REC-ERC-73-8

DISCHARGE AND TORQUE CHARACTERISTICS, 198-INCH BUTTERFLY VALVE, AUBURN DAM

REC-ERC-73-

Engineering and Research Center
Bureau of Reclamation

May 1973

MS-230 (8-70)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. REC-ERC-73-8	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE

Discharge and Torque Characteristics, 198-Inch Butterfly Valve, Auburn Dam

5. REPORT DATE

May 73

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

D. Colgate

8. PERFORMING ORGANIZATION REPORT NO.

REC-ERC-73-8

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Engineering and Research Center
Bureau of Reclamation
Denver, Colorado 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

Same

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A new cast-and-welded design has been proposed for the leaves of butterfly valves to be used as guard valves upstream from hydraulic turbines. Model studies were made to determine the head loss through the valve with the leaf fully opened for a valve with a straight-through body, and one with an expanding-contracting body so constructed that the flow passage area through the valve gradually decreases in the direction of flow. Geometrically similar butterfly leaves were used in the test valves. Head loss coefficient for the valve with the expanding-contracting body was about 71 percent less than the loss coefficient for the valve with the straight-through body. Discharge and torque coefficient charts were determined for a full range of valve leaf positions for the valve with the expanding-contracting body.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- / *butterfly valves/ hydraulic turbines/ *optimum design/ closed conduits/ *discharge coefficients/ *aerodynamics/ *head losses/ *torque/ model tests/ model studies/ laboratory tests/ test results/ penstocks/ hydraulics/ hydraulic machinery/ hydraulic design

b. IDENTIFIERS-- / converging sections

c. COSATI Field/Group 13G

18. DISTRIBUTION STATEMENT *Available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151.*	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 13
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE

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DISCHARGE AND TORQUE CHARACTERISTICS, 198-INCH BUTTERFLY VALVE, AUBURN DAM

by

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May 1973

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION
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Secretary

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PURPOSE

These model studies were made to compare the hydraulic losses through the full open valve for three butterfly installations, and to determine the discharge and torque characteristics for a full range of valve openings for the most economical of the three installations.

RESULTS

1. The butterfly valve with the expanding-contracting body was the most economical of the three installations studied (Figure 1). The initial cost of this valve would be greater than either of the other two; however, the smaller head loss across the 90° open leaf would result in increased power revenue to offset the higher initial cost.

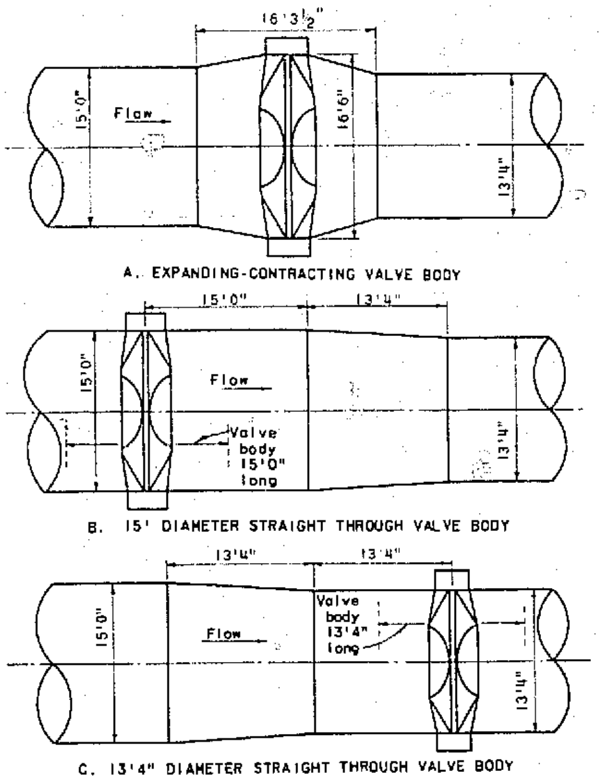


Figure 1. Various butterfly valve proportions. The butterfly leaves are geometrically similar.

2. The expanding-contracting design produced a high coefficient of discharge at the full open position. The total head loss across the butterfly valve would be 1.370 feet with the turbine passing 5,000 cfs.

3. The maximum possible torque forcing the leaf to close would occur with the leaf 70° open. The torque would be 1.2 x 10^7 foot-pounds with maximum reservoir and a fully open penstock downstream from the valve.

APPLICATION

The results of this study may be used in the evaluation of butterfly valves which are geometrically similar to the ones tested.

INTRODUCTION

The power penstocks at Auburn Dam will be 15 feet in diameter through the dam, and will reduce to 13 feet 4 inches just upstream from the turbines. A new cast-and-welded design was proposed for butterfly guard valves to be used upstream from the turbines. Three possible valve proportions and leaf diameters were proposed for the guard valves (Figure 1):

a. An expanding-contracting valve body with a 15-foot-diameter valve entrance, a 16-foot 6-inch diameter butterfly leaf, and a 13-foot 4-inch diameter valve exit.

b. A 15-foot-diameter, straight-through valve body and butterfly leaf in the 15-foot-diameter penstocks.

c. A 13-foot 4-inch diameter, straight-through valve body and butterfly leaf in the 13-foot 4-inch diameter portion of the penstock.

The butterfly leaves were geometrically similar in each of the locations.

This model study was made to measure the head losses through the fully open butterfly valves for each of the proposed installations, and to determine the discharge and torque characteristics for a full range of leaf settings for the most economical of the three.

The equivalent metric values for relevant British values in this report are:

	British value	Metric value
Leaf diameter	13 feet 4 inches	4,064mm
Leaf diameter	15 feet 0 inch	4,572mm
Leaf diameter	16 feet 6 inches	5,029mm
Maximum head	585 feet	178.3 meters
Design discharge	5,000 cfs	141.6 m^3/sec
Maximum torque	1.2×10^7 ft-lb	1.66×10^8 cm kg

THE MODEL

These model studies were made using air as a test fluid. For simplicity of model construction, and since the model would not be subjected to liquid flow, a butterfly leaf was fabricated of wood. The leaf was 7.000 inches in diameter, and fabrication was meticulous with dimensions being held to very close tolerances (Figure 2). Although the leaves in the three proposed installations were of different diameters, they were geometrically similar, thus the same leaf was used for all three tests with the model scale being changed to reflect the various valve sizes.

A model valve body 6.911 inches long, with a 6.364-inch-diameter inlet, 7.000 inches in diameter at the leaf trunnion centerline, and a 5.656-inch-diameter exit was fabricated of wood to represent the 16-foot 6-inch butterfly valve at a model scale of 1:28.29 (Figure 3).

One straight-through valve body with a 7.000-inch inside diameter and 7.000 inches long was fabricated of wood to represent the 15-foot-diameter butterfly valve at a scale of 1:25.71, and the 13-foot 4-inch diameter butterfly valve at a scale of 1:22.86.

Figure 4 shows the model butterfly leaf used in all three tests and the leaf installed in the expanding-contracting valve body.

The butterfly valve to be studied was installed in the laboratory air test facility (Figure 5). In Figure 5A the blower and air intake are enclosed behind the model. The blower is capable of a maximum discharge of 1,800 cfm of free air, and a maximum pressure of 9.9 inches of water. A 6.045-inch-diameter sharp-edge orifice is between two flanges

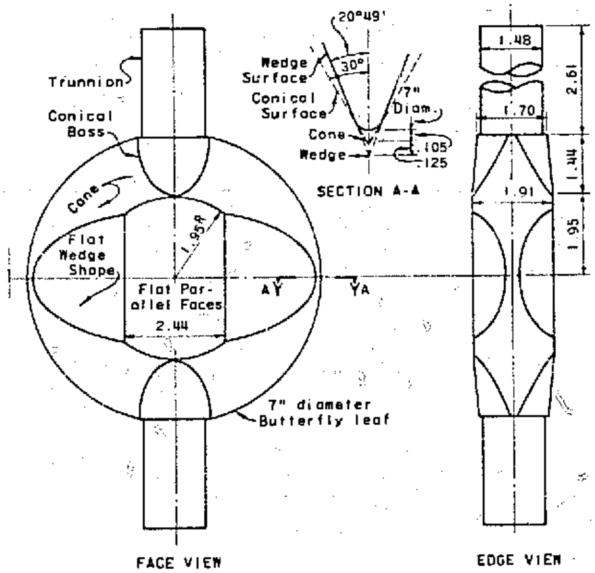


Figure 2. Model butterfly leaf—Wood.

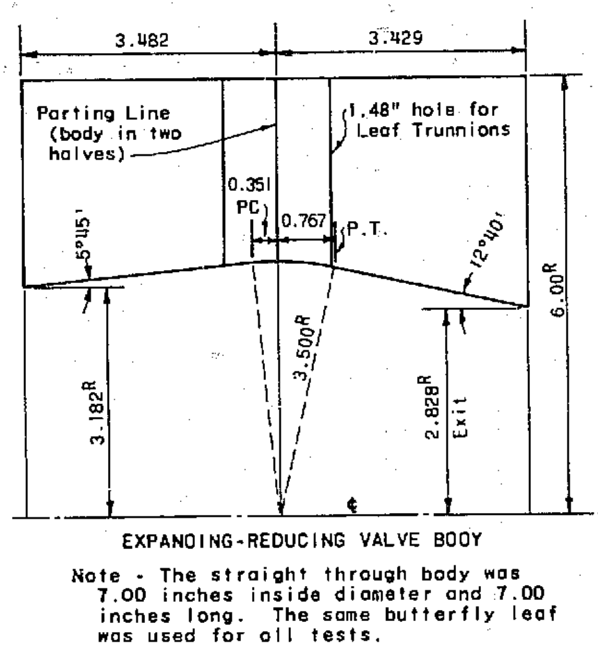
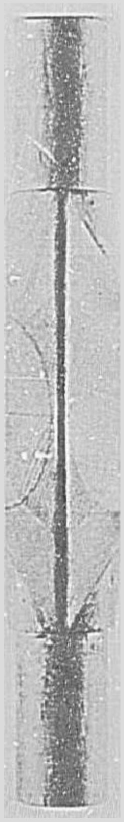
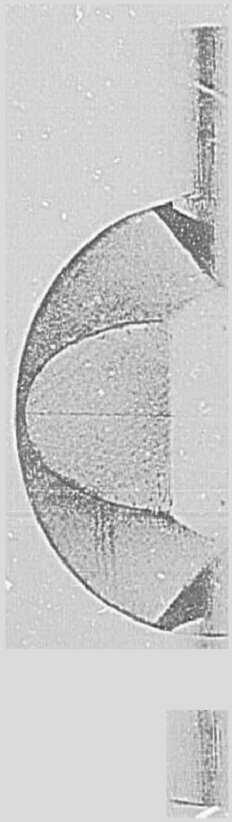


Figure 3. Expanding-contracting model butterfly valve body—Wood.





Leaf mounted in the expanding-contracting body.

Edge view.

Face view.

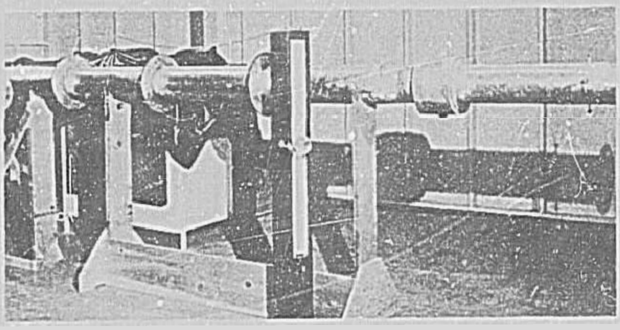
Leaf

Figure 4. Model leaf and body. Photos P801-D-73229, P801-D-73230, and P801-D-73228

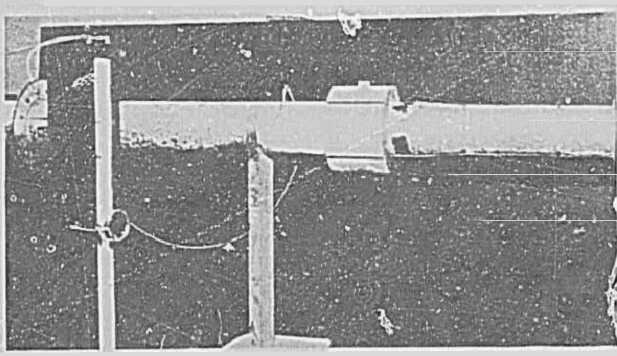
on the far left of the photograph. Flow straightening vanes upstream and downstream from the orifice assured uniform flow into the orifice and into the test valve. A manometer capable of displaying pressures, either differential or direct, to 1/1,000 inch of water, is in the center foreground. The wooden test valve representing the 13-foot 4-inch diameter valve is to the right of the manometer.

Figure 5B shows the installation for the model valve representing the 15-foot-diameter valve, and Figure 5C shows the installation representing the 16-foot 6-inch diameter valve. Tests were made with the butterfly leaf fixed in the 90° open position for all three installations.

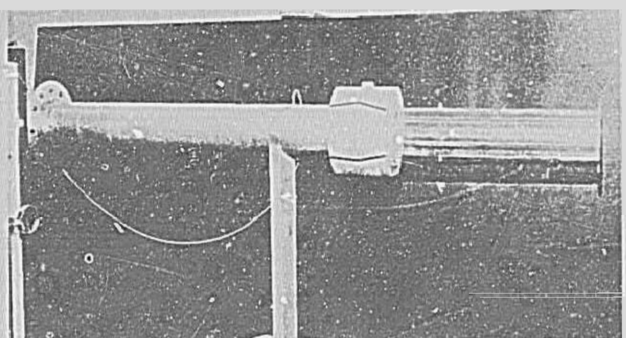
A plot of the variation in flow passage areas through the fully open valves is shown in Figure 6. The flow passage area in the straight-through valve contracts 33 percent between the valve inlet and the leaf trunnion centerline, and expands to the full pipe area at the exit. In the expanding-contracting body valve, the flow passage area gradually contracts 23 percent between the 15-foot-diameter valve inlet and a station 81 percent through the valve, and expands 3 percent to the 13-foot 4-inch diameter valve exit. Since the butterfly leaves in the three valves are geometrically similar, the head loss differences in the three installations would be due mainly to the contraction-expansion losses, and would be expected to be a minimum in the expanding-contracting body valve.



A. 13-foot 4-inch diameter straight-through body
Photo P801-D-73231



B. 15-foot 0-inch diameter straight-through body. Photo
P801-D-73232



C. Expanding-contracting body. Photo P801-D-73233

Figure 5. Laboratory installations.

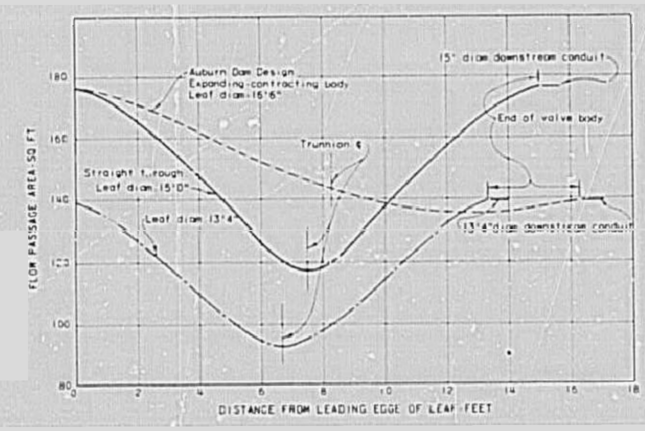


Figure 6. Flow passage areas.

VALVE COMPARISON STUDY

A series of test runs was made to evaluate the losses due to flow through the model conduits, and through the cones in the case of the straight-through valve bodies. For the tests with the expanding-contracting valve body, the valve was removed and replaced with a cone to permit the isolation and evaluation of the losses due solely to the butterfly valve body and leaf.

The prototype dimensions and scaled model dimensions for the three installations are shown in Figure 7. Computations were made to evaluate the head losses due only to the valve body and leaf. A coefficient of loss "K" was determined for each installation where:

$$\Delta H = K \, V_1^2/2g$$

ΔH is the head loss across the butterfly valve (ft)
K is the loss coefficient
V_1 is the velocity in the 15-foot-diameter upstream pipe (fps).

The values are:

Valve leaf diameter	K	Valve head loss for Q = 5,000 cfs (Auburn Dam turbine discharge)
16-foot 6-inch	0.110	1.370′
15-foot	0.380	4.724′
13-foot 4-inch	0.669	8.318′

(See Figure 7)

For the 13-foot 4-inch diameter valve, when the loss coefficient is based on the velocity in the 13-foot 4-inch conduit, the coefficient "K" is 0.418. Since the same model butterfly valve body and leaf were used for both straight-through valve tests, it appears that the loss coefficient for the two valves should be identical when based on the velocity in the section of penstock in which the valve is installed. However, it is felt that the location of the 13-foot 4-inch diameter valve body one-half pipe diameter downstream from a reducing cone created a small additional loss through the 90° open valve.

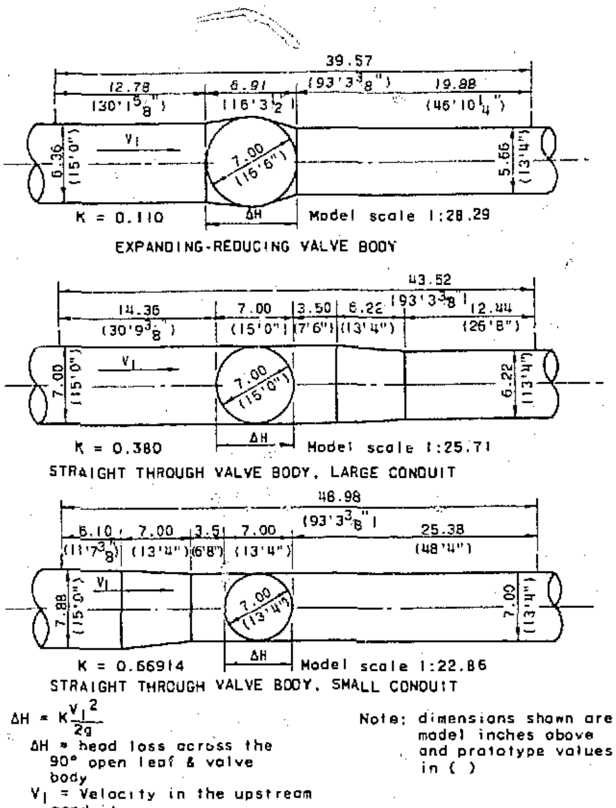


Figure 7. Head loss comparison for three installations. The same model valve leaf was used in all tests.

Design engineers computed the projected power revenue loss over the life of the project due to the head loss across each of the three valves, and considering the initial installation costs, it was determined that the expanding-contracting valve body was the most economical design.

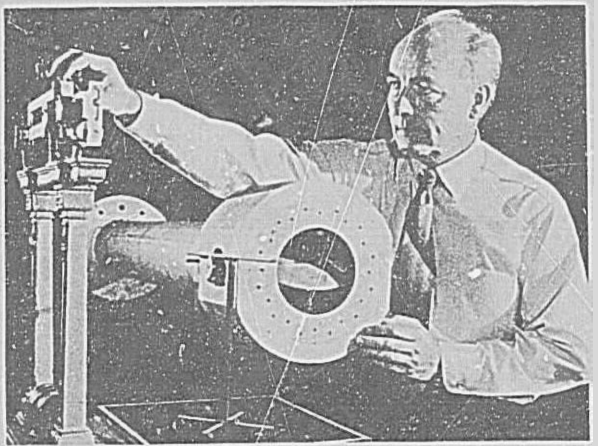
The necessary model modifications were made to continue the study on the chosen valve to determine the discharge and torque characteristics for the full range of valve openings.

TORQUE AND DISCHARGE STUDY

The torque on the model butterfly leaf as initially constructed, operating with air as a test fluid, was not great enough to overcome the friction between the wooden trunnions on the leaf rotating in the fixed wooden bearing surfaces in the valve body. To reduce this source of error for the torque measurements, the model was modified by counterboring the valve body bearing holes and machining the leaf trunnions to receive two free rotating metal bearings. The insertion of the bearings, with some slight additional dressing down of the leaf and body, allowed the leaf to rotate practically friction-free. The valve was reinstalled in the model penstock as shown in Figure 7A, but with the trunnions mounted horizontal. A centered and balanced leaf position indicator, with readings as small as 30 seconds of arc, was mounted on the end of one trunnion. An arm 12 inches long was clamped to the other trunnion. A platform scale, reading to 0.01 pound, was placed beneath the valve in such a position and elevation that one end of a vertical rod could be placed in the center of the platform, and the other end would support the 12-inch rod exactly horizontal. The top of the vertical rod was shaped to a knife edge (Figure 8).

With this arrangement, the lever arm through which the turning force of the leaf was applied to the platform was the horizontal distance between the centerlines of the trunnions and the vertical rod. All torque and discharge measurements were made with a length of conduit downstream from the butterfly valve. Care was taken to prevent stray air currents from blowing on the platform of the scale.

For each valve leaf position tested, the leaf was positioned by clamping the horizontal rod to the trunnion at the desired rotation of the leaf. A check



Butterfly valve with an expanding-contracting body. Photo PX-D-72575

Figure 8. Laboratory installation for torque measurements.

was made to be certain that the two rods were horizontal and vertical, respectively. The lever arm was measured and the platform scale was balanced to ascertain the tare caused by the rods.

Three test runs were made for each leaf position tested: the maximum discharge possible with the laboratory blower, and about two-thirds and one-third the maximum discharge controlled by restricting the exit end of the downstream conduit. For each test run, the air pressure was measured upstream and downstream from the orifice for discharge determinations. The pressure was measured at selected locations upstream and downstream from the butterfly valve. The leaf position was determined during each test run, and the platform scale was balanced and read. The local barometer was recorded every half hour, and the air temperature was read at the model for each test run. The tare was read after turning off the airflow and checked against the beginning tare as assurance that nothing had changed during the test run.

Typical Computation

The computations required to determine the coefficient of discharge, torque, and torque coefficient for one typical test run with the expanding-contracting body butterfly valve are as follows:

Test conditions:

Valve leaf setting	70°
Barometer	24.58" Hg
Temperature	75.2° F
Lever arm	3 inches

Test readings (pressures in inches of H_2O)

Tare (pounds)		Orifice pressure		Valve pressure		Scale (pounds)
Before	After	US	DS	US	DS	
0.20	0.20	9.171	6.073	5.880	3.632	1.54

Computations

Ambient air pressure corrections (barometer plus line pressure)

Orifice $24.58 + \frac{9.171}{13.57} = 25.26''$ Hg abs.

Valve, US $24.58 + \frac{5.880}{13.57} = 25.01''$ Hg abs.

Valve, DS $24.58 + \frac{3.632}{13.57} = 24.85''$ Hg abs.

Discharge corrected for ambient pressure:

Orifice	18.401 cfs air
Valve US	18.555 cfs air
Valve DS	18.690 cfs air

$\underline{V_1^2/2g} = (18.555/.219)^2/2g = 111.47'$ air

$\underline{V_2^2/2g} = (18.690/.173)^2/2g = 181.23'$ air

Ratio, ft of air/ft of H_2O

US from valve	1,009.0
DS from valve	1,016.0

Coefficient of discharge

Head loss across the valve:

Total head at US piezometer,

$$H_T = \text{(pressure head) (ratio)} + V_1^2/2g$$

$$H_T = \left(\frac{5.880}{12}\right) (1{,}009.0) + 111.47 = 605.88 \text{ ft air}$$

Head loss—piezometer to valve (see Figure 7A)

H_L = L/D f $V^2/2g$
L/D = length to diameter ratio of pipe
f = friction factor, determined from previous study
$V_1^2/2g$ = pipe velocity head, fps

$$H_L = \left(\frac{12.78}{6.36}\right) (.011)\ (111.47) = 2.46 \text{ ft air}$$

Total head US = 605.88 – 2.46 = 603.42 ft air

Total head at DS peizometer:

$$H_T = \left(\frac{3.632}{12}\right) (1{,}016.5) + 181.23 = 488.89 \text{ ft air}$$

Head loss—valve to piezometer:

$$H_L = \left(\frac{19.88}{5.66}\right) (.011)\ (181.23) = 7.00 \text{ ft air}$$

Total head DS = 488.89 + 7.00 = 495.87 ft. air

ΔH = 603.42 – 495.89 = 107.53 ft air

Coefficient computation:

$$Q = C_d A \sqrt{2g}\sqrt{\Delta H}$$

Q = 18.555 cfs air
A = 0.219 sq ft
ΔH = 107.53 ft air
$C_d = 18.555/[(0.219)\ (8.02)\ \sqrt{107.53}]$
$C_d = 1.018$

The coefficient of discharge (C_d) values were computed and averaged for each of the several test runs for each leaf position. The averaged C_d values were plotted against the leaf position and a best fit curve determined. The result is the coefficient of discharge curve, Figure 9.

Coefficient of torque (for the example above):

$$\text{Measured torque} = \left(\frac{3}{12}\right) (1.54\text{–}0.20) = 0.335 \text{ ft-lb}$$

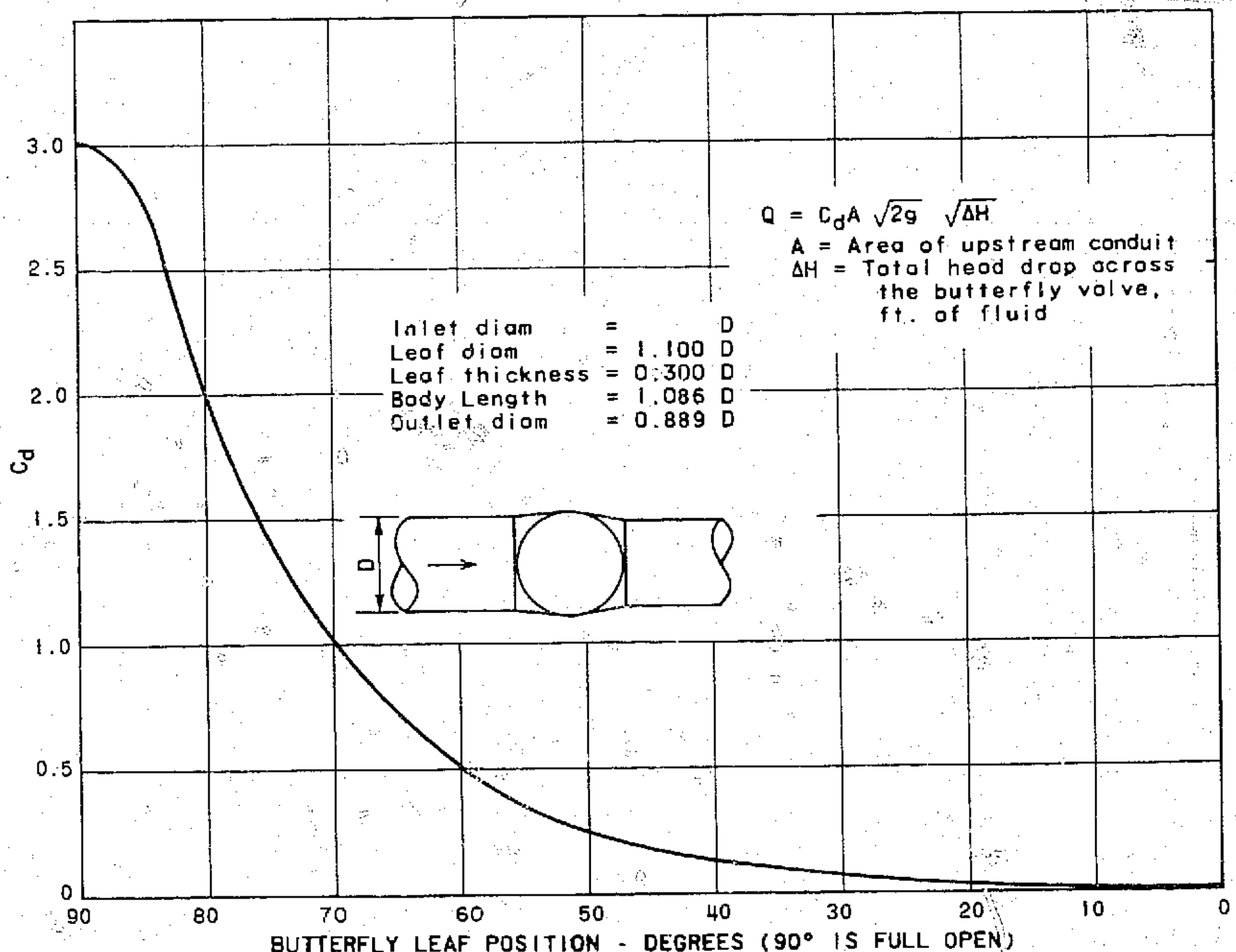


Figure 9. Discharge coefficient—Butterfly leaf position—Degrees (90° is full open)

$V_1^2/2g$ (corrected to feet of water)

$(111.47)/(1{,}009.0) = 0.110$ ft

An average curve, $V_1^2/2g$ vs torque, was drawn for each leaf position tested (Figure 10). A coefficient of torque for each leaf position was determined where:

$$T = C_T D^3 \Delta P$$

T	=	torque, ft-lb
C_T	=	coefficient of torque
D	=	diameter of the upstream pipe, ft
ΔP	=	pressure drop across the leaf, lb/sq ft
ΔP	=	$(V_1^2/2g)\ (1/C_d^2)\ (W)$
W	=	sp. weight of test fluid

The computed values for C_T vs leaf position were plotted and a best fit curve determined. The result is the coefficient of torque curve, Figure 11.

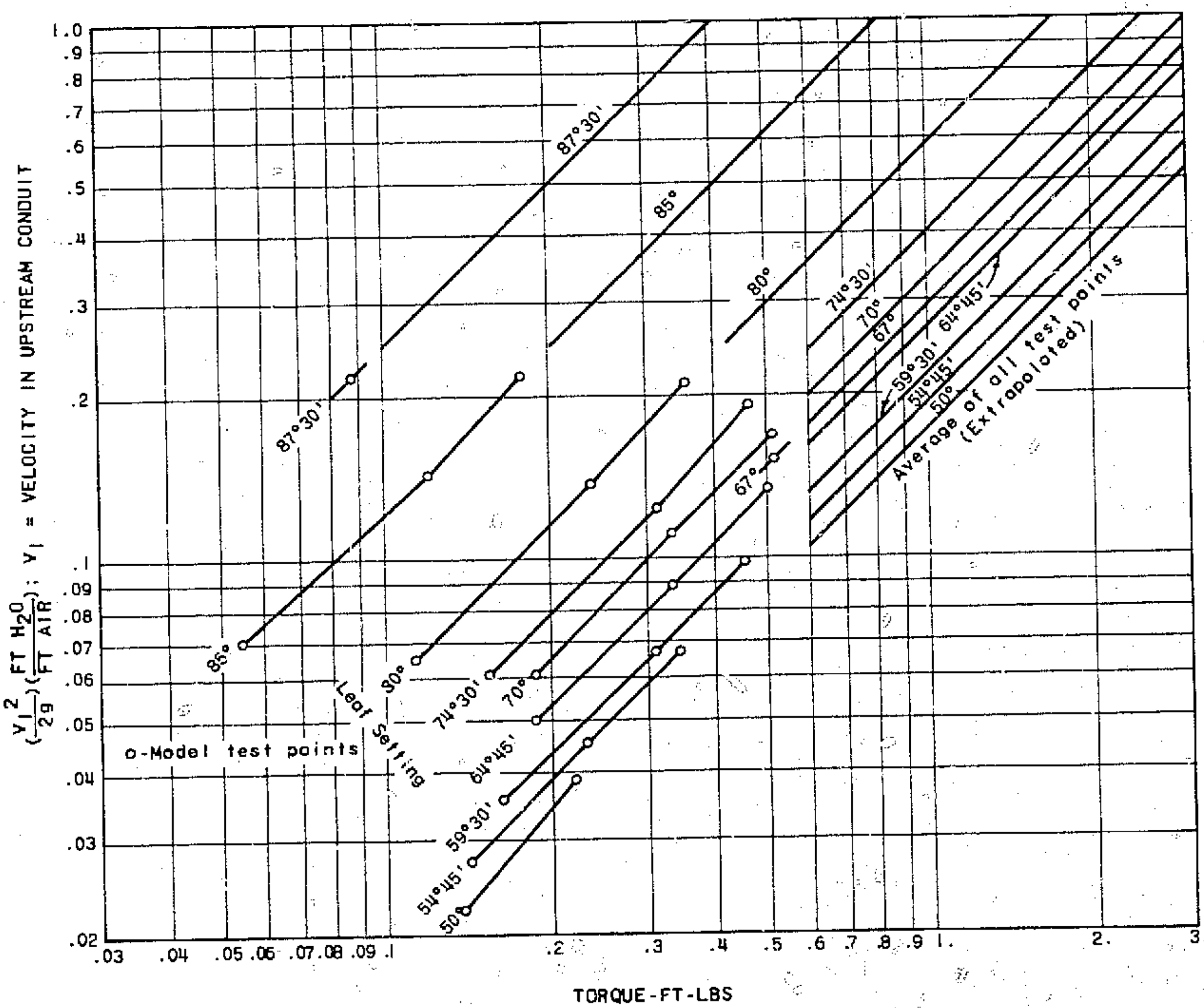


Figure 10. Model valve, torque vs $V_1^2/2g$.

The prototype values for torque and $V_1^2/2g$ may be computed from the values in the above example:

$$V_1^2/2g_{(P)} = (N)\left(V_1^2/2g_{(M)}\right)$$

where (P) denotes prototype
(M) denotes model
(N) is the scale ratio, 1:28.29

So $V_1^2/2g_{(P)} = (28.29)\ (0.110) = 3.112$ ft

$\text{Torque}_{(P)} = N^4\ \text{torque}_{(M)}$
$\text{Torque}_{(P)} = (28.29)^4\ (0.335)$
$= 214{,}574$ ft-lb

A family of curves showing Auburn Dam prototype values of torque vs $V_1^2/2g$ was drawn, Figure 12. (Note: The torque shown on the chart, Figure 12, for $V_1^2/2g = 3.112$ is slightly higher than that shown in the example due to the averaging of all data to produce the chart.)

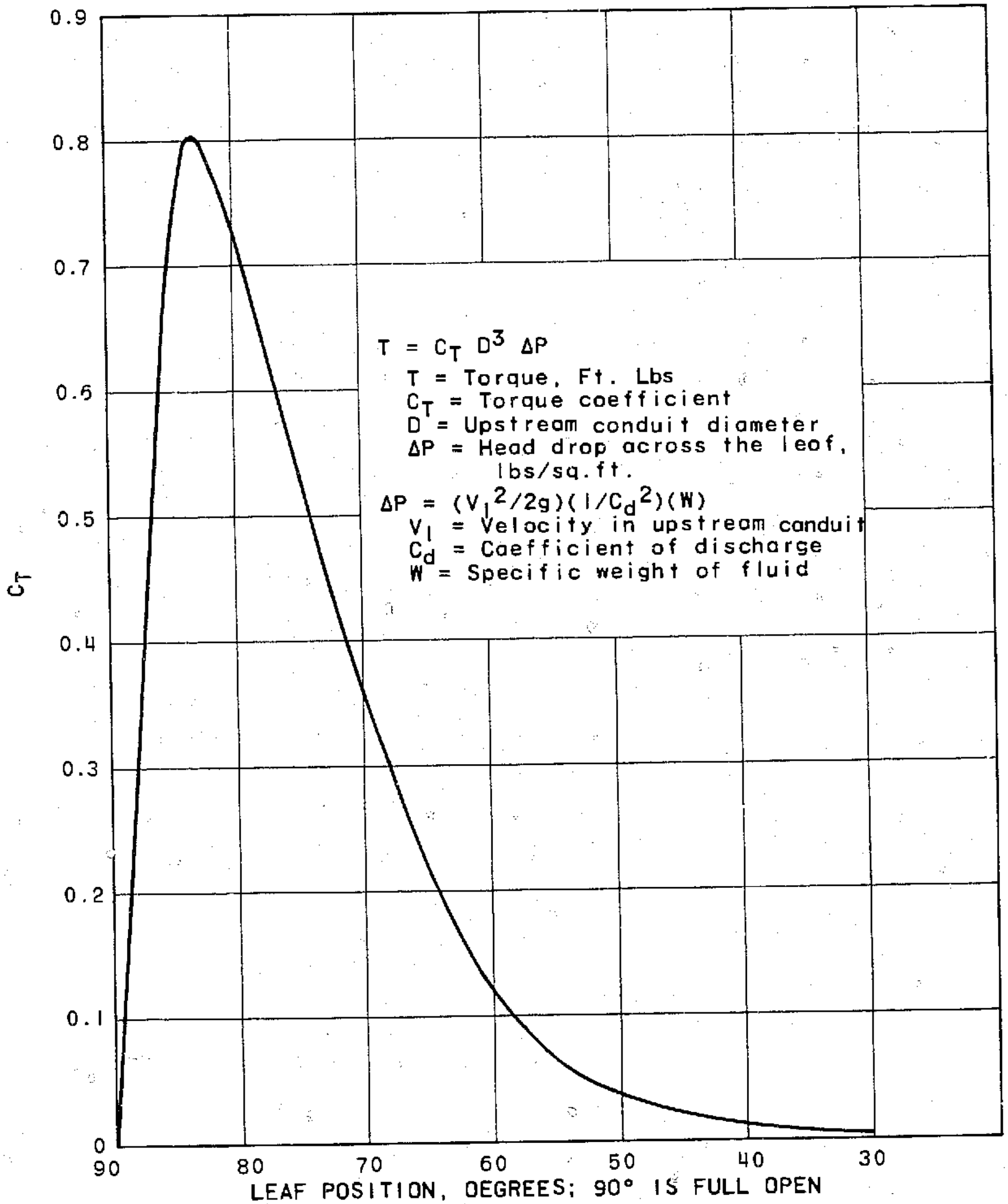


Figure 11. Torque coefficient—Leaf position, degrees, 90° is full open.

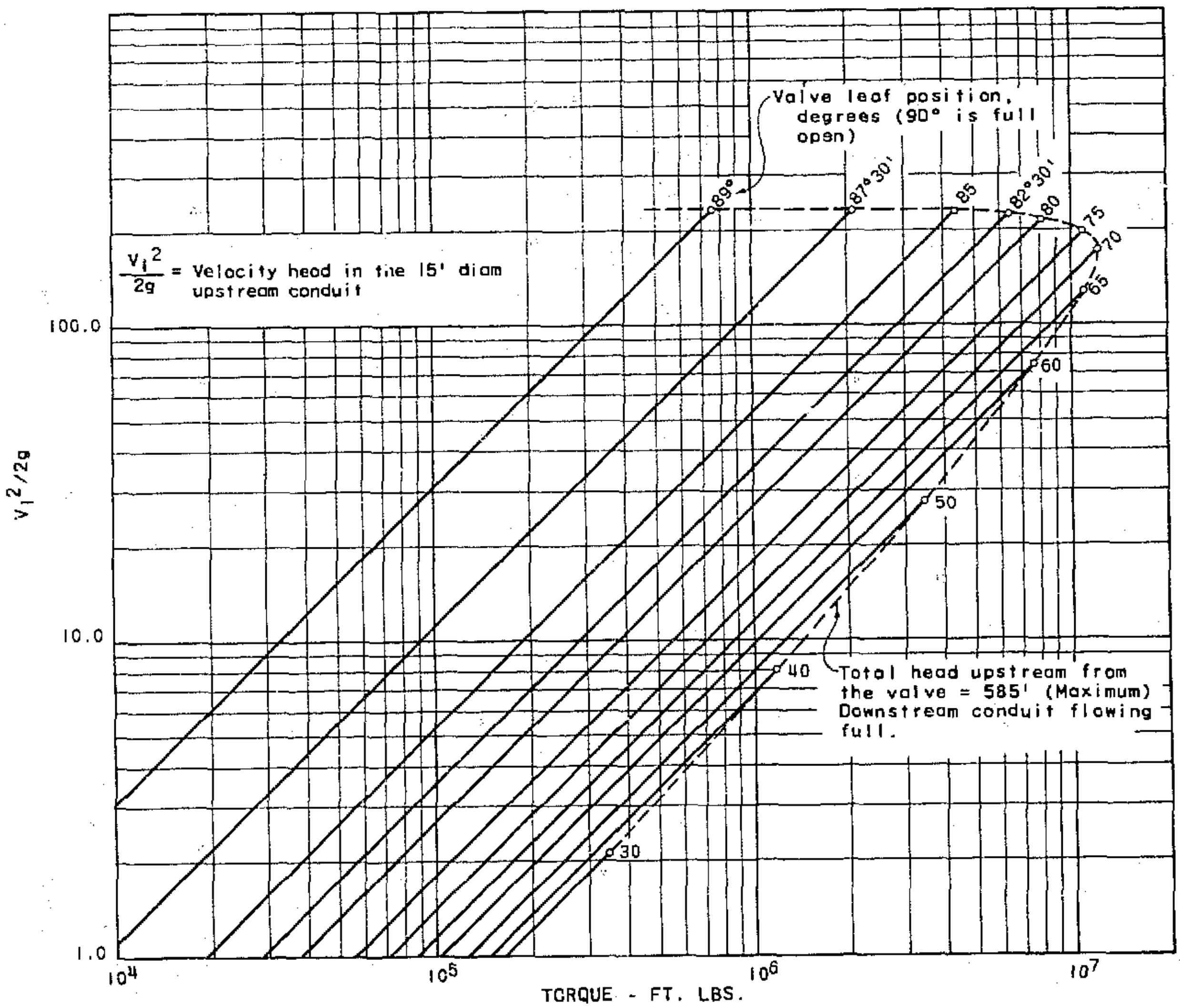


Figure 12. Prototype valve, torque vs $V_1^2/2g$. 15-foot-diameter upstream penstock—13-foot 4-inch diameter downstream penstock—16-foot 6-inch diameter leaf.

Using the C_T curve, a family of curves was drawn plotting torque vs ΔH where:

$$T = (C_T)\,(D^3)\,(\Delta H)\,(W)$$

T	=	torque, ft-lb
C_T	=	coefficient of torque
D	=	upstream pipe diameter (15 feet)
ΔH	=	total head drop across the valve
W	=	sp. weight of water—62.4 lb/cu ft

The results of the computation are shown on Figure 13.

The maximum torque which could be expected at Auburn Dam was computed using the maximum reservoir head, 585 feet above the valve centerline, and the penstock downstream from the valve flowing full. The computed values are shown as the limiting curve (dotted line) on Figures 12 and 13.

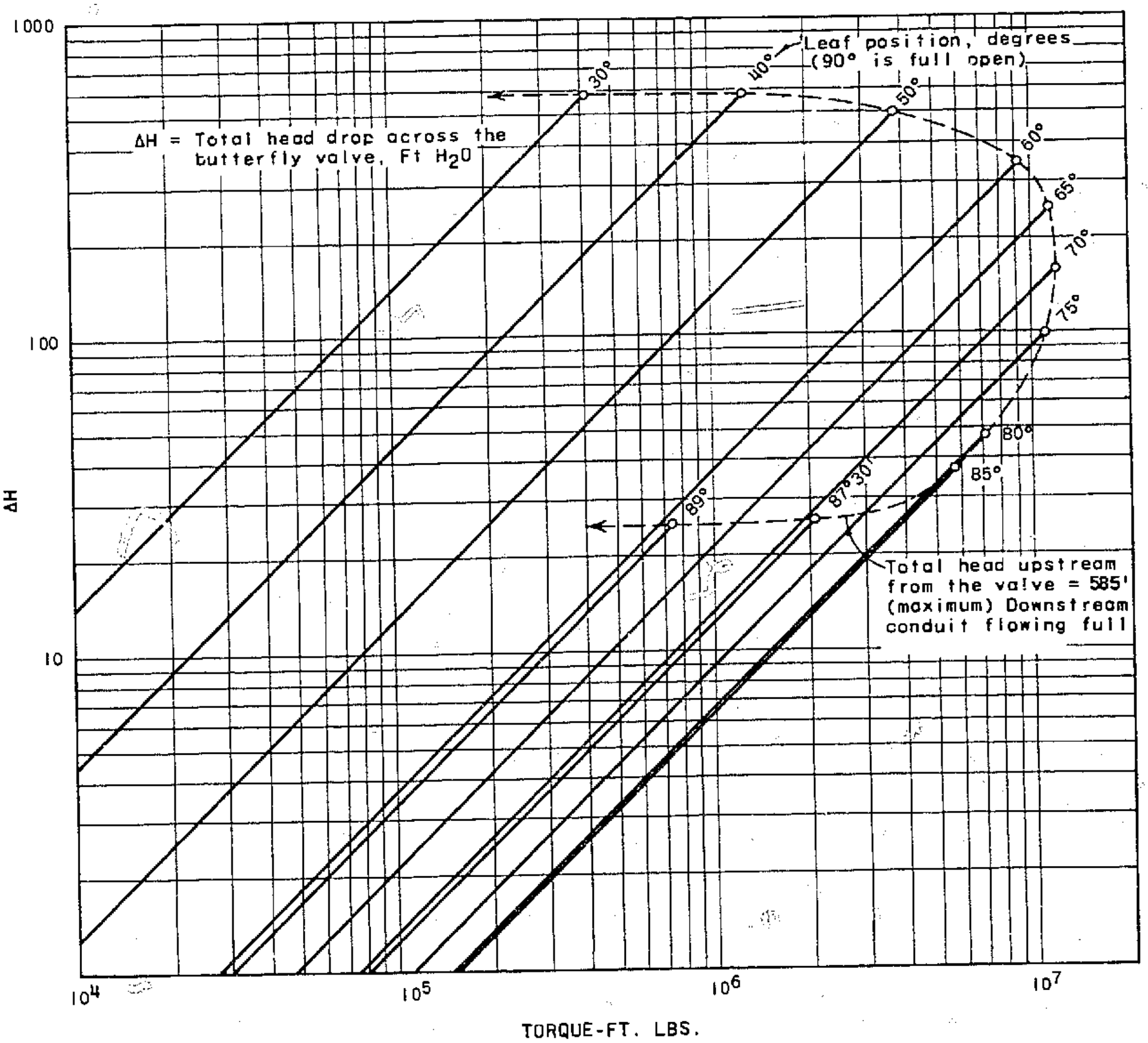


Figure 13. Prototype valve, torque vs ΔH. 15-foot-diameter upstream penstock—13-foot 4-inch diameter downstream penstock—16-foot 6-inch diameter leaf.

7-1750 (3-71)
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, 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	$*0.965873 \times 10^{-6}$	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	$*4.4482 \times 10^5$	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

GPO 835-168

ABSTRACT

A new cast-and-welded design has been proposed for the leaves of butterfly valves to be used as guard valves upstream from hydraulic turbines. Model studies were made to determine the head loss through the valve with the leaf fully opened for a valve with a straight-through body, and one with an expanding-contracting body so constructed that the flow passage area through the valve gradually decreased in the direction of flow. Geometrically similar butterfly leaves were used in the test valves. Head loss coefficient for the valve with the expanding-contracting body was about 71 percent less than the loss coefficient for the valve with the straight-through body. Discharge and torque coefficient charts were determined for a full range of valve leaf positions for the valve with the expanding-contracting body.

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REC-ERC-73-8
Colgate, D
DISCHARGE AND TORQUE CHARACTERISTICS, 198-INCH BUTTERFLY VALVE, AUBURN DAM
Bur Reclam Rep REC-ERC-73-8, Div Gen Res, May 1973. Bureau of Reclamation, Denver, 13 p, 13 fig

DESCRIPTORS—/ *butterfly valves/ hydraulic turbines/ *optimum design/ closed conduits/ *discharge coefficients/ *aerodynamics/ *head losses/ *torque/ model tests/ model studies/ laboratory tests/ test results/ penstocks/ hydraulics/ hydraulic machinery/ hydraulic design
IDENTIFIERS—/ converging sections

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