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Design and Calibration of Submerged Open Channel Flow Measurement Structures: Part 2 -Parshall Flumes

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Design and Calibration of Submerged

Open Channel Flow Measurement Structures

Part 2

PARSHALL FLUMES

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ABSTRACT

DESIGN AND CALIBRATION OF SUBMERGED OPEN CHANNEL FLOW MEASUREMENT STRUCTURES

PART 2, PARSHALL FLUMES

The general form of the equation describing submerged flow in Parshall flumes has been presented. The coefficients and exponents in the equation have been listed for flume sizes varying from 1 inch to 50 feet. The graphical presentation of the equation is a three-dimensional plot on log-log paper. Submerged flow rating curves are given for the various sizes of Parshall flumes. The transition from free flow to submerged flow has been discussed along with the relationship between constriction ratio and transition submergence. More data is needed for both free flow and submerged flow data in large Parshall flumes with throat widths varying from 10 feet to 50 feet.

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KEYWORDS — flow measurement hydraulics hydraulic structures open-channel flow *Parshall flumes *subcritical flow *submerged flow

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NOMENCLATURE

Symbol	Definition
B	constriction ratio, b_2/b_1 or W/b_a
b_1	bottom width at entrance of rectangular flume
b_2	bottom width at throat of rectangular flume
b_a	bottom width of Parshall flume at location of flow depth measured in entrance section, H_a
C	coefficient in the free flow equation
C_1	coefficient in the numerator of the approximate submerged flow equation
C_2	coefficient in the denominator of the approximate submerged flow equation
F_a	hydrostatic force at section a
F_b	hydrostatic force at section b
F_f	frictional force
F_m	maximum Froude number in flume throat
F_t	hydrostatic force acting in direction of flow on throat floor
F_w	hydrostatic force on flume walls in entrance section
g	acceleration due to gravity
H_a	flow depth at specified location in entrance section of Parshall flume
H_b	flow depth above flume crest at specified location in throat of Parshall flume
n_1	exponent of H_a in the free flow equation and exponent of $H_a - H_b$ in the submerged flow equation
n_2	exponent of the submergence term in the denominator of the submerged flow equation
n_{2t}	theoretical value of n_2
Q	flow rate or discharge
Q_t	theoretical discharge given by the momentum equation
S	submergence, which is the ratio of a downstream depth to an upstream depth, where the downstream measurement is the depth of flow above the flume floor at the point of upstream measurement
S_t	transition submergence
V	average velocity
W	throat width of Parshall flume
y_1	flow depth at entrance to flume
y_2	flow depth at a point in flume throat
y_m	minimum depth of flow in flume throat, which varies in location longitudinally
Δy	change in water surface elevation between two flow sections, $y_1 - y_2$
π_1	maximum Froude number, F_m
π_2	submergence, S
π_3	$\Delta y/y_m$

INTRODUCTION

As the value of water increases, the extent to which measurement is employed in an irrigation system also increases. Accurate measurement is required to properly manage this increasingly important resource. Of the many devices developed for this purpose, the Parshall measuring flume is one of the most widely accepted and used. Although the Parshall measuring flume is used primarily in irrigation systems, it can be used to measure water flowing in any open channel.

The two most desirable features of the Parshall flume are that it operates satisfactorily with a loss of head much less than required for a weir, and that under normal operating conditions, the discharge can be determined within an accuracy of 2 to 5 percent. However, a Parshall flume involves more expense than a weir. The discharge through the flume is considered free flow when the tailwater conditions do not affect the flow conditions upstream, and the discharge may be evaluated by measuring only one depth of flow, the upstream depth. However, when the tailwater, or downstream, conditions are such that the flow conditions upstream are affected by a change downstream, then submerged flow occurs. Submerged flow requires the measurement of both an upstream and downstream flow depth. Normally the Parshall flume is operated under free flow conditions.

This publication discusses the use of Parshall flumes operating under both flow conditions but utilizes a new approach for submerged flow which was developed at Utah State University by the writers. Through application of the momentum theory and dimensional analysis, calibration curves describing submergence in all Parshall measuring flumes have been developed and their use illustrated. The free flow condition and its application to the Parshall flume, as well as the practical aspects for operating the structure, are also discussed.

DEFINITION OF FREE FLOW AND SUBMERGED FLOW

Free flow and submerged flow are the two most significant flow regimes or flow conditions in a Parshall flume. The distinguishing difference between the two is the occurrence of critical depth, usually near the crest of the flume. Upstream from the flume crest the flow is subcritical (depth of flow greater than critical depth), whereas in the flume throat the flow is supercritical (depth of flow less than critical depth). With supercritical flow occurring in the flume throat, a change in flow depth downstream from the Parshall flume will not change the depth of flow upstream from the flume for the free flow condition. This critical-flow control requires only the measurement of a depth of flow at some location upstream from the point of critical depth for determining the free flow discharge. The location of the point of upstream depth, H_a, measurement in a Parshall flume is two-thirds the length of the entrance section upstream from the flume crest (Fig. 1).

In some cases, flumes designed to operate under free flow conditions will become submerged, either due to unusual operating conditions downstream or the accumulation of moss and/or vegetation in the channel. For a Parshall flume, however, the free flow-discharge relationship

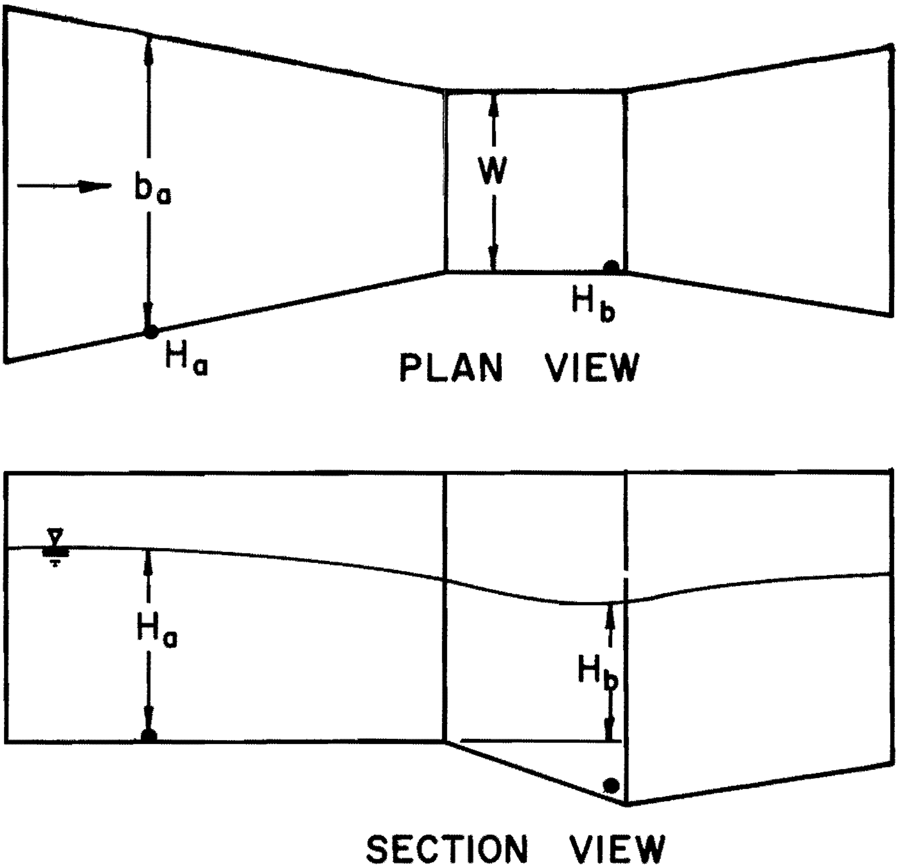


Fig. 1. Definition sketch for Parshall flume.

remains valid for a relatively high degree of submergence, thus allowing a wide range of downstream flow conditions.

Submerged flow conditions exist when the downstream or tailwater depth is raised to the point that the flow depths at every point through the structure become greater than the critical depth. In the submerged flow regime a change in the tailwater depth also affects the upstream depth, and a rating for the flume requires that two flow depths be measured, one upstream and one downstream from the flume crest. Further definition is given submerged flow by defining submergence, often expressed as a percentage, as the ratio of the downstream head, H_b, to the upstream head, H_a, for a Parshall flume (Fig. 1).

The flow condition at which the flow regime changes from free flow to submerged flow is a transition state that is unstable. The value of submergence at which this condition occurs is often referred to as the transition submergence, symbolized by S_t. This change from supercritical flow to subcritical flow (transition submergence) signifies that the Froude number is equal to 1 at a single flow cross-section (the cross-section at which critical depth occurs), and for every other cross-section the Froude number is less than 1 (subcritical flow). At the transition from free flow to submerged flow, the discharge equations for the two flow conditions should be equal. Consequently, if the discharge equations are known, the transition submergence can be obtained by setting the free and submerged flow equations equal to one another.

When compared with free flow, a Parshall flume operating under submerged flow conditions offers two principal advantages: (1) there is less energy loss, and (2) the inlet floor of the flume can be placed at the same elevation as the channel bottom. Oftentimes, to insure free flow in a Parshall flume, the inlet floor is elevated above the grade of the channel resulting in greater depths of flow upstream from the flume for flow rates less than the design discharge. This may cause additional silting and increased seepage losses in the upstream channel for the lower flow rates.

Fig. 2 illustrates free flow, submerged flow, and the transition submergence in a Parshall flume. Water surface profiles **a** and **b** in Fig. 2 represent free flow conditions whereas profiles **c** and **d** represent submerged flow conditions. Water surface profiles **a** and **b** both have the same upstream depth. Profile **a** represents a very low submergence resulting in a jetting action at the exit. The flow condition is near the transition submergence when a ripple or wave is formed at or near the downstream end of the throat due to a rising downstream depth of flow as depicted by profile **b.** The transition submergence is the maximum value of submergence that can occur for free flow conditions in the flume. Further illustrated by profiles **a** and **b** is the wide range of possible downstream conditions for free flow. Water surface profiles **c** and **d** illustrate submerged flow conditions with profile **c** having a value of submergence slightly greater than the transition submergence (profile **b**), whereas profile **d** represents an even higher submergence value. Of particular importance is the change in the upstream water depth, H_a, under submerged flow conditions (water surface profiles **c** and **d**).

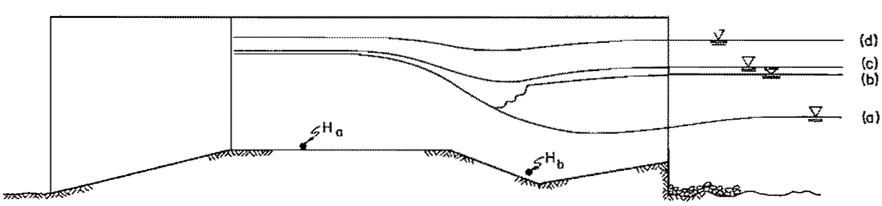


Fig. 2. Illustration of free flow and submerged flow in a Parshall flume.

CONCEPTS OF SUBMERGED FLOW

Momentum Theory

A theoretical submerged flow discharge equation has been developed for a flat-bottomed rectangular flume (Fig. 3) by employing momentum theory (Skogerboe, Hyatt, and Eggleston, 1967). The theoretical equation can be written as

$$Q_t = \frac{(g/2)^{1/2}\, b_2\, (y_1 - y_2)^{3/2}}{\sqrt{\dfrac{(1 - BS)\,(1 - S)^2}{S\,(1 + S)}}} \quad \ldots \quad 1$$

where

$$B = b_2/b_1 \quad \ldots \quad 2$$

$$S = y_2/y_1 \quad \ldots \quad 3$$

Eq. 1 can be applied to a Parshall flume by substituting H_a for y_1, H_b for y_2, and W for b_2.

$$Q_t = \frac{(g/2)^{1/2}\, W\, (H_a - H_b)^{3/2}}{\sqrt{\dfrac{(1 - BS)\,(1 - S)^2}{S\,(1 + S)}}} \quad \ldots \quad 4$$

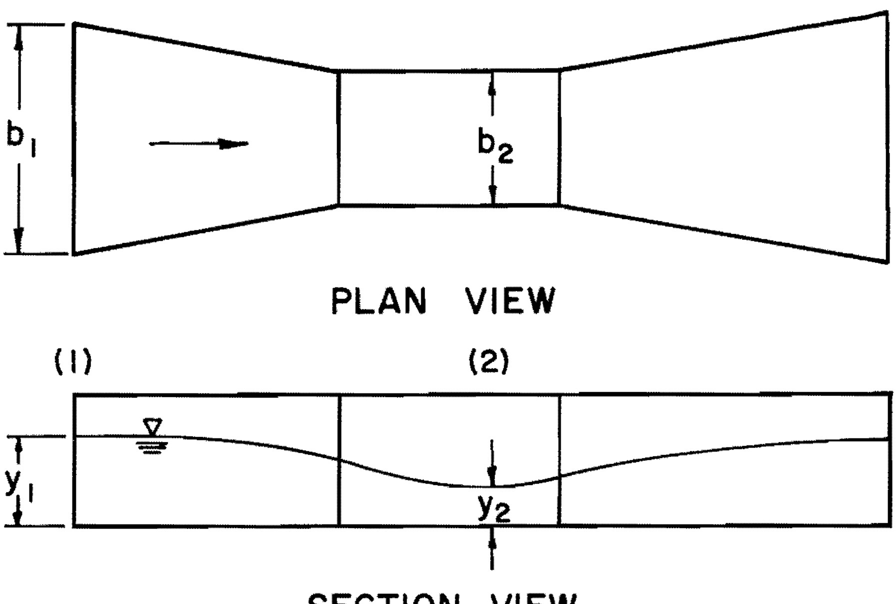


Fig. 3. Definition sketch for rectangular flat-bottomed flume.

where

$$B = W/b_a \quad \ldots \quad 5$$

$$S = H_b/H_a \quad \ldots \quad 6$$

The width of the flume at the point of upstream flow depth (H_a) measurement is given by b_a, whereas W represents the throat width.

The substitution of H_a and H_b for y_1 and y_2 in Eq. 1 implies some simplifying assumptions in addition to the assumptions required for the analysis of the flat-bottomed rectangular flume. The turbulence of the flow in the throat raises some doubts as to the validity of assuming hydrostatic pressure at section b (Fig. 4), or in applying the continuity equation at section b. Although Eq. 4 is questionable, it will be shown later that the discharge, Q, is a function only of H_a - H_b and S for any particular flume geometry, as implied by the theoretical submerged flow equation.

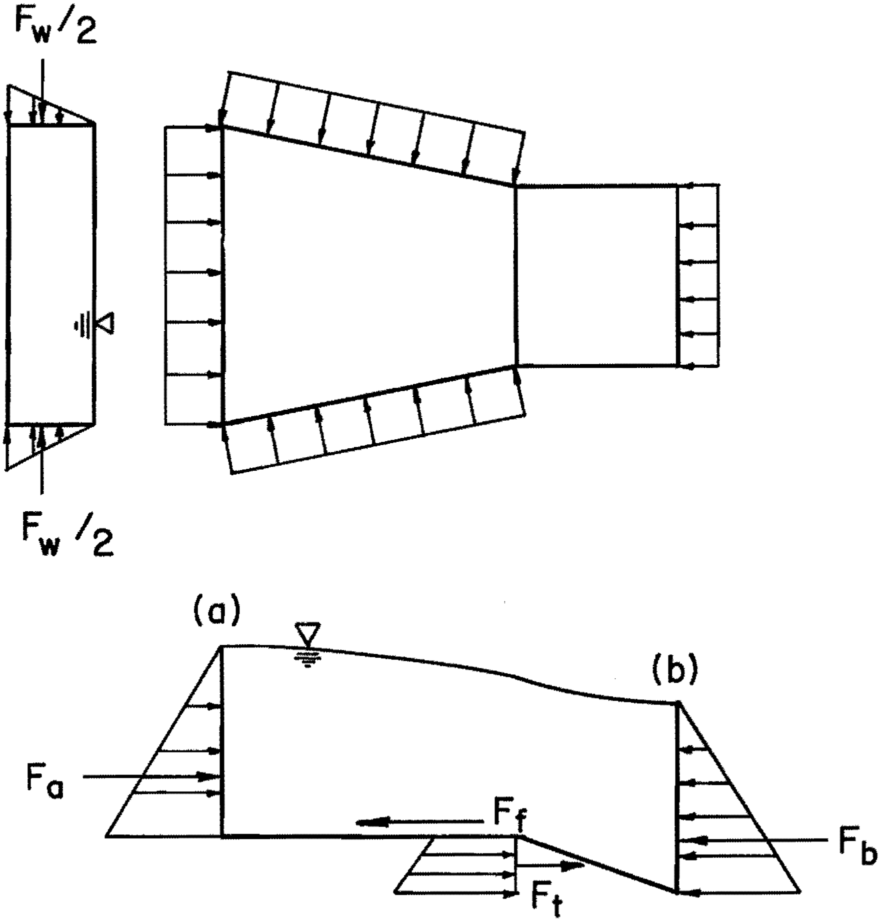


Fig. 4. Control volume for Parshall flume.

Empirical Approach

Dimensional analysis has been previously used (Hyatt, 1965) to develop the parameters describing submerged flow in flat-bottomed flumes. For any particular flume geometry, the dimensionless parameters become

$$\pi_1 = F_m = V/(g\, y_m)^{1/2} \qquad 7$$

$$\pi_2 = S \qquad 8$$

$$\pi_3 = \Delta y / y_m \qquad 9$$

In the above equations, F_m is the maximum Froude number occurring in the throat, y_m is the minimum depth of flow in the throat, V is the average velocity at section m, S is the submergence, and Δy is the change in water surface elevation between a flow depth measured upstream from section m and a flow depth measured downstream from section m.

A plot of log π_2 against π_3 for any flume is a curved line as shown in Fig. 5. The curved line plot can be approximated by a straight line over a large range of submergence with some sacrifice in accuracy, but still providing reasonable accuracy for submergence values up to 96 percent. The straight line in Fig. 5, in conjunction with other relationships developed from Eqs. 7, 8, and 9 (Skogerboe, Hyatt, and Eggleston, 1967), yields an equation having the format

$$Q = \frac{C_1 (\Delta y)^{n_1}}{[-(\log S + C_2)]^{n_2}} \quad . . . . 10$$

For a Parshall flume, Δy becomes $H_a - H_b$ and S is given by H_b/H_a.

$$Q = \frac{C_1 (H_a - H_b)^{n_1}}{[-(\log H_b/H_a + C_2)]^{n_2}} \quad . . . . 11$$

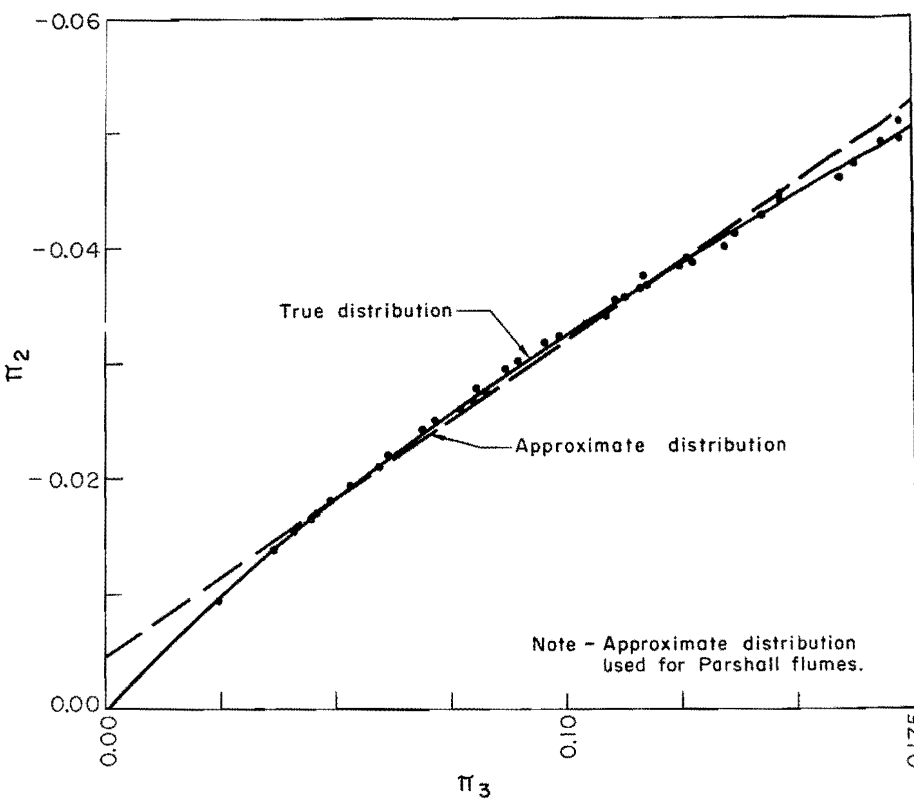


Fig. 5. Relationship between π_2 and π_3.

The submerged flow calibration curves are obtained according to Eq. 11 by plotting on log-log paper Q as the ordinate, H_a - H_b as the abscissa, and H_b/H_a as the varying parameter. The slope of the lines of constant submergence, H_b/H_a, is n_1. Typical submerged flow calibration curves are shown in Figs. 6 and 7 where Fig. 6 portrays full and half scale model data reported by Blaisdell (1944) for a 6-foot Parshall flume and the data in Fig. 7 is taken from a study by Hyatt, Skogerboe, and Eggleston (1966) of a 1-foot Parshall flume. The slope, n_1, of the lines of constant submergence in Fig. 6 is 1.58 whereas the slope in Fig. 7 is 1.52.

One factor discovered from various flume studies (Skogerboe, Hyatt, Johnson, and England, 1965; Hyatt, Skogerboe, and Eggleston, 1966) is the power on the H_a - H_b term in the submerged flow equation is identical to the power on the H_a term in the free flow equation for any given flume when the free flow relationship is expressed as

$$Q = C H_a^{n_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 12$$

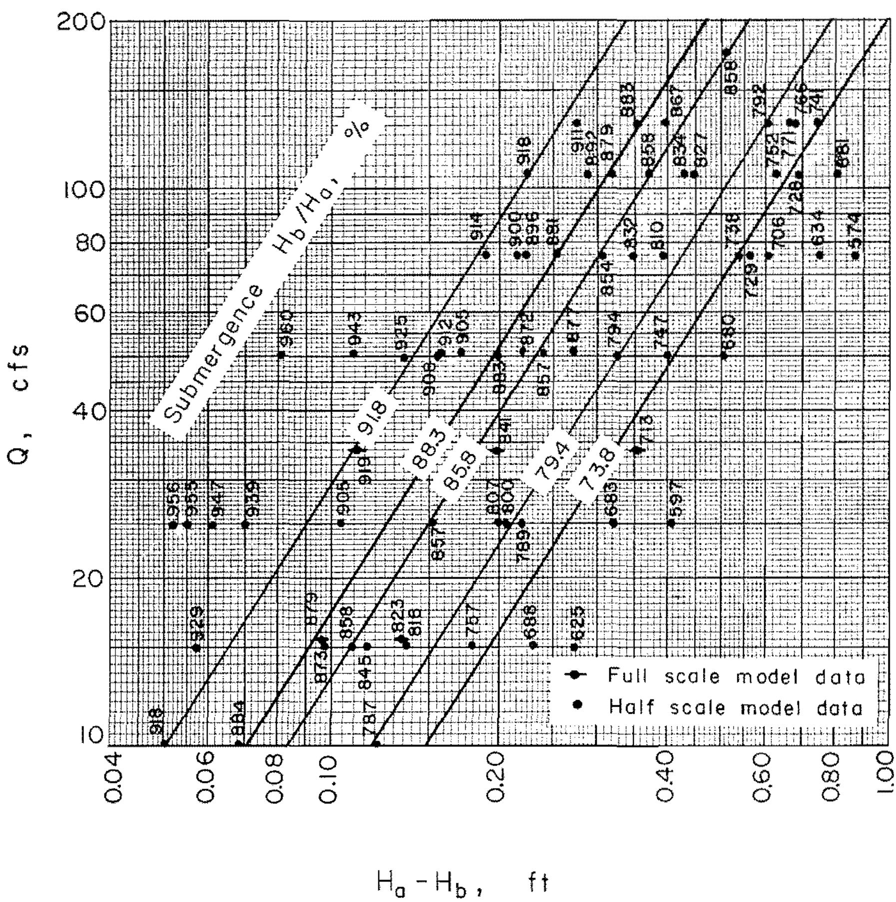


Fig. 6. Plot of 6-foot Parshall flume submerged flow data.

The power, n_1, in Eq. 12 is the slope of the free flow plot as well as the slope of the lines of constant submergence in a submerged flow calibration plot (e.g. Figs. 6 and 7). Hence, the slope of the lines of constant submergence — 1.59 for the 6-foot flume and 1.52 for the 1-foot flume — is the same value as the slope given by Parshall (1953) for the free flow plots.

Various studies (Hyatt, 1965; Skogerboe, Walker, and Robinson, 1965; Skogerboe, Hyatt, England, and Johnson, 1965; and Hyatt, Skogerboe, and Eggleston, 1966) have indicated that a constant value of 0.0044 for C_2 is suitable for Parshall flumes. This value of C_2 is also idicated by Fig. 5.

The submerged flow data collected by Robinson (1960), Hall (1959), Gunaji (1950), and Parshall (1932), along with data collected by the writers, has been subjected to analysis using the approximate submerged flow equation (Eq. 11). The free flow and submerged flow coefficients and exponents developed from this analysis are listed in Table 1 for Parshall flumes having throat widths between 1 inch and 50 feet. Also, the transition submergence, S_t, for each flume size is listed.

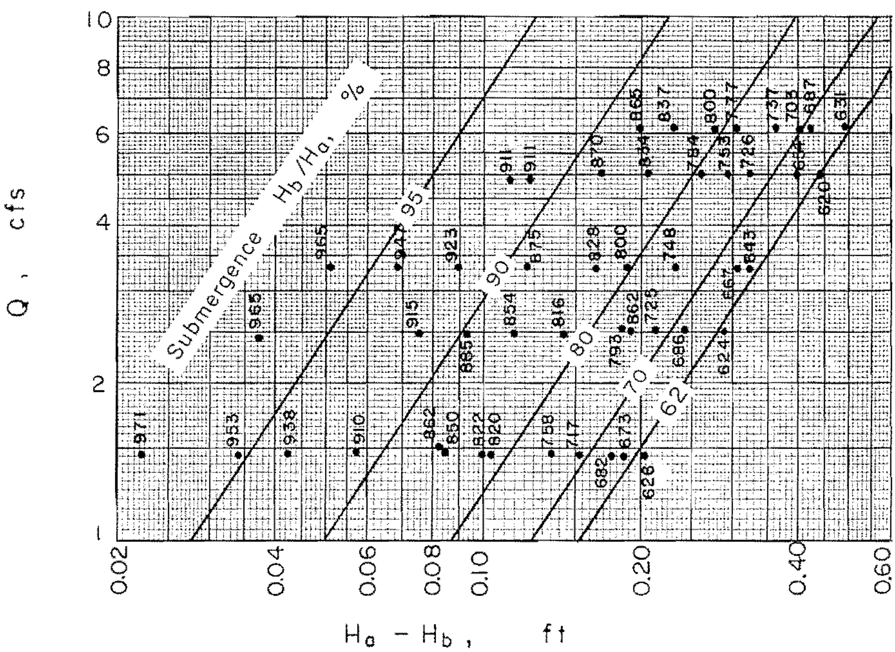


Fig. 7. Plot of 1-foot Parshall flume submerged flow data.

Table 1. **Free flow and submerged flow coefficients and exponents for Parshall flumes.**

W	C	C_1	C_2	n_1	n_2	S_t
1"	0.338	0.299	0.0044	1.55	1.000	0.56
2"	0.676	0.612	0.0044	1.55	1.000	0.61
3"	0.992	0.915	0.0044	1.55	1.000	0.64
6"	2.06	1.66	0.0044	1.58	1.080	0.55
9"	3.07	2.51	0.0044	1.53	1.060	0.63
12"	4.00	3.11	0.0044	1.52	1.080	0.62
18"	6.00	4.42	0.0044	1.54	1.115	0.64
24"	8.00	5.94	0.0044	1.55	1.140	0.66
30"	10.00	7.22	0.0044	1.555	1.150	0.67
3'	12.00	8.60	0.0044	1.56	1.160	0.68
4'	16.00	11.10	0.0044	1.57	1.185	0.70
5'	20.00	13.55	0.0044	1.58	1.205	0.72
6'	24.00	15.85	0.0044	1.59	1.230	0.74
7'	28.00	18.15	0.0044	1.60	1.250	0.76
8'	32.00	20.40	0.0044	1.60	1.260	0.78
10'	40.13	24.79	0.0044	1.59	1.275	0.80
12'	47.50	29.34	0.0044	1.59	1.275	0.80
15'	58.56	36.17	0.0044	1.59	1.275	0.80
20'	77.00	47.56	0.0044	1.59	1.275	0.80
25'	95.44	58.95	0.0044	1.59	1.275	0.80
30'	113.88	70.34	0.0044	1.59	1.275	0.80
40'	150.75	93.11	0.0044	1.59	1.275	0.80
50'	187.63	115.89	0.0044	1.59	1.275	0.80

Comparison of Momentum and Approximate Equations

An appraisal of Eqs. 4 and 11 discloses some similarities. For a particular Parshall flume with specified dimensions, the constriction ratio, B, and throat width, W, become constant. Consequently, the

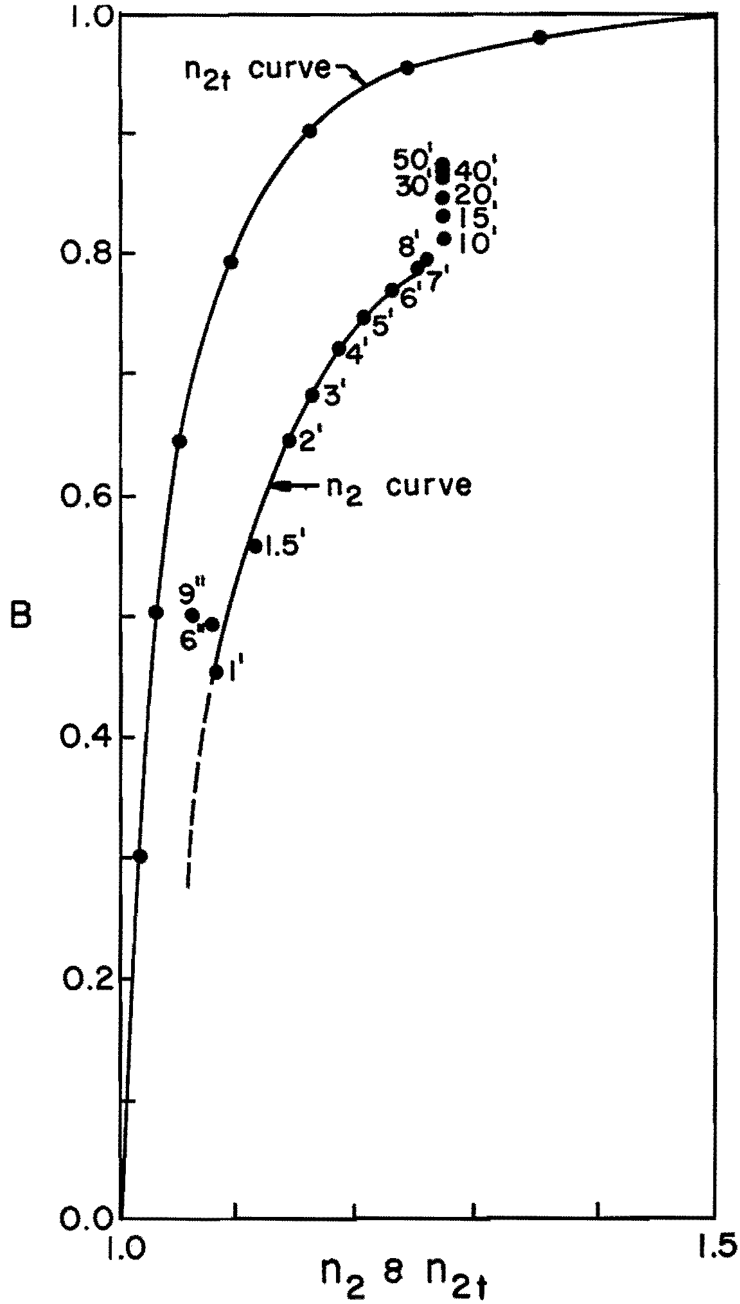


Fig. 8. Plot of constriction ratio, B, against n_2 and n_{2t}.

theoretical discharge, Q_t becomes a function of $(H_a - H_b)^{3/2}$ and S, which is similar to the results obtained empirically through dimensional analysis where the discharge, Q, is a function of $(H_a - H_b)^{n_1}$ and S. The n_1 values for all Parshall flumes (Table 1) are slightly in excess of 3/2, ranging in value from 1.52 to 1.60 (Parshall, 1950).

A comparison between the denominators of Eqs. 1 and 11 has shown the theoretical range of n_2 to be between 1.0 and 1.5 for corresponding B values of 0.0 and 1.0, respectively (Skogerboe, Hyatt, and Eggleston, 1967). The nomenclature n_{2t} is used to signify the theoretical value of n_2. The relationship between B and n_{2t} is shown in Fig. 8.

The values of n_2 obtained from Table 1 are also plotted versus B in Fig. 8. The values of n_2 for the 6- and 9-inch Parshall flumes do not conform with the relationship for the 1- to 8-foot Parshall flumes. The lack of geometric similarity between the small, intermediate, and large Parshall flumes partially explains the discontinuity of the relationships depicted in Fig. 8. A lack of considerable data for the large Parshall flumes (throat widths varying from 10 to 50 feet) has resulted in simplified free flow and submerged flow equations (Hyatt and Skogerboe, 1966). In essence, the n_2 plot for the large flumes would indicate that n_2 is independent of B, which is not the case.

TRANSITION SUBMERGENCE

The value of submergence at which the change from free flow to submerged flow occurs in a flume has been referred to as the critical submergence or incipient submergence. The terms critical and incipient have merit, but the writers have chosen the term transition submergence, which is designated by S_t. Since experimentation (Skogerboe, Hyatt, England, and Johnson, 1965; and Hyatt, Skogerboe, and Eggleston, 1966) does not always provide a unique submergence at which the change from free flow to submerged flow occurs, the word transition implies such a condition. The lack of a unique experimental results and the difficulty of producing the transition flow condition in the laboratory, can be attributed largely to the instability of the flow at critical depth.

The free flow and submerged flow equations tabulated in Table 1 for each size of Parshall flume can be equated to provide a unique solution for the transition submergence. As an example, the free flow equation for the 2-foot Parshall flume is

$$Q = 8.0\, H_a^{1.55} \qquad (13)$$

whereas the approximate submerged flow equation is

$$Q = \frac{5.94\,(H_a - H_b)^{1.55}}{[-(\log H_b/H_a + 0.0044)]^{1.14}} \qquad (14)$$

When equations 13 and 14 are equated to one another

$$8.0\, H_a^{1.55} = \frac{5.94\,(H_a - H_b)^{1.55}}{[-(\log H_b/H_a + 0.0044)]^{1.14}} \qquad (15)$$

$$[-(\log H_b/H_a + 0.0044)]^{1.14} = 0.745\,(1 - H_b/H_a)^{1.55} \qquad (16)$$

The solution, obtained by trial and error, is

$$H_b/H_a = S = 0.66 \quad (17)$$

The transition submergence of 66 percent corresponds with experimental results (Skogerboe, Hyatt, England, and Johnson, 1965). The transition submergence, S_t, for the remaining Parshall flumes can be computed as

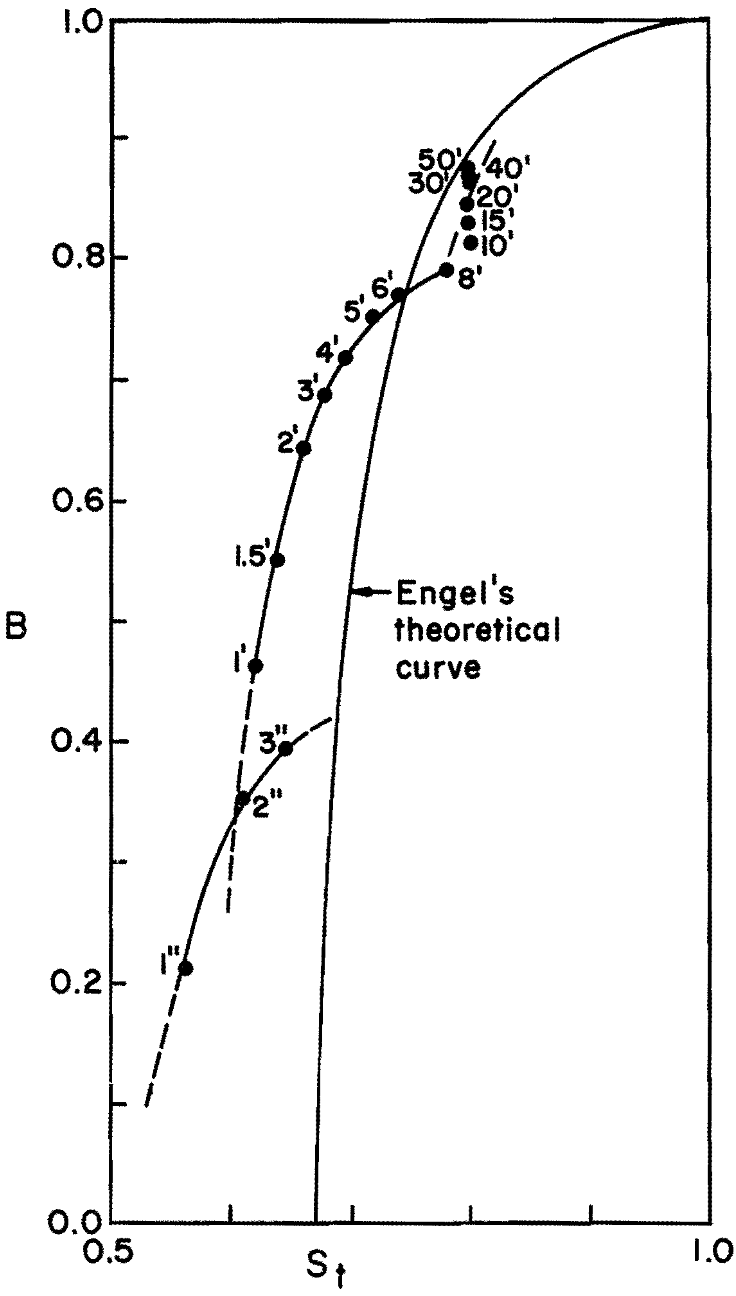


Fig. 9. Comparison of transition submergence with constriction ratio.

illustrated above and have been given in Table 1. A plot of transition submergence against the constriction ratio for each Parshall flume size is shown in Fig. 9.

Engel (1937) has developed a relationship between transition submergence and constriction ratio for flumes. This relationship was developed from the energy equation written between points 1 and 2 (Fig. 3). Engel's curve, which has also been plotted in Fig. 9, comes from the equation

$$S^3 - (3S-2)/B^2 = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad 18$$

A comparison of the transition submergence values for Parshall flumes having throat widths from 1 foot to 8 feet with Engel's curve shows fairly reasonable agreement. Considerable scatter exists in the data for Parshall flume sizes below 1 foot, which is partially due to the varying geometric properties of the smaller sizes as compared with the intermediate sizes (1 foot to 8 feet) which follow a geometric pattern. The transition submergence listed for large Parshall flumes (throat widths from 10 feet to 50 feet) is 80 percent (Parshall, 1932). Although the variation in constriction ratio for the large flumes is slight (0.810 to 0.868), Fig. 9 would indicate a change in transition submergence would be expected over such a range. The dashed line in Fig. 9 represents a possibility as to the relationship between transition submergence and constriction ratio, or flume size, which might be expected for large Parshall flumes. The lack of extensive data for both free flow and submerged flow in the larger flumes prohibits the development of relationships between the two flow conditions which would assist in providing correct values of the transition submergence. The submerged flow equations that have been developed (Hyatt and Skogerboe, 1966) are based on existing free flow equations (Blaisdell, 1944; Hyatt and Skogerboe, 1966; Parshall, 1932), a meager amount of submerged flow data, and a transition submergence of 80 percent.

APPLICATION PRINCIPLES

Since a Parshall flume is a water measurement device intended primarily for use in irrigation practice, some attention must be given the practical aspects of the use of the flume. Accurate measurements, correct operating procedures, and proper installation and maintenance are required to obtain accuracy from the flume.

Flume Dimensions

The flume structure itself consists of: a converging inlet section, a throat, and a diverging outlet section, each with vertical side walls. Figs. 10 and 11 show plan and sectional views of a Parshall flume, along with a letter for each dimension line. Fig. 12 is a plan view of a large Parshall flume. Listed in Table 2 are values of each dimension for various sizes of flumes which have a discharge capacity varying from 0.01 cfs to 3,000 cfs. The size of a particular Parshall flume is denoted by its throat width, W, as indicated in Table 2. The converging floor section is level both longitudinally and laterally. The floor of the throat is inclined downward with a slope of 9 inches vertically to 24 inches horizontally. The

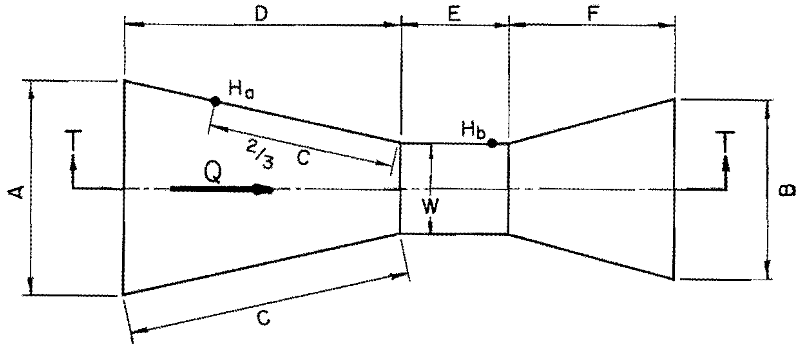


Fig. 10. Plan view of a Parshall measuring flume.

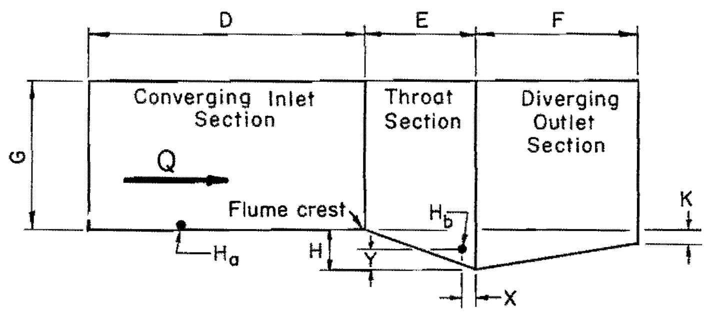


Fig. 11. Sectional view of a Parshall measuring flume.

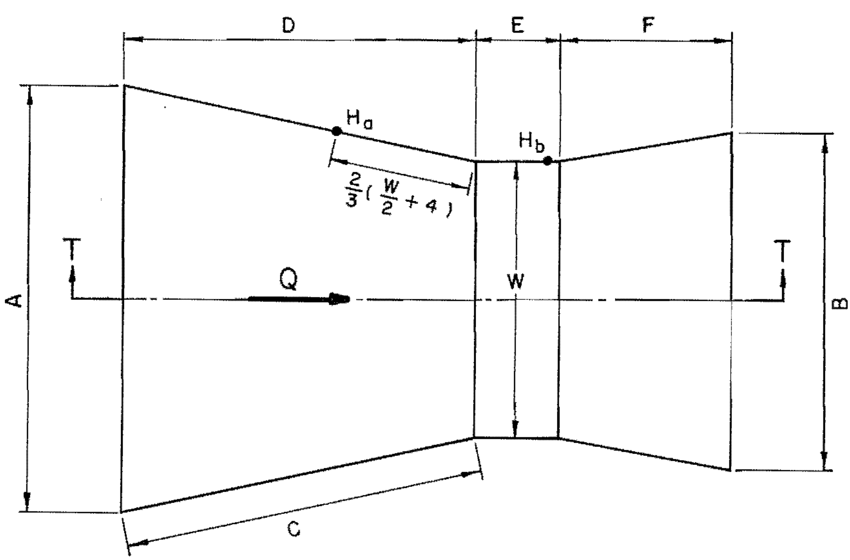


Fig. 12. Plan view of a large Parshall measuring flume.

Table 2. Dimensions and capacities for Parshall flumes.

Throat Width W	Dimensions in Feet and Inches												Free Flow Capacities	
ft. in.	A	B	C	2/3 C or 2/3(W/2+4)	D	E	F	G	H	K	X	Y	Min. cfs	Max. cfs
0' 1"	0' 6 19/32"	0' 3 21/32"	1' 2 9/32"	0' 9 17/32"	1' 2"	0' 3"	0' 8"	0' 6"	0' 1 1/8"	0' 0 3/4"	0' 5/16"	0' 1/2"	0.01	0.2
0' 2"	0' 8 13/32"	0' 5 5/16"	1' 4 5/16"	0' 10 7/8"	1' 4"	0' 4 1/2"	0' 10"	0' 8"	0' 1 11/16"	0' 0 7/8"	0' 5/8"	0' 1"	0.02	0.4
0' 3"	0' 10 3/16"	0' 7"	1' 6 3/8"	1' 0 1/4"	1' 6"	0' 6"	1' 0"	1' 3"	0' 2 1/4"	0' 1"	0' 1"	0' 1 1/2"	0.03	0.6
0' 6"	1' 3 1/2"	1' 3 1/2"	2' 0 7/16"	1' 4 5/16"	2' 0"	1' 0"	2' 0"	1' 6"	0' 4 1/2"	0' 3"	0' 2"	0' 3"	0.05	2.9
0' 9"	1' 10 5/8"	1' 3"	2' 10 5/8"	1' 11 1/8"	2' 10"	1' 0"	1' 6"	2' 0"	0' 4 1/2"	0' 3"	0' 2"	0' 3"	0.1	5.1
12"	2' 9 1/4"	2' 0"	4' 6"	3' 0"	4' 4 7/8"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	0.4	16.0
18"	3' 4 3/8"	2' 6"	4' 9"	3' 2"	4' 7 7/8"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	0.5	24.0
24"	3' 11 1/2"	3' 0"	5' 0"	3' 4"	4' 10 7/8"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	0.7	33.0
30"	4' 6 3/4"	3' 6"	5' 4 1/4"	3' 6 3/4"	5' 3"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	0.8	41.0
3' 0"	5' 1 7/8"	4' 0"	5' 6"	3' 8"	5' 4 3/4"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	1.0	50.0
4' 0"	6' 4 1/4"	5' 0"	6' 0"	4' 0"	5' 10 5/8"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	1.3	68.0
5' 0"	7' 6 5/8"	6' 0"	6' 6"	4' 4"	6' 4 1/2"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	2.2	86.0
6' 0"	8' 9"	7' 0"	7' 0"	4' 8"	6' 10 3/8"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	2.6	104.0
7' 0"	9' 11 3/8"	8' 0"	7' 6"	5' 0"	7' 4 1/4"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	4.1	121.0
8' 0"	11' 1 3/4"	9' 0"	8' 0"	5' 4"	7' 10 1/8"	2' 0"	3' 0"	3' 0"	0' 9"	0' 3"	0' 2"	0' 3"	4.6	140.0
10' 0"	15' 7 1/4"	12' 0"	14' 3 1/4"	6' 0"	14' 0"	3' 0"	6' 0"	4' 0"	1' 1 1/2"	0' 6"	1' 0"	0' 9"	6.0	200.0
12' 0"	18' 4 3/4"	14' 8"	16' 3 3/4"	6' 8"	16' 0"	3' 0"	8' 0"	5' 0"	1' 1 1/2"	0' 6"	1' 0"	0' 9"	8.0	350.0
15' 0"	25' 0"	18' 4"	25' 6"	7' 8"	25' 0"	4' 0"	10' 0"	6' 0"	1' 6"	0' 9"	1' 0"	0' 9"	8.0	600.0
20' 0"	30' 0"	24' 0"	25' 6"	9' 4"	25' 0"	6' 0"	12' 0"	7' 0"	2' 3"	1' 0"	1' 0"	0' 9"	10.0	1000.0
25' 0"	35' 0"	29' 4"	25' 6"	11' 0"	25' 0"	6' 0"	13' 0"	7' 0"	2' 3"	1' 0"	1' 0"	0' 9"	15.0	1200.0
30' 0"	40' 4 3/4"	34' 8"	26' 6 1/4"	12' 8"	26' 0"	6' 0"	14' 0"	7' 0"	2' 3"	1' 0"	1' 0"	0' 9"	15.0	1500.0
40' 0"	50' 9 1/2"	45' 4"	27' 6 1/2"	16' 0"	27' 0"	6' 0"	16' 0"	7' 0"	2' 3"	1' 0"	1' 0"	0' 9"	20.0	2000.0
50' 0"	60' 9 1/2"	56' 8"	27' 6 1/2"	19' 4"	27' 0"	6' 0"	20' 0"	7' 0"	2' 3"	1' 0"	1' 0"	0' 9"	25.0	3000.0

floor of the outlet or diverging section has a slope upward of 6 inches vertically to 36 inches horizontally with the downstream end of the flume 3 inches lower than the crest. These dimensions are for the more commonly used flumes having throat widths between 1 and 8 feet. The dimensions, discharge capacities, and location of the flow depth measurement points, H_a and H_b, are tabulated in Table 2 for each size of Parshall flume. The flume may be constructed of wood, concrete, metal, or any other material depending on existing conditions, and desired use and durability.

Free Flow Calibrations

Under free flow conditions the discharge depends upon only the upstream depth of flow, H_a. Utilizing this relationship, Tables 3, 4, and 5 have been prepared to give the free flow discharge in second-feet (cfs) for most possible H_a values, and for all Parshall flumes ranging from 1 inch to 50 feet. To illustrate the use of the tables, assume H_a has been measured as 2.19 feet in a 2-foot Parshall flume. Entering Table 4 at the left side with the H_a value of 2.19, and moving to the column headed by a throat width of 2 feet, a discharge of 27.0 cfs is obtained.

Submerged Flow Calibrations

As was previously discussed, submerged flow calibration curves have been prepared for each Parshall flume by plotting three-dimensionally on log-log paper: Q as the ordinate, H_a-H_b as the abscissa, and submergence (H_b/H_a) as the varying parameter. The calibration curves prepared for Parshall flumes from 1 inch to 50 feet are found in Figs. 13 to 35. These figures are used when the submergence ratio, H_b/H_a, exceeds the value of transition submergence listed in Table 1 for a particular flume size. Under submerged flow conditions, the discharge is dependent upon both H_a and H_b. To obtain the discharge both H_a and H_b are measured; then the difference, H_a - H_b, and the submergence ratio, H_b/H_a, exceeds the value Once the values of H_a-H_b and H_b/H_a are computed, it is possible to enter the submerged flow calibration curves to obtain the discharge. To illustrate the use of the calibration curves, a 2-foot Parshall flume will be selected. If H_a is measured as 2.19 feet and H_b as 1.97 feet, the difference becomes 0.22 feet and the submergence ratio is 90 percent. Enter the submerged flow calibration for the 2-foot flume (Fig. 20) from above with the value of $H_a - H_b = 0.22$, and then move vertically downward to the 90 percent submergence line. At the point of intersection move horizontally to the left and read the discharge value of 21.3 cfs.

Also noteworthy in Figs. 13 to 35 is the line of constant submergence corresponding to the transition submergence line as listed in Table 1. This transition submergence line can also be used as the calibration curve for the free flow discharge. To illustrate, the 2-foot Parshall flume will again be selected using an H_a reading of 2.19 feet. Fig. 20 is entered from below with H_a equal to 2.19. Moving vertically upward until the 66 percent submergence line (transition submergence) is intersected, and then horizontally to the left, results in a discharge of 27.0 cfs.

Upper Head H_a	Throat Width 1 in.	2 in.	3 in.	6 in.	9 in.	Upper Head H_a	Throat Width 1 in.	2 in.	3 in.	6 in.	9 in.	Upper Head H_a	Throat Width 2 in.	3 in.	6 in.	9 in.	Upper Head H_a	Throat Width 2 in.	3 in.	6 in.	9 in.
feet	Flow in cubic feet per sec.					feet	Flow in cubic feet per sec.					feet	Flow in cubic feet per sec.				feet	Flow in cubic feet per sec.			
0.05	0.0032	0.0065	-----	----	----	0.40	0.082	0.163	0.241	0.48	0.76	0.75	0.433	0.636	1.31	1.98	1.10	-----	-----	2.40	3.55
0.06	0.0043	0.0087	-----	----	----	0.41	0.085	0.170	0.250	0.50	0.78	0.76	0.442	0.649	1.34	2.02	1.11	-----	-----	2.43	3.60
0.07	0.0055	0.0109	-----	----	----	0.42	0.088	0.176	0.260	0.52	0.81	0.77	0.451	0.662	1.36	2.06	1.12	-----	-----	2.46	3.65
0.08	0.0068	0.0135	-----	----	----	0.43	0.091	0.182	0.269	0.54	0.84	0.78	0.459	0.675	1.39	2.10	1.13	-----	-----	2.50	3.70
0.09	0.0081	0.0162	-----	----	----	0.44	0.095	0.189	0.279	0.56	0.87	0.79	0.469	0.689	1.42	2.14	1.14	-----	-----	2.53	3.75
0.10	0.0095	0.0191	0.028	0.05	0.09	0.45	0.098	0.196	0.289	0.58	0.90	0.80	-----	0.702	1.45	2.18	1.15	-----	-----	2.57	3.80
0.11	0.0110	0.0221	0.033	0.06	0.10	0.46	0.101	0.203	0.299	0.61	0.94	0.81	-----	0.716	1.48	2.22	1.16	-----	-----	2.60	3.85
0.12	0.0126	0.0251	0.037	0.07	0.12	0.47	0.105	0.210	0.309	0.63	0.97	0.82	-----	0.730	1.50	2.27	1.17	-----	-----	2.64	3.90
0.13	0.0142	0.0284	0.042	0.08	0.14	0.48	0.108	0.217	0.319	0.65	1.00	0.83	-----	0.744	1.53	2.31	1.18	-----	-----	2.68	3.95
0.14	0.0160	0.0321	0.047	0.09	0.15	0.49	0.112	0.224	0.329	0.67	1.03	0.84	-----	0.757	1.56	2.35	1.19	-----	-----	2.71	4.01
0.15	0.0179	0.0358	0.053	0.10	0.17	0.50	0.115	0.230	0.339	0.69	1.06	0.85	-----	0.771	1.59	2.39	1.20	-----	-----	2.75	4.06
0.16	0.0196	0.0392	0.058	0.11	0.19	0.51	0.119	0.238	0.350	0.71	1.10	0.86	-----	0.786	1.62	2.44	1.21	-----	-----	2.78	4.11
0.17	0.0216	0.0433	0.064	0.12	0.20	0.52	0.123	0.245	0.361	0.73	1.13	0.87	-----	0.800	1.65	2.48	1.22	-----	-----	2.82	4.16
0.18	0.0237	0.0473	0.070	0.14	0.22	0.53	0.126	0.253	0.371	0.76	1.16	0.88	-----	0.814	1.68	2.52	1.23	-----	-----	2.86	4.22
0.19	0.0257	0.0513	0.076	0.15	0.24	0.54	0.130	0.260	0.382	0.78	1.20	0.89	-----	0.828	1.71	2.57	1.24	-----	-----	2.89	4.27
0.20	0.028	0.055	0.082	0.16	0.26	0.55	0.134	0.268	0.393	0.80	1.23	0.90	-----	0.843	1.74	2.61	1.25	-----	-----	----	4.32
0.21	0.030	0.060	0.089	0.18	0.28	0.56	0.138	0.275	0.404	0.82	1.26	0.91	-----	0.858	1.77	2.66	1.26	-----	-----	----	4.37
0.22	0.032	0.065	0.095	0.19	0.30	0.57	0.141	0.283	0.415	0.85	1.30	0.92	-----	0.872	1.81	2.70	1.27	-----	-----	----	4.43
0.23	0.035	0.070	0.102	0.20	0.32	0.58	0.145	0.290	0.427	0.87	1.33	0.93	-----	0.887	1.84	2.75	1.28	-----	-----	----	4.48
0.24	0.037	0.074	0.109	0.22	0.35	0.59	0.149	0.298	0.438	0.89	1.37	0.94	-----	0.902	1.87	2.79	1.29	-----	-----	----	4.53
0.25	0.039	0.079	0.117	0.23	0.37	0.60	0.153	0.306	0.450	0.92	1.40	0.95	-----	0.916	1.90	2.84	1.30	-----	-----	----	4.58
0.26	0.042	0.084	0.124	0.25	0.39	0.61	0.157	0.314	0.462	0.94	1.44	0.96	-----	0.931	1.93	2.88	1.31	-----	-----	----	4.64
0.27	0.045	0.089	0.131	0.26	0.41	0.62	0.161	0.322	0.474	0.97	1.48	0.97	-----	0.946	1.97	2.93	1.32	-----	-----	----	4.69
0.28	0.047	0.094	0.138	0.28	0.44	0.63	0.165	0.330	0.485	0.99	1.51	0.98	-----	0.961	2.00	2.98	1.33	-----	-----	----	4.75
0.29	0.050	0.099	0.146	0.29	0.46	0.64	0.169	0.338	0.497	1.02	1.55	0.99	-----	0.977	2.03	3.02	1.34	-----	-----	----	4.80
0.30	0.052	0.105	0.154	0.31	0.49	0.65	0.173	0.347	0.509	1.04	1.59	1.00	-----	0.992	2.06	3.07	1.35	-----	-----	----	4.86
0.31	0.055	0.110	0.162	0.32	0.51	0.66	0.177	0.355	0.522	1.07	1.63	1.01	-----	1.007	2.09	3.12	1.36	-----	-----	----	4.92
0.32	0.058	0.116	0.170	0.34	0.54	0.67	0.182	0.363	0.534	1.10	1.66	1.02	-----	1.023	2.12	3.17	1.37	-----	-----	----	4.97
0.33	0.061	0.121	0.179	0.36	0.56	0.68	0.186	0.372	0.546	1.12	1.70	1.03	-----	1.038	2.16	3.21	1.38	-----	-----	----	5.03
0.34	0.064	0.127	0.187	0.38	0.59	0.69	0.190	0.381	0.558	1.15	1.74	1.04	-----	1.054	2.19	3.26	1.39	-----	-----	----	5.08
0.35	0.066	0.132	0.196	0.39	0.62	0.70	-----	0.389	0.571	1.17	1.78	1.05	-----	1.070	2.22	3.31	1.40	-----	-----	----	----
0.36	0.069	0.139	0.205	0.41	0.64	0.71	-----	0.397	0.584	1.20	1.82	1.06	-----	1.086	2.26	3.36					
0.37	0.072	0.145	0.213	0.43	0.67	0.72	-----	0.406	0.597	1.23	1.86	1.07	-----	1.102	2.29	3.40					
0.38	0.075	0.151	0.222	0.45	0.70	0.73	-----	0.415	0.610	1.26	1.90	1.08	-----	1.118	2.32	3.45					
0.39	0.078	0.157	0.231	0.47	0.73	0.74	-----	0.424	0.623	1.28	1.94	1.09	-----	1.134	2.36	3.50					

Table 4. Free flow calibration tables for Parshall flumes from 1- to 8-foot throat width

Upper Head H_a	Throat Width										Upper Head H_a	Throat Width									
	12 in.	18 in.	24 in.	30 in.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.		12 in.	18 in.	24 in.	30 in.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
feet	Flow in cubic feet per second										feet	Flow in cubic feet per second									
0.10	----	----	----	----	----	----	----	----	----	----	0.50	1.39	2.06	2.73	3.39	4.05	5.36	6.66	7.94	9.23	10.5
0.11	----	----	----	----	----	----	----	----	----	----	0.51	1.44	2.13	2.82	3.50	4.18	5.53	6.87	8.20	9.53	10.9
0.12	----	----	----	----	----	----	----	----	----	----	0.52	1.48	2.19	2.90	3.61	4.31	5.70	7.09	8.46	9.83	11.2
0.13	----	----	----	----	----	----	----	----	----	----	0.53	1.52	2.25	2.99	3.72	4.44	5.88	7.30	8.72	10.1	11.5
0.14	----	----	----	----	----	----	----	----	----	----	0.54	1.57	2.32	3.08	3.83	4.57	6.05	7.52	8.98	10.5	11.9
0.15	----	----	----	----	----	----	----	----	----	----	0.55	1.62	2.39	3.17	3.94	4.70	6.23	7.74	9.25	10.8	12.2
0.16	----	----	----	----	----	----	----	----	----	----	0.56	1.66	2.45	3.26	4.05	4.84	6.41	7.97	9.52	11.1	12.6
0.17	----	----	----	----	----	----	----	----	----	----	0.57	1.70	2.52	3.35	4.16	4.98	6.59	8.20	9.79	11.4	13.0
0.18	----	----	----	----	----	----	----	----	----	----	0.58	1.75	2.59	3.44	4.28	5.11	6.77	8.43	10.1	11.7	13.3
0.19	----	----	----	----	----	----	----	----	----	----	0.59	1.80	2.66	3.53	4.39	5.25	6.96	8.66	10.4	12.0	13.7
0.20	0.35	0.51	0.66	0.81	0.97	1.26	----	----	----	----	0.60	1.84	2.73	3.62	4.51	5.39	7.15	8.89	10.6	12.4	14.1
0.21	0.37	0.55	0.71	0.88	1.04	1.36	----	----	----	----	0.61	1.88	2.80	3.72	4.63	5.53	7.34	9.13	10.9	12.7	14.5
0.22	0.40	0.59	0.77	0.95	1.12	1.47	----	----	----	----	0.62	1.93	2.87	3.81	4.75	5.68	7.53	9.37	11.2	13.0	14.8
0.23	0.43	0.63	0.82	1.01	1.20	1.58	----	----	----	----	0.63	1.98	2.95	3.91	4.87	5.82	7.72	9.61	11.5	13.4	15.2
0.24	0.46	0.67	0.88	1.08	1.28	1.69	----	----	----	----	0.64	2.03	3.02	4.01	4.99	5.97	7.91	9.85	11.8	13.7	15.6
0.25	0.49	0.71	0.93	1.15	1.37	1.80	2.22	2.63	----	----	0.65	2.08	3.09	4.11	5.11	6.12	8.11	10.1	12.1	14.1	16.0
0.26	0.51	0.76	0.99	1.23	1.46	1.91	2.36	2.80	----	----	0.66	2.13	3.17	4.20	5.24	6.26	8.31	10.3	12.4	14.4	16.4
0.27	0.54	0.80	1.05	1.30	1.55	2.03	2.50	2.97	----	----	0.67	2.18	3.24	4.30	5.36	6.41	8.51	10.6	12.7	14.8	16.8
0.28	0.58	0.85	1.11	1.38	1.64	2.15	2.65	3.15	----	----	0.68	2.23	3.31	4.40	5.49	6.56	8.71	10.9	13.0	15.1	17.2
0.29	0.61	0.90	1.18	1.45	1.73	2.27	2.80	3.33	----	----	0.69	2.28	3.39	4.50	5.61	6.71	8.91	11.1	13.3	15.5	17.6
0.30	0.64	0.94	1.24	1.53	1.82	2.39	2.96	3.52	4.08	4.62	0.70	2.33	3.46	4.60	5.74	6.86	9.11	11.4	13.6	15.8	18.0
0.31	0.68	0.99	1.30	1.61	1.92	2.52	3.12	3.71	4.30	4.88	0.71	2.38	3.54	4.70	5.87	7.02	9.32	11.6	13.9	16.2	18.5
0.32	0.71	1.04	1.37	1.70	2.02	2.65	3.28	3.90	4.52	5.13	0.72	2.43	3.62	4.81	6.00	7.17	9.53	11.9	14.2	16.6	18.9
0.33	0.74	1.09	1.44	1.78	2.12	2.78	3.44	4.10	4.75	5.39	0.73	2.48	3.69	4.91	6.12	7.33	9.74	12.1	14.5	16.9	19.3
0.34	0.77	1.14	1.50	1.87	2.22	2.92	3.61	4.30	4.98	5.66	0.74	2.53	3.77	5.02	6.25	7.49	9.95	12.4	14.9	17.3	19.7
0.35	0.80	1.19	1.57	1.95	2.32	3.06	3.78	4.50	5.22	5.93	0.75	2.58	3.85	5.12	6.38	7.65	10.2	12.7	15.2	17.7	20.1
0.36	0.84	1.25	1.64	2.04	2.42	3.19	3.95	4.71	5.46	6.20	0.76	2.63	3.93	5.23	6.52	7.81	10.4	12.9	15.5	18.0	20.6
0.37	0.88	1.30	1.72	2.11	2.53	3.34	4.13	4.92	5.70	6.48	0.77	2.68	4.01	5.34	6.65	7.97	10.6	13.2	15.8	18.4	21.0
0.38	0.92	1.36	1.79	2.22	2.64	3.48	4.31	5.13	5.95	6.76	0.78	2.74	4.09	5.44	6.79	8.13	10.8	13.5	16.2	18.8	21.5
0.39	0.95	1.41	1.86	2.31	2.75	3.62	4.49	5.35	6.20	7.05	0.79	2.80	4.17	5.55	6.92	8.30	11.0	13.8	16.5	19.2	21.9
0.40	0.99	1.47	1.93	2.40	2.86	3.77	4.68	5.57	6.46	7.34	0.80	2.85	4.26	5.66	7.06	8.46	11.3	14.0	16.8	19.6	22.4
0.41	1.03	1.53	2.01	2.49	2.97	3.92	4.86	5.80	6.72	7.64	0.81	2.90	4.34	5.77	7.20	8.63	11.5	14.3	17.2	20.0	22.8
0.42	1.07	1.58	2.09	2.59	3.08	4.07	5.05	6.02	6.98	7.94	0.82	2.96	4.42	5.88	7.34	8.79	11.7	14.6	17.5	20.4	23.3
0.43	1.11	1.64	2.16	2.68	3.20	4.22	5.24	6.25	7.25	8.24	0.83	3.02	4.50	6.00	7.48	8.96	11.9	14.9	17.8	20.8	23.7
0.44	1.15	1.70	2.24	2.78	3.32	4.38	5.43	6.48	7.52	8.55	0.84	3.07	4.59	6.11	7.62	9.13	12.2	15.2	18.2	21.2	24.2
0.45	1.19	1.76	2.32	2.88	3.44	4.54	5.63	6.72	7.80	8.87	0.85	3.12	4.67	6.22	7.76	9.30	12.4	15.5	18.5	21.6	24.6
0.46	1.23	1.82	2.40	2.98	3.56	4.70	5.83	6.96	8.08	9.19	0.86	3.18	4.76	6.33	7.91	9.48	12.6	15.8	18.9	22.0	25.1
0.47	1.27	1.88	2.48	3.08	3.68	4.86	6.03	7.20	8.36	9.51	0.87	3.24	4.84	6.44	8.05	9.65	12.8	16.0	19.2	22.4	25.6
0.48	1.31	1.94	2.57	3.19	3.80	5.03	6.24	7.44	8.65	9.80	0.88	3.29	4.93	6.56	8.20	9.82	13.1	16.3	19.6	22.8	26.1
0.49	1.35	2.00	2.65	3.29	3.92	5.20	6.45	7.69	8.94	10.20	0.89	3.35	5.01	6.68	8.34	10.0	13.3	16.6	19.9	23.2	26.5

Table 4. (Continued)

Upper Head H_a	Throat Width 12 in.	18 in.	24 in.	30 in.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	Upper Head H_a	Throat Width 12 in.	18 in.	24 in.	30 in.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
feet	Flow in cubic feet per second										feet	Flow in cubic feet per second									
0.90	3.41	5.10	6.80	8.49	10.2	13.6	16.9	20.3	23.7	27.0	1.30	5.96	8.99	12.0	15.05	18.1	24.2	30.3	36.5	42.6	48.8
0.91	3.46	5.19	6.92	8.64	10.4	13.8	17.2	20.7	24.1	27.5	1.31	6.03	9.09	12.2	15.23	18.3	24.5	30.7	36.9	43.1	49.4
0.92	3.52	5.28	7.03	8.79	10.5	14.0	17.5	21.0	24.5	28.0	1.32	6.10	9.20	12.3	15.42	18.5	24.8	31.1	37.4	43.7	50.0
0.93	3.58	5.37	7.15	8.93	10.7	14.3	17.8	21.4	24.9	28.5	1.33	6.18	9.30	12.4	15.60	18.8	25.1	31.4	37.8	44.2	50.6
0.94	3.64	5.46	7.27	9.08	10.9	14.5	18.1	21.8	25.4	29.0	1.34	6.25	9.41	12.6	15.79	19.0	25.4	31.8	38.3	44.7	51.2
0.95	3.70	5.55	7.39	9.23	11.1	14.8	18.4	22.1	25.8	29.5	1.35	6.32	9.52	12.7	15.97	19.2	25.7	32.2	38.7	45.3	51.8
0.96	3.76	5.64	7.51	9.38	11.3	15.0	18.8	22.5	26.2	30.0	1.36	6.39	9.63	12.9	16.16	19.4	26.0	32.6	39.2	45.8	52.5
0.97	3.82	5.73	7.63	9.53	11.4	15.3	19.1	22.9	26.7	30.5	1.37	6.46	9.74	13.0	16.34	19.6	26.3	33.0	39.7	46.4	53.1
0.98	3.88	5.82	7.75	9.69	11.6	15.5	19.4	23.2	27.1	31.0	1.38	6.53	9.85	13.2	16.53	19.9	26.6	33.3	40.1	46.9	53.7
0.99	3.94	5.91	7.88	9.84	11.8	15.8	19.7	23.6	27.6	31.5	1.39	6.60	9.96	13.3	16.71	20.1	26.9	33.7	40.6	47.4	54.3
1.00	4.00	6.00	8.00	10.00	12.0	16.0	20.0	24.0	28.0	32.0	1.40	6.68	10.1	13.5	16.90	20.3	27.2	34.1	41.1	48.0	55.0
1.01	4.06	6.09	8.12	10.16	12.2	16.3	20.3	24.4	28.4	32.5	1.41	6.75	10.2	13.6	17.09	20.6	27.5	34.5	41.5	48.5	55.6
1.02	4.12	6.19	8.25	10.32	12.4	16.5	20.6	24.8	28.9	33.0	1.42	6.82	10.3	13.8	17.28	20.8	27.8	34.9	42.0	49.1	56.2
1.03	4.18	6.28	8.38	10.47	12.6	16.8	21.0	25.2	29.4	33.6	1.43	6.89	10.4	13.9	17.47	21.0	28.1	35.3	42.5	49.6	56.9
1.04	4.25	6.37	8.50	10.63	12.8	17.0	21.3	25.6	29.8	34.1	1.44	6.97	10.5	14.1	17.66	21.2	28.5	35.7	42.9	50.2	57.5
1.05	4.31	6.47	8.63	10.79	13.0	17.3	21.6	25.9	30.3	34.6	1.45	7.04	10.6	14.2	17.85	21.3	28.8	36.1	43.4	50.8	58.1
1.06	4.37	6.56	8.76	10.95	13.2	17.5	21.9	26.3	30.7	35.1	1.46	7.12	10.7	14.4	18.04	21.7	29.1	36.5	43.9	51.3	58.8
1.07	4.43	6.66	8.88	11.11	13.3	17.8	22.3	26.7	31.2	35.7	1.47	7.19	10.8	14.5	18.23	21.9	29.4	36.9	44.4	51.9	59.4
1.08	4.50	6.75	9.01	11.28	13.5	18.1	22.6	27.1	31.7	36.2	1.48	7.26	11.0	14.7	18.43	22.2	29.7	37.3	44.9	52.4	60.1
1.09	4.56	6.85	9.14	11.44	13.7	18.3	22.9	27.5	32.1	36.8	1.49	7.34	11.1	14.9	18.62	22.4	30.0	37.7	45.3	53.0	60.7
1.10	4.62	6.95	9.27	11.60	13.9	18.6	23.3	27.9	32.6	37.3	1.50	7.41	11.2	15.0	18.82	22.6	30.3	38.1	45.8	53.6	61.4
1.11	4.68	7.04	9.40	11.76	14.1	18.9	23.6	28.4	33.1	37.8	1.51	7.49	11.3	15.2	19.02	22.9	30.7	38.5	46.3	54.2	62.1
1.12	4.75	7.14	9.54	11.93	14.3	19.1	23.9	28.8	33.6	38.4	1.52	7.57	11.4	15.3	19.22	23.1	31.0	38.9	46.8	54.7	62.7
1.13	4.82	7.24	9.67	12.09	14.5	19.4	24.3	29.2	34.1	38.9	1.53	7.64	11.5	15.5	19.41	23.4	31.3	39.3	47.3	55.3	63.4
1.14	4.88	7.34	9.80	12.26	14.7	19.7	24.6	29.6	34.5	39.5	1.54	7.72	11.7	15.6	19.61	23.6	31.6	39.7	47.8	55.9	64.0
1.15	4.94	7.44	9.94	12.43	14.9	19.9	25.0	30.0	35.0	40.1	1.55	7.80	11.8	15.8	19.81	23.8	32.0	40.1	48.3	56.5	64.7
1.16	5.01	7.54	10.1	12.60	15.1	20.2	25.3	30.4	35.5	40.6	1.56	7.87	11.9	15.9	20.01	24.1	32.3	40.5	48.8	57.1	65.4
1.17	5.08	7.64	10.2	12.77	15.3	20.5	25.7	30.8	36.0	41.2	1.57	7.95	12.0	16.1	20.21	24.3	32.6	40.9	49.3	57.7	66.1
1.18	5.15	7.74	10.3	12.94	15.6	20.8	26.0	31.3	36.5	41.8	1.58	8.02	12.1	16.3	20.41	24.6	32.9	41.4	49.8	58.2	66.7
1.19	5.21	7.84	10.5	13.11	15.8	21.1	26.4	31.7	37.0	42.3	1.59	8.10	12.2	16.4	20.61	24.8	33.3	41.8	50.3	58.8	67.4
1.20	5.28	7.94	10.6	13.28	16.0	21.3	26.7	32.1	37.5	42.9	1.60	8.18	12.4	16.6	20.81	25.1	33.6	42.2	50.8	59.4	68.1
1.21	5.34	8.05	10.8	13.45	16.2	21.6	27.1	32.5	38.0	43.5	1.61	8.26	12.5	16.7	21.01	25.3	33.9	42.6	51.3	60.0	68.8
1.22	5.41	8.15	10.9	13.63	16.4	21.9	27.4	33.0	38.5	44.1	1.62	8.34	12.6	16.9	21.22	25.5	34.3	43.0	51.8	60.6	69.5
1.23	5.48	8.25	11.0	13.80	16.6	22.2	27.8	33.4	39.0	44.6	1.63	8.42	12.7	17.1	21.42	25.8	34.6	43.4	52.3	61.2	70.2
1.24	5.55	8.36	11.2	13.98	16.8	22.5	28.1	33.8	39.5	45.2	1.64	8.49	12.8	17.2	21.63	26.0	34.9	43.9	52.8	61.8	70.9
1.25	5.62	8.46	11.3	14.15	17.0	22.8	28.5	34.3	40.0	45.8	1.65	8.57	13.0	17.4	21.83	26.3	35.3	44.3	53.3	62.4	71.6
1.26	5.69	8.56	11.5	14.33	17.2	23.0	28.9	34.7	40.5	46.4	1.66	8.65	13.1	17.6	22.04	26.5	35.6	44.7	53.9	63.0	72.3
1.27	5.76	8.67	11.6	14.51	17.4	23.3	29.2	35.1	41.1	47.0	1.67	8.73	13.2	17.7	22.24	26.8	35.9	45.1	54.4	63.6	73.0
1.28	5.82	8.77	11.7	14.69	17.7	23.6	29.6	35.6	41.6	47.6	1.68	8.81	13.3	17.9	22.45	27.0	36.3	45.6	54.9	64.3	73.7
1.29	5.89	8.88	11.9	14.87	17.9	23.9	30.0	36.0	42.1	48.2	1.69	8.89	13.5	18.0	22.66	27.3	36.6	46.0	55.4	64.9	74.4

Table 4. (Continued)

Upper Head H_a	Throat Width									
	12 in.	18 in.	24 in.	30 in.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
feet	Flow in cubic feet per second									
1.70	8.97	13.6	18.2	22.87	27.6	37.0	46.4	56.0	65.5	75.1
1.71	9.05	13.7	18.4	23.08	27.8	37.3	46.9	56.5	66.1	75.8
1.72	9.13	13.8	18.5	23.29	28.1	37.7	47.3	57.0	66.7	76.5
1.73	9.21	13.9	18.7	23.50	28.3	38.0	47.7	57.5	67.3	77.2
1.74	9.29	14.1	18.9	23.72	28.6	38.3	48.2	58.1	68.0	77.9
1.75	9.38	14.2	19.0	23.93	28.8	38.7	48.6	58.6	68.6	78.7
1.76	9.46	14.3	19.2	24.15	29.1	39.0	49.1	59.1	69.2	79.4
1.77	9.54	14.4	19.4	24.36	29.3	39.4	49.5	59.7	69.9	80.1
1.78	9.62	14.6	19.6	24.58	29.6	39.7	49.9	60.2	70.5	80.8
1.79	9.70	14.7	19.7	24.79	29.9	40.1	50.4	60.7	71.1	81.6
1.80	9.79	14.8	19.9	25.01	30.1	40.5	50.8	61.3	71.8	82.3
1.81	9.87	15.0	20.1	25.23	30.4	40.8	51.3	61.8	72.4	83.0
1.82	9.95	15.1	20.2	25.45	30.7	41.2	51.7	62.4	73.0	83.8
1.83	10.0	15.2	20.4	25.66	30.9	41.5	52.2	62.9	73.7	84.5
1.84	10.1	15.3	20.6	25.88	31.2	41.9	52.6	63.5	74.3	85.3
1.85	10.2	15.5	20.8	26.10	31.5	42.2	53.1	64.0	75.0	86.0
1.86	10.3	15.6	20.9	26.32	31.7	42.6	53.6	64.6	75.6	86.8
1.87	10.4	15.7	21.1	26.54	32.0	43.0	54.0	65.1	76.3	87.5
1.88	10.5	15.8	21.3	26.76	32.3	43.3	54.5	65.7	76.9	88.3
1.89	10.5	16.0	21.5	26.98	32.5	43.7	54.9	66.3	77.6	89.0
1.90	10.6	16.1	21.6	27.20	32.8	44.1	55.4	66.8	78.2	89.8
1.91	10.7	16.2	21.8	27.44	33.1	44.4	55.9	67.4	78.9	90.5
1.92	10.8	16.4	22.0	27.65	33.3	44.8	56.3	67.9	79.6	91.3
1.93	10.9	16.5	22.2	27.87	33.6	45.2	56.8	68.5	80.2	92.1
1.94	11.0	16.6	22.4	28.10	33.9	45.5	57.3	69.1	80.9	92.8
1.95	11.1	16.7	22.5	28.32	34.1	45.9	57.7	69.6	81.6	93.6
1.96	11.1	16.9	22.7	28.55	34.4	46.3	58.2	70.2	82.2	94.4
1.97	11.2	17.0	22.9	28.77	34.7	46.6	58.7	70.8	82.9	95.1
1.98	11.3	17.2	23.1	29.00	35.0	47.0	59.1	71.4	83.6	95.9
1.99	11.4	17.3	23.2	29.23	35.3	47.4	59.6	71.9	84.3	96.7
2.00	11.5	17.4	23.4	29.46	35.5	47.8	60.1	72.5	84.9	97.5
2.01	11.6	17.6	23.6	29.69	35.8	48.1	60.6	73.1	85.6	98.3
2.02	11.7	17.7	23.8	29.92	36.1	48.5	61.0	73.7	86.3	99.1
2.03	11.8	17.8	24.0	30.15	36.4	48.9	61.5	74.2	87.0	99.8
2.04	11.8	18.0	24.2	30.39	36.7	49.3	62.0	74.8	87.7	100.6
2.05	11.9	18.1	24.3	30.62	36.9	49.7	62.5	75.4	88.4	101.4
2.06	12.0	18.2	24.5	30.85	37.2	50.1	63.0	76.0	89.1	102.2
2.07	12.1	18.4	24.7	31.08	37.5	50.4	63.5	76.6	89.8	103.0
2.08	12.2	18.5	24.9	31.32	37.8	50.8	63.9	77.2	90.4	103.8
2.09	12.3	18.7	25.1	31.55	38.1	51.2	64.4	77.8	91.1	104.6

Upper Head H_a	Throat Width									
	12 in.	18 in.	24 in.	30 in.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
feet	Flow in cubic feet per second									
2.10	12.4	18.8	25.3	31.79	38.4	51.6	64.9	78.4	91.8	105.4
2.11	12.5	18.9	25.5	32.03	38.6	52.0	65.4	79.0	92.5	106.2
2.12	12.6	19.0	25.6	32.27	38.9	52.4	65.9	79.6	93.3	107.0
2.13	12.6	19.2	25.8	32.50	39.2	52.8	66.4	80.2	94.0	107.9
2.14	12.7	19.3	26.0	32.74	39.5	53.2	66.9	80.8	94.7	108.7
2.15	12.8	19.5	26.2	32.98	39.8	53.5	67.4	81.4	95.4	109.5
2.16	12.9	19.6	26.4	33.22	40.1	53.9	67.9	82.0	96.1	110.3
2.17	13.0	19.7	26.6	33.46	40.4	54.3	68.4	82.6	96.8	111.1
2.18	13.1	19.9	26.8	33.71	40.7	54.7	68.9	83.2	97.5	111.9
2.19	13.2	20.0	27.0	33.95	41.0	55.1	69.4	83.8	98.2	112.8
2.20	13.3	20.2	27.2	34.19	41.3	55.5	69.9	84.4	98.9	113.6
2.21	13.4	20.3	27.3	34.43	41.5	55.9	70.4	85.0	99.7	114.4
2.22	13.5	20.5	27.5	34.68	41.8	56.3	70.9	85.6	100.0	115.3
2.23	13.6	20.6	27.7	34.92	42.1	56.7	71.4	86.3	101.1	116.1
2.24	13.7	20.7	27.9	35.17	42.4	57.1	71.9	86.9	101.8	116.9
2.25	13.7	20.9	28.1	35.41	42.7	57.5	72.4	87.5	102.6	117.8
2.26	13.8	21.0	28.3	35.66	43.0	57.9	72.9	88.1	103.3	118.6
2.27	13.9	21.2	28.5	35.90	43.3	58.3	73.5	88.7	104.0	119.5
2.28	14.0	21.3	28.7	36.15	43.6	58.7	74.0	89.4	104.8	120.3
2.29	14.1	21.4	28.9	36.39	43.9	59.2	74.5	90.0	105.5	121.2
2.30	14.2	21.6	29.1	36.64	44.2	59.6	75.0	90.6	106.2	122.0
2.31	14.3	21.7	29.3	36.89	44.5	60.0	75.5	91.2	107.0	122.9
2.32	14.4	21.9	29.5	37.14	44.8	60.4	76.0	91.9	107.7	123.7
2.33	14.5	22.0	29.7	37.39	45.1	60.8	76.6	92.5	108.5	124.6
2.34	14.6	22.2	29.9	37.64	45.4	61.2	77.1	93.1	109.2	125.4
2.35	14.7	22.4	30.1	37.89	45.7	61.6	77.6	93.8	110.0	126.3
2.36	14.8	22.5	30.3	38.14	46.0	62.0	78.1	94.4	110.7	127.2
2.37	14.9	22.6	30.5	38.39	46.4	62.4	78.7	95.1	111.5	128,0
2.38	15.0	22.8	30.7	38.65	46.7	62.9	79.2	95.7	112.2	128.9
2.39	15.1	22.9	30.9	38.90	47.0	63.3	79.7	96.3	113.0	129.8
2.40	15.2	23.0	31.1	39.15	47.3	63.7	80.3	97.0	113.7	130.7
2.41	15.3	23.2	31.3	39.40	47.6	64.1	80.8	97.6	114.5	131.5
2.42	15.4	23.3	31.5	39.66	47.9	64.5	81.3	98.3	115.3	132.4
2.43	15.5	23.5	31.7	39.91	48.2	65.0	81.8	98.9	116.0	133.3
2.44	15.6	23.7	31.9	40.17	48.5	65.4	82.4	99.6	116.8	134.2
2.45	15.6	23.8	32.1	40.43	48.8	65.8	82.9	100.2	117.6	135.1
2.46	15.7	23.9	32.3	40.69	49.1	66.2	83.5	100.9	118.3	135.9
2.47	15.9	24.1	32.5	40.94	49.5	66.7	84.0	101.5	119.1	136.8
2.48	15.9	24.2	32.7	41.20	49.8	67.1	84.5	102.2	119.9	137.7
2.49	16.0	24.4	32.9	41.46	50.1	67.5	85.1	102.8	120.6	138.6
2.50	16.1	24.6	33.1	41.72	50.4	67.9	85.6	103.5	121.4	139.5

Table 5. Free flow calibration tables for Parshall flumes from 10- to 50-foot

Upper Head H_a	Throat Width								Upper Head H_a	Throat Width							
	10 ft.	12 ft.	15 ft.	20 ft.	25 ft.	30 ft.	40 ft.	50 ft.		10 ft.	12 ft.	15 ft.	20 ft.	25 ft.	30 ft.	40 ft.	50 ft.
feet	Flow in cubic feet per second								feet	Flow in cubic feet per second							
0.30	5.6	7.0	8.6	11.4	14.1	16.8	22.2	27.7	1.10	46.0	55.4	68.3	89.9	111.4	132.9	175.9	219.0
0.32	6.3	7.8	9.6	12.6	15.6	18.6	24.7	30.7	1.12	47.3	56.8	70.0	92.0	114.0	136.1	180.1	224.2
0.34	7.0	8.5	10.5	13.7	17.2	20.5	27.1	33.8	1.14	48.6	58.5	72.1	94.9	117.6	140.3	185.7	231.1
0.36	7.7	9.3	11.5	15.1	18.7	22.4	29.6	36.9	1.16	50.0	60.1	74.1	97.5	120.8	144.2	190.8	237.5
0.38	8.3	10.2	12.5	16.5	20.4	24.4	32.3	40.2	1.18	51.4	62.1	76.6	100.7	124.8	148.9	197.2	245.4
0.40	9.0	11.0	13.6	17.9	22.2	26.5	35.0	43.6	1.20	52.8	63.5	78.2	102.9	127.5	152.1	201.4	250.7
0.42	9.8	12.0	14.8	19.4	24.0	28.7	38.0	47.3	1.22	54.2	65.2	80.3	105.6	130.9	156.2	206.8	257.4
0.44	10.6	12.8	15.8	20.8	25.8	30.8	40.8	50.7	1.24	55.6	66.9	82.4	108.4	134.3	160.3	212.2	264.1
0.46	11.3	13.8	17.0	22.4	27.8	33.1	43.9	54.6	1.26	57.0	68.6	84.6	111.2	137.8	164.4	217.7	270.9
0.48	12.1	14.8	18.3	24.0	29.8	35.5	47.0	58.5	1.28	58.5	70.3	86.7	114.0	141.2	168.5	223.1	277.7
0.50	13.0	15.8	19.4	25.6	31.7	37.8	50.0	62.3	1.30	60.0	72.1	88.9	116.9	144.9	172.9	228.8	284.8
0.52	13.8	16.8	20.7	27.2	33.8	40.3	53.3	66.4	1.32	61.5	73.9	91.9	119.7	148.4	177.1	234.4	291.8
0.54	14.7	17.8	22.0	28.9	35.8	42.8	56.6	70.5	1.34	63.0	75.7	93.3	122.7	152.0	181.4	240.1	298.9
0.56	15.6	18.9	23.3	30.6	38.0	45.3	60.0	74.7	1.36	64.5	77.4	95.4	125.5	155.6	185.6	245.7	305.8
0.58	16.5	19.9	24.6	32.3	40.1	47.8	63.3	78.8	1.38	66.0	79.3	97.7	128.5	159.3	190.1	251.6	313.1
0.60	17.4	21.1	26.0	34.2	42.3	50.5	66.9	83.2	1.40	67.5	81.0	99.9	131.4	162.8	194.3	257.2	320.1
0.62	18.3	22.2	27.4	36.0	44.6	53.2	70.5	87.7	1.42	69.0	82.9	102.2	134.4	166.6	198.8	263.2	327.6
0.64	19.2	23.4	28.8	37.9	46.9	56.0	74.2	92.3	1.44	70.5	84.8	104.5	137.4	170.4	203.3	269.1	334.9
0.66	20.2	24.5	30.2	39.7	49.2	58.8	77.8	96.8	1.46	72.0	86.6	106.8	140.4	174.1	207.7	275.0	342.2
0.68	21.2	25.7	31.7	41.7	51.7	61.7	81.7	101.7	1.48	73.6	88.5	109.7	143.5	177.9	212.3	281.0	349.7
0.70	22.2	26.9	33.2	43.7	54.1	64.6	85.5	106.4	1.50	75.2	90.5	111.6	146.7	181.8	216.9	287.2	357.4
0.72	23.3	28.2	34.7	45.7	56.6	67.5	89.4	111.3	1.52	76.9	92.4	113.9	149.8	185.6	221.5	293.2	364.9
0.74	24.3	29.4	36.3	47.7	59.1	70.5	93.4	116.2	1.54	78.7	94.3	116.3	152.9	189.5	226.2	299.4	372.6
0.76	25.4	30.7	37.8	49.7	61.6	73.6	97.4	121.2	1.56	80.4	96.4	118.8	156.2	193.6	231.1	305.9	380.7
0.78	26.5	32.0	39.5	51.9	64.3	76.7	101.6	126.4	1.58	82.1	98.3	121.2	159.4	197.6	235.7	312.0	388.4
0.80	27.6	33.3	41.0	54.0	66.9	79.8	105.7	131.5	1.60	83.8	100.3	123.6	162.5	201.5	240.4	318.2	396.1
0.82	28.7	34.6	42.7	56.1	69.6	83.0	109.9	136.8	1.62	85.4	102.2	126.0	165.7	205.4	245.1	324.4	403.8
0.84	29.8	36.0	44.4	58.4	72.3	86.3	114.2	142.2	1.64	87.1	104.3	128.5	169.0	209.5	250.0	330.9	411.8
0.86	30.9	37.3	46.0	60.5	75.0	89.5	118.5	147.5	1.66	88.7	106.3	131.1	172.4	213.7	255.0	337.5	420.1
0.88	32.0	38.8	47.8	62.8	77.9	92.9	123.0	153.1	1.68	90.4	108.3	133.5	175.6	217.6	259.6	343.7	427.8
0.90	33.2	40.2	49.5	65.1	80.7	96.3	127.5	158.7	1.70	92.1	110.4	136.1	179.0	221.9	264.8	350.5	436.2
0.92	34.4	41.9	51.7	68.0	84.3	100.6	133.1	165.7	1.72	93.8	112.1	138.2	181.7	225.2	268.8	355.8	442.8
0.94	35.7	43.1	53.1	69.8	86.6	103.3	136.8	170.2	1.74	95.5	114.5	141.1	185.6	230.0	274.4	363.3	452.2
0.96	36.9	44.5	54.9	72.2	89.4	106.7	141.3	175.8	1.76	97.2	116.8	144.0	189.3	234.7	280.0	370.7	461.4
0.98	38.2	46.0	56.7	74.6	92.4	110.3	146.0	181.7	1.78	99.0	118.7	146.4	192.5	238.6	284.7	376.9	469.1
1.00	39.4	47.5	58.6	77.0	95.4	113.9	150.7	187.6	1.80	100.8	120.9	149.0	196.0	242.9	289.8	383.7	477.5
1.02	40.7	49.0	60.4	79.5	98.5	117.5	155.6	193.6	1.82	102.6	123.0	151.7	199.4	247.2	294.9	390.4	486.0
1.04	42.0	50.6	62.3	82.0	101.6	121.2	160.5	199.7	1.84	104.5	125.3	154.5	203.2	251.9	300.5	397.8	495.2
1.06	43.3	52.1	64.2	84.5	104.7	124.9	165.4	205.8	1.86	106.4	127.3	157.0	206.4	255.9	305.3	404.2	503.0
1.08	44.6	53.8	66.3	87.2	108.0	128.9	170.6	212.4	1.88	108.2	129.7	159.9	210.2	260.5	310.9	411.5	512.2

Table 5. (Continued)

Upper Head H_a	Throat Width								Upper Head H_a	Throat Width							
	10 ft.	12 ft.	15 ft.	20 ft.	25 ft.	30 ft.	40 ft.	50 ft.		10 ft.	12 ft.	15 ft.	20 ft.	25 ft.	30 ft.	40 ft.	50 ft.
feet	Flow in cubic feet per second								feet	Flow in cubic feet per second							
1.90	110.1	132.0	162.7	214.0	265.2	316.5	418.9	521.4	2.70	193	230	284	374	463	552	731	910
1.92	112.0	134.0	165.2	217.2	269.2	321.2	425.3	529.3	2.72	195	233	287	378	468	559	740	921
1.94	113.9	136.3	168.1	221.0	273.9	326.8	432.6	538.5	2.74	198	236	291	382	474	565	749	932
1.96	115.8	138.6	170.9	224.8	278.6	332.4	440.0	547.7	2.76	200	239	294	387	479	572	757	942
1.98	117.7	140.8	173.6	228.2	282.9	337.5	446.8	556.1	2.78	202	241	298	391	485	579	766	953
2.00	119.5	143.2	176.6	232.1	287.7	343.3	454.5	565.7	2.80	204	244	301	396	491	585	775	964
2.02	121.4	145.5	179.2	235.6	292.0	348.5	461.3	574.1	2.82	207	247	304	400	496	592	784	975
2.04	123.3	147.7	182.1	239.4	296.7	354.0	468.7	583.3	2.84	209	250	308	405	502	599	793	987
2.06	125.2	150.0	184.9	243.2	301.4	359.6	476.1	592.5	2.86	212	253	311	409	507	605	801	997
2.08	127.1	152.3	187.7	246.9	306.0	365.1	483.3	601.5	2.88	214	255	315	414	513	612	810	1005
2.10	129.1	154.6	190.6	250.6	310.7	370.7	490.7	610.7	2.90	216	258	318	419	519	619	820	1020
2.12	131.1	156.9	193.5	254.4	315.3	376.3	498.1	619.9	2.92	219	261	322	423	524	626	828	1031
2.14	133.1	159.3	196.4	258.2	320.1	381.9	505.6	629.3	2.94	221	264	325	427	530	632	837	1042
2.16	135.1	161.6	199.3	262.0	324.8	387.5	513.0	638.5	2.96	224	267	329	432	536	639	846	1053
2.18	137.1	164.0	202.2	265.9	329.5	393.2	520.5	647.9	2.98	226	270	332	437	542	646	855	1065
2.20	139.1	166.3	205.1	269.6	334.2	398.8	527.9	657.1	3.00	229	272	336	442	547	653	865	1076
2.22	141.1	168.8	208.1	273.7	339.1	404.7	535.8	666.8	3.02	231	275	340	446	553	660	874	1088
2.24	143.1	171.2	211.0	277.5	344.0	410.4	543.3	676.2	3.04	234	278	343	451	559	667	883	1099
2.26	145.1	173.7	214.1	281.5	348.9	416.3	551.1	686.0	3.06	236	281	347	456	565	674	892	1111
2.28	147.2	176.1	217.1	285.5	353.9	422.3	559.0	695.7	3.08	239	284	350	460	571	681	902	1122
2.30	149.3	178.6	220.1	289.4	358.8	428.1	566.7	705.3	3.10	241	287	354	465	577	688	911	1134
2.32	151.4	181.1	223.2	293.5	363.8	434.1	574.7	715.2	3.12	244	290	357	470	583	695	920	1145
2.34	153.6	183.6	226.3	297.6	368.9	440.1	582.6	725.2	3.14	246	293	361	475	589	702	930	1157
2.36	155.6	186.0	229.3	301.5	373.7	445.9	590.3	734.8	3.16	249	296	365	480	595	709	939	1169
2.38	157.7	188.6	232.5	305.7	378.9	452.1	598.5	744.9	3.18	251	299	369	485	601	717	949	1181
2.40	159.8	191.1	235.6	309.8	383.9	458.1	606.5	754.8	3.20	254	302	372	489	607	724	958	1193
2.42	161.9	193.7	238.7	313.9	389.1	464.3	614.6	765.0	3.22	256	305	376	494	613	731	968	1204
2.44	164.0	196.2	241.8	318.0	394.2	470.3	622.6	774.9	3.24	259	308	380	499	619	738	977	1216
2.46	166.1	198.7	245.0	322.2	399.3	476.5	630.7	785.0	3.26	261	311	383	504	625	745	987	1228
2.48	168.3	201.3	248.2	326.3	404.5	482.6	638.9	795.2	3.28	264	314	387	509	631	753	996	1240
2.50	170.5	203.9	251.3	330.5	409.6	488.8	647.0	805.3	3.30	266	317	391	514	637	760	1006	1252
2.52	172.7	206.5	254.6	334.7	414.9	495.0	655.5	815.6	3.32	269	320	395	519	643	767	1016	1264
2.54	174.9	209.1	257.8	338.9	420.4	501.3	664.0	825.9	3.34	271	323	398	524	649	775	1026	1277
2.56	177.1	211.7	261.1	343.3	425.5	508.1	672.0	836.4	3.36	274	326	402	529	656	782	1035	1289
2.58	179.3	214.4	264.3	347.4	430.7	513.9	680.0	846.6	3.38	276	329	406	534	662	790	1045	1301
2.60	181.5	217.0	267.5	351.7	436.0	520.2	688.6	857.1	3.40	279	332	410	539	668	797	1055	1313
2.62	183.8	219.9	269.8	356.1	441.4	526.7	697.2	867.8	3.42	282	336	414	544	674	805	1065	1326
2.64	186.1	222.3	274.1	360.4	446.7	533.0	705.5	878.4	3.44	284	339	418	549	681	812	1075	1338
2.66	188.4	225.0	277.5	364.9	452.0	540.7	714.4	889.2	3.46	287	342	421	554	687	819	1085	1350
2.68	190.7	228.0	280.7	369.1	457.5	545.9	722.7	899.5	3.48	289	345	425	559	693	827	1095	1363

Table 5. (Continued)

Upper Head H_a	Throat Width								Upper Head H_a	Throat Width							
	10 ft.	12 ft.	15 ft.	20 ft.	25 ft.	30 ft.	40 ft.	50 ft.		10 ft.	12 ft.	15 ft.	20 ft.	25 ft.	30 ft.	40 ft.	50 ft.
feet	Flow in cubic feet per second								feet	Flow in cubic feet per second							
3.50	292	348	429	564	700	835	1105	1375	4.30	406	483	595	782	970	1157	1532	1906
3.52	295	351	433	569	706	842	1115	1388	4.32	409	486	600	788	977	1166	1544	1921
3.54	297	354	437	575	712	850	1125	1400	4.34	412	490	604	794	984	1174	1554	1934
3.56	300	358	441	580	719	857	1135	1413	4.36	415	494	609	801	993	1184	1568	1951
3.58	303	361	445	585	725	865	1145	1426	4.38	418	497	613	806	999	1192	1578	1964
3.60	305	364	449	590	731	873	1155	1438	4.40	421	501	617	812	1006	1200	1589	1978
3.62	308	367	453	595	738	880	1166	1451	4.42	424	504	622	818	1014	1209	1601	1993
3.64	311	370	457	601	744	888	1176	1463	4.44	427	508	626	823	1020	1217	1612	2006
3.66	314	374	461	606	751	896	1186	1476	4.46	430	511	630	829	1027	1225	1622	2019
3.68	317	377	465	611	758	904	1197	1489	4.48	434	515	635	835	1035	1235	1634	2034
3.70	320	380	469	616	764	912	1207	1502	4.50	437	518	639	840	1041	1242	1645	2047
3.72	322	384	473	622	771	917	1217	1515	4.52	440	522	644	846	1049	1252	1657	2062
3.74	325	387	477	627	777	927	1228	1528	4.54	443	526	648	852	1057	1261	1669	2077
3.76	328	390	481	632	784	935	1238	1541	4.56	447	529	652	858	1063	1269	1680	2090
3.78	330	393	485	638	790	943	1249	1554	4.58	450	533	657	864	1071	1278	1692	2106
3.80	333	397	489	643	797	951	1259	1567	4.60	454	537	662	870	1079	1287	1704	2121
3.82	336	400	493	649	804	959	1270	1581	4.62	457	541	666	876	1086	1296	1716	2136
3.84	339	403	497	654	811	967	1280	1594	4.64	460	544	671	883	1094	1305	1728	2150
3.86	341	407	502	659	817	975	1291	1607	4.66	463	548	675	888	1101	1313	1738	2164
3:83	344	410	506	665	824	983	1302	1620	4.68	466	552	680	894	1108	1322	1750	2179
3.90	347	413	510	670	831	991	1312	1633	4.70	469	555	685	900	1116	1331	1763	2194
3.92	350	417	514	676	838	999	1323	1647	4.72	472	560	690	907	1124	1342	1776	2210
3.94	353	420	518	681	844	1007	1334	1660	4.74	475	563	695	913	1132	1351	1788	2225
3.96	356	424	522	687	851	1016	1344	1673	4.76	478	567	699	919	1140	1360	1800	2240
3.98	359	427	526	692	858	1024	1355	1687	4.78	481	571	704	926	1147	1369	1812	2255
4.00	362	430	531	698	865	1032	1366	1700	4.80	485	575	709	932	1156	1379	1826	2272
4.02	365	434	535	703	872	1040	1377	1714	4.82	488	578	712	936	1161	1385	1834	2282
4.04	368	437	539	709	879	1048	1388	1727	4.84	491	582	717	943	1169	1395	1847	2299
4.06	371	441	543	715	886	1057	1399	1741	4.86	494	586	722	950	1177	1404	1859	2314
4.08	374	444	548	720	893	1065	1410	1755	4.88	497	590	727	956	1185	1415	1872	2331
4.10	377	448	552	726	900	1073	1421	1769	4.90	501	594	732	963	1193	1424	1884	2345
4.12	380	451	556	731	907	1082	1432	1782	4.92	504	598	737	969	1202	1434	1898	2362
4.14	383	455	560	737	913	1090	1443	1796	4.94	507	602	742	976	1210	1444	1911	2379
4.16	386	458	565	743	920	1098	1454	1810	4.96	510	605	746	981	1216	1451	1921	2391
4.18	389	462	569	748	928	1107	1465	1824	4.98	513	609	751	987	1224	1460	1933	2406
4.20	392	465	574	754	935	1115	1477	1838	5.00	517	613	756	994	1232	1470	1958	2422
4.22	395	469	578	760	942	1124	1488	1851									
4.24	397	472	582	765	949	1132	1499	1865									
4.26	400	476	587	771	956	1141	1510	1880									
4.28	403	479	591	777	963	1149	1521	1893									

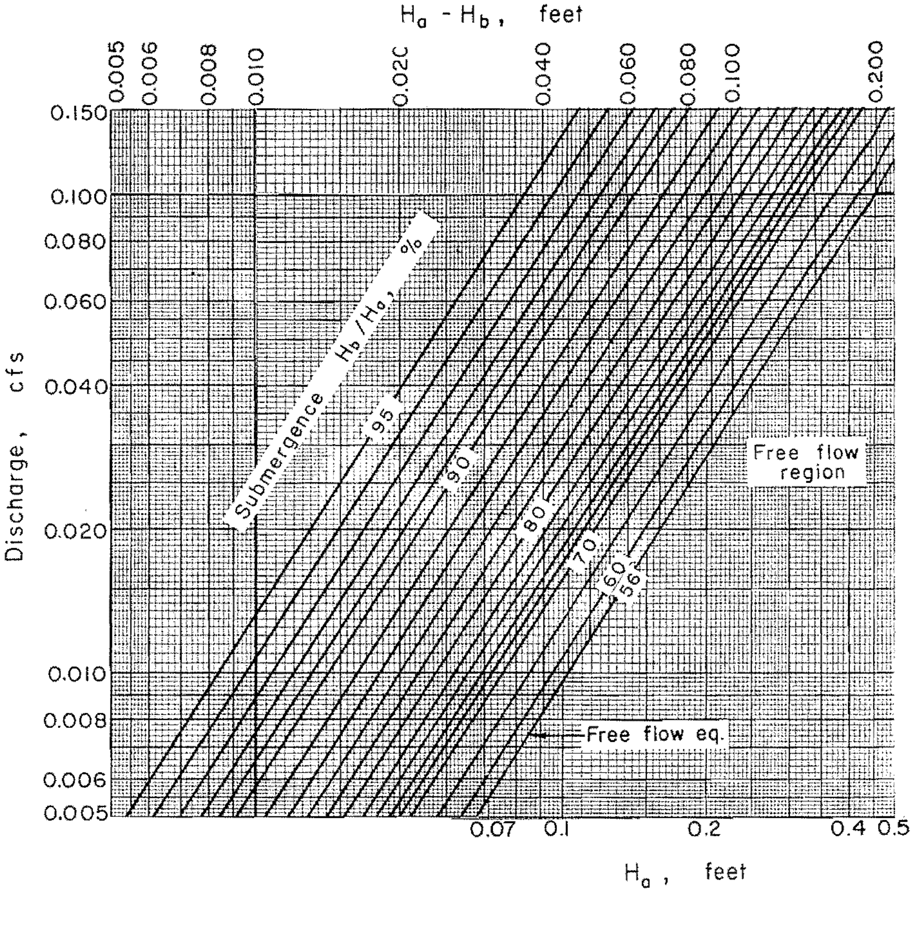


Fig. 13. Free and submerged flow calibration curves for 1-inch Parshall flume.

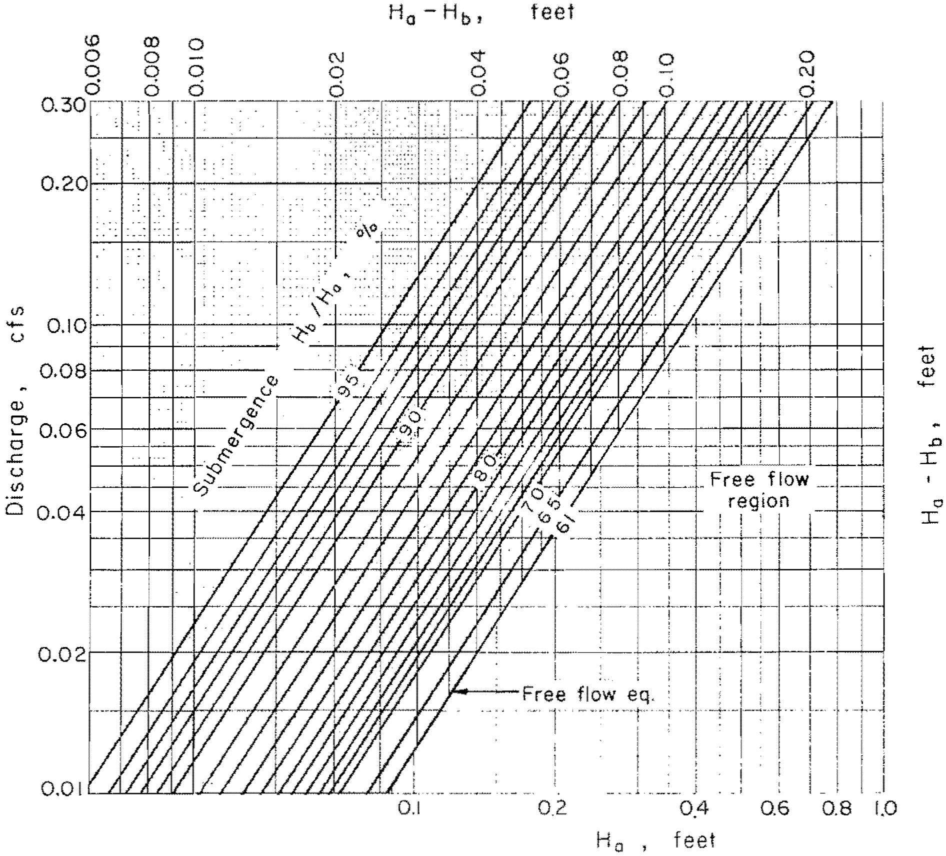
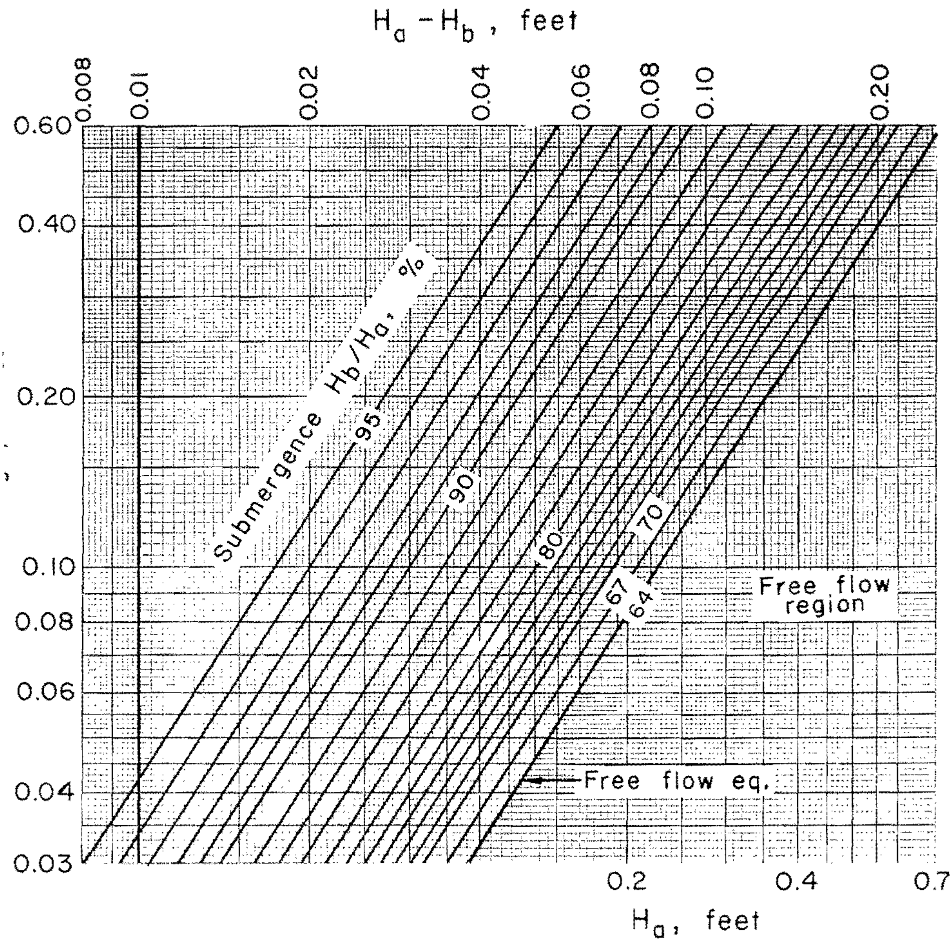


Fig. 14 Free and submerged flow calibration curves for 2-inch Parshall flume.



'ig. 15. **Free and submerged flow calibration curves for 3-inch Parshall flume.**

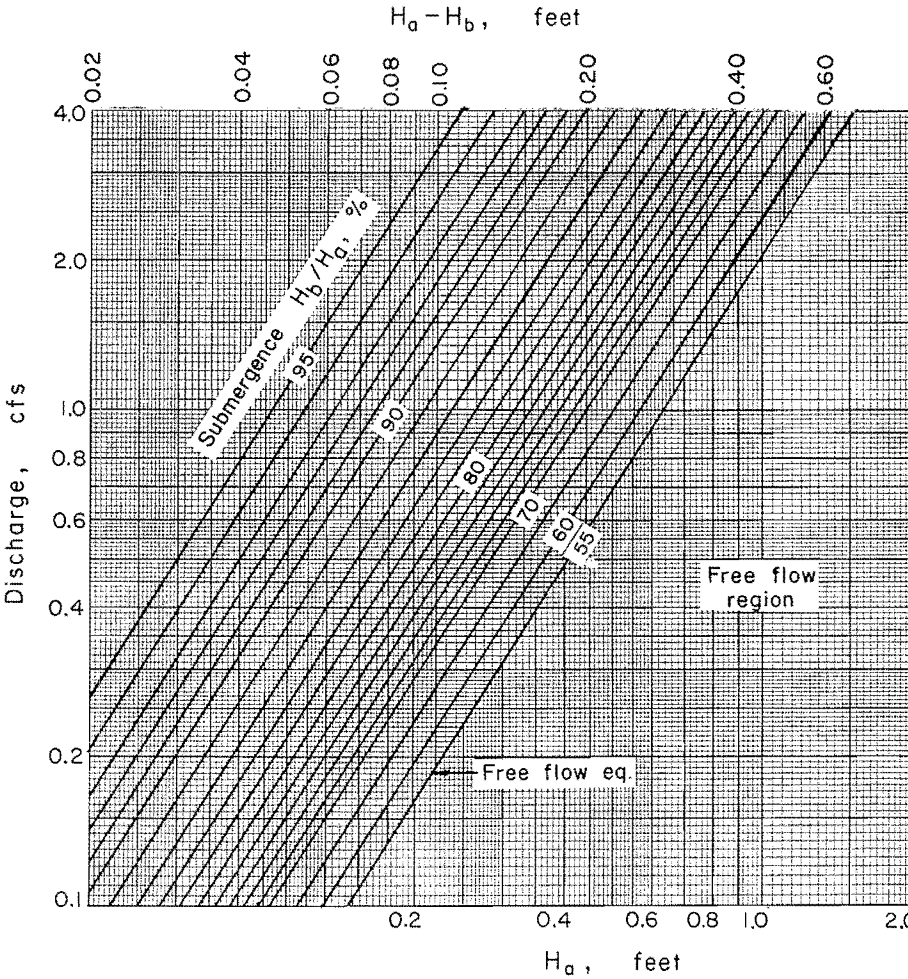


Fig. 16. Free and submerged flow calibration curves for 6-inch Parshall flume.

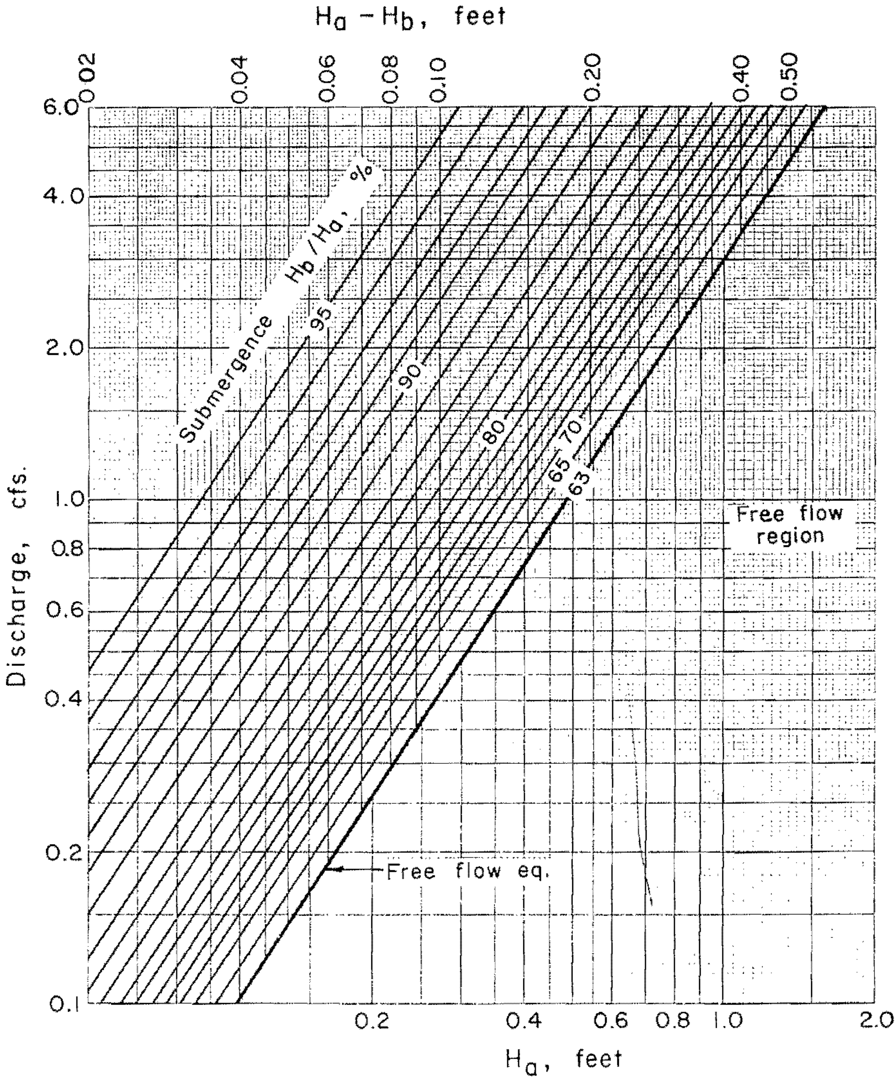


Fig. 17. Free and submerged flow calibration curves for 9-inch Parshall flume.

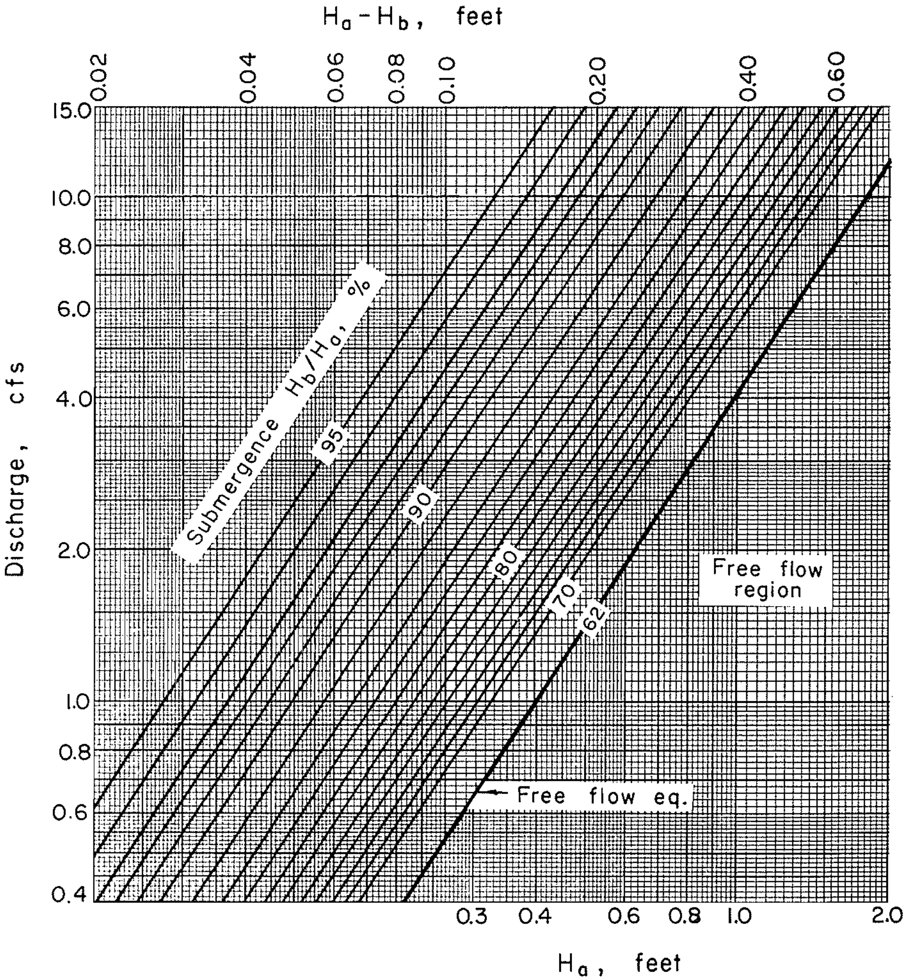


Fig. 18. Free and submerged flow calibration curves for 12-inch Parshall flume.

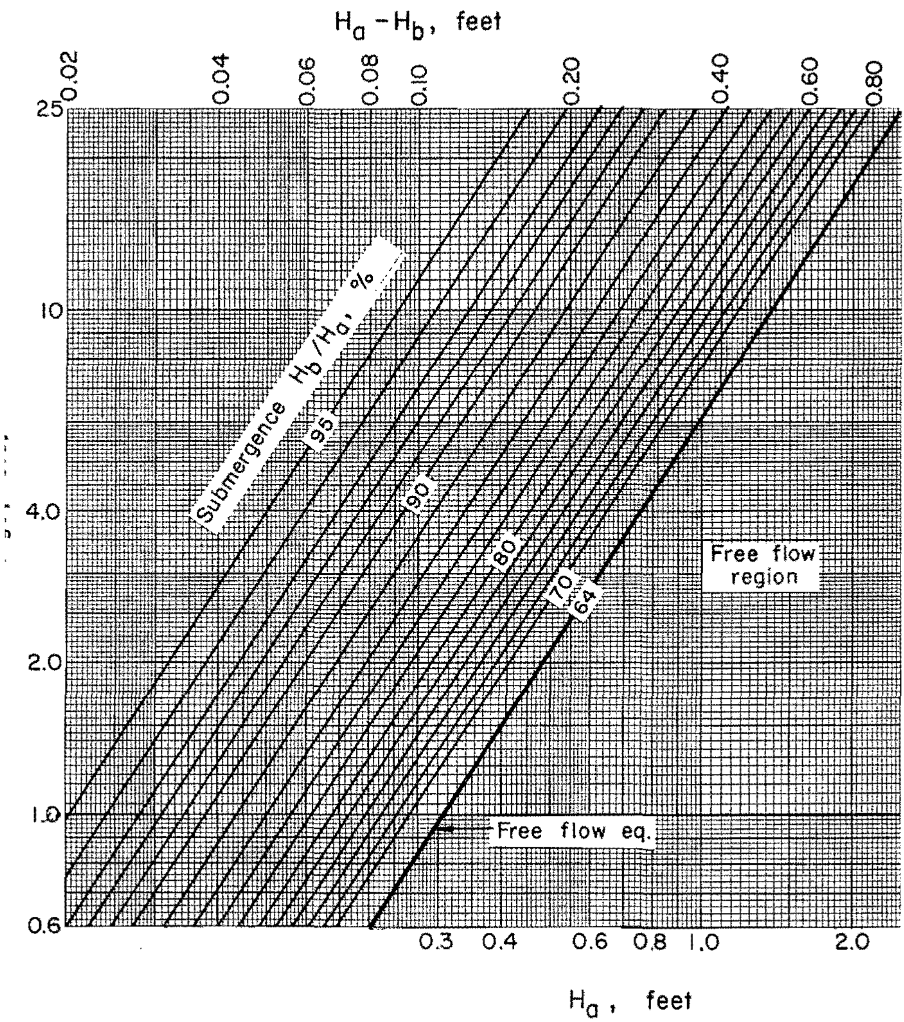


Fig. 19. Free and submerged flow calibration curves for 18-inch Parshall flume.

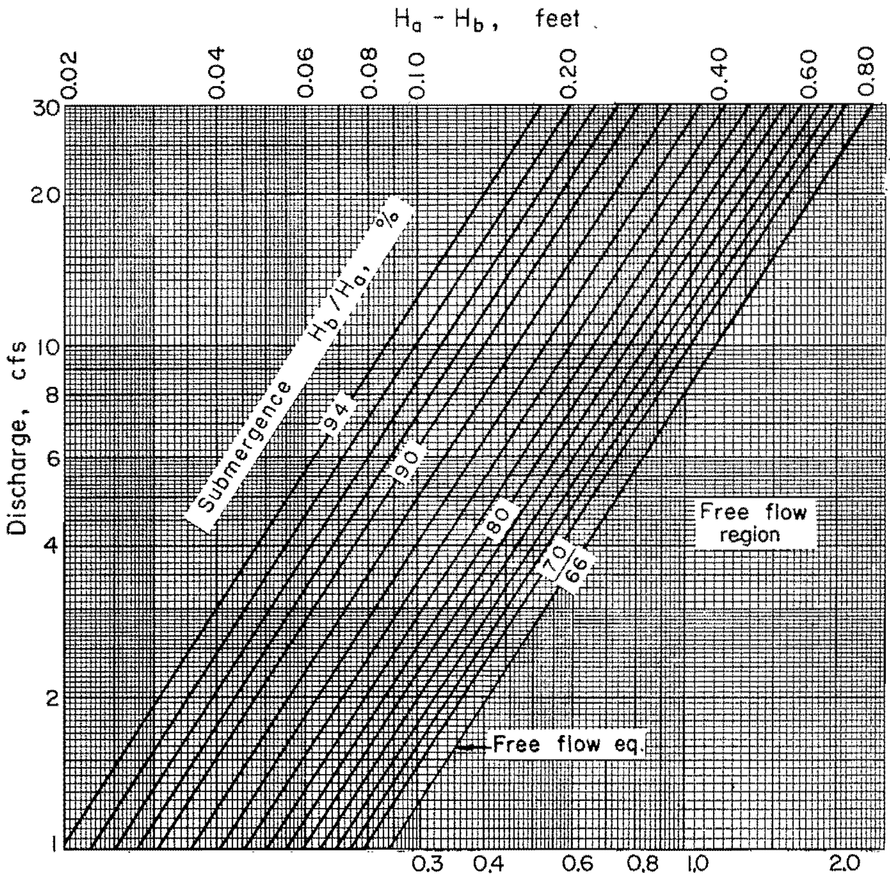


Fig. 20. Free and submerged flow calibration curves for 24-inch Parshall flume.

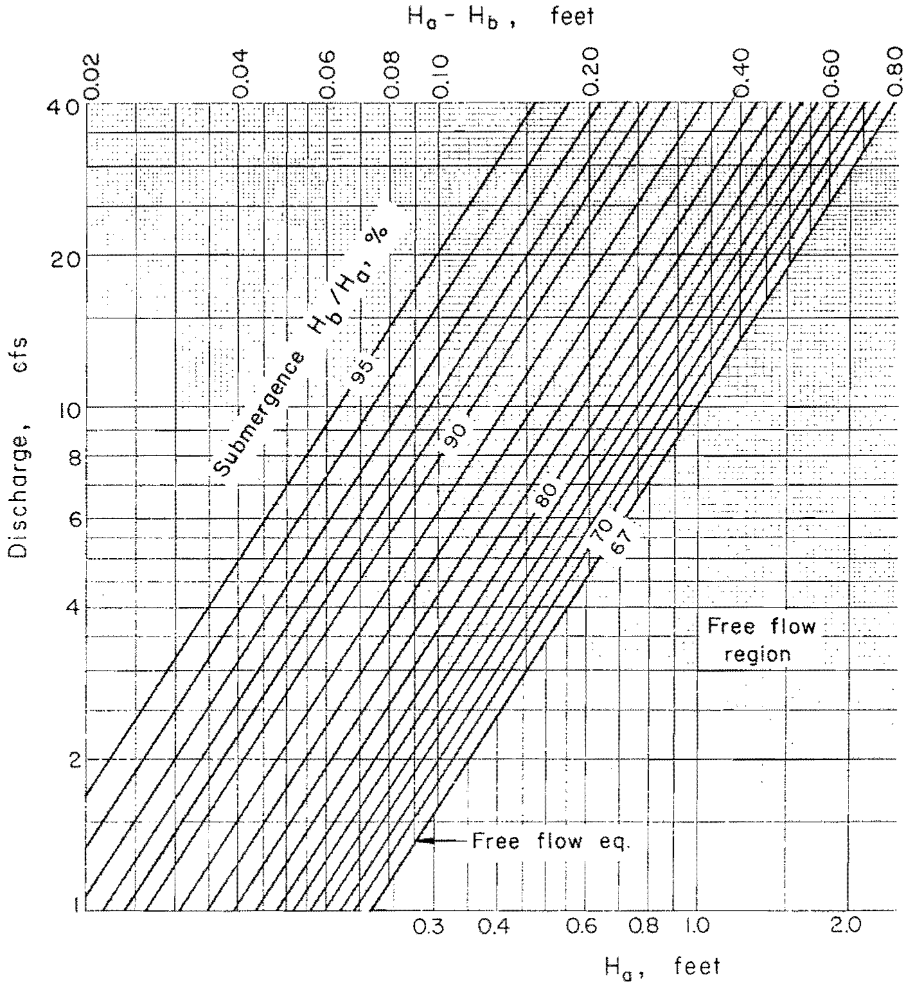


Fig. 21. Free and submerged flow calibration curves for 30-inch Parshall flume.

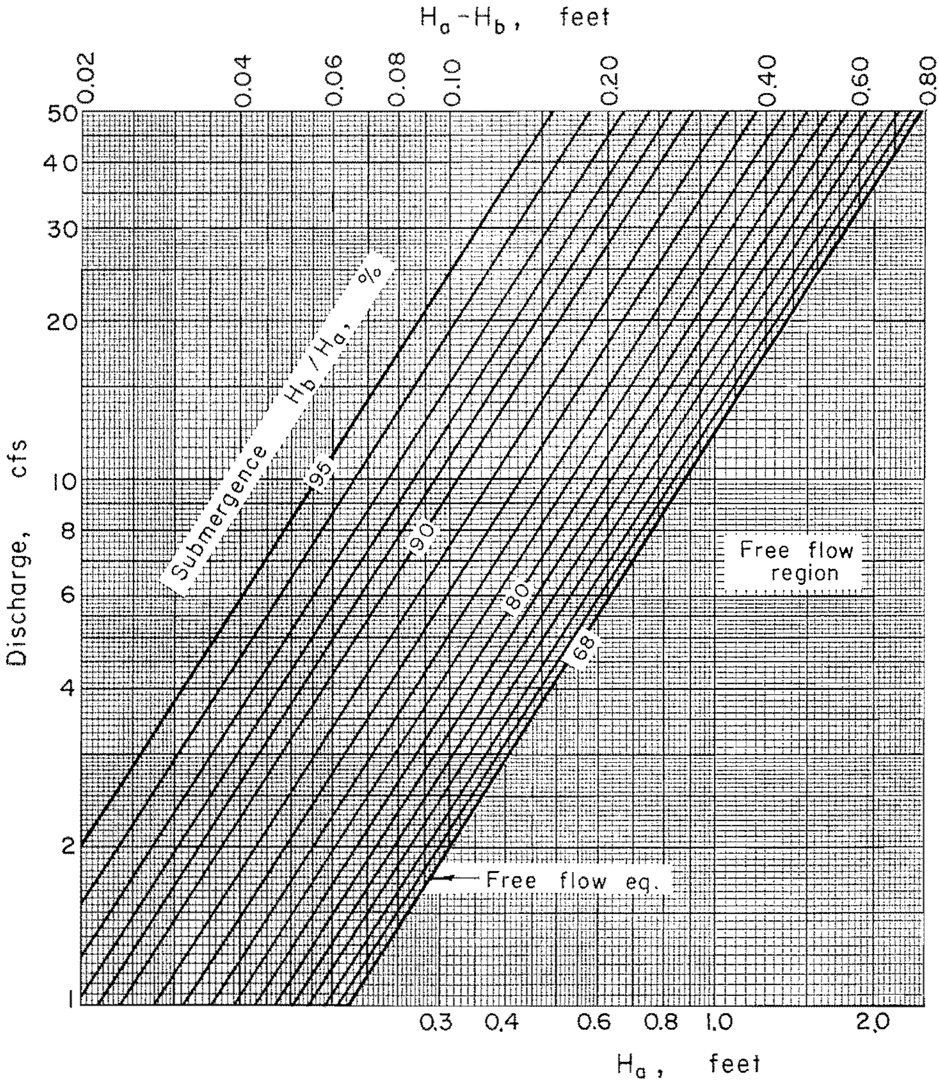


Fig. 22. Free and submerged flow calibration curves for 3-foot Parshall flume.

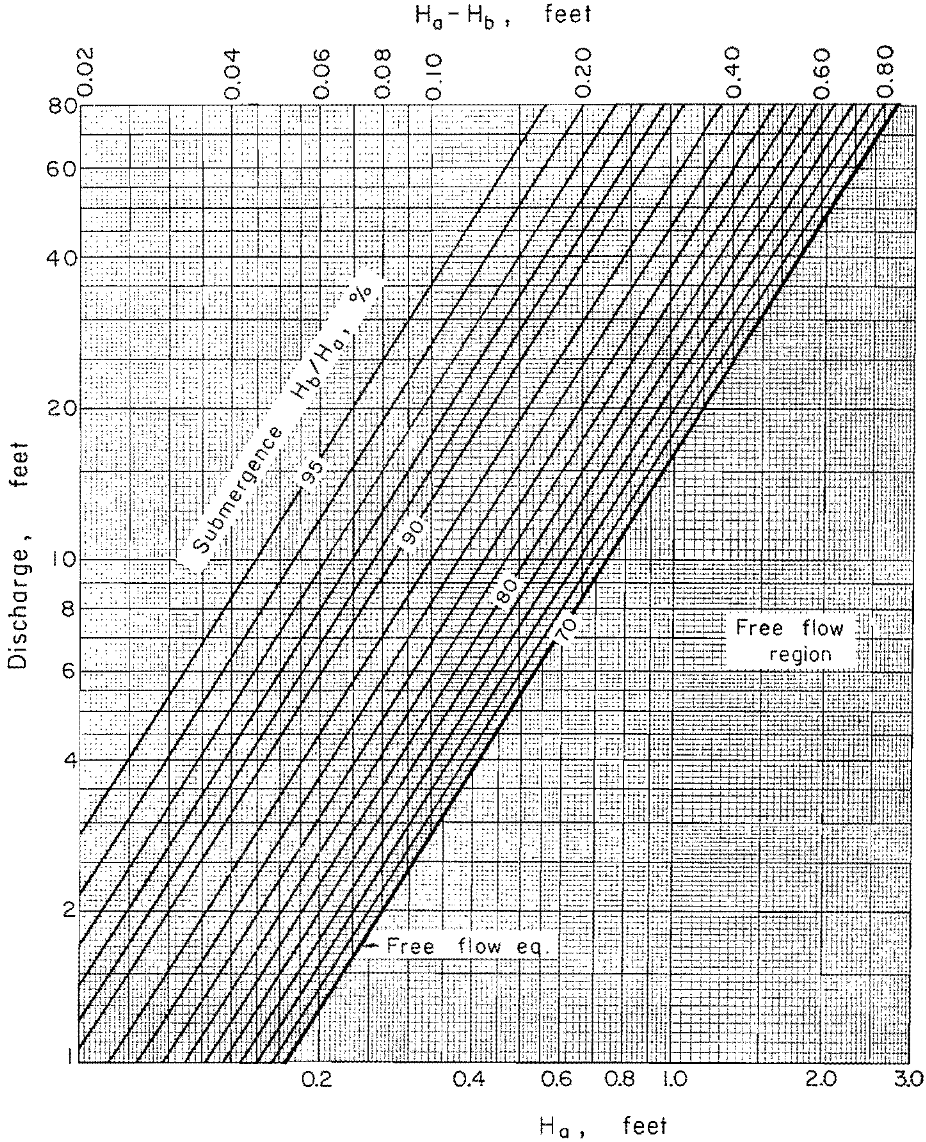


Fig. 23. Free and submerged flow calibration curves for 4-foot Parshall flume.

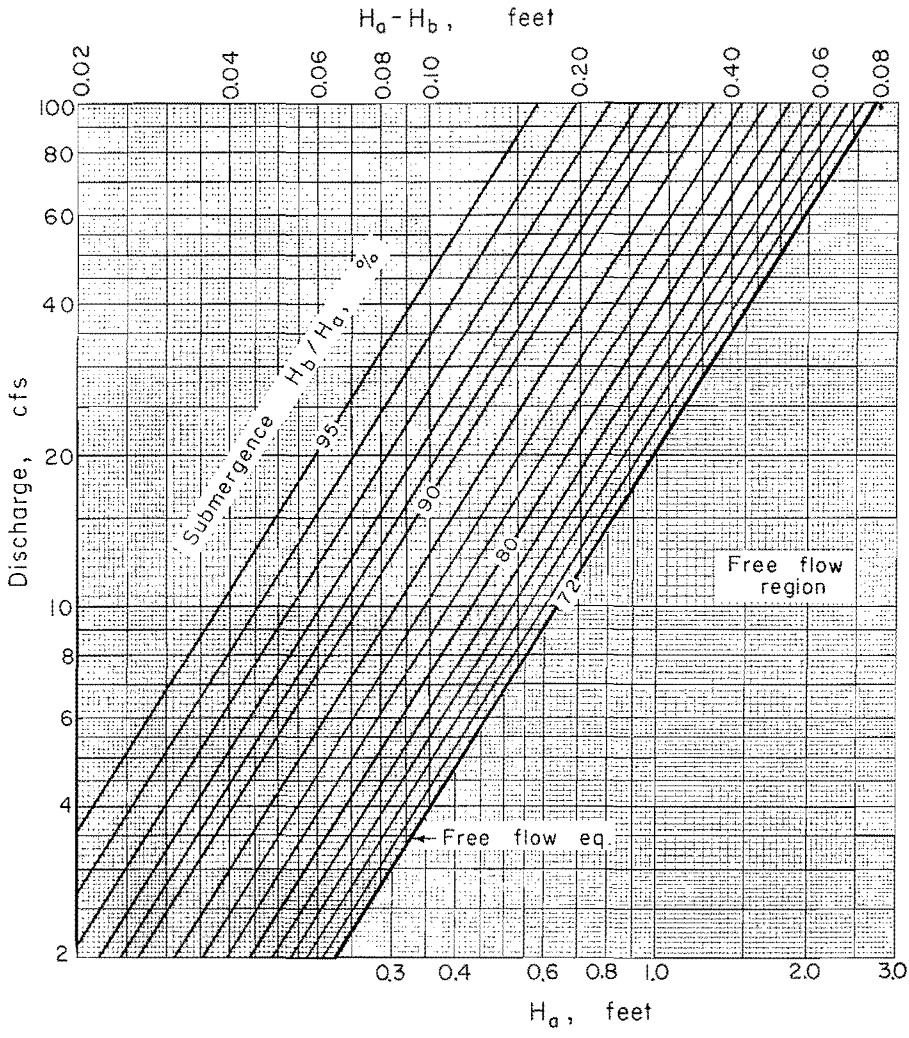


Fig. 24. Free and submerged flow calibration curves for 5-foot Parshall flume.

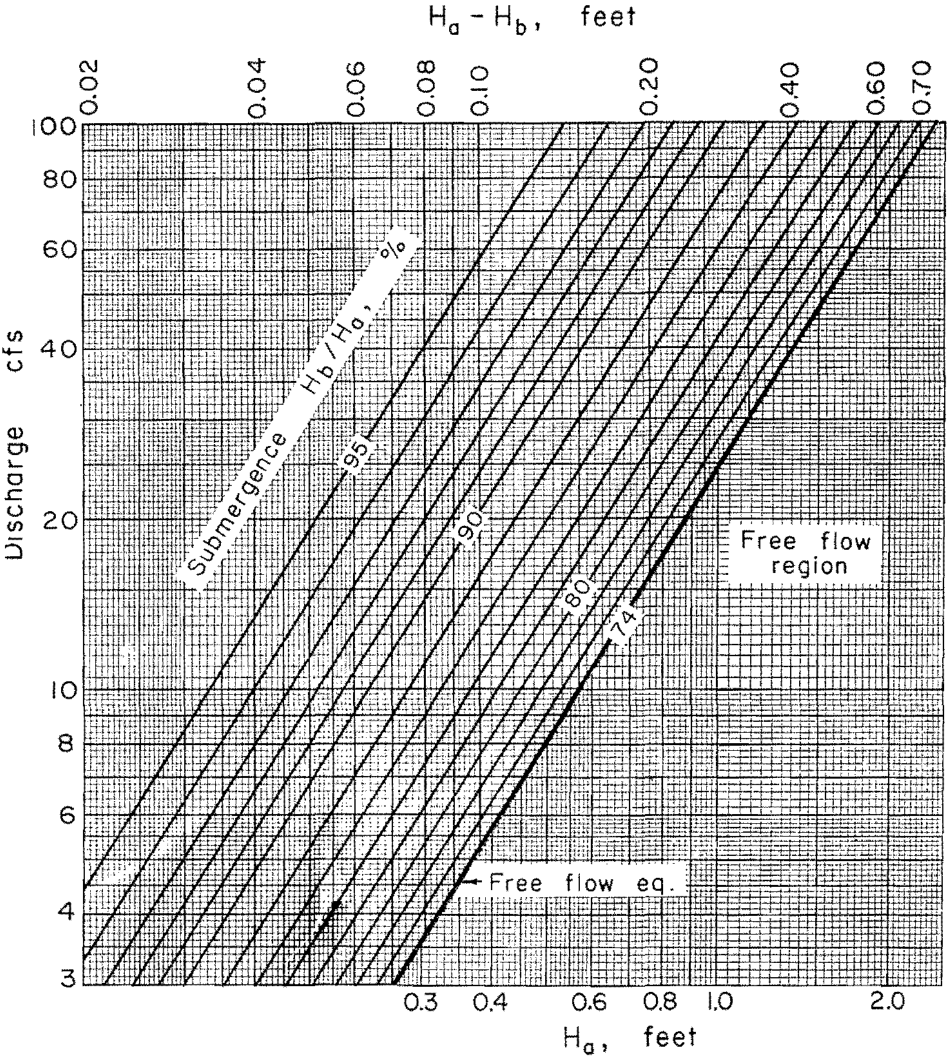


Fig. 25. Free and submerged flow calibration curves for 6-foot Parshall flume.

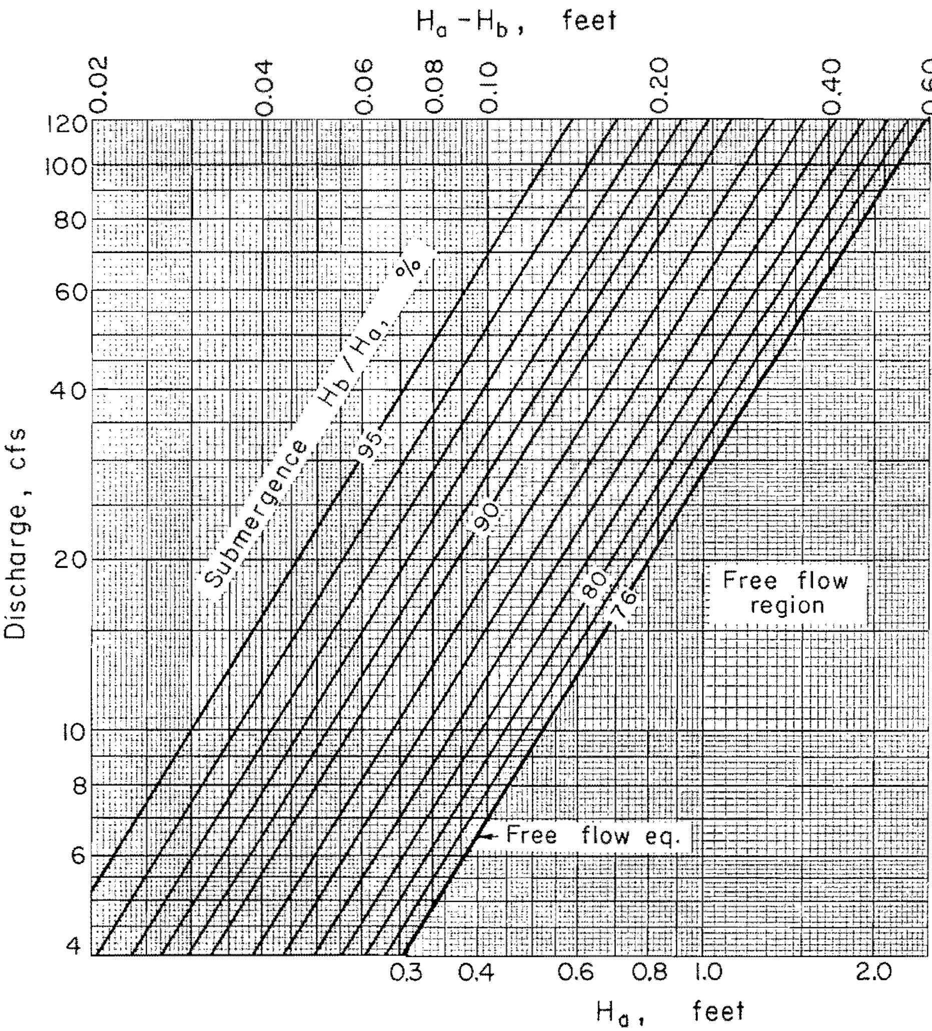


Fig. 26. Free and submerged flow calibration curves for 7-foot Parshall flume.

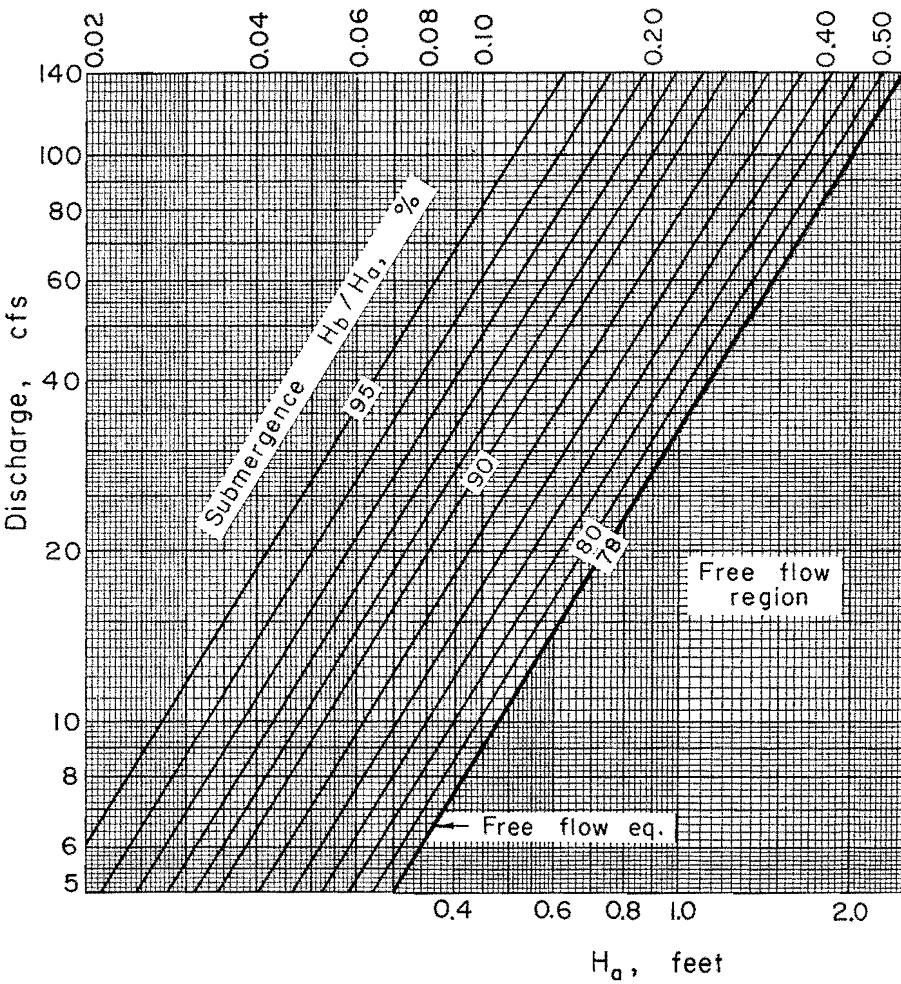


Fig. 27. Free and submerged flow calibration curves for 8-foot Parshall flume.

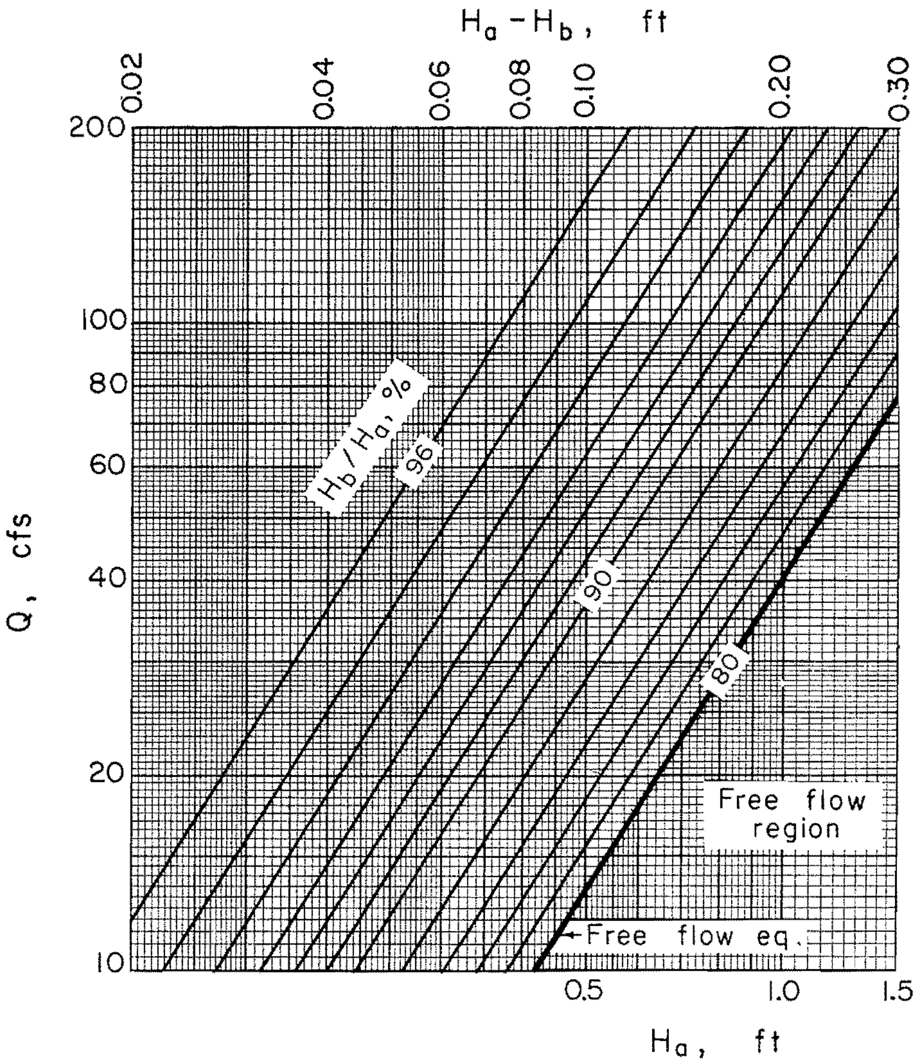


Fig. 28. Free and submerged flow calibration curves for 10-foot Parshall flume.

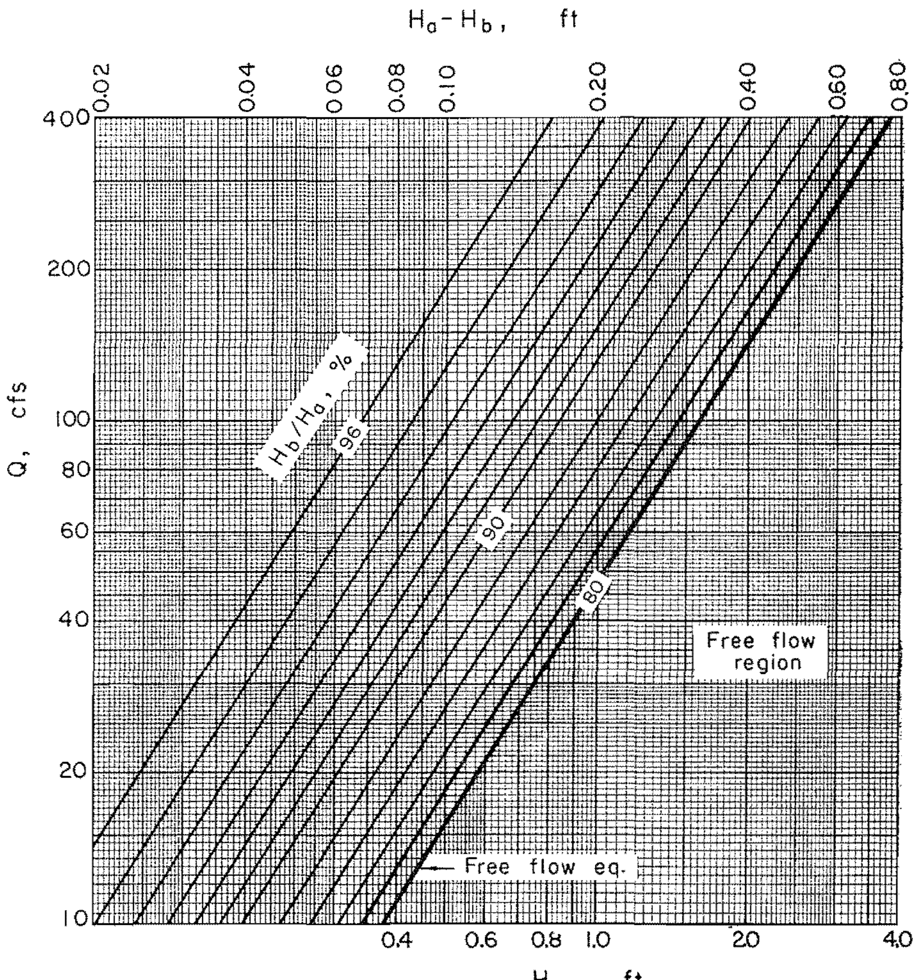


Fig. 29. Free and submerged flow calibration curves for 12-foot Parshall flume.

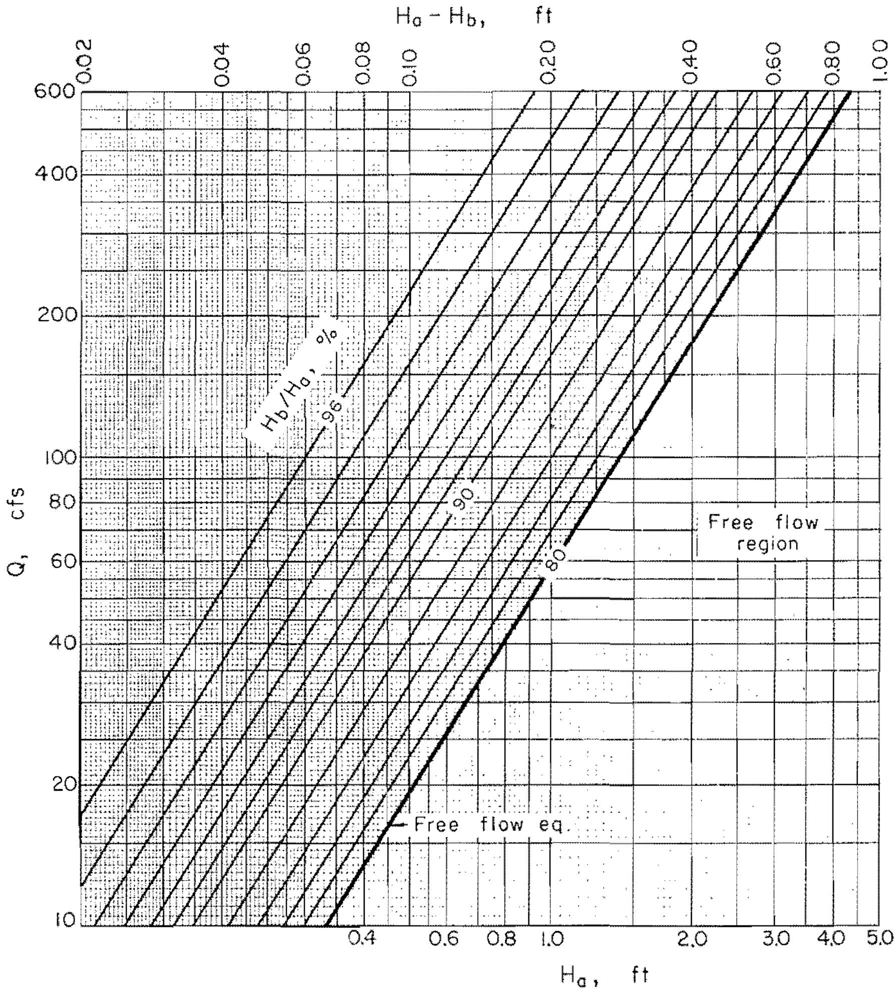


Fig. 30. Free and submerged flow calibration curves for 15-foot Parshall flume.

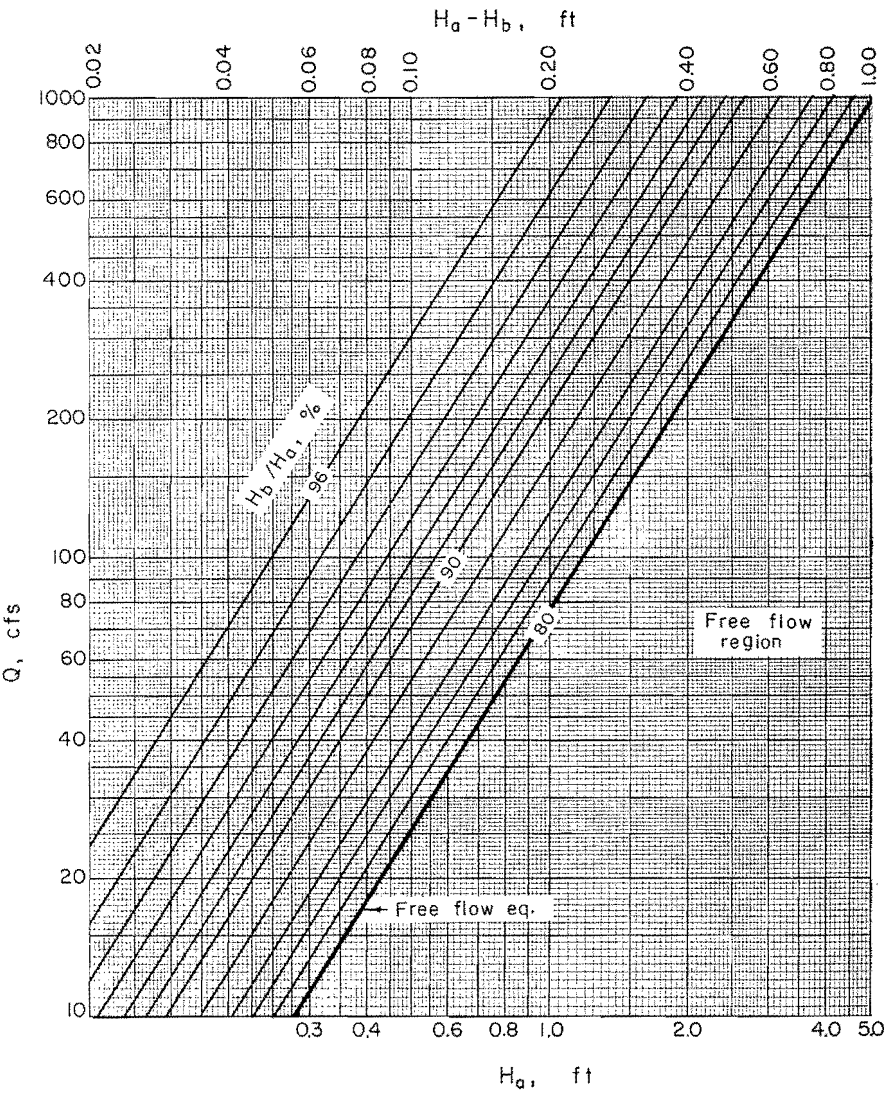


Fig. 31. Free and submerged flow calibration curves for 20-foot Parshall flume.

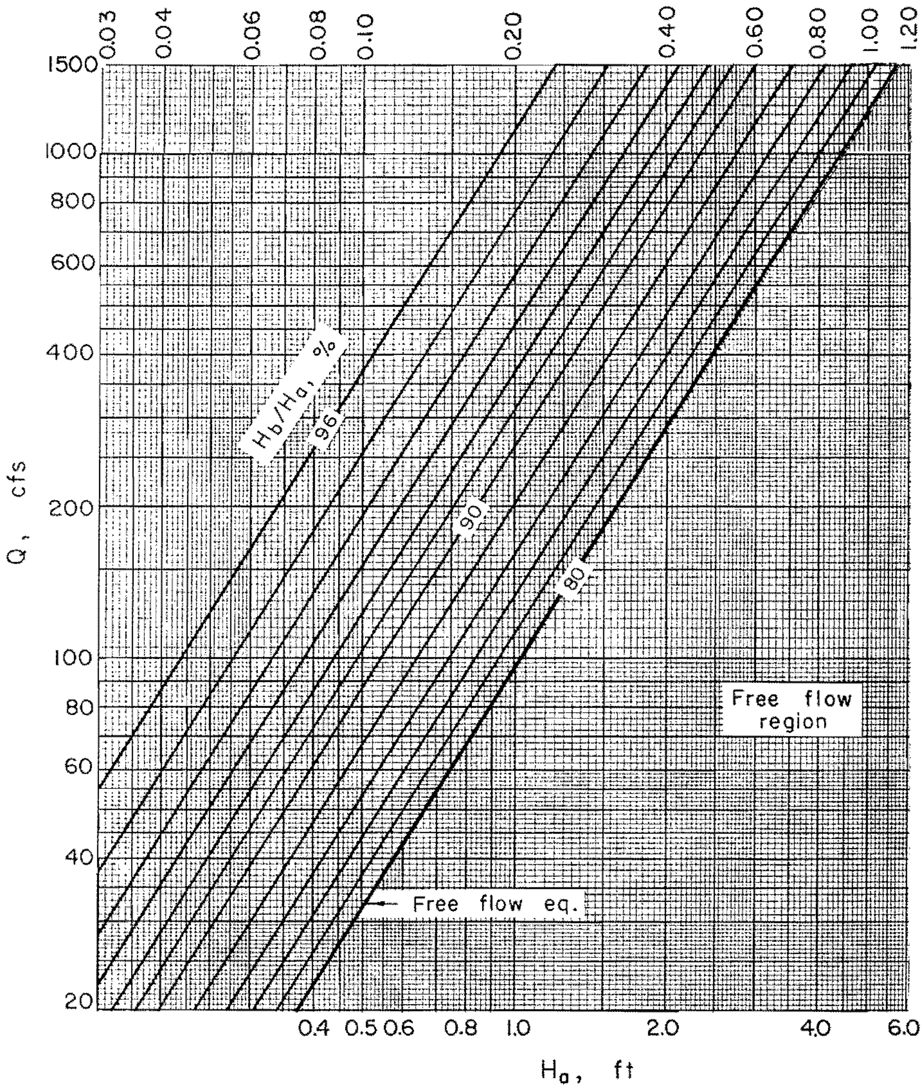


Fig. 32. Free and submerged flow calibration curves for 25-foot Parshall flume.

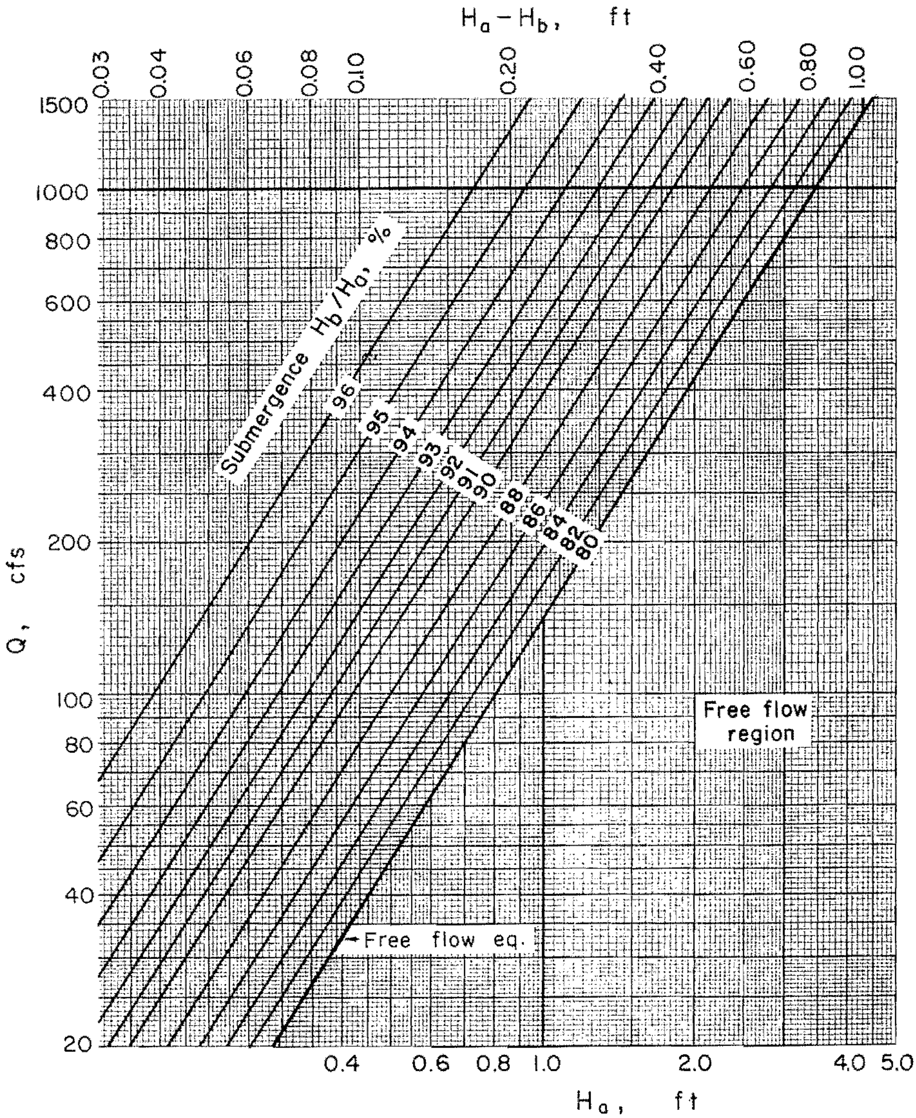


Fig. 33. Free and submerged flow calibration curves for 30-foot Parshall flume.

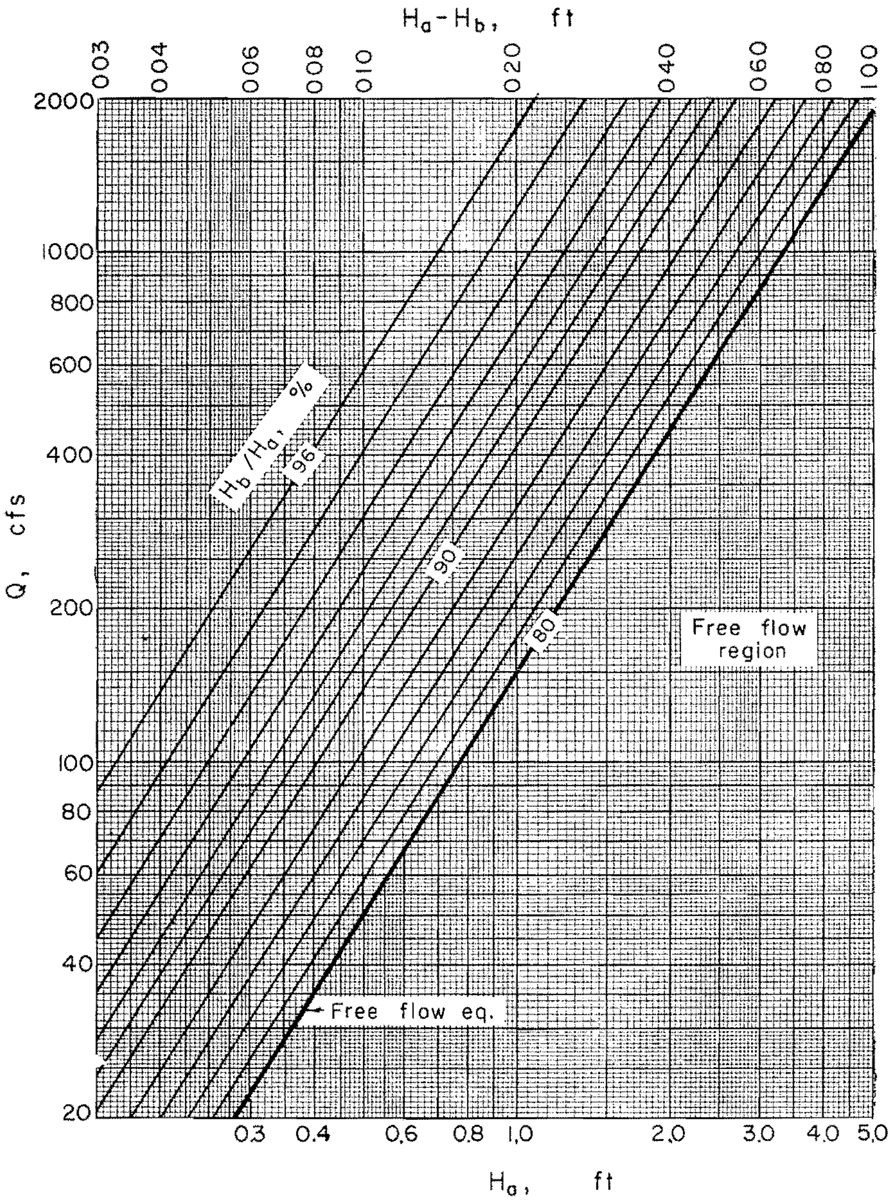


Fig. 34. Free and submerged flow calibration curves for 40-foot Parshall flume.

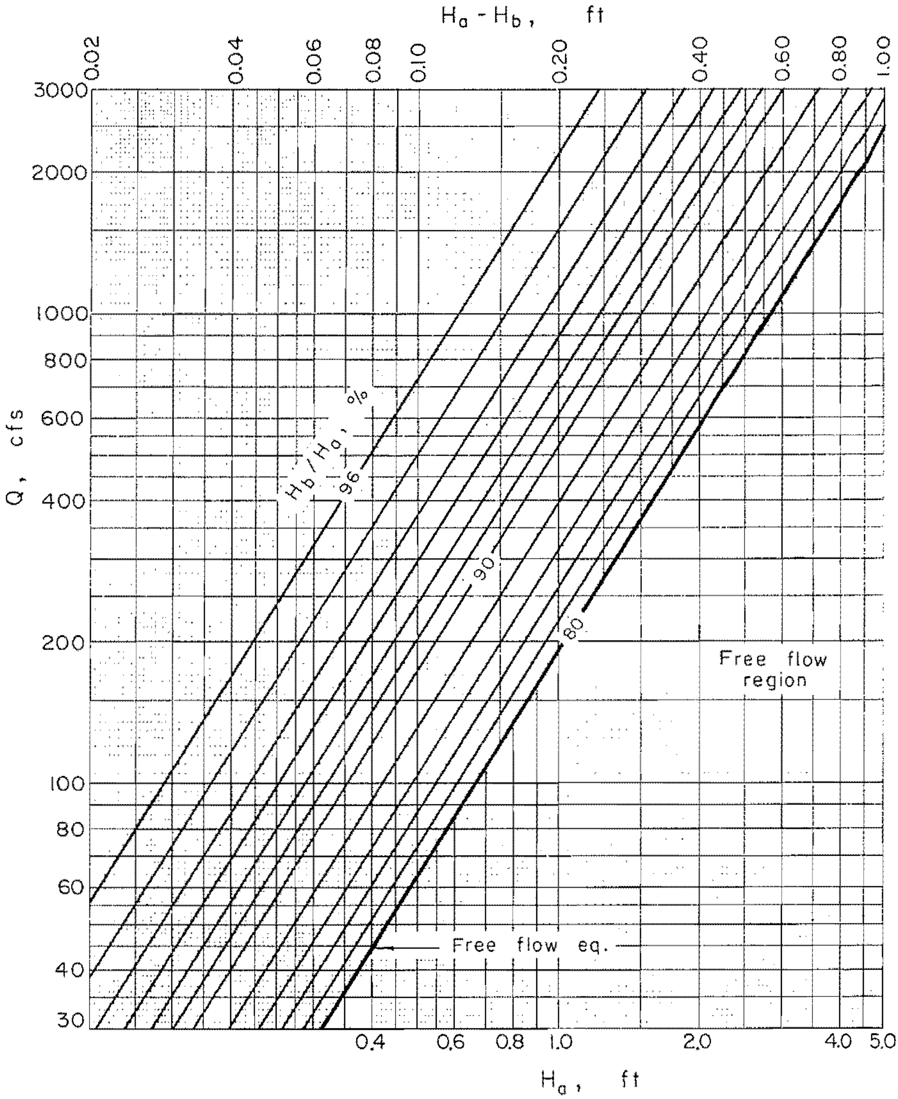


Fig. 35. Free and submerged flow calibration curves for 50-foot Parshall flume.

INSTALLATION OF PARSHALL FLUMES

The Parshall flume, like any other water-measuring structure, must be properly installed to give best results.

First, consideration should be given to the location or site for the structure. The flume should be located in a straight section of channel and, for convenience, near a point of diversion or a regulating gate, if operating conditions require frequent changing of the discharge. However, the flume should not be placed too near a gate because unbalanced flow or surging effects result from gate operation.

After selecting the site for the Parshall flume, it is necessary to determine the maximum quantity of water to be measured, the maximum depth of flow corresponding to this quantity of water, and the amount of head loss which can be allowed through the flume. For practical purposes, the head loss will be assumed as the change in water surface elevation between the entrance (inlet) and exit (outlet) of the flume. After a Par-

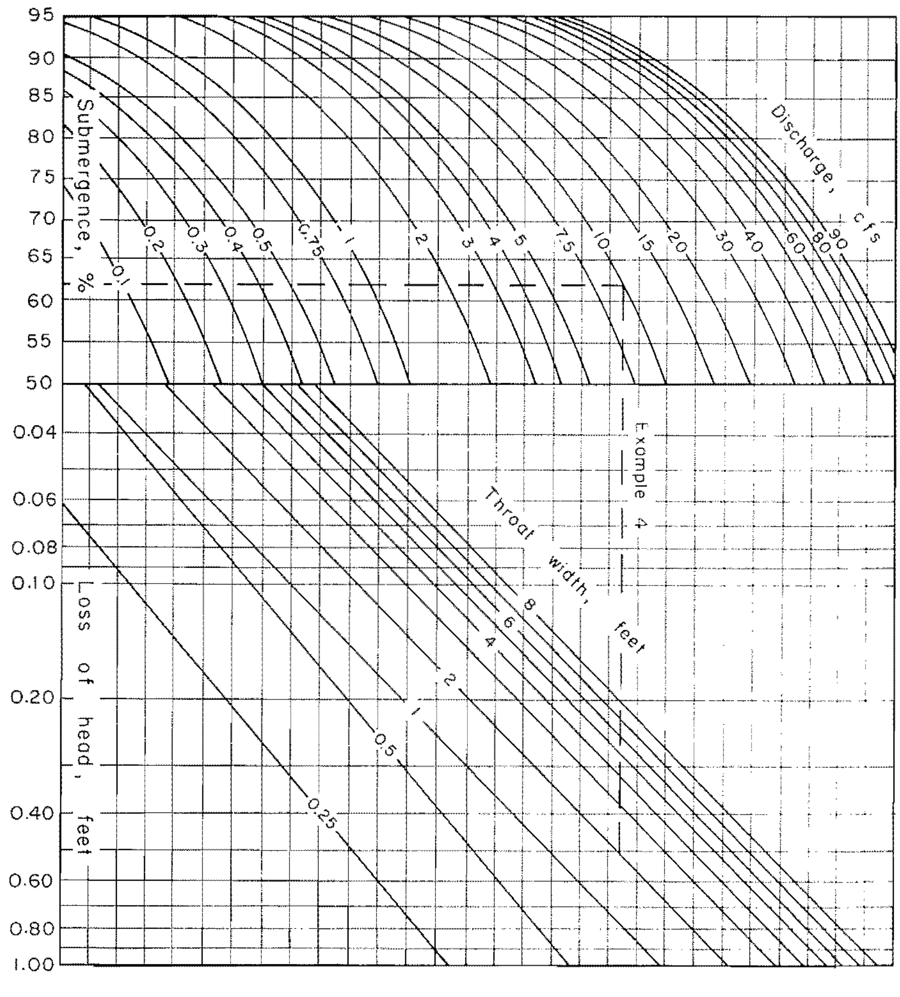


Fig. 36. Head loss through Parshall flumes.

shall flume has been installed, the flow depth downstream remains essentially the same as prior to installation, whereas the flow depth upstream from the flume is increased by approximately the amount of the head loss. The change in flow depths in a canal after installation of a Parshall flume is illustrated in Fig. 37. The amount of head loss that can be allowed through a flume is often limited by the height of the canal banks upstream from the flume. The diagram shown in Fig. 36 (Parshall, 1941) has been prepared to give assistance in the selection of the proper size of flume. Use of this diagram may best be illustrated by an example:

> Suppose it is necessary to find the smallest size flume capable of measuring a maximum discharge of 10 second-feet. The maximum flow depth in the present channel corresponding to 10 second-feet is 0.8 feet. The depth of flow in the channel can only be raised an additional 0.5 feet. Thus, after installation, the maximum downstream flow depth would still be 0.8 feet and the maximum upstream flow depth would be 1.3 feet (0.8 + 0.5 = 1.3). The submergence would be 62 percent (0.8/1.3 = 0.62). Fig. 36 is entered at the lower left on the 62 percent submergence line and followed vertically until the curved discharge line of 10 cfs is reached. At this point moving horizontally to the right, the vertical line representing 0.50 feet of head loss is intersected. This point is very near the diagonal line marked 2-foot throat width. Thus, a 2-foot Parshall flume would be used.

In some circumstances, several flume sizes might be considered for measurement of the water, but final selection is usually based on economic factors. Normally, the throat width of the flume will be from one-third to one-half the width of the channel.

The Parshall flume may be constructed of almost any material depending on the use and desired durability. The most commonly used materials are timber, steel, and concrete. When timber is used, it is important to allow for swelling (1/8-inch space between planks is advisable) and some effort must be made to preserve the timber. If greater permanency is desired, steel or concrete should be used. For the larger (10 - 50 foot) Parshall flumes, reinforced concrete is usually used. However, the forms should be carefully set to insure exact dimensions.

It is important that the crest of the flume be set at the correct elevation with reference to the channel bed. This elevation depends upon the size of the flume used and the quantity of water measured. Setting the crest at the proper elevation is not difficult if sufficient fall is available, but if the fall or grade in the channel is very flat, difficulty may be encountered and it may be necessary to operate under submerged flow conditions. The crest of the Parshall flume should be straight and level, and the flume floor should be installed so that the converging entrance section is level longitudinally and laterally.

The free flow and submerged flow calibrations given in this report correspond to flumes having the dimensions listed in Table 2. If the throat width is not constructed as specified in Table 2, adjustments can be made to the discharge tables or curves to arrive at the appropriate flow rate passing through a flume.

To illustrate adjustments which can be made, a 2-foot Parshall flume constructed of concrete is considered. After the concrete has been poured and the forms removed, a check measurement shows the throat width is 2.10 feet. Consequently, the discharge values obtained from the free flow table (Table 4), or the submerged flow calibration curves (Fig. 20) for a 2-foot Parshall flume, must be multiplied by a factor of 1.05 (2.10/2 = 1.05). For free flow then, the discharge for a 2-foot flume would be 27.0 cfs if the H_a gage reading were 2.19 feet, whereas the discharge is 28.4 cfs (27.0 x 1.05 = 28.4) for throat width of 2.10 feet.

Measurement of Flow Depths

The rate of flow through a Parshall flume is determined by the water depths in the entrance and throat sections. For free flow, only the depth, H_a, needs to be measured. A staff gage, set vertically at the specified location on the inside face of the converging entrance wall, can be used to determine the head, H_a, with fair accuracy. The staff gage for measuring H_a must be carefully referenced to the elevation of the flume crest, which is the elevation of the flume floor at the end of the entrance section (or the beginning of the throat section). For submerged flow, the depth of flow in the throat, H_b, must also be measured. Since the flow in the throat is quite turbulent, causing the water surface to fluctuate considerably, it is difficult to accurately measure H_b with a staff gage. Consequently, a stilling well placed just outside the flume wall is considered necessary. To connect the stilling well with the point in the throat for measuring H_b, as specified in Table 2, a short length of pipe is used. A staff gage can be placed vertically on the inside face of the stilling well and the zero point of the gage referenced to the elevation of the flume crest. If a Parshall flume is to be operated under submerged flow conditions, a stilling well should also be used for the H_a reading. Stilling wells provide a more accurate measurement of the flow depths than staff gages. Also, stilling wells are required if continuous recording instruments are to be used. For submerged flow, two stilling wells placed adjacent to one another are desirable when a double head recording instrument is used to record continuously the water depths H_a and H_b.

Concerning the location of H_b for a particular flume, Skogerboe, Hyatt, England, and Johnson (1965), found in their study of a 2-foot Parshall flume that the submerged flow analysis is valid for downstream depth measurements at points other than that specified in Table 2. A change in the point of downstream flow depth measurement will also change the submerged flow calibration curves. The general acceptance of the location of H_b as given by Table 2, however, justifies the continued use of this particular location.

Installation to Insure Free Flow

In most cases it is preferable to have a Parshall flume operate under free flow conditions. The principal advantage is that only the upstream flow depth, H_a, need be measured to determine discharge. Another advantage, if a continuous recorder is to be used, is the expense involved in purchasing a recorder that only measures one flow depth (H_a) rather than two (H_a and H_b) that would be required if the flume were submerged. The procedure for installing a Parshall flume in a canal to insure free flow is listed below.

1. Establish the maximum flow rate to be measured.
2. Locate the high water line on the canal bank where the flume is to be installed and determine the maximum depth of flow.
3. Select from the free flow discharge table (Table 3), the proper depth of water, H_a, corresponding with the maximum discharge capacity of the canal. For example, assuming that a 2-foot flume is to be used and the maximum discharge is 27.0 second-feet, the depth of water, H_a, on the crest is 2.19 feet.
4. Place the floor of the flume at a depth which does not exceed the transition submergence multiplied by H_a (S_t x H_a) below the high water line (Fig. 37). In general, the floor of the flume should be placed as high in the canal as grade and other conditions permit.

As an example, a 2-foot Parshall flume is shown in Fig. 37. The transition submergence for the 2-foot flume is 66 percent. The maximum discharge in the canal is 27.0 cfs, which for free flow conditions has an H_a value equal to 2.19 feet. Multiplying H_a (2.19) by the transition submergence (0.66), gives a depth to flume floor of 1.45 feet (2.19 x 0.66 = 1.45). Therefore, the flume crest should be set no lower than 1.45 feet below the original maximum water surface (Fig. 37). The loss of head through the structure will be the difference between 2.19 feet and 1.45 feet, which is 0.74 feet, as shown in Fig. 37. If the amount of head loss is too great, then a larger flume could be used with a resulting decrease in the head loss.

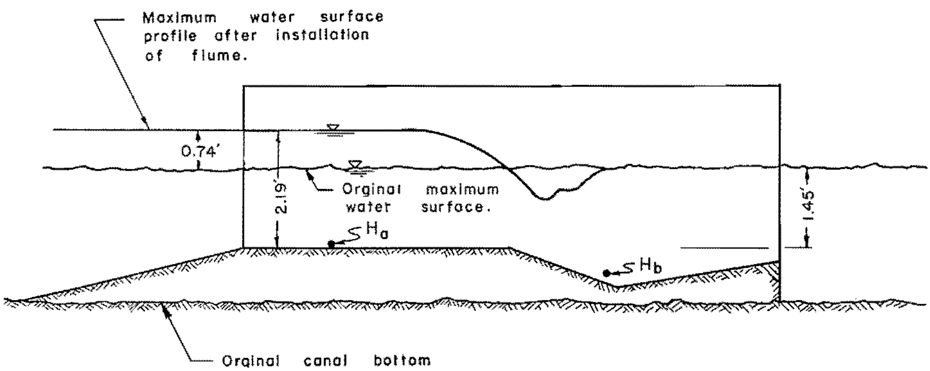


Fig. 37. Installation of 2-foot Parshall flume to operate under free flow conditions.

Installation for Submerged Flow

Some conditions exist, such as insufficient grade, where it is impossible or impractical to set the flume for operation under a free flow condition. Where this is the case, the flume may be placed in the canal to operate under submerged flow conditions. The principal advantage offered by submerged flow operation in Parshall flumes is the smaller head loss which occurs through the flume. The savings in head loss (as compared with free flow) may mean that canal banks upstream from the flume do not have to be raised in order to maintain the same maximum flow capacity in the canal that existed prior to the installation of the flume. Also, for submerged flow, the floor of the flume may be placed at the same elevation as the canal bottom, thus allowing quicker drainage of the canal section upstream from the flume, as well as reduced seepage losses upstream from the flume particularly for flow rates less than the maximum discharge. The procedure to follow in placing a Parshall flume in a canal to operate under submerged flow conditions is listed below.

1. Establish the maximum flow rate to be measured.

2. Locate high water line on the canal bank where the flume is to be installed, and determine maximum flow depth.

3. Taking into account the amount of freeboard in the canal at maximum discharge and maximum flow depth, determine how much higher the water surface can be raised in the canal above the location for the flume.

4. Select the required size of flume from the submerged flow calibration curves using trial and error. With the floor of the flume being placed at nearly the same elevation as the bottom of the canal, the maximum flow depth (item 2) can be used as H_b, and the additional amount that the water surface in the canal can be raised (item 3) will be used as H_a - H_b. With this information, the submergence, H_b/H_a, can be computed. Knowing H_a - H_b and H_b/H_a allows the size of flume to be selected from the submerged flow calibration curves. The trial and error procedure for selecting the size of flume can be illustrated as follows:

> A site for a Parshall flume has been selected in a canal having a maximum discharge of 27 cfs. Maximum depth of water in the canal corresponding to this flow rate is 1.8 feet. With the amount of existing freeboard in the canal, it is felt that the water surface should not be raised more than 0.2 foot, thereby resulting in a maximum flow depth of 2.0 feet (1.8 + 0.2 = 2.0) upstream from the flume after installation. Therefore, for purposes of selecting the flume size:
>
> H_b = 1.8 feet
> H_a = 2.0 feet
> H_a - H_b = 2.0 - 1.8 = 0.2 foot
> H_b/H_a = 1.8/2.0 = 0.90 = 90%
>
> As a beginning point, enter the submerged flow calibration curves for a 2-foot Parshall flume (Fig. 20). With the value of H_a - H_b = 0.20 foot, move vertically to the submergence line for 90 percent, and then read the discharge to the left as 18.5 cfs. Since this flow rate (18.5 cfs) is less than the maximum flow rate (27 cfs), a larger flume is required.
>
> Entering the submerged flow calibration curves for a 30-inch Parshall flume (Fig. 21) with H_a - H_b = 0.20 foot, move vertically to the 90 percent submergence line, and read the discharge as 22.8 cfs. Again, the flow rate is less than the

design maximum flow rate of 27 cfs, and a larger Parshall flume is required.

Entering the submerged flow calibration curves for a 3-foot Parshall flume (Fig. 22) with H_a - H_b = 0.20 foot, move vertically to the 90 percent submergence line, and read the discharge as 27.8 cfs. Since this flow rate (27.8 cfs) is larger than the maximum flow rate in the canal (27 cfs), a 3-foot Parshall flume may be used.

MAINTENANCE

After a Parshall flume has been properly installed, periodic maintenance is required to insure satisfactory operation. Moss may collect on the walls of the entrance section and must be removed. In certain channels, debris may collect on the floor of the entrance section, and should be removed. Walls of steel Parshall flumes may become encrusted and the encrustation should be removed with a steel-wire brush. Once the walls have been scraped clean, applying asphaltic paint will add to the life of the flume and delay the build-up of encrustation.

It is common for Parshall flumes to "settle" after being in operation for a period of time. The levelness of the entrance floor should be checked after a few months of operation, and again at the end of the season or year.

Either "settling" or improper installation, can cause a flume to tilt sideways as illustrated in Fig. 38. If the settling is minor, the discharge can still be estimated with fair accuracy by measuring the flow depths on both sides of the flume. By employing the average of the two readings when using the rating tables or calibration curves, the discharge can be determined.

Settlement near the entrance section of a Parshall flume is illustrated in Fig. 39. And again, if the settlement is not too great, discharge can be estimated with fair accuracy. For this particular situation, the flume crest is the controlling point and a staff gage or stilling well should be set at zero at the same elevation as the flume crest to properly measure H_a.

Settlement occurs most commonly near the exit section, as illustrated in Fig. 40. Settlement is more likely at the outlet because of channel erosion immediately downstream from the flume caused by the jetting action of the water. Use of the flow depths H_a or H_a and H_b to obtain discharge from the tables or curves, will yield values less than the true discharge. This discrepancy between the estimated discharge and the true discharge becomes greater as the amount of settlement increases. Satisfactory solutions to this problem include: raising the lower end of

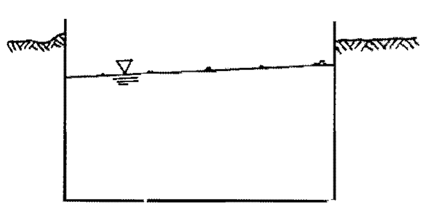


Fig. 38. Parshall flume tilted sideways.

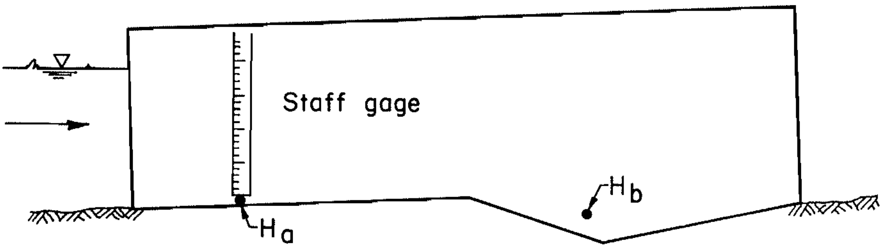


Fig. 39. Settlement of Parshall flume in vicinity of inlet section.

the flume so that it is level again; placing a new level floor in the flume; and purchasing a plastic or fibre-glass Parshall flume liner, placing it inside the existing flume, then grouting it into place.

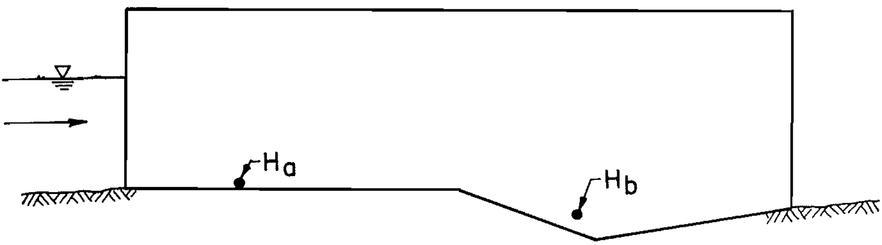


Fig. 40. Settlement of Parshall flume at exit section.

SUMMARY

Discussion is given to free flow and submerged flow conditions and their importance in the role of water measurement through the use of Parshall measuring flumes. The parameters which describe submerged flow in Parshall measuring flumes are developed by employing momentum relationships. Further verification of the resulting theoretical submerged flow equation is obtained through a combination of empiricism and dimensional analysis. The coefficients and exponents in the free flow and submerged flow equations have been listed (Table 1) for flume sizes varying from 1 inch to 50 feet. The graphical presentation of the submerged flow equation is a three-dimensional plot on log-log paper (Figs. 6 and 7). Submerged flow calibration curves are presented for the various sizes of Parshall flumes with the free flow calibration curve being superimposed on the same graph.

The transition from free flow to submerged flow has been discussed along with the relationship between constriction ratio and transition submergence. The installation of Parshall flumes to operate both under free flow and submerged flow is described, as well as the proper location and procedure for measuring the flow depths. The maintenance necessary to insure correct reading of the depths is also given. The writers feel more data are needed for both free flow and submerged flow in large Parshall flumes with throat widths varying from 10 feet to 50 feet.

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