UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF SWIFT DAM SPILLWAYS--PONDERA COUNTY CANAL AND RESERVOIR COMPANY, MONTANA

Report No. Hyd-548

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

November 24, 1965

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ABSTRACT

Hydraulic models of the two spillways for Swift Dam in Montana indicated that the general concept of modification to the side channel spillway and preliminary design of the emergency spillway were satisfactory. Swift Dam, formerly known as Birch Creek Dam, an earthfill structure built in 1914 and destroyed by the spring floods of 1964, will be replaced by a thin-arch concrete dam, and the existing channel spillway discharging into a gully leading to Birch Creek downstream from the dam will be rehabilitated. An overflow emergency spillway will be incorporated in the arch dam. Tests showed: /(1) Shortening the preliminary channel spillway about 125 feet provided better flow conditions with only a small reduction in capacity. (2) Dike abutment on left side of channel spillway should be paved to prevent erosion. (3) Flow from channel spillway discharged down the hillside into an eroded gully to the river channel satisfactorily. (4) The emergency spillway was lengthened about 5 percent to increase its capacity. (5) Jet leaving the emergency spillway flip bucket was very compact and its trajectory showed it would land well away from the structure. / Water surface profiles at design flow were used to fix channel lining heights. The coefficient of discharge for Swift Dam was estimated to be 4.00 at design head. This was determined by calibrating the model and comparing its crest shape with that of the Angostura and Anchor Dam spillways.

DESCRIPTORS-- spillway crests / hydraulic structures / dikes / research and development / arch dams / chutes / hydraulic models / hydraulic similitude / laboratory tests / erosion / drawdown / *discharge measurement / *discharge coefficients / submergence / stream channels / spillways / hydraulics / design / flip buckets / water surface profiles / disturbances
IDENTIFIERS-- *side channel spillways / Swift Dam, Mont / Montana / *emergency spillways / design modifications / Pondera Cnty Cnl & Resvr Co / crest shapes

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Office of Chief Engineer
Division of Research
Hydraulics Branch
Denver, Colorado
November 24, 1965

Report No. Hyd-548
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HYDRAULIC MODEL STUDIES OF SWIFT DAM SPILLWAYS--PONDERA COUNTY CANAL AND RESERVOIR COMPANY, MONTANA

PURPOSE

The studies were conducted to aid in the development of the hydraulic designs of proposed modifications to the existing side channel spillway and of the new arch dam emergency spillway.

RESULTS

1. The general concept of the modification to the side channel spillway and the preliminary design of the arch dam emergency spillway were satisfactory.

2. Shortening the preliminary channel spillway improved the flow pattern with very little loss in capacity.

3. The dike abutment on the left side of the spillway was paved to prevent erosion of the abutment.

4. Flow from the channel chute discharged down the hillside and into the gully leading to the river downstream in a satisfactory manner.

5. The preliminary arch dam emergency spillway was lengthened about 5 percent to compensate for a reduction in the originally anticipated capacity of the modified channel.

6. Flow approaching the emergency spillway crest was very smooth.

7. The jet leaving the emergency spillway flip bucket was very compact and its trajectory indicated it would land well away from the structure.

ACKNOWLEDGMENT

The final plans evolved from these studies were developed through the cooperation of the staffs of the Dams Branch and the Hydraulics Branch during the period September 1964 through April 1965. Most of the engineering work required for the construction and testing of the model and the compilation of the results from the test data was done by Pedro Arroyo, a foreign trainee from Caracas, Venezuela, assigned to the laboratory. Laboratory photography was by Mr. W. M. Batts, Office Services Branch.

INTRODUCTION

Swift Dam, also known as the Birch Creek Dam, was originally built in 1914. The dam was destroyed by floods during the spring of 1964. The original was a 160-foot-high, 465-foot-long, earthfill dam owned and operated by Pondera County Canal and Reservoir Company. It was located on Birch Creek, in northern Montana, about 90 miles northwest of Great Falls (Figure 1). Federal emergency relief funds are being used to replace the dam and to improve other facilities at the reservoir site.

The reconstruction program includes construction of a thin-arch concrete dam to replace the earthfill structure and the rehabilitation of the existing channel spillway (Figure 2). An overflow emergency spillway will be incorporated in the arch dam (Figure 3). Two 4- by 4-foot outlet conduits each having a capacity of 1,300 cfs (cubic feet per second) will be constructed through the lower central part of the dam.

The new dam is a 350-foot-radius thin-arch double-curvature structure approximately 205 feet high and 560 feet long at the crest. The emergency spillway is 210 feet long, measured along the axis of the dam. The crest of the emergency spillway is at elevation 4886, 6 feet below maximum reservoir water surface, elevation 4892 (Figure 4). The emergency spillway was designed for a discharge capacity of 12,500 cfs.

The existing channel spillway, Figures 5 and 6, located about 600 feet to the left of the dam, discharges into a gully leading to Birch Creek downstream from the dam. The existing spillway is to be widened, modified, and rehabilitated as shown in Figures 7 and 8. The length of the existing channel will be reduced approximately 125 feet, however, the spillway crest length will remain about 375 feet at elevation 4883.5. The modified spillway will be capable of discharging 3,500 cfs before the emergency spillway over the dam starts to discharge and will have a maximum capacity of 21,200 cfs at reservoir elevation 4892.00.

THE MODELS

The 1:42 scale model was used to study the modifications to the channel spillway (Figure 9).

The head box was lined with sheet metal and contained the channel spillway, a representative portion of the reservoir topography from elevation 4840 to elevation 4910, and part of an existing earth dike to the left of the spillway. Entering flow was stilled with a rock baffle to provide a smooth reservoir water surface. A point gage placed approximately 100 feet upstream of the existing channel spillway was used to measure the reservoir water surface elevation. A connecting section between the head box and the tail box contained the spillway chute and a substantial part of the hillside topography (elevation 4790 to elevation 4860) on which the chute discharges. A sheet-metal-lined tail box contained a sufficient portion of the river channel topography (elevation 4715 to elevation 4790) to simulate downstream flow conditions. The tailwater elevation in the main river channel downstream from the dam was controlled by an adjustable tailgate and measured by a staff gage.

The model topography was molded of concrete mortar placed on expanded metal lath which had been nailed over wooden templates shaped to the ground surface contours. The channel spillway and chute were formed of concrete mortar screeded to plywood templates. Proper invert slopes were maintained by screeding the concrete to sheet metal templates. Water was furnished to the model from the main laboratory supply system, and the flow rate was measured by either a 4- or 6-inch volumetrically calibrated Venturi meter.

The sectional model of the arch dam emergency spillway (Figure 10) was a 1:18 scale reproduction of a 27-foot-long section of the left side of the spillway and included the left approach wing wall. The section was placed in a 33-inch-wide flume having a glass wall at the crest section. Axis of the spillway crest was constructed in a straight line normal to the sides of the flume rather than as a segment of a 350-foot-radius arc as in the prototype (Figure 4). This slight discrepancy in the representation of the prototype is considered negligible for the purpose of the model study.

Water was supplied to the model and flow quantities were measured in the same manner as for the channel spillway model.

THE INVESTIGATION

The primary purpose of the investigation was to determine the discharge capacities of the channel spillway and of the emergency spillway over the dam. Observations were also made of the flow approaching the channel spillway, particularly at the dike abutment on the left side and of flow in the channel and on the hillside downstream from the channel. Tests on the emergency spillway were also concerned with approach flow and with the appearance and trajectory of the jet leaving the flip bucket.

Preliminary Design Channel Spillway

Flow characteristics in the channel.--In general, the flow conditions were satisfactory especially for flows of less than 14,000 cfs above which the crest submerged. For a discharge of 25,000 cfs the flow was fairly smooth and well distributed in the upstream part of the channel. However, disturbances formed along the right wall at a proposed cutoff or deflector wall near Station 10+00 and at about Station 11+40, where a typical cross wave pattern developed as a result of the curved wall alinement, Figure 11. On the left side of the spillway near the earth dike, at approximately Station 13+00, the ground surface was slightly higher than the crest. The flow velocity in this region increased and created a drawdown in the water surface, Figure 12A. At maximum discharge the resulting turbulence and cross waves caused overtopping of the channel walls downstream from the dike.

Flow characteristics downstream from the spillway channel.--The flow discharged from the spillway chute at elevation 4867 onto the hillside leading to an existing gully, Figure 12B. The flow on the hillside was partially deflected by an existing hump in the ground surface at the right of the chute centerline. The main part of the discharge followed the natural slope of the hillside to the eroded gully leading to the river channel. The portion of the flow that was deflected to the right of the hump followed a milder slope to the river channel and joined the main flow at the downstream end of the gully.

On reaching the foot of the hillside, the flow crossed the gully and climbed the opposite bank to elevation 4800 approximately 50 feet above the bottom of the gully. A relatively quiet pool formed in the gully to the left of the impact area. To the right of the impact area the flow moved rapidly down the steep gully to the relatively wide, flat channel of Birch Creek.

Discharge capacity.--The spillway discharge capacity was approximately 22,800 cfs at maximum reservoir water surface elevation 4892, Figure 13. This was about 2,200 cfs less than the preliminary design estimate.

Modifications to the Preliminary Design

Drawdown control.--Preliminary studies indicated that a vertical training wall at the dike abutment near the spillway channel would smooth the flow, reduce the drawdown of the flow entering the spillway, and eliminate the possibility of erosion along the upstream face of the embankment.

Several types of training wall configurations were tested, Figure 14. It was determined that a long wall approximately parallel to the embankment with a curved approach, as shown in Figure 14B, was effective in improving the flow conditions. Best results were obtained for walls 35 and 28 feet long. A 6-foot drop in water surface, however, was observed throughout the length of each of the walls. Because of this drawdown, it was decided not to use a training wall.

Another method of reducing the possibility of embankment erosion was to increase the height of the left wall of the channel so that its top sloped gradually from elevation 4895 at Station 13+56 near the dike to elevation 4883.4 at Station 12+85. The purpose of this modification was to move the high-velocity flow away from the dike abutment. However, this modification increased the drawdown of the flow along the left wall and reduced the discharge capacity of the spillway.

Spillway channel. --Field inspection had indicated that rehabilitation of the upstream end of the existing spillway would be difficult, so it was decided to build a new section of crest across the channel a short distance from the existing crest and to eliminate the proposed cutoff wall, Figure 9. Tests were run to determine the optimum length and arrangement of spillway crest that would provide adequate discharge capacity and acceptable flow conditions.

A crest section was installed across the upstream end of the channel, shortening the spillway channel approximately 100 feet. This modification reduced the discharge capacity by about 1,000 cfs from that of the preliminary design. Moving the new crest section downstream another 25 feet reduced the discharge capacity an additional 300 cfs. In view of the reduced discharge capacity, no further shortening of the channel was attempted.

With the new crest section installed across the spillway channel, the adverse flow condition caused by the channel curvature at Station 11+40 was eliminated, Figure 17A. For low flows, a turbulent boil formed at the toe of the new crest section close to the left wall, creating an asymmetrical flow pattern, Figure 16A; when the crest started to submerge, this adverse flow condition ceased. Tests showed that the crest started to submerge when the reservoir elevation reached 4889.5 feet (H = 6 feet); the crest was fully submerged at reservoir elevation 4891.5.

Recommended Design of the Channel Spillway

Flow characteristics and description.--The recommended channel spillway was similar to the second modification in which the channel length was reduced approximately 125 feet by installation of a new crest section across the upstream end of the channel. The upstream portion of the new crest section was divided into three short chords of a circular arc having a center angle of 90° and a radius of 23 feet measured from the crestline, and a straight section that angled downstream to the right, Figure 7. The right wall of the channel will be lined with concrete throughout its length, and the upstream slope of the dike abutment near the channel will be paved to protect the dike from erosion, Figures 7 and 8.

A boil formed at the toe of the upstream portion of the crest at low flows, Figure 15. However, the boil was near the center of the channel and the flow distribution in the downstream portion of the channel was symmetrical. For larger discharges, high-velocity flow and some drawdown still occurred near the dike abutment, (Figures 16 and 17). However, the possibility of erosion is eliminated by the paved area.

Water surface profiles along the right and left training walls of the channel were obtained to determine the height to which the concrete lining should be extended, Figure 18. The profiles were recorded for the maximum elevation to which the water surface fluctuates and are for a discharge slightly in excess of the maximum flow.

The right wall lining will be overtopped occasionally. However, the embankment supporting the right wall lining extends much higher than the lining in the vicinity of the overtopping as shown in Figures 7 and 8, and therefore is satisfactory.

The appearance of the flow on the hillside (Figures 15, 16 and 17) was improved when the large hump in the right side of the flow path was removed. However, removal of the hump is not necessary for satisfactory flow conditions and was not recommended for the prototype.

Discharge capacity.--Calibration of the spillway (Figure 13) showed the side channel spillway was capable of discharging 3,500 cfs at reservoir elevation 4886, which is the crest elevation of the arch dam emergency spillway. When the reservoir reaches approximately elevation 4889.5, the discharge is about 14,500 cfs and the crest begins to submerge (Figure 16A). At maximum reservoir elevation 4892, the spillway discharges approximately 21,200 cfs, Figure 13. This is approximately 300 cfs less than in the second modification and is due to the slightly different location of the crest section across the existing channel and to the drawdown created by the paved area on the dike abutment.

ARCH DAM EMERGENCY SPILLWAY

Since the spillway was located near the center of the arch dam, the flow approaching the spillway was assumed to be satisfactory. Only minor disturbances in the flow was observed, at the left approach wall, Figure 19, so no changes in the approach walls were recommended.

The jet leaving the flip bucket was very compact, and the trajectory indicated that the jet would impinge well downstream from the base of the dam, Figure 19B. No changes in the preliminary design of the flip bucket were recommended.

Initially the length of the arch dam emergency spillway was 200 feet as measured along the axis of the arch dam. However, due to the reduced capacity of the recommended channel spillway, the length of the arch dam emergency spillway was increased to 210 feet measured along the axis of the dam or to 212.40 feet measured along the axis of the spillway crest.

The discharge capacity of the spillway was determined from a straight 27-foot-long (prototype) sectional model. The reservoir elevations were measured at a point 85 feet upstream from the crest. For reservoir elevation 4892 (6 feet above the crest) the spillway capacity was 14,000, Figure 20. This flow results in a discharge coefficient of 4.48; however, the head used in computing the coefficient did not include velocity head. Dye streamers in the model reservoir area indicated that the flow currents were concentrated near the surface and extended only slightly below crest elevation. A velocity head based on the area of flow above crest elevation 4886 was computed and added to the measured head. The resulting discharge curve (H_T) is plotted in Figure 20 and shows a discharge that is probably slightly less than the true discharge, since the velocity head computation was based on a flow area that was smaller than the actual flow area. This interpretation of the velocity head provides a discharge coefficient of 3.90 at design reservoir elevation, Figure 20. It is, therefore, estimated that the true coefficient at design head should be approximately 4.00.

Using the method described in Engineering Monograph No. 9 1/, the dimensionless cross-sectional shape of Swift Dam emergency spillway

1/Engineering Monograph No. 9, U.S. Bureau of Reclamation, Discharge Coefficients for Irregular Overfall Spillways, March 1952, by J. N. Bradley.

was compared with those of Angostura Dam spillway and Anchor Dam spillway2/, whose coefficients of discharge are known. Because the crest shapes are similar, it was estimated that the coefficient of discharge for Swift Dam should be approximately 4.00 at design head, Figure 21. This is the same as estimated from the model test data presented above. Based on this coefficient, a discharge capacity curve was computed, and was indicated for the Swift Dam emergency spillway, Figure 20.

2/Report Hyd-289, U.S. Bureau of Reclamation, Hydraulic Model Studies of the Spillway and Outlet Works of Anchor Dam, Owl Creek Unit, Missouri River Basin Project, February 9, 1951, by W. P. Simmons, Jr.

Table 1

DIMENSIONS OF HYDRAULIC FEATURES

Feature	English	Metric
Height of old dam	160 ft	48.768 m
Length of old dam	465 ft	137.160 m
New arch dam radius	350 ft	106.680 m
New dam height	205 ft	60.960 m
New dam length	560 ft	170.688 m
Arch dam emergency spillway capacity (approximate)	12,500 cfs	354 cm
Channel spillway capacity (approximate)	21,200 cfs	600 cm
Channel spillway capacity with reservoir at crest of arch dam	3,500 cfs	99.1088 cm
Size of two outlet conduits	4 x 4 ft	1.2192 x 1.2192 m
Outlet conduit capacity (each)	1,300 cfs	36.81184 cm
Arch dam spillway crest length	212.40 ft	64.736472 m

SWIFT DAM

Existing Channel Spillway

A. Looking downstream. Side channel spillway.

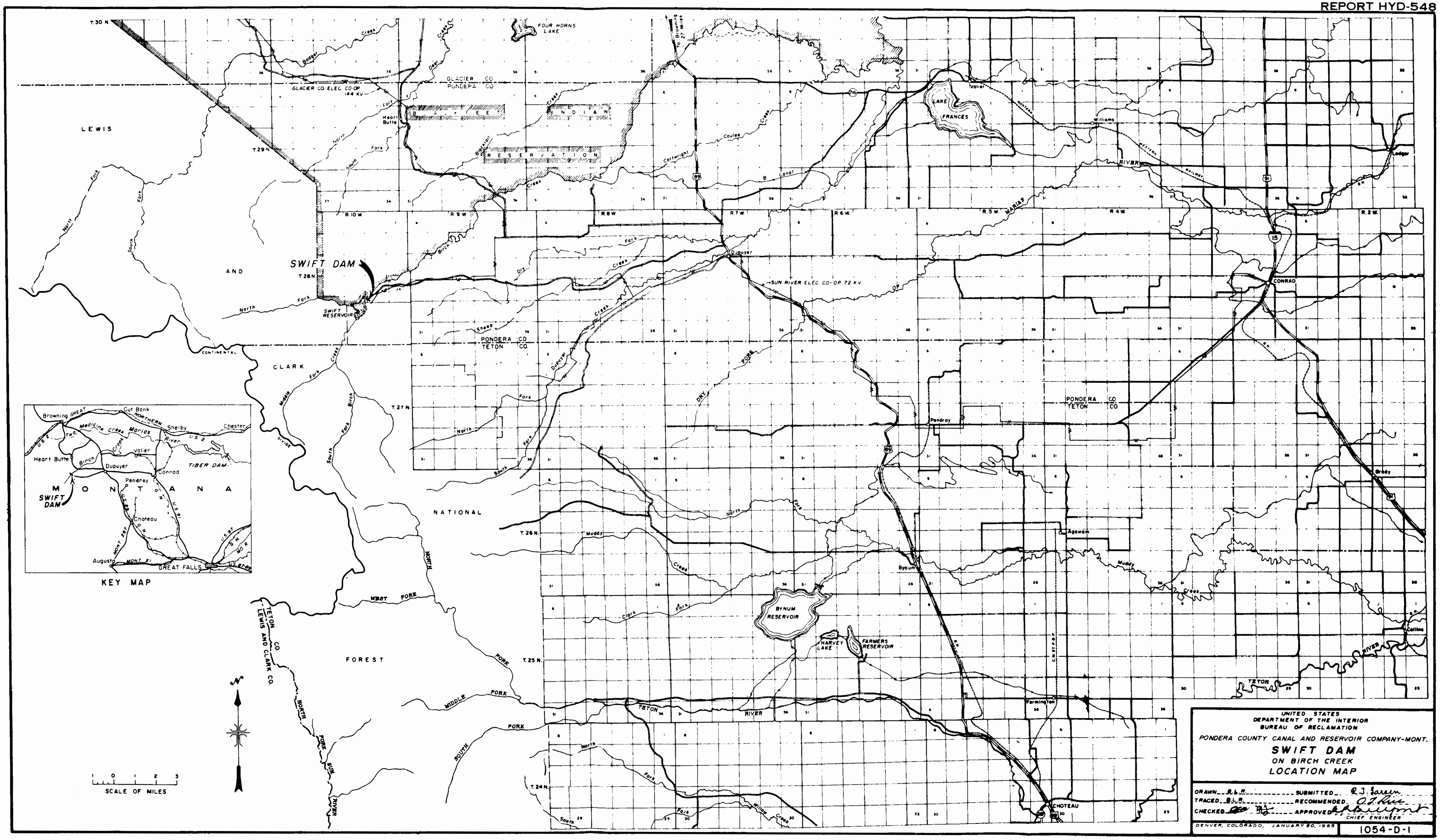
B. Looking downstream from end of spillway into eroded gully.

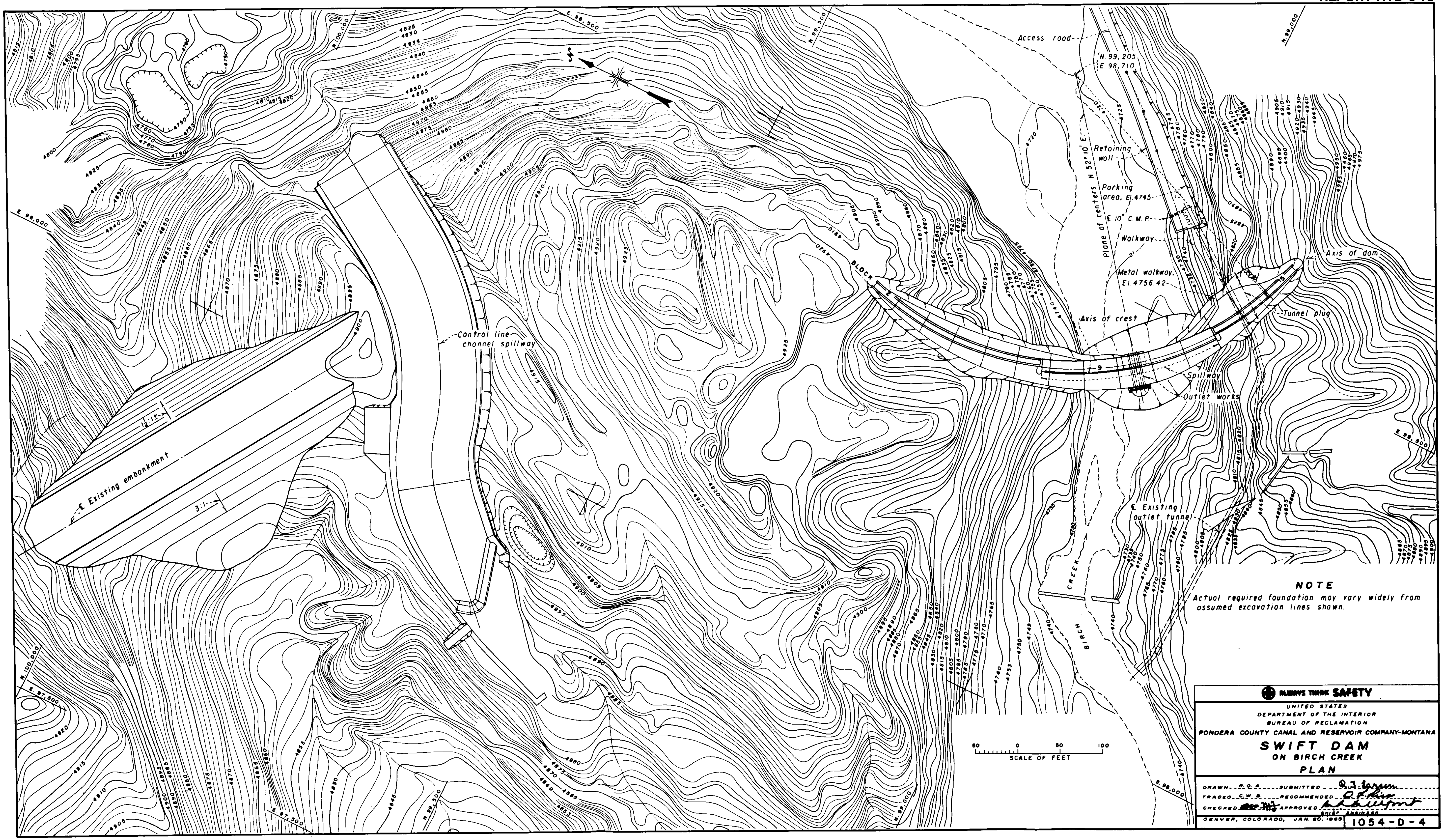
C. Looking upstream. Spillway flow is from the left.

SWIFT DAM

Existing Channel Spillway and Gully

FIGURE I
REPORT HYD-548




Access road
N. 99,205
E. 98,710
Retaining wall
Parking area, El. 4745
℄ 10" C.M.P.
Walkway
Metal walkway, El. 4756.42
Plane of centers N. 52° 10' E
Axis of dam
Tunnel plug
Axis of crest
BLOCK
Spillway
Outlet works
℄ Existing outlet tunnel
BIRCH CREEK
Control line channel spillway
℄ Existing embankment
NOTE
Actual required foundation may vary widely from assumed excavation lines shown.
50 0 50 100
SCALE OF FEET
ALWAYS THINK SAFETY
UNITED STATES
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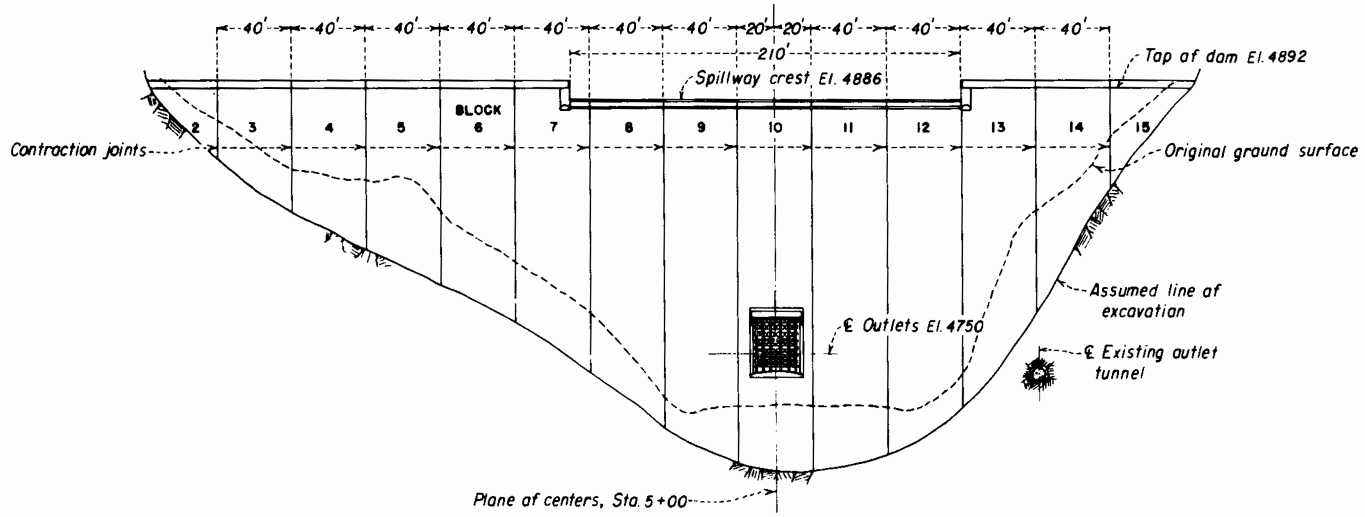
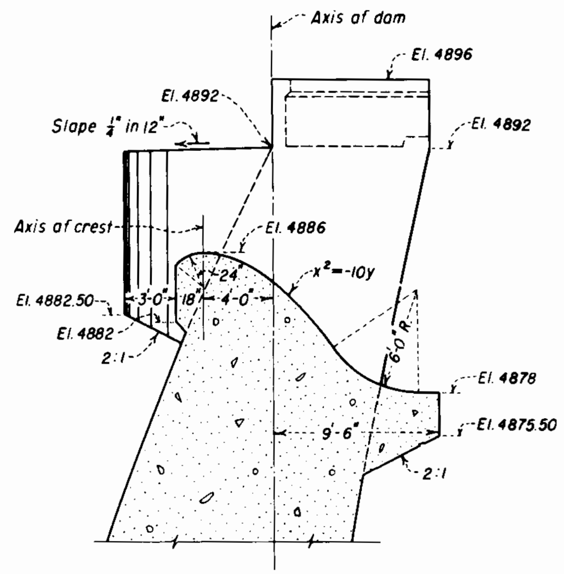
BUREAU OF RECLAMATION
PONDERA COUNTY CANAL AND RESERVOIR COMPANY-MONTANA
SWIFT DAM
ON BIRCH CREEK
PLAN
DRAWN R.O.A. SUBMITTED
TRACED C.W.B. RECOMMENDED
CHECKED APPROVED
CHIEF ENGINEER
DENVER, COLORADO, JAN. 20, 1965
1054-D-4



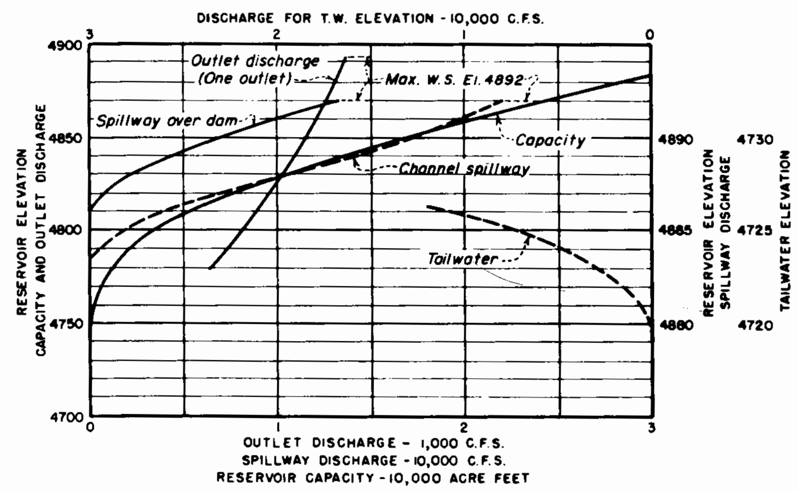
UPSTREAM ELEVATION
DEVELOPED ALONG AXIS

50 0 50 100 150
SCALE OF FEET

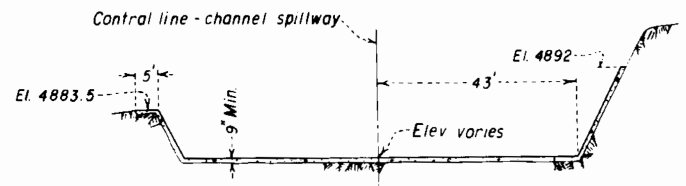


SECTION THRU SPILLWAY OVER DAM

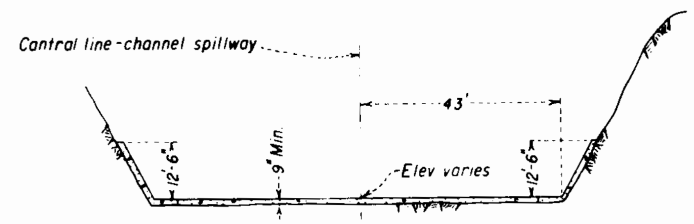
5 0 5 10 15
SCALE OF FEET



TAILWATER, AND CAPACITY CURVES - DISCHARGE CURVES FOR SPILLWAYS AND OUTLET



SECTION THRU CHANNEL SPILLWAY UPSTREAM OF DIKE

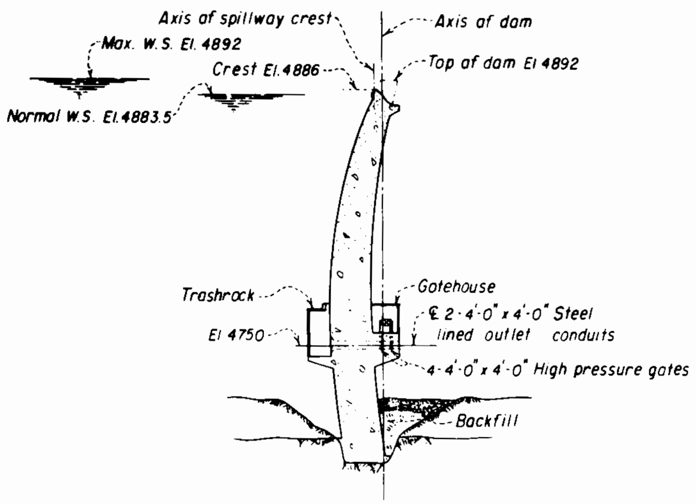


SECTION THRU CHANNEL SPILLWAY DOWNSTREAM OF DIKE

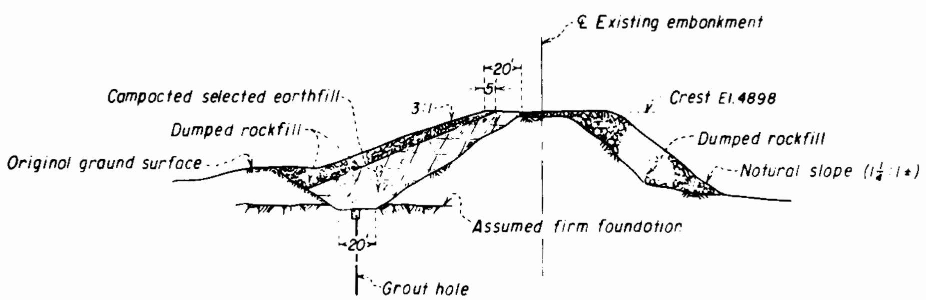
20 0 20 40 60
SCALE OF FEET

NOTE

Actual required foundation may vary widely from assumed excavation lines shown.

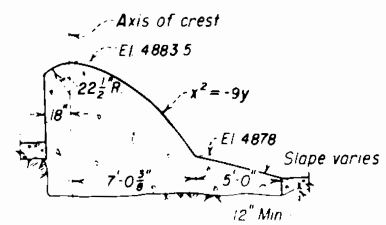


SECTION THRU ℄ OUTLET WORKS



MAXIMUM SECTION THRU DIKE

50 0 50 100 150
SCALE OF FEET



SECTION THRU CHANNEL SPILLWAY WEIR

5 0 5 10 15
SCALE OF FEET

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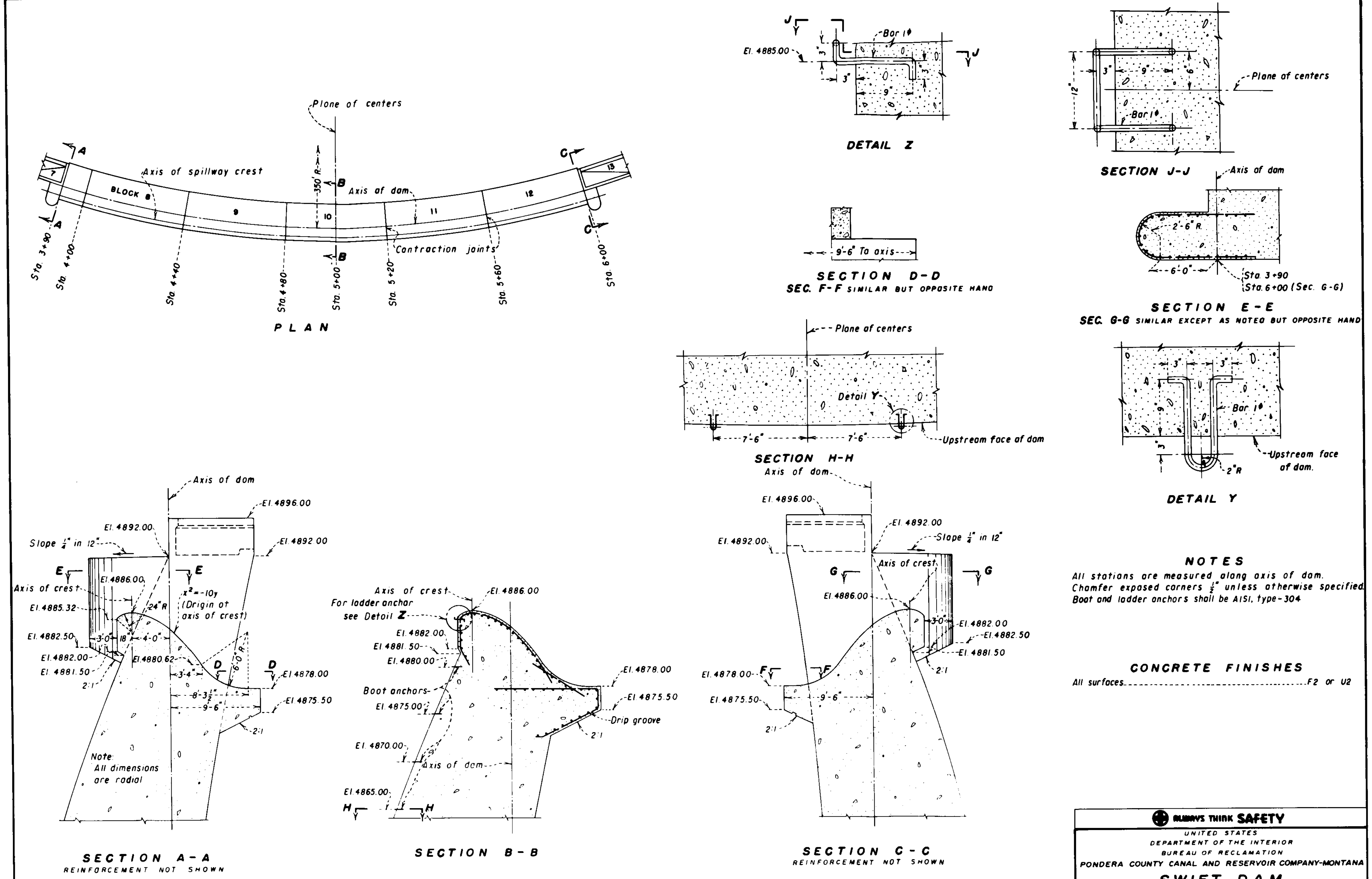
PONDERA COUNTY CANAL AND RESERVOIR COMPANY-MONTANA

SWIFT DAM
ON BIRCH CREEK
ELEVATION AND SECTIONS

DRAWN R.O.A. SUBMITTED May, [signature]
TRACED J.M. RECOMMENDED [signature]
CHECKED [signature] APPROVED [signature]
CHIEF DESIGNING ENGINEER
DENVER, COLORADO, JANUARY 20, 1955 1054-D-5



NOTES

All stations are measured along axis of dam.
Chamfer exposed corners 1/2" unless otherwise specified.
Boat and ladder anchors shall be AISI, type-304.

CONCRETE FINISHES

All surfaces..F2 or U2

ALWAYS THINK SAFETY

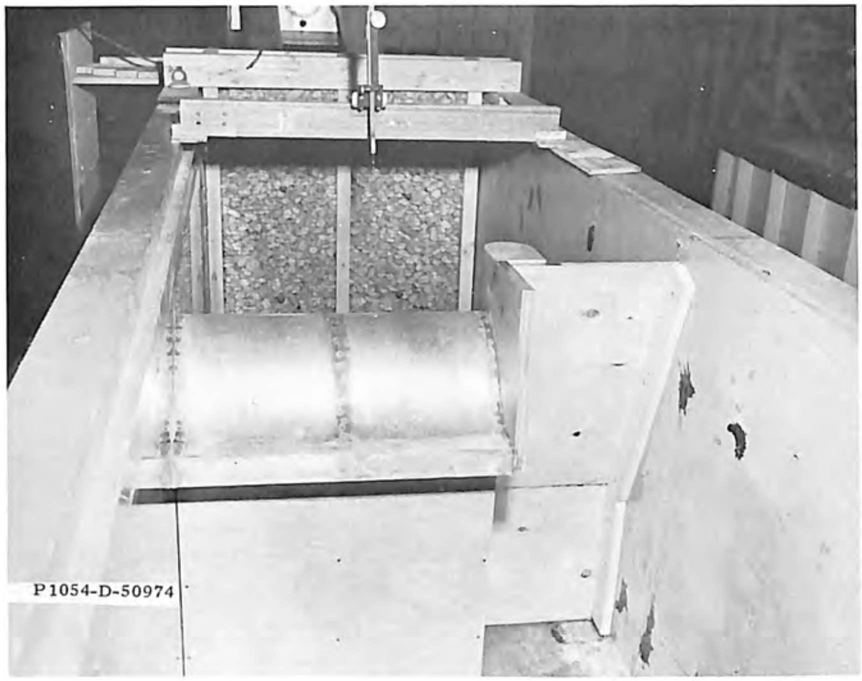
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PONDERA COUNTY CANAL AND RESERVOIR COMPANY-MONTANA

SWIFT DAM
ON BIRCH CREEK
SPILLWAY OVER DAM

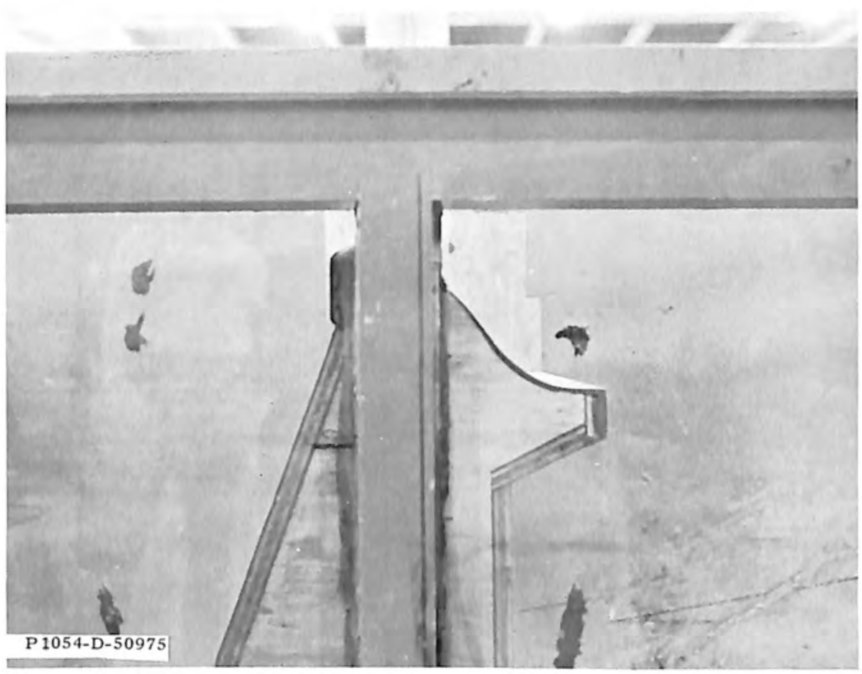
DRAWN: G.B. SUBMITTED: May Jones
TRACED: C.W.B. RECOMMENDED: R.J. Larsen
CHECKED: ... APPROVED: O.F. Rice, CHIEF DESIGNING ENGINEER
DENVER, COLORADO, JAN. 20, 1966 — 1054-D-13

SWIFT DAM SPILLWAYS

1:42 Scale Model
Channel Spillway Model



A. Looking upstream.

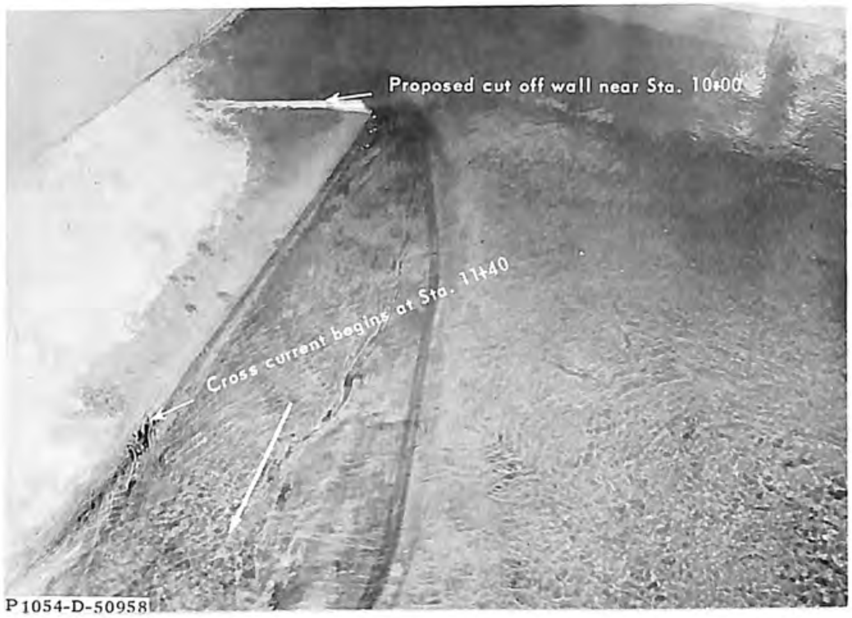


B. Side view, showing flip bucket.

SWIFT DAM SPILLWAYS

1:18 Scale Model
Sectional Model of the Arch Dam Emergency Spillway

Figure 11
Report Hyd-548



A. Upstream end of spillway.

B. Flow at the cutoff wall.

SWIFT DAM SPILLWAYS

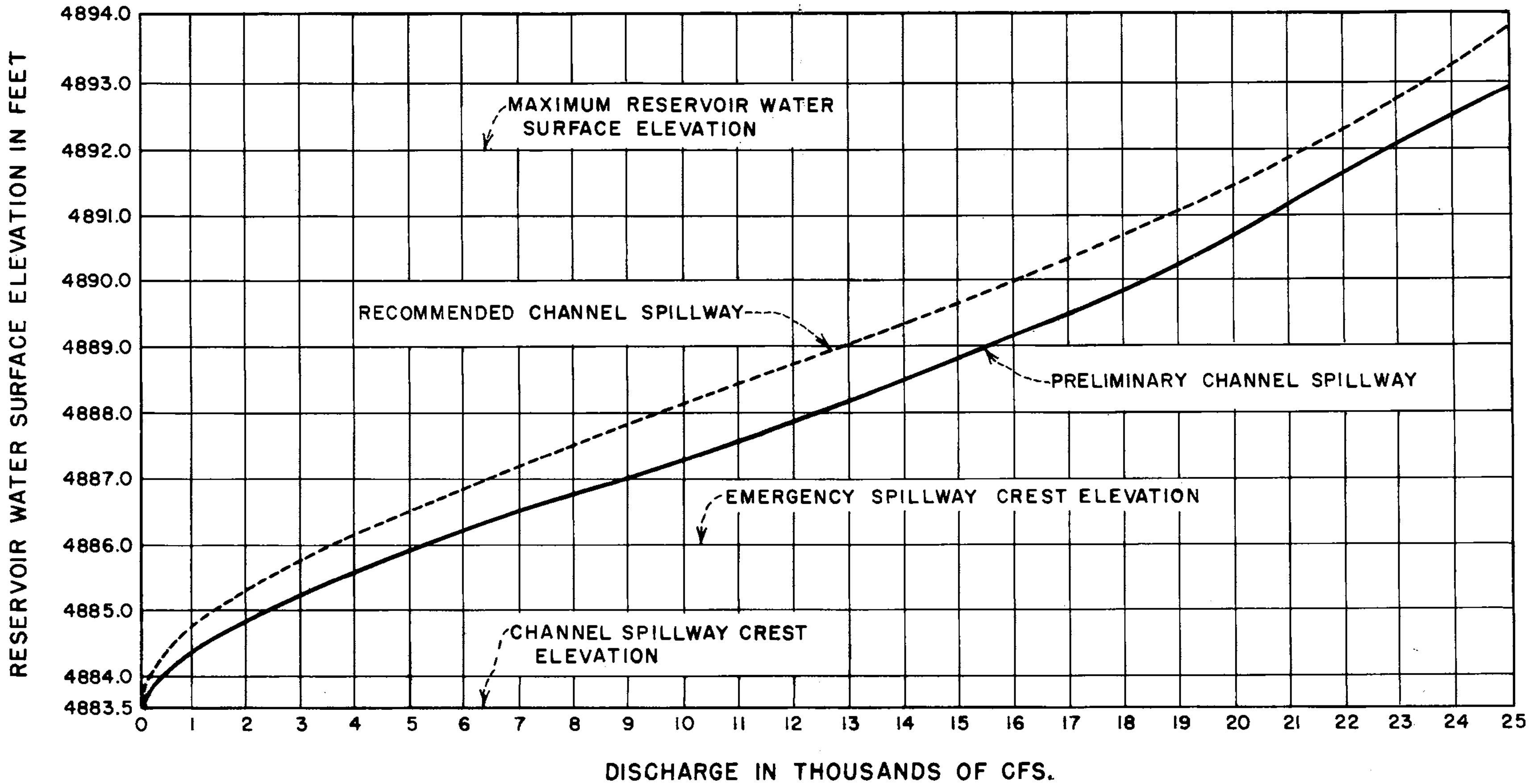
1:42 Scale Model
Flow in Preliminary Channel Spillway--25,000 cfs

A. Drawdown at left side near dike abutment.

B. Flow down hillside into gully.

SWIFT DAM SPILLWAYS

1:42 Scale Model
Flow in Preliminary Channel Spillway--25,000 cfs



SWIFT DAM SPILLWAYS
DISCHARGE CAPACITY OF THE CHANNEL SPILLWAY
1:42 SCALE MODEL

FIGURE 13
REPORT HYD. 548

A. Straight guide wall to reduce scour.

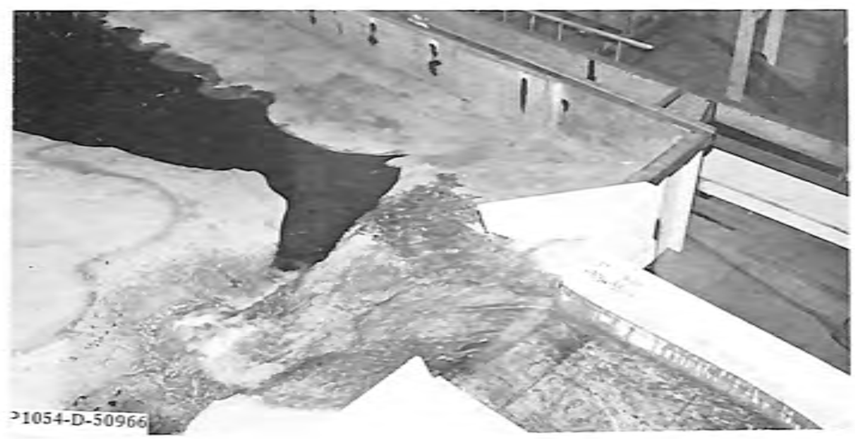
B. Straight guide wall with curved approach to reduce scour and drawdown.

SWIFT DAM SPILLWAYS

1:42 Scale Model
Discharge Capacity of the Channel Spillway

A. Channel spillway.

B. Channel spillway discharging 3,500 cfs.
Reservoir elevation 4886.0.



C. Flow down hillside into gully.
Q = 3,500 cfs.

SWIFT DAM SPILLWAYS

1:42 Scale Model
Recommended Channel Spillway

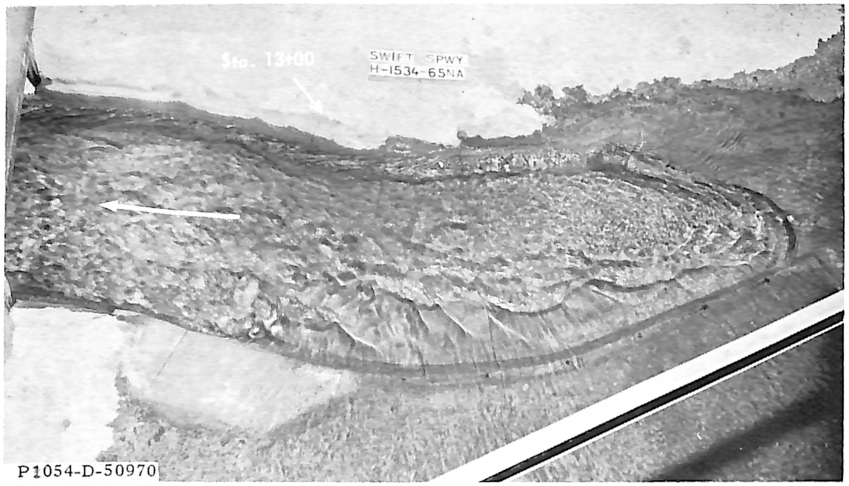
A. Side channel crest section.

B. Flow at dike abutment.

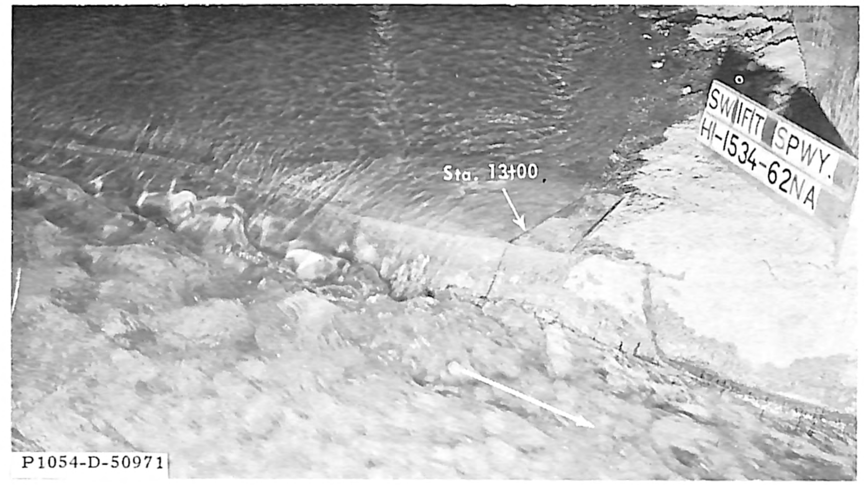
C. Flow down hillside into gully.

SWIFT DAM SPILLWAYS

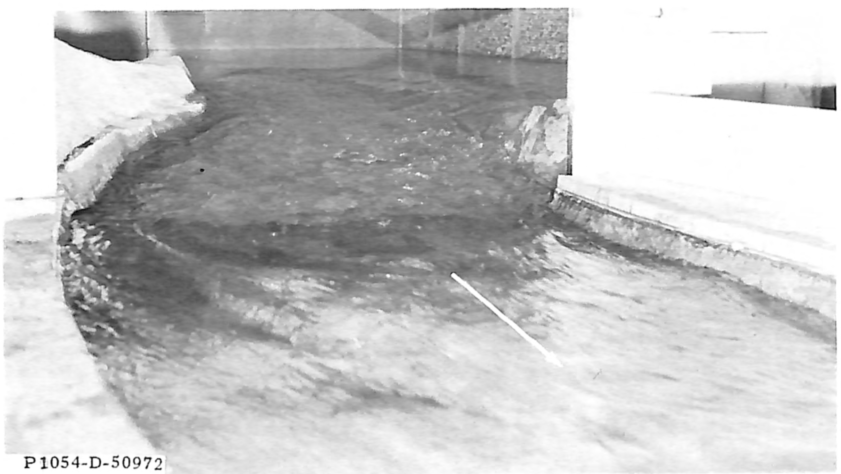
1:42 Scale Model
Flow in Recommended Channel Spillway--14, 500 cfs



A. Flow over crest into channel.



B. Flow at dike abutment.



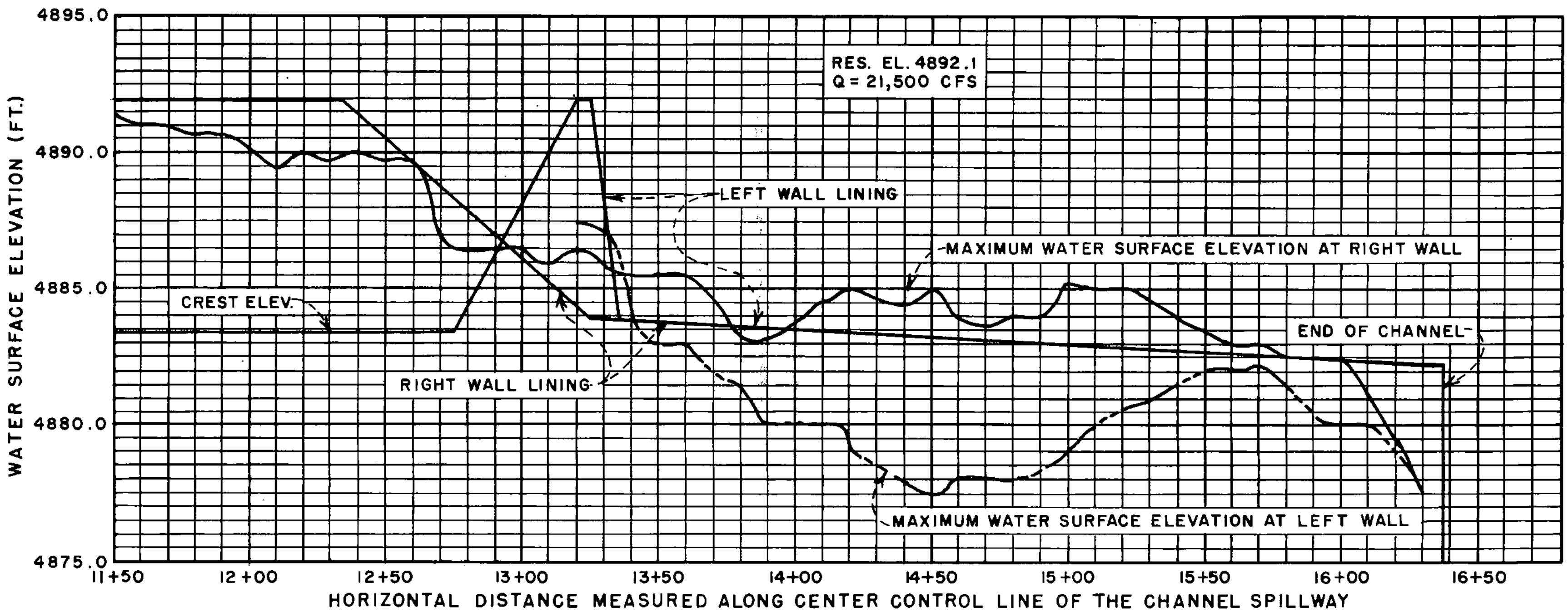
C. Flow in channel facing upstream.

D. Flow down hillside into gully.

SWIFT DAM SPILLWAYS

1:42 Scale Model

Flow in Recommended Channel Spillway - 11,200 cfs



SWIFT DAM SPILLWAYS
WATER SURFACE PROFILES
1:42 SCALE MODEL

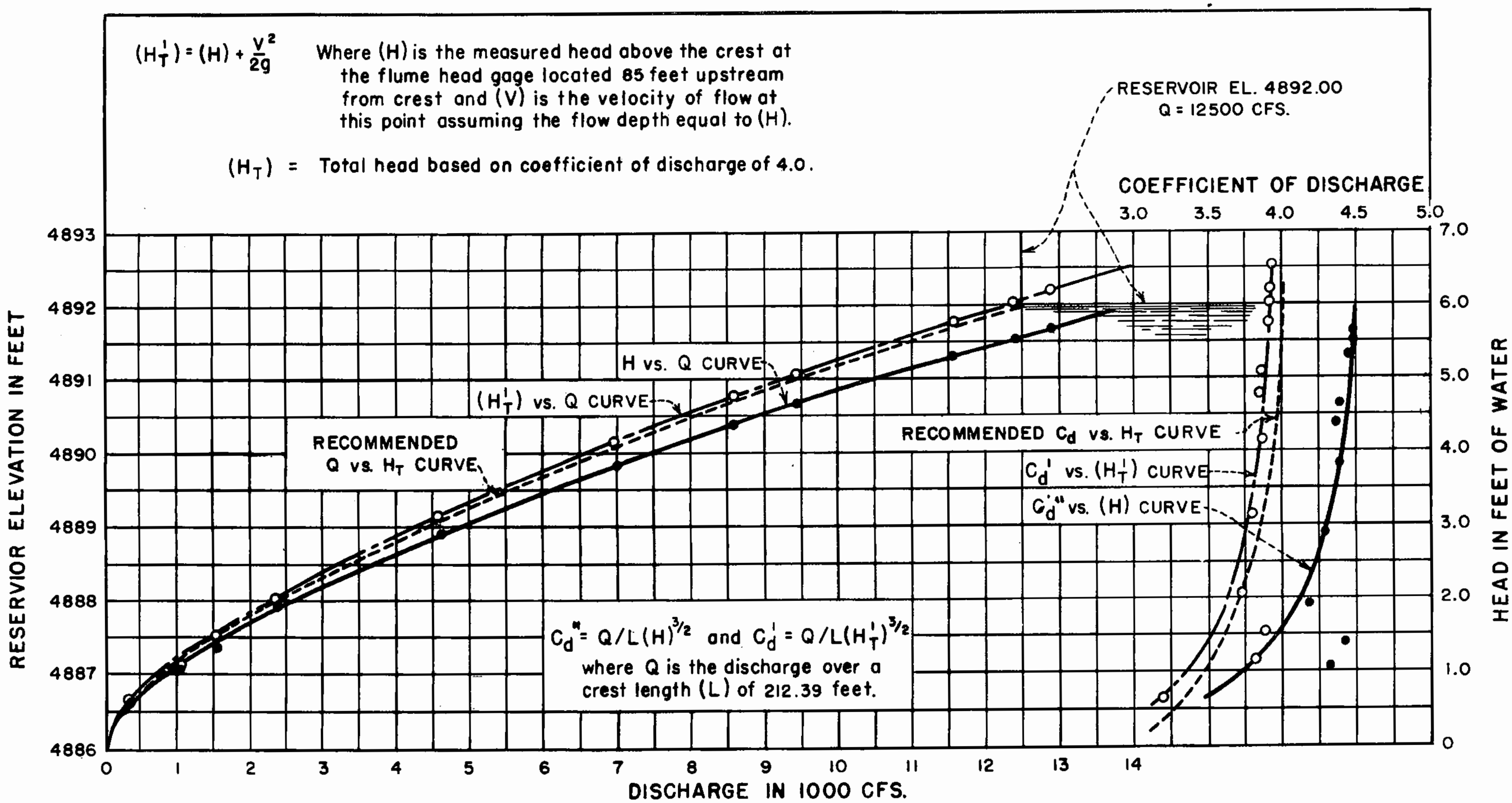
A. Spillway approach and left pier.

B. Flow from flip bucket.

SWIFT DAM SPILLWAYS

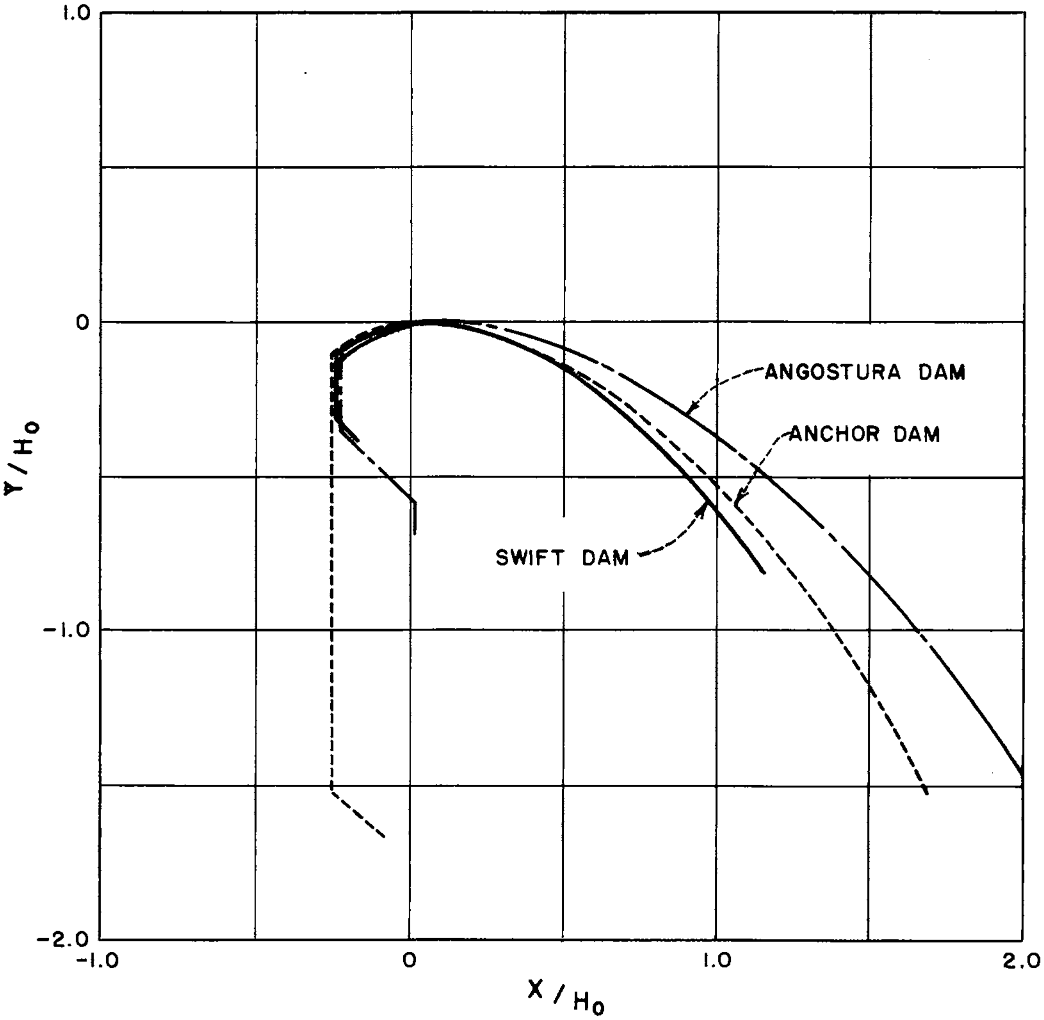
1:18 Scale Sectional Model
Flow in Arch Dam Emergency Spillway--13,800 cfs

Figure 20
Report Hyd-548



SYMBOL
- ● DATA POINTS
- ○ DATA POINTS INCLUDING A COMPUTED VELOCITY HEAD

SWIFT DAM SPILLWAYS
DISCHARGE CAPACITY OF THE EMERGENCY SPILLWAY
1:18 SCALE SECTIONAL MODEL



COEFFICIENT OF DISCHARGE FOR THE SPILLWAYS
AT DESIGN HEAD (H_0)

ANGOSTURA DAM	C_D = 3·88
ANCHOR DAM	C_D = 3·97
SWIFT DAM	C_D = 4·00 (ESTIMATED)

H_0 for the arch dam emegency spillway at Swift is 6 feet.

SWIFT DAM SPILLWAYS

DIMENSIONLESS SPILLWAY SHAPES AND THEIR DISCHARGE COEFFICIENTS

GPO 854-382

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

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

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

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

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

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

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

ABSTRACT

Hydraulic models of the two spillways for Swift Dam in Montana indicated that the general concept of modification to the side channel spillway and preliminary design of the emergency spillway were satisfactory. Swift Dam, formerly known as Birch Creek Dam, an earthfill structure built in 1914 and destroyed by the spring floods of 1964, will be replaced by a thin-arch concrete dam, and the existing channel spillway discharging into a gully leading to Birch Creek downstream from the dam will be rehabilitated. An overflow emergency spillway will be incorporated in the arch dam. Tests showed: /(1) Shortening the preliminary channel spillway about 125 feet provided better flow conditions with only a small reduction in capacity. (2) Dike abutment on left side of channel spillway should be paved to prevent erosion. (3) Flow from channel spillway discharged down the hillside into an eroded gully to the river channel satisfactorily. (4) The emergency spillway was lengthened about 5 percent to increase its capacity. (5) Jet leaving the emergency spillway flip bucket was very compact and its trajectory showed it would land well away from the structure. / Water surface profiles at design flow were used to fix channel lining heights. The coefficient of discharge for Swift Dam was estimated to be 4.00 at design head. This was determined by calibrating the model and comparing its crest shape with that of the Angostura and Anchor Dam spillways.

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Hyd-548
Beichley, G. L.
HYDRAULIC MODEL STUDIES OF SWIFT DAM SPILLWAYS--
PONDERA COUNTY CANAL AND RESERVOIR COMPANY,
MONTANA
Bureau of Reclamation, Denver, 29 p, including 3 tab, 21 fig,
2 ref, 1965

DESCRIPTORS-- spillway crests/ hydraulic structures/ dikes/ research and development/ arch dams/ chutes/ hydraulic models/ hydraulic similitude/ laboratory tests/ erosion/ drawdown/ *discharge measurement/ *discharge coefficients/ submergence/ stream channels/ spillways/ hydraulics/ design/ flip buckets/ water surface profiles/ disturbances
IDENTIFIERS-- *side channel spillways/ Swift Dam, Mont/ Montana/ *emergency spillways/ design modifications/ Pondera Cnty Cnl & Resvr Co/ crest shapes

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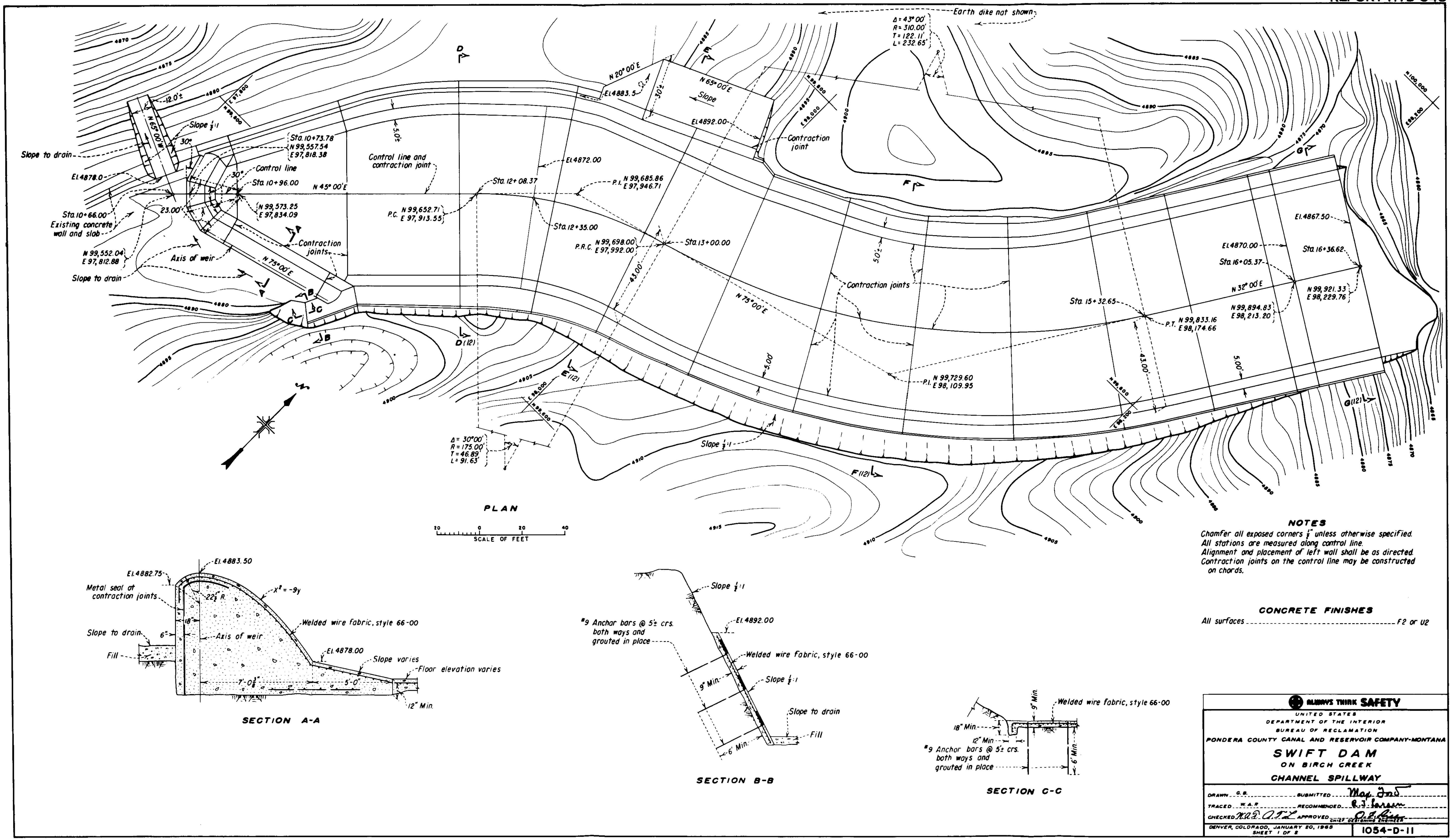
PLAN
SCALE OF FEET
SECTION A-A
SECTION B-B
SECTION C-C
Earth dike not shown
Control line and contraction joint
Contraction joints
Axis of weir
Slope to drain
Existing concrete wall and slab
NOTES
Chamfer all exposed corners 3/4" unless otherwise specified.
All stations are measured along control line.
Alignment and placement of left wall shall be as directed.
Contraction joints on the control line may be constructed on chords.
CONCRETE FINISHES
All surfaces F2 or U2
Metal seal at contraction joints
Welded wire fabric, style 66-00
#9 Anchor bars @ 5' crs. both ways and grouted in place
Floor elevation varies
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PONDERA COUNTY CANAL AND RESERVOIR COMPANY-MONTANA
SWIFT DAM
ON BIRCH CREEK
CHANNEL SPILLWAY
DENVER, COLORADO, JANUARY 20, 1965
SHEET 1 OF 2
1054-D-11

FIGURE 8
REPORT HYD-548