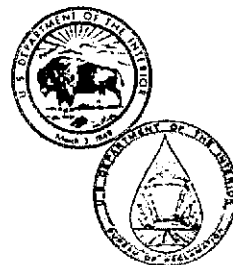REC-ERC-71-29

STUDIES TO DETERMINE THE FEASIBILITY OF A BAFFLED APRON DROP AS A SPILLWAY ENERGY DISSIPATOR CONCONULLY DAM SPILLWAY OKANOGAN PROJECT, WASHINGTON

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Engineering and Research Center
Bureau of Reclamation

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16. ABSTRACT

The existing spillway structure at Conconully Dam, Washington, was determined to be structurally unsafe and incapable of discharging the design flood. Installation of a conventional hydraulic jump stilling basin or flip bucket to handle the design flood was impractical because of poor foundation conditions. However, preliminary investigations showed that if the allowable unit discharge of a baffled apron drop could be increased from 60 cfs/ft of width to about 80 cfs, such a structure could be built on sound rock. Hydraulic model studies were performed to confirm a design for a baffled apron drop based on a unit discharge of 77.7 cfs/ft of width. The tests showed that the higher-capacity structure was an effective and safe energy dissipator, and could handle unit discharges up to twice the design discharge. The effect of baffle pier location on the reservoir elevation for maximum discharge was determined. An optimum configuration for the channel bed downstream of the concrete apron was developed to prevent erosion of the apron.

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OKANOGAN PROJECT, WASHINGTON

by
T. J. Rhone

June 1961

ACKNOWLEDGMENT

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PURPOSE

The studies were conducted to determine the feasibility of extending the standard design limitations of a baffled apron drop as established in Engineering Monograph No. 25,* from a unit discharge of 60 cfs per foot (5.6 cu m/sec per meter) of width to a larger unit discharge.** A larger unit discharge would allow a baffled apron drop to be used as a spillway energy dissipator where more conventional structures would be impractical.

CONCLUSIONS

1. A baffled apron designed according to the criteria in Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators," proved to be an effective spillway energy dissipator.

2. The baffled apron was designed for a unit discharge of 77.7 cfs (7.2 cu m/sec) of width but the studies indicated that it would handle a unit discharge as large as 150 cfs (13.9 cu m/sec).

3. The location of the top row of baffle piers affected the discharge capacity. With the base of the upstream face of the baffle piers 1 foot (0.3 m) below the spillway crest, the reservoir head above the crest at maximum discharge was 14 percent higher than with the first row removed. Placing the first row of baffle piers 1.8 feet (0.55 m) below the crest raised the reservoir head only 9 percent. Structural considerations dictated that the first row of baffle piers be placed 1.8 feet (0.55 m) below the crest.

4. Blocking off the top row of baffle piers to simulate clogging with debris increased the reservoir elevation 3.4 feet (1 m) at a unit discharge of 77.7 cfs (7.2 cu m/sec). This was 2.3 feet (0.7 m) below the crest of the dam embankment. The baffle piers were 1.8 feet (0.55 m) below the crest.

5. The channel bed downstream was sloped upward from the end of the apron to prevent movement of the riprap against the apron and possible erosion damage.

APPLICATION

The results of these studies are considered to be justification to increase the unit discharge used in the design of a baffled apron drop from 60 cfs (5.6 cu m/sec) to at least 78 cfs (7.3 cu m/sec). The tests also confirmed that this type of structure was feasible as a spillway energy dissipator and would be capable of handling discharges up to twice the design value in an emergency.

INTRODUCTION

Conconully Dam, a part of the Okanogan Project, is located in north central Washington about 15 miles (24.2 km) northwest of the town of Okanogan. The dam, used for storing irrigation water, is an earthfill structure 70 feet (21.3 m) high and 1,000 feet (305 m) long with a storage capacity of about 13,000 acre-feet (16 million cu m). The dam was constructed in 1910. The original spillway, in a saddle near the right abutment, has progressively deteriorated. In addition, completed hydrological studies and reports under the Safety of Dams program showed that the existing spillway had inadequate capacity.

It was decided to replace this spillway with one of adequate capacity. Extremely poor foundation conditions downstream from the dam precluded the use of a standard hydraulic jump energy dissipator or flip bucket as a part of the spillway. Therefore, a baffled apron was selected to pass the flood discharges. Use of a baffled apron drop as an energy dissipator for a spillway was a departure from the usual practice, so it was decided to perform a hydraulic model study to verify the design.

THE MODEL

A sectional model, on a 1:18 scale ratio, was constructed in a 30-inch (76-cm) wide flume. The model represented a 45.37-foot (13.8-m) wide section of the 149-foot (45.4-m) wide spillway. The crest and

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*Bureau of Reclamation Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators," by A. J. Peterka.
**Subsequent values given for the unit discharge will indicate the discharge per foot of width for English units and per meter of width for metric units.

full length, 150 feet (45.7 m), of the sloping apron were included in the model.

The channel approaching the crest was also included but the curved sidewalls of the approach channel and the wing walls at the downstream end of the apron were not modeled. The channel bed downstream from the apron was formed in sand. The baffle arrangement on the apron represented the portion of the apron adjacent to the left sidewall. The sidewall baffle arrangement was used because the action of the flowing water at the baffles and sidewall is important in determining the effectiveness of the design. It was also necessary to determine whether the sidewall height was adequate.

THE INVESTIGATION

Design Criteria

Usually, a baffled apron drop is limited to a maximum design unit discharge of 60 cfs (5.6 cu m/sec), Engineering Monograph No. 25, Section 9, page 153. The design unit discharge for Conconully spillway is 77.7 cfs (7.2 cu m/sec), or a total discharge of 11,580 cfs (328 cu m/sec). The design methods outlined in Engineering Monograph No. 25 were used in determining baffle pier dimensions and arrangement, Figure 1. However, the standard design specifies that the first row of baffle piers should be placed not more than 1 foot (0.3 m) below the crest. A construction joint near the crest made it necessary to place the first row of baffle piers either 1.8 feet (0.55 m) below the crest or almost on the crest. For the initial tests the first row of baffle piers was placed 1.8 feet (0.55 m) below the crest. To provide for future channel bed degradation, the downstream end of the apron extended below the channel bed sufficiently so that the last two rows of baffle piers were buried.

Flow on Apron

Flow conditions on the apron were satisfactory for all unit discharges up to and including the maximum of 77.7 cfs (7.2 cu m/sec). With the lowest test unit discharge of 15 cfs (1.4 cu m/sec), the flow appeared to accelerate slightly down the chute as shown by the higher rise of the water surface as the flow impinged on the lower baffle piers, Figure 2. However, the flow did not penetrate very far into the tailwater and there was no movement of the channel bed material.

With 30- and 45-cfs (2.8- and 4.2-cu m/sec) unit discharges, there was no noticeable increase in the height of the water surface and the flow did not penetrate the tailwater pool to an appreciable extent.

Waves on the water surface, which were negligible for the 15-cfs (1.4-cu m/sec) unit discharge, were about 12 to 18 inches (30 to 46 cm) high. There was no movement of the riverbed material.

With unit discharges of 60 and 77.7 cfs (5.6 and 7.2 cu m/sec) the apron baffle piers were completely submerged but they retarded the flow sufficiently that there was no deep penetration into the tailwater and only very slight movement of the channel bed, Figure 3. Waves on the water surface were about 18 to 24 inches (46 to 61 cm) high.

Tests were also run with unit discharges of 100 and 150 cfs (9.3 and 14.0 cu m/sec). Although there was considerable splash and spray from the flow coming down the apron, flow conditions at the end of the apron were satisfactory and there was only a small amount of channel bed erosion.

The test confirmed that the baffled apron drop was an effective energy dissipator for the design discharge and was also capable of handling flows up to almost twice the design discharge.

Channel Bed Modifications

For the initial tests the channel bed downstream from the apron was horizontal. The apron extended below the channel bed and the last two rows of baffle piers were covered with backfill. During operation at near maximum discharge it was noticed that there was some movement of the fill material adjacent to the apron. This type of action could abrade the concrete; therefore, the channel bed was modified to prevent the erosive action. The channel bed was sloped upward on a 2-1/2:1 slope from the end of the apron to the original bed level. The sloped surface was covered with 12- to 24-inch (30- to 61-cm) riprap. Subsequent tests at unit discharges up to 150 cfs (14.0 cu m/sec) showed that there was no riprap movement in the excavated area at any discharge.

Discharge Capacity

The discharge capacity of the structure was determined for four conditions: with the first row of baffle piers 1.8 feet (0.55 m) below the crest (the design location), with the first row of baffle piers in the design location but completely blocked off to simulate clogging with debris, with the first row of baffle piers 1 foot (0.3 m) below the crest, and with the first row of baffle piers removed.

With the design configuration the design discharge of 11,580 cfs (328 cu m/sec) was obtained at reservoir elevation 2295.3 (699.6 m), Figure 4. When the top

2

PLAN

SCALE OF FEET
10 0 10 20 30

SCALE OF METERS
3 0 3 6 9

SECTION A-A

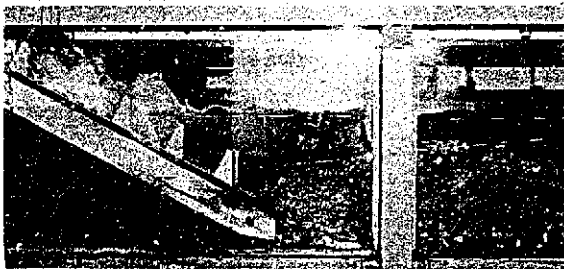Figure 1. Details of structure.

3

Figure 2. Unit discharge = 15 cfs (1.4 cu m/sec). Top Photo PX-D-69008 and bottom Photo PX-D-69006

Figure 3. Unit discharge = 77.7 cfs (7.2 cu m/sec). Top Photo PX-D-69009 and bottom Photo PX-D-69007

row of baffle piers was blocked off to simulate clogging, the reservoir water surface rose to elevation 2298.6 (700.6), 3.4 feet (1 m) below the crest of the dam embankment.

Figure 4 also shows how the location of the first row of baffle piers affects the discharge capacity. The reservoir elevations obtained with the first row of baffle piers removed were used as a basis for comparison. The tests showed that near the design discharge the baffle piers installed 1 foot (0.3 m) below

the crest raised the reservoir elevation about 14 percent, and with the baffle piers 1.8 feet (0.55 m) below the crest the reservoir elevation increased about 9 percent. At about 25 percent of the design discharge the baffle piers in the higher position raised the reservoir elevation about 17 percent while the baffle piers 1.8 feet (0.55 m) below the crest raised the reservoir only about 4 percent. In the final design the baffle piers were placed 1.8 feet (0.55 m) below the crest.

4
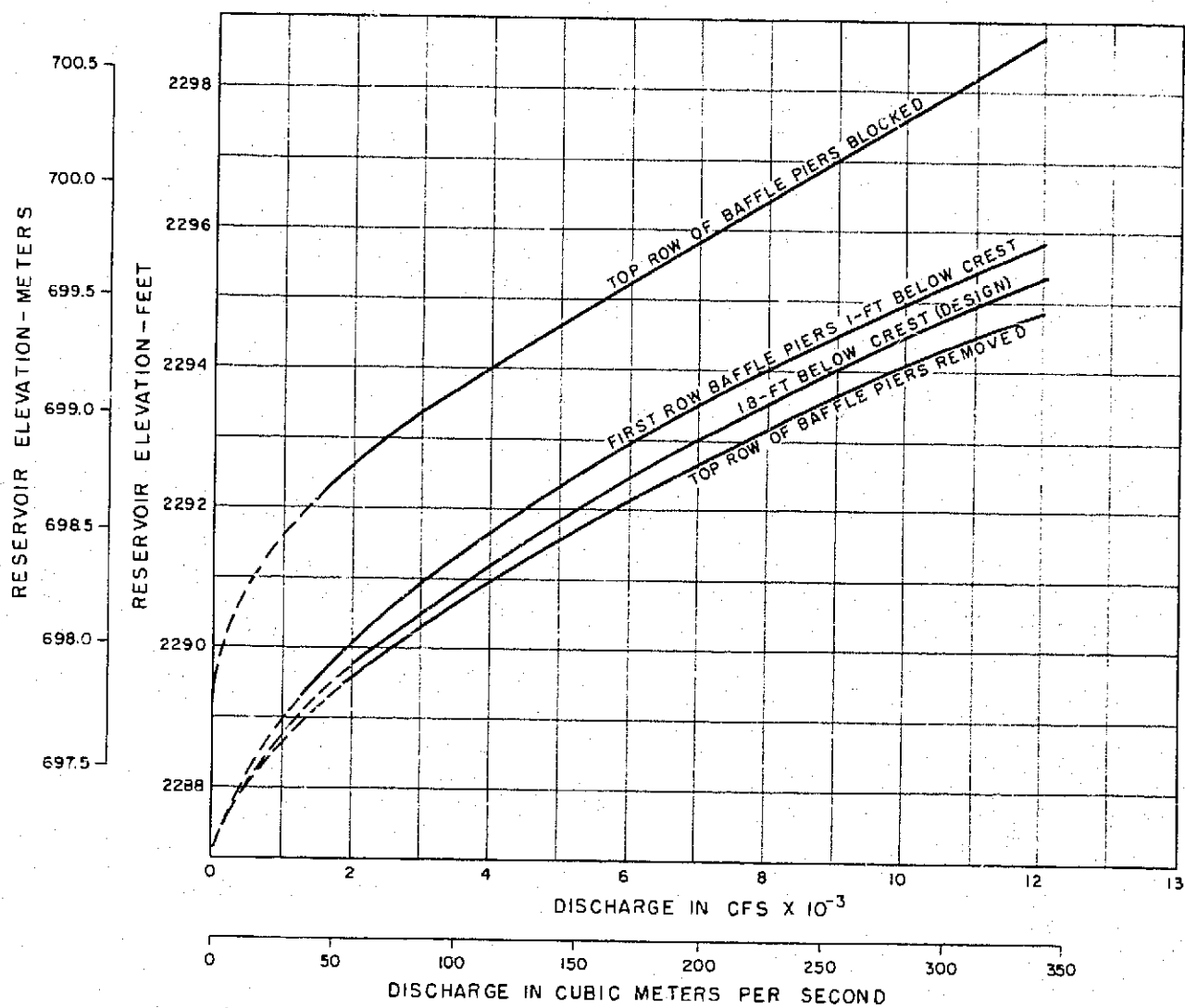
Figure 4. Effect of top row of baffle piers on discharge capacity.

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain

MASS

Multiply	By	To obtain
Grains (1/7,000 lb)	64.78891 (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
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms

FORCE/AREA

Multiply	By	To obtain
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter

MASS/VOLUME (DENSITY)

Multiply	By	To obtain
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter

MASS/CAPACITY

Multiply	By	To obtain
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

Multiply	By	To obtain
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters

VELOCITY

Multiply	By	To obtain
Feet per second	30.48 (exactly)	Centimeters per second
Feet 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
Miles per hour	0.44704 (exactly)	Meters per second

ACCELERATION

Multiply	By	To obtain
Feet per second^2	0.3048	Meters per second^2

FLOW

Multiply	By	To obtain
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

Multiply	By	To obtain
Pounds	0.453592	Kilograms
Pounds	4.4482	Newtons
Pounds	4.4482×10^5	Dynes

Table II—Continued

Multiply	By	To obtain

WORK AND ENERGY

Multiply	By	To obtain
British thermal units (Btu)	0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582	Joules

POWER

Multiply	By	To obtain
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts

HEAT TRANSFER

Multiply	By	To obtain
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	0.09290	M^2/hr

WATER VAPOR TRANSMISSION

Multiply	By	To obtain
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)	4.8924	Kilogram second per square meter
Square feet per second (viscosity)	0.092903	Square meters per second
Fahrenheit degrees (change)	5/9 exactly	Celsius or Kelvin degrees (change)
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147	Millicuries per cubic meter
Milliamps per square foot	10.7639	Milliamps per square meter
Gallons per square yard	4.527219	Liters per square meter
Pounds per inch	0.17858	Kilograms per centimeter

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, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in 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.

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

Table I

QUANTITIES AND UNITS OF SPACE

Multiply		To obtain

LENGTH

Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly) *	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly) *	Meters
Feet	0.0003048 (exactly) *	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly) *	Meters
Miles	1.609344 (exactly)	Kilometers

AREA

Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*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
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

ABSTRACT

The existing spillway structure at Conconully Dam, Washington, was determined to be structurally unsafe and incapable of discharging the design flood. Installation of a conventional hydraulic jump stilling basin or flip bucket to handle the design flood was impractical because of poor foundation conditions. However, preliminary investigations showed that if the allowable unit discharge of a baffled apron drop could be increased from 60 cfs/ft of width to about 80 cfs, such a structure could be built on sound rock. Hydraulic model studies were performed to confirm a design for a baffled apron drop based on a unit discharge of 77.7 cfs/ft of width. The tests showed that the higher-capacity structure was an effective and safe energy dissipator, and could handle unit discharges up to twice the design discharge. The effect of baffle pier location on the reservoir elevation for maximum discharge was determined. An optimum configuration for the channel bed downstream of the concrete apron was developed to prevent erosion of the apron.

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IDENTIFIERS—/ Conconully Dam, Wash/ Okanogan Project, Wash