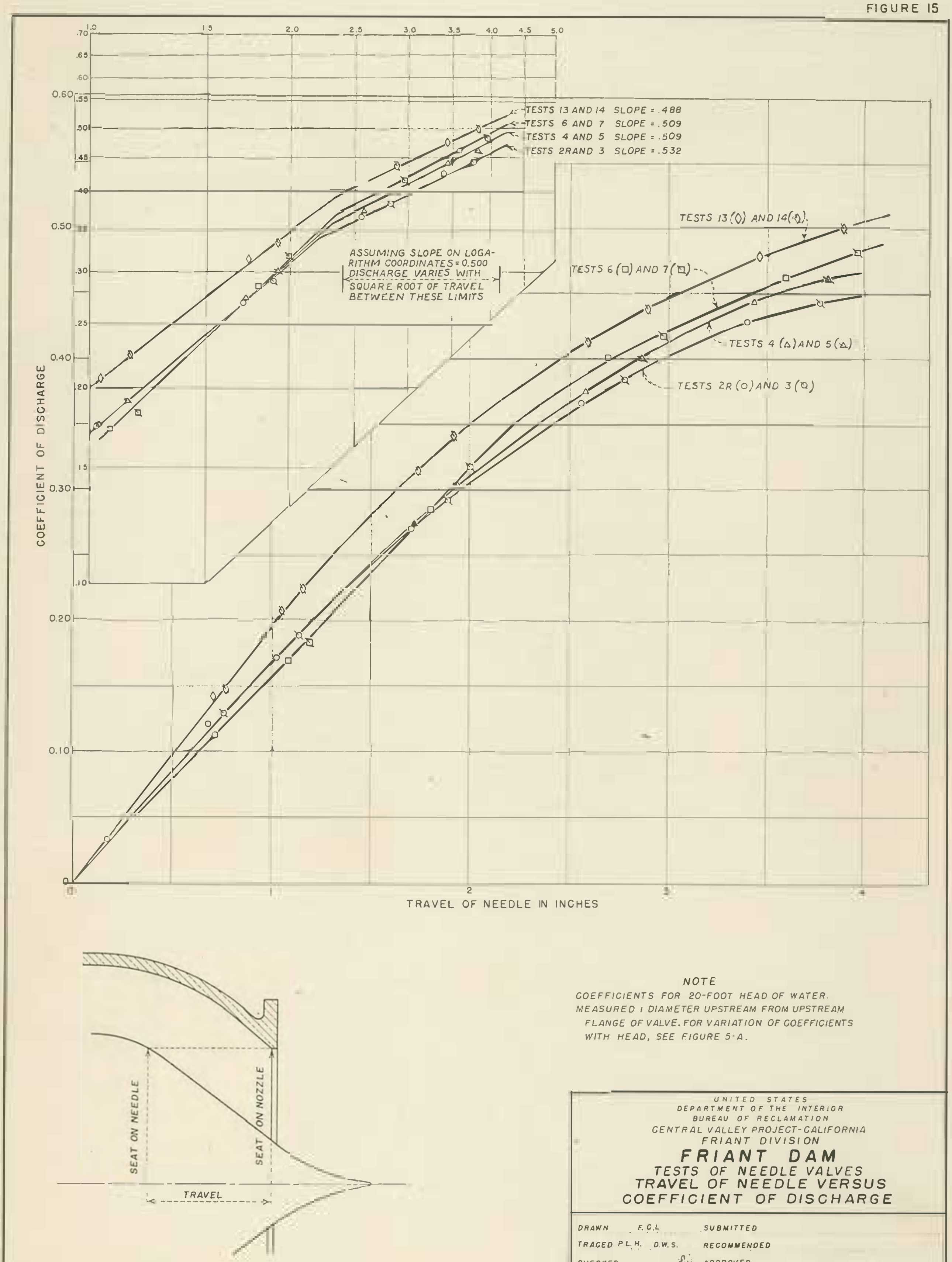
14. Discharge studies. A pressure criterion which selects a given divergence or convergence of the outlet section does not specify the actual values of α and β, but only their difference. Therefore, it follows that the values of α and β may be selected so as to give a maximum coefficient of discharge.

In comparing the discharge coefficients based on the intake diameter of 9.875 inches (121-1/2 inches prototype), it should be pointed out that the different valves did not have the same outlet diameter nor the same needle travel. As these features determined the size of the valve, any fair comparison should be based on valves having the same outlet diameter and needle travel. As the control of the valves was at their exit, it follows that the coefficient of discharge, based on the intake diameter, varied directly with the square of the exit diameter. To find a rule which governs changes of the coefficient with changes of needle travel, the curves of figure 15 were plotted. The increased travel of tests 3, 5, 7, and 14 was obtained by lengthening the valves of tests 2-R, 4, 6, and 13. Thus, the respective tests fell on the same curves when plotted on the needle travel-discharge coefficient coordinates of figure 15. Plotted on logarithmic coordinates, the coefficient of discharge was approximately proportional to the square root of the needle travel at valve openings greater than 2.5 inches (60 percent). The discharge coefficients were corrected to a valve having an outlet diameter of 8.300 inches and a needle travel of 3.187 inches.

Different values of α, β, $\alpha - \beta$, and the coefficient of discharge are shown in figure 16 and in the table below. As explained above, the discharge coefficients were based on an intake diameter of 9.875 inches and corrected to the selected needle travel and outlet diameter. Tests 2-R to 7, inclusive, were represented by test 4, for their discharge coefficient was the same when corrected to the selected outlet diameter and needle travel. For the same reason, tests 11 through 14 were represented by test 11.

Test No.	α, degrees	β, degrees	Divergence $\alpha - \beta$, degrees	Corrected discharge coefficient
4	37	40	-3	0.424
8	45	37	8	0.474
9	45	41	4	0.462
10	45	45	0	0.450
11	39	40	-1	0.439

The valves of tests 8, 9, and 10 of constant α (45 degrees) formed a straight line (curve A, figure 16). Assuming that a similar relationship would exist for other angles, curves B and C were drawn. The rel-



NOTE

COEFFICIENTS FOR 20-FOOT HEAD OF WATER. MEASURED 1 DIAMETER UPSTREAM FROM UPSTREAM FLANGE OF VALVE. FOR VARIATION OF COEFFICIENTS WITH HEAD, SEE FIGURE 5-A.

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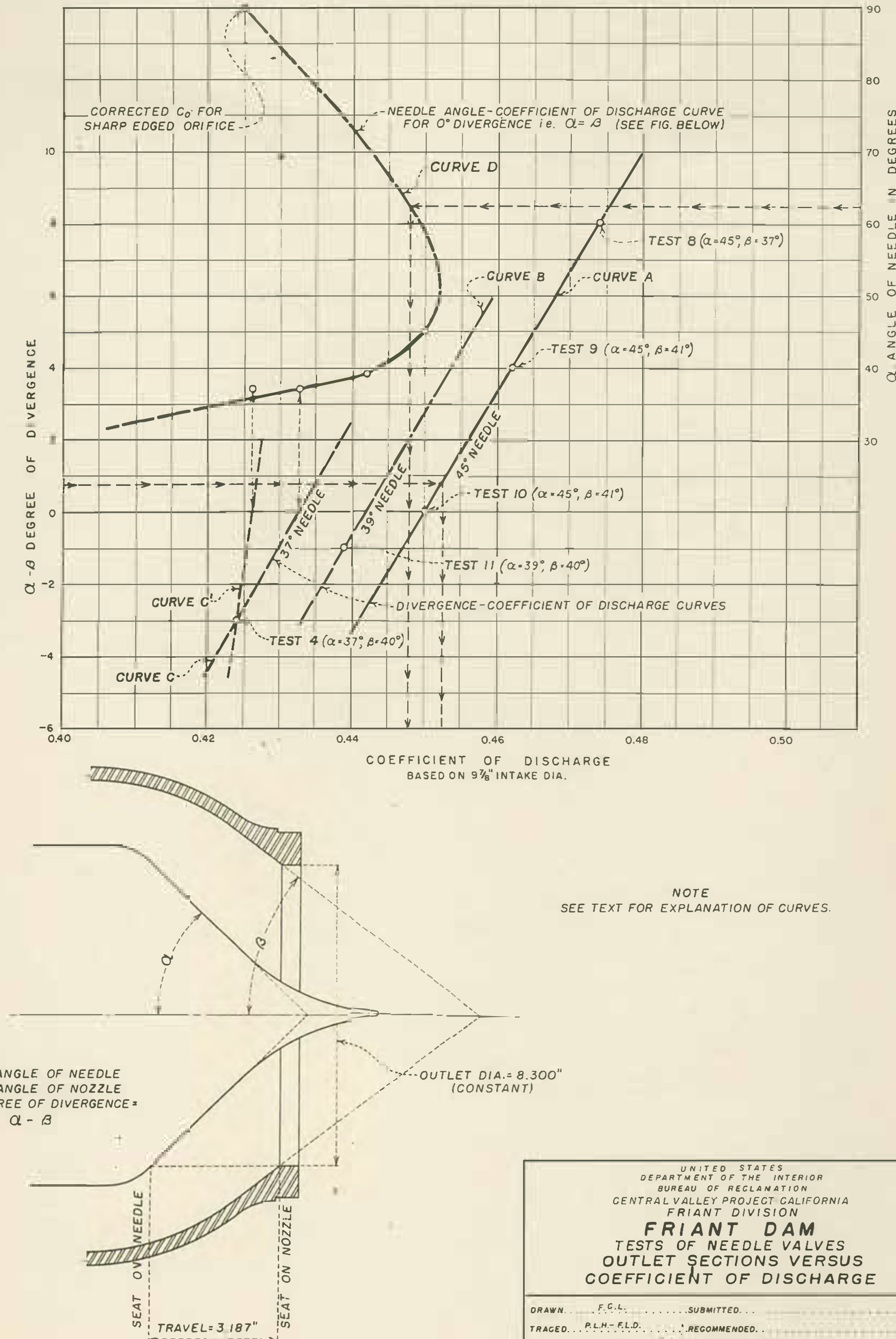
FRIANT DAM
TESTS OF NEEDLE VALVES
TRAVEL OF NEEDLE VERSUS COEFFICIENT OF DISCHARGE

DRAWN F.C.L.		SUBMITTED
TRACED P.L.H.	D.W.S.	RECOMMENDED
CHECKED		APPROVED
	DENVER, COLORADO, AUGUST 2, 1940	



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FRIANT DAM

TESTS OF NEEDLE VALVES
OUTLET SECTIONS VERSUS
COEFFICIENT OF DISCHARGE

DRAWN F.C.L. SUBMITTED
TRACED P.L.H.-F.L.D. RECOMMENDED
CHECKED APPROVED

DENVER, COLORADO. - JULY 31, 1940

lation between α and the coefficient of discharge for zero divergence was then drawn (curve D).

The points forming curve D were located by assuming curves B and C as straight lines with the same slope as curve A, inasmuch as the latter was a straight line. Curve C' shows that if curves B and C did not have the same slope, curve D would still retain the same general shape. To set a lower limit for curve D it can be shown that as α and β approach zero, the discharge coefficient also approaches zero. To determine an upper limit, as α and β approach 90 degrees, the nozzle would become a sharp-edged orifice which has a discharge coefficient of 0.60 when unobstructed. By assuming that the obstruction caused by the needle would be slight, this value, 0.60, may be used to approximate the coefficient of a valve having $\alpha - \beta = 90$ degrees. As the value 0.60 is based upon the exit area while the desired coefficient must be based upon the inlet area, in accordance with the definition of the discharge coefficient given in section 7, the correction $0.60 \frac{(8.300)^2}{(9.875)^2} = 0.425$ was applied where 8.300 is the exit diameter and 9.875 is the inlet diameter. The coefficient, 0.425, is shown on curve D for $\alpha = 90$ degrees. Curve D is only an indicated curve, and its actual shape must be found through additional tests.

Curve D is important for it indicates that there is a value of α and β which will give a maximum coefficient of discharge for a valve of zero divergence. Similar curves can be found for any divergence or convergence desired. This curve shows that the valve selected for the Friant design does not have an optimum coefficient of discharge, for the coefficient could be increased by changing the angles of the needle and the nozzle from 39 and 40 degrees to about 45 degrees without changing the size of the valve. The determination of optimum values of α and β suggests future needle-valve tests, as the original object of these tests was to develop a valve having positive pressures and at the same time the highest possible coefficient of discharge.

A different approach might lead to the same conclusions as obtained from curve D by determining the area of passage at the nozzle exit and the area of the jet at its vena contracta as the values of α and β change. As α and β increase, the area of passage at the exit increases, but the area of the jet at the vena contracta decreases. There must be some value of α and β at which these opposing factors are balanced. However, additional tests would be necessary to study the discharge characteristics of the valve from this approach.

CHAPTER IV - TUBE VALVE TESTS

15. Tube valve models. Both the preliminary and the final tube valve models had a scale ratio of 1:18.33 which was established by using a 6-inch approach conduit in the models as compared with the 110-inch prototype conduits (figure 17A).

To have reasonable similitude between the model and the prototype, it was expedient to measure the energy head one diameter upstream from the valve to eliminate the difference between the model and the prototype losses in the approach conduit and to avoid pressure disturbances caused by the valve. This was established by needle-valve tests. It was also necessary to have a proper velocity distribution of flow approaching the valve, this being obtained by using a straight brass pipe 14 feet long for the approach conduit.

The model differed from the prototype in that the prototype conduit was sloping while that of the model was tested in a horizontal position. By measuring the energy head near the valve, however, the data obtained in these tests is applicable to any valve regardless of the alinement or length of its approach conduit.

The testing procedure was to record the pressures and discharge for heads ranging from 4 to 30 feet (70 to 550 feet, prototype), and for valve openings ranging from 15 to 100 percent. The pressures through the valve were obtained from piezometers located as shown in figure 17A, and the discharge was measured over a V-notched weir.

16. The preliminary test. Hydraulic model studies on needle and

tube valves for the outlets at Friant Dam and on tube valves for outlets at Shasta Dam were commenced at about the same time. Model studies on the tube valves at Shasta Dam are described in the report "Hydraulic Studies for the Design of the Tube Valves in the Outlets in Shasta Dam" by D. J. Hebert, Associate Engineer. The tube valves at Shasta and Friant dams could not be designed from the same model studies because the Shasta valves are to be placed in the conduit near the entrance, while the Friant valves are to be placed at the exit end of the conduit. Nevertheless, the preliminary test of the Friant tube valve was made with a Shasta model by removing all of the conduit downstream from the valve so that it would discharge freely into the atmosphere. The test was described as test 7 in the report "Hydraulic Model Studies for the Design of the Tube Valves in the Outlets in Shasta Dam."

This Shasta valve had a curved nozzle exit, slightly diverging, which caused negative pressures on the nozzle near the exit. To avoid this condition for the Friant tests, a sharp-edged exit was used which successfully eliminated the negative pressures on the nozzle, but it reduced the exit area 30 percent and lowered the coefficient of discharge (figure 17).

Although the sharp-edged exit eliminated negative pressures on the nozzle, negative pressures developed on the lip of the tube at openings less than 50 percent (piezometer A). This lip was shaped so as to cause a divergence in the passage between the lip of the tube and the body of the valve, and this condition was assumed to be the cause of the negative pressures.

Another function of the preliminary test was to observe the form of the jet at various valve openings. At wide openings, a solid jet was formed, but as the valve closed the diameter of the jet became smaller until, at approximately 15 percent open or less, the jet disintegrated and formed considerable spray. Such spray would be undesirable at most prototype structures; so the use of a tube valve should be limited to larger valve openings. The form of the jet appeared to bear a direct relation to the pressures inside the tube, for when a solid jet was being ejected the tube was full of water under pressure. As the valve closed, the pressure inside the tube was reduced, and when the valve was 15 percent open the pressure became slightly negative so that the tube filled with air instead of water, the air apparently causing the jet to disintegrate.

17. The final design. The Friant tube valves were designed similar to the adjacent needle valves in the river and the Friant-Kern canal outlets, since they were connected to the same size conduits and operated under the same heads. To maintain positive pressures in the tube valve, a sharp-edged nozzle exit was used, but no divergence was permitted in the passage between the lip of the tube and the nozzle such as occurred in the preliminary test. As a result, positive pressures were recorded in the valve through the entire range of heads and valve openings.

The characteristics of the jet were similar to those of the preliminary tube valves since the jet caused spray at small valve openings, in this case openings of less than 30 percent as compared to 15 percent in the preliminary test. The spray condition was easier to observe on the final design because the jet formed a more regular pattern with less disintegration. At small valve openings the tube was filled with air and the pressure inside was slightly negative, as observed during the preliminary test; but it was further observed that the jet formed a hollow cone with its base at the nozzle. At the apex of this cone, approximately one diameter downstream, the impact of the water was unbalanced, causing the jet to flutter and disintegrate into spray.

Although the operation of the tube valve under these conditions was not desirable at openings of less than 30 percent, it was anticipated that such operation may be necessary in an emergency, in which case the negative pressures inside the tube should be eliminated. It was proposed that they be relieved by aeration, but this was found to be unnecessary, since air broke through the walls of the cone-shaped part of the jet, relieving the negative pressures and making the tube self-aerating (piezometer inside the tube).

A test was conducted to determine the tendency for the tube to vibrate. To do this, a loosely fitting tube was installed and the valve was operated at several heads and openings. Since no vibrations were apparent, a weight was then added to the inside of the tube to throw it off balance, but no vibrations occurred. It was concluded that the model tube valve was free from vibration, but it is impossible from this test to state that no vibration will occur in the prototype tube valve.

The coefficient of discharge of the tube valve of the final design was 0.51, which does not compare too favorably with the coefficient of the needle valves which was 0.59 (figure 17B). In future designs of tube valves the coefficient could be improved by increasing the exit diameter a small amount and by shortening the lip of the tube, such revisions being checked by model tests. The limit of the latter revision would be to cut off the lip at its point of seat. This would have the same effect upon increasing the travel of the tube and is substantiated from tests which showed that the coefficient of discharge could be increased by increasing the travel of the needle. A possible disadvantage of increasing the coefficient of discharge of the tube valve would be a reduction in the range of regulation. This was indicated from comparing the preliminary and the final valves, the former having a lower coefficient but a greater range of regulation.

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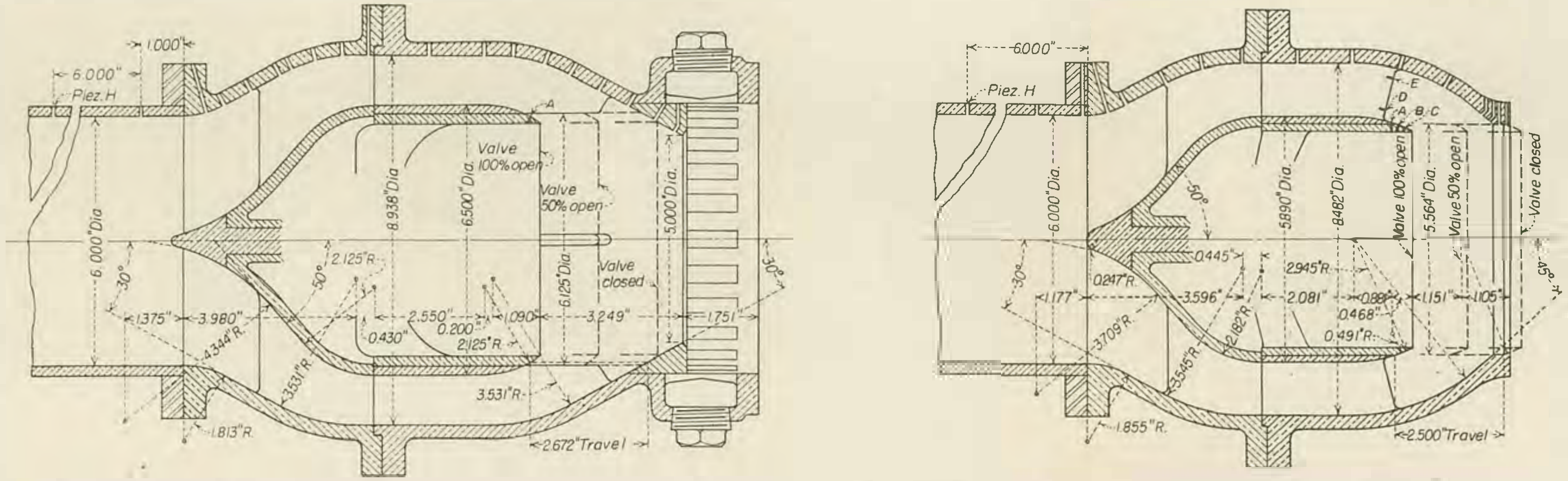
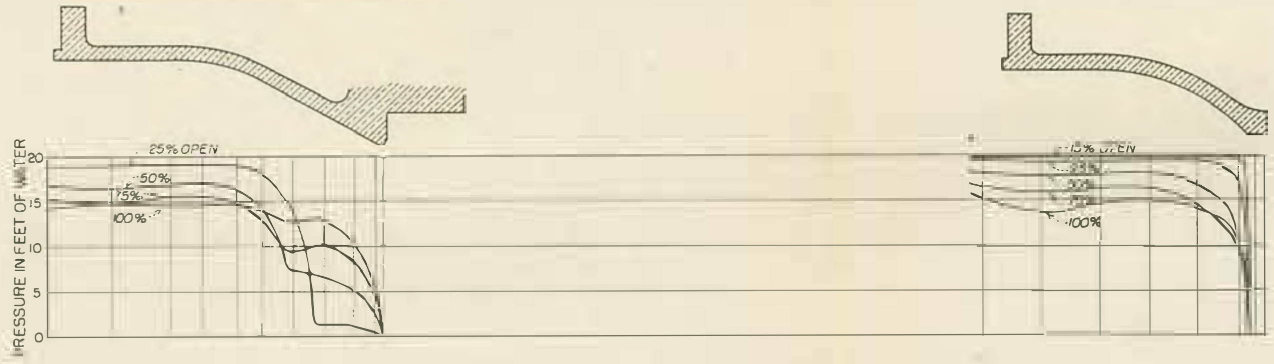
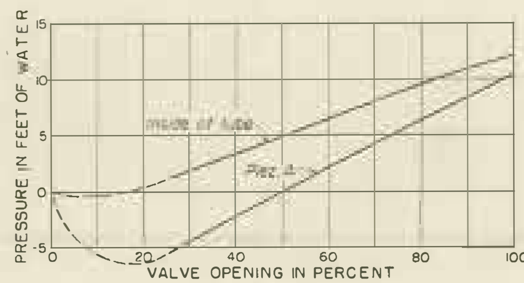
F. C. Lowe

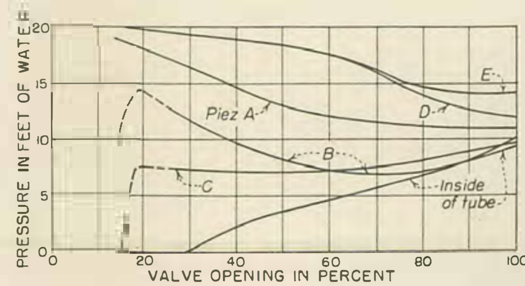


Piezometer locations



PRESSURE CONDITIONS ON NOZZLE



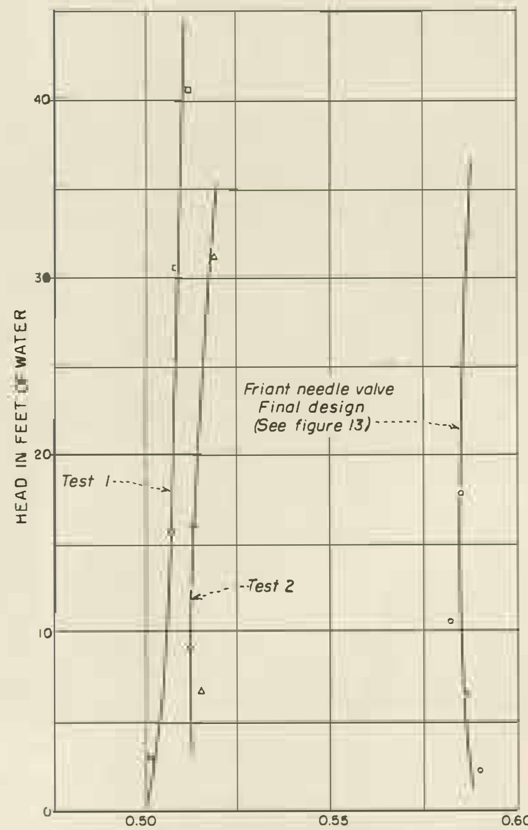


PRESSURE CONDITIONS ON VALVE INTERIOR

TEST 1

TEST 2

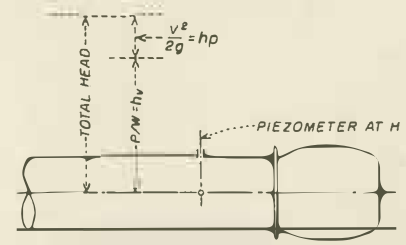
A PRESSURE CONDITIONS FOR VALVE TESTS



COEFFICIENT OF DISCHARGE BASED ON $C_D = \frac{Q}{A\sqrt{2gH}}$

H = Total head in feet – 1 dia. upstream from upstream flange of valve. (At "H")
Q = Discharge in cubic feet per second.
A = Area at point where H is measured.

B. COEFFICIENTS OF DISCHARGE FOR 100 PERCENT OPENING



DEFINITION OF HEAD

1 - In Figure 17A the total head, $(h_v + h_p)$ in all cases, was 20 feet of water.
2 - Valve openings were measured in percent of travel of the tube.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
FRIANT DIVISION

FRIANT DAM
TESTS OF TUBE VALVES
PRESSURE AND DISCHARGE DATA
TESTS 1 AND 2

DRAWN H.R.S.	SUBMITTED.
TRACED J.E.V.–J.F.S.	RECOMMENDED.
CHECKED.	APPROVED.
	DENVER, COLORADO —