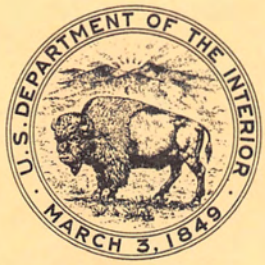
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MODEL-PROTOTYPE CONFORMANCE OF RADIAL GATE DISCHARGE CAPACITY CANYON FERRY DAM, MONTANA

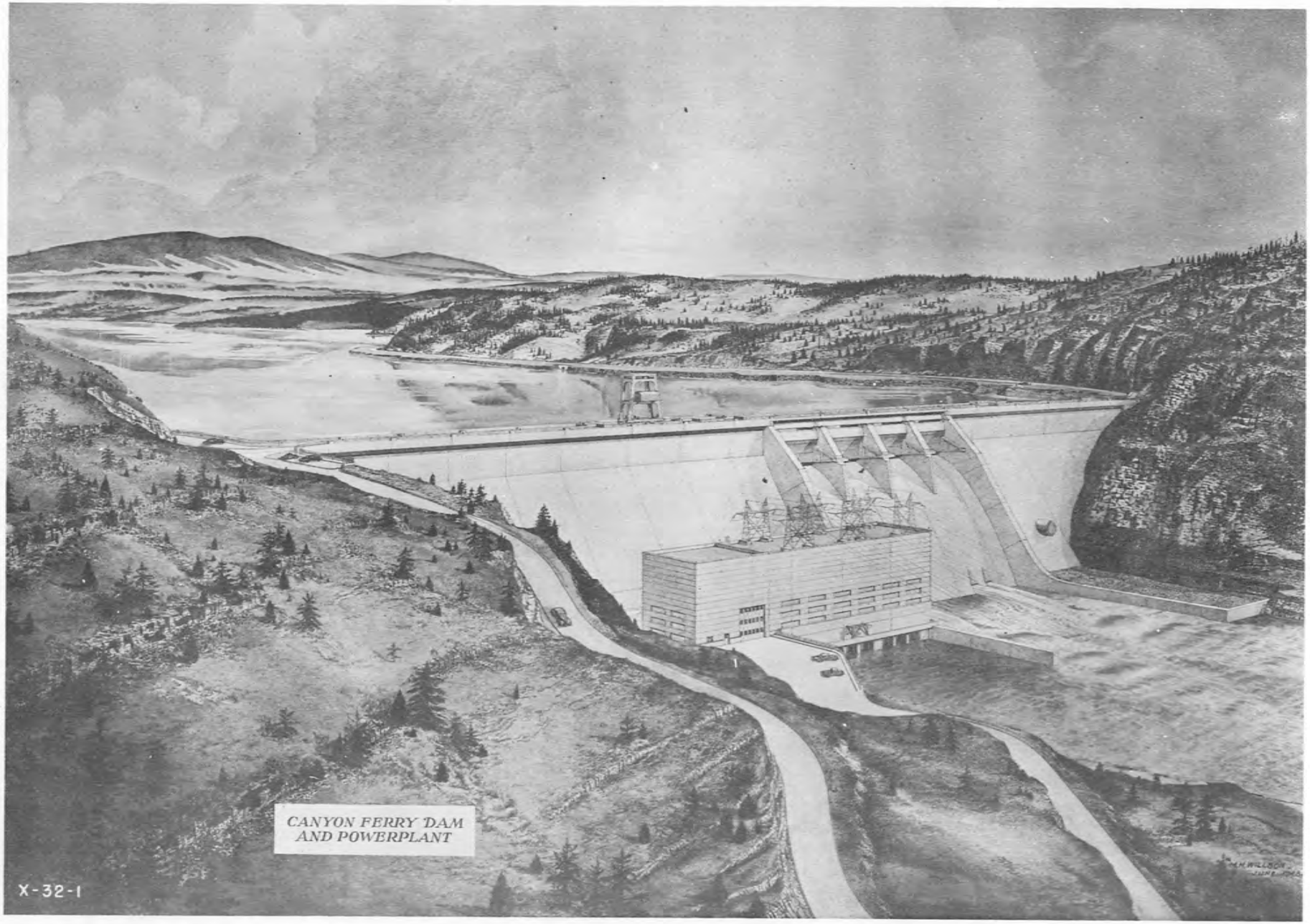
Hydraulic Laboratory Report No. Hyd 433

DIVISION OF ENGINEERING LABORATORIES



COMMISSIONER'S OFFICE
DENVER, COLORADO

March 4, 1957


CANYON FERRY DAM
AND POWERPLANT
X-32-1

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Commissioner's Office--Denver
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Hydraulic Investigations Section
Denver, Colorado
March 4, 1957

Laboratory Report No. Hyd-433
Compiled by: J. C. Schuster
Checked and
reviewed by: C. W. Thomas
Submitted by: H. M. Martin

MODEL-PROTOTYPE CONFORMANCE OF RADIAL GATE DISCHARGE CAPACITY CANYON FERRY DAM, MONTANA

PURPOSE

The purpose of this report is to compare the measured discharge capacity of the Canyon Ferry Dam radial gates with that predicted from its model.

INTRODUCTION

Canyon Ferry Dam and Powerplant are located on the Missouri River about 17 miles east of Helena, Montana. The multipurpose project generates power, provides for irrigation and some measure of flood control.

The dam is a concrete gravity structure, approximately 1,000 feet long at the crest, with a maximum height of about 225 feet above the excavated foundation, Figure 1. The spillway consists of an overflow section in the central portion of the dam, controlled by four 51- by 34.5-foot-high radial gates. The spillway crest is designed for a maximum discharge of approximately 150,000 cubic feet per second. The top of the radial gate in the seated position is elevation 3800, the maximum high water surface for the reservoir.

Four river outlets, each 84 inches in diameter, are installed through the spillway section of the dam. The outlets are controlled by 77-inch regulating gates and are protected by fixed-wheel gates.

Model studies of the spillway and river outlets of Canyon Ferry Dam were performed in the Hydraulic Laboratory during the year 1945. The results were published in March 1946 in Hydraulic Laboratory Report No. 197, Hydraulic Model Studies of the Spillway and River Outlets of Canyon Ferry Dam, Missouri River Basin Project, Montana. During the studies a calibration of the uncontrolled spillway was obtained but a calibration of the proposed five 51- by 34.5-foot radial gates was not completed. The prototype spillway as constructed contained four 51- by 34.5-foot gates for which capacity curves were predicted from a model

study in 1953. These curves were later contained in the Designers' Operating Instructions published in August 1954. In June of 1956, it became possible through the cooperation of Region 6 to make field discharge measurements at Canyon Ferry Dam for comparison with the laboratory studies. This report brings together the results of the laboratory and field measurements.

ACKNOWLEDGMENT

The information and data used in compiling the Field Study section of this report were taken from a copy of a letter dated June 29, 1956, to Regional Director, Billings, Montana, from the Project Superintendent, Canyon Ferry, Montana. The subject of this letter was "Spillway discharge at Canyon Ferry Dam--Canyon Ferry Unit--Missouri River Basin Project." This copy of the letter had the following enclosures:

1. Prints of original test data (7 sheets)
2. Prints of wattmeter calibration tests (2 sheets)
3. Calculation of vertical gate opening versus arc travel of gate skin plate (2 sheets)
4. Letter dated June 25, 1956, from U. S. Geological Survey, Helena, Montana, to Mr. H. M. Gronhovd, Canyon Ferry Dam, with attached test data sheet
5. One print each of 11 films taken June 2, 1956, with 4 gates open 4.2 feet, spilling a total of 24,000 cubic feet per second
6. One print each of 7 films taken June 10, 1956, with Number 2 gate open 10 feet, spilling 13,700 cubic feet per second
7. One print of tabulation of turbine discharge versus megawatt load.

Statements from the letters have been used in this report where applicable. These statements are signified by quotation marks or by a credit phrase. The cooperation of Mr. H. M. Gronhovd, Project Superintendent, Canyon Ferry Project; Mr. Frank Stermitz, District Engineer, U. S. Geological Survey, Helena, Montana, and their assistants is gratefully acknowledged.

Data used in the Laboratory Study section of the report were obtained by personnel of the Hydraulic Laboratory.

Photographs of the flow conditions at Canyon Ferry Dam were taken by P. M. Schwartz, Canyon Ferry Project.

LABORATORY STUDY

The Model

Only one radial gate and equivalent spillway length were calibrated in the second study of Canyon Ferry. The type of construction used for the 1:40 scale model is shown in Figure 2A. An approach channel equal to the width of the gate directed the water from the head box to the test section which contained the gate and profile of the spillway, Figure 2B. A hook gage with vernier graduations to 1/1000 of a foot was used to measure the head on the gate. Discharges were measured by calibrated Venturi meters. Gate openings were measured vertically from the spillway crest to gate bottom with an allowance for the vertical distance between the seat and crest.

Model Flow Conditions

The flow in the model, directed parallel to the test section center line from the head box, differed from the radial flow pattern of the water flowing to a single gate discharging from the reservoir. This difference of flow pattern would not be evident in a comparison of the model and prototype gate capacity at small openings but could become apparent at large openings for the same accuracy of measurement. Prototype discharges scaled from the model would tend to be lower than the measured values because of the model approach channel head loss. Because of these differences in physical setting and flow conditions between the single gate of the model and a single gate or multiple gates of the prototype, it was of considerable interest to compare the model and prototype measurements.

FIELD STUDY

Prototype Measurements

Seven discharge determinations were made at Canyon Ferry Dam in the period June 6 to June 17, 1956, under the direction of the Project Superintendent assisted by the District Engineer, U. S. Geological Survey. The setting of the gates, reservoir elevations and turbine discharge measurements were made by project personnel. Total flow in the river was measured by Survey personnel.

Gate Openings

"Gate openings were set by measuring with a steel tape, along the arc of the skin plate of the gate, the length which would give the desired vertical gate openings. These measurements are believed to be accurate to within one-sixteenth inch." 1/ The arc lengths corresponding to the vertical rise were established previously by the sketch and formulas and Table 1 in Appendix 1.

1/Letter of June 29, 1956

Water Levels

"The reservoir and tail water elevations were read on the gages on the main control board. These gages are checked frequently and are very accurate."1/

A float-operated forebay level indicator, recorder and transmitter are located in a chamber in the dam above a 30-inch inside diameter lined stilling well. This instrument transmits the forebay water level to an indicating receiver located on a panel in the control room of the Canyon Ferry Powerplant. 2/

A stilling well, lined with 1/4-inch thick steel pipe, 18 inches outside diameter, is provided in the powerhouse and connected to the tail water by a 1-inch pipe extending downstream from the end of the draft tubes approximately 50 feet to its inlet. A float-operated tail water level indicator and transmitter are located at the top of the 18-inch well and tail water levels are transmitted to an indicating receiver mounted in the control room. 2/

Turbine Discharge

"The discharge through the turbines was obtained by taking an average reading of generator megawatts and using the table (Enclosure 7)3/ which has been made up from the drawing entitled 'Canyon Ferry Powerplant--Turbine Operation Curves--Derived from Gibson Test.' Those curves were drawn up in the Reservoir Regulation Branch of your office. The generator indicating wattmeters were calibrated against the generator watthour meters, which are believed to be accurate within one-half of one percent. Corrected values of megawatts were recorded on the original test data. During the tests the turbine governor limit switches were set to block the wicket gates, thus maintaining a constant load on the machines."1/

River Discharge Measurements

"Current-meter measurements were made from the upstream side of the timber bridge below the dam and appreciable turbulence was encountered. Velocity surges appear to vary in character and location with the various gate settings and considerable care was taken in defining the mean velocity for each sounding. We found through study of vertical velocity curves, as well as by comparison of velocities at 0.2, 0.6 and 0.8 of the depth, that the effect of turbulence on the current meter was compensated, taking the cross-section as a whole. We believe that while measuring conditions were only fair that our results may be rated good and within probable errors of less than 5 percent. The discharge measurements are being retained in our files. Copies will be furnished, if desired."4/

1/Letter of June 29, 1956.
2/Designers' Operating Instructions, Canyon Ferry Dam, Power-Plant and Switchyard, Bureau of Reclamation, August 1954.
3/Appendix 2.
4/Letter of June 25, 1956.

Gate Discharge Capacity

The discharge capacity of the gates was taken as the difference between the river discharge and the turbine discharge measurements. The results are contained in Table 1. Since the curves in the Designers' Operating Instructions, Figure 3, correspond to one gate and spillway section, the discharges of Table 1 have been reduced to the same basis. As noted in Column 2, Table 1, discharges were measured for 1 to 4 gates opened. When more than one gate was open the individual gate discharge was determined from the total discharge divided by the number of equally opened gates. No attempt was made to separate the gate capacity according to position on the spillway.

A comparison of the field measurements and the curve resulting from the model study is shown in Figure 4. Good agreement resulted for gate openings of 10, 6 and 4 feet. To obtain a curve corresponding to the 3-foot prototype gate opening, a fairing was made of the predicted discharge curves for various gate openings at four different reservoir elevations, Figure 5. This fairing assumed that a zero discharge would occur at a zero gate opening and that interpolation of a 3-foot opening was valid in lieu of model data at that opening. The resulting curve shows satisfactory agreement with the prototype measurements, Figure 4.

An inspection of Figure 5 discloses the possibility that the predicted 2-foot opening curve might justifiably be moved to the left. A decrease in the indicated discharge for a given reservoir elevation would result. This decrease would vary between 150 and 190 cubic feet per second. A relocation of the curve might be further justified by the agreement of model and prototype measurements at the larger gate openings. Such a shift would result in satisfactory accordance of the model and prototype discharges at a 2-foot gate opening, Figure 4, Curve a.

Prototype Flow Conditions

Flow conditions of the prototype during the capacity tests are shown in Figure 6 and 7. In Figure 6A, all four gates were open 4.2 feet and the total discharge was approximately 24,000 cubic feet per second for a reservoir elevation of approximately 3,798 feet. The head on the center line of the gate opening was approximately 30 feet. Spillway flow appears satisfactory with no undue spreading of the flow from the gate as evidenced by the absence of fins along the training wall and piers or in the flow downstream of the piers. Energy dissipation in the stilling basin for the 24,000 cubic feet per second discharge also appears satisfactory, Figure 6B.

A closer view of the water on the spillway face for the 4.2-foot gate opening, Figure 7A, shows a serrated surface with air entrainment beginning at the gate. The quantity of air entrained does not appreciably increase as the flow progresses down the face of the spillway. Air entrainment at the surface in the main body of the flow appears to be reduced for larger openings. With a 10-foot opening of the Number 2 gate for a discharge

of 13,800 cubic feet per second, Figure 7B, less air is evident at the surface than for the 4.2-foot opening, Figure 7A. Some transverse spreading of the jet is evident from the fins of water at the pier walls for the increased flow depth, Figure 7B. These fins apparently do not rise high enough to strike the gate hinge directly and thus are not objectionable.

The overall flow conditions for the spillway discharging 24,000 cubic feet per second from uniformly opened gates and 13,800 cubic feet per second from a single gate appear to be satisfactory.

CONCLUSIONS

1. The agreement between the predicted and measured discharge capacity of the gates at Canyon Ferry Dam is good except for the 2-foot gate opening.

2. A modification of the predicted 2-foot gate opening curve to indicate a smaller discharge for at least the higher reservoir elevations may be in order based on the review of model data and the comparison with the prototype measurements, Figures 4 and 5.

3. Field discharge measurements for the 2-, 3-, 4-, 6- and 10-foot gate openings for a reservoir elevation between 3785 and 3790 would be valuable for a correlation of the model and prototype at a head lower than available for this study.

4. The sectional model such as used in this experiment was capable of predicting prototype discharges within the degree of accuracy of laboratory and field measurements.

3766.00 crest elev
3765.50 gate seat elev.

Table 1
Taken from table prepared by
U.S. DEPARTMENT OF THE INTERIOR
Geological Survey
Water Resources Branch
Helena, Montana
CANYON FERRY RESERVOIR

Radial Gate Discharge Tests

Date June 1956	*Gate Open. Vert. (Ft)	Pond Elev. (Ft)	Number of Soundings	Total Area	Mean Vel.	Total Flow meas. From .2, .6 & .8 (CFS)	Total Flow Meas. From .2 & .8d (CFS)	Total Penstock Flow (CFS)	Net Per Gate (CFS)
6	#1 & 2 at 3 ft	3797.44	35	3,860	3.58	-	13,800	5,250	4,280
6	#2 at 6 ft	97.50	35	3,880	3.53	-	13,700	5,250	8,450
7	All at 4 ft	97.87	35	4,250	6.68	-	28,400	5,280	5,780
8	All at 2 ft	97.88	35	3,970	4.23	16,600	16,800	5,240	2,890
10	#2 at 10 ft	97.95	32	3,990	3.73	14,900	14,900	1,150	13,800
11	#1 & 2 at 3 ft	97.82	34	4,000	3.50	14,000	14,000	5,200	4,400
17	#2 at 2 ft	99.01	35	3,770	1.24	4,690	4,660	1,650	3,010

*Gates are numbered with #1 nearest right bank.

APPENDIX 1

SPILLWAY GATES
CANYON FERRY POWERPLANT
BUREAU OF RECLAMATION
Taken from Enclosure 3, Letter of June 29

Formulas for determining travel along arc of skin plate for various vertical gate openings

Vertical gate opening = 8.5 feet - a

$\text{Sin } \alpha = \frac{a}{40}$

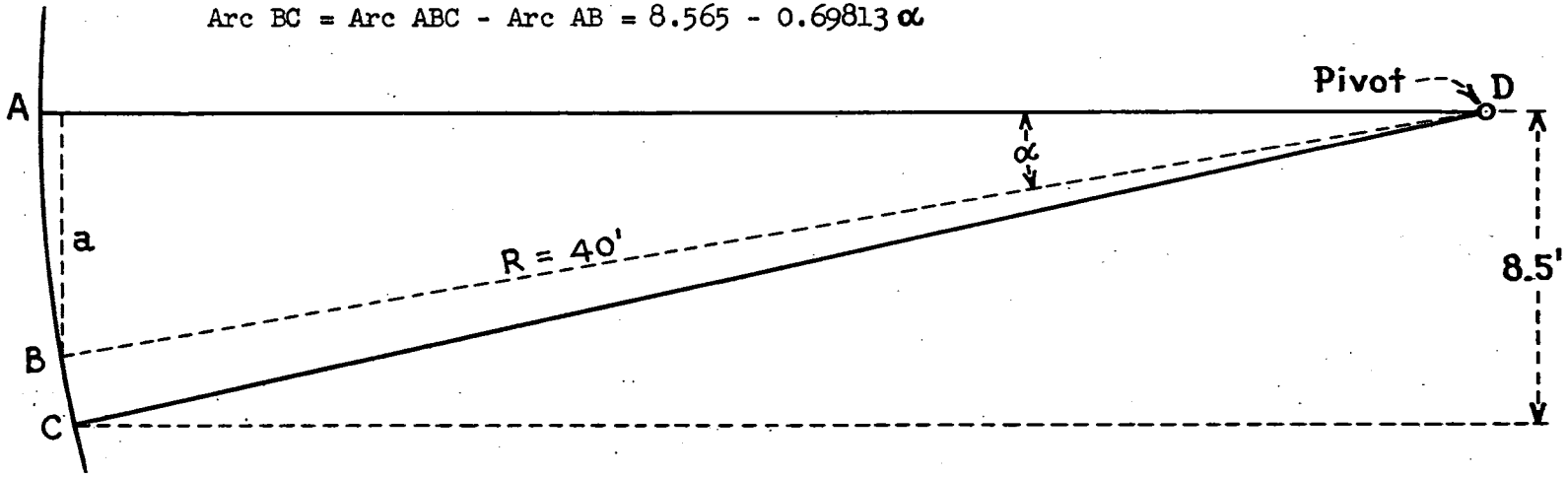
Obtain value of α in degrees from trig tables

Angle ADC = 12.269 degrees

$\text{Arc ABC} = \frac{12.269}{360} \times 2\pi 40 = 8.565 \text{ feet}$

$\text{Arc AB} = \frac{\alpha}{360} \times 2\pi 40 = 0.69813\,\alpha$

$\text{Arc BC} = \text{Arc ABC} - \text{Arc AB} = 8.565 - 0.69813\,\alpha$



Reference Drawing 296-D-86

SPILLWAY GATES
CANYON FERRY POWERPLANT
BUREAU OF RECLAMATION
Taken from Enclosure 3, Letter of June 29

Vertical gate opening	a	Sin α	α degrees	Arc AB 0.69813 α feet	Gate opening measured along skin plate arc 8.565 - Arc AB	
					Feet	Inches
0	8.5	$\frac{8.5}{40} = 0.2125$	12.269	8.565	0	0
1	7.5	$\frac{7.5}{40} = 0.1875$	10.807	7.545	1.020	12.24
2	6.5	$\frac{6.5}{40} = 0.1625$	9.352	6.529	2.036	24.43
3	5.5	$\frac{5.5}{40} = 0.1375$	7.903	5.517	3.048	36.58
4	4.5	$\frac{4.5}{40} = 0.1125$	6.459	4.509	4.056	48.67
5	3.5	$\frac{3.5}{40} = 0.0875$	5.020	3.505	5.060	60.72
6	2.5	$\frac{2.5}{40} = 0.0625$	3.583	2.501	6.064	72.77
7	1.5	$\frac{1.5}{40} = 0.0375$	2.149	1.500	7.065	84.78
8	0.5	$\frac{0.5}{40} = 0.0125$	0.7161	0.500	8.065	96.78
8.5	0	0 0	0	0	8.565	102.78

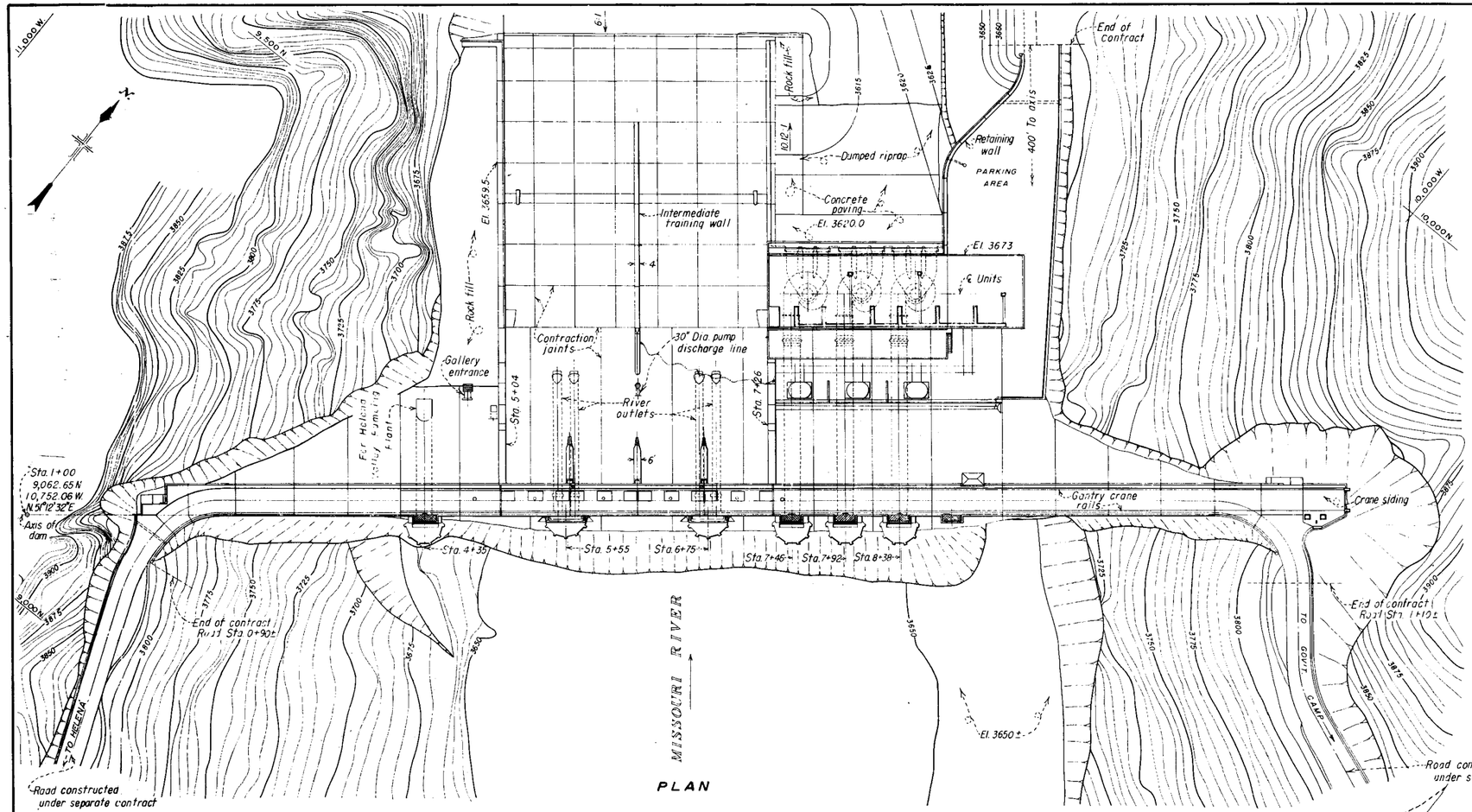
APPENDIX 2

Appendix 2
Taken from Enclosure 7, letter June 29
CANYON FERRY POWERPLANT

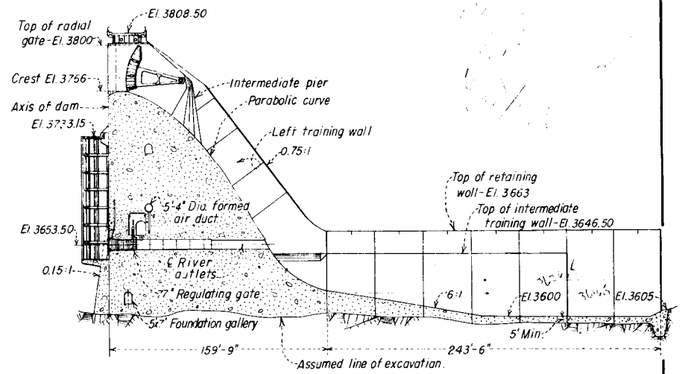
Turbine Discharge - c.f.s.

Gross Head-Feet

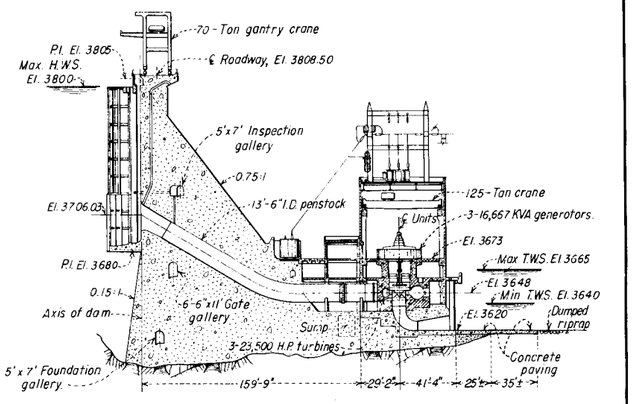
One Unit Load - Megawatts	141	142	143	144	145	146	147	148	149	150
0.5	250	250	250	250	250	250	250	250	250	250
1	290	290	290	290	290	290	290	290	290	290
2	350	350	350	350	345	345	345	345	345	345
3	430	430	430	430	425	425	425	425	425	425
4	505	505	500	500	500	500	495	495	495	490
5	600	595	595	590	585	585	585	580	580	575
6	680	675	675	675	670	665	665	660	660	655
7	765	760	755	755	750	745	740	740	735	735
8	845	840	840	835	830	825	825	820	815	815
9	930	925	920	915	910	905	900	900	895	890
10	1010	1000	1000	990	985	980	975	970	965	960
11	1095	1090	1085	1080	1070	1065	1060	1055	1050	1040
12	1180	1170	1165	1155	1150	1140	1135	1130	1125	1115
13	1260	1250	1245	1235	1230	1225	1215	1210	1205	1200
14	1340	1330	1325	1315	1305	1300	1295	1290	1280	1275
15	1430	1420	1415	1405	1395	1390	1380	1375	1365	1355
16	1515	1505	1495	1490	1475	1470	1460	1455	1445	1435
17	1605	1590	1580	1570	1555	1550	1540	1530	1520	1510
18	1700	1675	1670	1660	1645	1635	1620	1615	1600	1590
19	1810	1790	1770	1760	1740	1725	1710	1695	1680	1670
20	1950	1915	1895	1870	1850	1830	1810	1795	1775	1760
21	2105	2075	2050	2030	2005	1985	1960	1940	1920	1900
22					2155	2130	2105	2085	2060	2040



PLAN



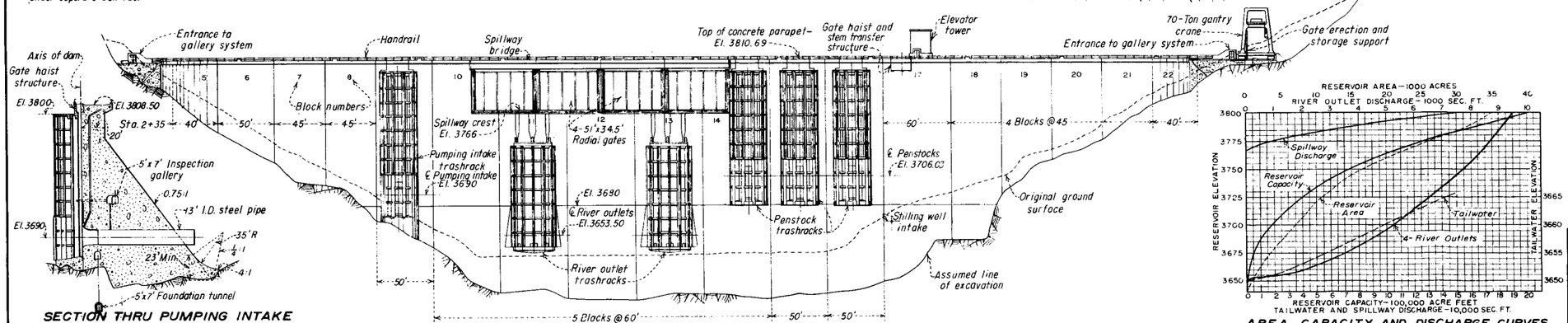
MAXIMUM SPILLWAY SECTION



MAXIMUM SECTION THRU POWERPLANT

NOTE

Actual required foundations may vary widely from profile and assumed excavation lines shown.



SECTION THRU PUMPING INTAKE

UPSTREAM ELEVATION

AREA, CAPACITY AND DISCHARGE CURVES

REV. 5-6-52	J.E.P.
REVISED 11-15-48	A.O.
REVISED AND REDRAWN 3-15-48	A.O.
DR. A.O. TR. R.V.S. CH. R.M.C.	

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
CANYON FERRY UNIT-MONTANA

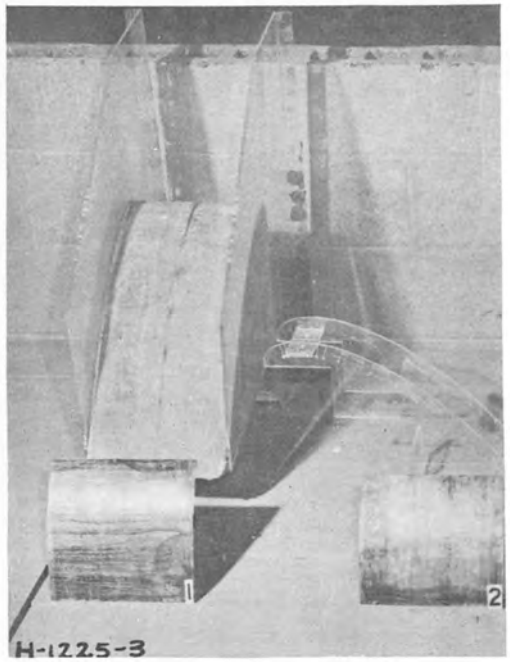
CANYON FERRY DAM AND POWERPLANT

PLAN, ELEVATION AND SECTIONS

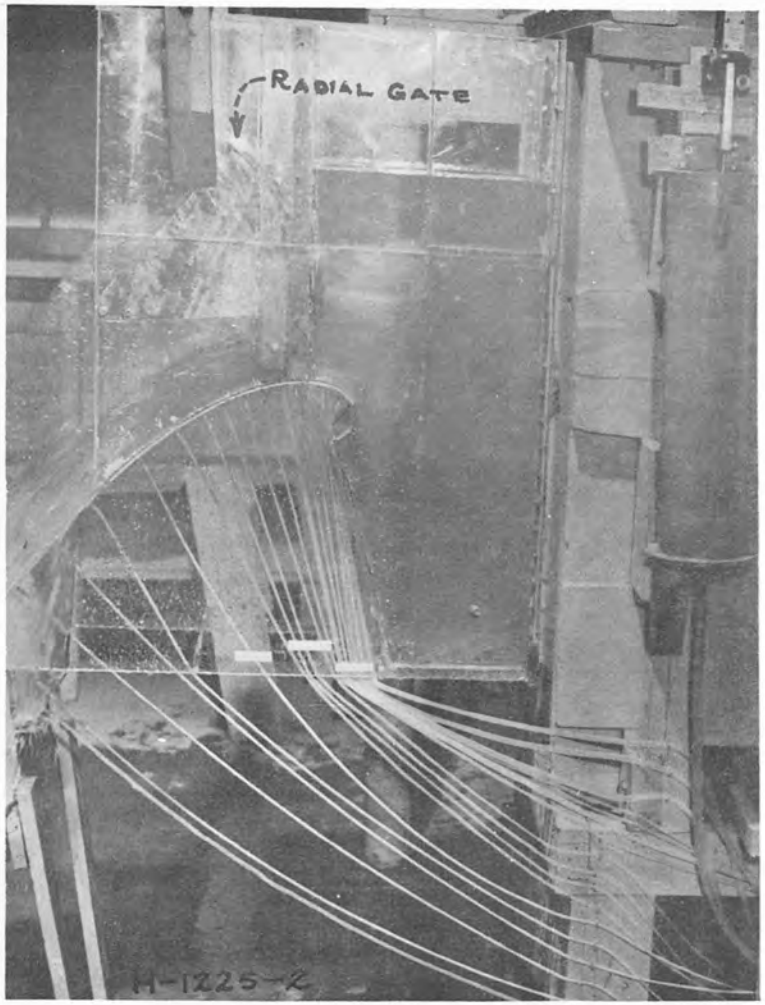
DRAWN A.O. SUBMITTED
TRACED R.E. WCD.-R.V.S. RECOMMENDED
CHECKED P.M.S. APPROVED
ACTING CHIEF ENGINEER

DENVER, COLORADO, APRIL 15, 1946

296-D-47



A. 1. Typical Spillway Section and Radial Gate Prepared for Installation
2. Typical Radial Gate and Plastic Template of Spillway Section Before Assembly with Side Walls

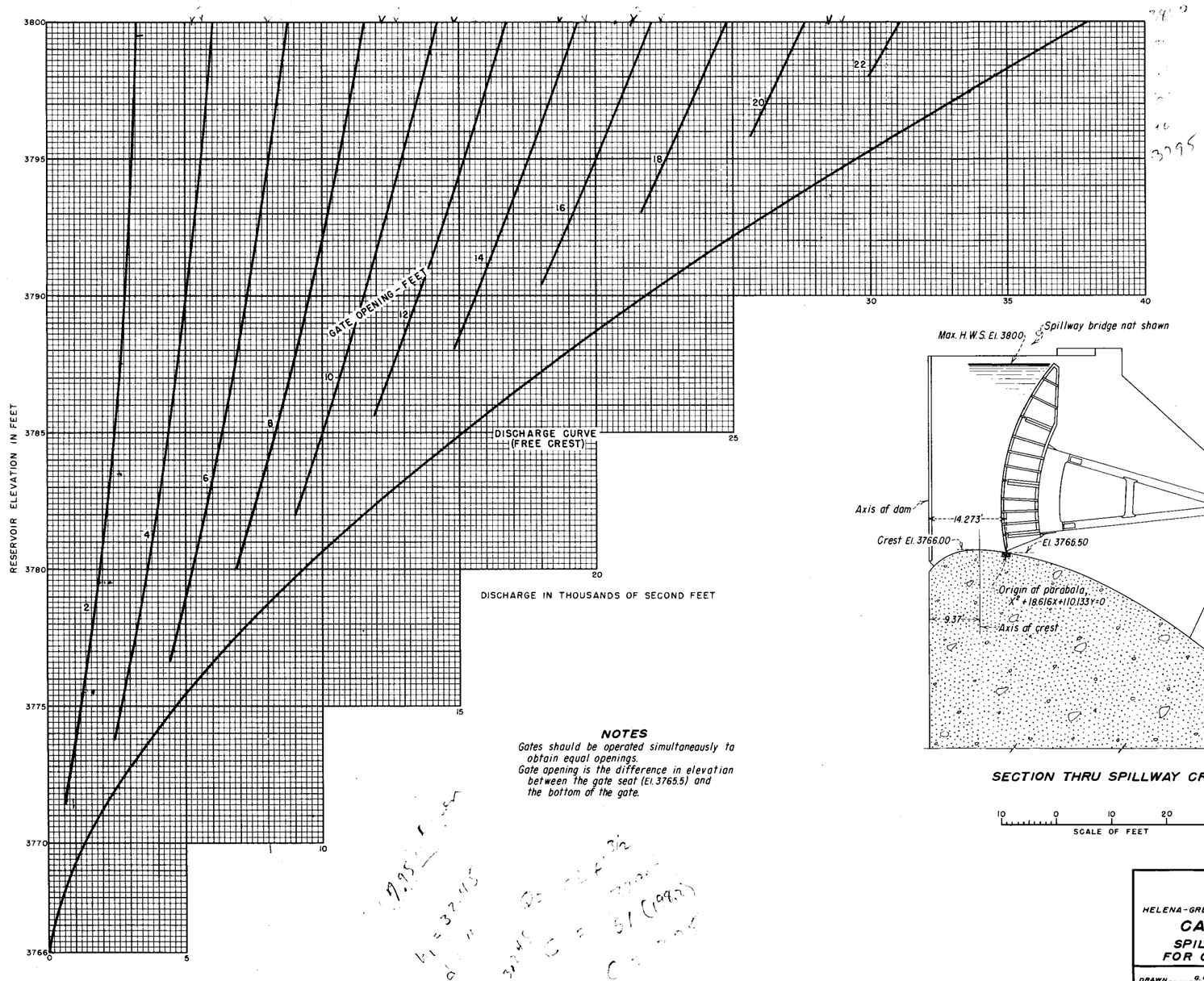


B. Typical Model Installed and Operating

CANYON FERRY DAM
Laboratory Facilities for Model Calibration

Figure 2
Report Hyd 433

FIGURE 3
REPORT HYD. 433



NOTES

Gates should be operated simultaneously ta obtain equal openings.
Gate opening is the difference in elevation between the gate seat (El. 3765.5) and the bottom of the gate.

SECTION THRU SPILLWAY CREST

10 0 10 20 30
SCALE OF FEET

UNITED STATES
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MISSOURI RIVER BASIN PROJECT
HELENA-GREAT FALLS DIV.- CANYON FERRY UNIT - MONT.

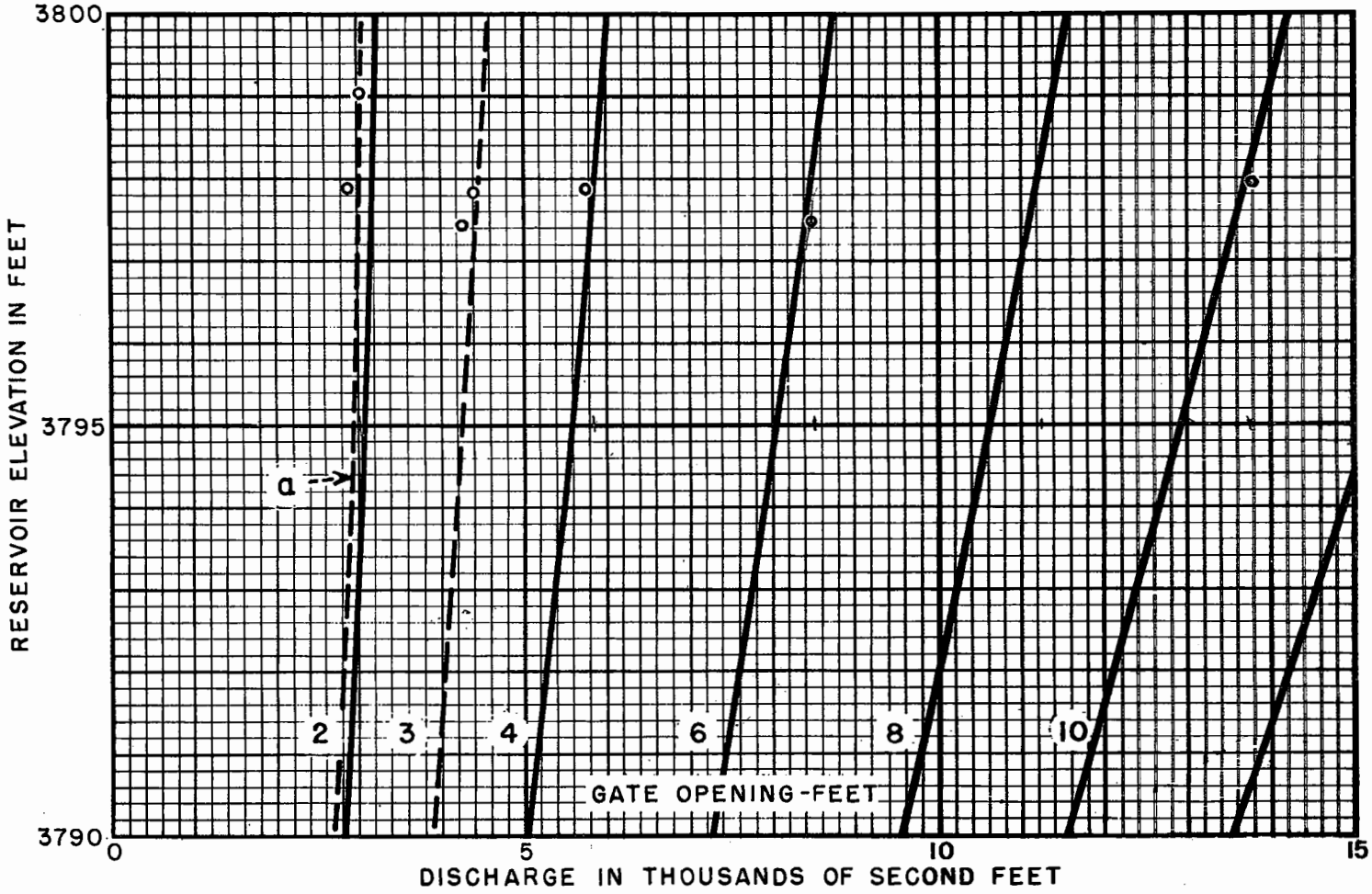
CANYON FERRY DAM

SPILLWAY DISCHARGE CURVES FOR ONE 51' x 34.5' RADIAL GATE

DRAWN	G.C.F.	SUBMITTED	L.G. Puls
TRACED	P.W.S.	RECOMMENDED	J.J. Hammond
CHECKED	A.S.S.	APPROVED	W.P. Kiesel, CHIEF DESIGNING ENGINEER

DENVER, COLORADO, JULY 1, 1953

296-D-1058

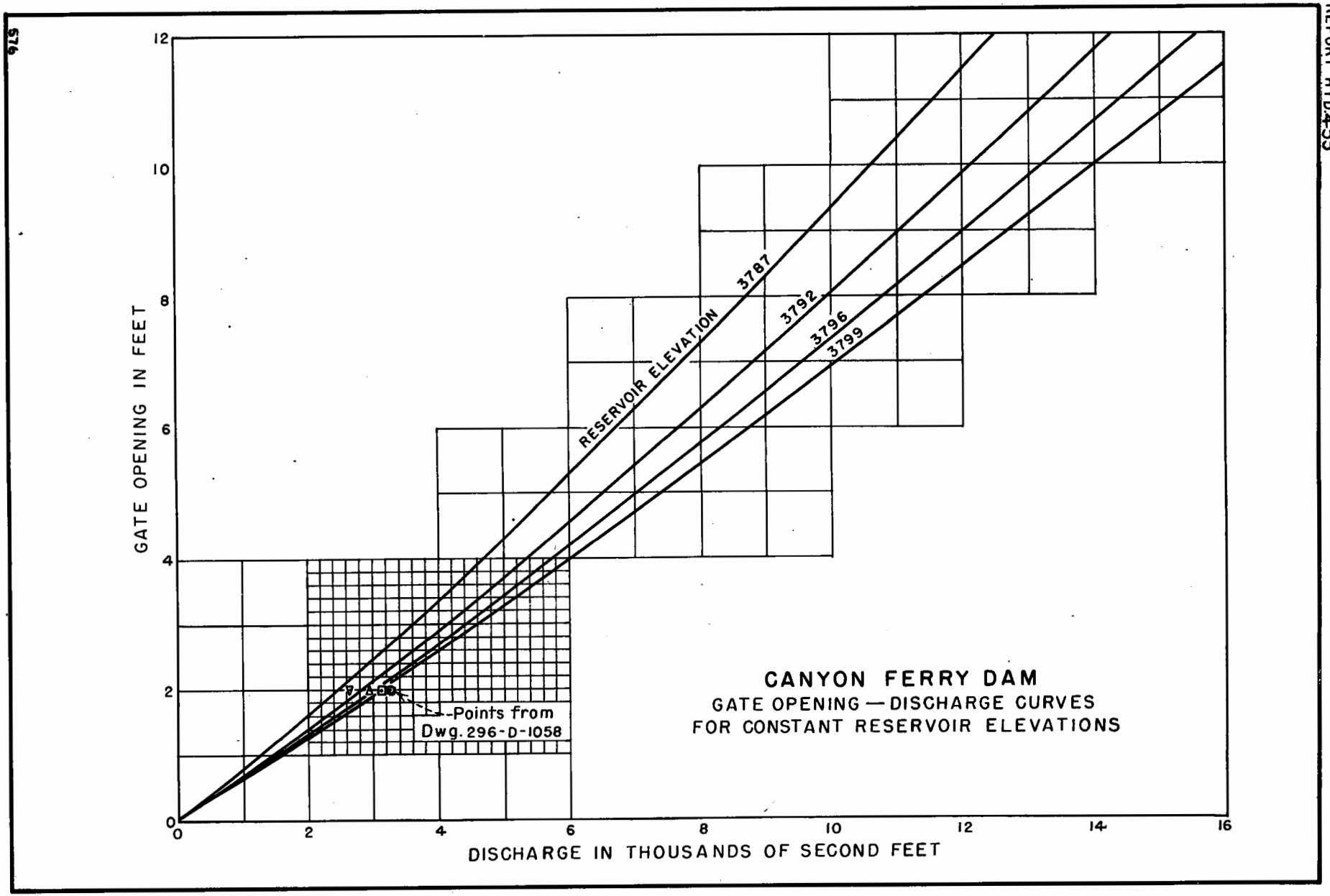


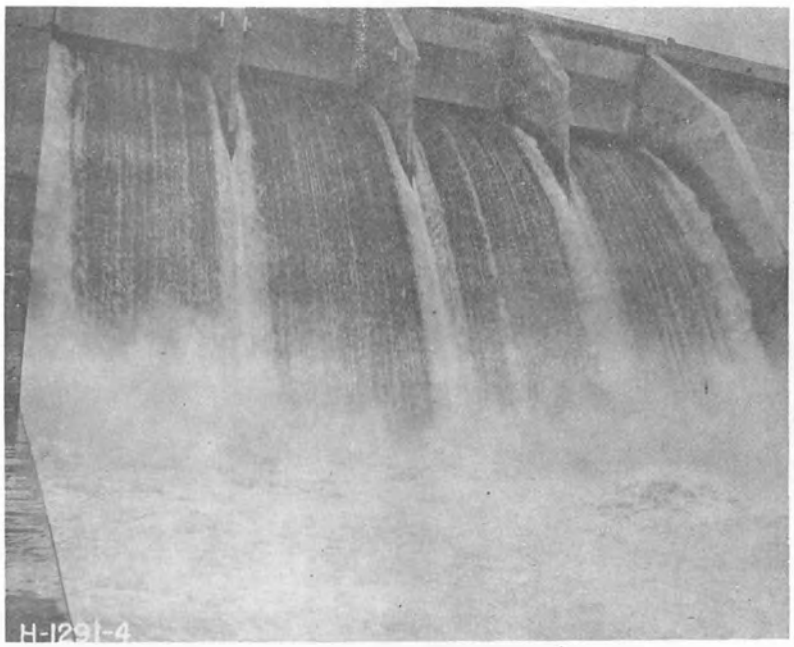
CANYON FERRY DAM

DISCHARGE COMPARISON OF MODEL AND PROTOTYPE

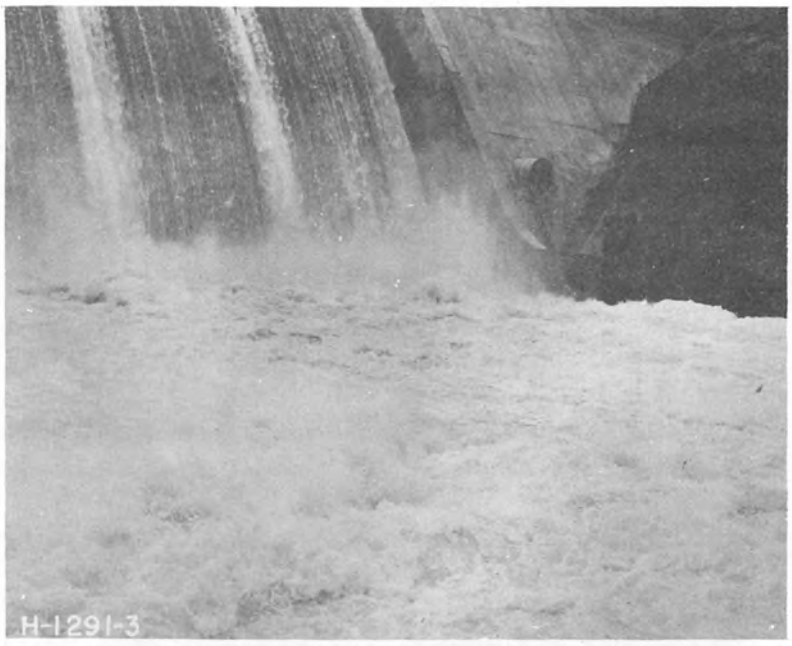
FIGURE 4
REPORT HYD. 433

FIGURE 5
REPORT HYD-433





A. Performance of Spillway

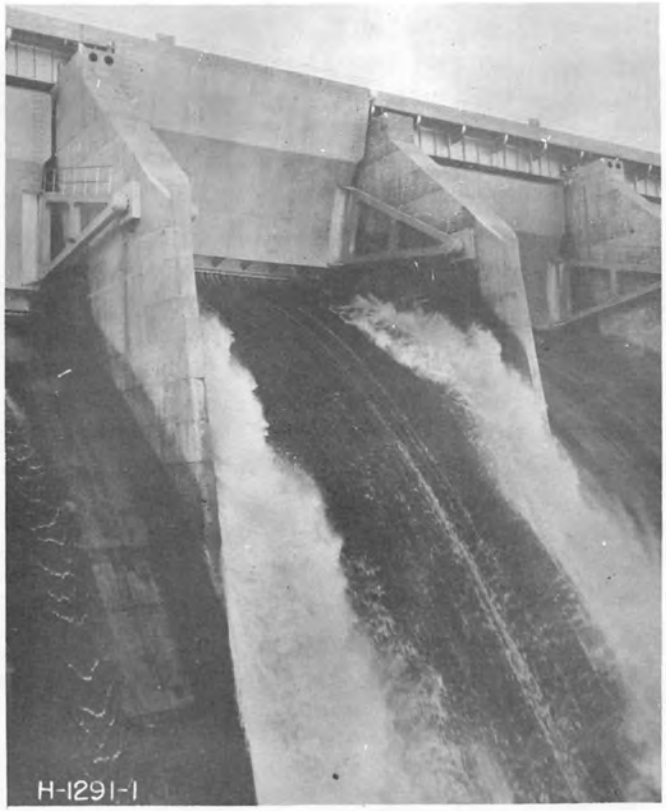


B. Stilling Basin Operation at Approximately 16 percent of Design Capacity

CANYON FERRY DAM
Spillway Flow Conditions for a Discharge of 24,000 cfs
Four Gates 4.2 Feet Open

Figure 7
Report Hyd 433

A. Flow Conditions for Discharge of 24,000 cfs with Four Gates Open 4.2 Feet



B. Blow Conditions for Discharge of 13,800 cfs--Gate Number 2, 10 Feet Open

CANYON FERRY DAM
Flow Conditions on Spillway Face for Discharges of 24,000 cfs and 13,800 cfs