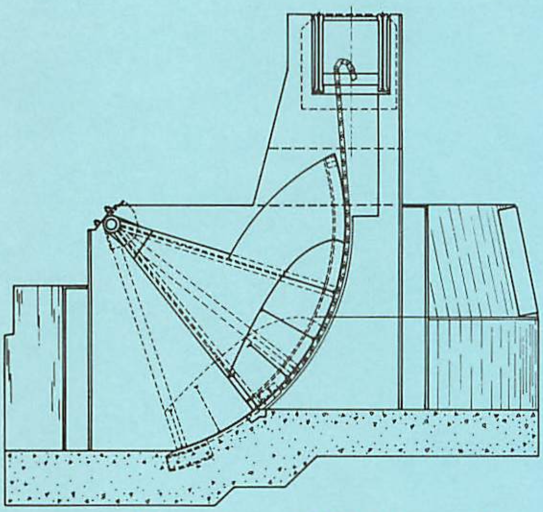
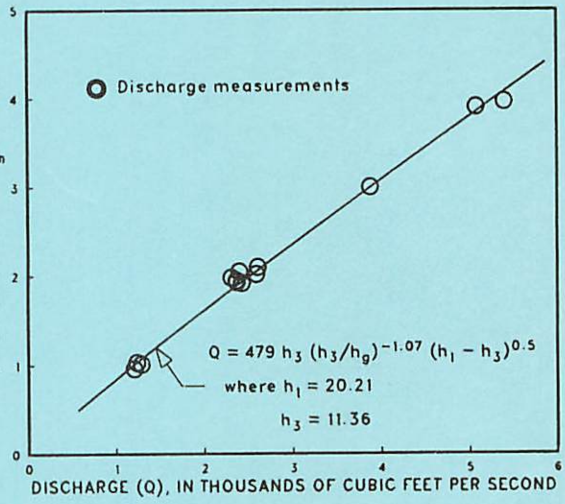
DISCHARGE RATINGS FOR CONTROL GATES AT MISSISSIPPI RIVER LOCK AND DAM 13, FULTON, ILLINOIS

U.S. GEOLOGICAL SURVEY

Water Resources Investigations Report 86-4134



TAINTER GATE - SECTIONAL VIEW



Prepared in cooperation with the

U.S. ARMY CORPS OF ENGINEERS,
ROCK ISLAND DISTRICT

DISCHARGE RATINGS FOR CONTROL GATES AT MISSISSIPPI RIVER LOCK AND DAM 13, FULTON, ILLINOIS

By Albert J. Heinitz

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Iowa City, Iowa
1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, SECRETARY

GEOLOGICAL SURVEY

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SYMBOLS AND UNITS

Symbol	Definition	Unit
A	Area of lock chamber	ft^2
a	Elevation difference, trunnion centerline to sill	ft
B	Lateral width of a tainter or roller gate	ft
B_s	Length of fixed spillway	ft
C	Free-orifice flow coefficient of discharge	
C_{gs}	Submerged-orifice flow coefficient of discharge	
C_{sw}	Free-weir flow coefficient of discharge, fixed spillway	
C_{sws}	Submerged-weir flow coefficient of discharge, fixed spillway	
C_w	Free-weir flow coefficient of discharge, gate crest	
C_{ws}	Submerged-weir flow coefficient of discharge, gate crest	
g	Acceleration due to gravity	ft/s^2
G	Gage indicator reading	ft
H_1	Total headwater head including velocity head referenced to gate sill	ft
h_1	Static-headwater head referenced to gate sill	ft
h_3	Static-tailwater head referenced to gate sill	ft
H_{1s}	Total headwater head including velocity head referenced to the gate crest	ft
h_{1s}	Static-headwater head referenced to gate crest	ft
h_{3s}	Static-tailwater head referenced to gate crest	ft
h_g	Gate opening	ft
N	Number of lockages occurring between recordings	

SYMBOLS AND UNITS--continued

Symbol	Definition	Unit
Q	Computed discharge per gate	ft^3/s
Q_s	Computed fixed-spillway discharge	ft^3/s
Q_L	Computed lock-chamber discharge	ft^3/s
R	Radius from trunnion centerline to upstream face of a tainter gate	ft
R.P.	Reference point to which elevations are run for the purpose of computing the gate opening	
r	Radius from trunnion centerline to gate R.P.	ft
$\Delta h = h_1 - h_3$	Static-head loss through structure	ft
Δt	Time between recordings	sec
θ	Included angle between radial lines from the trunnion centerline through the R.P. and through the lower lip of the gate	deg
ϕ_u	The angle measured from the horizontal to the radial line from the trunnion centerline through the gate R.P. with the gate in a closed position	deg
$<$	Less than	
$>$	Greater than	
$\geq$	Equal to or greater than	

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM UNITS (SI)

The following factors may be used to convert the inch-pound units published herein to the International System of Units (SI)

Multiply inch-pound units	By	To obtain SI units
	-Length-	
foot (ft)	0.3048	meters
mile	1.609	kilometers
	-Area-	
square foot (ft^2)	0.0929	square meter
	-Flow-	
cubic feet per second (ft^3/s)	0.02832	cubic meters per second
	-Acceleration-	
foot per second squared (ft/s^2)	0.3048	meter per second squared
	-Weight-	
pound	0.4536	kilogram

DISCHARGE RATINGS FOR CONTROL GATES AT MISSISSIPPI RIVER LOCK AND DAM 13, FULTON, ILLINOIS

By Albert J. Heinitz

ABSTRACT

The water level of the navigation pools on the Mississippi River are maintained by the operation of tainter and roller gates at the locks and dams. Discharge ratings for the gates on Lock and Dam 13, at Fulton, Illinois, were developed from current-meter discharge measurements made in the forebays of the gate structures. Methodology is given to accurately compute the gate openings of the tainter gates. Discharge coefficients, in equations that express discharge as a function of tailwater head, forebay head, and height of gate opening, were determined for conditions of submerged-orifice and free-weir flow. A comparison of the rating discharges to the hydraulic-model rating discharges is given for submerged orifice flow for the tainter and roller gates.

INTRODUCTION

The present navigation system on the upper Mississipppi River between St. Paul, Minnesota, and St. Louis, Missouri, was initiated in 1930 when Congress passed the River and Harbor Act authorizing funds for its development. This legislation provided for a navigation channel at least 9 feet deep and 400 feet wide, to be established by constructing a series of locks and dams, and maintained by channel dredging. The dams create a series of "steps" which allow towboats or other river vessels to travel upstream or downstream. Each dam controls the level of its pool and the locks lift or lower vessels from one pool to the next. Lock and Dam 13 was placed in operation May 13, 1939.

This is the fifth in a series of reports relating to discharge ratings and hydraulic characteristics of the control gates at locks and dams on the Mississippi River. The reports for Locks and Dams 11, 12, 14 and 16 (Heinitz, 1985a, 1985b, 1986a, 1986b) preceded this report. Discharge ratings for these Locks and Dams corroborated rating development for Lock and Dam 13.

Purpose and Scope

Central to the efficient operation of the navigation system is the availability of reliable discharge ratings for the flow-control structures. The purpose of this report is to describe the results of a study to develop discharge ratings for the control gates at Lock and Dam 13. The ratings were developed by using the results of current-meter discharge measurements, made in the forebays of the control-gate structures, to verify and evaluate the discharge coefficients for the theoretical discharge equations. Discharge ratings (U.S. Army Corps of Engineers, 1940) originally developed from laboratory tests on hydraulic models of the gates had never been verified with field data.

The scope of the work covered in this report includes results of current-meter discharge measurements, methodology for computing tainter-gate openings, development of discharge coefficients and equations of discharge, definition of rating tables of discharge for submerged-orifice flow, comparison of submerged-orifice flow discharges to hydraulic-model rating discharges, and a comparison of discharges computed from methods described in this study to those listed in the U.S. Army Corps of Engineers' gate operation schedule for Lock and Dam 13.

Acknowledgments

This project was completed in cooperation with the U.S. Army Corps of Engineers, Rock Island District. Personnel from the Corps assisted in making current-meter discharge measurements at the dam. Special acknowledgement is given to the Corps' Lockmaster for arranging to have the gates adjusted as needed for the measurements.

LOCATION OF STUDY AREA

Lock and Dam 13, located at Fulton, Illinois, is a unit of the Inland Waterway Navigation System of the upper Mississippi River Basin. The part of the navigation system within the Rock Island District (U.S. Army Corps of Engineers, 1980, pl. 1) is shown in figure 1.

FLOW-CONTROL STRUCTURES

Four types of flow-control structures are present at Lock and Dam 13. These are tainter gates, roller gates, navigation lock and a fixed spillway. Detailed theoretical as well as physical descriptions of these flow-control structures are beyond the scope of this report, and, therefore, are not included. Readers interested in this subject are referred to Davis and Sorensen (1952), Rouse (1949), Creager and Justin (1950) and King and Brater (1954). The hydraulic conditions that define each flow regime and the corresponding generalized steady-state discharge equations for the flow-control structures are summarized in table 1. An important parameter common to all types of flow-control structures is the discharge coefficient.

The discharge coefficients are functions of various independent hydraulic-control variables, of which the most significant are: the static-headwater head (h_1), the static-tailwater head (h_3), and the gate opening (h_g). A discharge coefficient is defined as the ratio of measured discharge to theoretical discharge (ASCE, 1962). Discharge coefficients are determined by measuring discharge during conditions when the hydraulic-control variables are known and fixed. This procedure, referred to as calibration, may be performed on a hydraulic model under controlled laboratory conditions or in the field at the dam.

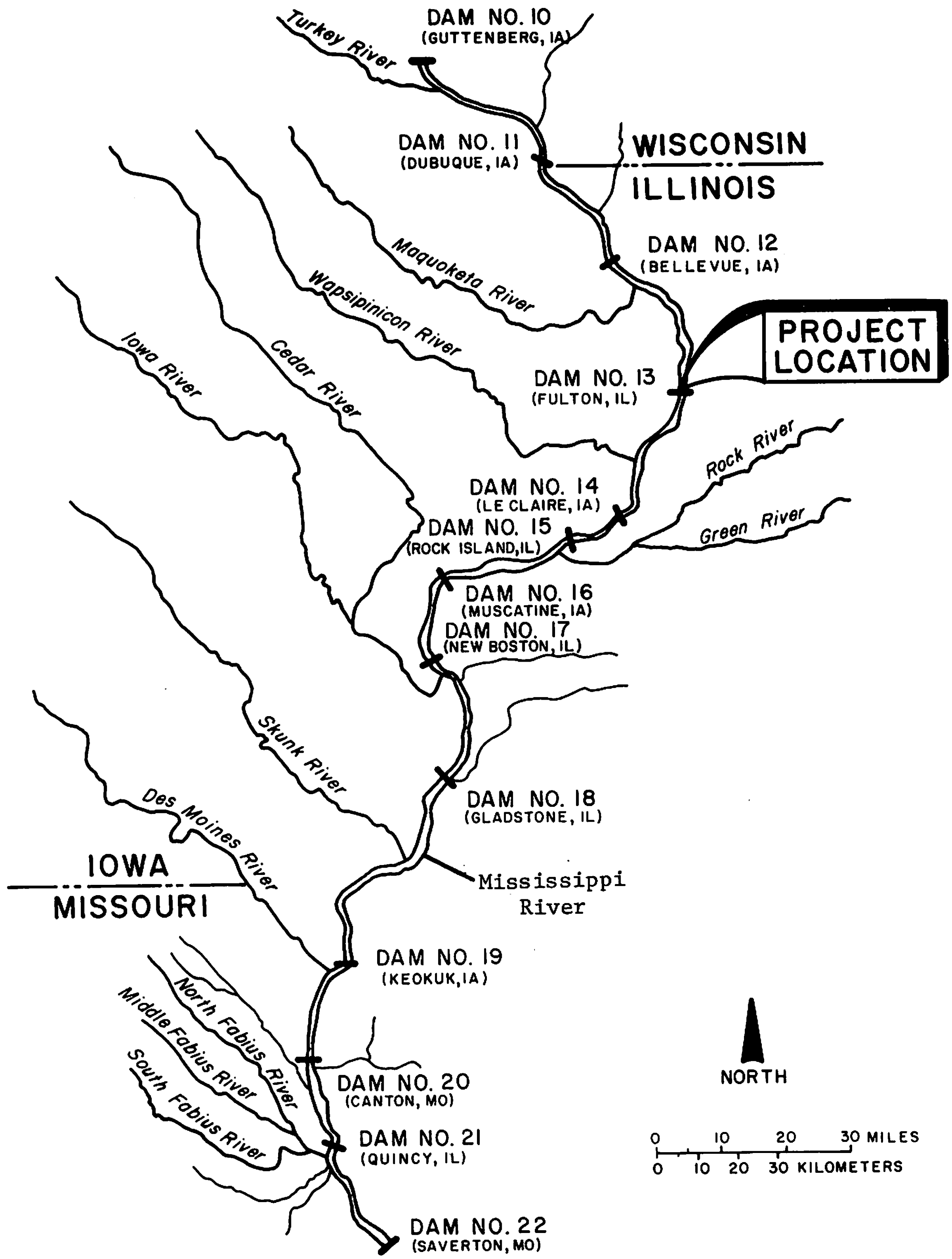


Figure 1.--Inland Waterway Navigation System of the upper Mississippi River basin (modified from U.S. Army Corps of Engineers, 1980, pl. 1).

Table 1.--Flow-control structures and their respective flow regimes and hydraulic equations

Flow-control structure	Flow regimes possible 1/	Hydraulic conditions necessary	Equations 2/	Equation number
Tainter and roller gates	Free orifice	$h_g < 0.67\ h_1$ and $h_3 < h_g$	$Q = C[h_g\ B(2g\ h_1)^{0.5}]$	(1)
	Submerged orifice	$h_g < 0.67\ h_1$ and $h_3 \geqslant h_g$	$Q = C_{gs}[h_3\ B(2g\ \ h)^{0.5}]$	(2)
	Free weir	$h_g \geqslant 0.67\ h_1$ and $h_3/h_1 < 0.6$	$Q = C_w[Bh_1{}^{1.5}]$	(3)
	Submerged weir	$h_g \geqslant 0.67\ h_1$ and $h_3/h_1 \geqslant 0.6$	$Q = C_w C_{ws}[Bh_1{}^{1.5}]$	(4)
Fixed spillway 3/	Free weir	$h_{3s}/h_{1s} < 0.6$	$Q_s = C_{sw}[B_s h_{1s}{}^{1.5}]$	(5)
	Submerged weir	$h_{3s}/h_{1s} \geqslant 0.6$	$Q_s = C_{sw} C_{sws}[B_s h_{1s}{}^{1.5}]$	(6)
Locks	--	$h > 0$	$Q_L = NA\ \Delta h/\Delta t$	(7)

1/The criteria used to separate orifice flow from weir flow is based on the fact that critical depth of flow in a rectangular channel is equal to two-thirds of the total head in the approach section. As the gate opening is increased above critical depth, the gate no longer acts as a control of discharge.

2/The bracketed parts of equations 1 through 6 represent the theoretical expression for discharge through a gate B units in width. The independent hydraulic-control variables are static-headwater head (h_1) static-tailwater head (h_3), and gate opening (h_g). The variable, Δh, represents the difference between the static-headwater and static-tailwater heads, and Δt, represents a time interval. N is the number of lockages and A is the area or width times length of the lock. The gravitational constant, g, is equal to 32.2 ft/s². Static-headwater and static-tailwater heads are the vertical distances from the gate sill or spillway crest to upstream and downstream pool elevations, respectively.

3/Same for flow over gate crest with gate in submerged position.

Tainter and roller gates are the only controls for which data are evaluated in this report. Coefficients for the fixed spillway are not defined. Flow through the locks can be computed by multiplying the volume of water contained in the lock times the number of lockages during a fixed period of time.

DAM OPERATION

Lock and Dam 13 contains 10 tainter gates and 3 roller gates for controlling the pool elevation upstream from the dam. Each tainter gate is 64.2 feet wide and 20 feet high and operates between the piers with 64.2-foot clear openings. The tainter gates are of the submergible type, capable of being lowered 8 feet below the sill elevation. Each roller gate is 100 feet wide and 20 feet high and operates between piers with 100-foot clear openings. The roller gates are of the submergible type, capable of 8 feet of submergence. Four of the tainter gates, located adjacent to the lock, are separated from the remainder of the tainter gates by the three roller gates, which are situated at about mid-channel (fig. 2). Sectional views of the tainter and roller gates are shown in figure 3.

Submerged-orifice flow predominates when the control gates at Dam 13 are in operation (U.S. Army Corps of Engineers, 1980, pl. 31). Free orifice flow rarely occurs at a low-head, navigation-type structure such as Dam 13 and would not occur at this dam under normal operating conditions.

Free-weir flow at Dam 13 would occur primarily with the gates in a submerged condition with flow over the crests of the gates. The gates are operated in the submerged position in the winter when there is no commercial navigation. Submerged weir flow could occur with the gates in a submerged condition at a time of high flow in the river. However, the gates would

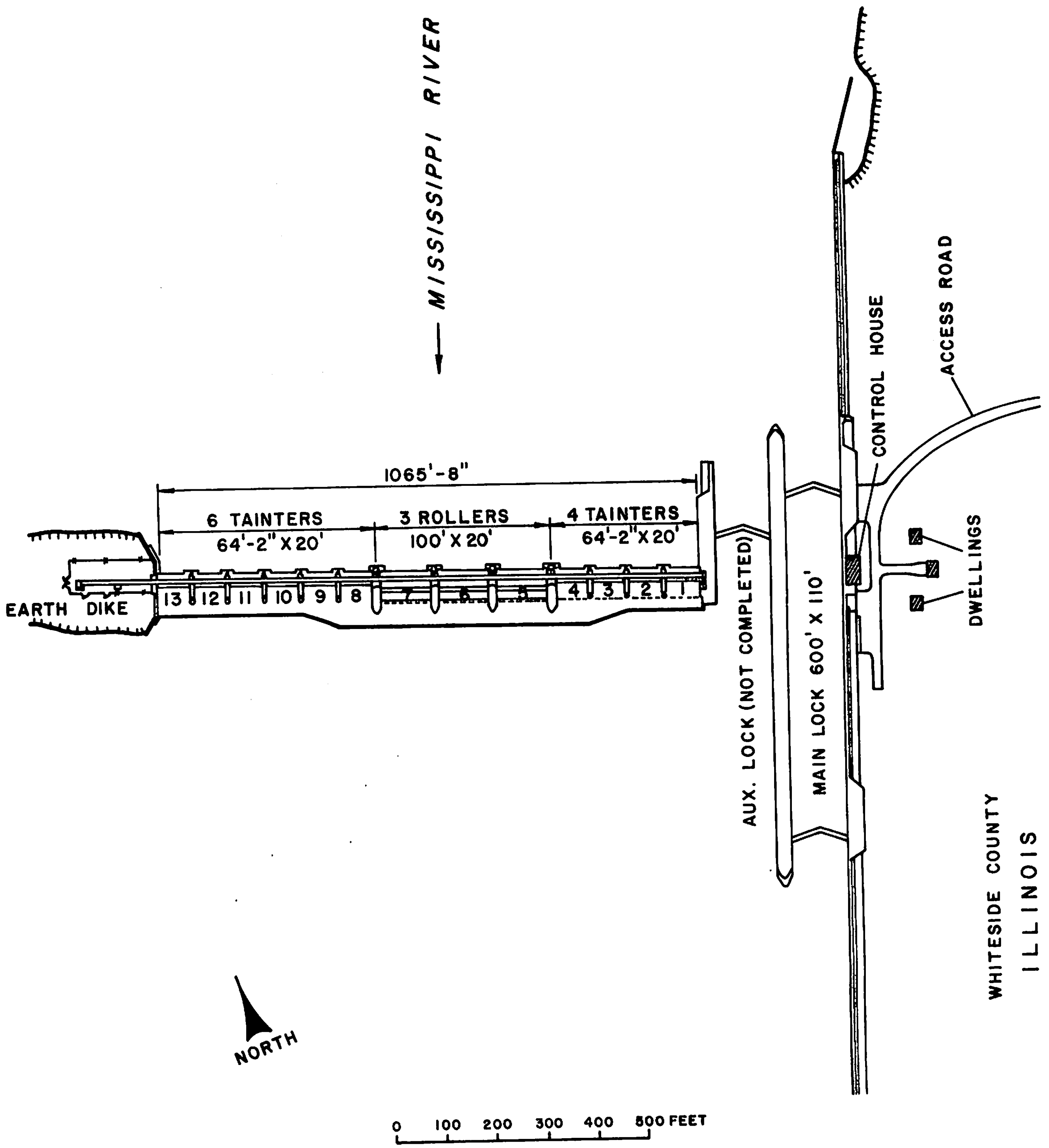
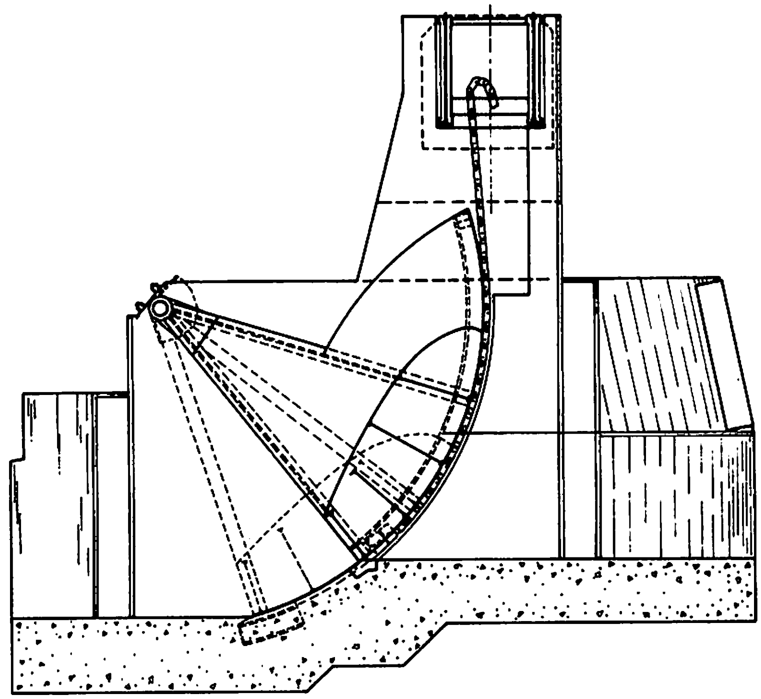
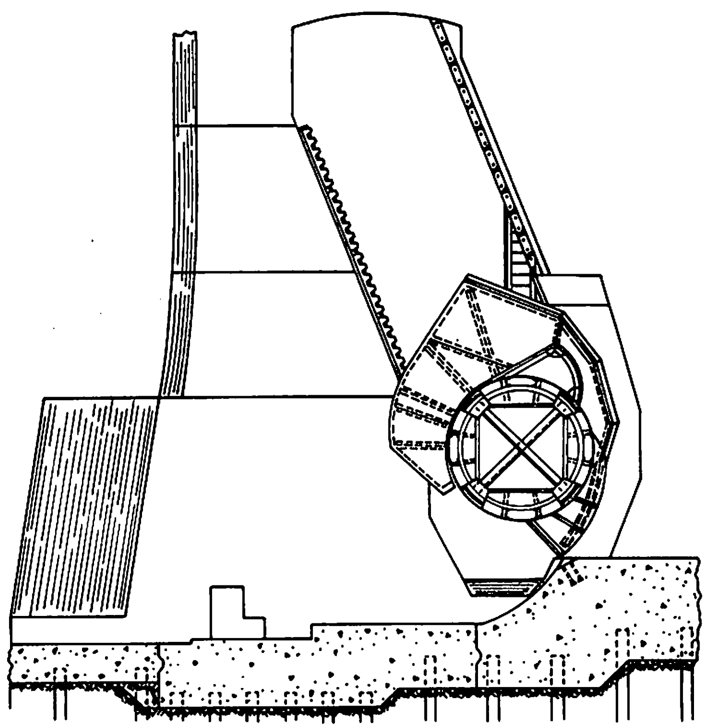


Figure 2.--Location of flow-control structures (modified from U.S. Army Corps of Engineers, 1980, pl. 2).



TAINTER GATE - SECTIONAL VIEW



ROLLER GATE - SECTIONAL VIEW

Figure 3.--Sectional views of tainter and roller gates (modified from U.S. Army Corps of Engineers, 1980, pls. 5 and 6).

normally be raised above the water surface before submerged weir flow would occur over the gate crests. Submerged-weir flow would also occur over the gate sills with the gates raised above the water surface when the dam is out of operation. This type flow is not evaluated in this report.

Operation of the control gates for maintaining the pool elevation is based on a study (U.S. Army Corps of Engineers, 1980) conducted to determine the optimum use of the dam for river flowage, conservation interests, and towboat service. Operation "Plan A" (U.S. Army Corps of Engineers, 1980, pl. 31) was adopted and put into use on April 17, 1940 and remains in effect. Plan "A" allows the high water levels to recede naturally until the authorized pool elevation for lower flows is reached.

Dam 13 is a run-of-the-river dam and cannot store water for flood control purposes. The pool is maintained between stages 13.9 and 14.4 feet. When the river is rising and the tailwater stage reaches 13.5 feet, the tainter and roller gates are raised above the water surface. During flood periods, the gates are raised out of the water allowing run-of-the-river flow to occur. During winter, when there is no commercial navigation and the pools become ice covered, the tainter and roller gates at Dam 13 are placed in the submerged position. The pool is maintained within the winter operating stage of 13.3 to 14.3 feet.

DISCHARGE AND STAGE MEASUREMENTS

The tainter and roller gates are built with a roadway over the structures giving access to the forebays with standard current-meter measuring equipment. The discharge measurements were made from the upstream edge of the roadway which is about 20 feet upstream from the downstream edge of the tainter-gate sills and about 25 feet upstream for the roller gates. The distance of the measuring equipment from the orifice and control structure appeared to be adequate to allow accurate measurements to be made. Some velocity measurements were made to define vertical velocity curves and to verify the standard 0.2 and 0.8 method of velocity observation. The measurements were made with equipment normally used for measuring large streams, velocity was measured using a type AA current meter suspended with Columbus-type sounding weights (50-150 pounds) from a collapsible crane (Rantz and others, 1982). A cable stay was used on top of the upstream piers to prevent the meter from running downstream into the gate orifice when the gates were opened 5 feet or more.

A total of 51 measurements of discharge ranging from 1,120 to 21,600 cubic feet per second in a gate were made in the forebays of the tainter and roller gate structures of Lock and Dam 13. Discharge coefficients for all the gates of the same design could be developed from measurements on a single gate. However, to insure greater accuracy because of the fluctuations of the pool and tailwater during the measurements and to account for variations in entrance and exit conditions, several gates were selected for calibration. Discharge was measured at least once through all but three (1, 10 and 13) of the gate bays for submerged orifice flow. Only tainter gate numbers 3, 9 and 12 and roller gate number 7 were measured with the gates in a free weir flow position. The results of these measurements are listed in table 2.

Table 2.--Summary of current-meter discharge measurements and hydraulic-control data for control gates at Mississippi River Lock and Dam 13

Gate number	Date	Head-water head h_1 1/ (feet)	Tail-water head h_3 2/ (feet)	Gage reading G (feet)	Gate opening h_g (feet)	Dis-charge (ft³/s)	Deviation from rating (percent)	Sub-mer-gence ratio (h_3/h_g)	Flow coef-ficent (C_{gs})	Flow 3/ regime
2	08-26-85	20.20	11.41	2.00	2.10	2,610	- 1.5	5.43	0.150	SO
3	08-26-85	20.23	11.31	1.00	1.03	1,240	- 0.8	10.98	0.071	SO
3	08-26-85	20.24	11.31	2.00	2.02	2,590	+ 1.2	5.60	0.149	SO
3	08-26-85	20.20	11.41	3.00	3.00	3,880	0	3.80	0.223	SO
3	08-26-85	20.20	11.41	5.00	4.95	7,080	+ 6.8	2.30	0.407	SO
3	03-19-85	20.13	16.91	8.00	8.01	6,460	- 1.1	2.11	0.414	SO
3	03-19-85	20.13	16.91	9.00	9.00	7,810	+ 5.5	1.88	0.500	SO
3	03-19-85	20.13	16.94	10.00	10.05	9,290	+12.1	1.69	0.596	SO
3	08-26-85	20.23	11.30	2.00s	2.33b	1,280	+11.3		5.61w	FW
3	08-26-85	20.23	11.30	4.00s	4.33b	2,490	- 0.4		4.30w	FW
3	11-06-85	19.85	14.25	5.00s	4.95b	2,920	- 2.0		4.13w	FW
3	11-06-85	19.86	14.26	6.00s	5.96b	3,740	- 1.8		4.00w	FW
3	11-06-85	19.87	14.26	7.00s	6.97b	4,640	- 1.3		3.93w	FW
4	08-26-85	20.23	11.30	2.00	2.05	2,400	- 7.7	5.51	0.138	SO
5	08-26-85	20.23	11.30	2.50		3,950	- 1.5	4.52	0.146	SO
5	08-28-85	19.97	11.19	3.00		5,080	+ 6.5	3.73	0.191	SO
5	08-28-85	19.97	11.19	4.00		6,660	+ 4.7	2.80	0.250	SO
6	08-26-85	20.23	11.31	2.50		3,670	- 8.5	4.52	0.135	SO
6	03-19-85	20.06	17.00	7.50		8,340	+ 1.8	2.27	0.350	SO
6	03-19-85	20.13	16.95	8.40		11,800	- 8.5	2.02	0.487	SO
6	03-19-85	20.06	17.02	9.00		16,200	- 0.6	1.89	0.681	SO
6	03-19-85	20.10	16.98	9.50		20,300	- 0.5	1.79	0.844	SO
6	03-19-85	20.08	17.00	10.00		21,600	-11.8	1.70	0.903	SO
7	08-27-85	20.23	11.37	2.10		3,150	- 6.2	5.41	0.116	SO
7	08-27-85	20.21	11.37	3.50		5,580	- 0.2	3.25	0.206	SO
7	08-27-85	20.25	11.37	4.50		7,510	+ 4.3	2.53	0.276	SO
7	11-06-85	19.91	14.27	6.00		8,420	+10.1	2.38	0.310	SO
7	08-27-85	20.25	11.34	2.00s	2.70b	2,310	- 5.3		5.21w	FW
7	11-06-85	19.96	14.28	2.00s	2.41b	1,980	- 8.3		5.29w	FW
7	08-27-85	20.25	11.32	4.00s	4.70b	4,580	+ 5.5		4.49w	FW
7	11-06-85	19.92	14.27	5.00s	5.37b	4,850	- 2.6		3.90w	FW
7	11-06-85	19.93	14.27	6.00s	6.38b	5,750	- 3.5		3.57w	FW
8	08-27-85	20.25	11.29	2.00	1.95	2,370	- 4.0	5.79	0.136	SO
9	08-27-85	20.20	11.42	1.00	1.01	1,290	+ 6.6	11.31	0.074	SO
9	08-27-85	20.21	11.38	2.00	1.98	2,310	- 7.2	5.75	0.133	SO
9	08-27-85	20.20	11.40	4.00	3.96	5,400	+ 3.2	2.88	0.310	SO
9	03-20-85	20.00	16.90	7.00	6.96	5,840	+ 5.8	2.43	0.381	SO
9	03-20-85	19.99	16.92	8.00	7.96	6,260	- 1.3	2.13	0.410	SO
9	08-27-85	20.24	11.28	2.00s	2.34b	1,170	+ 0.9		5.09w	FW
9	08-27-85	20.23	11.30	4.00s	4.33b	2,520	+ 0.8		4.34w	FW
9	11-06-85	19.97	14.32	5.00s	5.07b	3,050	- 0.7		4.16w	FW
9	11-06-85	19.97	14.36	6.00s	6.07b	3,800	- 2.6		3.96w	FW
11	08-27-85	20.18	11.42	2.00	1.92	2,430	+ 1.2	5.95	0.140	SO
12	08-28-85	19.99	11.25	1.00	0.96	1,210	+ 6.1	11.72	0.071	SO
12	08-27-85	20.17	11.42	2.00	1.93	2,370	- 1.7	5.92	0.136	SO
12	08-27-85	20.17	11.42	4.00	3.90	5,080	- 1.0	2.93	0.292	SO
12	03-20-85	20.00	16.88	6.00	5.91	4,380	- 5.8	2.86	0.285	SO
12	03-20-85	20.00	16.88	7.00	6.88	5,400	- 1.3	2.45	0.352	SO
12	03-20-85	20.00	16.88	8.00	7.89	6,170	- 2.5	2.14	0.402	SO
12	08-28-85	19.98	11.21	2.00s	2.08b	1,120	+10.9		5.82w	FW
12	08-28-85	19.98	11.20	4.00s	4.08b	2,370	+ 2.2		4.48w	FW

1/ h_1 = Pool stage + 5.70 feet.
2/ h_3 = Tailwater stage + 5.70 feet.
3/ SO designates submerged-orifice flow.
FW designates free-weir flow.
b Computed headwater, h_{1s}, over gate crest.
s Gate in submerged position
w Coefficient, C_{sw}, for free-weir flow.

Leakage, which is common to submergible gates because of the clearance provided between the gate and sill for lowering the gates, was not separately determined. The flow attributable to leakage is included in the discharge measurements and in the discharge equations.

The concurrent pool and tailwater stages for the measurements were obtained from the gages in the operations control building. The static-headwater head (h_1) and static-tailwater head (h_3) referenced to the gate sill are obtained by adding 5.70 feet to the gage readings. The stages can be referenced to sea level by adding the zero gage datum, 568.70 feet (1912 adjustment), to the stages. The gate-opening settings for the tainter gates were read from the staff-indicator gages on the tainter gates and those for the roller gates were read from the shaft-indicator marks on the operating machinery.

TAINTER-GATE FLOW

Computation of Gate Opening

The gate opening, h_g, is the most important variable in calibrating the flow through tainter gates. In most cases, the gate opening cannot be measured directly in the field during operation of the structure. Therefore, the gate opening is computed indirectly using pertinent geometric properties of the gates and direct measurements of the elevation of a selected reference point on each gate. Dimensions of gate-structure members that can not be measured on the gate are obtained from the construction plans. These include the gate radius, R, and the included angle, θ, of the gate structure (fig. 4).

The reference point (R.P.) established for computing the gate opening, h_g, for the tainter gates on Dam 13 is the top of a rivet on an angle iron connecting the top gate arm to the arched crest of the gate structure. The rivet is the second, of four rivets, from the pier and is 0.5 foot below the top edge of the gate arm (fig. 4). The R.P. is 15.37 feet from the trunnion centerline and is the same for all the gates. The elevation of each R.P. and the trunnion centerlines was determined by levels from established benchmarks on the piers between the gates (U.S. Army Corps of Engineers, 1974). The vertical gate opening, h_g, is computed from the equation:

$$h_g = 24.00 - 30.04 \sin(36.390 + \phi_u) \qquad (8)$$

where $\phi_u = \sin^{-1}$ [(Trunnion elev. - R.P. elev.)/15.37]

The terms in the equation are graphically displayed in figure 4. The average elevation of the trunnion centerlines was found at 586.96 feet with variations from 586.92 to 587.00 feet.

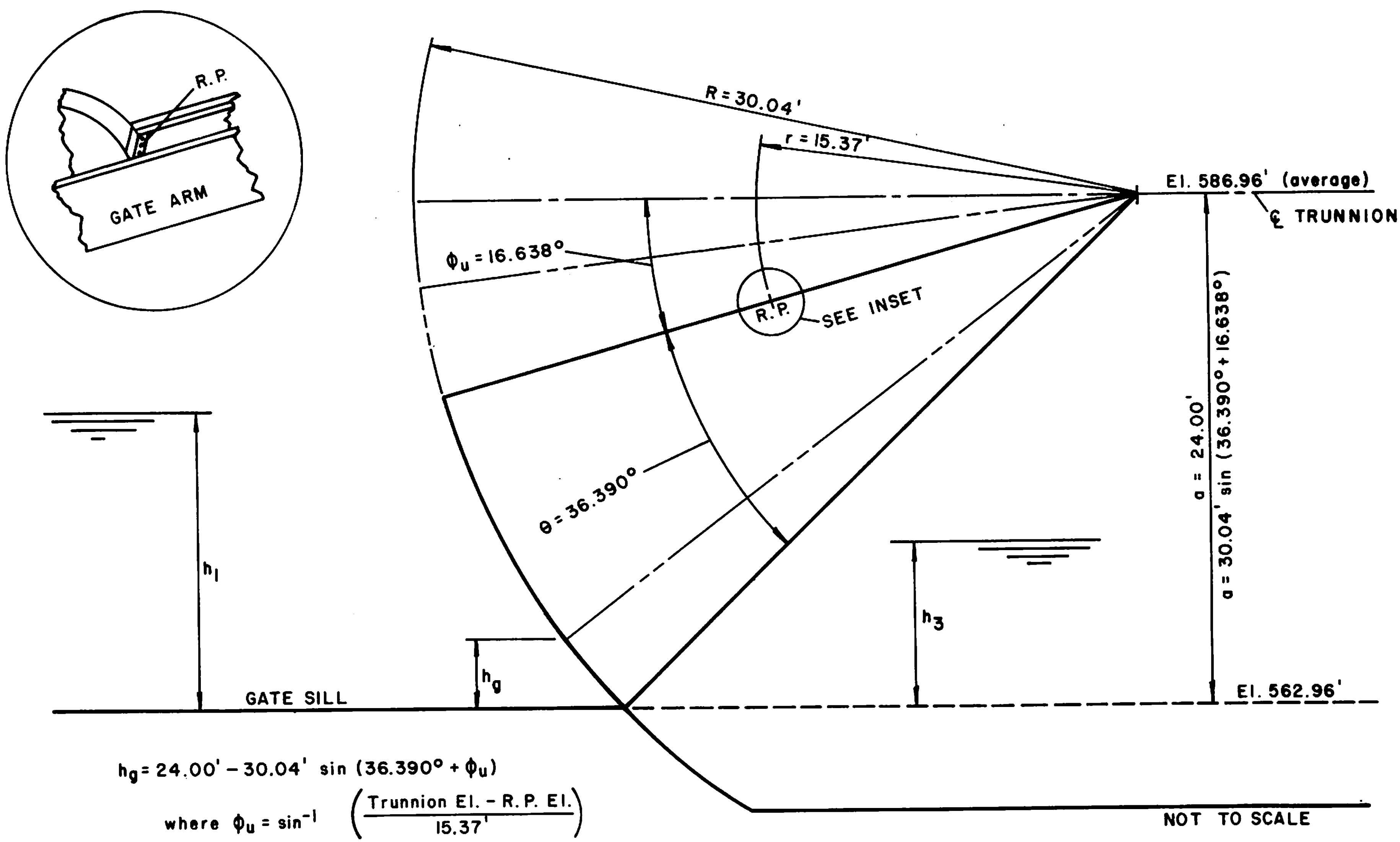


Figure 4.--Details of tainter gates at Mississippi River Lock and Dam 13.
See page vi for definition of symbols.

Because the gates are submergible, there is no way to determine at what position the gates are in a "closed" position. Defining the relation between the "true" gate opening (h_g) and the gage indicator is relatively straight forward for non-submergible gates, such as those for Lock and Dam 14, where $h_g = 0$ can be determined by closing the gate. (With the gates at Dam 14 in a closed position ($h_g = 0$), computations of the gate openings (h_g) erroneously indicate that the gates are open an average of 0.19 foot. This 0.19 foot error was eliminated by adjusting the included angle of the gate). The decision was arbitrarily made to adjust the included angle of the dam 13 tainter gate structure so that the average computed gate openings (h_g) would be the same as the gage-indicator readings. The resulting angle of the gate structure is 36.390 degrees (fig. 4). Note that the angle of 36.390 degrees is not the full included angle of the gate structure because the R.P. is 0.5 foot below the top edge of the upper gate arm. The advantage of using this approach is that the discharge for the average gate openings can be computed using the gage-indicator readings directly. The adjusted h_g values for a 2.00 foot gate opening range from 1.92 to 2.10 feet. Corrections (e) for the individual gates and the relation of the gate openings (h_g) to the 2.00-foot gage-indicator setting are shown in figure 5.

A gage-indicator error of 0.10 foot will result in about a 5-percent deviation in discharge from the rating discharge at the 2.00 foot gage setting. This deviation from the rating discharge increases with lower gage settings (about 10 percent at the 1.00-foot gage setting) and decreases at higher gage settings (about 3 percent at the 4.00-foot gage setting). The deviation of discharge from the rating discharge for the individual gates could be minimized by adjusting the gage indicators to more nearly reflect the computed gate opening, h_g.

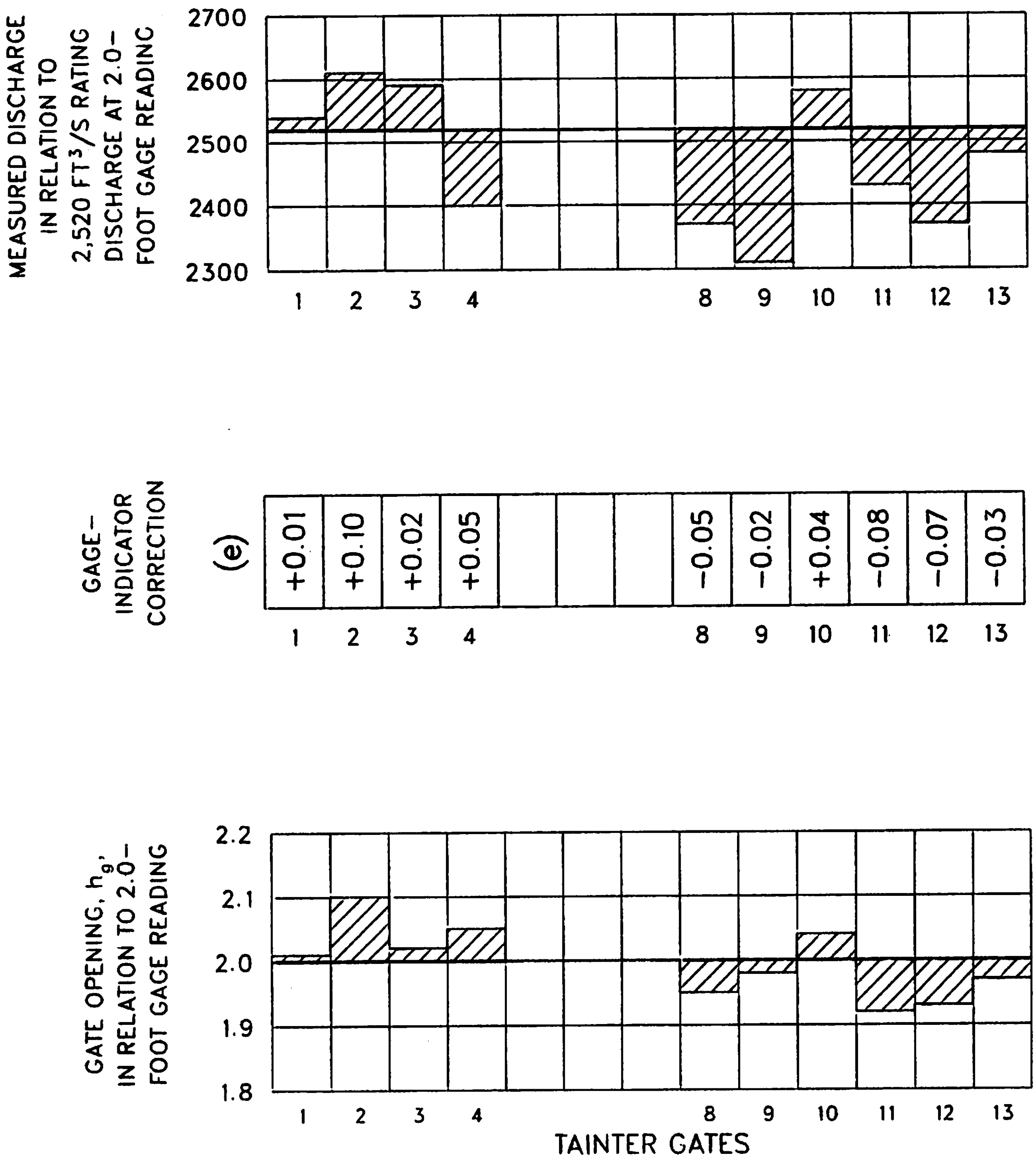


Figure 5.—Gage-indicator corrections and comparison of gate openings and discharges at 2.0-foot gage-indicator settings for tainter gates on Mississippi river Lock and Dam 13.

Submerged-Orifice Flow Coefficients

Discharge coefficients for submerged orifice flow were computed by solving equation 2 in table 1 for C_{gs} using the results of the discharge measurements (table 2) that were made with the gates in submerged-orifice flow conditions. The submerged-orifice flow coefficients, C_{gs}, are listed in table 2 and a graph defining the relationship of C_{gs} to the orifice-submergence ratio is shown in figure 6. The resulting equation, relating the submerged-orifice coefficient, C_{gs}, to the orifice submergence ratio, h_3/h_g, is:

$$C_{gs} = 0.93\ (h_3/h_g)^{-1.07} \tag{9}$$

The submerged-orifice flow coefficient, C_{gs}, at submergence ratios less than about 1.9 are greater than those extrapolated from the curve relation (fig. 6) and indicates that a new coefficient relation may exist in this range. This trend was also noted by Collins (1977).

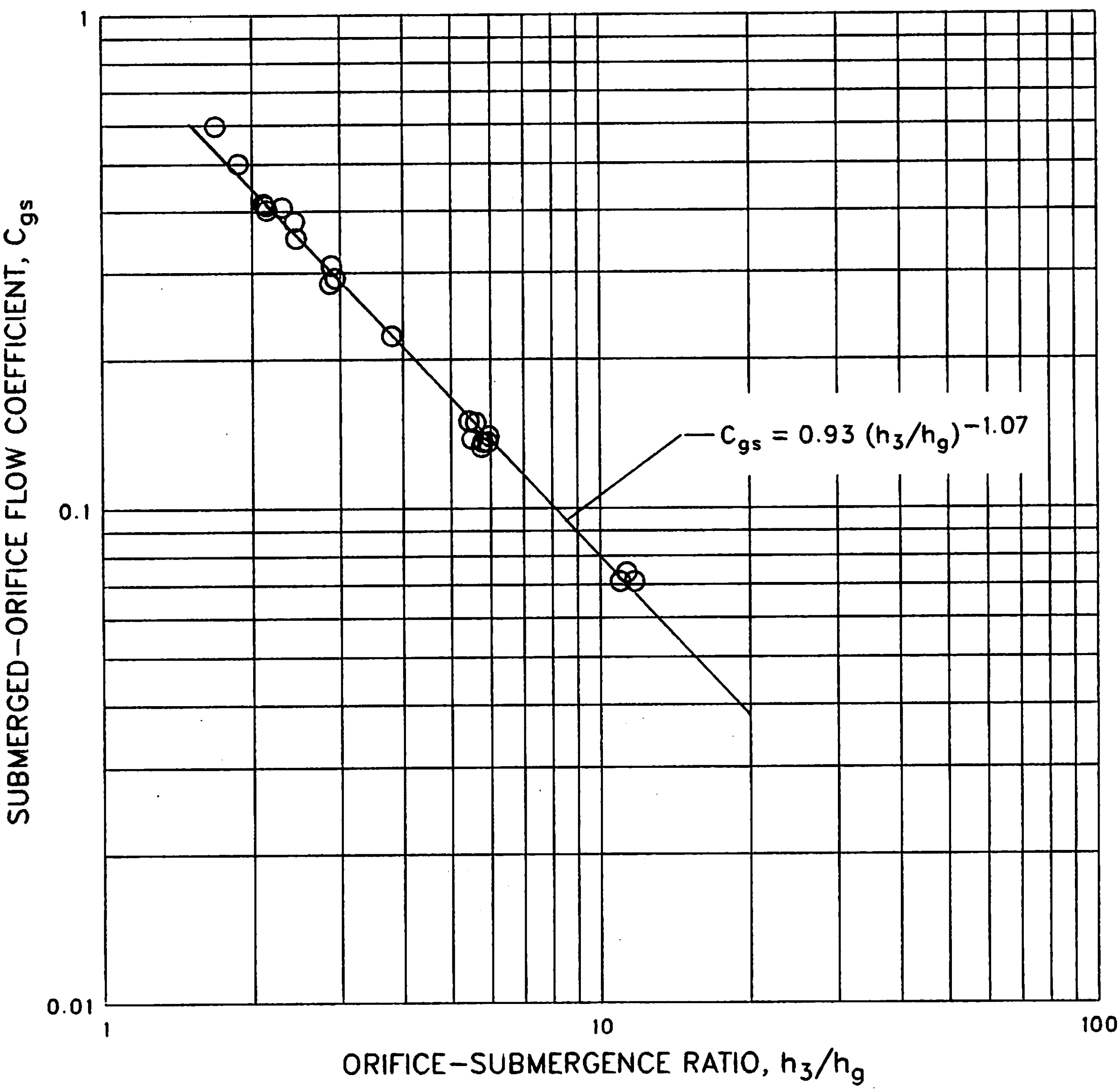


Figure 6.—Relation between submerged–orifice flow coefficient and orifice–submergence ratio for Lock and Dam 13 tainter gates.

Submerged-Orifice Discharge Equation

An equation for computing discharge for submerged-orifice flow in the tainter gate bays was developed using the submerged-orifice equation (2) and substituting equation 9 for the submerged-orifice coefficient, C_{gs}. The resulting equation relating the discharge (Q) to the orifice-submergence ratio (h_3/h_g) and the static-headloss $(h_1 - h_3)$ is:

$$Q = 479\ h_3\ (h_3/h_g)^{-1.07}\ (h_1 - h_3)^{0.5} \qquad (10)$$

where h_g = gage-indicator reading + the individual gage-indicator correction (e) shown in figure 5 (the average correction, e, for all the tainter gage indicators is 0), h_3 = the tailwater gage reading plus 5.70 feet and $h_1 - h_3$ = the difference between the pool and tailwater gage readings.

The relation of the current-meter discharge measurements made at the tainter gates on August 26-28, 1985, to the discharge curve defined by equation 10 is shown in figure 7.

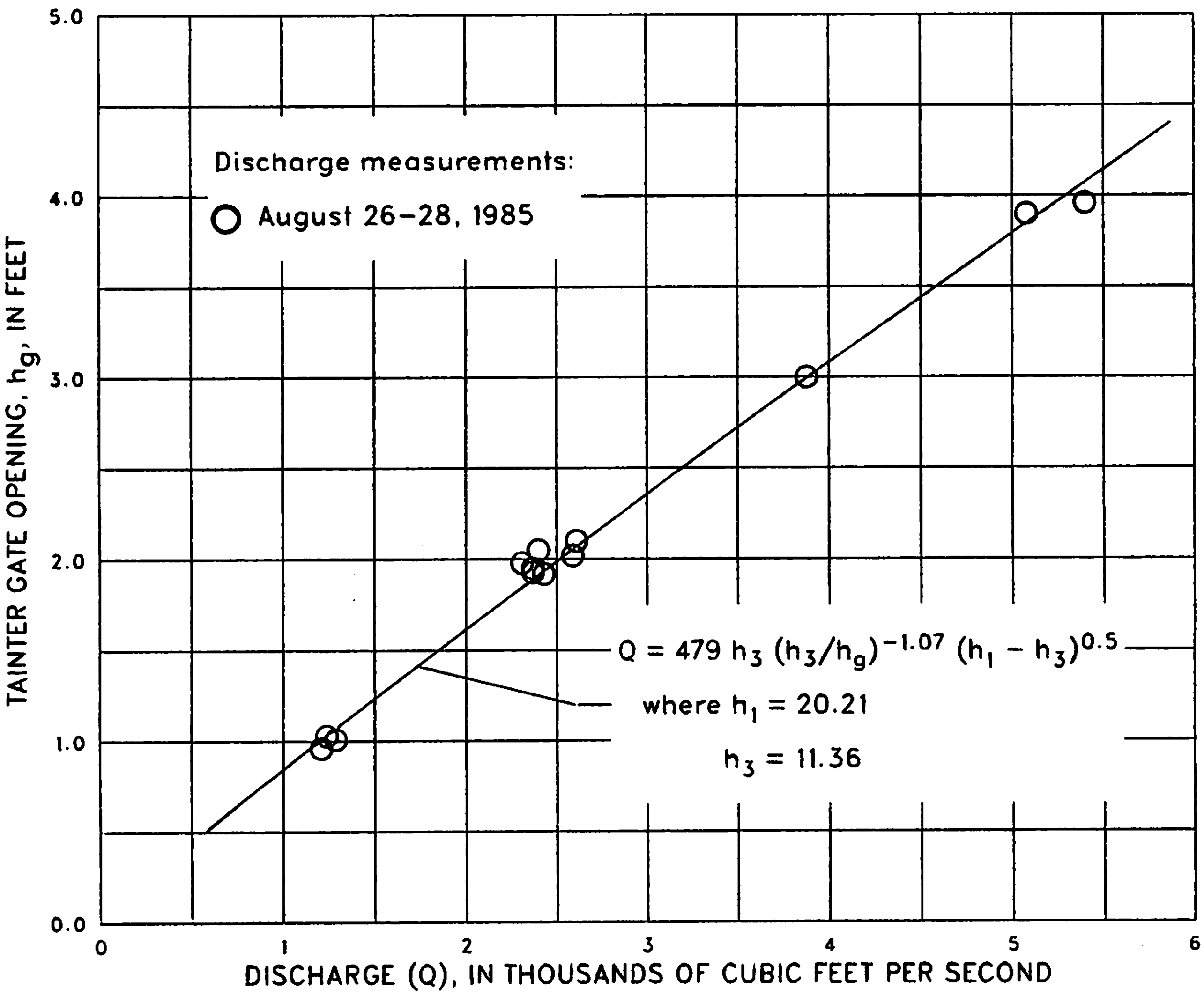


Figure 7.--Comparison of current-meter discharge measurements of August 26-28, 1985, to rating curves for tainter gates at Mississippi River Lock and Dam 13.

Free-Weir Flow Coefficients

Discharge coefficients for free-weir flow for tainter gates 3, 9 and 12 were computed by solving equation 5 in table 1 for C_{sw} using the results of the discharge measurements (table 2) that were made with the gate in a submerged position. The free-weir coefficients, C_{sw}, are listed in table 2 and a graph defining the relationship of C_{sw} to the static-headwater head (h_{1s}) over the gate crest is shown in figure 8. The resulting equation, relating the free-weir coefficient, C_{sw}, to the static-headwater head, h_{1s}, is:

$$C_{sw} = 3.6\ (h_{1s})^{-0.86} + 3.3 \tag{11}$$

where h_{1s} = gage reading + 0.10 + (pool stage - 14.30). Also shown in figure 8 are the coefficients for Locks and Dams 11 and 12. These coefficients were used to cooborate the coefficient-headwater relation for Lock and Dam 13. The correction to the gage readings was derived from the observed gage reading at the point of zero flow over the gate crests for gates 3, 9 and 12 and elevations of the R.P. taken at each of the gate settings when a measurement of discharge was made.

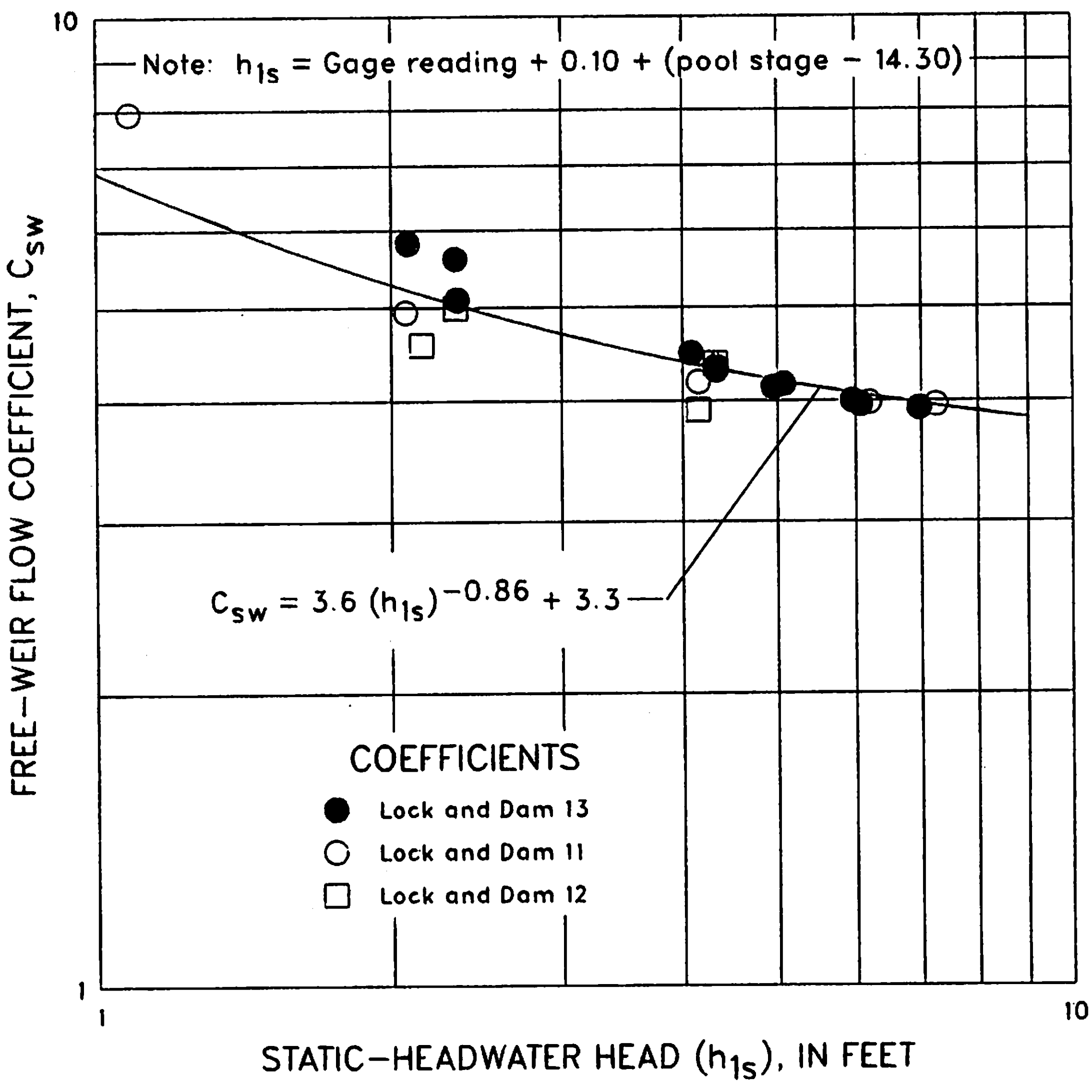


Figure 8.−−Relation between free−weir flow coefficient and static−headwater head for tainter gates in submerged position for Lock and Dam 13.

Free-Weir Discharge Equation

An equation for computing free-weir flow in the tainter gates was developed using the free-weir flow equation (5) and substituting equation 11 for the free-weir coefficient, C_{sw}. The resulting equation, graphically illustrated in figure 9, relating the discharge (Q_s) to the static-headwater (h_{1s}) over the gate crest is:

$$Q_s = 212\ (1.09\ h_{1s}^{0.64} + h_{1s}^{1.50}) \tag{12}$$

where h_{1s} is as defined for equation 11 above. Also shown in figure 9 are the discharge measurements made at Locks and Dams 11 and 12. For comparison, however, the discharges for the measurements at Lock and Dam 11 were adjusted from the 60.0 feet tainter gate width to the 64.2 feet tainter gate width of the Lock and Dam 13 gates. These measurements were used to corroborate the rating development for Lock and Dam 13.

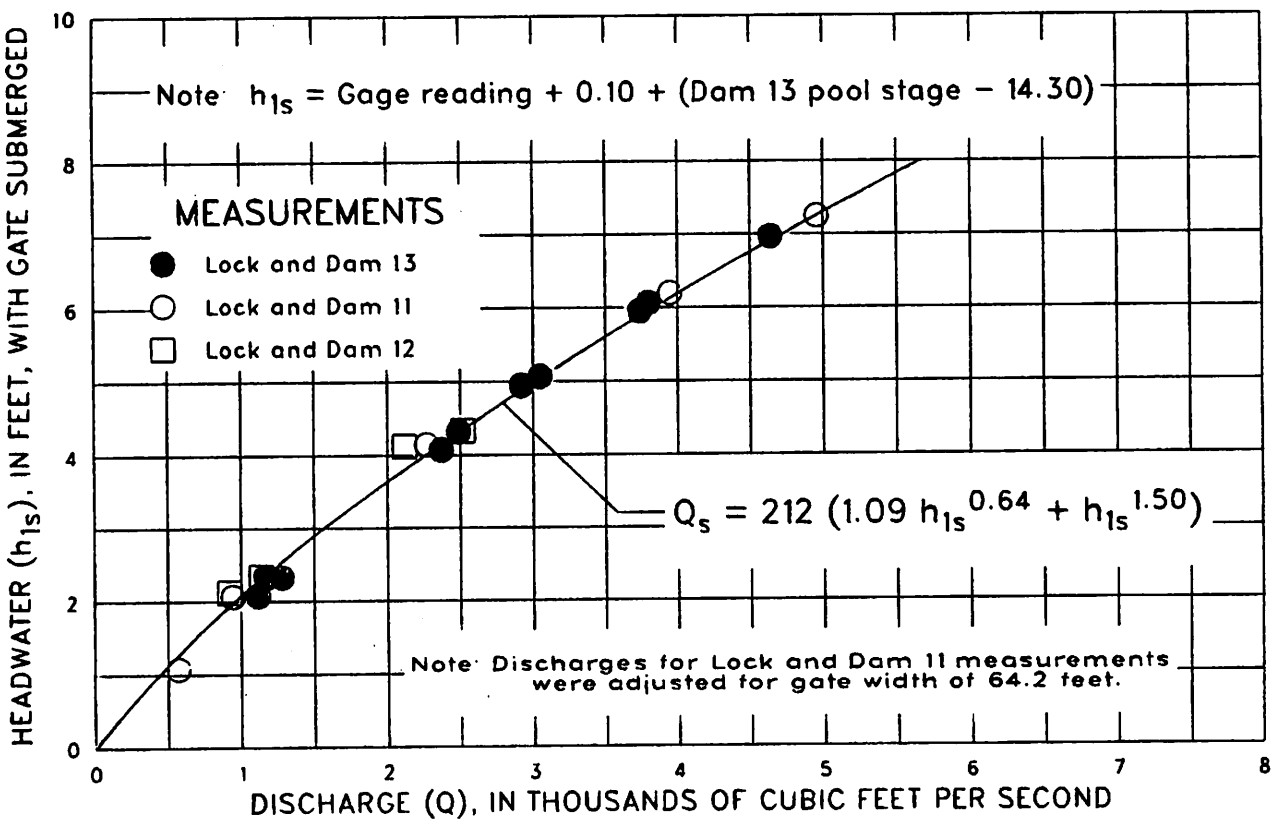


Figure 9.--Relation between discharge and headwater for free-weir flow for tainter gates in submerged position for Lock and Dam 13.

ROLLER-GATE FLOW

Gate Opening

The gate-opening indicator marks for the roller gates are an integral part of the operating machinery of the gate. These indicators presumably give a fairly accurate reading of the gate opening. A method for measuring the actual gate openings was not developed.

Submerged-Orifice Flow Coefficient

Discharge coefficients for submerged-orifice flow for Dam 13 were used to define the relation with the orifice-submergence ratio, h_3/h_g. The coefficients were computed by solving equation 2 in table 1 for C_{gs} using the results of the discharge measurements (table 2) that were made under submerged-orifice flow conditions.

The relation of the submerged-orifice flow coefficient, C_{gs}, to the orifice-submergence ratio, h_3/h_g, for the roller gates on Dam 13 is shown in figure 10. Also shown is the relation developed for Lock and Dam 12 and the coefficients for Lock and Dam 11. These data are shown for corroboration of the coefficient relation development and also to show the similarity of the relations for the various Dams. The break in the relation occurs at a point when the gate is open 7 feet or more and the submergence ratio is less than 2.4 for the Dam 13 roller gates. The break in the relationship apparently occurs when control of flow of the roller gate transfers from the lower apron (appendage to the drum) on the roller to the drum of the gate structure. The control positions of the roller gate are illustrated in figure 11 and show that the effective gate opening increases significantly when control transfers from the apron to the drum when the gate is opened more than 7.0 feet.

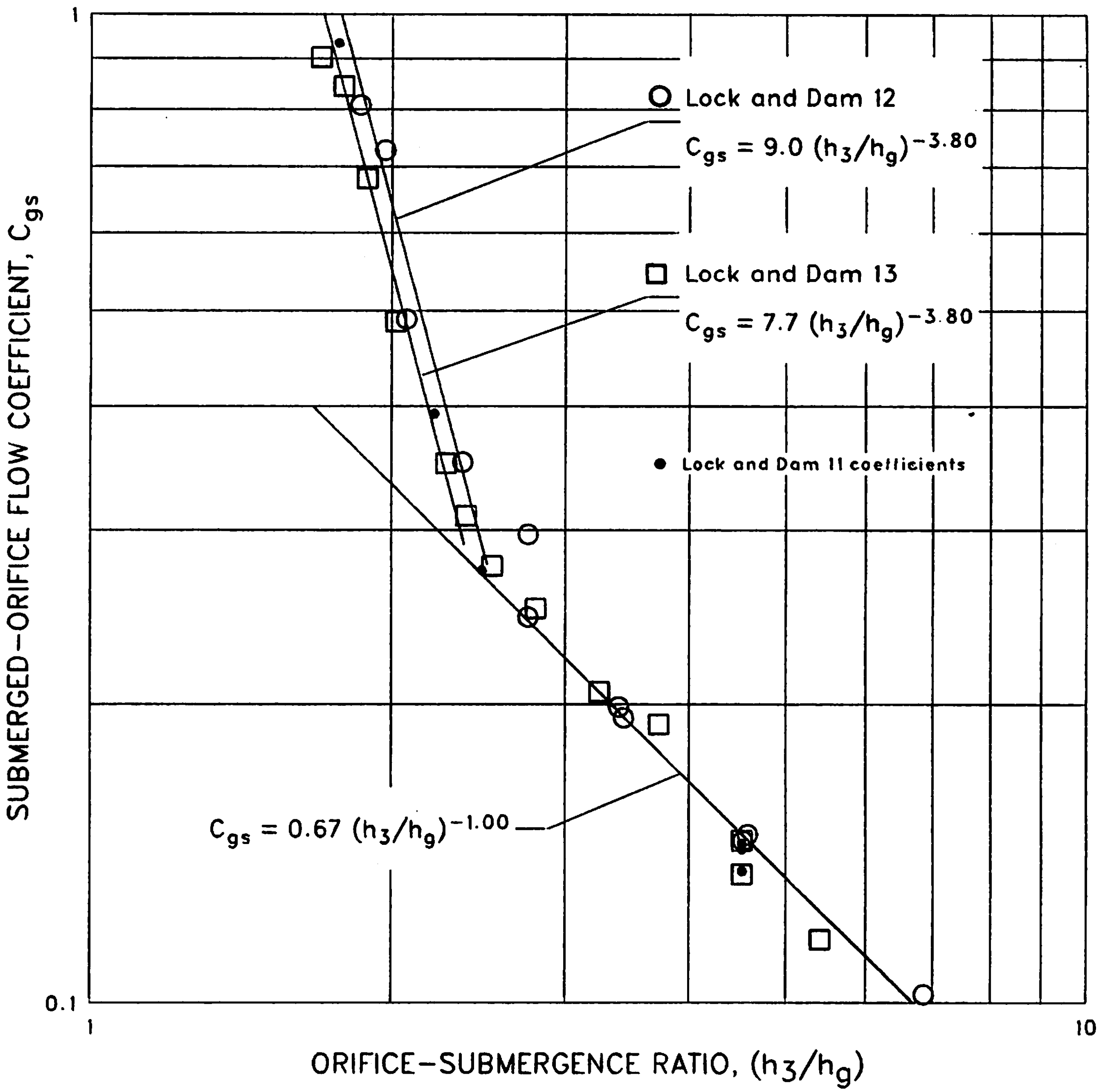


Figure 10.--Relation between submerged-orifice flow coefficient and orifice-submergence ratio for Lock and Dam 13 roller gates

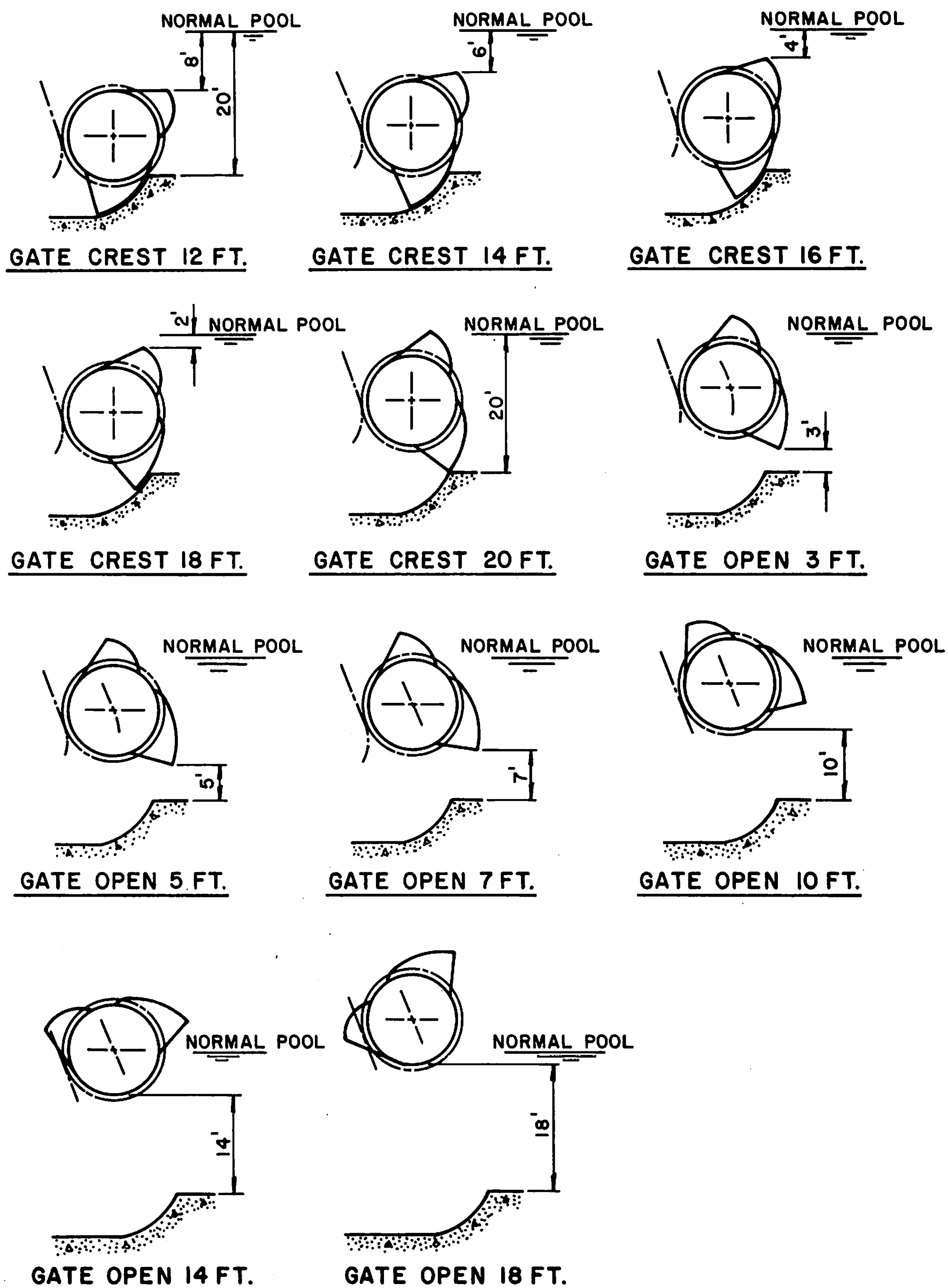


Figure 11.—Positions of roller gates for selected crests and openings (modified from U.S. Army Corps of Engineers, 1940, fig. 35).

The exact gate opening where the control changes has not been defined. The resulting equation, relating the submerged-orifice coefficient, C_{gs}, to the orifice-submergence ratio, h_3/h_g, for the roller gates when the gates are open less than 7 feet is defined by the equation:

$$C_{gs} = 0.67\ (h_3/h_g)^{-1.00} \tag{13}$$

As noted by Collins (1977) and described by King and Brater (1954), many structures calibrated by the procedures outlined above are found to be independent or nearly independent of submergence. If the coefficient is independent of the submergence, the slope of the straight line relation will be -1.00 as in equation 13. When substituted for the coefficient in the submerged-orifice flow equation (2), the equation reduces to the free-orifice equation (1). The average of the coefficients computed for the roller gates at Dam 12 using the free-orifice equation (1) was 0.67. This same coefficient was also computed for the roller gates at Locks and Dams 11, 12 and 14. The 0.67 coefficient is in total agreement with those in King and Brater (1954, table 26) for rectangular orifices with partially suppressed contraction.

For conditions when the gates are open 7 feet or more and the orifice-submergence ratio is less than 2.4, the submerged-orifice coefficient, C_{gs}, for the Dam 13 roller gates is defined by the equation:

$$C_{gs} = 7.70\ (h_3/h_g)^{-3.80} \tag{14}$$

The computed coefficients and the results of the measurements made for the roller gates at Dam 13 are listed in table 2.

Submerged-Orifice Discharge Equation

An equation for computing discharge for submerged-orifice flow when the roller gates are open less than 7.0 feet was developed using the submerged-orifice flow equation (2) and substituting equation 13 for the submerged-orifice coefficient, C_{gs}. The resulting equation relating the discharge (Q) to the gate opening (h_g) and the static-headloss ($h_1 - h_3$) is:

$$Q = 537 \; h_g \; (h_1 - h_3)^{0.5} \tag{15}$$

where $h_1 - h_3$ = the difference between the pool and tailwater gage readings.

An equation for computing discharge for submerged-orifice flow when the roller gates are open 7.0 feet or more and h_3/h_g is less than 2.4 feet was developed using the submerged-orifice flow equation (2) and substituting equation 14 for the discharge coefficient, C_{gs}. The resulting equation, relating the discharge (Q) to the static-tailwater head (h_3), orifice-submergence ratio (h_3/h_g) and the static-headloss ($h_1 - h_3$) is:

$$Q = 6{,}170 \; h_3 \; (h_3/h_g)^{-3.80} \; (h_1 - h_3)^{0.5} \tag{16}$$

where h_3 = tailwater-gage reading plus 5.70 feet, h_g = gate opening and $h_1 - h_3$ = difference between the pool and tailwater-gage readings.

Free-Weir Flow Coefficient

Discharge coefficients for free-weir flow for the roller gates in a submerged position were computed by solving equation 5 in table 1 for C_{sw} using the results of the discharge measurements (table 2) that were made with the gates in a submerged position. A graph showing the relationship of C_{sw} to the static-headwater head (h_{1s}) over the gate crest is shown in figure 12. The equation, relating the discharge coefficient to the headwater (h_{1s}) is:

$$C_{sw} = 8.67\ (h_{1s})^{-0.46} \tag{17}$$

where h_{1s} = Gage reading + 0.45 + (pool stage - 14.30) for Dam 13. The coefficient-headwater relation is further corroborated by data from Locks and Dams 11, 12 and 14 which are also shown in figure 12. The correction to the gage readings was derived from the observed gage reading at the point of zero flow over the gate crest.

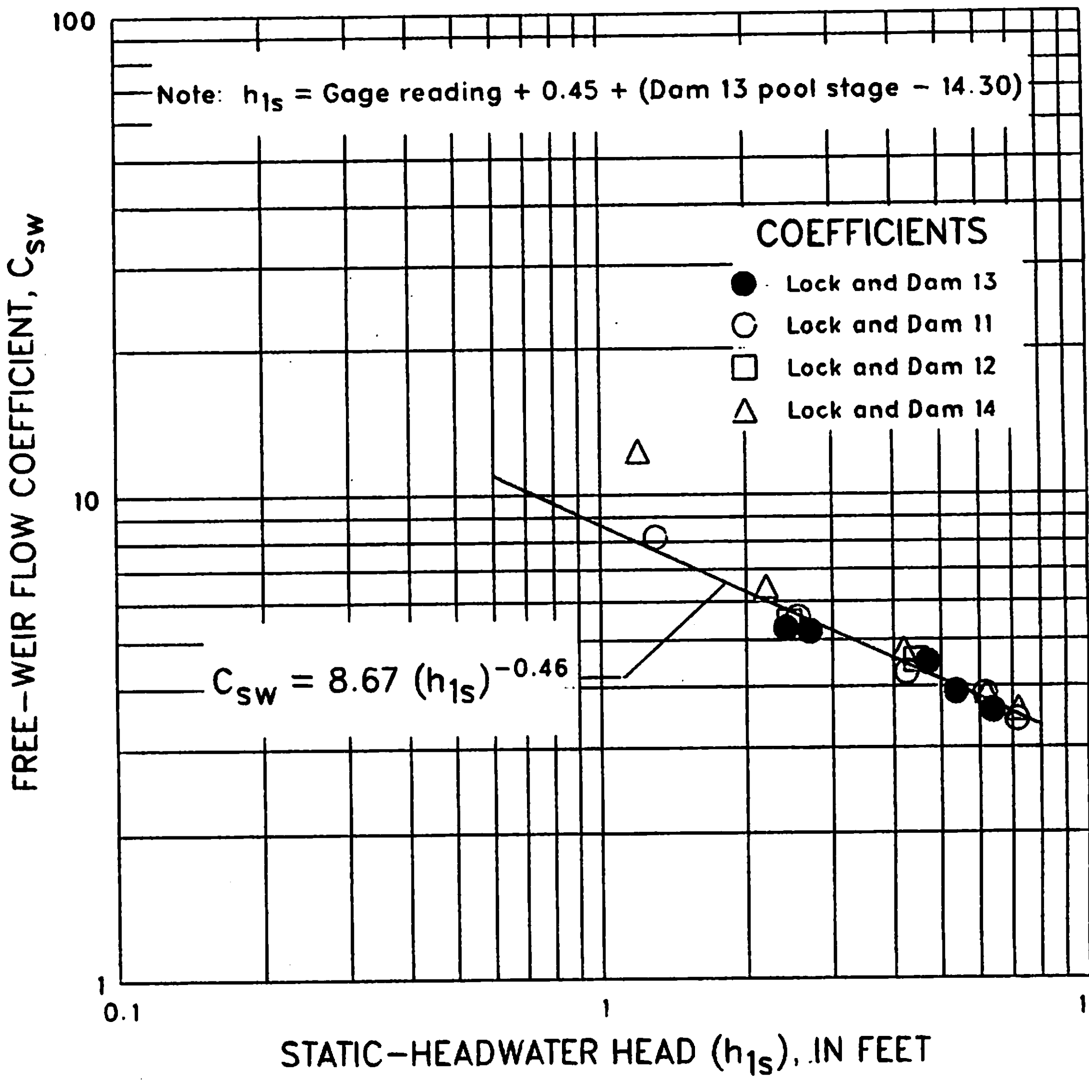


Figure 12.--Relation between free-weir flow coefficient and static-headwater head for roller gates in submerged position for Lock and Dam 13.

Free-Weir Discharge Equation

An equation for computing discharge for free-weir flow for the roller gates in a submerged position at Dam 13 was developed using the free-weir flow equation (5) and substituting equation 17 for the free-weir coefficient, C_{sw}.

The resulting equation, graphically illustrated in figure 13, relating the discharge (Q_s) to the static-headwater head (h_{1s}) over the gate crest is:

$$Q_s = 867 (h_{1s})^{1.04} \tag{18}$$

where h_{1s} is as defined for equation 17 above. Also shown in figure 13 are the discharge measurements made at Locks and Dams 11, 12 and 14. These measurements were used to corroborate the rating development for Lock and Dam 13.

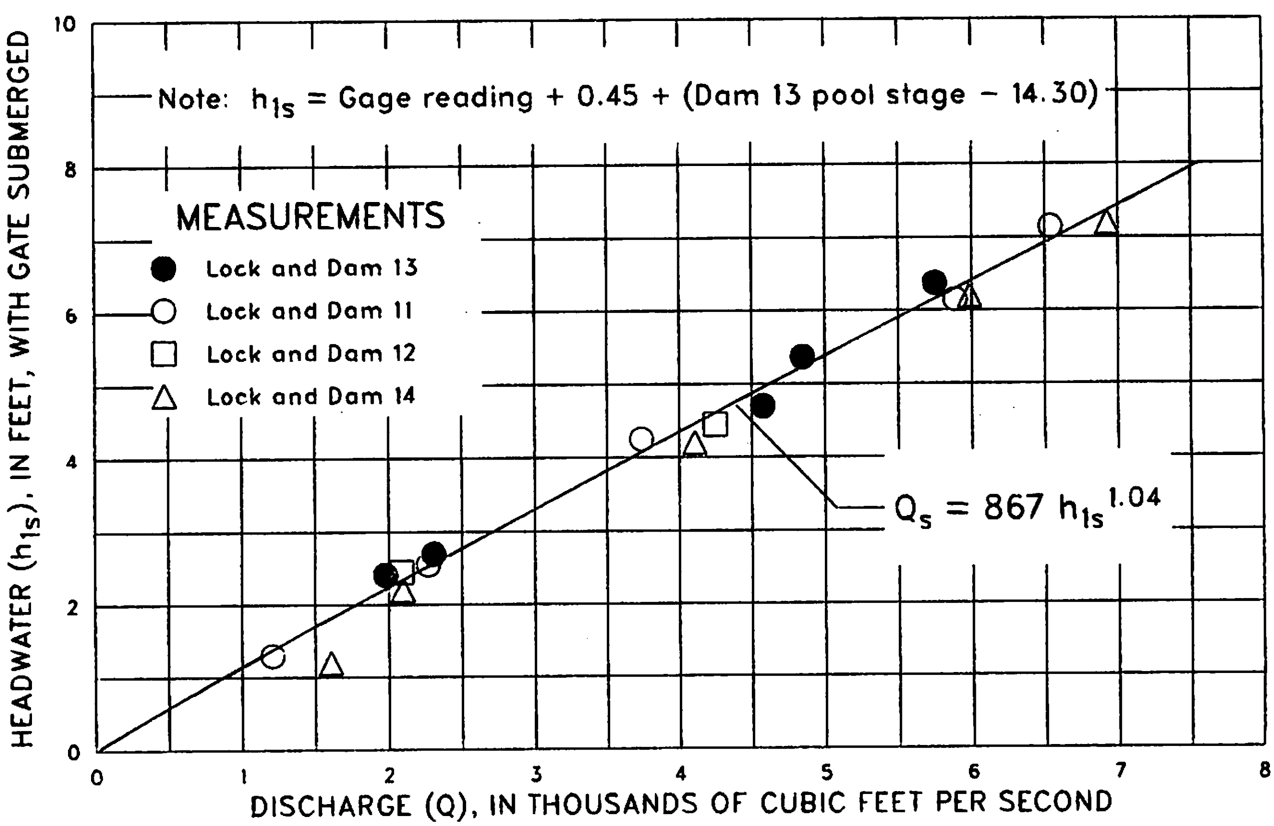


Figure 13.--Relation between discharge and headwater for free-weir flow for roller gates in submerged position for Lock and Dam 13.

DISCHARGE EQUATIONS AND RATINGS

The discharge equations applicable to the control gates when Dam 13 is in operation have been compiled and are listed in table 3.

Rating tables for both the tainter and roller gates were developed for the predominant flow regime of submerged-orifice flow when Dam 13 is in operation. These ratings, tables 4 and 5, list discharges for tailwater stages at 1 foot increments and gate openings at 0.5 foot increments and are applicable only with the upstream pool stage at 14.30 feet (h_1 = 20.00 feet). Discharges for any other headwater, tailwater, and gate-opening relations encountered can easily be computed using the applicable equations in table 3 with a small programable computer.

Discharge rating curves for submerged-orifice flow at selected gate openings (h_g) for the tainter and roller gates, prepared from laboratory tests using hydraulic models of gates, are shown in figures 14 and 15. Corresponding discharge-rating curves defined by methods outlined in this report are shown for comparison. Discharges defined by the 2 methods for the tainter gates are comparable (within about 10 percent) until the gates are opened beyond the allowable gate opening for safe gate operation. At this point, the discharges defined by the two methods begin to deviate considerably. Discharges defined by the 2 methods for the roller gates are also comparable except those in the range of 7 to 8 feet of gate opening. In this range, the discharges computed by equation 16 increases at a much greater rate than those shown by the hydraulic-model rating curves.

Table 3.--Summary of discharge equations for control gates at Mississippi River Lock and Dam 13.

Gate	Flow regime	Equation of discharge 1/, 3/	Equation number
Tainter gates	Submerged orifice	$Q = 479\ h_3 (h_3/h_g)^{-1.07} (h_1 - h_3)^{0.5}$	(10)
Tainter gates	Free Weir 2/	$Q_s = 212\ (1.09\ h_{1s}{}^{0.64} + h_{1s}{}^{1.50})$	(12)
Roller gates	Submerged orifice $h_g < 7.0$ or $\geqslant 7.0$ when $h_3/h_g > 2.4$	$Q = 537\ h_g (h_1 - h_3)^{0.5}$	(15)
Roller gates	Submerged orifice $h_g \geqslant 7.0$ and $h_3/h_g < 2.4$	$Q = 6{,}170\ h_3 (h_3/h_g)^{-3.80} (h_1 - h_3)^{0.5}$	(16)
Roller gates	Free weir 2/	$Q_s = 867\ h_{1s}{}^{1.04}$	(18)

1/ Q = Discharge, in cubic feet per second
h_1 = Pool stage + 5.70 feet
h_3 = Tailwater stage + 5.70 feet
h_g for tainter gages = gage reading + gage indicator correction, e (fig. 5).
(average e for all the tainter gates = 0.0)
h_g for roller gates = gage reading

2/ For free weir flow over gate crest:
Tainter gate: h_{1s} = gage reading + 0.10 + (pool stage - 14.30)
Roller gate: h_{1s} = gage reading + 0.45 + (pool stage - 14.30)

3/ The approach velocity head is included in $(h_1 - h_3)$.

Table 4.--Discharge rating table for submerged-orifice flow for a single tainter gate at Mississippi River Lock and Dam 13 with upstream pool stage of 14.30 feet

Gage reading (feet)	Tainter gate discharge, in ft^3/s, for indicated tailwater stage (feet)								
	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
.5	625	589	553	516	477	435	390	340	283
1.0	1310	1240	1160	1080	1000	914	819	715	594
1.5	2020	1910	1790	1670	1540	1410	1260	1100	917
2.0	2750	2600	2440	2270	2100	1920	1720	1500	1250
2.5	3500	3300	3100	2890	2670	2440	2180	1900	1580
3.0	4250	4010	3760	3510	3240	2960	2650	2310	1920
3.5	<u>5010</u>	4730	4440	4140	3820	3490	3130	2730	2270
4.0	5780	<u>5450</u>	5120	4770	4410	4030	3610	3150	2620
4.5	6560	6190	<u>5810</u>	5420	5000	4570	4100	3570	2970
5.0	7340	6920	6500	<u>6060</u>	5600	5110	4580	4000	3320
5.5	8130	7670	7200	6710	6200	5660	5080	4430	3680
6.0	8920	8420	7900	7370	<u>6810</u>	6210	5570	4860	4040
6.5	9720	9170	8610	8030	7420	6770	6070	5290	4400
7.0	10500	9930	9320	8690	8030	<u>7330</u>	6570	5730	4770
7.5	11300	10700	10000	9360	8640	7890	7070	6170	5130
8.0	12100	11500	10700	10000	9260	8450	7580	6610	5500
8.5	12900	12200	11500	10700	9880	9020	<u>8090</u>	7050	5870
9.0	13800	13000	12200	11400	10500	9590	8600	7500	6240
9.5	14600	13800	12900	12000	11100	10200	9110	7950	6610
10.0	15400	14500	13600	12700	11800	10700	9620	8390	6980

Note: Discharges greater than those underlined may exceed those allowable for safe gate operation (USCE, 1980).

Discharges for table 4 were computed using equation:

$$(10) \quad Q = 479\, h_3 (h_3/h_g)^{-1.07} (h_1 - h_3)^{0.5}$$

where h_g = gage reading + (average e = 0)
h_1 = 20.00 feet (14.30 + 5.70)
h_3 = tailwater stage + 5.70 feet

Table 5.--Discharge rating table for submerged-orifice flow for a roller gate at Mississippi River Lock and Dam 13 with upstream pool stage of 14.30 feet

Gage reading (feet)	Roller gate discharge, in ft^3/s, for indicated tailwater stage (feet)								
	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
.5	862	819	774	725	674	618	557	488	407
1.0	1720	1640	1550	1450	1350	1240	1110	976	814
1.5	2590	2460	2320	2180	2020	1850	1670	1460	1220
2.0	3450	3280	3090	2900	2700	2470	2230	1950	1630
2.5	4310	4090	3870	3630	3370	3090	2780	2440	2040
3.0	5170	4910	4640	4350	4040	3710	3340	2930	2440
3.5	6030	5730	5410	5080	4720	4330	3900	3410	2850
4.0	6890	6550	6190	5800	5390	4950	4450	3900	3260
4.5	7760	7370	6960	6530	6070	5560	5010	4390	3660
5.0		8190	7740	7250	6740	6180	5570	4880	4070
5.5			8510	7980	7410	6800	6120	5370	4480
6.0			9280	8710	8090	7420	6680	5850	4890
6.5				9430	8760	8040	7240	6340	5290
7.0					16500	12500	9330	6880	5700
7.5						16200	12100	8940	6340
8.0	Discharges in this area may						15500	11400	8100
8.5	be greater than those allowable							14400	10200
9.0	for safe gate operation (USCE, 1980).								12700
9.5									15600

Note: Underline denotes change in rating from equation 15 to equation 16.

Discharges for table 5 were computed using equations:

$$(15)\quad Q = 537\ h_g(h_1 - h_3)^{0.5}$$

$$(16)\quad Q = 6{,}170\ h_3(h_3/h_g)^{-3.80}(h_1 - h_3)^{0.5}$$

where h_g = gage reading
h_1 = 20.00 feet (14.30 + 5.70)
h_3 = tailwater stage + 5.70 feet

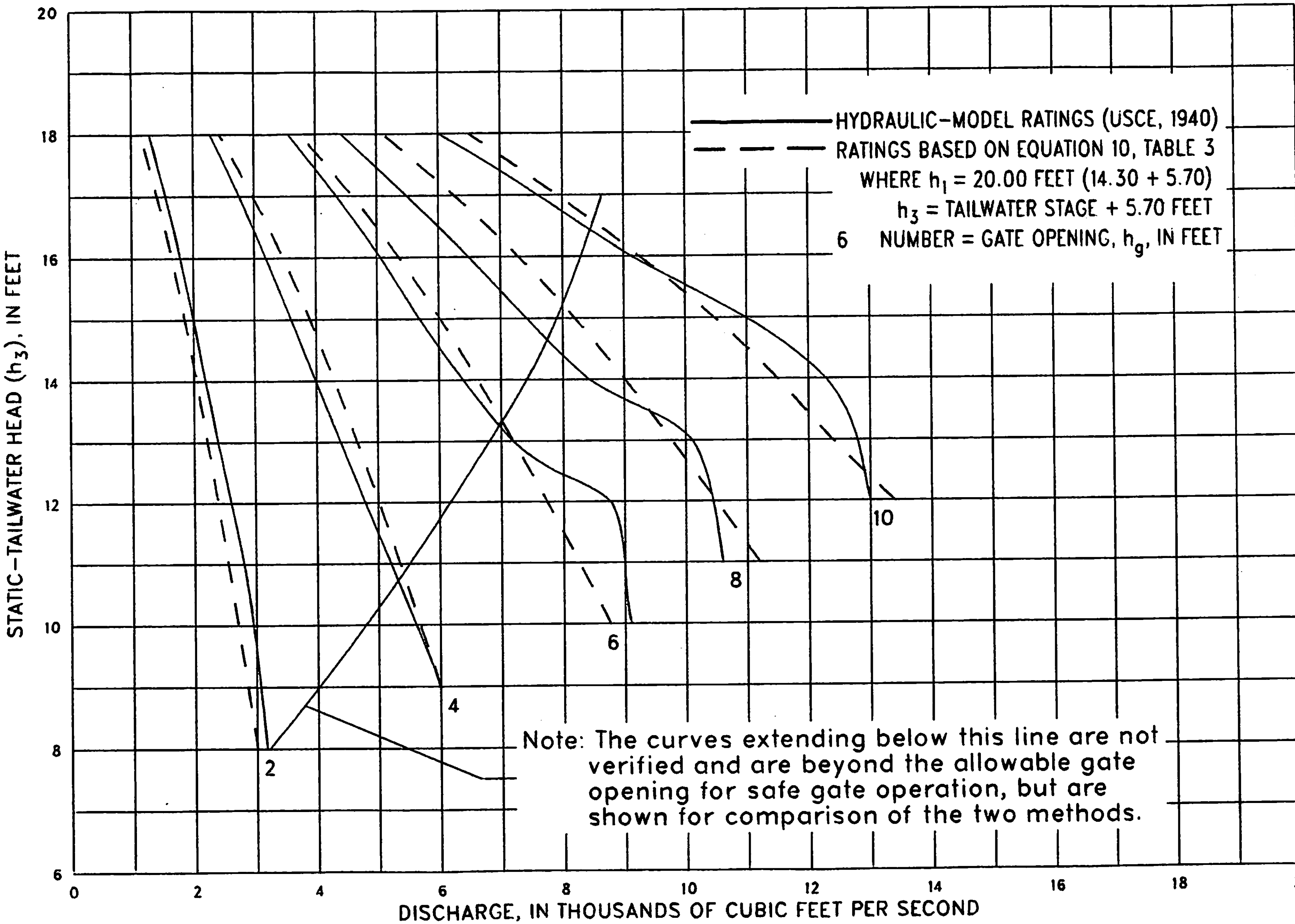


Figure 14.--Discharge ratings for submerged-orifice flow for a single tainter gate at Mississippi River Lock and Dam 13 compared to hydraulic-model ratings.

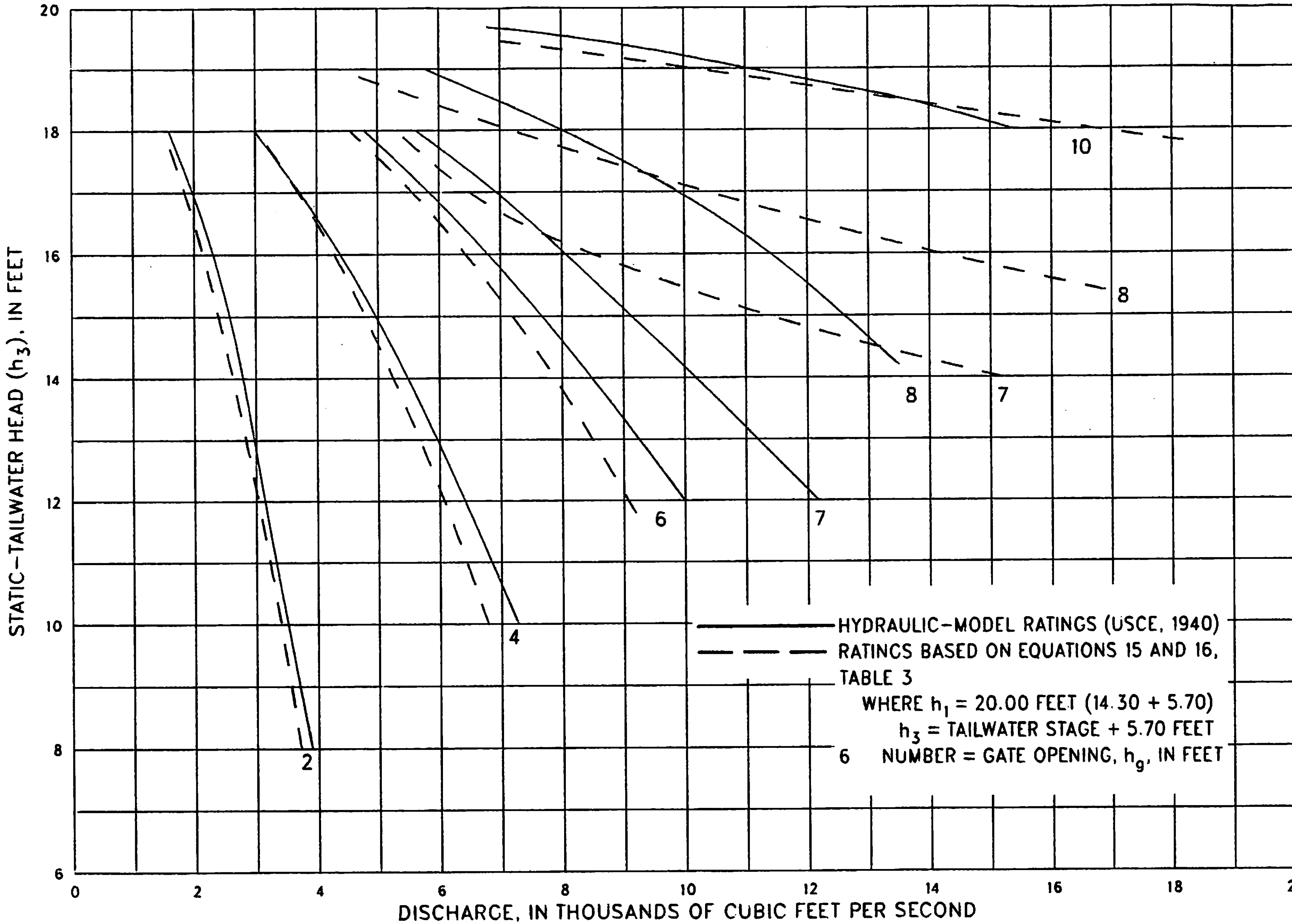


Figure 15.−−Discharge ratings for submerged−orifice flow for a single roller gate at Mississippi River Lock and Dam 13 compared to hydraulic−model ratings.

The equations in table 3 were used to compute the discharges for the gate settings indicated in the operation schedule, Plan A, shown in table 6 which is in use for operation of Dam 13. Discharges for the two methods were generally within 4 percent until the roller gate openings exceeded 7 feet at which time the discharges defined by the equations in table 3 increased to 30 percent greater than those shown in Plan A.

Table 6.--Comparison of rating discharges (column 1) to discharges specified in Gate Operation Schedule Plan A for Mississippi River Lock and Dam 13
[Modified from U.S. Army Corps of Engineers, 1980, pl. 31]

Rating 1/ discharge (ft³/s)	Gate Operation Schedule Plan A for controlled tailwater stages with headwater stage of 14.30 feet															
	Discharge (ft³/s)	Tailwater stage (feet)	Head (feet)	Gate opening, (feet), for gate indicated												
				Tainter				Roller			Tainter					
				1	2	3	4	5	6	7	8	9	10	11	12	13
17,600	17,000	4.0	10.3	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0.5
20,400	19,700	4.2	10.1	2.0	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0.5
22,600	22,000	4.4	9.9	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	0.5	0.5	0.5
25,800	24,800	4.6	9.7	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.0	1.0	0.5	0.5
27,000	26,700	4.8	9.5	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.0	1.0	1.0	0.5
29,000	28,600	5.0	9.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.0	1.0	1.0	1.0
31,400	30,500	5.2	9.1	2.5	2.5	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.0	1.0
33,000	32,100	5.4	8.9	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.0	1.0
34,200	34,000	5.6	8.7	2.5	2.5	2.5	2.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.0	1.0
35,900	35,800	5.8	8.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.5	1.0
37,400	37,200	6.0	8.3	3.0	2.5	2.5	2.5	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5
39,600	39,000	6.2	8.1	3.0	3.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5
41,600	41,000	6.4	7.9	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	1.5	1.5
43,200	43,000	6.6	7.7	3.5	3.5	3.0	3.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5
45,200	45,000	6.8	7.5	3.5	3.5	3.5	3.0	3.5	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0
47,200	47,000	7.0	7.3	3.5	3.5	3.5	3.5	3.5	3.5	3.0	3.0	3.0	2.0	2.0	2.0	2.0
49,000	48,800	7.2	7.1	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.0
51,300	50,600	7.4	6.9	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5
52,900	52,200	7.6	6.7	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.0	3.0	2.5	2.5
54,200	54,100	7.8	6.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	2.5	2.5
56,200	56,000	8.0	6.3	4.5	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.0	3.0
58,800	58,000	8.2	6.1	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.5	4.0	3.5	3.5	3.0	3.0
60,200	60,000	8.4	5.9	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	3.5	3.0	3.0
62,600	62,000	8.6	5.7	5.0	5.0	5.0	4.5	5.0	4.5	4.5	4.5	4.0	4.0	3.5	3.5	3.5
65,000	64,100	8.8	5.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.5	4.5	4.5	4.0	3.5	3.5
65,400	66,200	9.0	5.3	5.5	5.0	5.0	5.0	5.5	5.0	5.0	4.5	4.5	4.5	4.0	4.0	4.0
69,600	68,300	9.2	5.1	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.0	5.0	5.0	4.5	4.0	4.0
72,000	70,600	9.4	4.9	6.0	6.0	6.0	5.5	6.0	6.0	5.5	5.0	5.0	5.0	4.5	4.5	4.5
74,700	73,000	9.6	4.7	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.5	5.5	5.0	5.0	4.5
77,200	75,000	9.8	4.5	6.5	6.5	6.5	6.5	6.5	6.5	6.0	6.0	5.5	5.5	5.5	5.0	5.0
81,000	77,200	10.0	4.3	7.0	7.0	7.0	6.5	7.0	6.5	6.5	6.0	6.0	5.5	5.5	5.5	5.5
87,700	79,700	10.2	4.1	7.0	7.0	7.0	7.0	7.5	7.0	7.0	6.5	6.0	6.0	6.0	6.0	6.0
93,500	82,000	10.4	3.9	7.0	7.0	8.0	8.0	7.5	7.5	7.5	7.0	6.5	6.5	6.5	6.0	6.0
101,000	84,600	10.6	3.7	7.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.0	6.5	6.5	6.5	6.5
110,000	87,000	10.8	3.5	8.0	8.0	8.0	8.0	8.5	8.5	8.5	8.0	8.0	7.0	7.0	7.0	7.0
112,000	89,400	11.0	3.3	8.0	9.0	9.0	9.0	8.5	8.5	8.5	9.0	9.0	8.0	8.0	7.0	7.0
113,000	91,800	11.2	3.1	9.0	10.0	10.0	10.0	8.5	8.5	8.5	9.0	9.0	9.0	8.0	8.0	8.0
123,000	97,000	11.6	2.7	10.0	11.0	11.0	11.0	9.0	9.0	9.0	11.0	10.5	10.0	10.0	10.0	10.0
132,000	101,800	12.0	2.3	12.0	12.0	12.0	12.0	9.5	9.5	9.5	12.0	12.0	12.0	12.0	12.0	12.0
136,000	105,000	12.3	2.0	13.0	13.0	13.0	13.0	10.0	10.0	10.0	13.0	13.0	13.0	13.0	13.0	13.0

1/ Computed using equations in table 3 with headwater stage of 14.30 feet.

SUMMARY

Current-meter discharge measurements made in the forebays of the tainter and roller gates of Lock and Dam 13 were used to develop discharge coefficients and equations of discharge for submerged-orifice and free-weir flow for all the gates.

Methodology has been described to compute the actual gate openings of the tainter gates. The indicator gages for the tainter gates could be accurately set to the true gate opening (h_g) using the techniques described in case the gages were accidentally knocked out of alignment or if the bottom seals on the gates were changed. The deviation of the discharge from the rating discharge for the individual gates could be minimized by adjusting the gage indicators to more nearly reflect the computed gate opening, h_g.

Discharge rating tables were developed for discrete combinations of tailwater stages and gate openings for submerged-orifice flow, which is the predominant flow regime when the dam is in operation.

Comparisons of the discharges defined by the hydraulic-model ratings and those computed by the equations developed in this study are given for selected gate openings. Discharges defined by methods outlined in this study are also given for comparison to those used in the operation schedule, Plan A, which is in use for the operation of Lock and Dam 13.

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