

**DISCHARGE RATING FOR TAINTER GATES AT LOCK AND DAM NO. 24
ON THE MISSISSIPPI RIVER AT CLARKSVILLE, MISSOURI**

By Terry W. Alexander

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CONTENTS

	Page
Abstract	1
Introduction	1
Purpose and scope.....	4
Acknowledgments	4
Theoretical equations of discharge for tainter gates.....	4
Tainter gate flow regimes	5
Measurements of hydraulic-control variables and discharges	7
Submerged-orifice discharge coefficients.....	7
Submerged-orifice discharge equations.....	12
Discharge rating.....	13
Summary	15
Selected references.....	16

ILLUSTRATIONS

		Page
Figure	1. Map showing location of Lock and Dam No. 24 on the Mississippi River.....	2
	2-5. Diagrams showing:	
	2. Location of flow controls at Lock and Dam No. 24	3
	3. Sectional view of tainter gate	6
	4. Velocity observations of May 11-12, 1988, for a 2-foot gate opening at tainter gates 2, 5, 9, and 13	10
	5. Velocity observations of July 12, 1990, for a 15-foot gate opening at tainter gates 2, 5, 9, and 13	11
	6. Graph showing relation of submerged-orifice discharge coefficients and orifice-submergence ratios for tainter gates	12

TABLES

		Page
Table	1. Theoretical equations of discharge for flow controlled by a tainter gate	5
	2. Summary of hydraulic-control variables and current-meter discharge measurements.....	8
	3. Summary of theoretical discharge equations for submerged-orifice flow under a single tainter gate.....	13
	4. Discharge rating table for a tainter gate with submerged-orifice flow for normal headwater and tailwater elevations	14

CONVERSION FACTORS AND VERTICAL DATUM

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
mile (mi)	1.609	kilometer
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
foot per second squared (ft/s ²)	0.3048	meter per second squared
pound, avoirdupois (lb)	0.4536	kilogram

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Note: The non-dimensionless constants used in some of the equations in this report can be used only with inch-pound units.

SYMBOLS AND UNITS

<u>Symbol</u>	<u>Definition</u>	<u>Unit</u>
B	Width of tainter gate	ft
C	Free-orifice flow coefficient of discharge	
C_{gs}	Submerged-orifice flow coefficient of discharge	
C_w	Free-weir flow coefficient of discharge	
C_{ws}	Submerged-weir flow coefficient of discharge	
g	Acceleration due to gravity (32.15 ft/s ²)	ft/s ²
h_g	Vertical height of tainter gate opening	ft
h_1	Static-headwater depth above gate sill	ft
h_3	Static-tailwater depth above gate sill	ft
Q	Discharge	ft ³ /s
q_{GL}	Leakage discharge per gate	ft ³ /s
Δh	Static head differential ($h_1 - h_3$)	ft

DISCHARGE RATING FOR TAINTER GATES AT LOCK AND DAM NO. 24 ON THE MISSISSIPPI RIVER AT CLARKSVILLE, MISSOURI

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ABSTRACT

The water-surface elevation of the navigation pool at Lock and Dam No. 24 on the Mississippi River at Clarksville, Missouri, is controlled during normal operating conditions by the regulation of 15 tainter gates. The development of a stage-discharge rating for these tainter gates can be used to compute discharge through Dam No. 24, and to aid in regulating the navigation pool (headwater) elevation within its normal operational limits of 445.50 to 449.00 feet. Hydraulic-control variables and discharge data were collected at selected tainter gates and analyzed for this report.

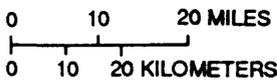
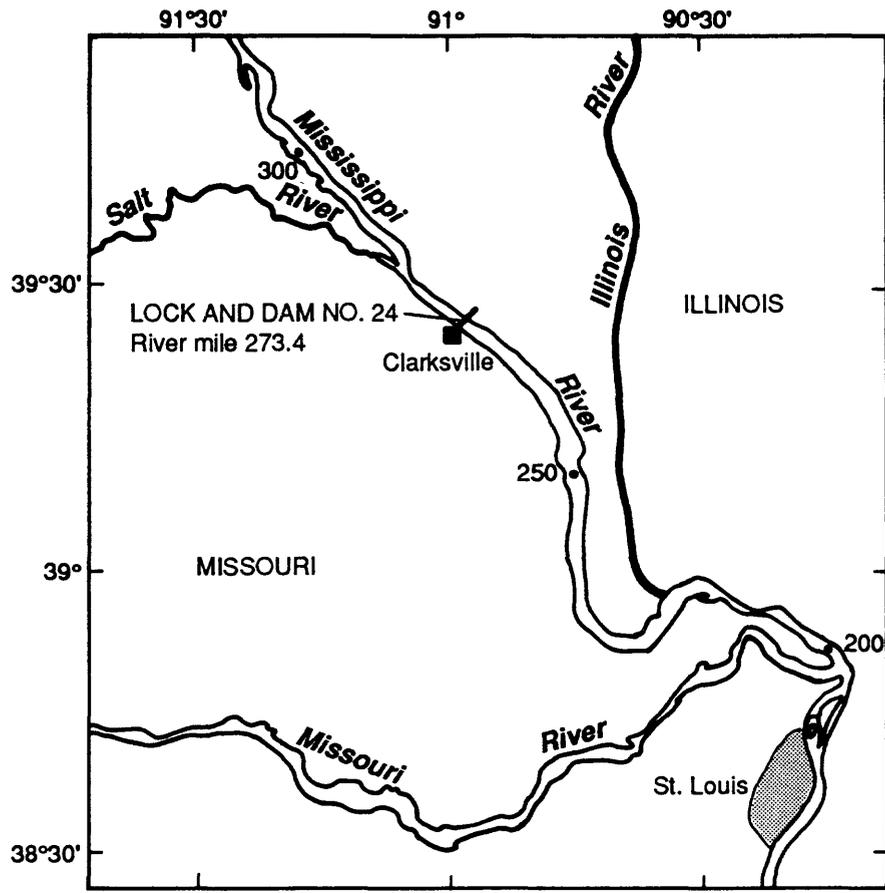
A total of 46 current-meter discharge measurements that ranged from 891 to 17,500 cubic feet per second were made in the tainter gate forebays. The measured discharges were used to identify flow regimes as a function of static-headwater depth (h_1), static-tailwater depth (h_3), and vertical height of tainter gate opening (h_g). Submerged-orifice flow is the predominant flow regime under the tainter gates at Lock and Dam No. 24.

Forty-three discharge measurements were used to define coefficients of discharge (C_{gs}), which ranged from 0.072 ($h_g = 0.5$ foot) to 1.04 ($h_g = 15$ feet). These coefficients were used to develop the discharge coefficient relation for the submerged-orifice flow regime. Three discharge measurements ($h_g = 0$) were made to evaluate the tainter gate leakage discharge relation. Theoretical equations that express discharge per gate (Q) as a function of discrete hydraulic-control variables were developed from the discharge coefficient and gate leakage relations. The resulting equations of discharge are applicable to gate openings of 0.5 foot to 15 feet with orifice-submergence ratios (h_3/h_g) from 1.4 to 27.9; thus, the equations can be used to compute discharges for regulated flow conditions not otherwise defined by the current-meter discharge measurements. Using these equations, a discharge rating table was computed for the normal headwater operational limits of 445.50 to 449.00 feet and selected tailwater elevations.

INTRODUCTION

The Inland Waterway Navigation System of the upper Mississippi River basin was authorized by Congress in July 1930 with passage of the River and Harbor Act. This act provided for the construction of a series of lock and dam flow-regulating structures to maintain a 9-ft deep and 400-ft wide navigation channel from Minneapolis, Minnesota, to St. Louis, Missouri. The efficient operation of the navigation system for the upper Mississippi River requires reliable stage-discharge relations for all flow controls within the system.

Lock and Dam No. 24 at river mi 273.4 at Clarksville, Missouri (fig. 1), is one of 29 flow-regulating structures in the upper Mississippi River basin that are maintained and operated by the U.S. Army Corps of Engineers. The length of Dam No. 24 is 4,280 ft (fig. 2) and consists of 1,340 ft of tainter gates, 120 ft of storage yard (non-overflow earth dike), and 2,820 ft of overflow earth dike. The navigation lock is 110 ft wide by 600 ft long.



EXPLANATION

•250 RIVER MILEAGE



Figure 1.--Location of Lock and Dam No. 24 on the Mississippi River.

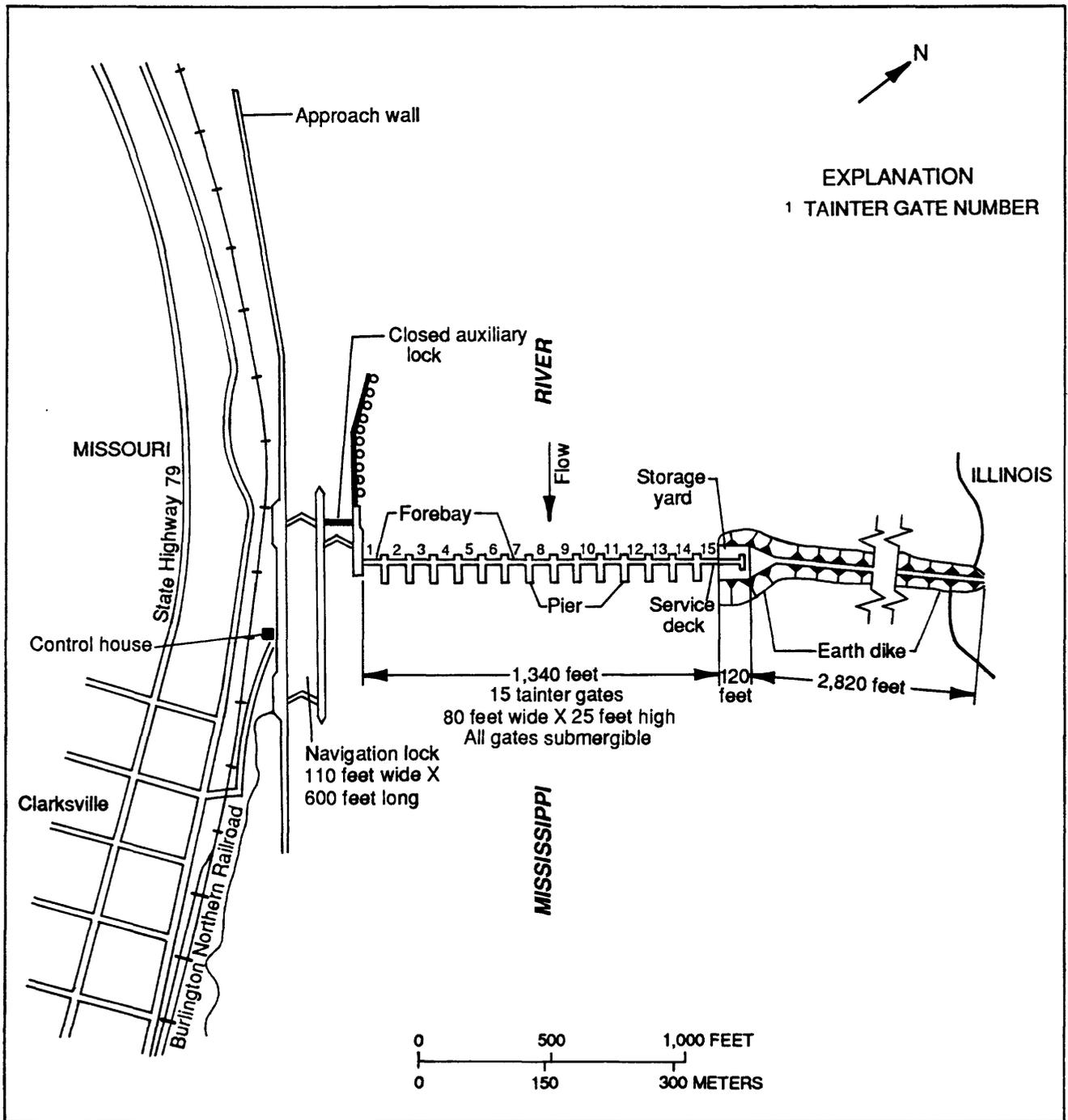


Figure 2.--Location of flow controls at Lock and Dam No. 24 (modified from U.S. Army Corps of Engineers, 1980).

The principal responsibilities of water-control management are assigned to the St. Louis District office, Potamology Section of the Hydrologic and Hydraulics Branch, Engineering Division. Lock and Dam No. 24, a run-of-the-river dam, cannot be used for flood-control purposes. Various combinations of tainter gate openings are currently (1992) used to maintain the navigation pool (headwater) elevation within the normal operational limits of 445.50 and 449.00 ft (L.E. Kent, U.S. Army Corps of Engineers, oral commun., 1990).

Because the water-surface slope between flow-regulating structures can approach zero during periods of low flow, the traditional flow-determination methods that require slope to calculate discharge are not satisfactory. Therefore, a cooperative effort between the U.S. Geological Survey and the U.S. Army Corps of Engineers, St. Louis District, was begun in 1988 to develop a stage-discharge relation for the 15 tainter gate flow controls at Lock and Dam No. 24.

Purpose and Scope

The purpose of this report is to present a discharge rating for the 15 tainter gate flow controls at Lock and Dam No. 24. A stage-discharge relation (equations of discharge) was developed by using results from current-meter discharge measurements made in the forebays of selected tainter gates. These discharge measurements were used to develop discharge coefficient relations for all possible flow regimes that occur during normal operating conditions. Consequently, the equations of discharge can be used to compute a discharge rating for most combinations of headwater and tailwater elevations and vertical height of gate openings, including those not represented by the discharge measurements made during this study.

This study was limited to the analysis of the submerged-orifice flow regime under the tainter gates. No attempts were made to define or develop discharge ratings for the navigation lock or the earth dike.

Acknowledgments

A special thanks is extended to Lockmasters, J.D. Buckley (1988) and L.E. Kent (1989), who were helpful in arranging desired tainter gate openings during a variety of dam operating conditions, and in providing a crane operator when needed.

THEORETICAL EQUATIONS OF DISCHARGE FOR TAITER GATES

Three types of flow controls are present at Lock and Dam No. 24. These are tainter gates, a navigation lock, and an earth dike (fig. 2). The 15 tainter gates are the only flow controls for which hydraulic theory is used to develop a method for computing a reliable stage-discharge relation.

Collins (1977, p. 2-3) and Stuthmann and Sanders (1982, p. A-36 to A-40) summarize the hydraulic-control conditions that define flow regimes possible at multipurpose flow-regulating structures and give their corresponding theoretical equations of discharge. The hydraulic theory used to develop these equations of discharge assumes steady, uniform flow. This theory requires that the energy and continuity equations are balanced between the approach section and a section just downstream from the control structure. Possible flow regimes, necessary hydraulic-control conditions, and theoretical equations of discharge for flow controlled by a tainter gate at Lock and Dam No. 24 are given in table 1.

Table 1.--Theoretical equations of discharge for flow controlled by a tainter gate (modified from Collins, 1977)

[h_g , vertical height of tainter gate opening; <, less than; h_1 , static-headwater depth; h_3 , static-tailwater depth; Q , discharge; C , free-orifice flow coefficient of discharge; B , tainter gate width; g , acceleration due to gravity; \geq , greater than or equal to; C_{gs} , submerged-orifice flow coefficient of discharge; Δh , static head differential ($h_1 - h_3$); >, greater than; C_w , free-weir flow coefficient of discharge; C_{ws} , submerged-weir flow coefficient of discharge]

Flow regime	Hydraulic-control conditions	Equation of discharge	Equation number
Free-orifice	$h_g < 0.67 h_1$ and $h_3 < h_g$	$Q = C [h_g B (2gh_1)^{0.5}]$	1
Submerged-orifice	$h_g < 0.67 h_1$ and $h_3 \geq h_g$, or ^a $h_g > 0.67 h_1$ and $h_3 > h_g$	$Q = C_{gs} [h_3 B (2g\Delta h)^{0.5}]$	2
Free-weir	$h_g \geq 0.67 h_1$ and $h_3/h_1 < 0.6$	$Q = C_w [B h_1^{1.5}]$	3
Submerged-weir	$h_g \geq 0.67 h_1$, $h_3/h_1 \geq 0.6$, and ^a $h_3 < h_g$	$Q = C_w C_{ws} [B h_1^{1.5}]$	4

^a Stuthmann and Sanders (1982, p. A-37).

The bracketed part of these equations represents the theoretical expression of discharge for a tainter gate B units in width. The independent hydraulic-control variables are static-headwater depth (h_1), static-tailwater depth (h_3), and vertical height of tainter gate opening (h_g). The static depths (h_1 and h_3) are the vertical distances of the headwater and tailwater elevations above the sill (fig. 3). The coefficients of discharge (C , C_{gs} , C_w , and C_{ws}) are unknown, but can be determined through a calibration process. These coefficients are defined by the ratio of measured discharge to theoretical discharge; therefore, a coefficient of discharge can be computed from each current-meter measurement of discharge if all other independent hydraulic-control variables are known or fixed.

TAINTER GATE FLOW REGIMES

The vertical height of tainter gate opening, h_g , is the most important hydraulic-control variable in determining tainter gate flow regimes. The hydraulic-control condition that separates orifice and weir flow regimes is based on a critical depth analysis of flow in a rectangular section. If the tainter gate opening (h_g) is less than the computed critical depth ($0.67h_1$), then orifice flow occurs under the gate. If the gate opening equals or exceeds the computed critical depth, the gate opening has no effect on the discharge and thus weir flow occurs with the gate sill functioning as a broad-crested weir (Collins, 1977, p. 4). However, Stuthmann and Sanders (1982, p. A-37) provide additional hydraulic-control conditions for consideration when distinguishing the submerged-orifice flow regime from the submerged-weir flow regime. For this study, the hydraulic-control conditions defining the tainter gate flow regimes at Lock and Dam No. 24 are listed in table 1.

Because of the difficulties in raising Lock and Dam No. 24 tainter gates (which can be submerged 8 ft) from a submerged position, the tainter gates are only submerged (free-weir flow) for flushing ice or other debris (J.D. Buckley, U.S. Army Corps of Engineers, oral commun., 1988). The submerged-weir flow regime may infrequently occur for periods of 24 hours or less, usually just before or just after open-river conditions [h_g > (greater than) 15 ft]. Also, Dam No. 24 is never operated within the free-orifice flow regime; therefore, it is like most navigation-type structures (Collins, 1977, p. 11). Consequently, the free- and submerged-weir flows, and free-orifice flow regimes were not evaluated in this study. The predominant flow regime is submerged-orifice flow.

In this report, a stage-discharge relation will be developed for only the submerged-orifice flow regime. Therefore, at least one current-meter discharge measurement was made at 8 of the 15 tainter gates during submerged-orifice operating conditions, while only gates 2, 5, 9, and 13 were measured throughout the normal range of gate openings [$0.5 \leq$ (less than or equal to) $h_g \leq 15$].

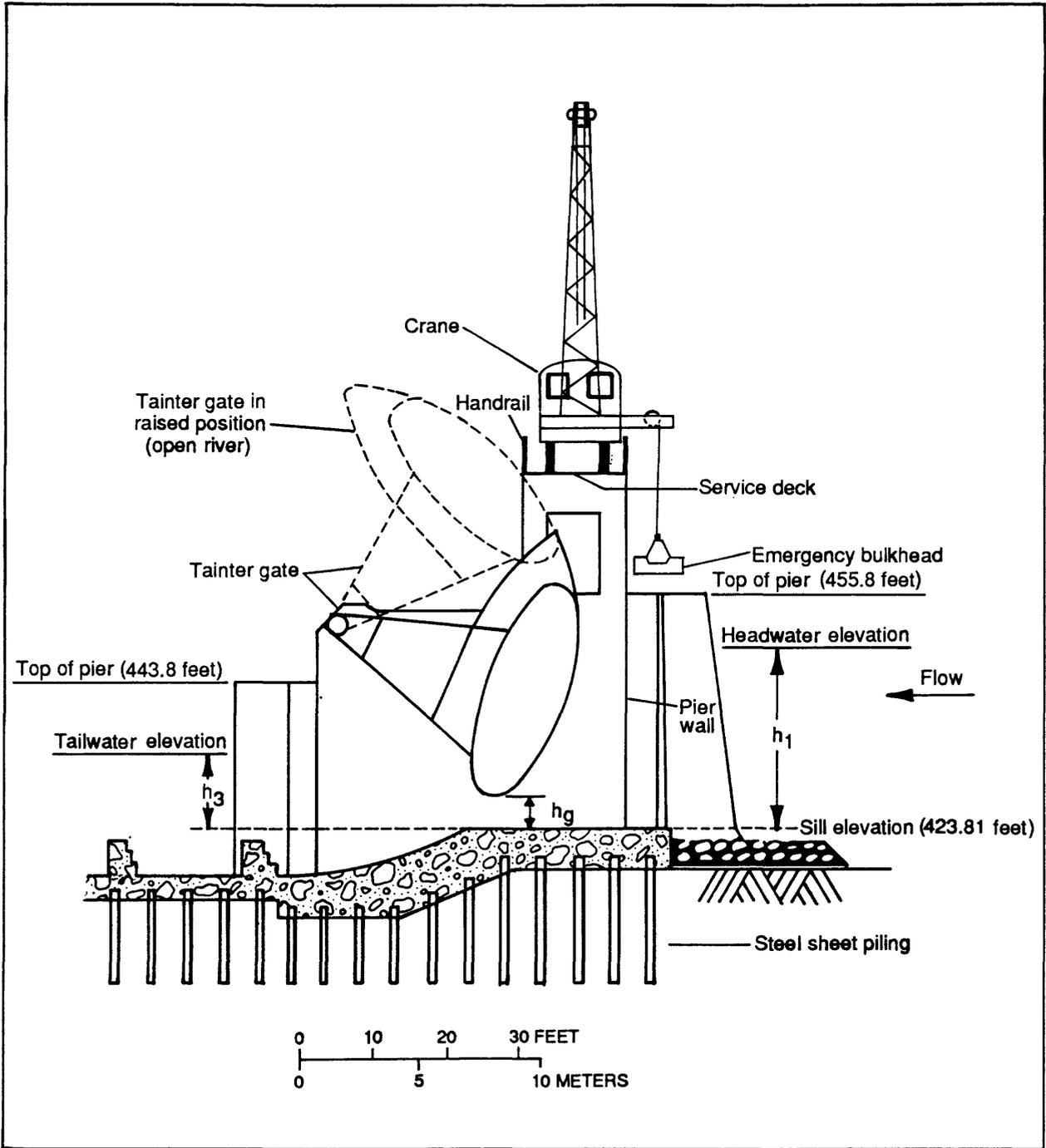


Figure 3.--Sectional view of tainter gate (modified from U.S. Army Corps of Engineers, 1980).

MEASUREMENTS OF HYDRAULIC-CONTROL VARIABLES AND DISCHARGES

Each of the 15 tainter gates at Lock and Dam No. 24 is 80-ft wide and 25-ft high and operates between pier walls with an 80-ft opening. The tainter gates are built under a service deck, and the service deck also provides access to each gate from a movable crane. Thus, both the service deck and crane (fig. 3) provide access to individual forebays allowing for use of standard U.S. Geological Survey current-meter measuring equipment.

Stage-discharge relations for all flow regimes can be developed from measurements of hydraulic-control variables and discharges at a single tainter gate if all gates are of the same design (Collins, 1977, p. 4). However, in an attempt to average variations in both entrance and exit losses, 43 current-meter discharge measurements were made in the forebays of eight tainter gates during normally regulated flow conditions [$0 < (\text{less than}) h_g \leq 15$]. Three discharge measurements ($h_g = 0$) were made to evaluate the tainter gate leakage discharge resulting from the lower gate seal being worn or dented and not forming a tight fit against the concrete sill. These 46 measurements of hydraulic-control variables and discharges that were used to develop the stage-discharge relations are listed in table 2.

Discharge measurements for gate openings of 2 ft or less ($h_g \leq 2$) were made along the upstream handrail of the service deck, whereas discharge measurements for gate openings greater than 2 ft ($h_g > 2$) were made from the movable crane (emergency bulkhead) to prevent the measuring equipment from drifting downstream into the tainter gate opening (orifice section). During each discharge measurement, velocity observations at 0.2 and 0.8 of the static-headwater depth (two-point method) were obtained using a Price-type AA current meter suspended with a Columbus sounding weight (100 or 150 lbs) from a collapsible bridge boom. However, a set of velocity observations (one vertical) was made for each discharge measurement using the vertical-velocity curve method (0.1-depth increments between 0.1 and 0.9 of the static-headwater depth) to verify that the two-point method was acceptable for determining the mean velocity in each vertical (Rantz and others, 1982, p. 132-134). The two-point method gave mean velocities that are within 2 percent (on the average) of the vertical-velocity curve method (figs. 4 and 5). Thus, the standard two-point method for determining mean velocities was used in this study.

To minimize fluctuations in headwater and tailwater elevations, all gate openings were held constant during each discharge measurement to best simulate steady-flow conditions. The tainter gate-openings were set by U.S. Army Corps of Engineers personnel from the service deck by referencing the tainter gate-indicator gages located on the downstream pier walls. Because all 15 tainter gates are of the submergible type, there is no means to accurately calculate the true gate opening. Therefore, corrections to individual gate-indicator gages are unobtainable and were assumed to be correct within plus or minus 0.1 ft. Gate leakage ($h_g = 0$) is common to submergible tainter gates because of the clearance needed between the tainter gate and sill. In this study, the leakage discharge per gate (q_{GL}) was not separated from the current-meter discharge measurements. The headwater and tailwater elevations were monitored from U.S. Army Corps of Engineers continuous recording gages located in the control house. The static-headwater and static-tailwater depths, h_1 and h_3 , are referenced from the gate concrete sill elevation of 423.81 ft.

Submerged-Orifice Discharge Coefficients

Forty-three coefficients of discharge, C_{gs} , were computed by solving equation 2 (table 1) using the results of the current-meter discharge measurements made under hydraulic-control conditions that satisfy the submerged-orifice flow criteria. The computed coefficients ranged from 0.072 ($h_g = 0.5$) to 1.04 ($h_g = 15$) and are listed in table 2. The coefficient of discharge (C_{gs}) and orifice-submergence ratio (h_3/h_g) relation was graphically determined and is represented by the straight-line logarithmic relation

Table 2.--Summary of hydraulic-control variables and current-meter discharge measurements

[Measurements are listed in order of increasing tainter gate opening; static depth, headwater and tailwater elevations minus 423.81; h_1 , static-headwater depth; h_3 , static-tailwater depth; h_g , static-tailwater depth; h_g , vertical height of tainter gate opening; h_3/h_g , orifice-submergence ratio; Q , discharge; C_{gs} , submerged-orifice flow coefficient of discharge; ft, feet; ft^3/s , cubic feet per second; --, not definable]

Tainter gate number (fig. 2)	Date of measurement	Static depth			h_g (ft)	h_3/h_g	Q (ft^3/s)	C_{gs}
		h_1 (ft)	h_3 (ft)	h_g (ft)				
2	5-13-88	25.17	13.95	0.5	27.9	2,450	0.082	
	5-12-88	25.12	13.55	1.0	13.6	3,770	.127	
	5-12-88	25.19	13.52	2.0	6.8	6,210	.210	
	5-12-88	25.20	13.56	3.0	4.5	8,790	.296	
	4-05-88	23.86	17.64	4.0	4.4	7,810	.277	
	4-07-88	23.41	17.80	5.5	3.2	10,100	.373	
	5-09-90	23.13	17.69	7.0	2.5	12,100	.457	
	7-13-90	21.90	19.58	9.0	2.2	9,630	.504	
	7-13-90	21.89	19.60	11	1.8	12,200	.641	
	7-12-90	21.67	20.39	15	1.4	14,400	.974	
4	10-24-90	25.26	12.20	.5	24.4	2,210	.078	
	9-18-90	25.00	13.88	1.0	13.9	3,210	.108	
5	6-29-88	25.18	10.60	0	--	898	--	
	6-28-88	25.15	10.88	.5	21.8	2,620	.099	
	5-10-88	25.27	13.19	1.0	13.2	3,090	.105	
	5-12-88	25.10	13.55	2.0	6.8	5,630	.191	
	5-13-88	25.17	13.95	3.0	4.6	8,260	.276	
	4-06-88	23.80	17.73	4.0	4.4	7,660	.273	
	4-07-88	23.40	17.80	5.5	3.2	9,750	.361	
	5-09-90	23.12	17.65	8.0	2.2	14,200	.536	
	7-13-90	21.88	19.58	9.0	2.2	9,750	.512	
	5-08-90	22.55	18.69	11	1.7	17,100	.726	
7-12-90	21.65	20.47	15	1.4	14,300	1.00		

Table 2.--Summary of hydraulic-control variables and current-meter discharge measurements--Continued

Tainter gate number (fig. 2)	Date of measurement	Static depth		h_g (ft)	h_3/h_g	Q (ft^3/s)	C_{gs}
		h_1 (ft)	h_3 (ft)				
6	9-18-90	24.99	13.87	1.0	13.9	3,070	0.103
8	9-18-90	24.98	13.87	1.0	13.9	3,690	.124
9	6-29-88	25.17	10.56	0	--	891	--
	5-12-88	25.20	13.54	.5	27.1	2,220	.075
	5-11-88	25.09	13.25	1.0	13.2	3,420	.117
	5-11-88	25.11	13.33	2.0	6.7	6,040	.206
	4-07-88	23.48	17.80	4.0	4.4	7,610	.280
	4-08-88	23.23	17.48	5.5	3.2	10,300	.383
	5-09-90	23.27	17.46	8.0	2.2	15,000	.556
	7-13-90	21.85	19.57	9.0	2.2	9,950	.525
	5-08-90	22.54	18.69	11	1.7	17,500	.744
	7-12-90	21.61	20.58	15	1.4	14,000	1.04
11	10-24-90	25.26	12.22	.5	24.4	2,260	.080
	9-18-90	24.98	13.87	1.0	13.9	3,170	.107
13	5-12-88	25.13	13.53	0	--	904	--
	5-12-88	25.10	13.54	.5	27.1	2,140	.072
	5-11-88	25.11	13.25	1.0	13.2	3,370	.115
	5-11-88	25.10	13.28	2.0	6.6	5,760	.197
	4-07-88	23.45	17.78	4.0	4.4	7,310	.269
	4-08-88	23.18	17.50	5.5	3.2	10,100	.378
	5-09-90	23.28	17.43	8.0	2.2	14,700	.544
	5-08-90	22.51	18.71	11	1.7	17,400	.744
	7-12-90	21.60	20.79	15	1.4	11,500	.958

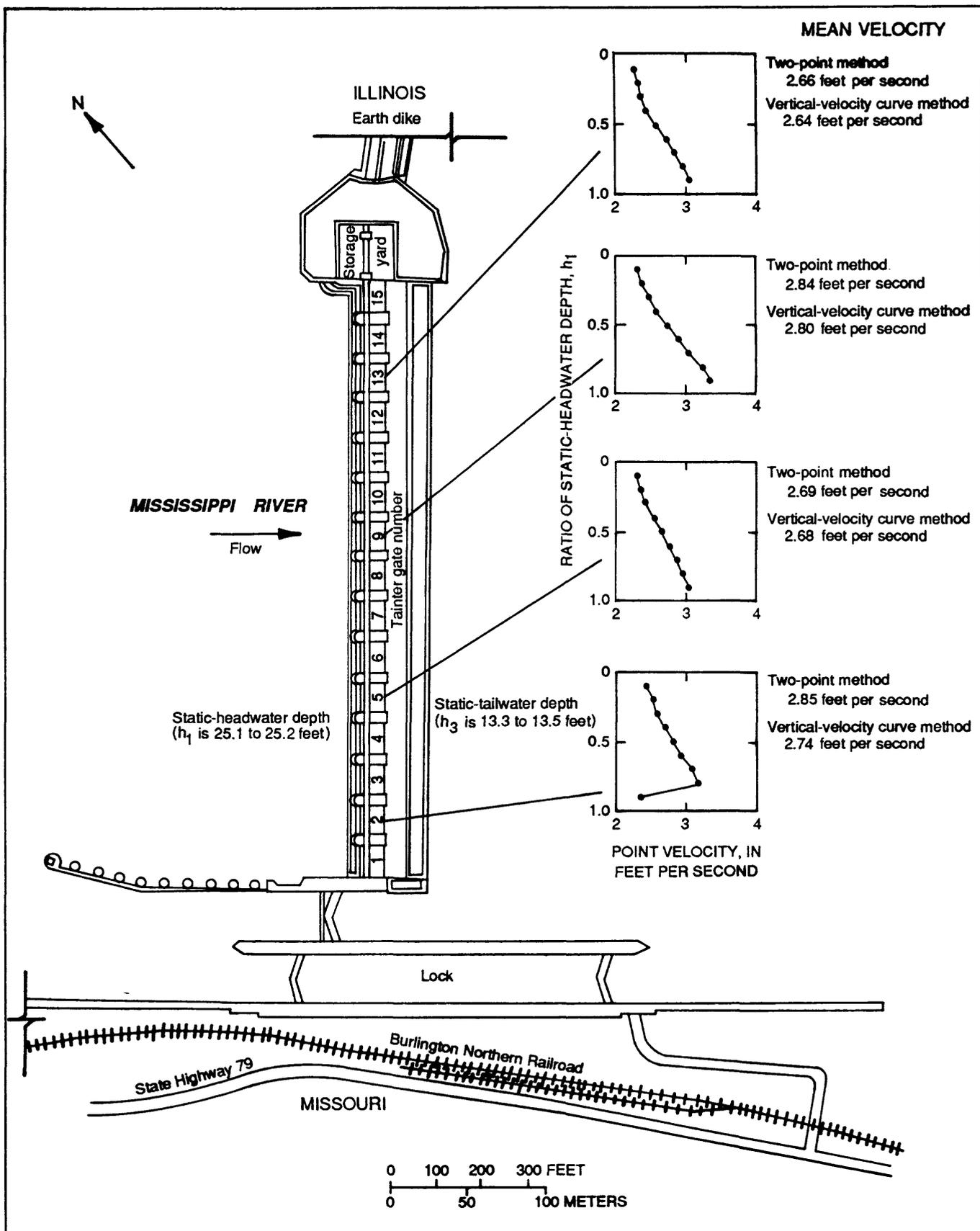


Figure 4.--Velocity observations of May 11-12, 1988, for a 2-foot gate opening at tainter gates 2, 5, 9, and 13.

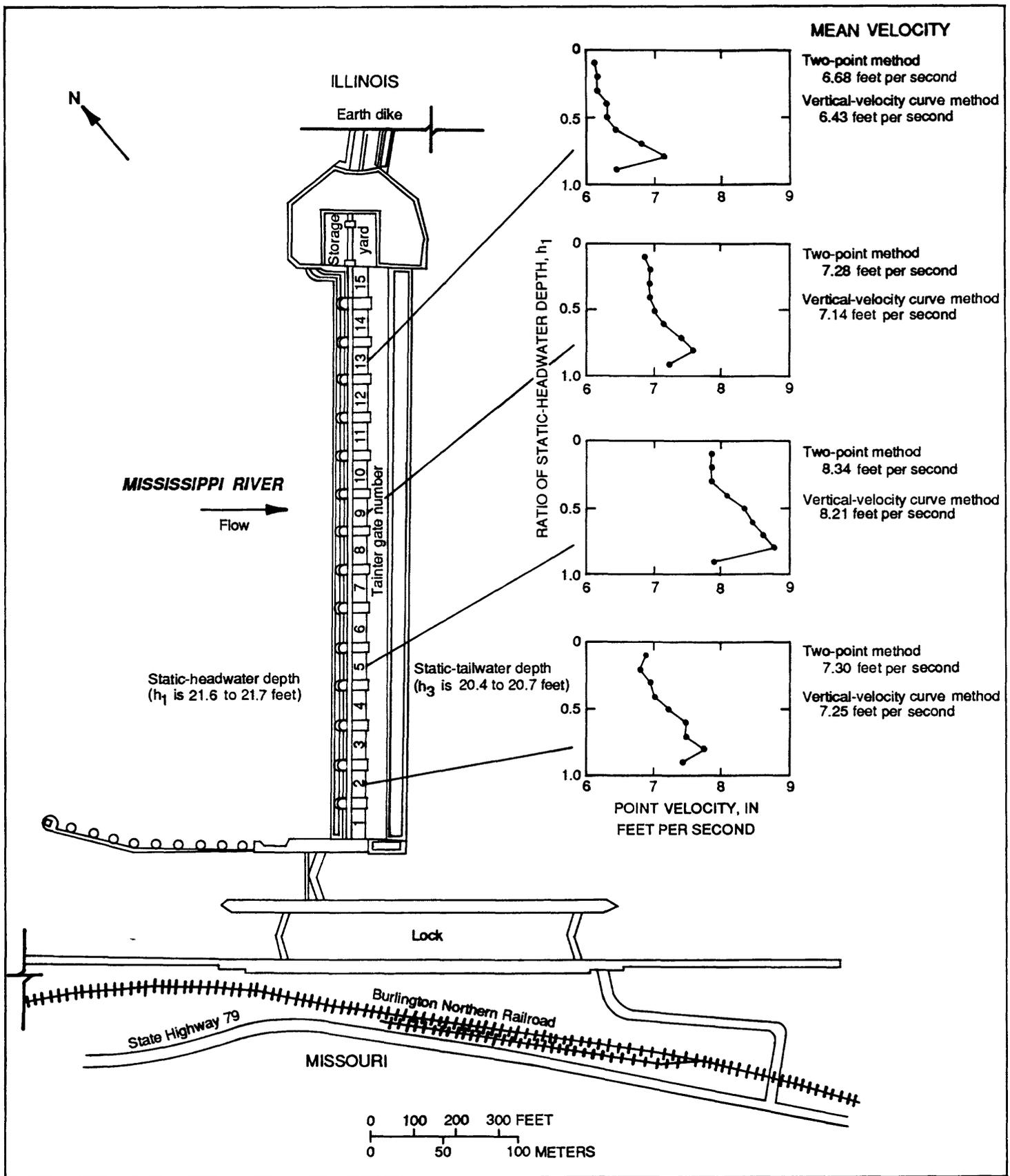


Figure 5.--Velocity observations of July 12, 1990, for a 15-foot gate opening at tainter gates 2, 5, 9, and 13.

shown in figure 6. As indicated by Collins (1977, p. 12), a break in the relation did occur when the orifice-submergence ratios were less than 2. Therefore, the resulting equation for orifice-submergence ratios from 2.0 to 27.9 is:

$$C_{gs} = 1.02 \left(\frac{h_3}{h_g} \right)^{-0.847} \quad (5)$$

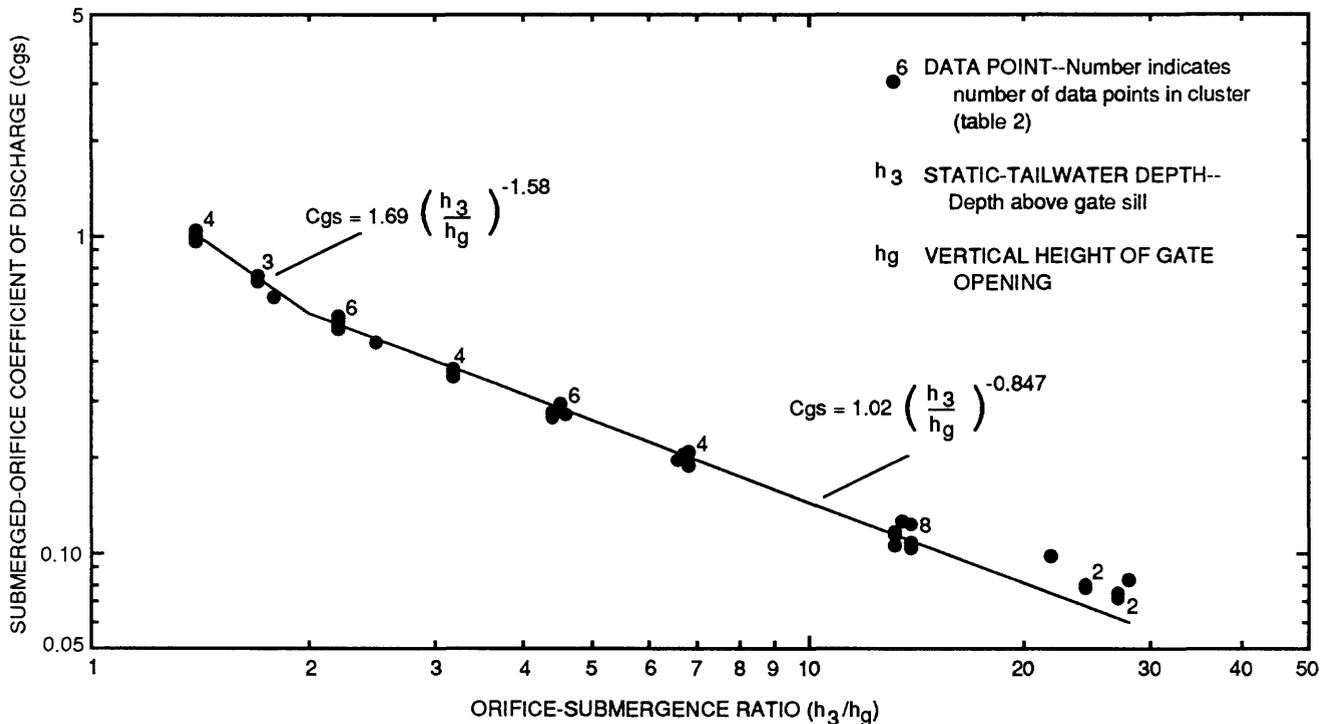


Figure 6.--Relation of submerged-orifice discharge coefficients and orifice-submergence ratios for tainter gates.

Three current-meter discharge measurements made at $h_g = 0$ (table 2) indicate about 900 ft³/s leakage discharge per gate does exist because the lower seal of each gate is worn or dented and does not form a tight fit against the concrete sill. The gate leakage discharge did affect the six coefficients of discharge computed for orifice-submergence ratios greater than 13.9 ($h_g = 0.5$) as shown in figure 6. For these six discharge measurements, the computed coefficients of discharge are greater than those extrapolated from figure 6. Thus, a current (1992) adjustment for leakage discharge per gate (q_{GL}) is developed in the next section.

The 14 computed coefficients of discharge with orifice-submergence ratios of 1.4 to 2.2 indicate a transition occurs in the submerged-orifice flow regime (fig. 6). Thus, a second equation for orifice-submergence ratios of 1.4 to 2.0 is:

$$C_{gs} = 1.69 \left(\frac{h_3}{h_g} \right)^{-1.58} \quad (6)$$

Submerged-Orifice Discharge Equations

An equation for computing submerged-orifice flow under a single tainter gate at Lock and Dam No. 24 was developed for orifice-submergence ratios from 2.0 to 27.9 using the theoretical submerged-orifice equation of discharge (eq. 2) and substituting equation 5 for the discharge

coefficient, C_{gs} . The resulting equation that relates discharge per gate (Q) to the hydraulic-control variables of static-tailwater depth (h_3), orifice-submergence ratio (h_3/h_g), and static head differential (h_1-h_3) is:

$$Q = 654h_3 \left(\frac{h_3}{h_g} \right)^{-0.847} (h_1 - h_3)^{0.5}. \quad (7)$$

Under existing (1992) conditions, an average linear leakage discharge per gate (q_{GL}) adjustment of 0 ($h_g = 1$) to 900 ft^3/s ($h_g = 0$) is required to adjust for the difference between measured discharge (table 2) and the discharge calculated by equation 7. Equation 7 then becomes:

$$Q = 654h_3 \left(\frac{h_3}{h_g} \right)^{-0.847} (h_1 - h_3)^{0.5} + q_{GL}; \quad (8)$$

however, the leakage discharge per gate (q_{GL}) may require updating as worn gate seals are replaced or dented gate lips are repaired.

An equation for computing submerged-orifice flow under a tainter gate was developed for orifice-submergence ratios from 1.4 to 2.0 using the theoretical submerged-orifice equation of discharge (eq. 2) and substituting equation 6 for the discharge coefficient, C_{gs} . The resulting equation of discharge is:

$$Q = 1,084h_3 \left(\frac{h_3}{h_g} \right)^{-1.58} (h_1 - h_3)^{0.5}. \quad (9)$$

DISCHARGE RATING

The discharge equations applicable to submerged-orifice flow under each tainter gate at Lock and Dam No. 24 have been developed and are summarized in table 3.

Table 3.--*Summary of theoretical discharge equations for submerged-orifice flow under a single tainter gate*

[\leq , less than or equal to; h_3 , static-tailwater depth; h_g , vertical height of tainter gate opening; Q , discharge per gate; h_1 , static-headwater depth; q_{GL} , leakage discharge per gate; ft, feet; ft^3/s , cubic feet per second]

Hydraulic-control conditions	Equation of discharge	Equation number
$2.0 \leq h_3/h_g \leq 27.9$	$Q = 654h_3 \left(\frac{h_3}{h_g} \right)^{-0.847} (h_1 - h_3)^{0.5} + q_{GL}$	8
$1.4 \leq h_3/h_g \leq 2.0$	$Q = 1,084h_3 \left(\frac{h_3}{h_g} \right)^{-1.58} (h_1 - h_3)^{0.5}$	9

Note: q_{GL} is a linear adjustment of 0 ($h_g = 1$ ft) to 900 ft^3/s ($h_g = 0$ ft).

A discharge rating table for normal headwater and tailwater elevations (table 4) was developed from equations 8 and 9 for submerged-orifice flow under a single tainter gate with orifice-submergence ratios from 1.4 to 27.9 ($0.5 \leq h_g \leq 15$). The discharges for any combination of headwater-tailwater elevations, during normal submerged-orifice operating conditions, can readily be computed with a small programmable calculator using the equations of discharge given in table 3.

Table 4.--Discharge rating table for a tainter gate with submerged-orifice flow for normal headwater and tailwater elevations
 [ft³/s, cubic feet per second; ft, feet; --, outside the hydraulic-control conditions listed in table 3]

Gate opening (ft)	Discharge, in ft ³ /s, for a headwater elevation of 449.00 ft and indicated tailwater elevations in ft					
	438.00	437.50	437.00	436.50	436.00	435.50
0.5	--	2,290	2,320	2,350	2,370	2,400
1.0	3,250	3,310	3,360	3,410	3,460	3,500
2.0	5,850	5,950	6,050	6,140	6,220	6,300
Gate opening (ft)	Discharge, in ft ³ /s, for a headwater elevation of 448.00 ft and indicated tailwater elevations in ft					
	440.50	440.00	439.50	439.00	438.50	438.00
3.0	6,990	7,180	7,370	7,540	7,710	7,870
4.0	8,910	9,160	9,400	9,620	9,840	10,000
5.0	10,800	11,100	11,400	11,600	11,900	12,100
Gate opening (ft)	Discharge, in ft ³ /s, for a headwater elevation of 447.00 ft and indicated tailwater elevations in ft					
	442.50	442.00	441.50	441.00	440.50	440.00
6.0	9,900	10,400	10,900	11,300	11,700	12,100
7.0	11,300	11,800	12,400	12,900	13,300	13,800
8.0	12,600	13,300	13,900	14,400	14,900	15,400
Gate opening (ft)	Discharge, in ft ³ /s, for a headwater elevation of 446.00 ft and indicated tailwater elevations in ft					
	444.00	443.50	443.00	442.50	442.00	441.50
9.0	9,420	10,500	11,400	12,300	13,100	14,000
10	10,300	11,600	12,900	14,100	15,300	16,500
11	11,900	13,400	15,000	16,400	17,800	19,200
12	13,600	15,400	17,200	18,800	20,400	22,000
Gate opening (ft)	Discharge, in ft ³ /s, for a headwater elevation of 445.50 ft and indicated tailwater elevations in ft					
	445.00	444.50	444.00	443.50	443.00	442.50
13	7,510	10,800	13,400	15,700	17,800	19,800
14	8,440	12,100	15,000	17,600	20,000	22,400
15	9,410	13,500	--	--	--	--

SUMMARY

Lock and Dam No. 24, by regulation of 15 tainter gates, controls the water surface elevation of the navigation pool and discharge of the Mississippi River at Clarksville, Missouri. The development of stage-discharge relations for these gates can be used to compute discharge through Dam No. 24, and to aid in regulating the headwater elevation within its normal operational limits of 445.50 to 449.00 feet. During high flow, the tainter gates are raised out of the water to allow open-river flow. This unregulated condition was not evaluated in this study.

A total of 46 current-meter discharge measurements that ranged from 891 to 17,500 cubic feet per second were made in 8 of the 15 tainter gate forebays. Forty-three coefficients of discharge (C_{gs}) ranging from 0.072 ($h_g = 0.5$ foot) to 1.04 ($h_g = 15$ feet) were used to define the discharge coefficient relation for submerged-orifice flow, which is the predominant flow regime when Lock and Dam No. 24 is the control. Three discharge measurements ($h_g = 0$) were made to evaluate the gate leakage discharge relation resulting from worn gate seals or dented gate lips that do not form a tight fit against the sill. A linear leakage discharge per gate (q_{GL}) adjustment of 0 cubic foot per second ($h_g = 1$ foot) to 900 cubic feet per second ($h_g = 0$) is needed under current (1992) conditions. From the discharge coefficient and leakage discharge relations, equations of discharge were developed that express discharge per gate (Q) as a function of the discrete hydraulic-control variables of static-headwater depth (h_1), static-tailwater depth (h_3), and vertical height of gate opening (h_g). These equations are applicable to tainter gate openings of 0.5 foot to 15 feet with orifice-submergence ratios (h_3/h_g) ranging from 1.4 to 27.9.

Two equations of discharge are presented so that a tainter gate elevation-discharge rating can be computed for any discrete combination of headwater-tailwater elevations not summarized in this report. A discharge rating table is given for navigation pool (headwater) elevations within the normal operating limits of 445.50 to 449.00 feet and selected tailwater elevations.

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