UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SUPPLEMENTAL TESTS OF MORROW POINT SPILLWAY STILLING BASIN AND POWERPLANT TAILRACE COLORADO RIVER STORAGE PROJECT CURECANTI UNIT, COLORADO

Report No. HYD-586

HYDRAULICS BRANCH
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

JANUARY 1969

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. A table of conversion factors--BRITISH TO METRIC UNITS OF MEASUREMENT--is provided at the end of this report.

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by

D. L. King

January 1969

HYDRAULICS BRANCH
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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Office of Chief Engineer . Denver, Colorado

ACKNOWLEDGEMENT

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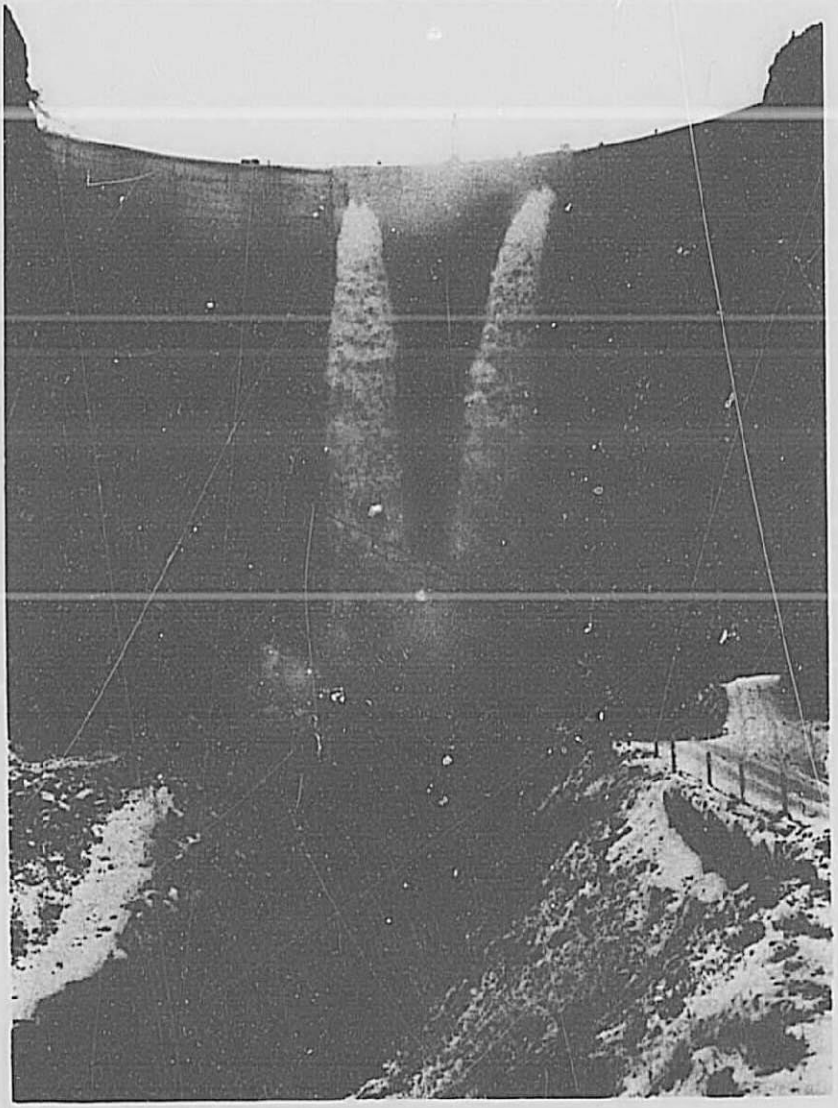


FRONTISPIECE--Morrow Point Spillway - Approximate Discharge of 5,000 cfs through Gates 1 and 4. Photo P622-D-63079.

CONTENTS

ABSTRACT

Design modifications required additional model tests after completion of the original study and issuance of the final report. This report describes the supplemental hydraulic model studies. Operation of the modified stilling basin and tailrace was very similar to operation of the original recommended design described in Report No. Hyd-557. Rock movement and riprap stability tests yielded results similar to the original study. Pressure distribution on the weir was very similar but the distribution on the stilling basin floor was different from the original study. However, the maximum observed pressures were not much larger than those recorded previously. Pressure fluctuation frequency analyses were also made which were not included in the original study. Approximate rating curves for the spillway fixed-wheel gates were derived from model data.

DESCRIPTORS--/ *arch dams/ *spillways/ *free fall/ *model tests/ hydraulic models/ tailrace/ water pressures/ weirs/ instrumentation/ frequency/ analyzers/ piezometers/ pressure measuring equipment/ underground powerplants/ impact/ energy dissipation/ riprap/ research and development/ fixed-wheel gates/ discharge coefficients
IDENTIFIERS--/ Morrow Point Dam, Colorado/ Curecanti Unit, Colorado/ Colorado River Storage Project/ Colorado

PURPOSE

This report describes supplemental tests completed after issuance of Report No. Hyd-557, "Hydraulic Model Studies of Morrow Point Dam Spillway, Outlet Works, and Powerplant Tailrace."1/ The primary purpose of the supplemental tests was to investigate a slightly modified stilling basin shape based on an updated location of sound rock determined during excavation of the prototype stilling basin.

RESULTS

1. The modified stilling basin and tailrace performed satisfactorily. Operation was very similar to that observed for the recommended design described in Report No. Hyd-557. Waves inundated the bulkhead gate deck and visitor area during spillway discharges above about 26,000 cfs. This was also true for the earlier recommended design.

2. Gravel which was hand placed in the stilling basin prior to operation was moved to the downstream portion of the basin near the upstream face of the weir during operation at maximum or one-half maximum design discharge. Some rock was swept out of the basin and deposited in the downstream channel, but no rock was found in the tailrace channels. Similar observations were reported in Report No. Hyd-557, with the exception that some material was deposited in the right tailrace channel in the earlier tests.

3. Only the left upstream corner of the riprap bed downstream from the weir was disturbed after 3 hours' model operation at a spillway discharge representing 34,400 cfs. During an 8-hour run at 34,400 cfs, one stone was deposited in the right tailrace channel.

4. No large waves overtopped the riprapped bank on the right side of the downstream channel at maximum discharge. Some waves splashed over the top of the riprap at elevation 6790.

5. Dynamic pressures on the stilling basin floor were distributed differently than those recorded for the earlier recommended design. However, maximum impact pressures were not much higher than those previously observed. Pressures on the upstream face of the weir were similar to those reported in Report No. Hyd-557.

6. An analysis of the frequency spectrum of the pressure fluctuations on the stilling basin floor showed that the "random"

1/Refers to references at end of report.

fluctuations consisted of a combination of periodic fluctuations with frequencies between 0 and 8 cps (0 to 40 cps in the model). Significant amplitudes occurred at less than 1 cps. Analysis of pressures on the weir face was not possible because of dynamic response in the lead lines between the piezometer opening and the pressure transducer.

7. Approximate discharge curves for the spillway fixed-wheel gates were derived from model data. Dissimilarities between the model and prototype gates for the inside conduits required adjustments to the data.

APPLICATIONS

The results of these tests are generally applicable only to spillways similar to the Morrow Point spillway. Results of analyses of stilling basin pressure fluctuations are of a research nature and should be of interest to designers of hydraulic structures.

INTRODUCTION

The original model studies were completed in June 1965. However, the model was retained so that any unforeseen design changes or difficulties that arose during construction of the prototype structure could be immediately investigated. Excavation of the stilling basin area in the fall of 1966 showed the location of sound rock was different from that previously assumed. The basin was redesigned and the model was modified accordingly. Other design details, including the visitor area and the embankment over the cut-and-cover section of the diversion tunnel, were finalized by this time; therefore, they were also included in the model. Also, recently acquired instrumentation was used to more closely examine the fluctuations in pressure occurring on the basin floor.

INVESTIGATION

Modifications to the Stilling Basin and Tailrace

Figure 1 compares the original recommended design (from Report No. Hyd-557) with the modified design. The modified stilling basin had a flat bottom and was generally wider and deeper than the previous basin. The left side of the stilling basin near the weir was modified to represent the correct topography. The surface of the rock between the tailrace channels was lowered approximately

5 feet to conform to the excavated rock in the prototype, and a corbel-type flood wall was installed in place of the 4-foot-high concrete wall originally developed to protect the visitor area.

Operation at spillway discharges of 34,400 cfs (maximum design) and 25,800 cfs (three-fourths maximum design), Figure 2, was only slightly improved over operation with the original recommended design. The visitor area continued to be inundated by waves at spillway discharges above 26,000 cfs.

The concrete wall on the left side of the weir was raised 5 feet and the surface of the excavated rock between the tailrace channels was raised to the original position shown in Figure 1A to provide additional protection for the bulkhead gate deck and visitor area. The higher rock surface provided some protection for the visitor area but the gate deck continued to be flooded. With the original rock surface and the higher wall on the left side of the weir, the submergence over the gate deck was slightly reduced, Figure 3A, but waves continued to move into the visitor area. Figure 3B shows operation with both the wall and topography raised. Even though some improvement was noted it was decided that, in light of the very low frequency of spillway discharges above 26,000 cfs and the high cost of the modifications, the design as shown in Figure 1B would be retained.

Movement of Rock in the Stilling Basin

Tests reported in Report No. Hyd-557 showed that during spillway operation rock material which falls into the stilling basin will circulate between the jet impingement area and the weir and to a lesser extent immediately upstream from the jet impingement area. Tests on the modified recommended design resulted in the same conclusion. Figure 4 shows the position of gravel after several hours of on-off operation at spillway discharges varying from 17,200 to 34,400 cfs. The gravel had been hand placed along the floor prior to operation. Most of the material was swept to the downstream end of the basin near the weir; several fragments were swept out of the basin and deposited in the center of the main channel. No gravel was found in the tailrace channels.

Riprap Stability

Because the shape of the riprap bed downstream from the weir was changed, Figure 1B, additional riprap stability tests were required. The model was operated for 3 hours with a spillway discharge of 34,400 cfs. Only the left upstream corner of the bed was disturbed (the corner near the right tailrace channel). After 5 hours of operation at a spillway discharge of 8,600 cfs, no apparent disturbance of the bed was noted. These tests indicated that the riprap bed was stable. During an 8-hour run at 34,400 cfs, one stone was deposited in the right tailrace channel.

Wave Test

A portion of the length of the cut-and-cover section over the diversion tunnel was simulated to determine the riprapped berm height required to prevent overtopping by waves. Figure 5 shows a wave near its highest position on the slope with a spillway discharge of 34,400 cfs. The top of the slope was at elevation 6790. Some splashing occurred over the berm but no large waves moved across the top of the slope.

Pressure Measurements

Six piezometers were installed in the floor of the stilling basin. Dynamic pressures were recorded at these piezometers and at six existing piezometers on the upstream face of the weir for spillway discharges of 25,800 and 34,400 cfs. The maximum pressures are compared with those recorded for the earlier recommended configuration in Figure 6. The pressure distribution on the weir was similar to that recorded earlier; however, the pressure distribution on the floor of the stilling basin was quite dissimilar. Part of the dissimilarity was due to the change in basin shape.

Figure 7 compares typical cross sections of the original and modified designs. The sections are near the downstream pair of piezometers in Figure 6. On the left side of the basin the slopes are very similar and the modified basin is only about 6 feet deeper than the original basin at the location of the piezometer. The right side of the modified basin is about 3 feet deeper and has a flatter slope than the original basin.

Assuming that the additional depth has little added cushioning effect, the flatter slope on the right side would explain the higher pressure at the point of jet impact. However, this is not an adequate explanation for the left side where the impact pressure is more than twice that measured in the original basin with nearly identical slope and depth.

The modified basin shows a symmetry of pressures which was lacking in the original basin. This indicates that the pressure distribution may depend on the general shape of the basin as well as the slope and depth at particular points.

Also, the distribution was for isolated maximum pressures which occurred only once during a recording of several seconds. A recording during a different time interval would show different maximum pressures. This was especially true on the stilling basin floor where very large pressure fluctuations occurred.

Pressure Frequency Analyses

After completion of the earlier study, electronic frequency analysis equipment was purchased for the purpose of determining the frequency spectrum of pressure fluctuations in models and prototypes of hydraulic structures. This equipment was used to analyze the pressure fluctuations at a piezometer on the stilling basin floor of the original recommended design. The piezometer location is shown in Figure 8A and the frequency analysis equipment is shown in Figure 8B. The signal from the pressure transducer was amplified by a direct writing oscillograph, then analyzed by either the spectrum analyzer or the accompanying spectral density analyzer. The spectrum analyzer determines the amplitude-frequency relationship over a frequency range of approximately 1/2 to 2,000 cps. The spectral density analyzer determines the average or peak value of the voltage (corresponding to pressure magnitude) or power at a given frequency, or the integral of the voltage or power over a frequency interval. Reference2/ gives a detailed explanation of the theory of the frequency analyses and the significance of the results.

The Morrow Point pressure fluctuations were analyzed to determine the coefficients of a Fourier series, and the integral

$\int_{t_1}^{t_2}$ (amplitude)^2 dt was obtained to determine the root-mean-square

(RMS) of the amplitude in various frequency bands.

Figure 9A shows the oscillograph record of pressure fluctuations for a spillway discharge of 34,400 cfs. This record demonstrates the complexity and apparent randomness of the signal. The components of amplitudes and frequencies cannot be separated.

The frequency range 0-50 cps was examined over a scan period of 2 hours. The analysis showed that all frequencies present were less than 50 cps. Figure 9B shows the results of the two analyses. Amplitudes in the upper trace of Figure 9B correspond to coefficients in the Fourier series:

$$F(t) = \frac{ao}{2} + \sum_{n=1}^{\infty} (a_n \cos n\omega_1 t + b_n \sin n\omega_1 t)$$

where ω_1 = fundamental angular frequency in radians/sec

$= 2\pi f_1$ (f_1 = fundamental frequency in cps)

$\frac{a_o}{2}$ is the steady, static value around which the pressures fluctuate. A lesser effective value of the pressure or force is used in calculating work done on the structure. This effective value is the RMS value, calculated by:

$$H_{eff} = \frac{1}{\Delta t} \sqrt{\int_{t}^{t+\Delta t} [H_t]^2 \, dt}$$

H_t represents instantaneous pressure heads in the frequency interval corresponding to the time interval Δt.

In this case, $\frac{a_o}{2}$ in the Fourier series had a value of 57.6 feet of water. Therefore, from the lower trace of Figure 9B, the effective pressure head at 0.4 cps (about 2 cps model) is

$$\sqrt{57.6^2 + 2.3^2} = 57.7 \text{ feet of water.}$$

This indicates that the dynamic contribution to the effective pressure head is negligible and that vibration is not an important problem. However, these discrete signals, when combined, result in superposition of the various peaks and accompanying growth or reduction of the peak sizes. Also, larger amplitudes with frequencies below the lower limit of the analyzer are present. Isolated peaks of much larger amplitudes than indicated by the frequency analysis are therefore generated. The largest recorded values of these maximum peaks are shown in Figure 6.

It would be improper to use these maximum values to determine loading for structural design. On the other hand, the effective pressure head determined from the frequency analysis would be too small for this purpose. Application of the low-frequency surges as a static load is probably the best approach. The pattern of the surges can be estimated from the oscillograph record, Figure 9A.

Pressure fluctuations on the weir could not be analyzed because the natural frequency of the system (lead line and pressure transducer) was in the range of frequencies of the pressure fluctuations being examined. This caused response peaks which gave a false indication of the relative amplitudes of the various signals.

Calibration of Fixed-Wheel Gates

The head-discharge relationships for the fixed-wheel gates were required to establish spillway operating criteria. Although the model and prototype gate leaves were not identical, the gates were considered sufficiently similar to estimate the prototype rating curves from calibration of the model gates.

Table 1 lists the data used in developing the rating curves. The data for the outside gates are as obtained from the model. The data for the inside gates have been adjusted for the gate angle. The model inside gates were mounted perpendicular to the direction of the flow, whereas in the prototype they are vertical (27° from perpendicular to the direction of flow). The discharges were adjusted upward according to data presented in a textbook of fluid mechanics.3/

At large gate openings, control by the gate was not maintained and the discharge increased due to reduced pressure in the conduits. The data in Table 2 were taken to more accurately define the discharge capacity of the inside and outside conduits for gate openings of 14 feet and larger.

The data in Tables 1 and 2 were used in preparation of the final rating curves, Figures 10 and 11. The curves for gate control are terminated at elevation 7160 because the operating criteria call for the gates to be fully open when the reservoir is above that elevation.

REFERENCES

1. "Hydraulic Model Studies of Morrow Point Dam Spillway, Outlet Works, and Powerplant Tailrace," by D. L. King, Hydraulics Branch Report No. Hyd-557, April 1, 1966

2. "Analysis of Random Pressure Fluctuations in Stilling Basins," by D. L. King, paper for Twelfth Congress of IAHR, Fort Collins, Colorado, September 11-14, 1967

3. "Elementary Mechanics of Fluids," by Hunter Rouse, John Wiley, and Sons, Inc., New York, 1959, Table I, p. 57

Table 1

RATING DATA FOR FIXED-WHEEL GATES

Outside gate			Inside gate		
Gate opening, feet	Reservoir elevation	Discharge, cfs	Gate opening, feet*	Reservoir elevation	Discharge, cfs
3.75	7133.8	804	4.2	7145.6	1,535
	7139.6	1,070		7149.8	1,685
	7151.4	1,324		7155.4	1,864
	7152.8	1,394		7158.6	1,967
	7153.8	1,541		7160.4	2,015
	7160.8	1,730			
	7165.1	1,870	8.4	7142.7	2,845**
				7143.6	3,149**
7.5	7130.2	796**		7144.5	3,434**
	7132.0	1,177**		7144.8	3,556**
	7133.1	1,405**		7153.0	3,488
	7139.9	1,899		7155.3	3,645
	7144.5	2,277		7157.1	3,746
	7154.9	3,028		7159.1	3,885
	7161.9	3,401		7160.1	3,944
				7162.3	4,125
11.25	7135.3	1,891**			
	7142.8	3,169	12.6	7148.5	4,984**
	7153.5	4,504		7149.3	5,382**
	7158.0	4,992		7156.0	5,866
	7162.1	5,633		7157.7	6,096
	7171.3	6,251		7160.0	6,300
				7163.6	6,608
15	7140.1	3,003**			
(100%)	7145.5	5,700**	16.8	7149.9	5,644**
	7153.2	7,817**	(100%)	7151.5	7,241**
	7158.5	8,906**		7152.6	8,077**
	7165.3	10,173**		7158.7	9,177**

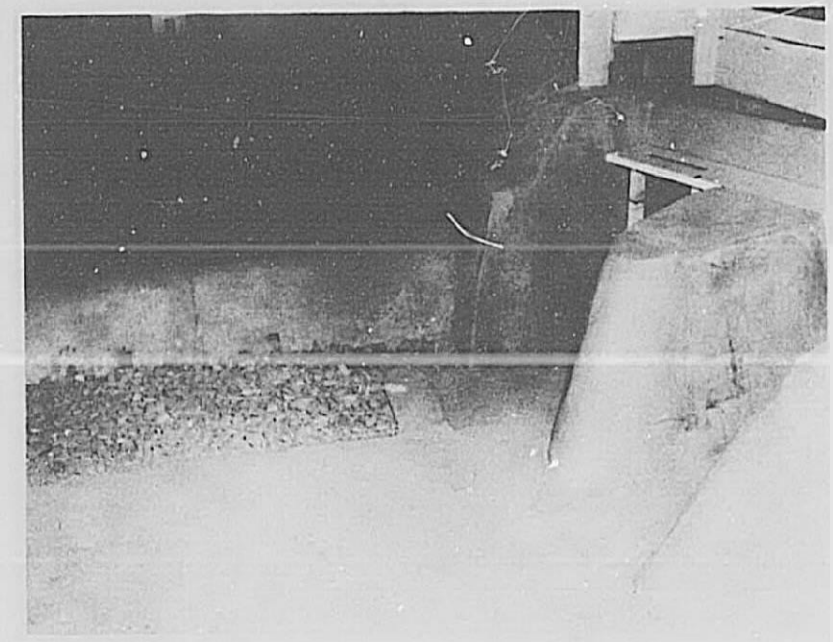
*Measured vertically from gate seat. Discharges corrected for gate angle.
**Free discharge.

Table 2

RATING DATA FOR FIXED-WHEEL GATES AT
LARGE GATE OPENINGS

Outside gate			Inside gate		
Gate opening, feet	Reservoir elevation	Discharge, cfs	Gate opening, feet	Reservoir elevation	Discharge, cfs*
14	7135.3	2,077**	14	7135.3	821**
	7139.0	3,056**		7140.3	2,063**
	7140.5	3,564**		7143.5	3,042**
	7141.5	4,019**		7144.7	3,457**
	7145.5	5,006		7146.3	4,044**
	7150.5	6,014		7148.7	5,015**
	7157.3	7,100		7155.6	6,084
				7165.3	7,100
15	7145.8	6,014**			
(100%)	7150.1	7,190**	15	7148.7	4,941**
				7150.1	5,867
				7156.0	6,561
				7160.3	7,100
			16	7150.8	6,189
				7152.7	7,250
				7156.4	7,823
				7160.3	8,356
			16.8 (100%)	7151.7	7,190**

*No correction for gate angle applied. Value of correction would be small and uncertain.
**Free discharge.

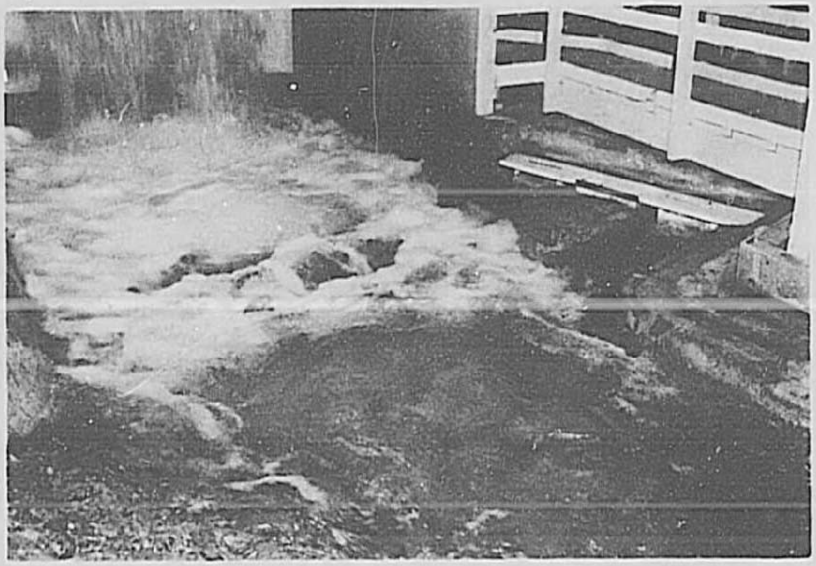


A. Original recommended design. (From Report Hyd-557.) Photo P622-D-54136.

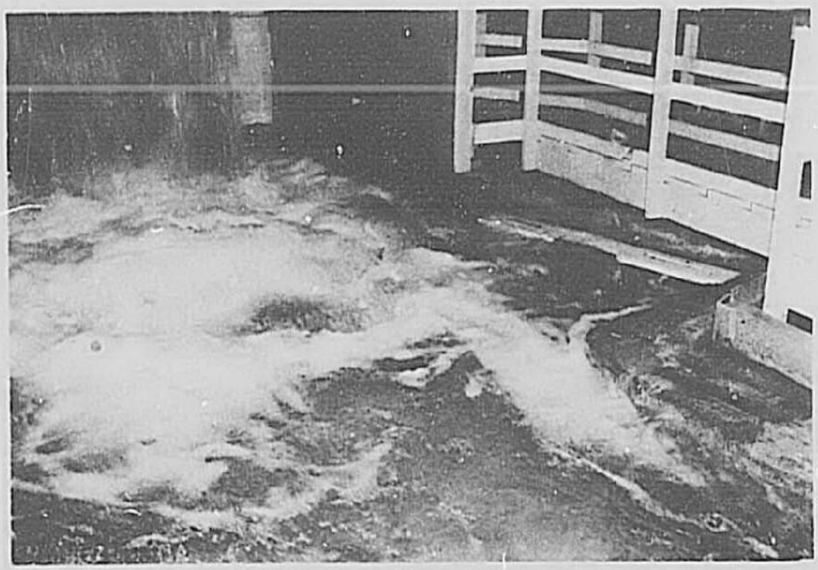
B. Modified design. Photo P622-D-63020

MORROW POINT SPILLWAY STILLING BASIN
AND POWERPLANT TAILRACE
SUPPLEMENTAL TESTS
1:24 Scale Model

Comparison of original and modified recommended designs



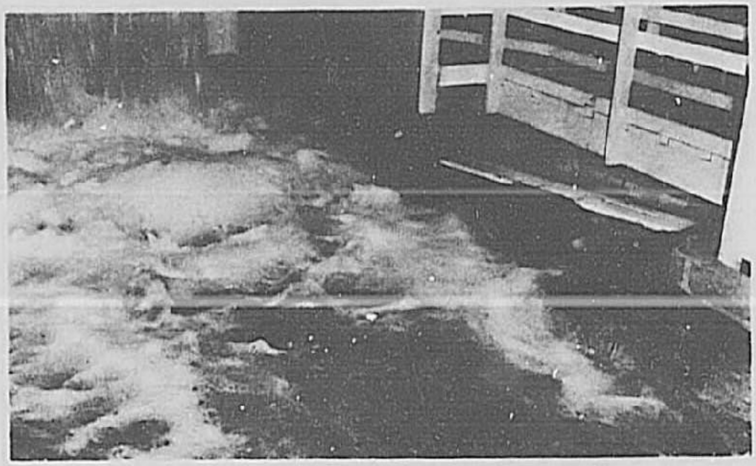
A. Spillway Q = 34, 400 cfs. Photo P622-D-63021.



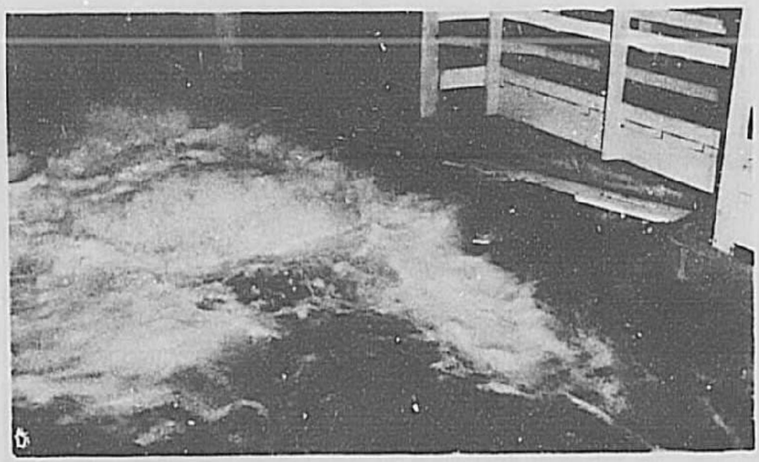
B. Spillway Q = 25, 800 cfs. Photo P622-D-63022.

MORROW POINT SPILLWAY STILLING BASIN
AND POWERPLANT TAILRACE
SUPPLEMENTAL TESTS
1:24 Scale Model

Operation of modified recommended design



A. Higher wall at left side of weir.
Photo P622-D-63023.



B. Higher wall and higher rock surface between tailrace channels. Photo P622-D-63024.

MORROW POINT SPILLWAY STILLING BASIN
AND POWERPLANT TAILRACE
SUPPLEMENTAL TESTS
1:24 Scale Model

Effects of topography modifications
Spillway Q = 34, 400 cfs

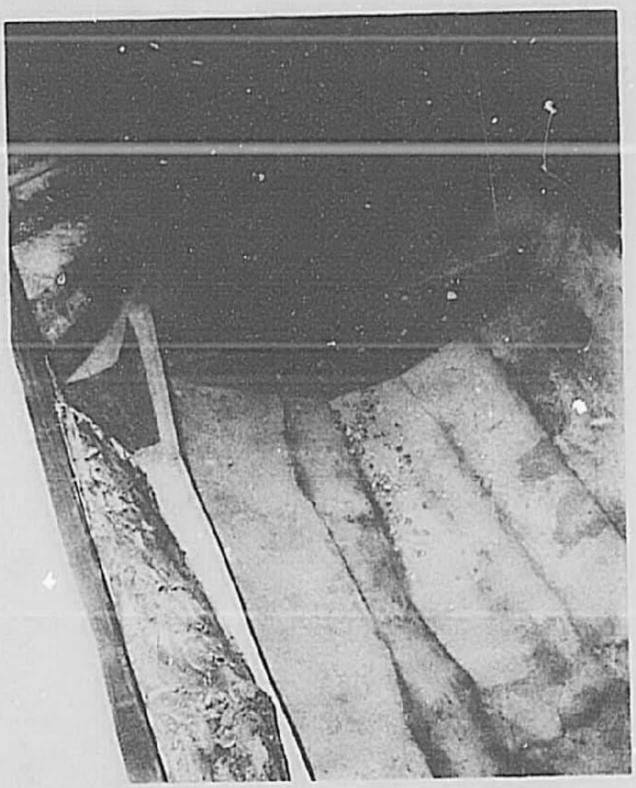


Photo P622-D-63025

MORROW POINT SPILLWAY STILLING BASIN
AND POWERPLANT TAILRACE
SUPPLEMENTAL TESTS
1:24 Scale Model

Rock movement test

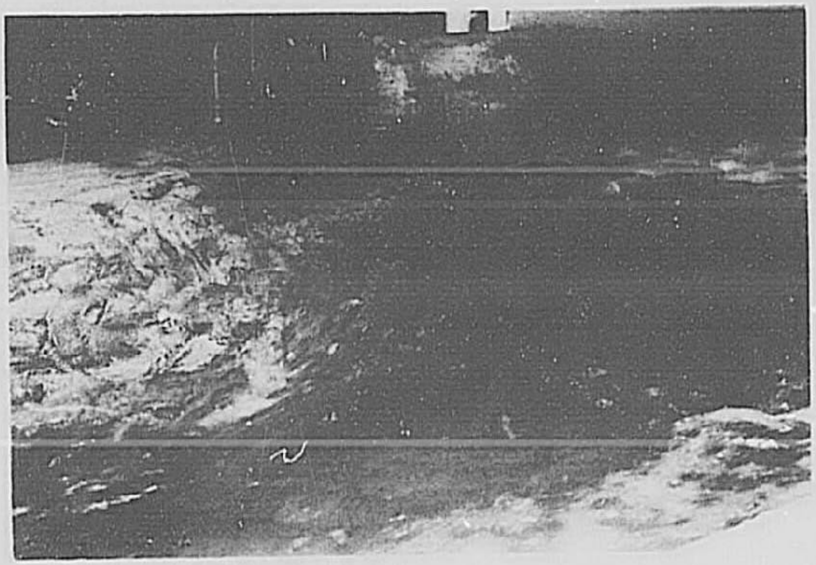
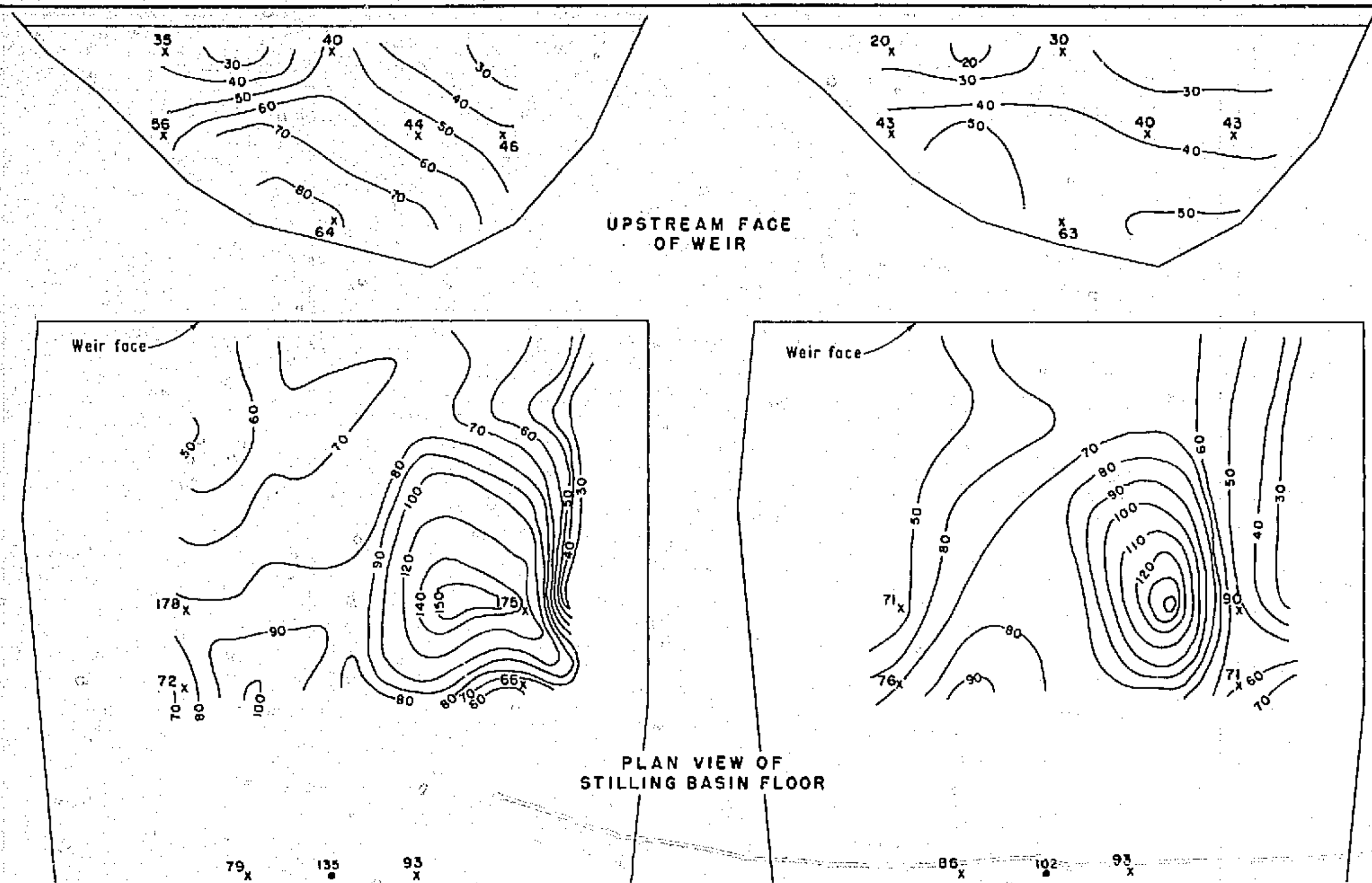


Photo P622-D-63026

MORROW POINT SPILLWAY STILLING BASIN
AND POWERPLANT TAILRACE
SUPPLEMENTAL TESTS
1:24 Scale Model

Wave test on cut-and-cover section

FIGURE 6
REPORT HYD 586



MAXIMUM RESERVOIR ELEVATION (7165)
ALL GATES EQUALLY OPEN
SPWY. Q = 34,400 C.F.S.

NORMAL RESERVOIR ELEVATION (7160)
ALL GATES EQUALLY OPEN
SPWY. Q = 25,800 C.F.S.

Contours are for original recommended design (Hyd.-557)
X 64 etc. are for modified recommended design

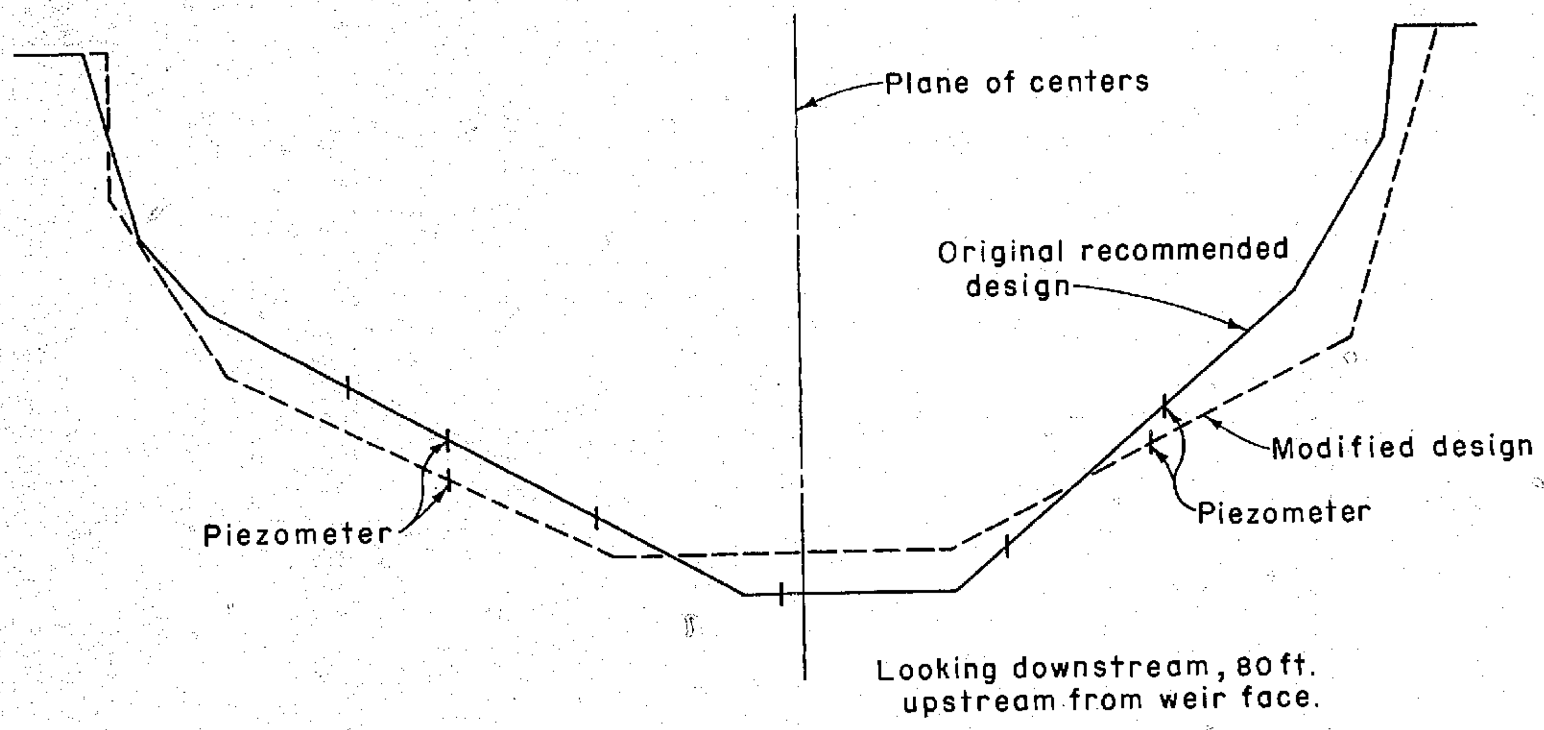
MORROW POINT SPILLWAY STILLING BASIN AND POWERPLANT TAILRACE - SUPPLEMENTAL TESTS

1:24 SCALE MODEL

PRESSURE DISTRIBUTION PATTERNS

707

707

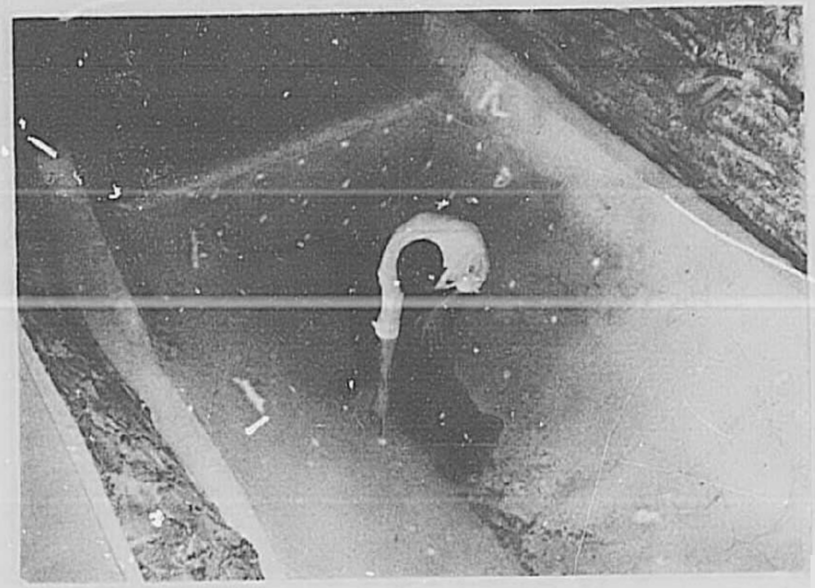


MORROW POINT SPILLWAY STILLING BASIN AND POWERPLANT TAILRACE - SUPPLEMENTAL TESTS

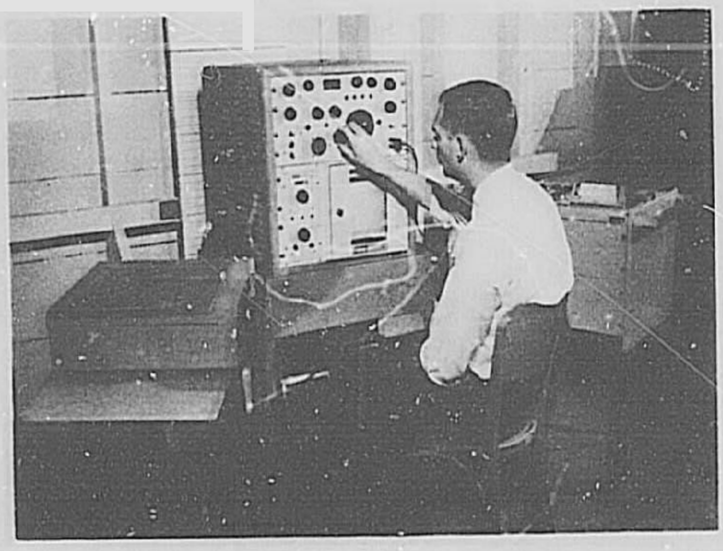
1:24 SCALE MODEL

COMPARISON OF TYPICAL CROSS-SECTIONS ORIGINAL AND MODIFIED BASINS

Figure 8
Report Hyd-586



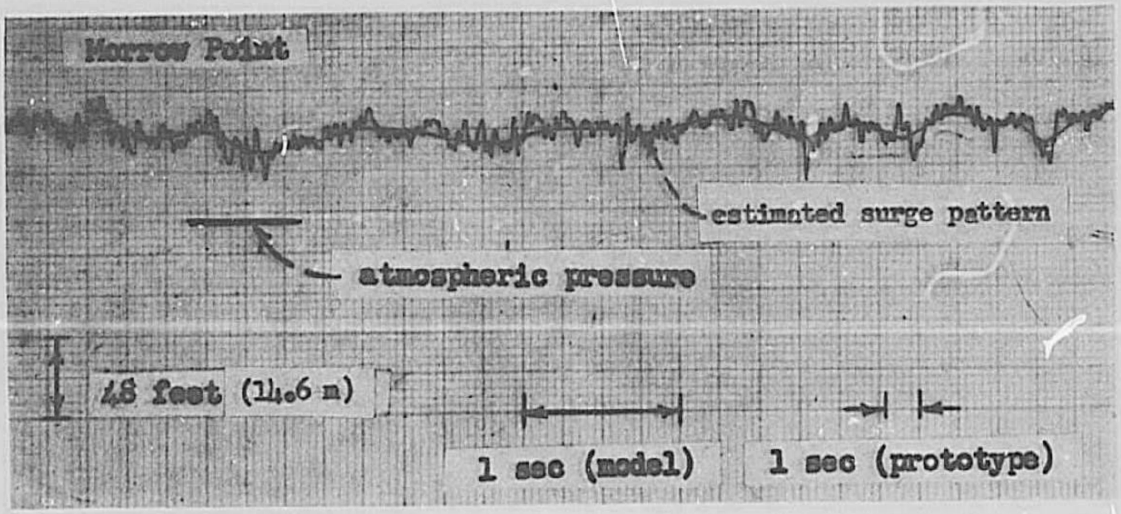
A. Photo P622-D-63027



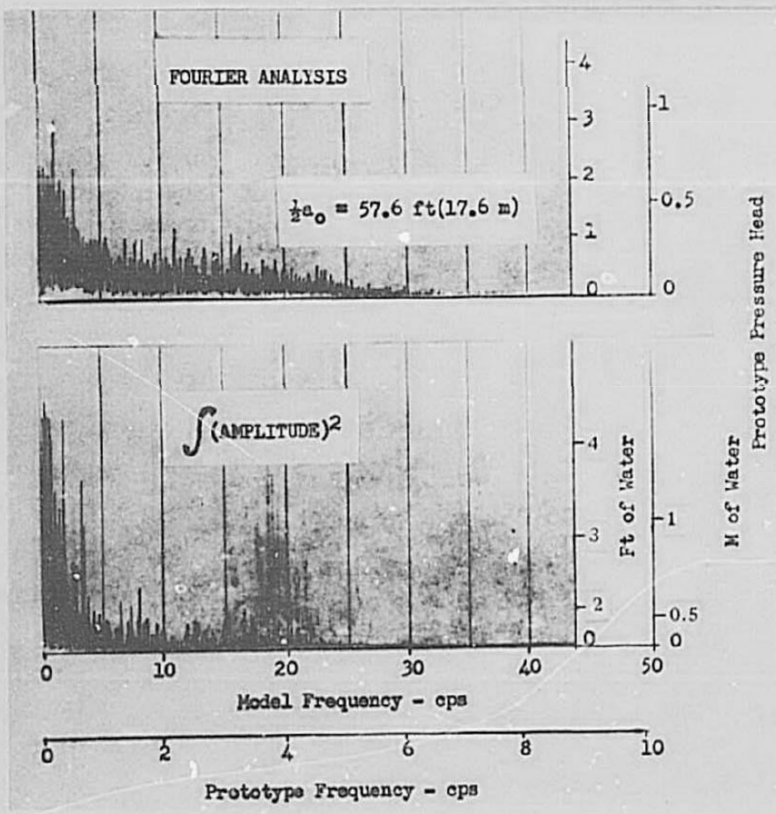
B. Photo P622-D-63028

MORROW POINT SPILLWAY STILLING BASIN
AND POWERPLANT TAILRACE
SUPPLEMENTAL TESTS
1:24 Scale Model

Piezometer location and instrumentation for frequency analyses



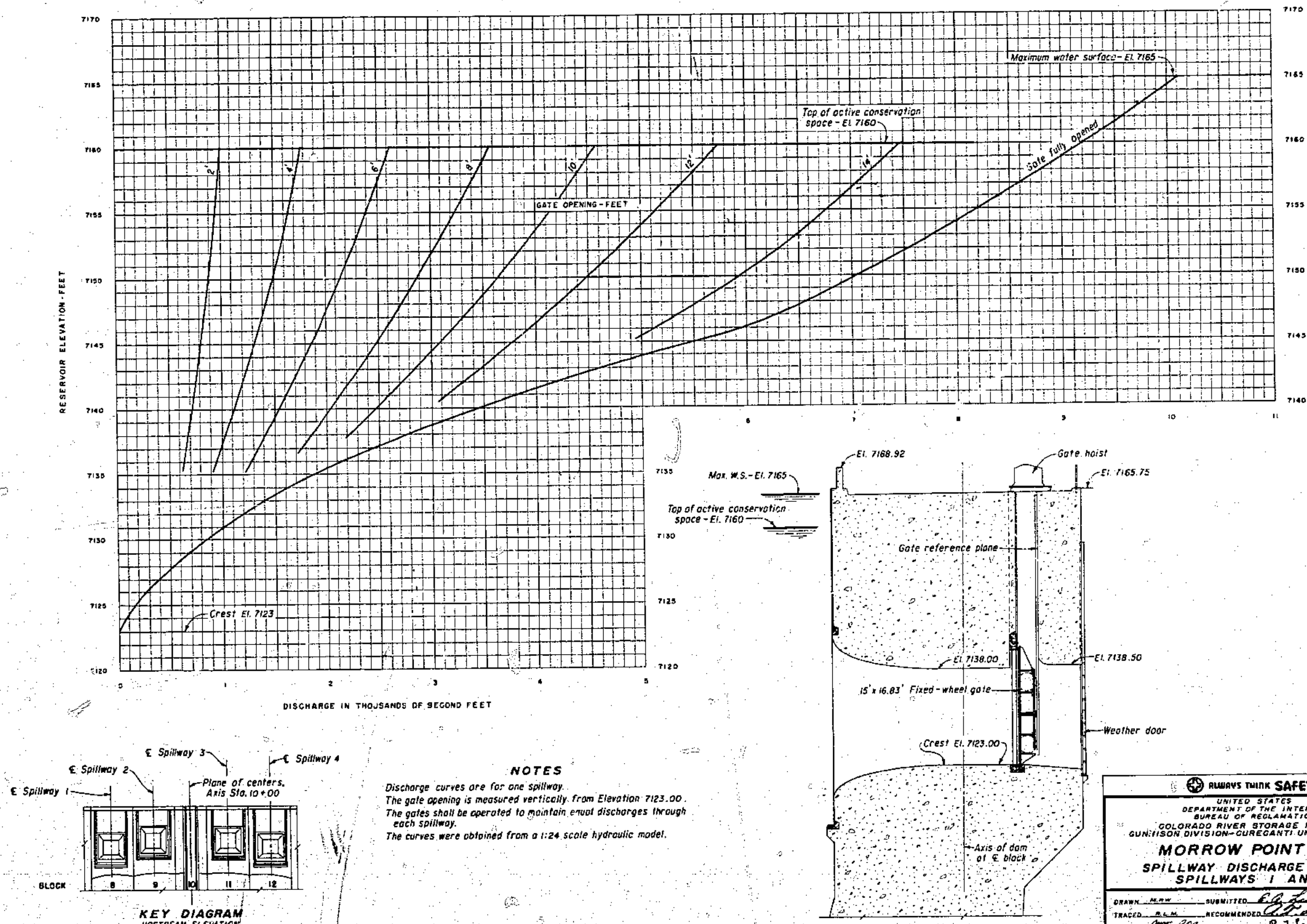
A. Oscillograph record



B. Frequency analysis records

MORROW POINT SPILLWAY STILLING BASIN
AND POWERPLANT TAILRACE
SUPPLEMENTAL TESTS
1:24 Scale Model

Oscillograph and Frequency Analysis Records
Spillway Q = 34,400 cfs



KEY DIAGRAM
UPSTREAM ELEVATION

SECTION THRU SPILLWAYS 1 AND 4

NOTES

Discharge curves are for one spillway.
The gate opening is measured vertically from Elevation 7123.00.
The gates shall be operated to maintain equal discharges through each spillway.
The curves were obtained from a 1:24 scale hydraulic model.

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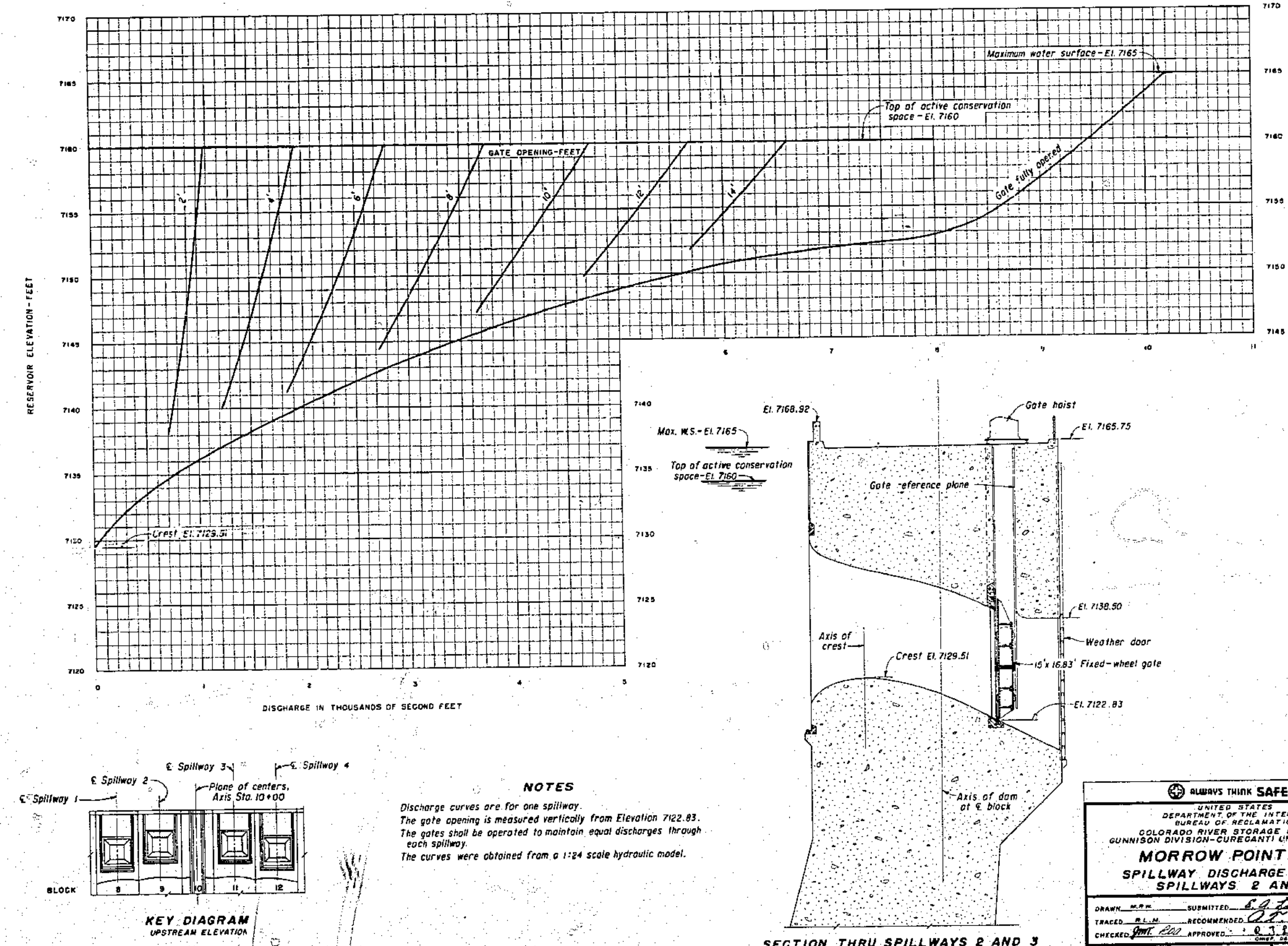
MORROW POINT DAM
SPILLWAY DISCHARGE CURVES
SPILLWAYS 1 AND 4

DRAWN M.R.W. SUBMITTED [signature]
TRACED R.L.M. RECOMMENDED [signature]
CHECKED [signature] APPROVED R. J. [signature]
DENVER, COLORADO, APRIL 18, 1966 SHEET 1 OF 2 622-D-2396

FIGURE 11
REPORT HYD-586



SECTION THRU SPILLWAYS 2 AND 3

KEY DIAGRAM
UPSTREAM ELEVATION

NOTES

Discharge curves are for one spillway.
The gate opening is measured vertically from Elevation 7122.83.
The gates shall be operated to maintain equal discharges through each spillway.
The curves were obtained from a 1:24 scale hydraulic model.

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MORROW POINT DAM
SPILLWAY DISCHARGE CURVES
SPILLWAYS 2 AND 3

DRAWN M.R.W. SUBMITTED E. J. Lindholm
TRACED R.L.M. RECOMMENDED A. J. Lewis
CHECKED [illegible] APPROVED Q. J. Larson CHIEF, DAMS BRANCH
DENVER, COLORADO, APRIL 18, 1966 SHEET 2 OF 2 622-D-2397

7-1750
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Bureau of Reclamation

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 I

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*	Square centimeters
	0.092903	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.)	946.358*	Cubic centimeters
	0.946331*	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 x 10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582 x 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 x 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 x 10^{-5}*	Dynes

Multiply	By	To obtain
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)	0.092903*	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

GPO 835-159

ABSTRACT

Design modifications required additional model tests after completion of the original study and issuance of the final report. This report describes the supplemental hydraulic model studies. Operation of the modified stilling basin and tailrace was very similar to operation of the original recommended design described in Report No. Hyd-557. Rock movement and riprap stability tests yielded results similar to the original study. Pressure distribution on the weir was very similar but the distribution on the stilling basin floor was different from the original study. However, the maximum observed pressures were not much larger than those recorded previously. Pressure fluctuation frequency analyses were also made which were not included in the original study. Approximate rating curves for the spillway fixed-wheel gates were derived from model data.

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Hyd-586
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SUPPLEMENTAL TESTS OF MORROW POINT SPILLWAY STILLING BASIN AND POWERPLANT TAILRACE, COLORADO RIVER STORAGE PROJECT, CURECANTI UNIT, COLORADO. Bur Reclam Lab Rep Hyd-586, Hydraul Br, Sept 1968. Bureau of Reclamation, Denver, 8 p, 11 fig, 4 tab, 3 ref

DESCRIPTORS--/ *arch dams/ *spillways/ *free fall/ *model tests/ hydraulic models/ tailrace/ water pressures/ weirs/ instrumentation/ frequency/ analyzers/ piezometers/ pressure measuring equipment/ underground powerplants/ impact/ energy dissipation/ riprap/ research and development/ fixed-wheel gates/ discharge coefficients
IDENTIFIERS--/ Morrow Point Dam, Colorado/ Curecanti Unit, Colorado/ Colorado River Storage Project/ Colorado

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