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HYDRAULIC MODEL STUDIES OF FOLSOM SPILLWAY-OUTLET JUNCTION

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Engineering and Research Center
Bureau of Reclamation

February 1971

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16. ABSTRACT

Model studies performed to investigate damage to the area surrounding the Folsom Dam outlet works-spillway junctions and to aid development of corrective modifications are described. Model data indicated that when spillway releases are made prior to repair and modification of the damaged areas, outlet releases should be made with 60% gate openings. For spillway releases only, an eyebrow placed on the spillway face above the outlet opening deflected spillway flow away from the outlet works-spillway face junction, eliminated surge in the outlet, and prevented development of low pressures on the spillway face. A flow splitter-eyebrow combination completely eliminated all damaging pressures in the flow junction area for all operating conditions, but was considered extremely difficult structurally to anchor to the spillway face, and was abandoned. Use of the eyebrow without the splitter is recommended. If simultaneous releases are necessary, the outlet gate openings should be limited to 40 to 70% to provide for maximum air demand from the outlet air header system.

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b. IDENTIFIERS--/ Folsom Dam, Calif/ *remedial treatment/ splitters/ design improvements/ cavitation control/ hydrodynamic pressures

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by

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Hydraulics Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION
Rogers C. B. Morton, Secretary
Ellis L. Armstrong, Commissioner

ACKNOWLEDGMENT

These studies were conducted during the period 1965-67, under the supervision of W. E. Wagner, formerly Head, Hydraulic Structures and Equipment Section (presently Chief, Hydraulics Branch), and under the direction of H. M. Martin, former Chief, Hydraulics Branch. Prototype photographs and field data were furnished by Region 2. Model photographs were taken by W. M. Batts, Office Services Branch. The computer program for spillway flow depths was furnished by Dr. H. T. Falvey, Hydraulics Branch. During the study, close cooperation was maintained between the Dams Branch and the Hydraulics Branch, Office of Chief Engineer, Denver, Colorado.

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1964 flood at Folsom Dam. Note aerated flow extending down spillway face, and jets from Outlets 6, 7, and 8 penetrating spillway jet. Photo P485-200-3975 NA

FOLSOM SPILLWAY-OUTLET JUNCTION REPAIRS

1964 Flood at Folsom Dam

PURPOSE

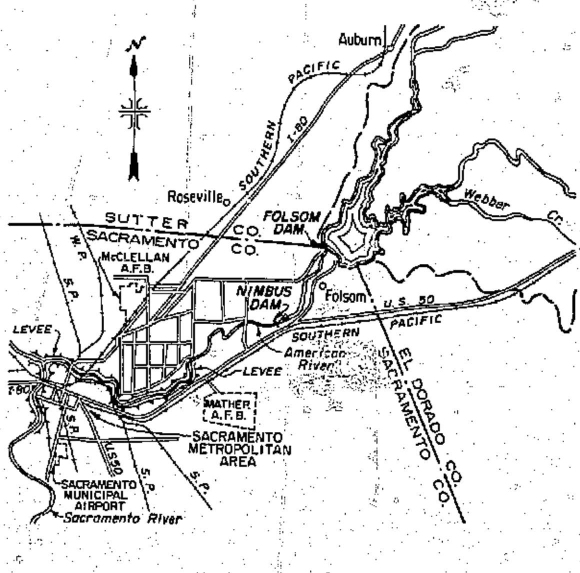
The model study was required to investigate the cavitation damage to the areas surrounding the outlet works-spillway junction, and to develop corrective modifications. The study also was needed to determine a mode of operation which would minimize damage to the structure prior to the completion of field modifications.

APPLICATIONS

The damage encountered at Folsom Dam points out the need for supplying adequate aeration to protect surfaces surrounding the junction of high-velocity flows. While the Folsom Dam study dealt with a specific design, the principle of supplying air to flow junctions has wide application, and should be considered whenever structures of this nature are designed.

INTRODUCTION

Folsom Dam is on the American River about 20 miles (32 kilometers) northeast of Sacramento, California, (location map). The dam was built by the Corps of Engineers and transferred to the Bureau of Reclamation for operation on May 14, 1956. The dam (Figure 1) is a concrete gravity structure 340 feet (103.63 meters) high and 1,400 feet (426.72 meters) long, capable of impounding approximately 1,010,000 acre-feet (1,250 million cubic meters) of water.



Location map.

*Numbers refer to references listed at end of report.

Normal river regulation is maintained by two tiers of four outlets each (Figure 2), controlled by 5- by 9-foot (1.52- by 2.74-meter) slide gates. The outlets consist of rectangular conduits through the dam which exit on the spillway face and discharge into the spillway stilling pool. Spillway releases are made through five 42- by 50-foot (12.80- by 15.24-meter) radial gates located near the crest of the dam. Three additional 42- by 50-foot (12.80- by 15.24-meter) radial gates for extremely large flood releases are located to the left of the main spillway, and release flow to a flip bucket on the downstream face of the dam.

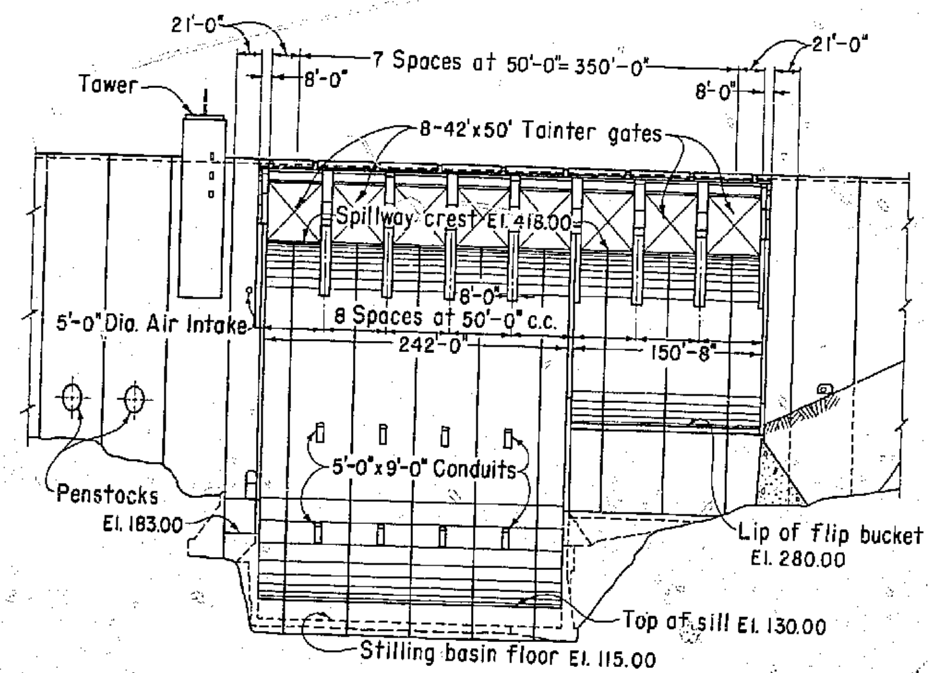
The spillway face and downstream end of the outlets at Folsom Dam incurred considerable damage during passage of flood releases in 1955[1], 1963, and 1964. The spillway face damage occurred immediately downstream of the junction formed by the spillway face and outlet conduit invert (Figure 3). Damage in the outlets occurred on the side walls just downstream of the constriction in the crown and extended to the spillway face (Figure 4).

The 1955 and 1964 flood releases were made with simultaneous operation of the spillway and outlet works. The 1963 flood was passed over the spillway only. The most extensive damage occurred with simultaneous operation.

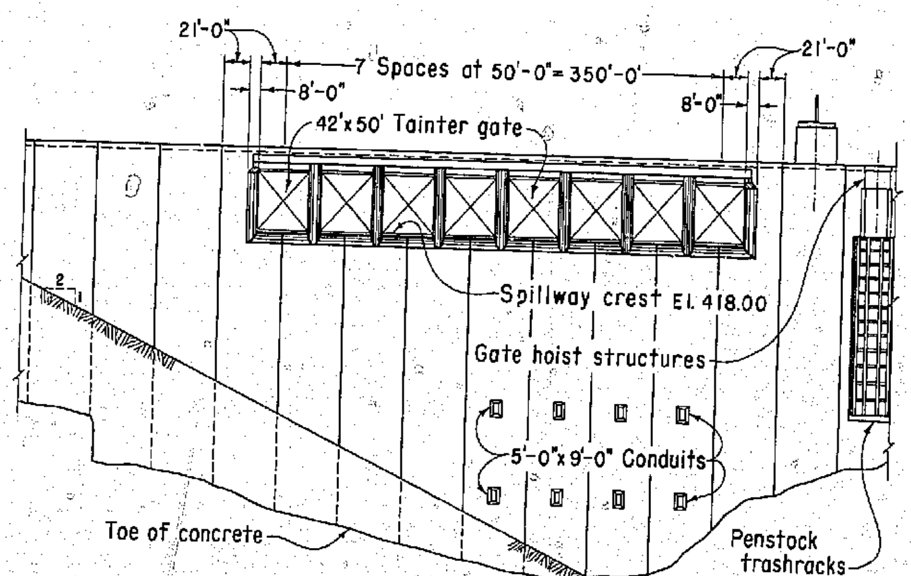
The flow conditions resulting in the 1955 flood damage have been studied by the Corps of Engineers in conjunction with tests for Red Rock Dam[2]. In this study, a 1:16 model of the Folsom sluice outlet was placed in the Red Rock model. The minimum pressure recorded was 49 feet (14.94 meters) of water below atmospheric. A range of pressure heads was recorded at some piezometer locations, indicating large pressure fluctuations of as much as 32 feet (9.75 meters) of water. Since water columns probably were used to read the fluctuating pressures, peak instantaneous fluctuations could be expected to be considerably greater.

THE MODEL

A 1:16.7 sectional model was built to investigate the damaged areas and to aid the development of corrective modifications (Figure 5). The model was a scaled representation of the upper tier outlets which were more severely damaged. The model contained a single outlet, and a section of spillway face. Flow was supplied to the outlet through a baffled-head tank containing a 5- by 9-foot (1.52- by 2.74-meter) (prototype) slide gate. An air vent was placed in the crown immediately downstream of the gate. The vent

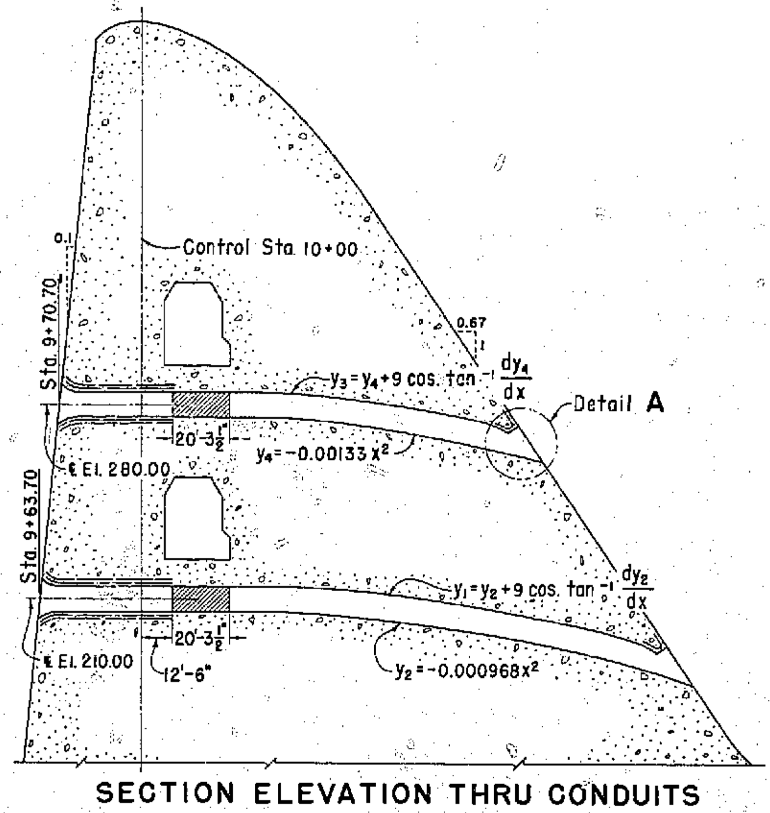


DOWNSTREAM ELEVATION



UPSTREAM ELEVATION

Figure 1. Spillway section of concrete dam.



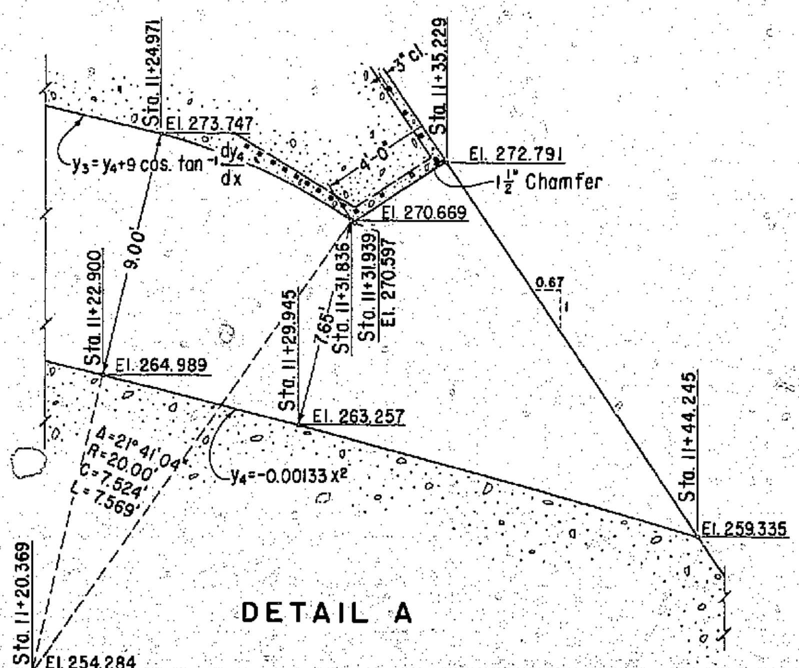
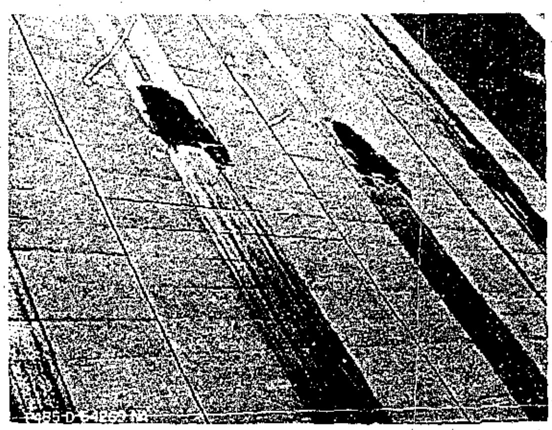


Figure 2. River outlets.

Damage to lower tier outlets 2, 3, and 4. Outlet 1, closed during flood to minimize spray on powerplant, not shown. Photo P485-D-54270 NA



Damage to upper tier outlets 6, 7, and 8. Outlet 5, closed during flood to minimize spray on powerplant, not shown. Photo P485-D-54269 NA

Figure 3. Damage on spillway face.

was designed to accommodate various sizes of orifice plates. A plastic conduit at the end of the gate extended to the spillway face. The flow junction containing the constriction in the crown was generously equipped with piezometers in areas which received severe damage in the prototype (Figure 6).

The model spillway was equipped with a slide gate in order to simulate flow velocities occurring over both upper and lower tier outlets. The spillway section was 20.87 feet (6.36 meters) wide, which was the largest width which could be supplied by a single 12-inch (30.48-centimeter) laboratory pump. The flow from the spillway and outlet works was deposited in a 4- by 4- by 15-foot-long (1.22- by 1.22- by 4.57-meter-long) tailbox with an adjustable tailgate. The gate could be set to provide partial submergence of the junction to simulate flow conditions surrounding the lower tier outlets.

Model Prototype Differences

The model spillway flow differed from the prototype because the entire spillway crest structure was not represented. The prototype has radial gate support piers located directly above and in line with the outlet conduits (Figure 1). These piers divide the flow over the crest and tend to maintain some degree of separation on the spillway face between flow from adjacent gates (frontispiece). The flow moving along the support piers contains a considerable amount of entrained air introduced through vortex action in the corners upstream from the radial gates. Whether or not the flow rejoins on the spillway face cannot be definitely determined. However, photographs of the prototype in operation indicate that the flow has rejoined near the outlets and would prevent aeration of the outlet through the spillway jet.

INVESTIGATION

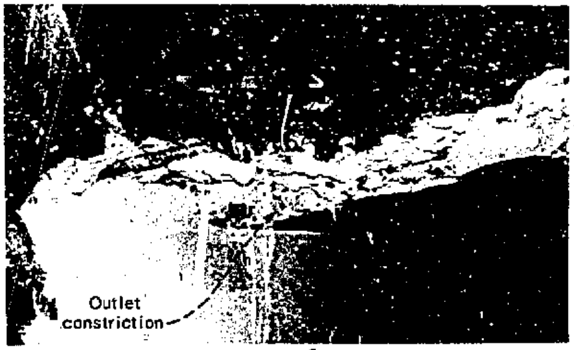
Instrumentation

Water manometers were initially used to read pressure heads at the piezometers surrounding the flow junction. Large fluctuations in the water column levels made reading the column heights very difficult. Therefore, piezometers with the most severe fluctuations or lowest pressures were connected to electronic pressure sensors so that the fluctuations could be more accurately measured.

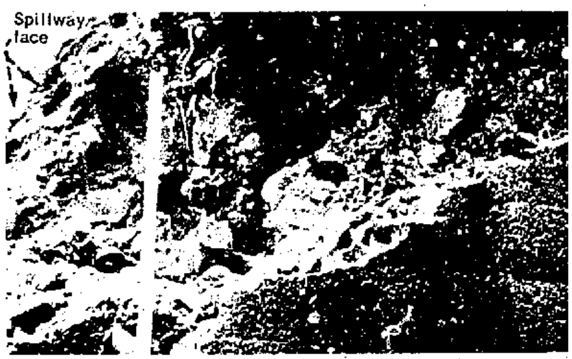
Spillway Operation of As-Built Structure

Spillway flow velocities.—A computer program was utilized to provide spillway flow depth and velocities in the vicinity of the upper and lower tier outlets for spillway releases of 41,600 cfs (1,180 cu m/sec), 85,500 cfs (2,420 cu m/sec), and 115,000 cfs (3,260 cu m/sec). The program included the effects of centrifugal force for flow moving over curved surfaces.

Surge process.—A surge occurred in the model outlet works conduit when spillway releases were



Damage began at constriction in crown, and progressed downstream on sidewalls. Photo P485-D-54267 NA



Damage on sidewalls reached spillway face (portion of conduit right wall shown). Photo P485-D-54265 NA

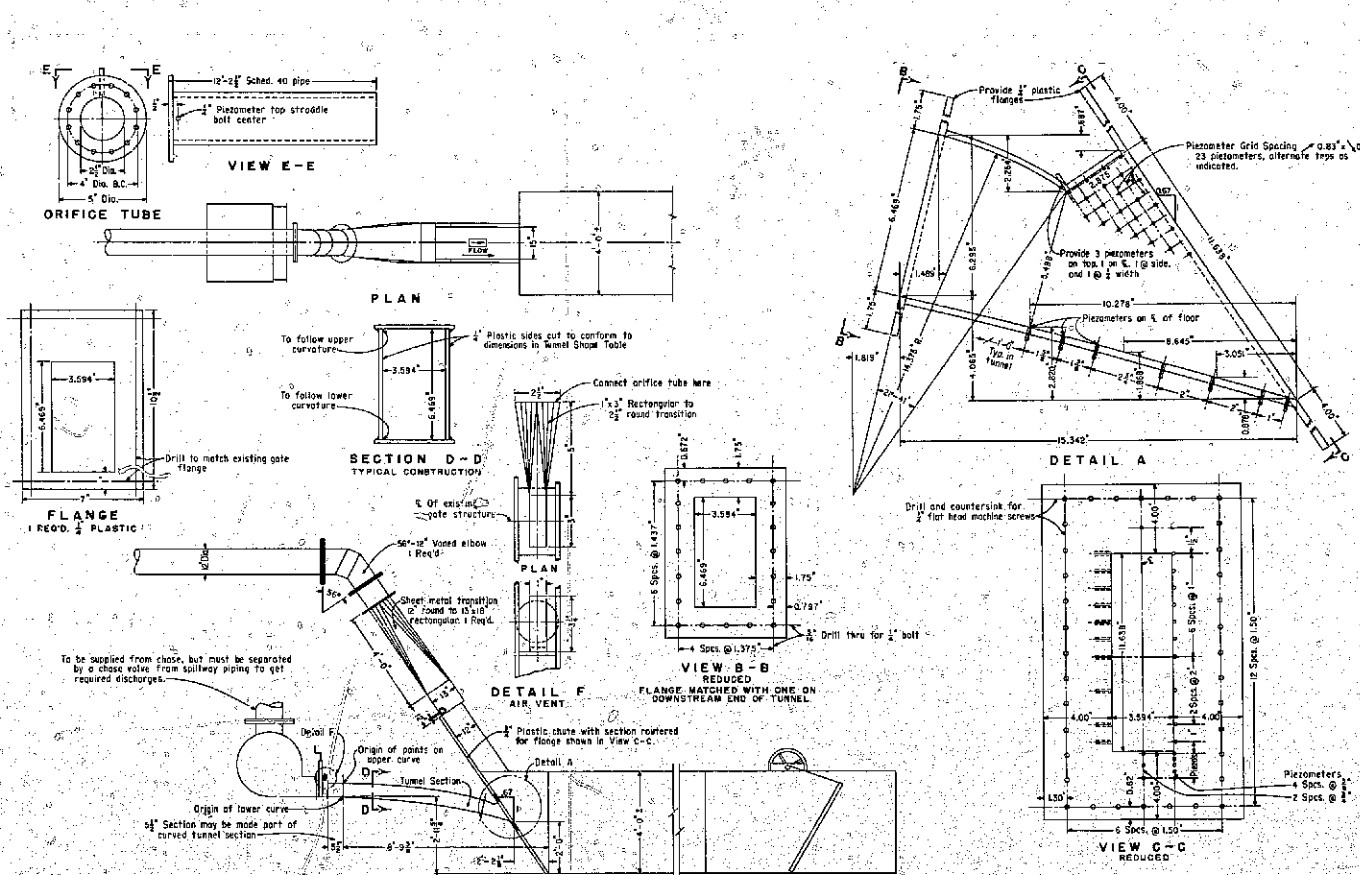
Damage progressed down spillway face (conduit invert and left wall shown). Photo P485-D-54248 NA

Figure 4. Typical damage patterns in outlets.

made (Figure 7). The surge resulted in alternate partial filling and rapid evacuation of the outlet conduit with the outlet gate closed. The frequency appeared to be from 1.5 to 2.5 cycles per minute (prototype). The surge formed when spillway flow struck the invert of the outlet works conduit slightly upstream of the outlet invert-spillway junction. High pressure resulted at the impact point, and a portion of the flow was directed upstream into the outlet works conduit. The water surface in the conduit continued to rise until the constriction in the outlet crown was submerged, cutting off the air supplied to the spillway flow from the outlet works air vent. Low pressure then resulted in the conduit downstream of the constriction in the crown, and at the outlet works-spillway junction. The low pressure caused the water surface in the outlet works conduit to recede permitting air from the outlet works air vent to relieve the low-pressure area, and the process repeated itself. The air supply to the model conduit varied greatly during a surge and was directly related to the water volume changes in the conduit. In the model, heavy audible pulsations resulted at the air intake. During a surge, pressure fluctuations at the outlet works-spillway junction were extremely large (Figure 8). The largest fluctuations were noted in areas which were the most heavily damaged in the prototype.

A similar surge in the prototype has not been reported, possibly because of a degree of separation in spillway flow from the radial gate piers providing some aeration and preventing its development.

Pressure for spillway operation.—Pressures downstream of the junction of the spillway face and outlet works invert were in the cavitation range for the three spillway releases tested [41,600 cfs (1,180 cu m/sec), 85,500 cfs (2,420 cu m/sec), and 115,000 cfs (3,260 cu m/sec)]. The high velocity flow moving down the spillway face impinged on the invert of the outlet conduit and separated from the surface at the junction to the spillway face. Pressures within the conduit fluctuated greatly during the surge. However, by slightly splitting the spillway flow upstream of the junction, the surge could be eliminated, and only the pressures downstream of the junction on the spillway face remained damagingly low.



TUNNEL SHAPE TABLE

Lower Curve Point	Distance from origin X	Distance from origin Y	Upper Curve Point	Distance from origin X	Distance from origin Y
0			0		
1	7.187"	0.096"	1	7.358"	0.098"
2	14.375"	0.383"	2	14.718"	0.392"
3	21.562"	0.861"	3	22.077"	0.881"
4	28.750"	1.530"	4	29.434"	1.566"
5	35.937"	2.390"	5	36.790"	2.447"
6	43.125"	3.442"	6	44.144"	3.522"
7	50.312"	4.685"	7	51.496"	4.793"
8	57.500"	6.118"	8	58.845"	6.259"
9	63.897"	7.556"	9	65.384"	7.728"
10	68.961"	8.801"	10	67.029"	8.222"
11	72.594"	9.753"	11	68.675"	8.947"
12	76.188"	10.743"	12	70.318"	9.941"
13	79.238"	11.621"	13	70.388"	9.993"

Figure 5. Details of the 1:16.7 Model.

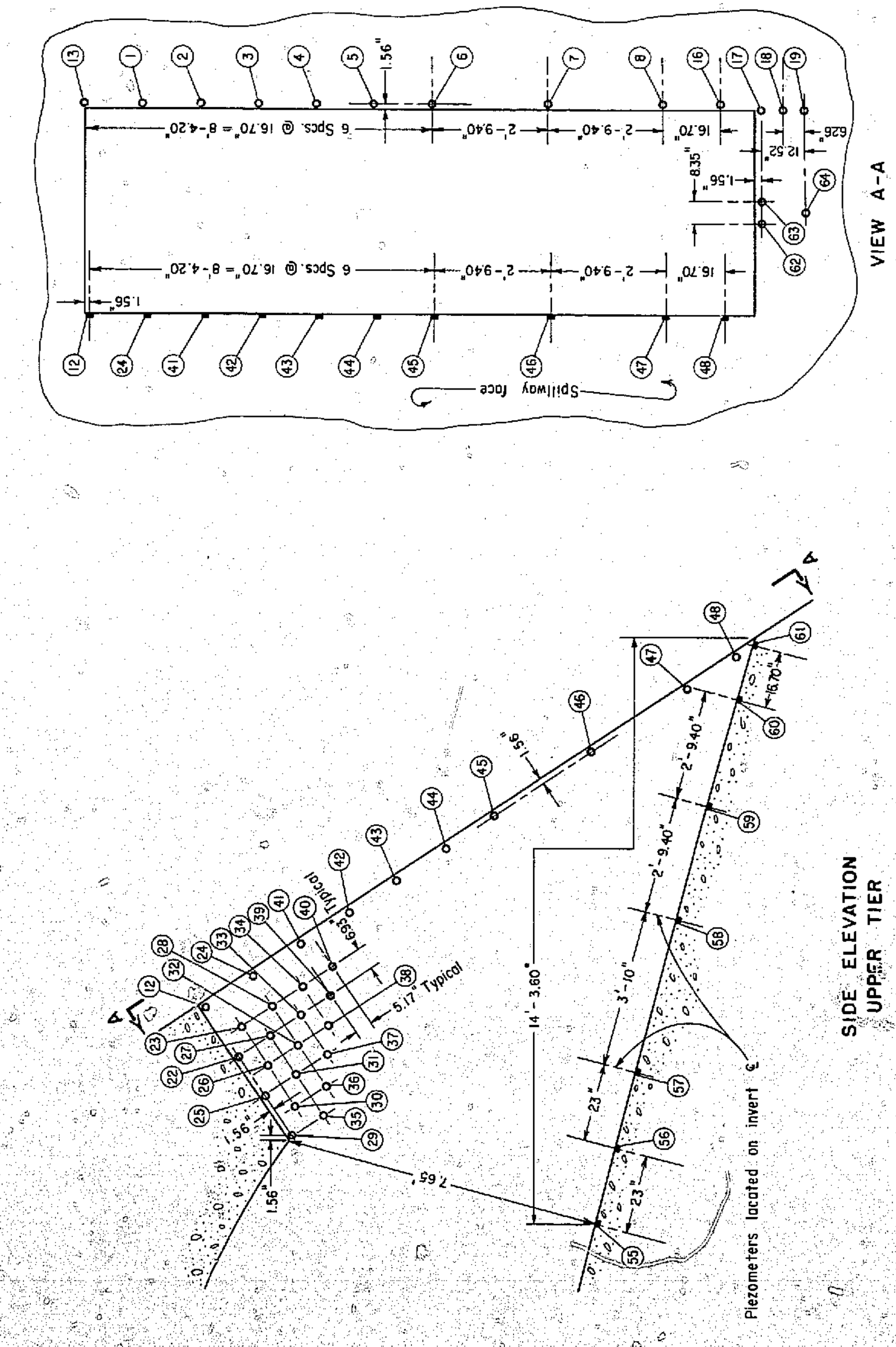
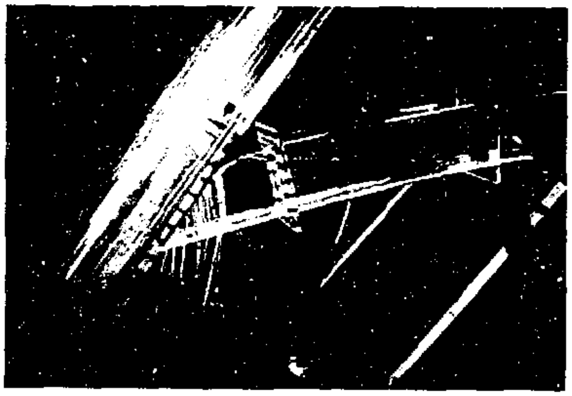
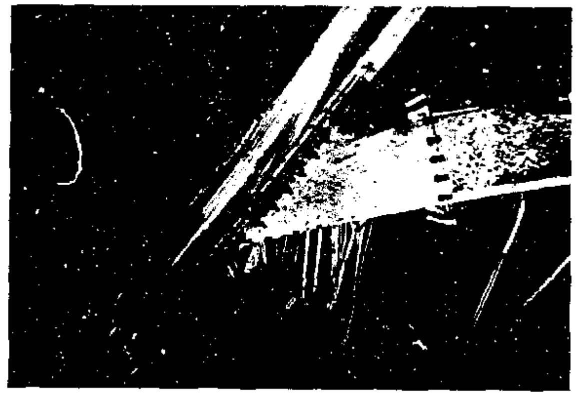


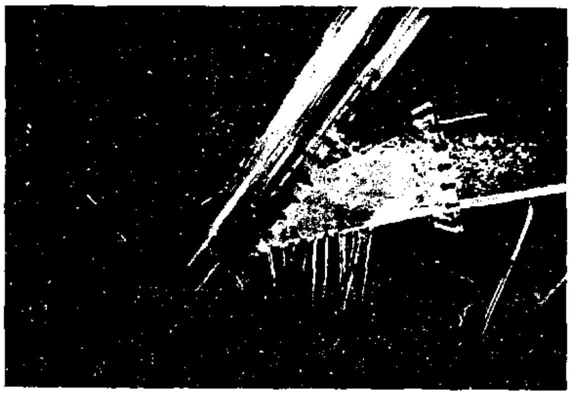
Figure 6. Piezometer Locations—1:16.7 Model.



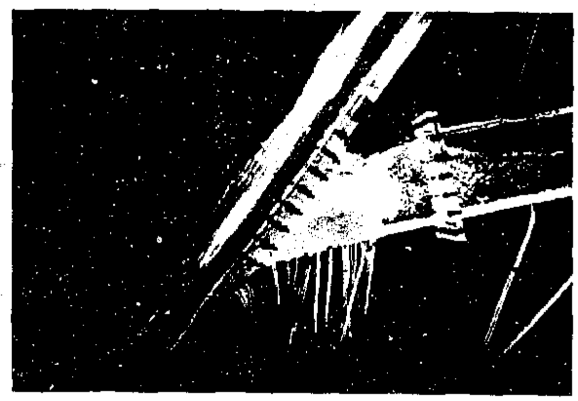
A. Water surface in outlet above constriction in crown. Note spillway jet parallel to spillway face. Photo P485-D-68563



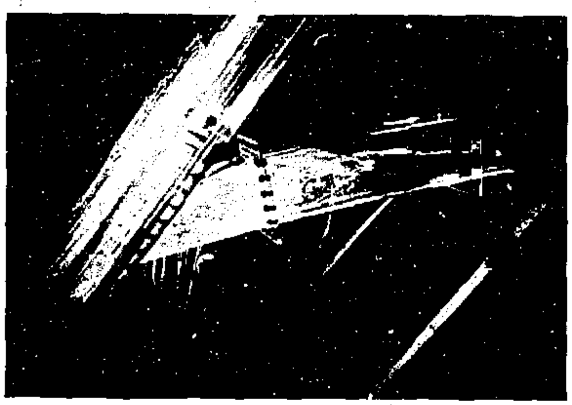
B. Low pressure occurs downstream of constriction and deflects the jet inward causing circulation. Photo P485-D-68565



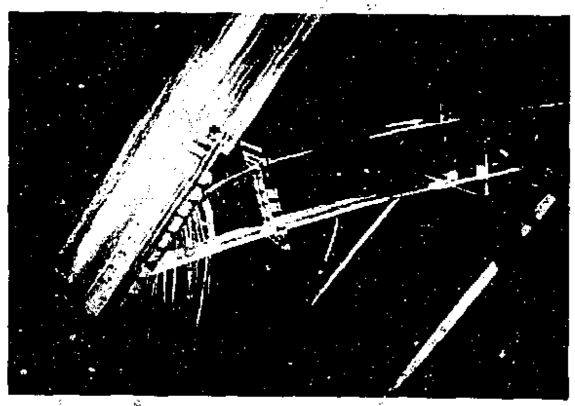
C. Air pocket downstream of crown constriction. Photo P485-D-68566



D. Intense circulation continues with air and water mixture. Photo P485-D-68567



E. Water level raising in outlet. Photo P485-D-68564



F. Water level prior to repeating cycle. Photo P485-D-68562

Figure 7. Surge in the outlet conduit (spillway flow only).

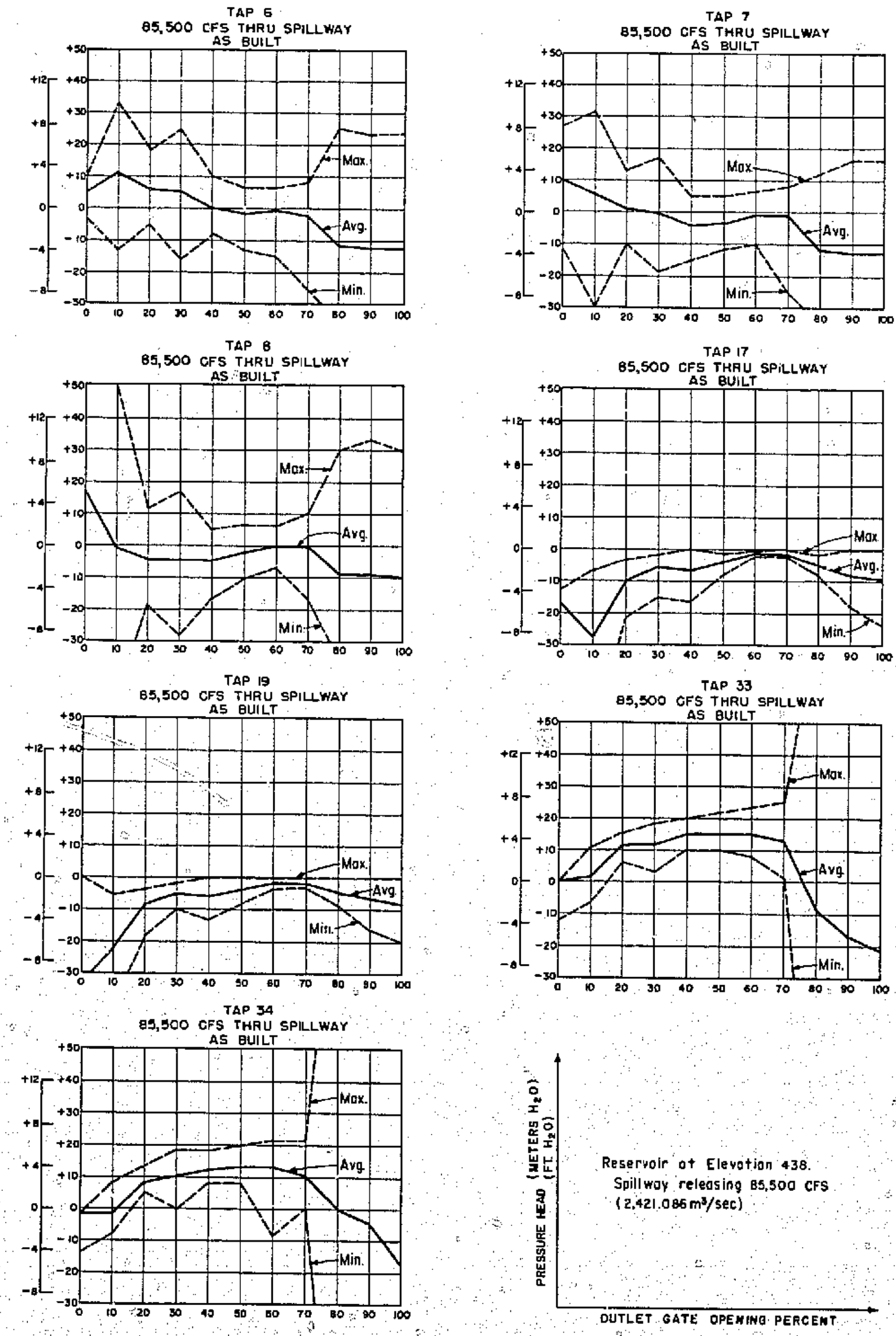


Figure 8. Dynamic Pressures Acting on As-Built Spillway-Outlet Junction—Data from 1:16.7 Model.

Simultaneous Operation for As-Built Structure

Spillway flow combined with releases from small outlet gate settings resulted in cavitation pressures on the spillway face below the outlet works-spillway junction. The pressures were raised as the outlet gate opening was increased to 60 percent. At this opening, a large amount of air from the outlet airheader system (Figure 9) was entrained in the flow (peak air demand occurred between 50 and 60 percent open). At 60 percent outlet gate opening, the pressures on the spillway face averaged near atmospheric, with minimum fluctuations to 10 feet (3.05 meters) of water subatmospheric. Increasing the outlet gate opening from 60 to 100 percent reduced the pressures on the spillway face to approximately 24 feet (7.32 meters) of water subatmospheric, while at the same time air demand was reduced to zero (no air demand above approximately 85 percent outlet gate opening), Figure 10.

On the outlet works conduit sidewall downstream from the constriction in the crown, pressures were lowest for large gate openings. Outlet works releases with 100 percent gate openings produced highly fluctuating pressures in the cavitation range on the sidewalls downstream of the constriction in the crown. Reducing the gate setting to 60 percent raised the minimum pressure from cavitation range to about 8 feet (2.5 meters) of water subatmospheric. The outlet gate opening could be reduced below 60 percent without lowering the pressures to the cavitation range on the sidewalls downstream of the constriction in the crown.

The curves in Figure 8 show the optimum outlet gate setting for simultaneous releases to be 60 percent open. Damage should be minimized or should not occur while making simultaneous releases from the structure before modifications are completed.

Outlet Works Operation

The outlet works functions properly when operated alone. No adverse pressures were encountered in the study for this type of operation. Past prototype experience also supports this conclusion.

MODIFICATIONS

Recommended Eyebrow

The modification recommended to correct the cause of cavitation damage resulted from a compromise between the best hydraulic design and the most practical structural design. The modification consisted of an eyebrow located on the spillway face above each outlet to impart a lift to the spillway flow and prevent the flow from striking the invert of the outlet conduit (Figure 11). The eyebrow began 10 feet (3.05 meters) upstream of the outlet and sloped outward from the spillway face 18 inches (0.46 meters) at the top of the outlet. The top surface of the eyebrow was 5 feet (1.52 meters) wide. The sides rejoined the spillway face on a 1:1 slope, varying in plan from 0 at the upstream end to 18 inches (0.46 meters) on the downstream end.

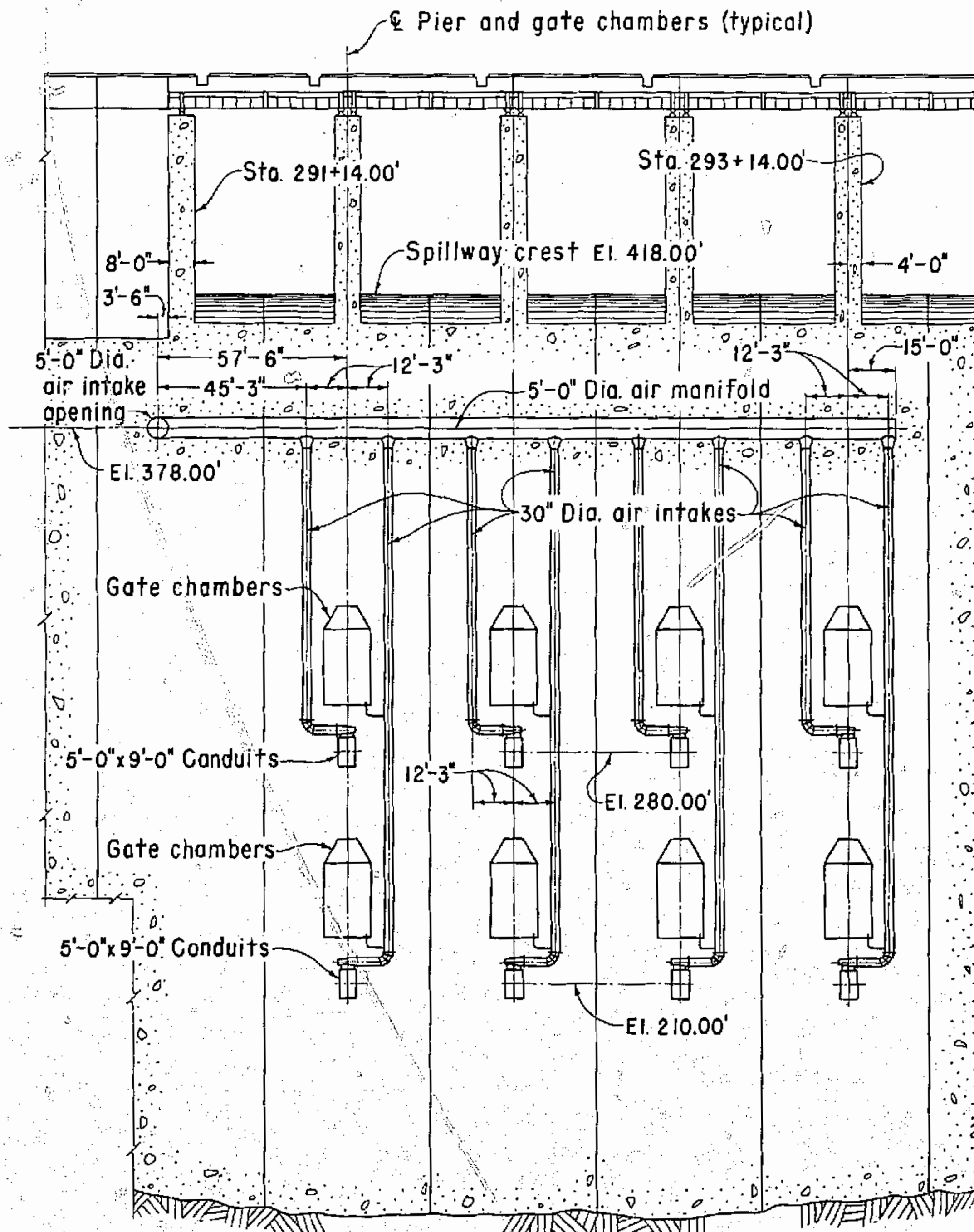
Spillway releases.—The eyebrow lifted the spillway flow over the outlet and the flow rejoined the spillway face well below the outlet works spillway junction. The outlet works air vent manifold system supplied air continuously to the underside of the spillway flow lifted by the eyebrow. No operating restrictions are necessary for spillway releases only.

Simultaneous spillway-outlet releases.—Simultaneous releases resulted in pressure conditions very similar to those of the unmodified structure (Figure 12). If simultaneous releases must be made, the outlet gates should be set at 40 to 70 percent open to take advantage of the maximum air entrainment. This mode of operation should be avoided if possible.

Eyebrow-flow Splitter Combination

An eyebrow with flow splitter attached proved to be the most positive solution to eliminate low pressures in the damaged areas. The flow splitter consisted of a pier attached to the top of the eyebrow which extended 7 feet above and perpendicular to the spillway face. The splitter provided positive aeration through the spillway jet to the flow junction. Thus, simultaneous releases could be made for any combination of spillway-outlet gate settings without inducing cavitation pressures on the flow surfaces.

The flow splitter was considered very difficult structurally to anchor to the spillway face. Also, after viewing photographs of the passage of the 1964 flood, it was felt that splitter piers placed over the lower outlets would be in danger of being torn out by debris tossed about in the basin. Therefore, even though the splitter functioned perfectly in the model, it was eliminated from the prototype modification.



SECTIONAL ELEVATION
THRU AIR SUPPLY SYSTEM

Figure 9. Outlet airheader system.

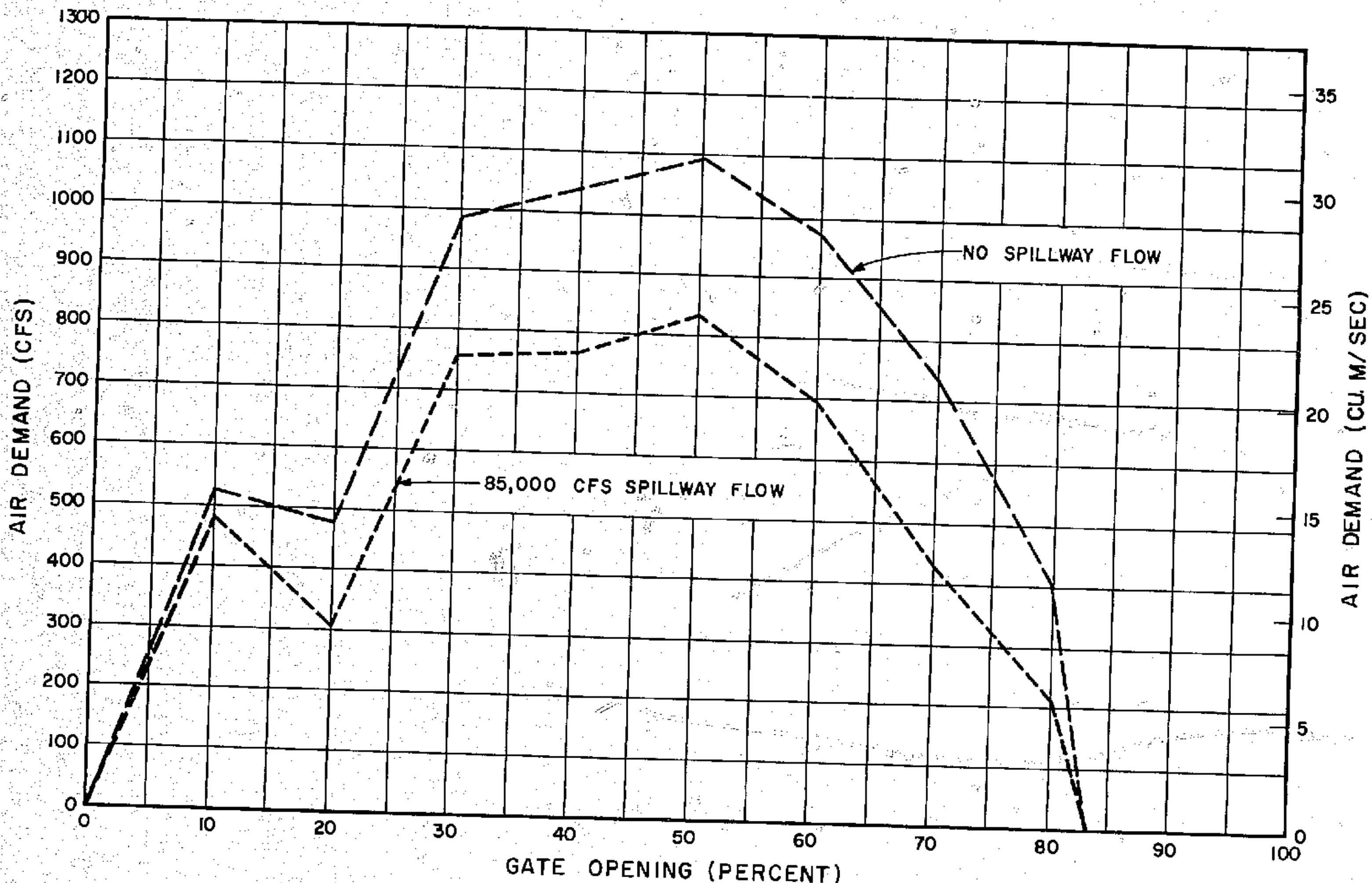


Figure 10. Model Air Demand—1:16.7 Model.

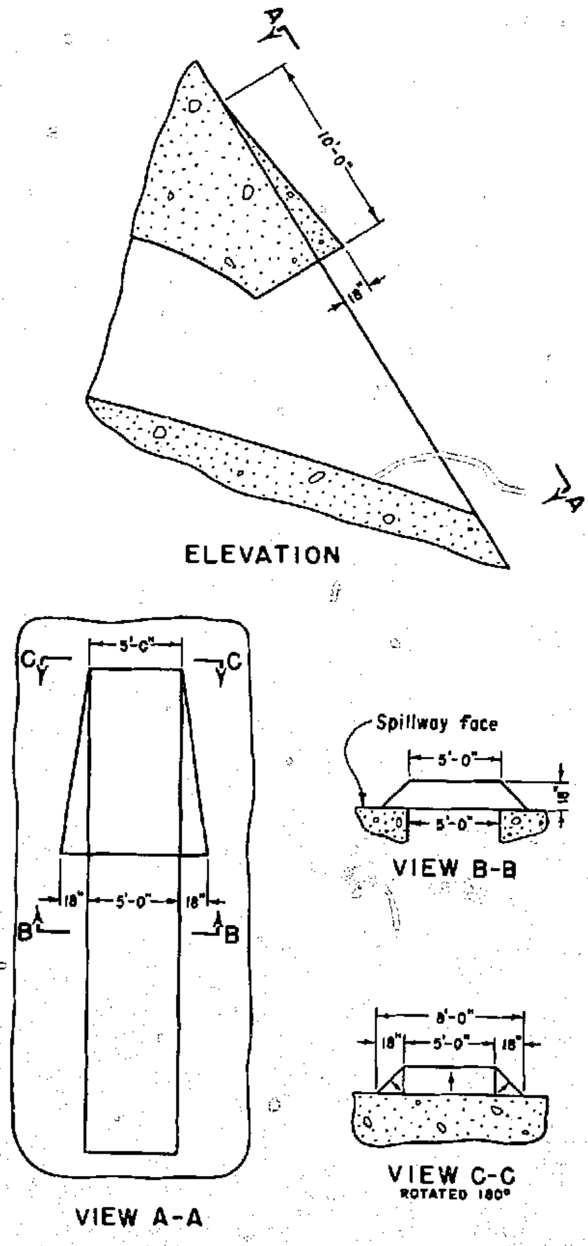


Figure 11. Recommended eyebrow.

CONCLUSIONS

1. Cavitation pressures existed in the model for spillway releases only, and for simultaneous spillway-outlet works releases (Figure 8).

2. A surge occurred in the inactive outlet conduit when spillway releases were made (Figure 7).

3. Spillway releases should be made with outlet gates 60 percent open to minimize damage to the structure prior to completion of repairs and modification.

4. An eyebrow (Figure 11) placed on the spillway face above the outlet opening deflected spillway flow away from the outlet works-spillway face junction. The eyebrow eliminated the surge, and prevented the development of low pressures on the spillway face.

5. An eyebrow-flow splitter combination provided positive aeration to the flow junction and eliminated any danger of cavitation for all operating conditions. The flow splitter was not included in the prototype modification because of structural problems in adequately anchoring it to the spillway face.

6. After installation of the eyebrows, simultaneous releases should be made with the outlet gates set at 40 to 70 percent open to take advantage of maximum air entrainment (Figures 10 and 12).

REFERENCES

1. Brown, F. R., "Cavitation in Hydraulic Structures: Problems Created by Cavitation Phenomena," *Proceedings* American Society of Civil Engineers, Vol. 89, January 1963.

2. Technical Report No. 2-673, "Spillway and Sluices, Red Rock Dam, Des Moines River, Iowa," U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, March 1965.

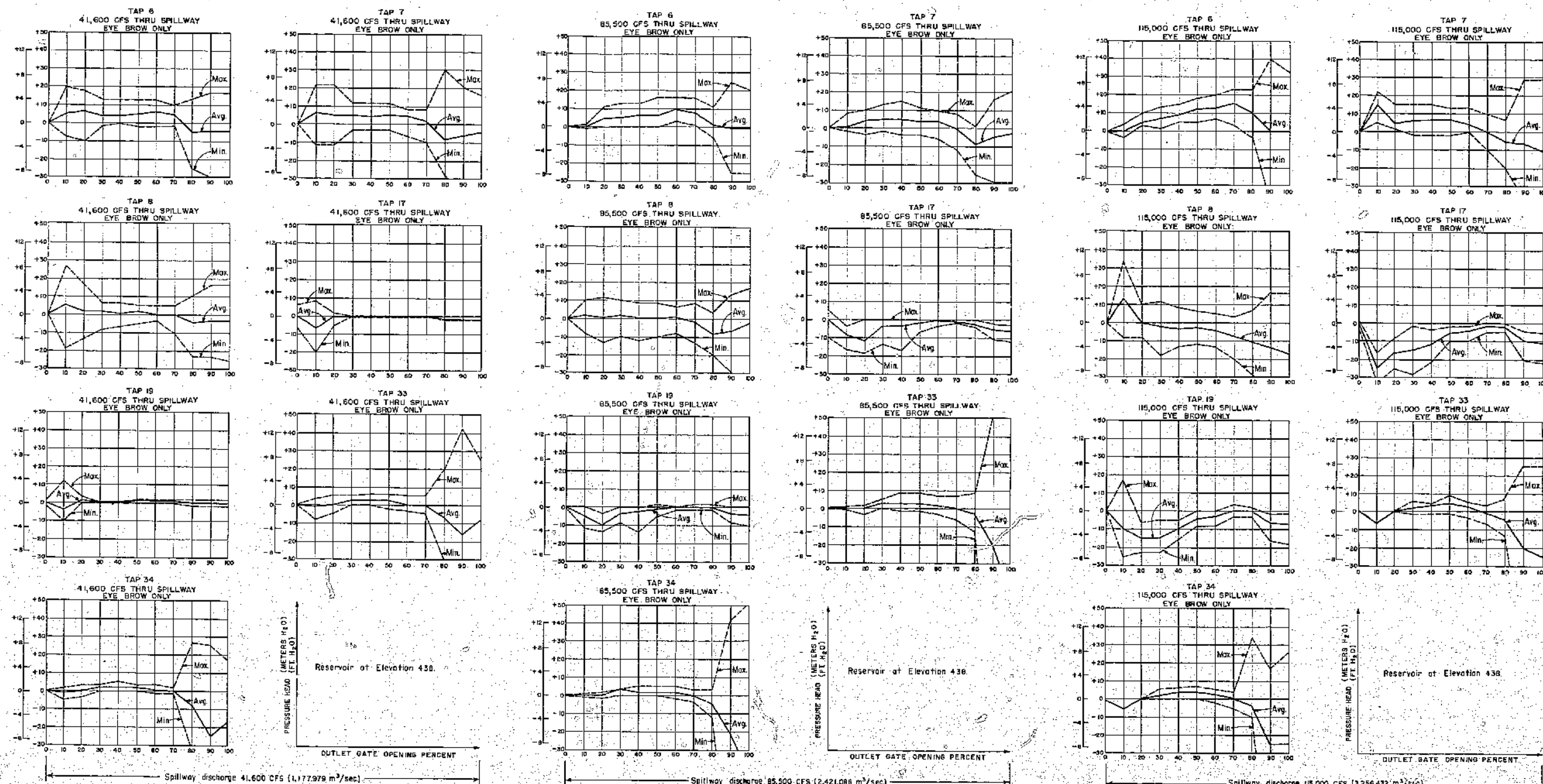


Figure 12. Dynamic Pressures Acting on Spillway-Outlet Junction with Eyebrow Only—Recommended Design—Data from 1:16.7 Model.

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	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
	1.12985×10^6	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)	0.092903*	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

ABSTRACT

Model studies performed to investigate damage to the area surrounding the Folsom Dam outlet works-spillway junctions and to aid development of corrective modifications are described. Model data indicated that when spillway releases are made prior to repair and modification of the damaged areas, outlet releases should be made with 60% gate openings. For spillway releases only, an eyebrow placed on the spillway face above the outlet opening deflected spillway flow away from the outlet works-spillway face junction, eliminated surge in the outlet, and prevented development of low pressures on the spillway face. A flow splitter-eyebrow combination completely eliminated all damaging pressures in the flow junction area for all operating conditions, but was considered extremely difficult structurally to anchor to the spillway face, and was abandoned. Use of the eyebrow without the splitter is recommended. If simultaneous releases are necessary, the outlet gate openings should be limited to 40 to 70% to provide for maximum air demand from the outlet air header system.

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DESCRIPTORS—/ *spillways/ *outlet works/ *hydraulic models/ hydraulics/ *air demand/ *model tests/ piezometers/ *cavitation/ damages/ junctions/ negative pressure/ low pressures/ vapor pressure/ jets/ aeration/ model studies/ surges/ fluid mechanics/ hydraulic structures/ pressure
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