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HYDRAULIC MODEL STUDIES OF THE TETON CANAL OUTLET WORKS ENERGY DISSIPATOR

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16. ABSTRACT

Studies were made on a 1:5.66 scale model of a single jet-flow gate and sudden expansion energy dissipator to determine discharge coefficients for full and partial gate openings, head losses through the facility, cavitation characteristics, and the back-pressure requirements for the submerged jet-flow gate. The two-diameter expansion was inadequate and was replaced by a three-diameter section. A method of cavitation scaling is discussed whereby visible and/or aurally detectable model incipient cavitation is used to determine incipient cavitation lines for a series of single gate openings and a range of discharges from no-flow through that obtained at maximum head. Using the slope of the model line and the scale vapor pressure, the prototype incipient cavitation line was obtained. A white-pigmented concrete curing compound was found to be satisfactory for use as a cavitation indicator. (8 ref)

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HYDRAULIC MODEL STUDIES OF THE TETON CANAL OUTLET WORKS ENERGY DISSIPATOR

by

T. J. Isbester

October 1974

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

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

ACKNOWLEDGMENT

The study was accomplished through a cooperative effort of the Hydraulic Structures and Mechanical Branches of the Division of Design, and the Hydraulics Branch of the Division of General Research. The studies were performed under the general supervision of D. L. King, Head, Applied Hydraulics Section, under the overall direction of W. E. Wagner, former Chief, Hydraulics Branch (retired). Special thanks to D. Colgate for his ideas on problems associated with scaling of cavitation. Photography was by W. M. Batts of the General Services Branch, Division of Management Support.

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PURPOSE

The model study was necessary to evaluate the control gate-energy dissipator combination proposed for the canal outlet works at Teton Dam. Head losses, discharge coefficients, cavitation characteristics, and backpressure requirements were needed from the model study.

CONCLUSIONS

1. A two-diameter expansion located downstream from the jet-flow gate was not large enough to eliminate the possibility of damage from cavitation occurring on the expansion walls.

2. A three-diameter expansion greatly reduced the model cavitation index and will eliminate the possibility of damage to the expansion section for the canal outlet works operating conditions.

3. The model gate cavitation characteristics are the most severe at a 75-percent gate opening with either the two-diameter or three-diameter sudden expansion.

4. Head losses for the structure equipped with the three-diameter expansion are acceptable and will provide the required capacity of 110 ft^3/s (3.115 m^3/s) per gate.

5. Canal outlet works back pressure should be adequate to prevent damaging cavitation at all releases. Incipient cavitation, however, will occur at some combinations of releases and gate openings.

6. No cavitation pressures were measured at the piezometer locations in the model for a maximum single-gate release of 110 ft^3/s or at a maximum reservoir head of 310 feet (94.5 meters) for the smaller gate openings.

7. Although the model was not equipped to measure hydraulic downpull, operating the lifting stem revealed that downpull is a sizable quantity and appears to reach a maximum at openings between 45 and 55 percent.

8. A white-pigmented concrete curing compound, used during the tests, provides good results as a cavitation damage indicator.

APPLICATIONS

This report contains information pertaining to use of a control gate and sudden expansion energy dissipator under submerged conditions. Discharge coefficients, incipient cavitation curves, head loss values, and cavitation scaling problems are contained in the report, and should be useful in designing future facilities. Also, a material which may be used as a cavitation damage indicator was obtained and tested in the laboratory.

INTRODUCTION

Teton Dam will be located on the Teton River in southeastern Idaho. The canal outlet works will draw water from a branch pipe attached to the 9-foot-diameter river outlet works pipe as shown on figure 1. By branching from the river outlet works, the requirement for a separate canal headworks structure is eliminated, resulting in a large cost savings.

Canal outlet works flow will be regulated by two side-by-side 20-inch (50.80-centimeter) jet-flow gates which discharge into sudden expansion energy dissipators. The expanded sections will be attached to a common well where the flow will be directed into a single 72-inch-diameter (183-centimeter) pipeline. The system will provide a maximum discharge of 220 ft^3/s (6.23 m^3/s) or 110 ft^3/s per gate while operating at a back pressure of about 108 feet (32.92 meters) of water.

The jet-flow gate developed by the Bureau of Reclamation was intended for releases made to atmospheric (free discharge) or very nearly atmospheric pressure (highly aerated downstream pipe). The use of a jet-flow gate discharging to an unaerated closed pipe is unusual. Only a slight deviation in the concentricity of releases to an expanded section can increase the cavitation potential considerably [1].* This is supported by the increase in the cavitation index measured when going from a gate opening of 100 percent to an opening of 90 percent with the jet-flow gate, as described later in this report. From a flow standpoint, the most appropriate control for concentric releases would be a valve where all partial openings also produce a concentric release. A needle valve seems best suited to this end; however, the cost is considerably greater than for a jet-flow gate. Some of the major advantages in the use of the jet-flow gate for free discharge are eliminated when the gate is operated submerged. Hydraulic

*Numbers in brackets designate references listed at the end of this report.

downpull, nonexistent with free flow, becomes a sizable quantity. Also, flow into the gate slots becomes a problem with submergence. Downpull and flow into the gate slot are common problems encountered with conventional slide gates operating under similar submerged conditions. The gate slot of the jet-flow gate, which is considerably wider than the slot in present-day high-pressure slide gates, could be a source of low pressure and possible cavitation damage if high back pressure were not maintained. A subsequent design [2], which was in part due to findings from this study, utilizes a very narrow slot far removed from the orifice flow area, and should provide excellent circulation to the jet and provide a minimum potential for cavitation damage.

THE MODEL

The structure was modeled on a scale of 1:5.66 to conform to the orifice size of an existing model gate shown in figure 2. The model components upstream of the gate were made of metal for strength as observation of flow in this area was unnecessary. Downstream components, including the initial two-diameter expansion section, subsequent three-diameter expansion, and rectangular well, were made of transparent acrylic plastic. A 10-inch (25.4-centimeter) gate valve was placed downstream of the well to adjust back pressure and an elbow downstream of the valve was turned vertically upward to maintain the pipe full at all times. Flow was supplied to the model from permanent laboratory pumps through calibrated 4-, 6-, and 8-inch (10.16-, 15.24-, and 20.32-centimeter) venturi meters.

THE INVESTIGATION

The initial phase of the investigation was to determine whether the gate size was adequate to pass the required flow; therefore, head losses only for the fully opened gate were investigated. See head loss curves shown on figure 3. Later, while checking partial gate openings, mild cavitation was observed at several gate settings. With cavitation occurring in the model, prototype cavitation could be expected to be more severe. This expectation is based on past experience of other observers, and on the fact that in scaling by Froude relationships, atmospheric pressure and vapor pressure are not scaled. Only one instance can be recalled in which cavitation appeared to be greater in a scaled model than in the prototype which it represented. Mention of this is found in reference [1], page 1633, where it states that cavitation formed at an index of less than about 0.7 in the prototype, compared to 1.5 in the model.

A series of tests was performed to define the cavitation characteristics of the model gate with the two-diameter expansion attached downstream. A hydrophone and a sound level meter were initially used in an attempt to detect the presence of cavitation in the model. Construction work adjacent to the model produced an extremely high level of background noise and made the electronic equipment readings unreliable. As the tests were performed in a clear plastic pipe, visual and aural observations were finally used as the method to determine when cavitation is just beginning (i.e., incipient cavitation). For these tests, incipient cavitation was arbitrarily defined as that magnitude which:

1. Produced a crackling sound which could just be heard when the ear was placed on the wall of the expanded pipe near the gate. The sound had to be present between 50 and 75 percent of the time.

2. Produced a faintly visible vortex emanating from the gate-orifice intersection. The vortex had to be visible between 50 and 75 percent of the time. Intensity with a fully opened gate was based on sound alone, as the origin of the vortex varied, making its presence difficult to detect.

If on a particular run the cavitation intensity was too low, a reduction in back pressure was made. Conversely, if the intensity was too high, an increase in back pressure was made. In both cases, slight adjustments in discharge were required so as to maintain a constant total upstream head for all gate openings.

To better define the cavitation characteristics of the gate, an index K was used as defined by Ball [3]:

$$K = \frac{h_2 - h_v}{h_t - h_2}$$

where: h_2 = pressure head downstream of the gate in an area where flow is uniform,

h_v = vapor pressure head of water relative to atmospheric pressure (i.e., approximately 27 feet (8.23 meters) of water below atmospheric at approximately 5280 feet of elevation).

h_t = upstream total head (pressure head plus velocity head in the pipe upstream of the jet-flow gate).

The heads h_t and h_2 were obtained while operating the model at the conditions defined as incipient cavitation for a range of gate openings. A peak cavitation index value of 4.2 at a gate opening of 75 percent was determined for the initial model configuration. The curve of model incipient cavitation versus gate opening is shown on figure 4.

An attempt to lower the index by increasing the back pressure was suggested by engineers of the Design Division. This was accomplished by the addition of an orifice at the downstream end of the two-diameter expansion. As flow conditions near the gate and upstream end of the expansion section were not affected and system capacity was decreased, this method was not pursued for the recommended design.

Within limits, a larger diameter expansion was expected to improve the circulation to the jet and reduce the cavitation potential.

A length of three-diameter expansion was installed downstream of the gate as shown in figure 5. To simplify the model modifications, only three diameters of length were included. After the system was tested for losses (figure 6), the cavitation index was investigated as before. A sizable improvement to the cavitation characteristics resulted from this modification, as can be seen by comparing the test results shown in figure 7 to those in figure 4. While possessing the same general shape, the peak index value was lowered from 4.2 to 2.7. As before, the peak value occurred at a 75-percent gate opening. This improvement was considered adequate for the Teton installation. Similar improvements resulting from the use of larger expansions to improve circulation are discussed by Tullis and Marschner [4]. Rouse [5] discusses the advantage of larger expansions on the index of incipient damage for a submerged jet. He states "From knowledge of the characteristics of submerged jets, one would expect the index for incipient damage - necessarily 0 at the expansion limit 1:∞ - to increase with increasing expansion ratio. The eddy zone of the submerged jet, in other words, expands linearly, and the intensity of the turbulence varies inversely, with distance from the efflux section; the length of the zone of eddy cavitation should therefore increase with decreasing cavitation index, as should the diameter of an expansion chamber barely subject to damage from the collapsing cavitation pockets."

With cavitation occurring in the model, the possibility exists that it may be more severe in the prototype. As scaling of cavitation from model to prototype (see reference [6], page 254, summary item 2) does not follow the Froude relationships, an attempt was made to establish some significant values through a series of graphs. The graphs were made for a range of gate openings which show the expected conditions for prototype incipient cavitation. Shown on figure 8 are graphs which cover gate openings from 100 percent to 25 percent in 5-percent increments. The graphs are all similar and are based on the assumption that incipient cavitation in the model is a valid starting point. Working with water and using Froude relationships, no similarity exists between model and prototype when operating below a model head which scales to prototype vapor pressure. However, no error is expected when merely increasing pressure from the observable (not measurable) point of model vapor pressure to a value in the model which corresponds to vapor pressure in the prototype.

Beginning with a discharge coefficient curve for partial openings (figure 9) and the incipient cavitation coefficient curve (figure 7), the graphs were developed in the following manner. Plotting total head upstream against total head downstream, a no-flow line was established on a 1:1 slope. Above and parallel to the no-flow line a series of lines of constant discharge was laid out. In addition, beginning at a vapor pressure head of minus 27 feet of water, a model incipient cavitation line was drawn which was determined from the back-pressure requirements to barely maintain incipient cavitation in the model. Based on tests in the model, which were limited by model structural strength, the incipient cavitation coefficient was found to be a constant for a fixed-gate opening. This is supported by reference [7], page 423, where pressure scale effects on orifices are discussed. By dividing vapor pressure head by the model scale ratio (-27/5.66), the prototype incipient cavitation point for no-flow was obtained (-4.77). Based on the fact that a pressure scale effect does not exist for orifices, the prototype cavitation characteristics were determined from figure 7. As an approximation to the prototype incipient cavitation characteristics, a line could be drawn parallel to the model incipient cavitation line, but displaced to the right and passing through vapor pressure condition in the prototype. The slope of the constant discharge lines to the left of the incipient line was not investigated to any great extent in the model; however, it was assumed that an extremely high degree of cavitation would be required before the discharge coefficient would be affected (choking).

While it was considered possible to extend the operation of the prototype beyond the point of incipient cavitation without incurring damage, the point at which damage would occur could not be determined from the model or the series of graphs. While other investigators feel that incipient cavitation is not a practical design limit [8], the only scalable cavitation condition was thought to be that of inception. With incipient conditions defined for a range of gate openings, releases may be made to avoid cavitation. For example, gate openings of 75 percent should be restricted to low-head operation only, as the cavitation index is a maximum for this setting. Full gate opening with its reduced index may be used to release the maximum discharge per gate (110 ft^3/s) without the occurrence of cavitation. Figure 10 relates the discharge for incipient cavitation for both single gate and double gate operation. The symmetry of the full gate opening makes it less conducive to cavitation than partial openings. With partial openings, a vortex emanates from the points of intersection of the straight horizontal gate bottom and circular orifice.

Some additional cavitation tests were performed at exaggerated heads and discharges to seek out areas of potential damage for the jet-flow gate. Initially, sections of the gate, gate slot, and downstream conduit expansion were spray painted with machinist's dye with the thought that the fairly mild cavitation would remove the dye where the cloud contacted the solid boundary. Model parts were first painted on a Friday, reassembled, allowed to cure over the weekend, and tested on Monday. No removal was observed during a 2-hour test at a gate opening of 75 percent and a single gate discharge of 208 ft^3/s (5.89 ft^3/s) (nearly double the maximum of 110 ft^3/s per gate). The long curing time allowed the machinist's dye to become highly resistive to cavitation erosion. Additional tests on the machinist's dye were performed in a cavitation test facility in the laboratory. A sample sprayed with the dye was allowed to cure for varying lengths of time before testing. Removal characteristics were found to vary greatly with curing time, making the dye very resistive to cavitation if cured for more than an hour before testing. As more than an hour was required to reassemble the model after coating, another material was sought which would have removal characteristics that were nearly independent of curing time and which was readily erodible, not water soluble, and was easy to apply. A white-pigmented concrete curing compound was found to meet these requirements. The compound felt waxy and could remain under water for long periods of time without changing its feel or appearance after an initial 1- to 2-hour air-drying period. The photographs in figure 11 show compound removal for 1-hour continuous cavitation tests with curing times of 4, 24, and 312 hours. Very little difference can be seen for the large variation in curing time. The compound has been used as a cavitation damage indicator on other valves with good success since its initial use.

The compound was applied to the gate and frame area and to the left half of the plastic three-diameter expansion. To increase the contrast, the compound was oversprayed with machinist's dye. The gate and piping were reassembled and an 8-hour (model) test was run the following day at a gate opening of 75 percent with a discharge of 207 ft^3/s (5.86 m^3/s). No erosion was observed in the three-diameter expansion; however, the sides of the parallel gate frame showed some pitting from the test (figure 12). The damage was heaviest along the downstream side of the parallel frame and almost nonexistent along the upstream corner. To improve circulation to the upstream corner of the frame, a divergence at a 45° angle away from the flow would minimize the potential for cavitation erosion. The vortex which caused the pitting of the downstream frame is shown in figure 13. The vortex intensity varies somewhat with time and was photographed at, or very near, peak intensity.

Piezometer taps were installed on the model gate in selected areas to detect adverse pressures (figure 14). Tap 1 was placed on the downstream side of the orifice at an elevation which corresponded to a 72-percent gate opening. Tap 2 was placed at the same elevation as tap 1 but on the upstream corner of the parallel frame downstream of the orifice. Taps 3 and 4 were placed on the upstream and downstream corners, respectively, of the parallel frame at an elevation corresponding to a 40-percent gate opening. Electronic transducers were used to record instantaneous pressures at various gate openings and discharges. Data were taken at upstream total head levels of about 260 feet (79.25 meters) and 120 feet (36.58 meters) while incipient cavitation was occurring in the model. (Refer to figure 8 to define discharge and back pressure for the particular gate opening). Traces of these pressures are shown in figure 15. Note that only at a 100-percent gate opening and low back pressure were low pressures observed on the oscillograph, and that at no time were model cavitation pressures recorded. This indicates a slight separation of the vortex from the gate frame boundary. Additional pressures were recorded at gate openings of 100, 75, 60, 50, and 30 percent while operating at maximum discharge of 110 ft^3/s or maximum head. Sections of these oscillographs are shown in figure 16. Note the existence of positive pressures for all tests.

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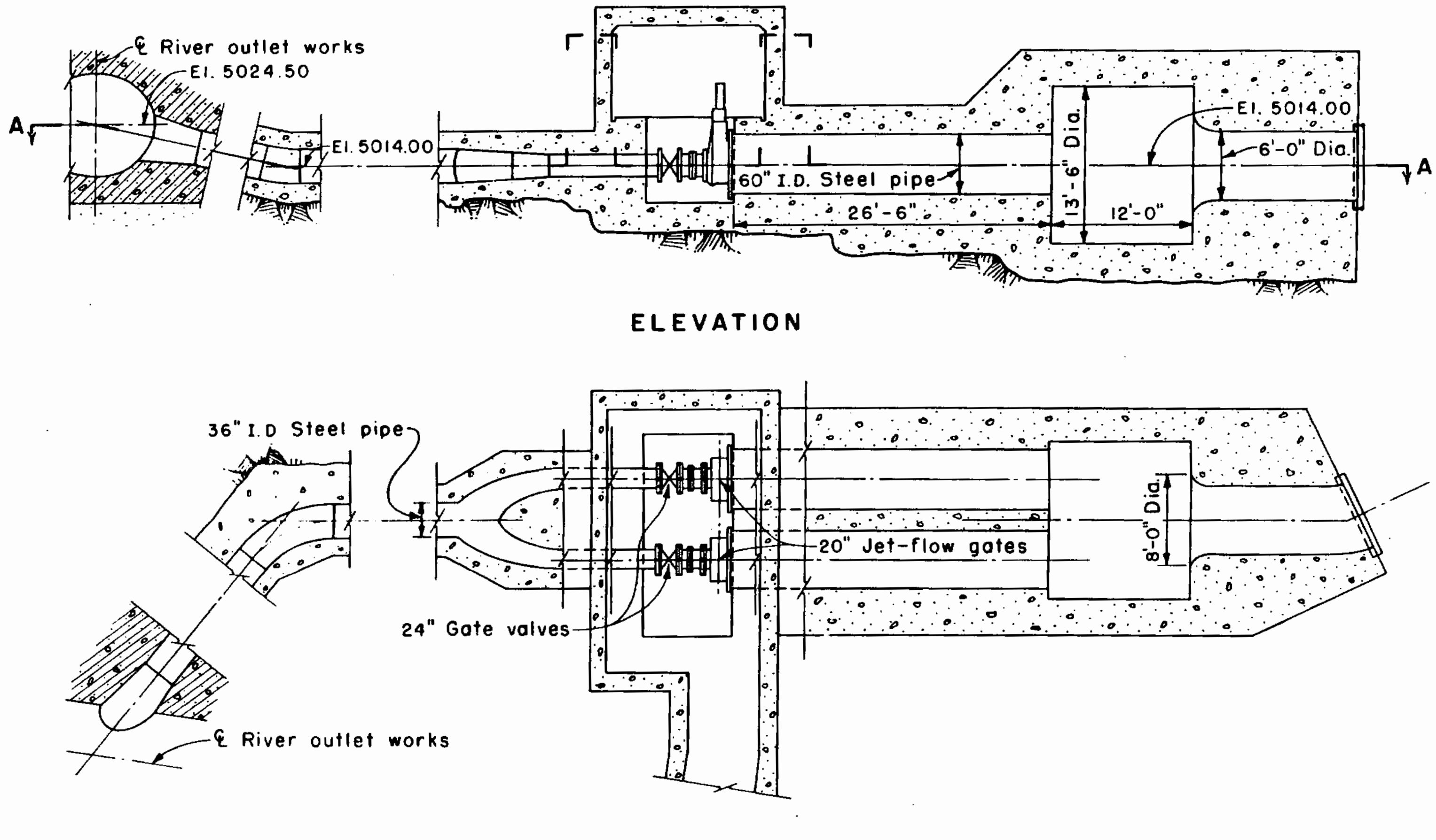


Figure 1.—Canal outlet works jet-flow gate—sudden expansion energy dissipator.

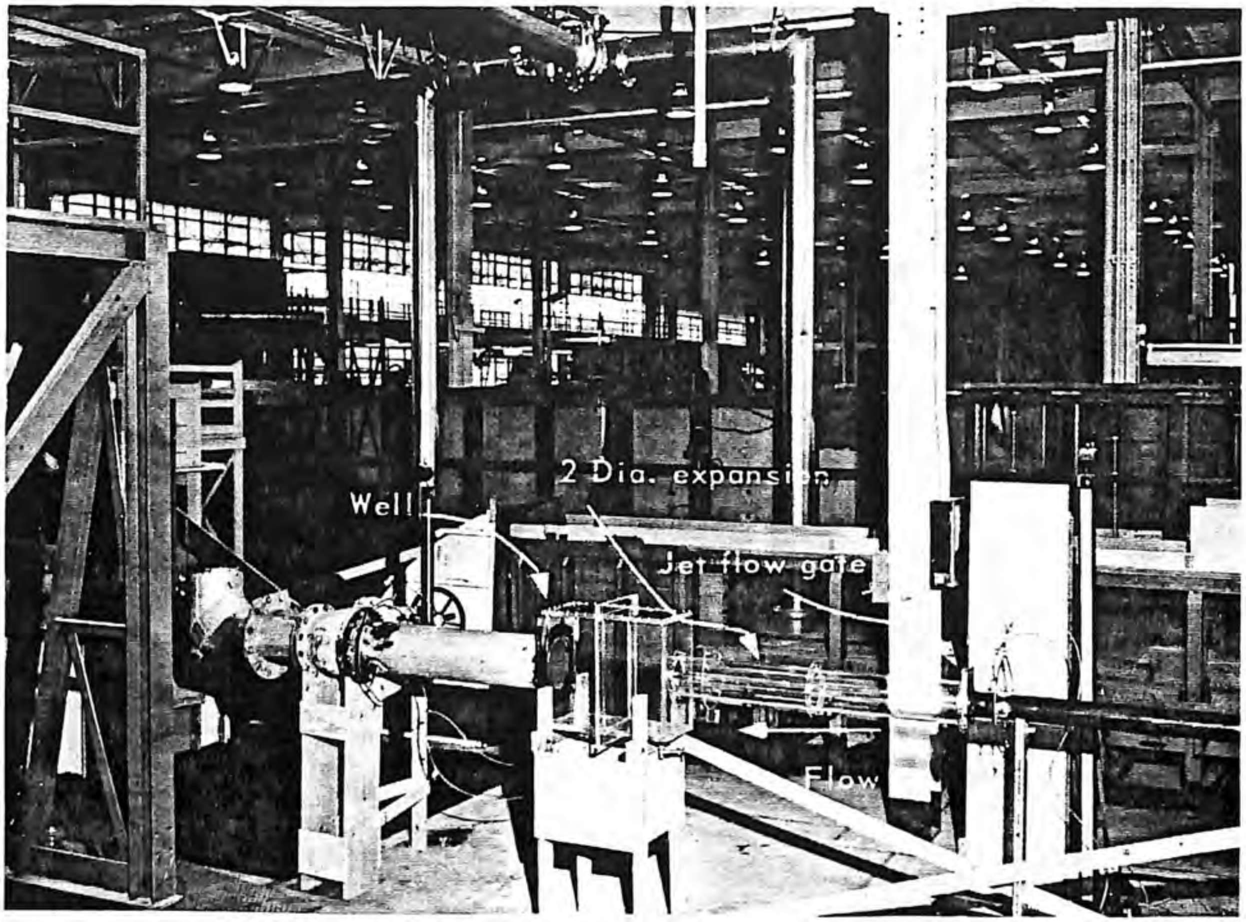


Figure 2.—1:5.66 model equipped with two-diameter expansion. P801-D-74766

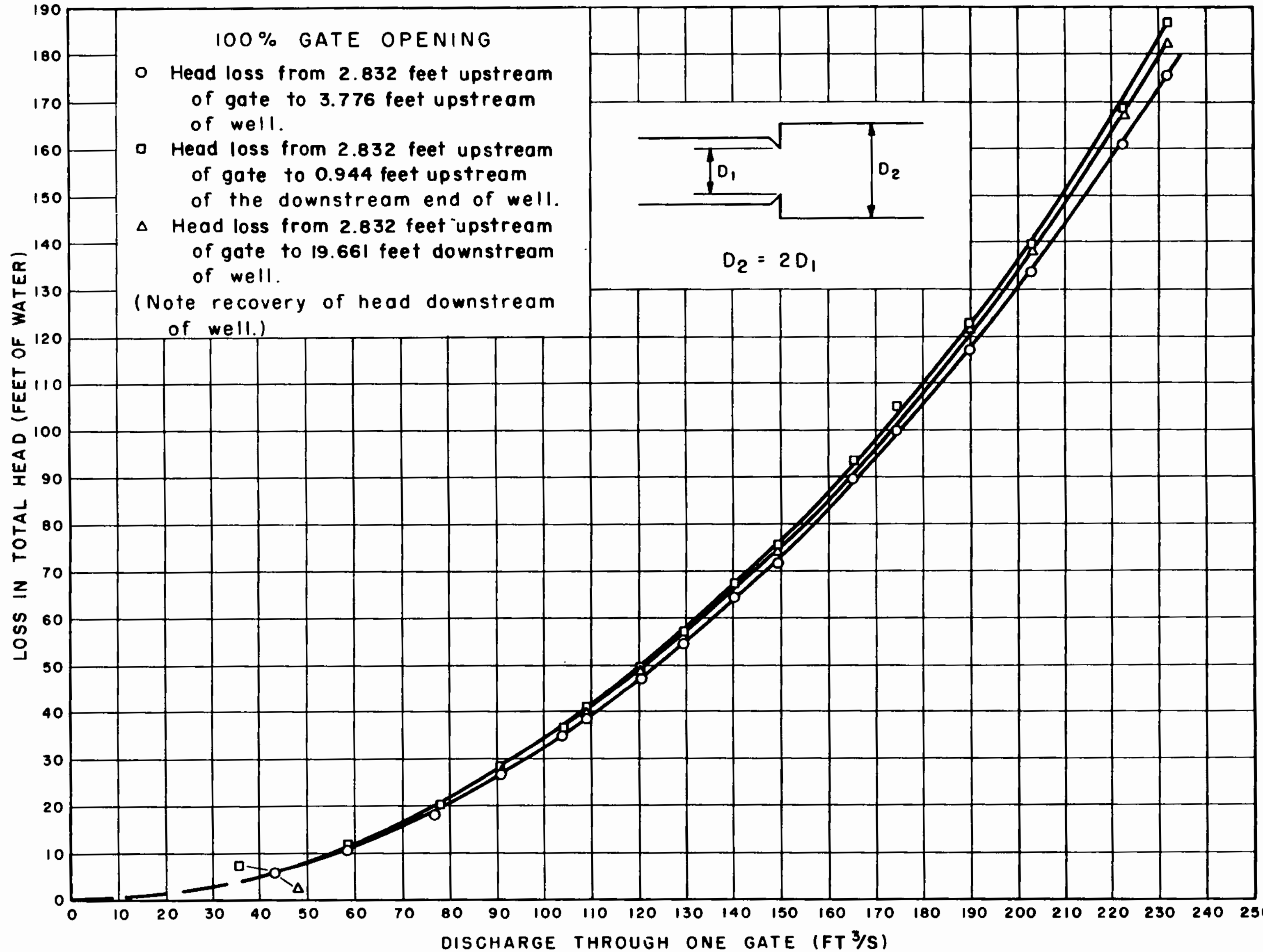


Figure 3.—Head losses for two-diameter expansion (100-percent gate opening).

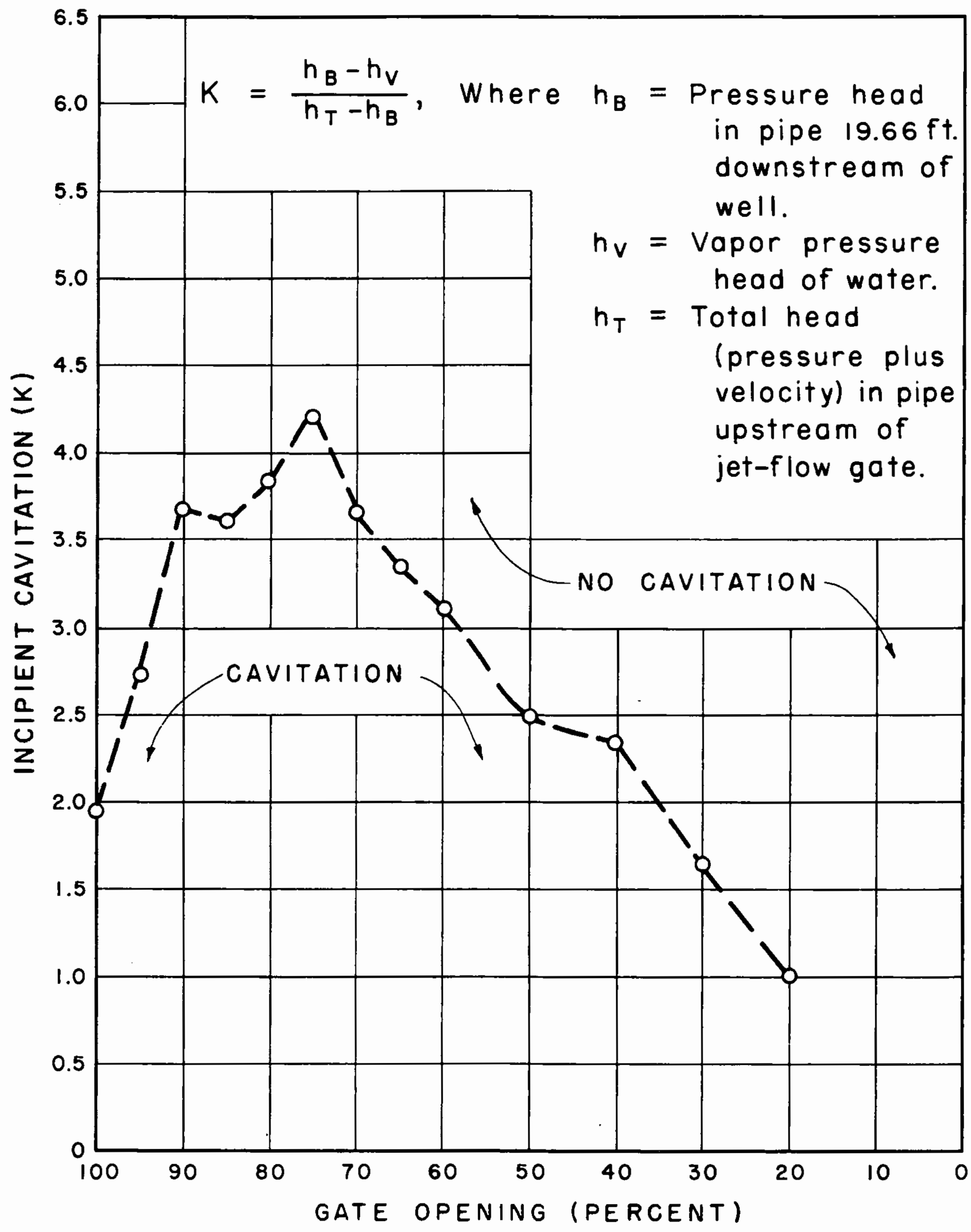


Figure 4.—Model incipient cavitation curve (two-diameter expansion).

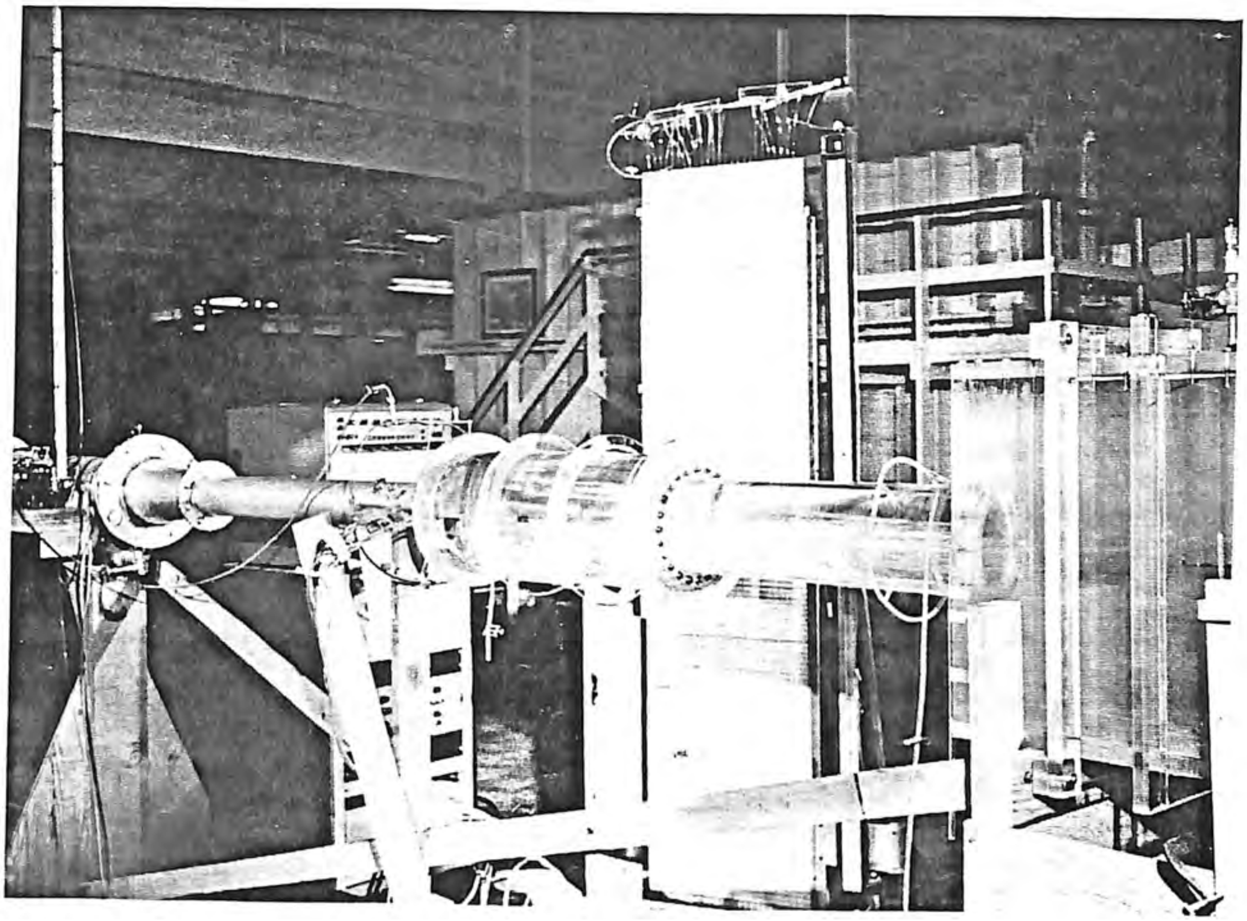


Figure 5.—Model equipped with a three-diameter length of three-diameter expansion. P801-D-74768

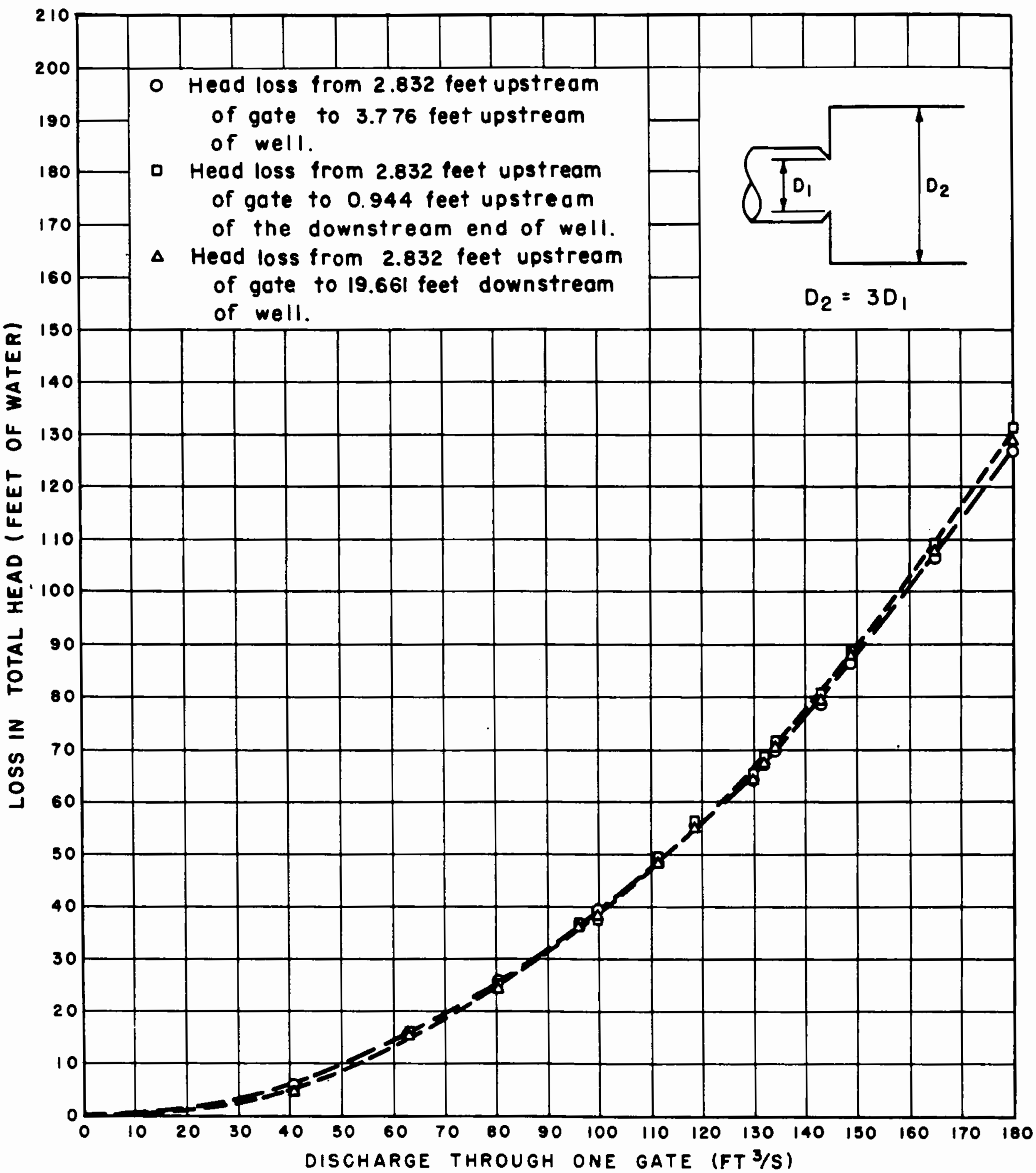


Figure 6.—Head losses with three-diameter expansion.

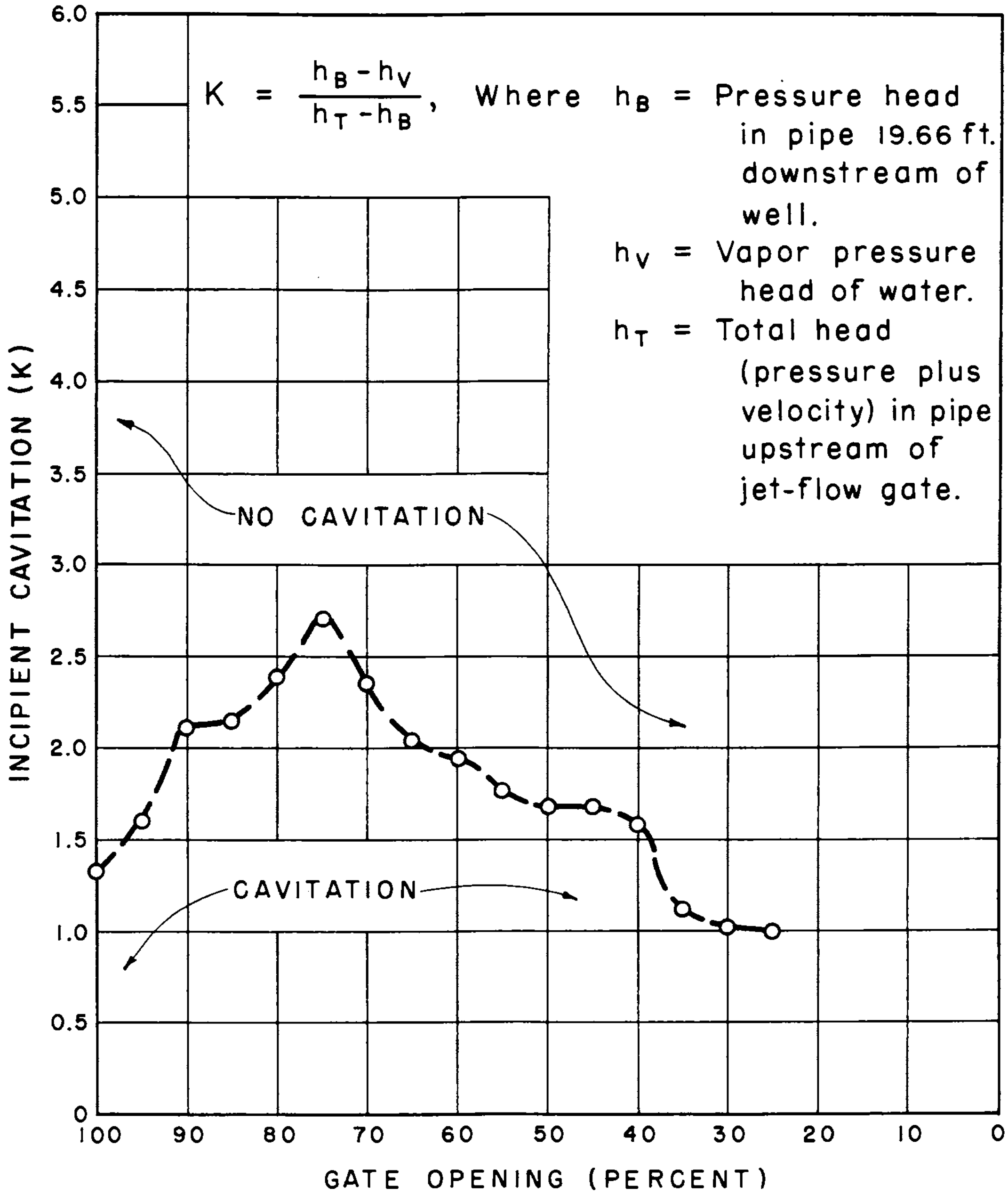


Figure 7.—Model incipient cavitation curve (three-diameter expansion).

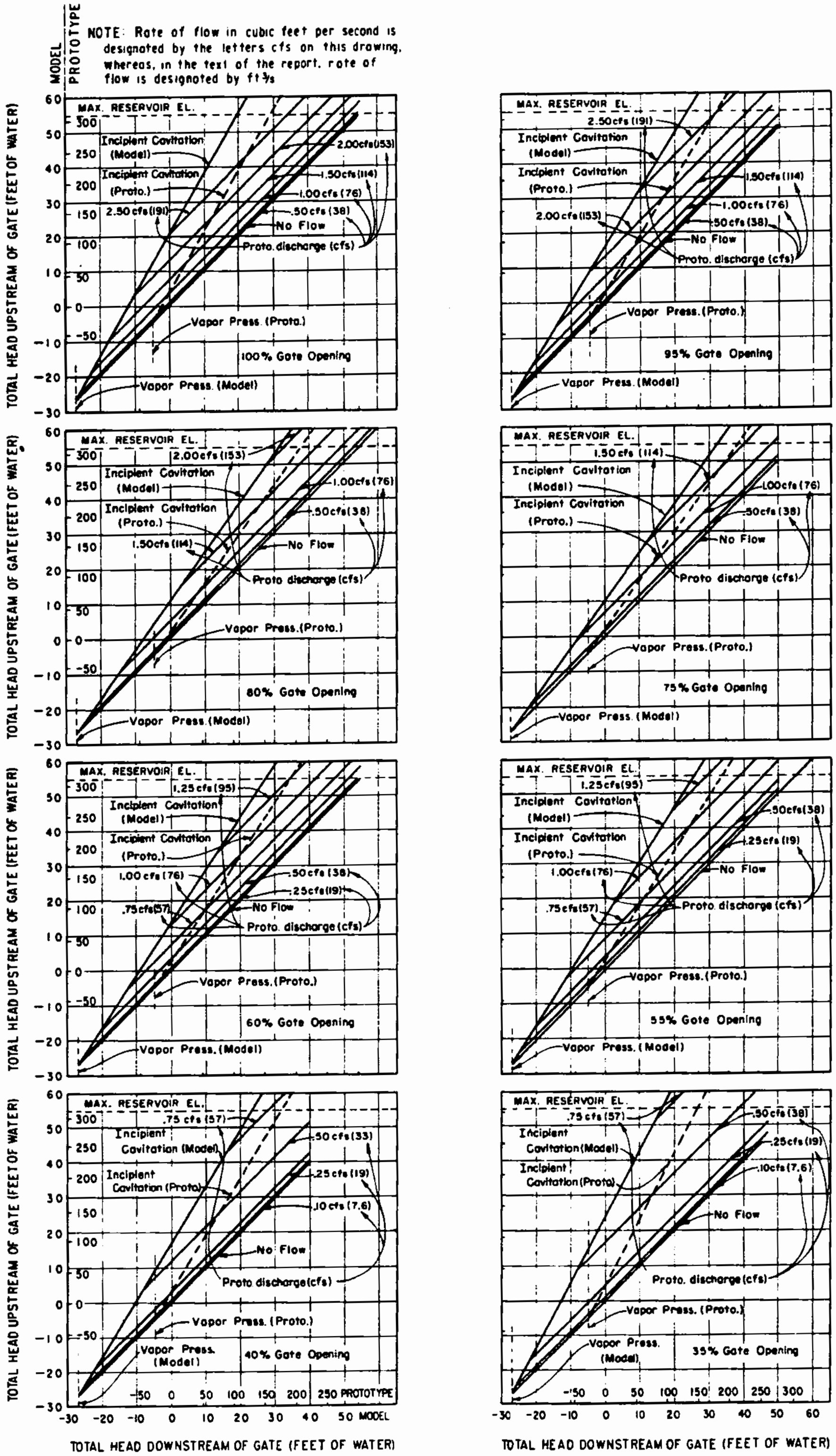


Figure 8.—Proposed scaling curves.

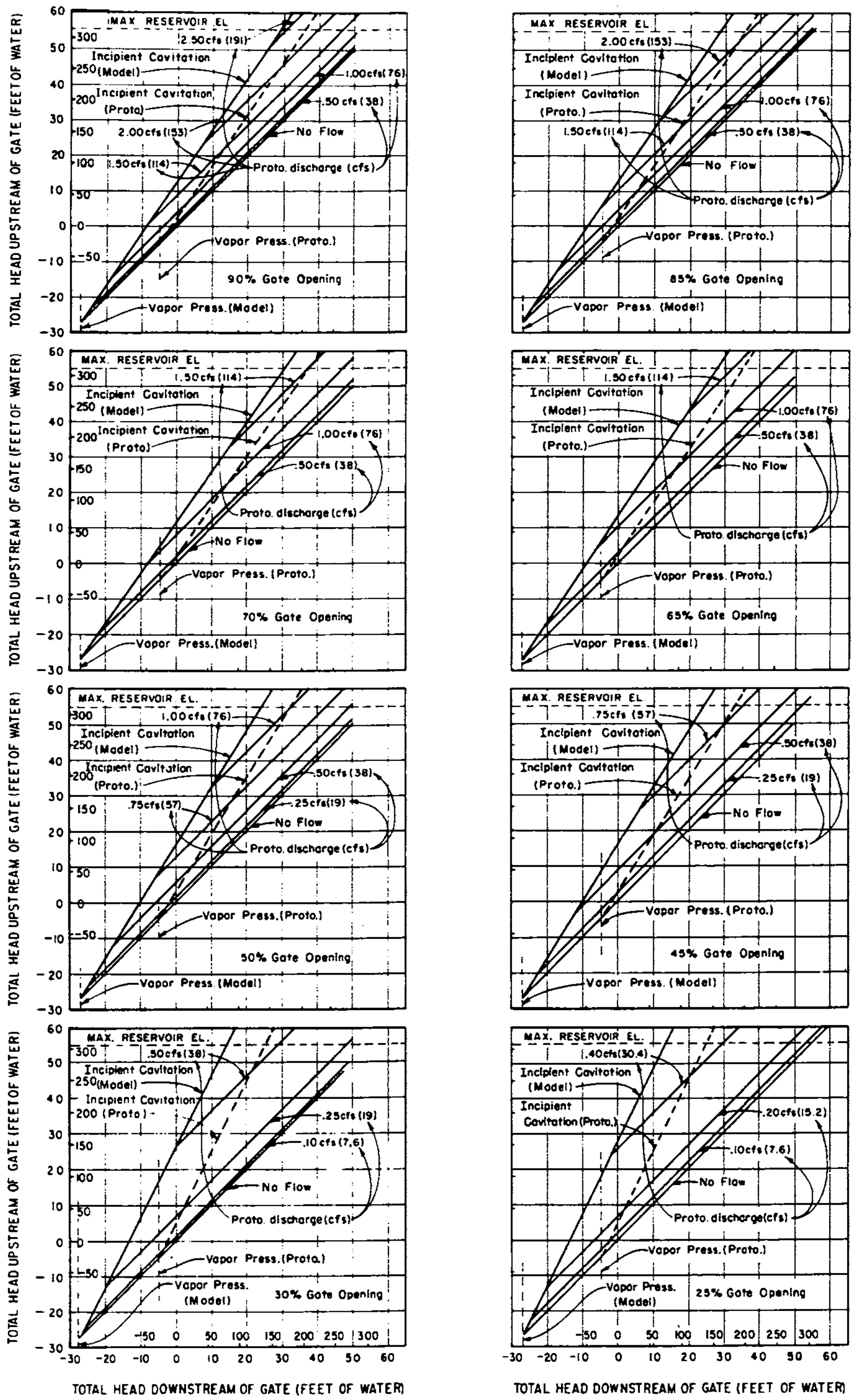


Figure 8.—Continued.

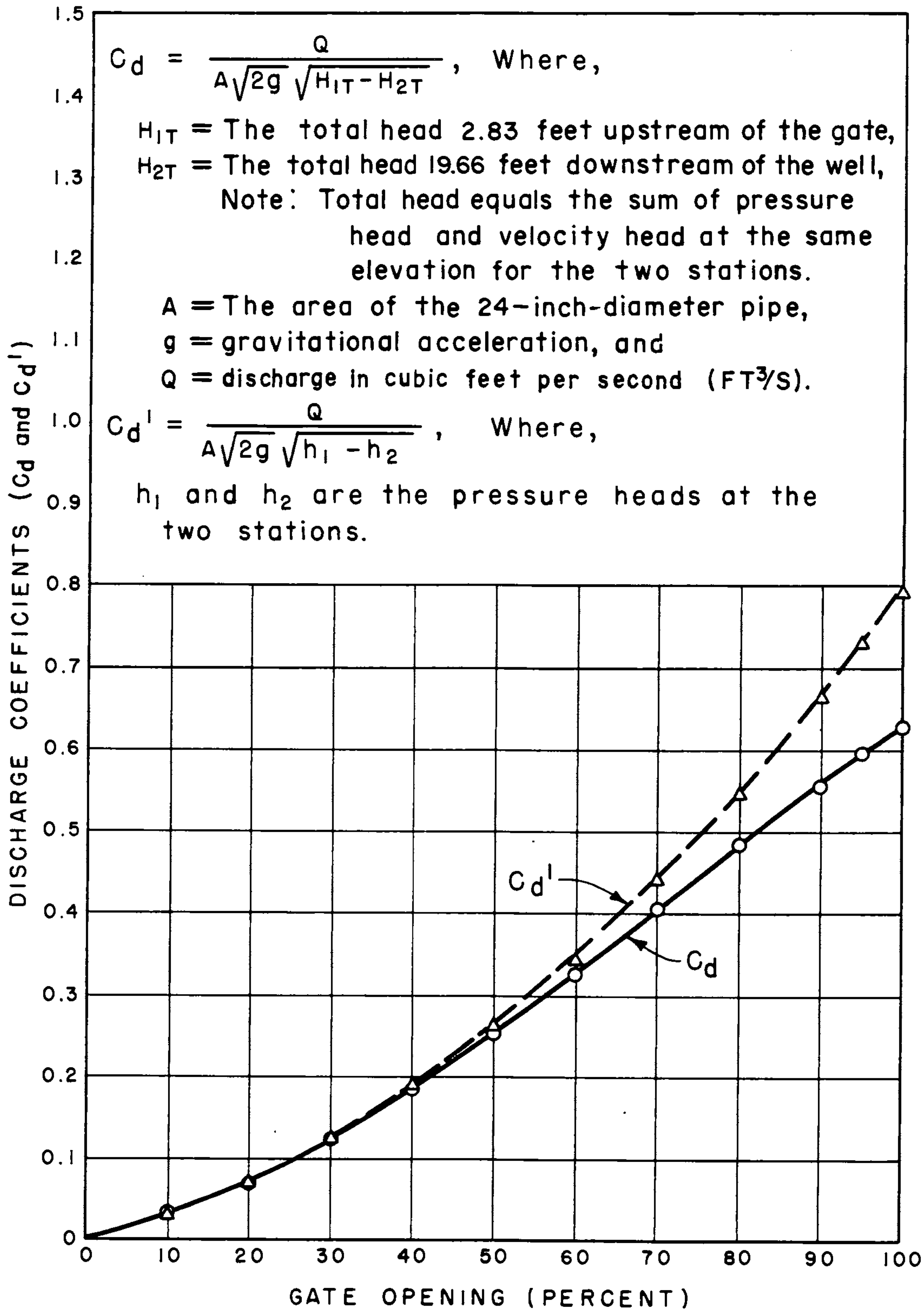


Figure 9.—Discharge coefficient curves for gate with three-diameter expansion.

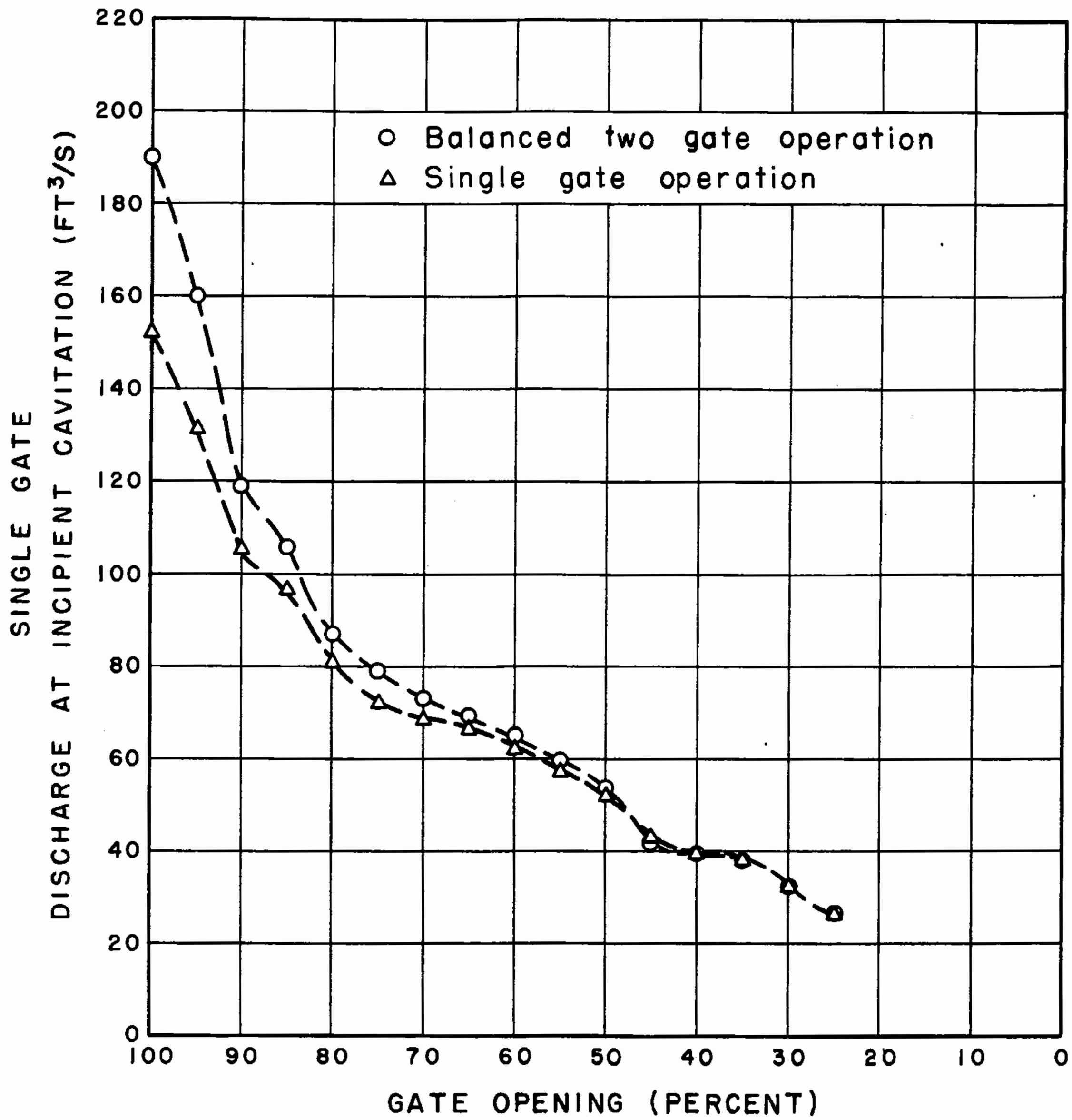


Figure 10.—Discharge versus gate opening for incipient cavitation.

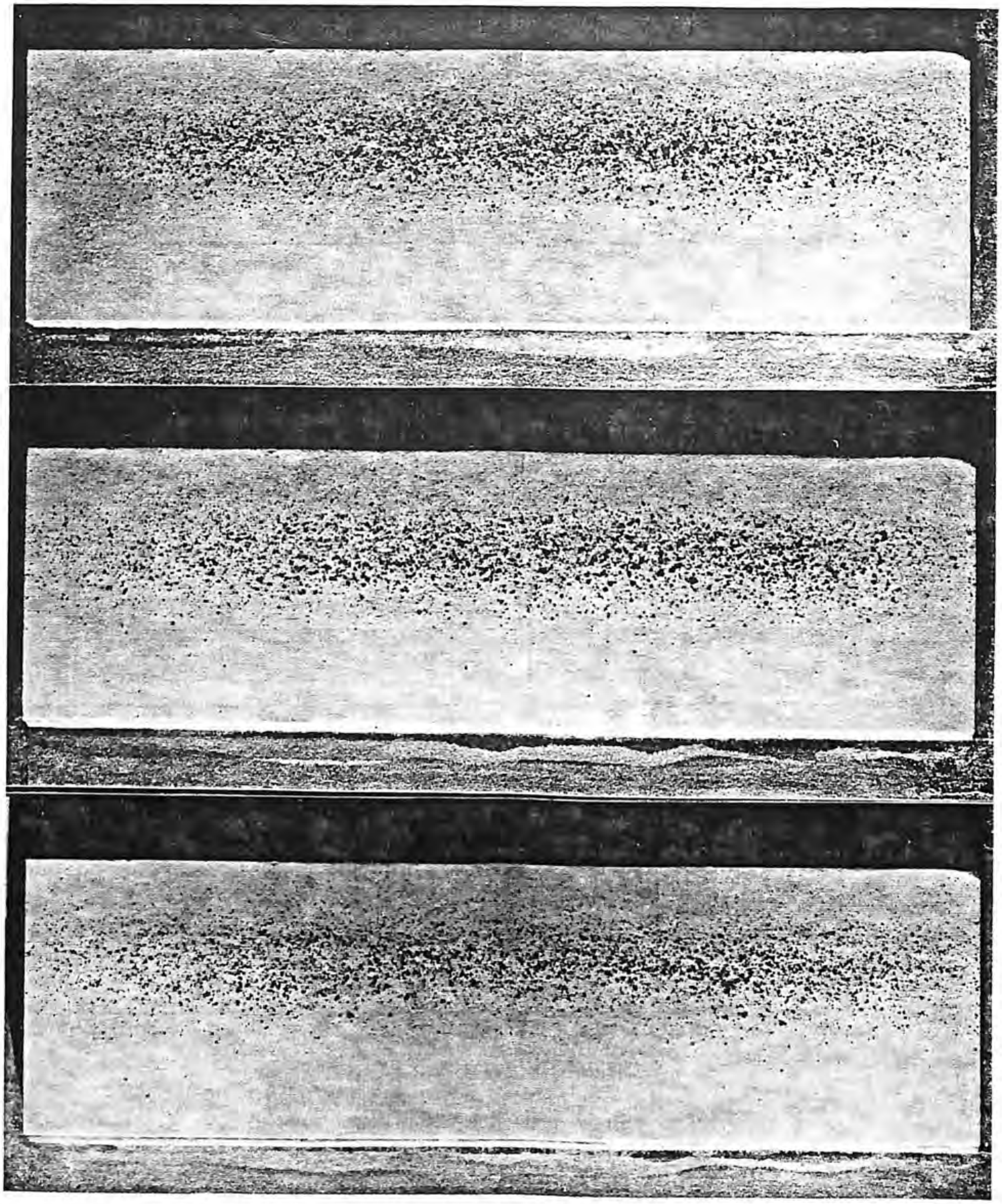


Figure 11.—Compound treated test plates run for 1 hour in a venturi-type cavitation test facility. Curing time 4 hours, 24 hours, and 312 hours, from top to bottom. P801-D-74770, -74771, -74772

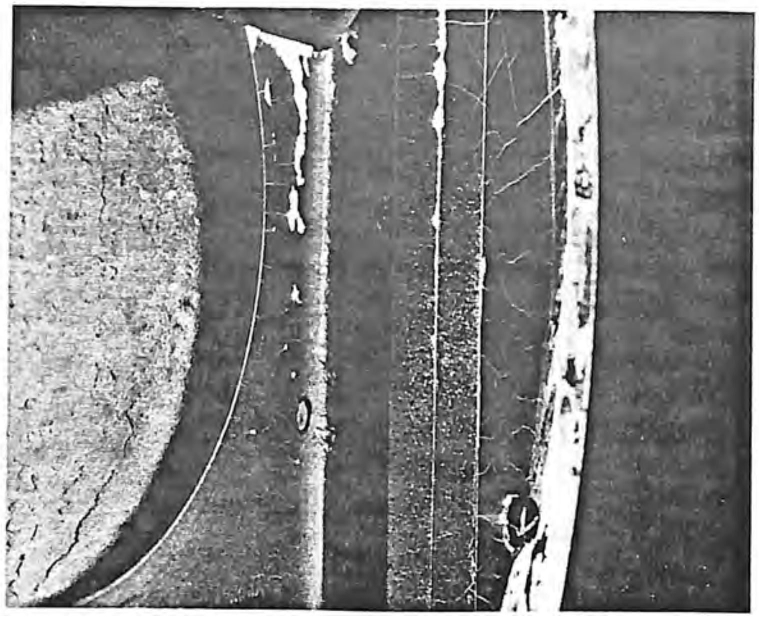


Figure 12.—Erosion to parallel frame downstream of gate slot resulting from an 8-hour test (model) with a release of 207 ft^3/s and 75-percent gate opening. P801-D-74767

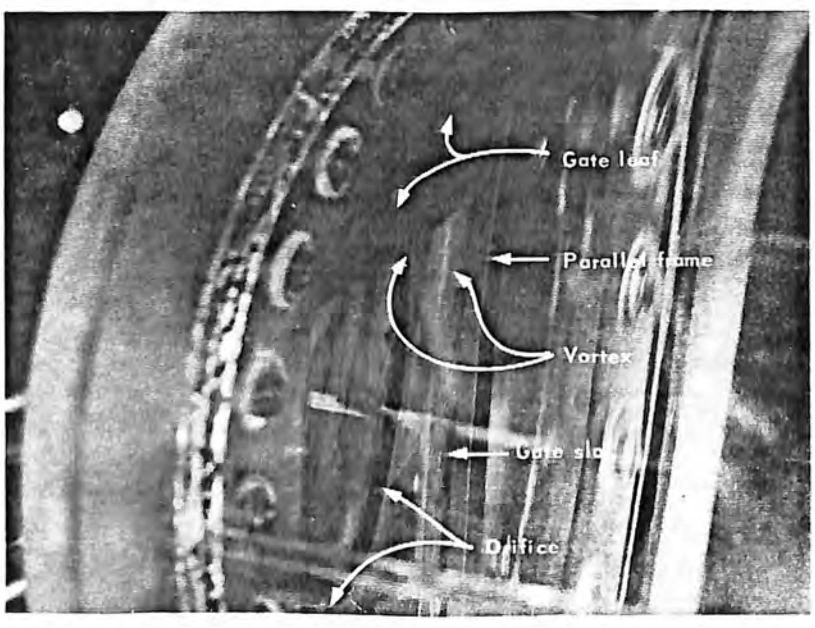


Figure 13.—Vortex emanating from the junction of the circular orifice and the horizontal bottom of the gate. P801-D-74769

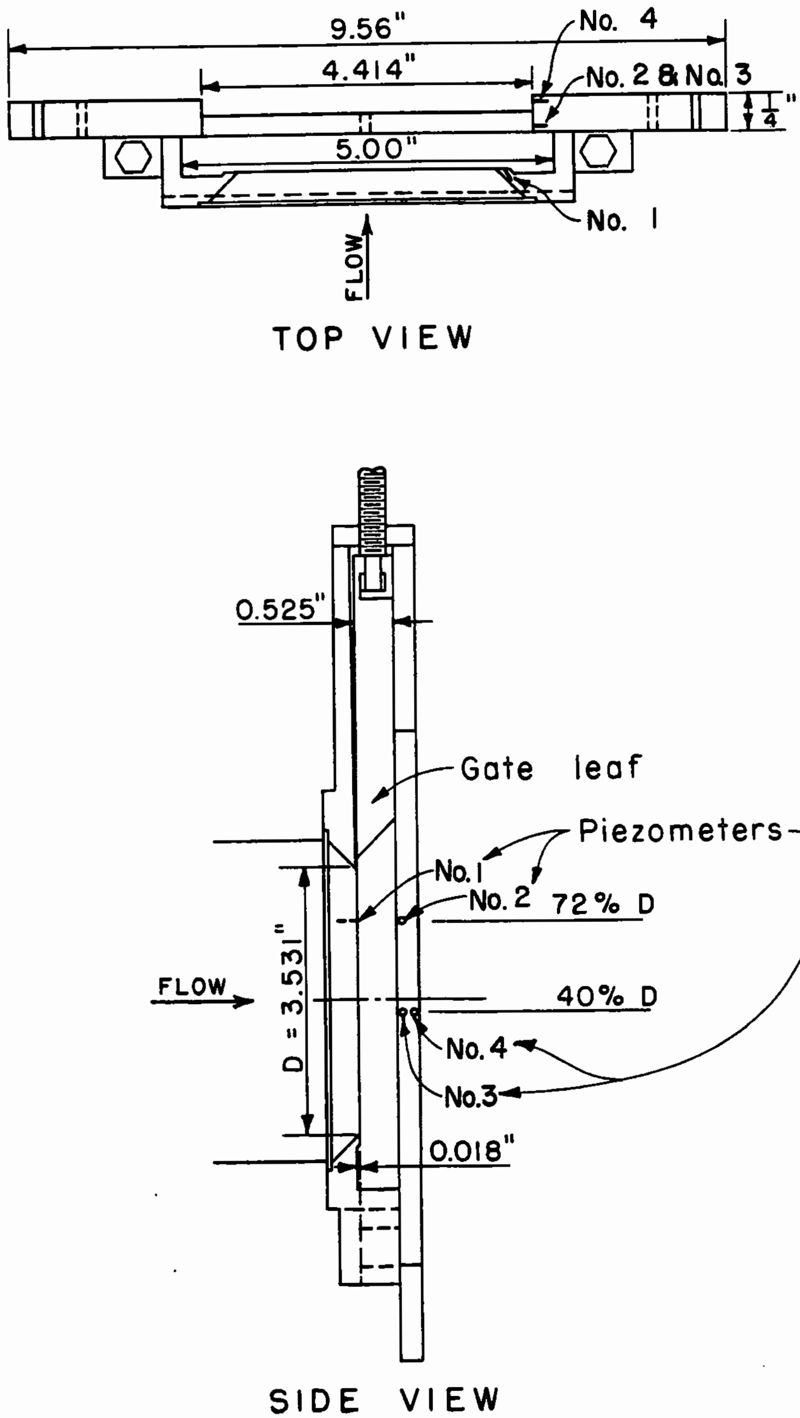
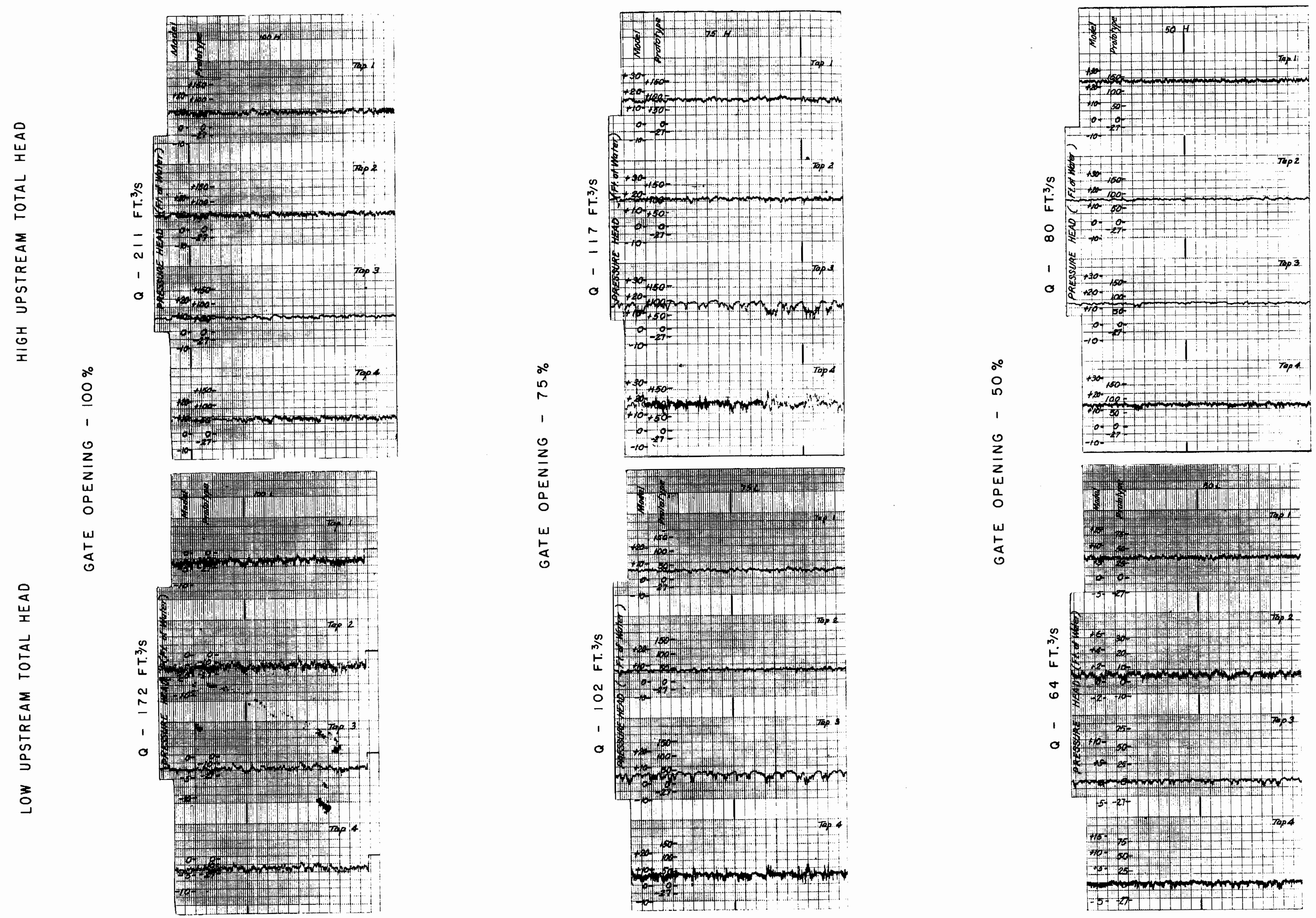
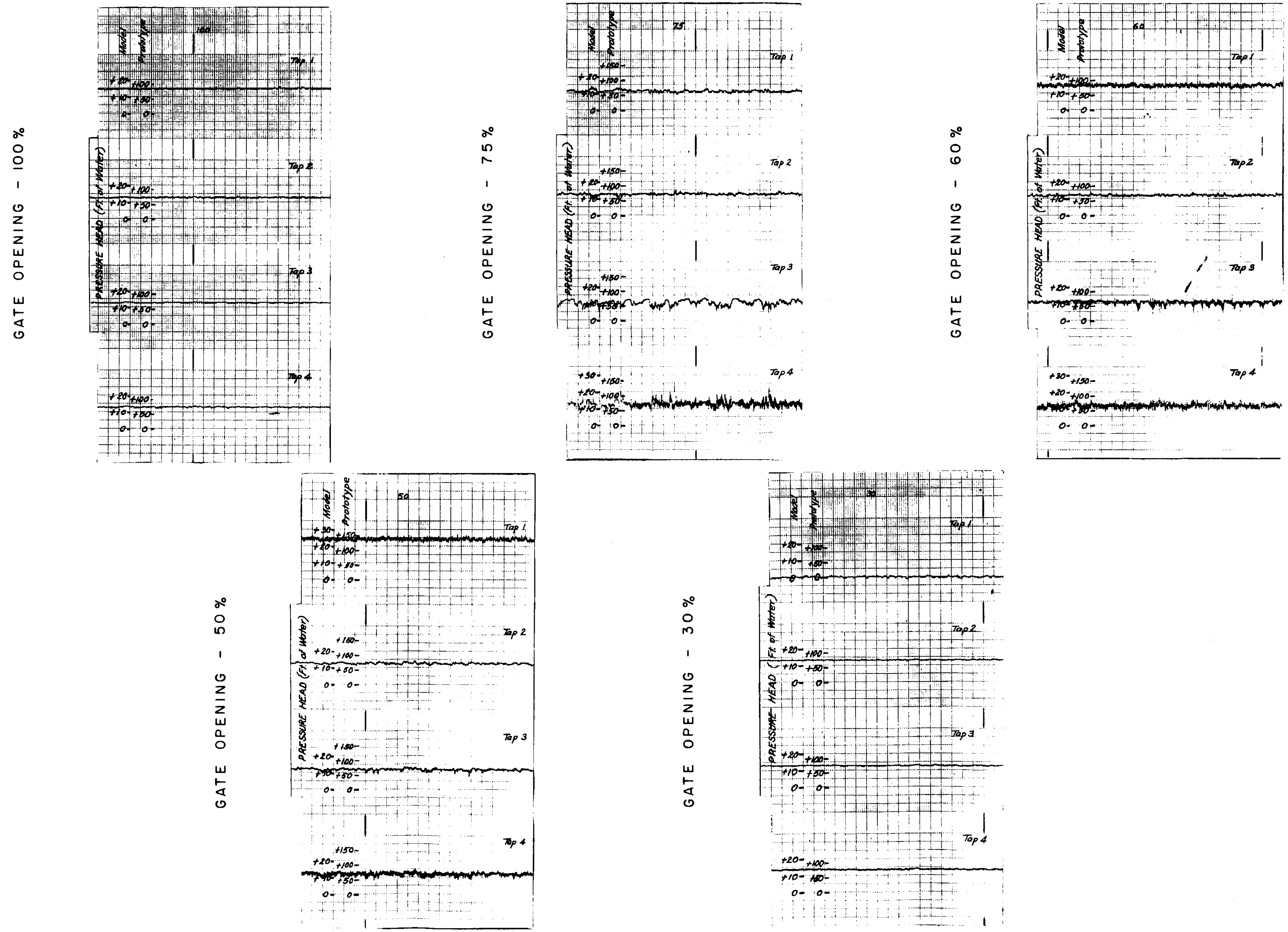


Figure 14.—Model jet-flow gate.



TETON CANAL OUTLET WORKS

Figure 15.–Oscillographs of pressures at piezometers in Jet-flow gate while incipient cavitation was occurring in the model.



TETON CANAL OUTLET WORKS

Figure 16.—Oscillographs of pressures occurring at piezometers in Jet-flow gate at maximum discharge or maximum head.

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
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

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
Short tons (2,000 lb)	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
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)		
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		
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
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		
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*		
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
Pounds	*4.4482	Newtons
Pounds	*4.4482×10^5	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
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		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot pounds per second	1.35582	Watts
HEAT TRANSFER		
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		
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

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ABSTRACT

Studies were made on a 1:5.66 scale model of a single jet-flow gate and sudden expansion energy dissipator to determine discharge coefficients for full and partial gate openings, head losses through the facility, cavitation characteristics, and the back-pressure requirements for the submerged jet-flow gate. The two-diameter expansion was inadequate and was replaced by a three-diameter section. A method of cavitation scaling is discussed whereby visible and/or aurally detectable model incipient cavitation is used to determine incipient cavitation lines for a series of single gate openings and a range of discharges from no-flow through that obtained at maximum head. Using the slope of the model line and the scale vapor pressure, the prototype incipient cavitation line was obtained. A white-pigmented concrete curing compound was found to be satisfactory for use as a cavitation indicator. (8 ref)

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DESCRIPTORS--/ *model tests/ *cavitation/ energy dissipation/ *discharge coefficients/ hydraulic downpull/ instrumentation/ cavitation index/ vortices/ sudden enlargements/ erosion/ cavitation noise

IDENTIFIERS--/ jet-flow gates/ cavitation parameters

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