UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE SPILLWAY AND OUTLET WORKS FOR LOWER TWO MEDICINE DAM BLACKFEET INDIAN IRRIGATION PROJECT MONTANA

Report No. Hyd-554

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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ABSTRACT

A 1:24-scale sectional model of the spillway and outlet works of Lower Two Medicine Dam in Montana indicated that the stilling basin, common to both features, would operate satisfactorily as a USBR Type II basin, but that the basin performance could be improved by the addition of an intermediate row of baffle piers. The piers eliminated a "reverse roller" observed in the river channel immediately downstream from the Type II basin, which conceivably could result in river bed material being pulled upstream into the stilling basin with possible accompanying abrasive damage. The spillway and outlet works had sufficient capacity to pass the required flows. Sand erosion and riprap tests were applied to both the preliminary and recommended basins and the movement of rock and sand material was observed in both basins.

DESCRIPTORS--*spillways/ *outlet works/ *stilling basins/ *hydraulic models/ research and development/ appurtenances/ dentated sills/ earth dams/ hydraulic structures/ hydraulic jumps/ hydraulics/ model tests/ spillway crests/ baffles/ erosion/ scour/ riprap/ laboratory tests/ discharge measurement

IDENTIFIERS--Lower Two Medicine Dam/ Blackfeet Indian Irrigation Project/ Montana/ Bureau of Indian Affairs/ baffle piers/ discharge capacity

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PURPOSE

The study was performed to determine the hydraulic operating characteristics of the overflow spillway and slide-gate-controlled outlet works, with particular regard to the performance of the hydraulic jump stilling basin.

RESULTS

1. The preliminary designs of the spillway crest and the outlet works were satisfactory. Discharge capacities were adequate to pass the required maximum flows, Figures 7 and 9.

2. The outlet conduits downstream from the gates were enlarged to eliminate surging in the conduits when the outlet works operated alone, Figures 12 and 15.

3. Flow conditions in the stilling basin and downstream river channel were satisfactory except for a reverse roller downstream from the dentated end sill during simultaneous operation of the spillway and outlet works at the maximum design discharge. Erosion tests, Figure 10, indicated that material might be pulled into the stilling basin, and cause subsequent abrasive damage.

4. The model indicated that the proposed riprap, Figure 11, would be adequate to protect the river channel against erosion; however, a row of intermediate baffle piers was added to the basin to provide additional protection against material being pulled into the basin. The baffle piers altered the jump profile and eliminated the reverse roller, Figure 13.

5. The model indicated that without baffle piers in the basin, rock with a maximum dimension equivalent to 4 feet prototype (this was maximum

size tested in model) or less would be swept from the basin for the maximum spillway discharge of 20,600 cfs (cubic feet per second). A few pieces were lodged between the dentates. For a spillway discharge of 12,300 cfs, some material larger than 3 feet was deposited against the end sill but most of the material was swept from the basin. For a spillway discharge of 5,900 cfs, most of the material was deposited in the downstream portion of the basin. Material remaining in the basin did not circulate. The smallest rock size tested had a maximum dimension equivalent to a prototype size of about 1 foot. The model also showed that sand might circulate in the upstream portion of the basin during small spillway discharges.

6. With the baffle piers in place, rock material remained at different sections in the basin, depending on the rock size and the spillway discharge. A negligible amount of material was swept from the basin. Rock material remaining in the basin maintained a stable position without circulation. Sand circulated upstream from the baffle piers for discharges up to about 4,000 cfs, then moved to the downstream end of the basin with little circulation.

7. During operation of the outlet works alone, eddies in the basin resulted in the circulation of sand and other small particles, which represented an estimated maximum prototype size of about 3 to 6 inches. The circulation was relatively slow. At the outlet on the downstream face of the spillway, the sudden expansion of the outlet works discharge could cause circulation of abrasive material in the immediate vicinity of the outlet.

8. All practical precautions should be taken to keep the stilling basin free of rock and sand before and during spillway or outlet works operation. Since the most probable source of material is the downstream channel, the inclusion of baffle piers was recommended.

ACKNOWLEDGMENT

This study was accomplished through cooperation between the Concrete Dams Section of the Dams Branch, Division of Design, and the Hydraulics Branch, Division of Research. Photography was by Mr. W. M. Batts, Office Services Branch.

INTRODUCTION

Lower Two Medicine Dam is located on Two Medicine Creek about 40 miles west of Cut Bank in northwestern Montana, Figure 1. The dam is an earthfill structure with a height of approximately 56 feet and a crest length of about 1,100 feet, Figure 2.

The spillway, Figures 2 and 3, is an overflow crest with a width of 185 feet, located 16.78 feet below the crest of the dam. The outlet works, Figure 4, consists of two 3-foot-wide by 3-1/2-foot-high rectangular conduits, controlled by slide gates. The outlet works passes under the spillway section and discharges into a depressed section of the spillway stilling basin. The stilling basin discharges into the river channel, which is protected by riprap for a distance of 40 feet downstream from the end of the basin. The use of a common stilling basin for both the spillway and outlet works indicated that problems might be encountered during simultaneous operation of these features, therefore hydraulic model studies were requested.

THE MODEL

The 1:24 scale sectional hydraulic model represented about 65 feet (or about 35 percent) of the total width of the overflow spillway, measured from the right side of the spillway. The outlet works was included in this section. The spillway crest, outlet works, and stilling basin were fabricated from sheet metal. The chute blocks and dentated end sill were made from wood. These portions of the model are shown in Figure 5.

Water was supplied to the model through the permanent laboratory supply system and discharges were measured with volumetrically calibrated venturi meters or orifice meters (for very small discharges). Reservoir water surface elevations were measured by a point gage upstream from the spillway crest. Tailwater elevations were measured by a staff gage marked on the wall of the model near the downstream end of the stilling basin. Tailwater settings were made with an adjustable tailgate, according to the curve in Figure 6.

The outlet works discharge was regulated by slide gates located under the spillway crest, in the same position as the prototype gate section. The gates were reached by removing a small cover plate from the downstream face of the spillway.

THE INVESTIGATION

The preliminary design was tested to determine the discharge capacities of the spillway and outlet works and to observe flow conditions in the stilling basin and downstream river channel. Several relatively minor modifications were made to the preliminary design to improve the flow conditions.

The Preliminary Design

Discharge Capacity of the Spillway

The discharge capacity of the spillway was determined to check the capacity assumed for design purposes. The reservoir elevation versus discharge curve is shown on Figure 7, which includes a correction for velocity head. This correction was necessary because the model configuration did not allow water surface elevation measurement at a sufficient distance from the crest to ensure low velocity and negligible velocity head. The section at which the model water surface elevation was measured was about 50 feet (prototype) upstream from the spillway crest. The water surface drawdown as the flow passed over the spillway caused a sufficient lowering of the water surface elevation at the measuring section to require a correction. The drawdown at any point is equal to the velocity head at that point. Velocity head corrections were negligible below a reservoir elevation of about 4890 (discharge = 15,000 cfs).

The spillway capacity was 20,500 cfs at maximum reservoir elevation 4891.5 or approximately 0.5 percent less than the assumed design capacity of 20,600 cfs. Velocity distribution 50 feet (prototype) upstream from the spillway crest for the maximum discharge is shown in Figure 8.

Discharge Capacity of the Outlet Works

The two-conduit outlet works was calibrated with the gates equally opened to 100, 75, 50, and 25 percent, and a curve showing discharge versus reservoir elevation was derived for each gate opening, Figure 9. Because the slide gates were not accurately represented in the model, the curves of Figure 9 for partial gate openings should be considered only an approximation of the discharge capacity of the outlet works. The model indicated that the outlet works discharge would be 770 cfs with the reservoir water surface at the spillway crest (elevation 4882.22) and with both gates 100 percent open. This is about 4 percent higher than the assumed design discharge of 740 cfs.

Stilling Basin Operation

The preliminary spillway stilling basin, shown in Figure 5, was Type II, designed according to the guidelines of Engineering Monograph 25.1/ The spillway stilling basin was 74 feet long and included chute blocks and a dentated end sill. The horizontal portion

1/"Hydraulic Design of Stilling Basins and Energy Dissipators," by A. J. Peterka, Engineering Monograph No. 25, U.S. Bureau of Reclamation, July 1963.

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of the outlet works stilling basin was 52 feet 3-5/8 inches long, with the floor 4 feet below the floor of the spillway basin. The outlet works basin was 15 feet wide and also included chute blocks. The downstream portion sloped upward to the common dentated end sill.

Simultaneous operation of the spillway and outlet works at the maximum combined design discharge (20,500 cfs over the spillway and approximately 716 cfs through the outlet works) indicated generally satisfactory operation of the stilling basin. However, a "reverse roller" formed immediately downstream from the dentated end sill. This roller pulled material from the channel bed downstream of the basin, moved it upstream toward the basin, and deposited it on the downstream side of the end sill. High velocity downstream currents along the basin floor prevented this material from moving into the basin.

Sand Erosion Test.--To evaluate the effects of the "reverse roller," an erosion test was conducted in which the movement and deposition of sand in the downstream channel were observed. Figure 10A shows the configuration of the sand bed before the test. The bed sloped upward at 6:1 for a distance of about 23 feet (prototype) from the end sill and then became level. The model was operated with the maximum combined design discharge (spillway and outlet works) for approximately 100 minutes (equivalent to about 8 hours prototype operation) as pictured in Figure 10B. Within a few minutes after the start of the test, the configuration of the sand bed had shifted to that shown in Figures 10B and C. The motion of particles can be detected in the blurred areas of Figure 10C, immediately downstream from the end sill. Figures 10D and E show the final bed configuration. The ridge in Figure 10D is immediately downstream from the outlet works portion of the stilling basin, and indicates that either the lower floor in that area or the sloping floor leading to the end sill has some effect on bottom flow currents. Figure 10E illustrates the deposition of material on the downstream side of the end sill.

At a spillway discharge of approximately 7,000 cfs (the outlet works was not operating), with the tailwater at elevation 4865.8, some sand moved into the basin and circulated near the downstream end of the basin. Although the tailwater elevation was higher than that predicted for the 7,000-cfs discharge, this observation indicated that for certain combinations of tailwater elevation and discharge riverbed material might move upstream into the stilling basin.

Riprap Test.--The sand erosion test was indicative of the flow conditions downstream from the stilling basin but was not truly representative of the movement of material to be expected in the prototype river channel, which will be protected by riprap for a distance of 40 feet downstream from the stilling basin. Rock with a maximum size of about 1-1/2 inches was installed in the model to represent the prototype riprap, which has a maximum size of 3 feet. The riprapped model channel bed is shown in Figure 11A. After about 100 minutes operation at the maximum combined design discharge (Figure 11B), the bed appeared as shown in Figure 11C. There was some displacement of the riprap; the amount of movement was directly related to the fragment size. Several small pieces moved short distances upstream along the riprap bed but no rock entered the basin. The sand bed downstream from the riprap assumed a configuration similar to that observed following the sand erosion test. The velocity along the bottom was high enough to move the sand downstream. The test indicated that the riprap was sufficient to protect the riverbed from scour in the immediate vicinity of the stilling basin.

Movement of Rock in the Stilling Basin.--A test was conducted to determine the movement of material in the stilling basin, assuming that such material had been previously deposited in the basin by some unknown means. Rock fragments with maximum dimensions ranging from about 1/2 inch to about 2 inches (model) were hand placed in the upstream end of the basin during spillway operation. Results were essentially the same either with or without concurrent outlet works operation.

For the maximum design discharge of 20,500 cfs, all the material was swept to the downstream end of the stilling basin. Several large fragments became lodged between the end sill dentils but most of the material was swept completely out of the basin.

At a spillway discharge of 12,300 cfs, all the 1/2- and 1-inch material was swept from the basin; the 1-1/2- and 2-inch fragments were either swept from the basin or were deposited on the upstream side of the end sill.

With the spillway discharging 5,900 cfs, some of the 1/2-inch material was swept from the basin but the largest portion was deposited on the upstream side of the end sill. The 1-inch material was initially moved by the flow to an area near the midpoint of the basin then moved along the floor to the end sill. 1-1/2-inch fragments reacted very similarly, but moved more slowly. Most of the 2-inch material came to rest at about three-fourths the basin length and moved very slightly after the initial deposition. Several fragments were placed by hand in the downstream end of the outlet works conduit and remained there during spillway operation, when the outlet works was not operating.

The test indicated that no circulation of large material in the stilling basin would occur during operation of the spillway. The material would either be swept from the basin or deposited in a relatively stable position, depending upon the fragment size and spillway discharge.

The movement of sand in the stilling basin also was observed. Sand was initially placed in the basin and observed as the spillway discharge increased. Shortly after the start of spillway operation, sand circulated in the extreme upstream end of the basin. As the discharge increased the sand moved downstream and very little circulation was observed. At a discharge of 7,000 cfs all the sand had been swept from the upper level of the basin; some sand remained on the sloping apron in the downstream portion of the lower level of the basin. As the discharge increased more sand was swept from the lower level. Some particles moved laterally and circulated for a short time on the upper level before being swept out of the basin. At a discharge of 11,000 cfs all sand material had been swept into the downstream channel.

Operation of the Outlet Works Alone.--The outlet works was operated with the reservoir water surface at the spillway crest and the gates slightly closed to limit the discharge to the design value of 740 cfs. Eddies formed in both sides of the basin, but their intensity and extent were not large enough to cause riverbed material to be pulled into the stilling basin. However, the eddies in the basin caused the opening at the spillway face to alternately flow full then partially full, causing surging in the conduit downstream from the gates. Such surging might damage the gates and the gate controls. Figures 12A and B show the conduit flowing partially full (12A) and full (12B).

Modifications to the Preliminary Design

Although the model indicated that the prototype riprap would provide adequate protection against erosion of the river channel at the end of the stilling basin, a row of intermediate baffle piers was placed at one-third the length of the basin to eliminate the reverse roller, thus providing more absolute insurance that riverbed material would not be moved upstream into the basin.

The outlet works was modified to eliminate the surging condition observed during operation of the outlet works alone. The roof of the outlet conduit downstream from the gates, which previously sloped downward, was raised to a horizontal position, resulting in a larger outlet opening.

The modifications to the preliminary design resulted in completely satisfactory operation of the spillway and outlet works. The modified design was therefore recommended as the final design. Tests applied to the preliminary basin were repeated for the recommended basin, as described below.

The Recommended Design

Since no changes were made to the spillway crest or to the outlet works conduits upstream from the gates, the spillway and outlet works discharge capacities remained the same as in the preliminary design.

Stilling Basin Operation

Flow conditions in the stilling basin during simultaneous operation of the spillway and outlet works were very good. The "reverse roller" was eliminated and all bottom turbulence was confined to the stilling basin. The profile of the hydraulic jump was altered, becoming steeper in the vicinity of the baffle piers and essentially horizontal downstream from the piers.

Sand Erosion Test.--A 100-minute test at the maximum combined design discharge of the spillway and outlet works, Figure 13A, indicated a very different erosion pattern than that observed for the preliminary basin without baffle piers. No material was deposited on the downstream side of the end sill; instead the bed immediately downstream from the end sill was lowered slightly, as can be seen in the profile of Figure 13A. The velocity in the downstream channel was sufficient to move material downstream, the same as in the preliminary design.

The ridge of material immediately downstream from the outlet works portion of the basin was again apparent, Figure 13B.

Riprap Test.--A 100-minute test at the maximum combined discharge with the riprapped bed did not move the rock protection, Figure 14. The sand bed downstream from the riprap, Figure 14B, assumed a configuration very similar to that of the preliminary design, Figure 11C.

Movement of Rock in the Stilling Basin.--The test used with the preliminary design was duplicated. With the spillway operating alone at 20,500 cfs, 1/2-inch material was swept downstream and deposited immediately upstream from the end sill. There was some downstream movement after deposition and several pieces moved through the dentils. Most of the 1-, 1-1/2-, and 2-inch material was initially moved by the flow to the area between the baffle piers and the end sill, then moved slowly along the floor, finally coming to rest immediately upstream from the end sill. Several 2-inch fragments lodged between the baffle piers. Some of the 1-inch material moved through the dentils. Also, several pieces of the 2-inch material were deposited along the slope in the outlet works portion of the stilling basin.

For a spillway discharge of 12,300 cfs, the 1/2-inch material was initially moved to the area between the baffle piers and end sill, then moved downstream to the end sill. Some fragments moved through the dentils. Most of the 1-, 1-1/2, and 2-inch material was deposited in the downstream one-third of the basin; several large fragments lodged between the baffle piers. No material moved through the dentils. Fragments placed by hand in the downstream end of the outlet remained in that position.

With the spillway discharging 5,900 cfs, 1/2-inch material was moved to a position 15 to 20 feet (prototype) downstream from the baffle piers and exhibited some subsequent movement. 1- and 1-1/2-inch material was either lodged upstream from the baffle piers or deposited immediately downstream from the piers. Nearly all the 2-inch material was moved to an area upstream from the baffle piers. Fragments which were hand placed downstream from the piers remained in that position.

The movement of sand was observed during an increasing spillway discharge, as in the preliminary design. Again, sand circulated in the upstream portion of the basin for low spillway discharges. The presence of the baffle piers caused some of the material to be held upstream from the piers for discharges below approximately 4,000 cfs. At this discharge some sand was circulated rapidly around the baffle piers. As the discharge increased the turbulence around the baffle piers increased, then moved to the downstream side of the piers. At a discharge of about 8,000 cfs the sand had moved out of the zone of high turbulence and practically no material was lifted off the floor. At a discharge of approximately 16,000 cfs all material had moved downstream to an area immediately upstream from the dentated end sill and sand was moving between the dentils into the downstream channel. At the maximum spillway discharge of 20,500 cfs the sand continued to exhibit slow movement from the basin into the downstream river channel.

In general the recommended basin exhibited a greater tendency to retain material within the basin than the preliminary design. In either case, the only indication of possible damaging circulation of abrasive material occurred during small spillway discharges when the turbulence was confined to the upstream portion of the basin. The question remains as to whether the available energy will be sufficient to cause abrasive damage if the material is available. It is recommended that all practical precautions be taken to eliminate the presence of abrasive material in the basin before and during operation of the spillway.

The most probable source of abrasive material is the downstream channel. The model indicated that the addition of baffle piers eliminated the possibility of material being pulled into the basin during spillway operation. For discharges above approximately 8,000 cfs, any material in the basin will move downstream and eventually enter the downstream channel. In view of these findings, the inclusion of baffle piers is recommended. If the baffle piers become severely damaged by freezing and thawing during the winter months, the basin should continue to operate satisfactorily with the configuration of the preliminary design.

Operation of the Outlet Works Alone.--The operation of the modified outlet works was satisfactory, Figure 15. The larger opening eliminated the surging described earlier. Eddies which formed in the basin caused slow circulation of sand and other small particles which represented an estimated prototype size of 3 to 6 inches. Flow conditions at the outlet indicated that abrasive material might circulate rapidly near the outlet, because of the sudden expansion of flow and accompanying turbulence. This again stresses the importance of keeping the stilling basin free of sand and rock material.

FIGURE I
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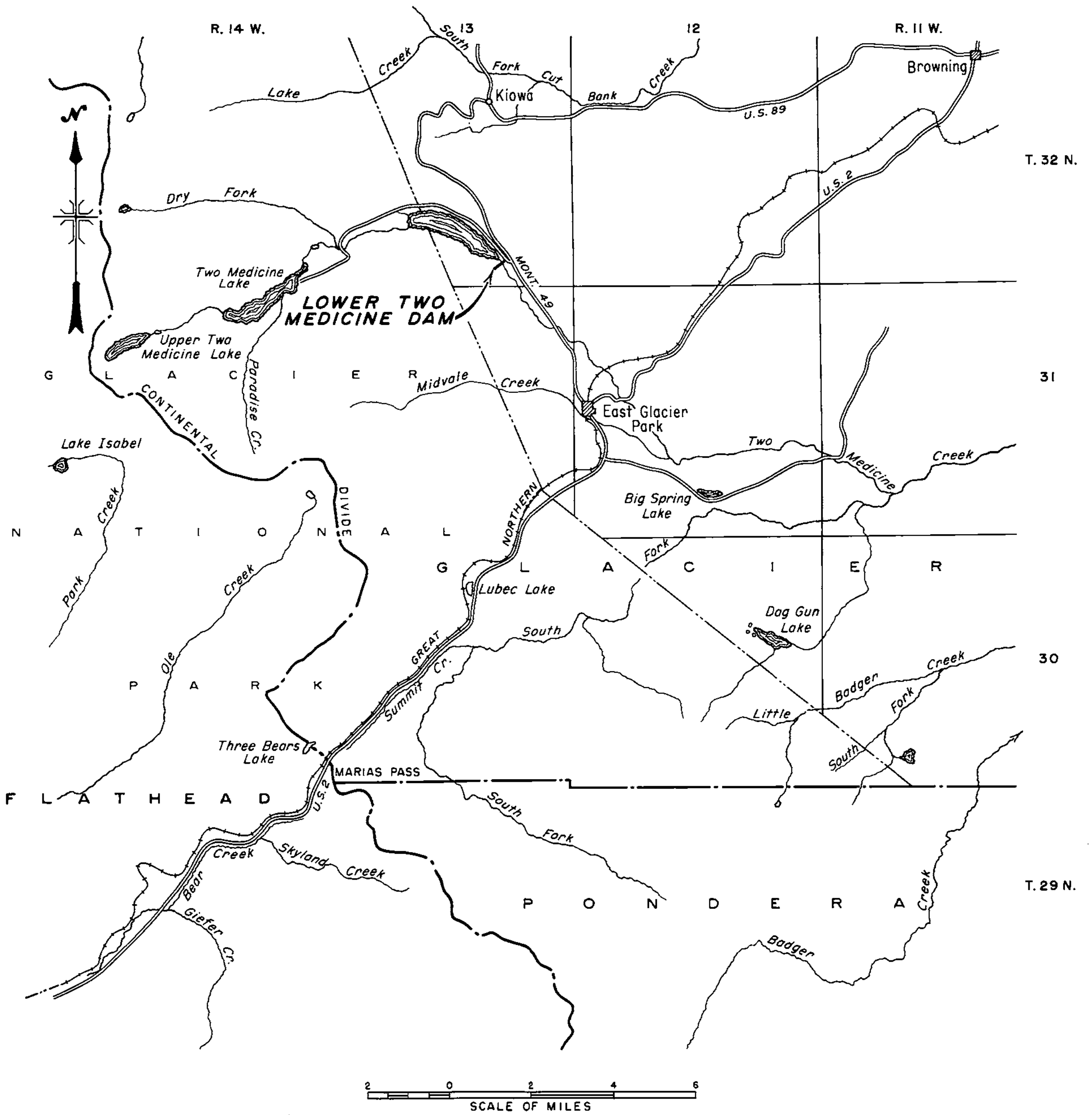
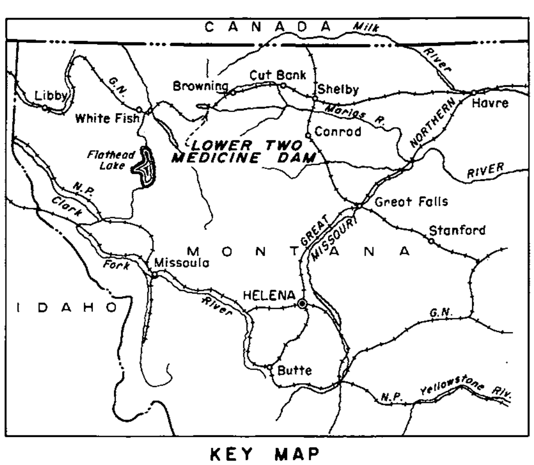




KEY MAP

ALWAYS THINK SAFETY

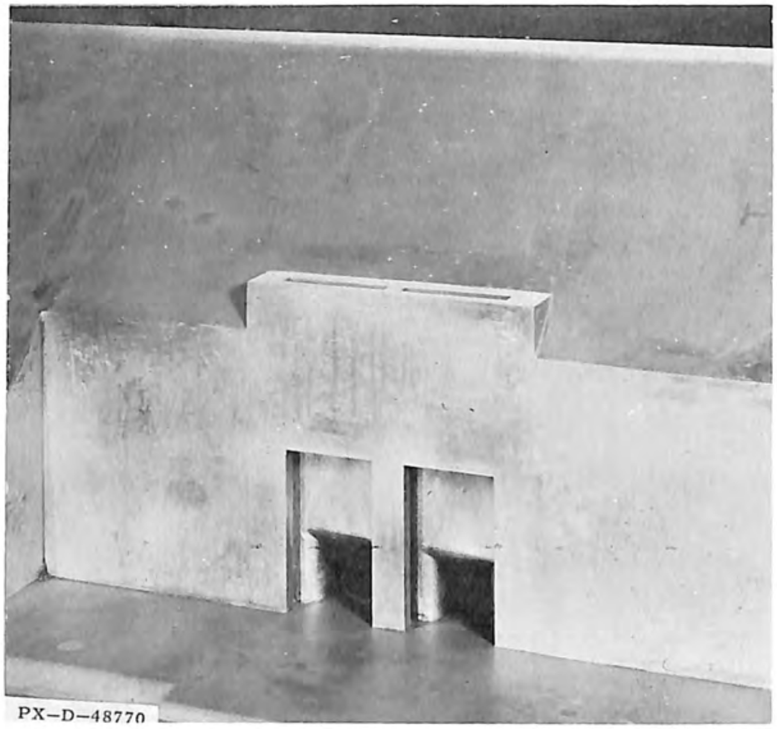
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BLACKFEET INDIAN IRRIGATION PROJECT-MONTANA

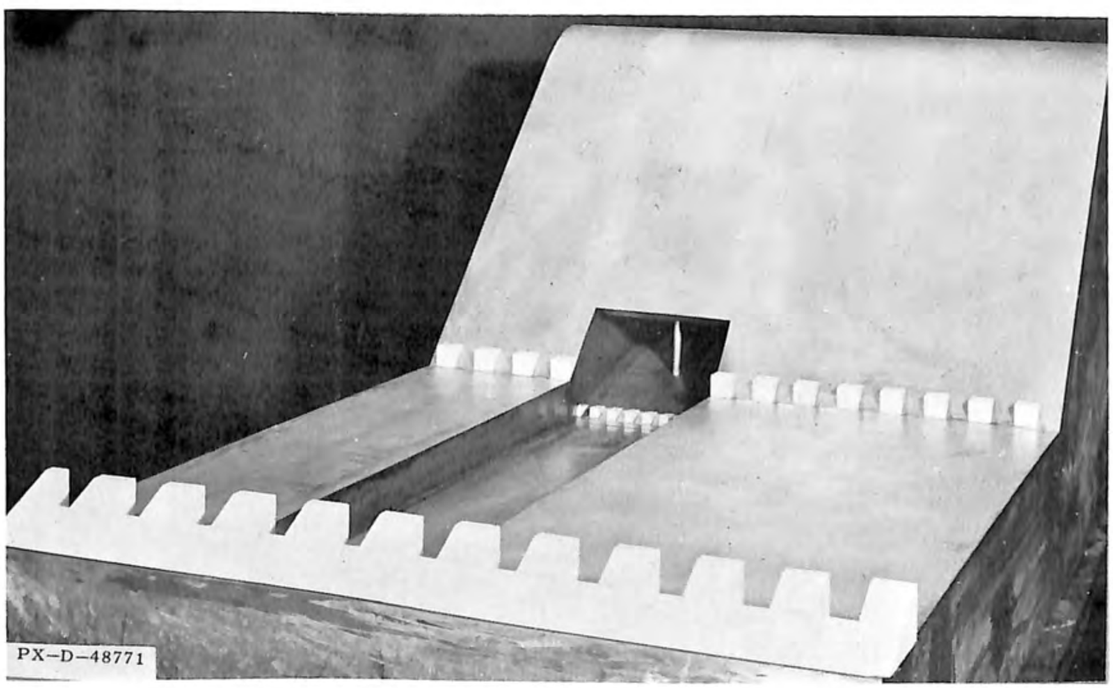
LOWER TWO MEDICINE DAM

LOCATION MAP

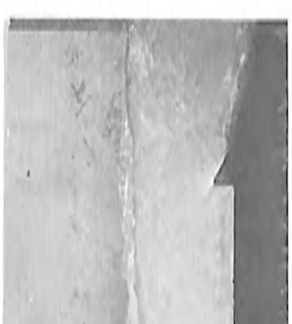
DRAWN A.B.-M.A. SUBMITTED R. J. Larsen
TRACED G.L.S. RECOMMENDED H. J. Arthur
CHECKED ABK ATL APPROVED A. P. Billport
CHIEF ENGINEER
DENVER, COLORADO, JUNE 1, 1955 2-D-35



A. Outlet works entrances and upstream face of spillway



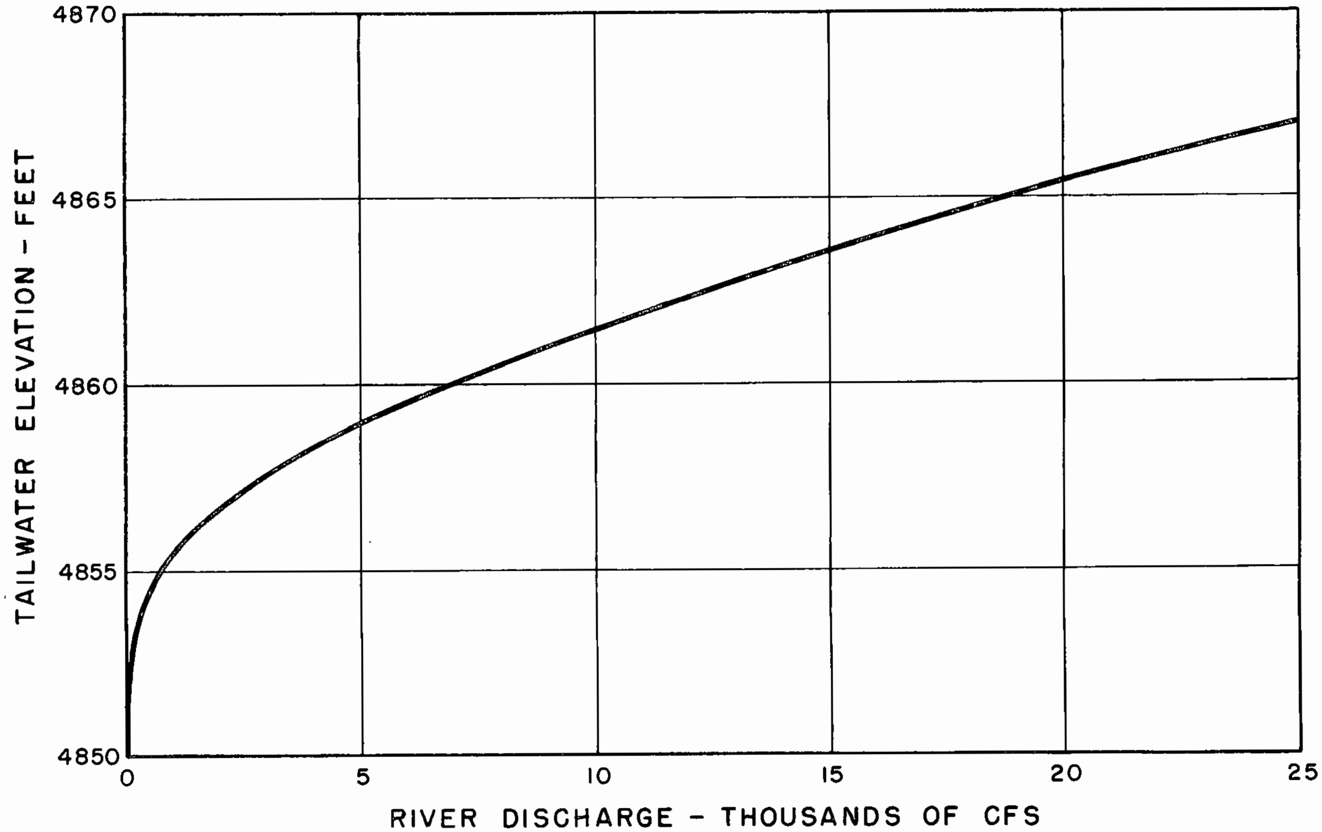
B. Outlet works exit, downstream face of spillway, and stilling basin



Lower Two Medicine Dam
Spillway and Outlet Works

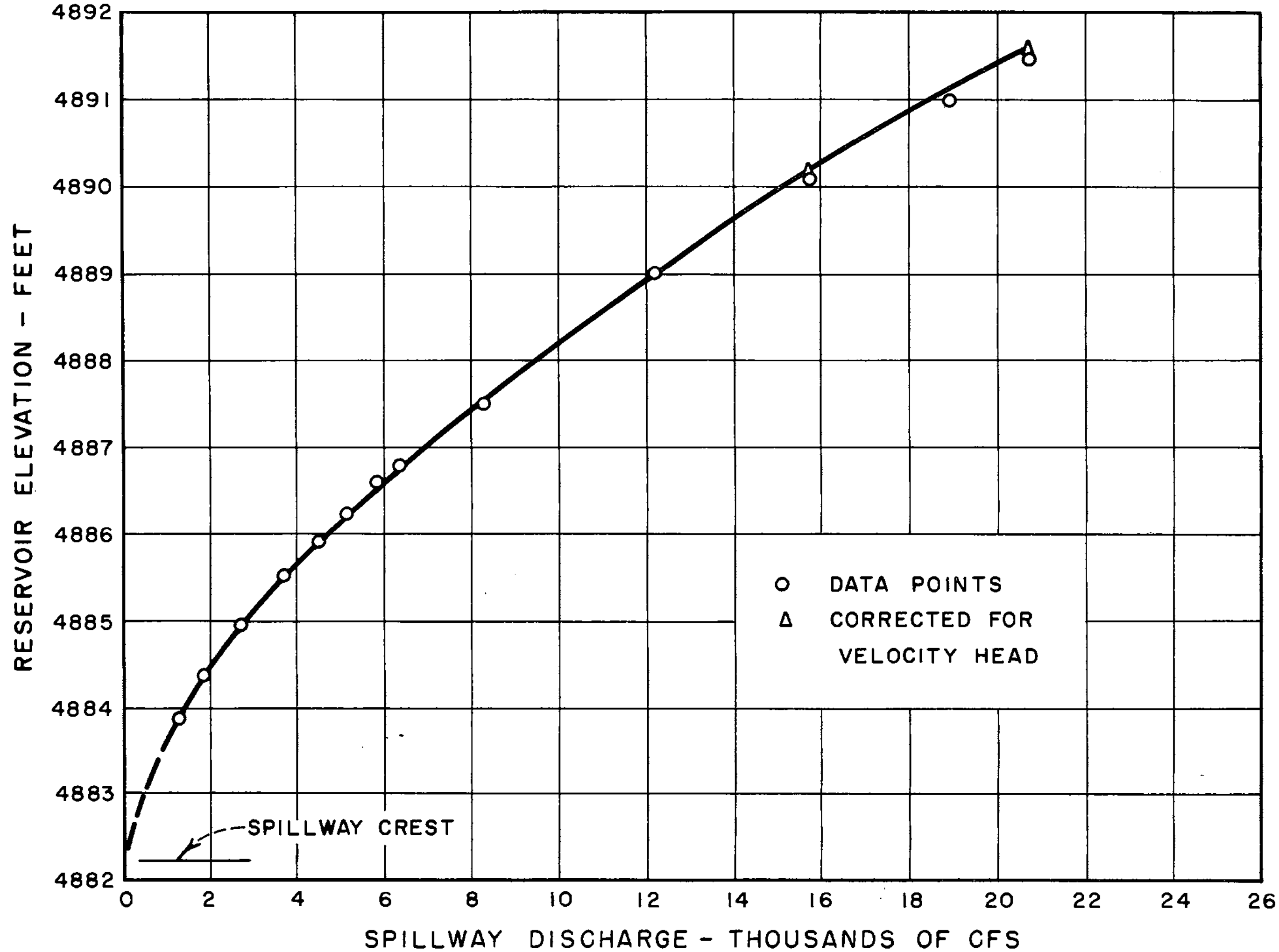
1:24 Scale Model

SECTIONAL MODEL OF SPILLWAY AND OUTLET WORKS



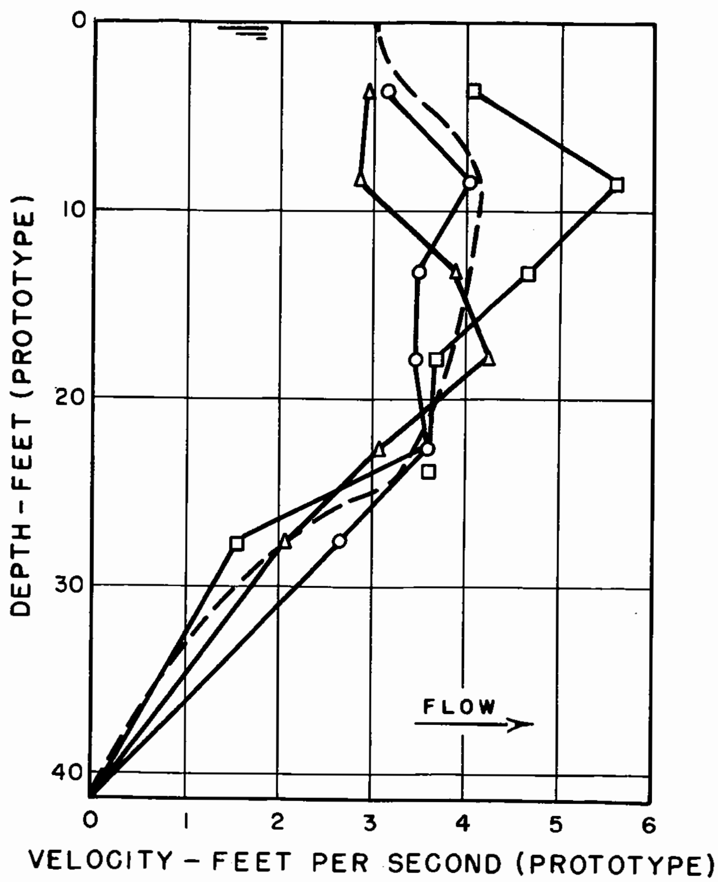
LOWER TWO MEDICINE DAM
SPILLWAY AND OUTLET WORKS
1:24 SCALE MODEL

TAILWATER RATING CURVE
(EXTRACTED FROM COMPUTED RATING CURVES)



LOWER TWO MEDICINE DAM
SPILLWAY AND OUTLET WORKS
1:24 SCALE MODEL
SPILLWAY DISCHARGE CAPACITY

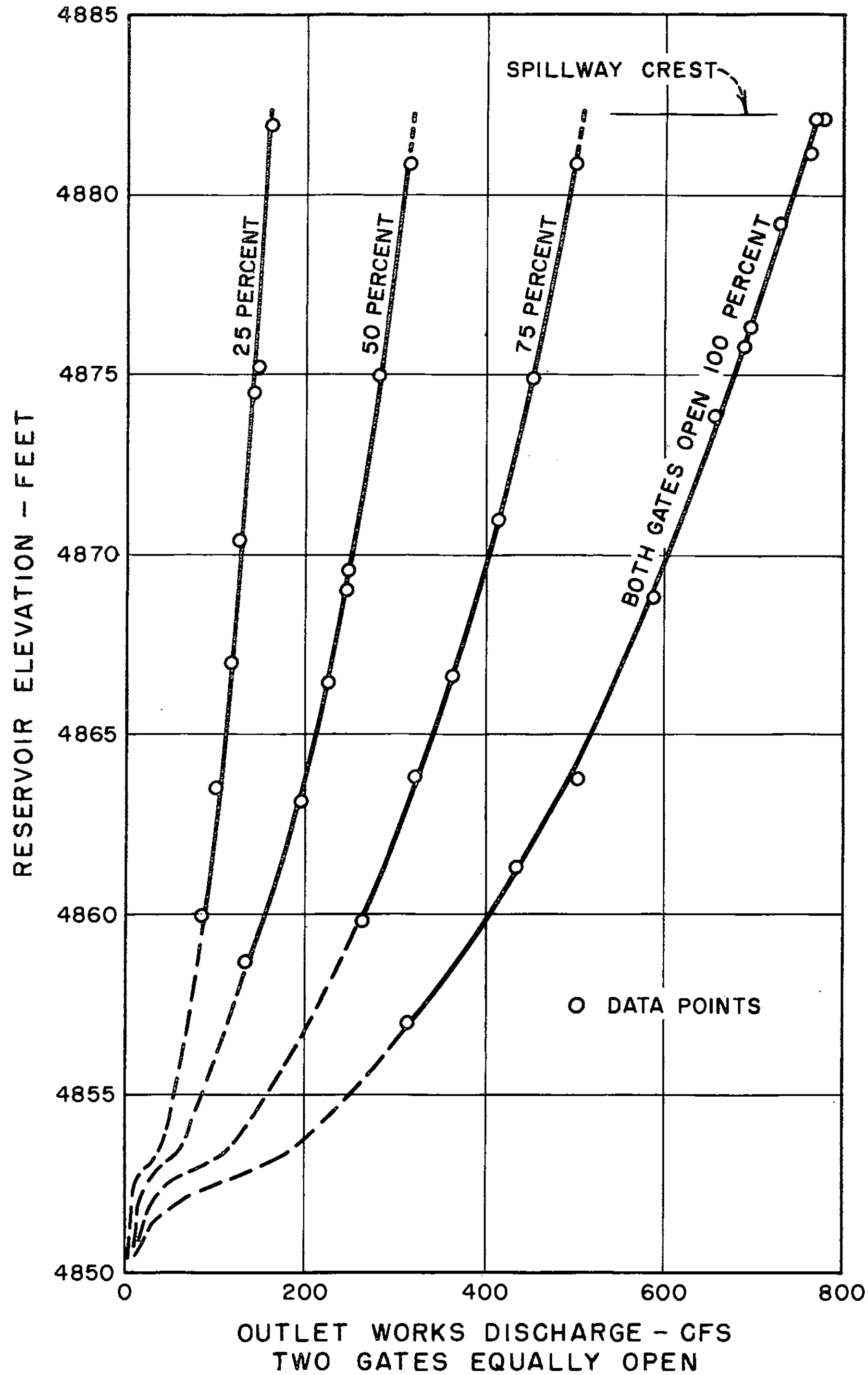
FIGURE 7
REPORT HYD-554



○ 24' (prototype) left of model ℄
△ Model ℄
□ 24' right of model ℄
---- Average of 3 sections
Velocities measured 50' (prototype) upstream from spillway crest.

LOWER TWO MEDICINE DAM
SPILLWAY AND OUTLET WORKS
1:24 SCALE MODEL

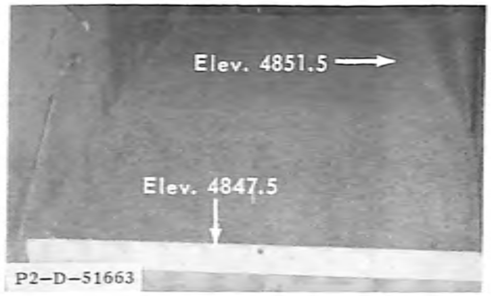
VELOCITY IN THE SPILLWAY APPROACH
Q = 20,500 CFS



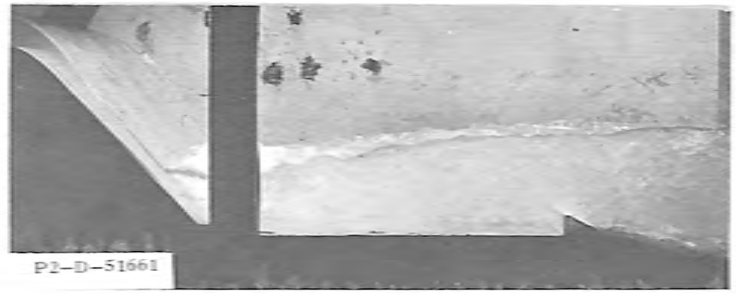
LOWER TWO MEDICINE DAM
SPILLWAY AND OUTLET WORKS

1:24 SCALE MODEL

OUTLET WORKS DISCHARGE CAPACITY

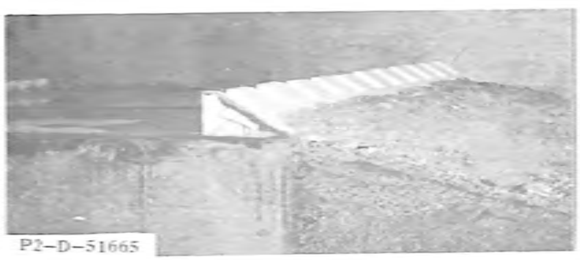


A. Sand bed before test (facing downstream)



B. Spillway discharge = 20,500 cfs
Outlet works discharge = 716 cfs

D. After test



E. Deposition of sand on end sill after test

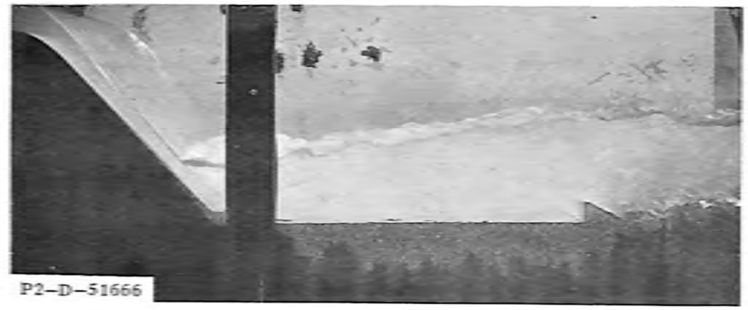
C. Closeup of action at end sill

Lower Two Medicine Dam
Spillway and Outlet Works

1:24 Scale Model

SAND EROSION TEST, PRELIMINARY DESIGN

A. Riprap bed before test



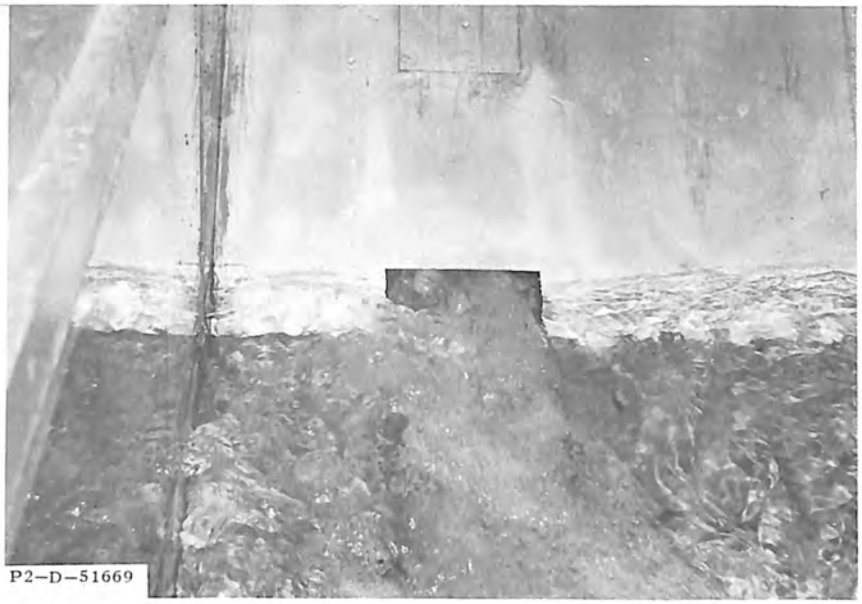
B. Spillway discharge = 20, 500 cfs
Outlet works discharge = 716 cfs

C. After test

Lower Two Medicine Dam
Spillway and Outlet Works

1:24 Scale Model

RIPRAP TEST, PRELIMINARY DESIGN



A. Conduit flowing partially full
outlet works discharge = 740 cfs
tailwater elevation 4855.2

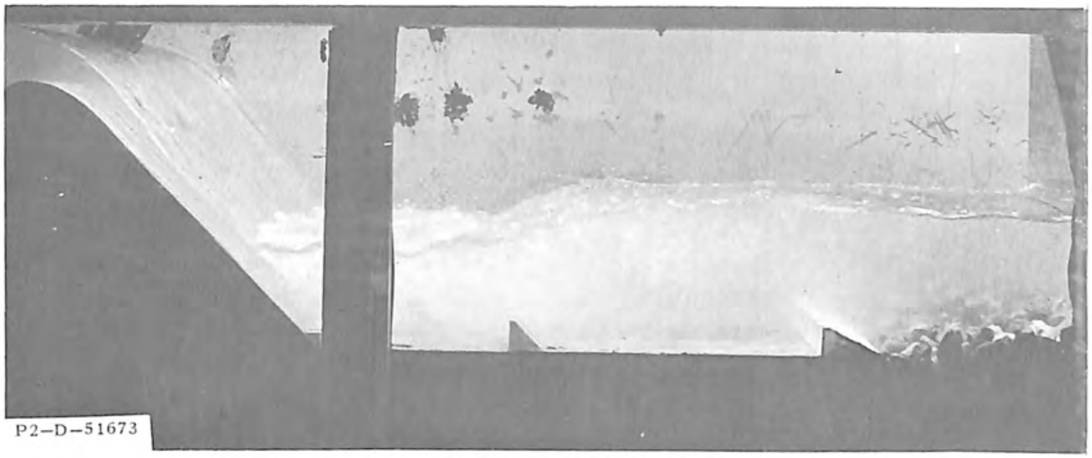
B. Conduit flowing full

Lower Two Medicine Dam
Spillway and Outlet Works

1:24 Scale Model

OUTLET WORKS OPERATION, PRELIMINARY DESIGN

Figure 14
Report Hyd-554



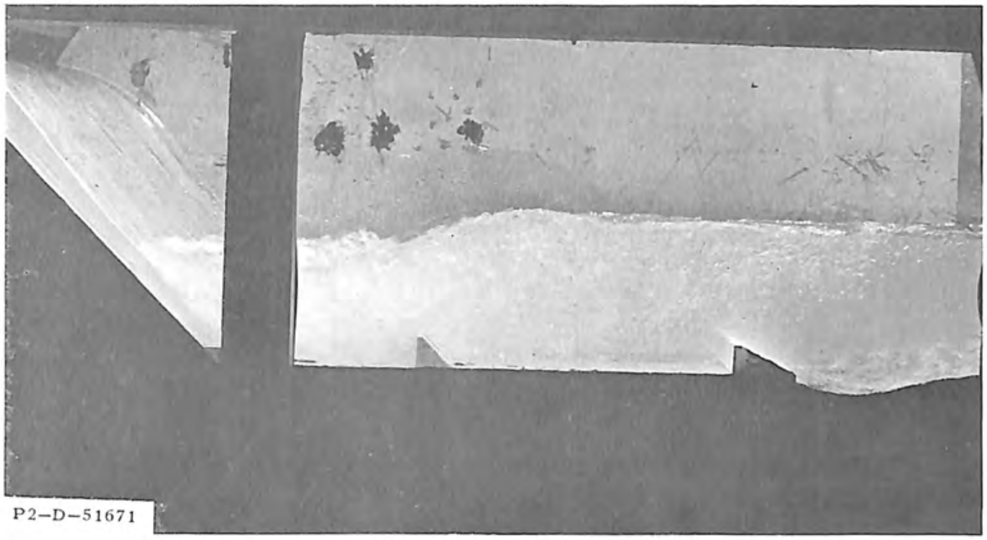
A. Spillway discharge = 20, 500 cfs
Outlet works discharge = 716 cfs

B. After test

Lower Two Medicine Dam
Spillway and Outlet Works

1:24 Scale Model

RIPRAP TEST, RECOMMENDED DESIGN



A. Spillway discharge = 20, 500 cfs
Outlet works discharge = 716 cfs

B. After test

Lower Two Medicine Dam
Spillway and Outlet Works

1:24 Scale Model

SAND EROSION TEST, RECOMMENDED DESIGN

P2-D-51675

Outlet works discharge = 740 cfs
Tailwater elevation 4855.2

Lower Two Medicine Dam
Spillway and Outlet Works

1:24 Scale Model

OUTLET WORKS OPERATION, RECOMMENDED DESIGN

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

GPO 845-237

ABSTRACT

A 1:24-scale sectional model of the spillway and outlet works of Lower Two Medicine Dam in Montana indicated that the stilling basin, common to both features, would operate satisfactorily as a USBR Type II basin, but that the basin performance could be improved by the addition of an intermediate row of baffle piers. The piers eliminated a "reverse roller" observed in the river channel immediately downstream from the Type II basin, which conceivably could result in river bed material being pulled upstream into the stilling basin with possible accompanying abrasive damage. The spillway and outlet works had sufficient capacity to pass the required flows. Sand erosion and riprap tests were applied to both the preliminary and recommended basins and the movement of rock and sand material was observed in both basins.

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Hyd-554
King, D. L.
HYDRAULIC MODEL STUDIES OF THE SPILLWAY AND OUTLET WORKS FOR LOWER TWO MEDICINE DAM, BLACKFEET INDIAN IRRIGATION PROJECT, MONTANA
Laboratory Report, Bureau of Reclamation, Denver, 10 p, 15 fig, 2 tab, 1 ref, 1966

DESCRIPTORS--*spillways/ *outlet works/ *stilling basins/ *hydraulic models/ research and development/ appurtenances/ dentated sills/ earth dams/ hydraulic structures/ hydraulic jumps/ hydraulics/ model tests/ spillway crests/ baffles/ erosion/ scour/ riprap/ laboratory tests/ discharge measurement

IDENTIFIERS--Lower Two Medicine Dam/ Blackfeet Indian Irrigation Project/ Montana/ Bureau of Indian Affairs/ baffle piers/ discharge capacity

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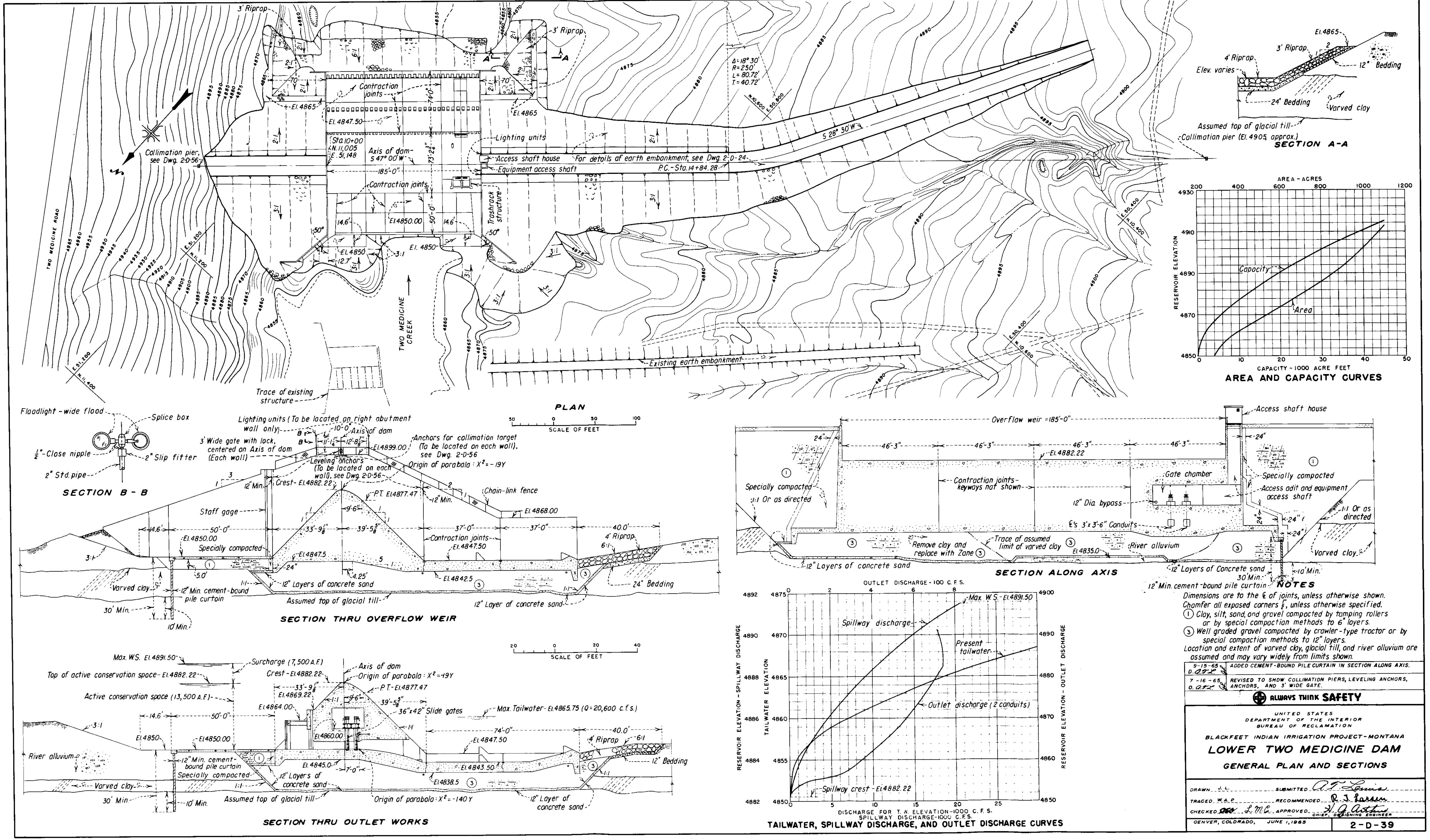
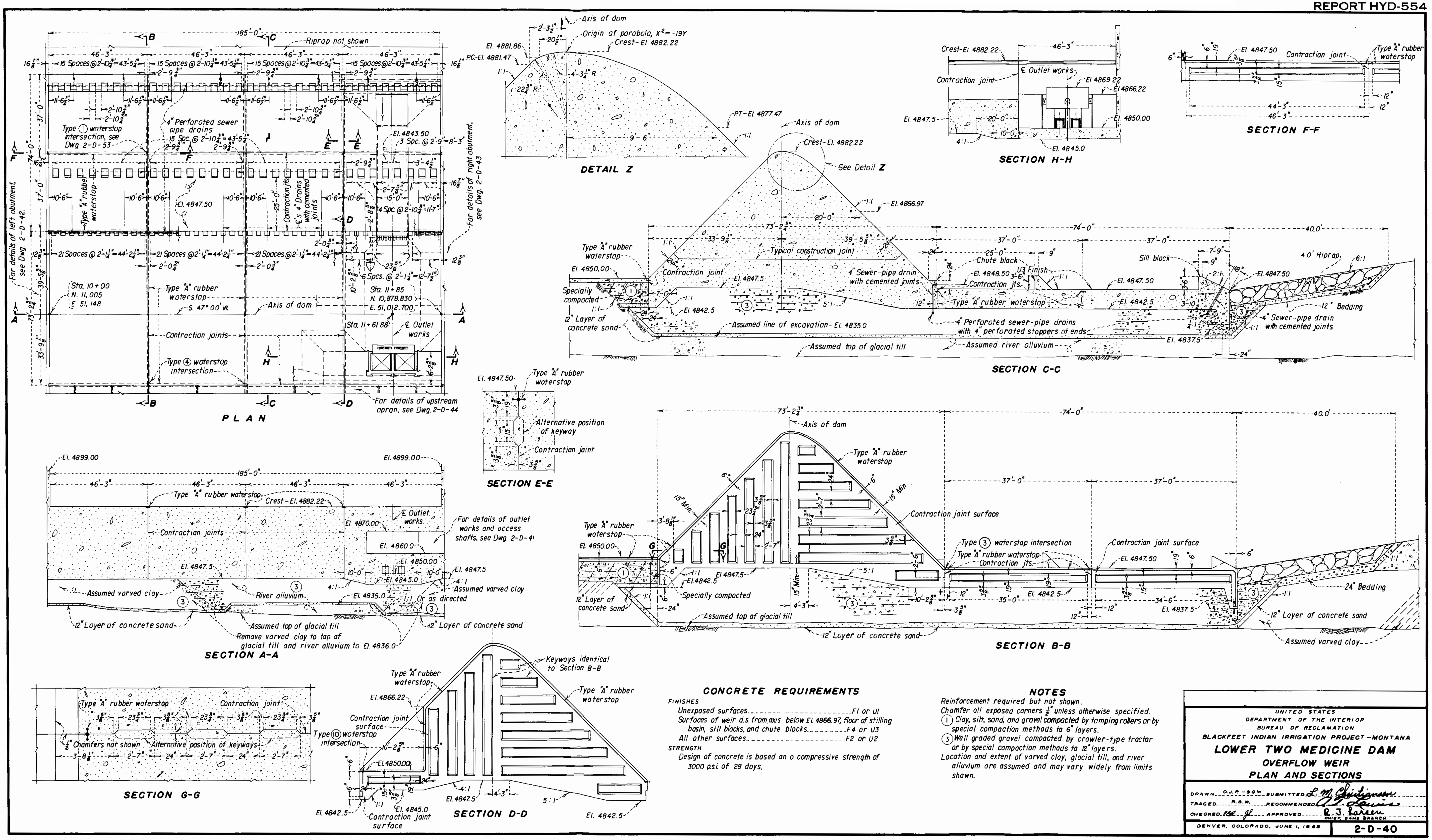
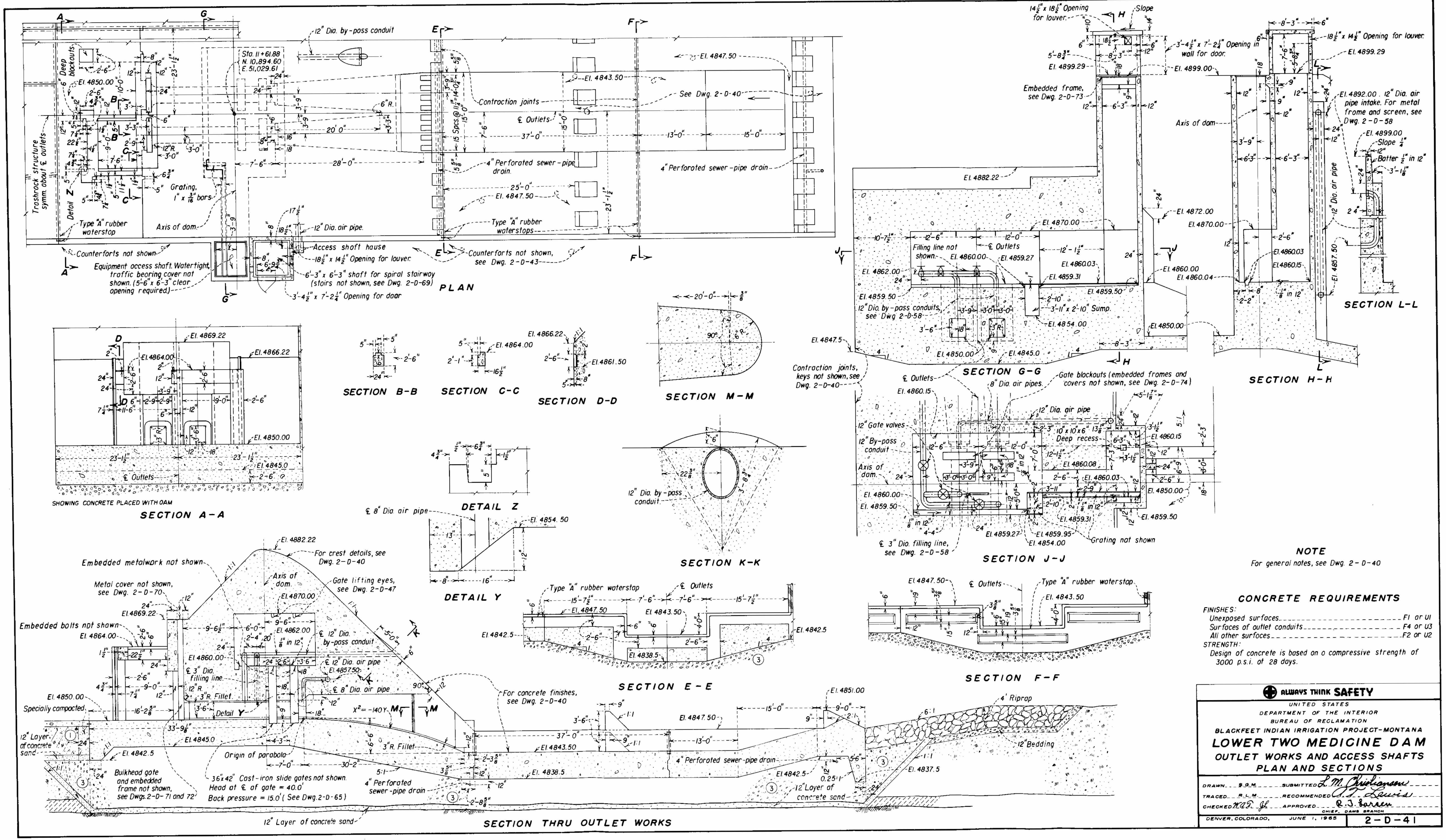
IDENTIFIERS--Lower Two Medicine Dam/ Blackfeet Indian Irrigation Project/ Montana/ Bureau of Indian Affairs/ baffle piers/ discharge capacity

FIGURE 2
REPORT HYD-554




PLAN
SECTION A-A
SECTION G-G
SECTION D-D
DETAIL Z
SECTION E-E
SECTION C-C
SECTION B-B
SECTION H-H
SECTION F-F
Riprap not shown
185'-0"
46'-3"
15 Spaces @ 2'-10¾" = 43'-5¼"
21 Spaces @ 2'-1¼" = 44'-2¼"
Type ① waterstop intersection, see Dwg 2-D-53
4" Perforated sewer pipe drains
Type "A" rubber waterstop
℄'s 4" Drains with cemented joints
Contraction jts.
El. 4847.50
El. 4843.50
Sta. 10+00
N. 11,005
E. 51,148
Sta. 11+85
N. 10,878.830
E. 51,012.700
Sta. 11+61.88
℄ Outlet works
S. 47° 00' W.
Axis of dam
Contraction joints
Type ④ waterstop intersection
For details of left abutment, see Dwg. 2-D-42.
For details of right abutment, see Dwg. 2-D-43
For details of upstream apron, see Dwg. 2-D-44
El. 4899.00
Type "A" rubber waterstop
Crest - El. 4882.22
El. 4870.00
El. 4860.0
El. 4850.00
El. 4845.0
El. 4847.5
El. 4835.0
Assumed varved clay
River alluvium
Or as directed
Assumed top of glacial till
12" Layer of concrete sand
Remove varved clay to top of glacial till and river alluvium to El. 4836.0
For details of outlet works and access shafts, see Dwg. 2-D-41
Chamfers not shown
Alternative position of keyways
Contraction joint
Keyways identical to Section B-B
Type ⑩ waterstop intersection
Contraction joint surface
El. 4866.22
El. 4842.5
Axis of dam
Origin of parabola, X² = -19Y
Crest - El. 4882.22
El. 4881.86
PC - El. 4881.47
P.T. - El. 4877.47
See Detail Z
Alternative position of keyway
Typical construction joint
Chute block
Sill block
4" Sewer-pipe drain with cemented joints
4.0' Riprap
12" Bedding
Specially compacted
12" Layer of concrete sand
Assumed line of excavation - El. 4835.0
4" Perforated sewer-pipe drains with 4" perforated stoppers at ends
Assumed river alluvium
El. 4837.5
U3 Finish
Type ③ waterstop intersection
Contraction joint surface
24" Bedding
Assumed varved clay
Crest - El. 4882.22
℄ Outlet works
El. 4869.22
El. 4866.22
El. 4850.00
El. 4845.0
Type "A" rubber waterstop
Contraction joint
CONCRETE REQUIREMENTS
FINISHES
Unexposed surfaces ... F1 or U1
Surfaces of weir d.s. from axis below El. 4866.97, floor of stilling basin, sill blocks, and chute blocks ... F4 or U3
All other surfaces ... F2 or U2
STRENGTH
Design of concrete is based on a compressive strength of 3000 p.s.i. of 28 days.
NOTES
Reinforcement required but not shown.
Chamfer all exposed corners ½" unless otherwise specified.
① Clay, silt, sand, and gravel compacted by tamping rollers or by special compaction methods to 6" layers.
③ Well graded gravel compacted by crawler-type tractor or by special compaction methods to 12" layers.
Location and extent of varved clay, glacial till, and river alluvium are assumed and may vary widely from limits shown.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLACKFEET INDIAN IRRIGATION PROJECT - MONTANA
LOWER TWO MEDICINE DAM
OVERFLOW WEIR
PLAN AND SECTIONS
DRAWN O.J.R.-S.G.M. SUBMITTED L. M. Christiansen
TRACED R.S.W. RECOMMENDED
CHECKED APPROVED R. J. Larsen
CHIEF, DAMS BRANCH
DENVER, COLORADO, JUNE 1, 1965
2-D-40


PLAN
SECTION A-A
SHOWING CONCRETE PLACED WITH DAM
SECTION B-B
SECTION C-C
SECTION D-D
SECTION M-M
SECTION K-K
DETAIL Z
DETAIL Y
SECTION G-G
SECTION H-H
SECTION L-L
SECTION J-J
SECTION E-E
SECTION F-F
SECTION THRU OUTLET WORKS
NOTE
For general notes, see Dwg. 2-D-40
CONCRETE REQUIREMENTS
FINISHES:
Unexposed surfaces — F1 or U1
Surfaces of outlet conduits — F4 or U3
All other surfaces — F2 or U2
STRENGTH:
Design of concrete is based on a compressive strength of 3000 p.s.i. at 28 days.
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BLACKFEET INDIAN IRRIGATION PROJECT-MONTANA
LOWER TWO MEDICINE DAM
OUTLET WORKS AND ACCESS SHAFTS
PLAN AND SECTIONS
DRAWN G.G.M. SUBMITTED L. M. Christiansen
TRACED R.L.M. RECOMMENDED A. J. Lewis
CHECKED W.A.G. APPROVED R. J. Larsen
CHIEF, DAMS BRANCH
DENVER, COLORADO, JUNE 1, 1965
2-D-41