OPENCHANNELFLOW

PARSHALL FLUME

User's Manual

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INTRODUCTION TO THE PARSHALL FLUME

The Parshall flume is a fixed hydraulic structure used to measure the flow of sub-critical waters in open channels. Although originally developed to measure irrigation / water rights flow, the use of the flume has been expanded and now includes:

- *Cooling water discharge*
- *Dam seepage*
- *Industrial effluent*
- *Irrigation / water rights*
- *Landfill leachate*
- *Mine discharge / dewatering*
- *Sanitary sewage (piped and treatment plant)*
- *Storm water*

DEVELOPMENT

While working at the U.S. Soil Conservation Service, Dr. Ralph L. Parshall saw a need for a more accurate way to measure surface waters – particularly those used for irrigation / water rights. At the time, flows were commonly measured with weirs or Venturi flumes – both of which had sizeable shortcomings.

Starting in 1915 with the sub-critical Venturi flume, Dr. Parshall made a series of modifications which lead, six years later, to his filing of a patent for his new "Parshall Flume".

Over the years Dr. Parshall's work has been extended to flumes both larger and smaller than his original investigations. Today there are 22 standard sizes of Parshall flume.

FUNCTION

Sub-critical flumes like the Parshall flume operate by accelerating slow, sub-critical flow (Fr<1) to a supercritical state (Fr>1) by restricting the flow as it passes through the flume. The Parshall flume accomplishes this restriction by contracting the side walls and dropping the floor.

DESIGN

When viewed from above, the Parshall flume has an hourglass shape.

As flow enters the flume it is accelerated in the flat-bottomed, uniformly converging inlet. It then enters a narrow, constant width throat section in which the floor drops. Existing the throat, the flow rises in the uniformly expanding discharge section.

Although higher than the lowest portion of the throat, the outlet of the diverging section of the flume is always lower than the floor of the converging section.

STANDARDS

The design and discharge characteristics of the Parshall flume have been standardized in:

- *ASTM D1941 – 91 (2013) Standard Test Method for Open Channel Flow Measurement of Water with the Parshall Flume*
- *ISO 9826:1992 Measurement of Liquid Flow in Open Channels – Parshall and SANIIRI Flumes*
- *JIS B7553 Parshall Flume Type Flowmeters*

Parshall flumes of non-standard (commonly 21-inch, 30-inch, and 42-inch) sizes or those not conforming to the published standard dimensions should be considered to be non-conforming and should be replaced or field rated.

ACCURACY

Under controlled, laboratory conditions, Parshall flumes have been observed to accurate to within +/-2%.

However, the free-flow accuracy of Parshall flumes under field conditions is usually within +/- 5% when practical considerations such as approach flow, installation, and dimensional tolerance accounted for.

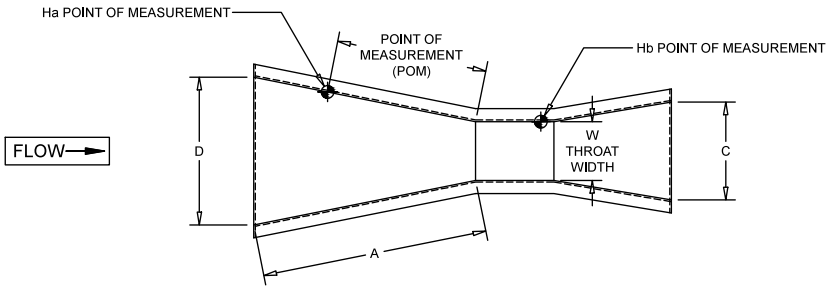
DIMENSIONS

The master dimensions for Parshall flumes with throat widths from 1-inch to 144-inches are found in Figure 1.

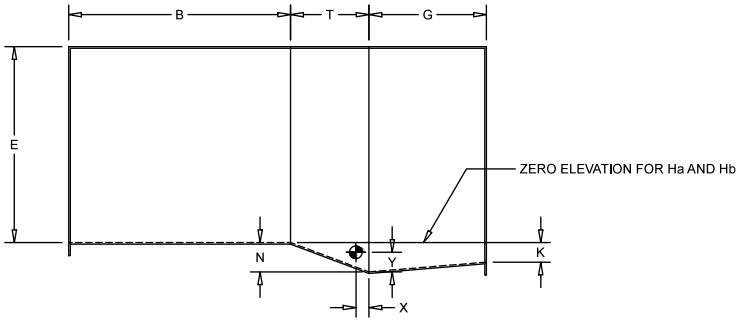
DIMENSIONAL TOLERANCES

ASTM D1941 requires that Parshall flume dimensions be within 2% of nominal, while JIS B7553 requires tolerance of +/- 1 to 1.5%, depending upon flume size.

Parshall flumes with dimensions outside of these ranges should be considered to be non-conforming and should be either replaced or field rated.



PLAN VIEW



ELEVATION VIEW

W (SIZE)	A	POM	B	C	D	E	T	G	K	N	X	Y
1" [2.54 CM]	1'-2 9/32" [36.27 CM]	9 17/32" [24.21 CM]	1'-2" [35.56 CM]	3 21/32" [9.29 CM]	6 19/32" [16.75 CM]	9" [22.86 CM]	3" [7.62 CM]	8" [20.32 CM]	3/4" [1.91 CM]	1 1/8" [2.86 CM]	5/16" [0.79 CM]	1/2" [1.27 CM]
2" [5.08 CM]	1'-4 5/16" [41.43 CM]	10 7/8" [27.62 CM]	1'-4" [40.64 CM]	5 5/16" [13.49 CM]	8 13/32" [21.35 CM]	10" [25.4 CM]	4 1/2" [11.43 CM]	10" [25.4 CM]	7/8" [2.22 CM]	1 11/16" [4.29 CM]	5/8" [1.59 CM]	1" [2.54 CM]
3" [7.62 CM]	1'-6 3/8" [46.67 CM]	1'-0 1/4" [31.12 CM]	1'-6" [45.72 CM]	7" [17.78 CM]	10 3/16" [47.23 CM]	2' [60.96 CM]	6" [15.24 CM]	1' [30.48 CM]	1" [2.54 CM]	2 1/4" [5.72 CM]	1" [2.54 CM]	1 1/2" [3.81 CM]
6" [15.24 CM]	2'-0 7/16" [62.07 CM]	1'-4 5/16" [41.44 CM]	2' [60.96 CM]	1'-3 1/2" [38.74 CM]	1'-3 5/8" [39.69 CM]	2' [60.96 CM]	1' [30.48 CM]	2' [60.96 CM]	3" [7.62 CM]	4 1/2" [11.43 CM]	2" [5.08 CM]	3" [7.62 CM]
9" [22.86 CM]	2'-10 5/8" [87.95 CM]	1'-11 1/8" [58.74 CM]	2'-10" [86.36 CM]	1'-3" [38.1 CM]	1'-10 5/8" [57.47 CM]	2'-6" [76.2 CM]	1' [30.48 CM]	1'-6" [45.72 CM]	3" [7.62 CM]	4 1/2" [11.43 CM]	2" [5.08 CM]	3" [7.62 CM]
12" [30.48 CM]	4'-6" [137.2 CM]	3' [91.44 CM]	4'-4 7/8" [134.3 CM]	2' [60.96 CM]	2'-9 1/4" [84.46 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
18" [45.72 CM]	4'-9" [144.8 CM]	3'-2" [96.52 CM]	4'-7 7/8" [141.9 CM]	2'-6" [76.2 CM]	3'-4 3/8" [102.6 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
24" [60.96 CM]	5' [152.4 CM]	3'-4" [101.6 CM]	4'-10 7/8" [149.5 CM]	3' [91.44 CM]	3'-11 1/2" [120.7 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
36" [91.44 CM]	5'-6" [167.6 CM]	3'-8" [111.8 CM]	5'-4 3/4" [164.5 CM]	4' [121.9 CM]	5'-1 7/8" [157.2 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
48" [121.9 CM]	6' [182.9 CM]	4' [121.9 CM]	5'-10 5/8" [179.4 CM]	5' [152.4 CM]	6'-4 1/4" [193.7 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
60" [22.86 CM]	6'-6" [198.1 CM]	4'-4" [132.1 CM]	6'-4 1/2" [194.3 CM]	6' [182.9 CM]	7'-6 5/8" [230.2 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
72" [182.9 CM]	7' [213.4 CM]	4'-8" [142.2 CM]	6'-10 3/8" [209.2 CM]	7' [213.4 CM]	8'-9" [266.7 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
84" [213.4 CM]	7'-6" [228.6 CM]	5' [152.4 CM]	7'-4 1/4" [224.2 CM]	8' [243.8 CM]	9'-11 3/8" [303.2 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
96" [243.8 CM]	8' [243.8 CM]	5'-4" [162.6 CM]	7'-10 1/8" [239.1 CM]	9' [274.3 CM]	11'-1 3/4" [339.7 CM]	3' [91.44 CM]	2' [60.96 CM]	3' [91.44 CM]	3" [7.62 CM]	9" [22.86 CM]	2" [5.08 CM]	3" [7.62 CM]
120" [304.8 CM]	14'-3 21/64" [435.2 CM]	6' [182.9 CM]	14' [426.7 CM]	12' [365.8 CM]	15'-7 1/4" [475.6 CM]	4' [121.9 CM]	3' [91.44 CM]	6' [182.9 CM]	6" [15.24 CM]	1'-1 1/2" [34.29 CM]	1' [30.48 CM]	9" [22.86 CM]
144" [365.8 CM]	16'-3 51/64" [497.3 CM]	6'-8" [203.2 CM]	16' [487.7 CM]	14'-8" [447.0 CM]	18'-4 3/4" [560.7 CM]	5' [152.4 CM]	3' [91.44 CM]	8' [243.8 CM]	6" [15.24 CM]	1'-1 1/2" [34.29 CM]	1' [30.48 CM]	9" [22.86 CM]

Figure 1 – Parshall Flume Master Dimensions

POINTS OF MEASUREMENT

The primary, free-flow, point of measurement, Ha, is located in the converging section of the flume at the location indicated in Figure 1. For all but the largest Parshall flumes this location is 2/3 length of the converging section wall "A" *upstream* of the throat. For large Parshall flumes, Ha is located closer to the throat.

The secondary point of measurement, Hb, used to determine the submergence of a Parshall flume is located in the throat of the flume, close the junction of the throat and the discharge section. The

Note that although the intake point for stilling wells measuring Hb is below the floor of the converging section, the zero elevation for both Ha and Hb is the converging floor level.

FLOW EQUATIONS

For free-flow conditions, the level-to-flow equation for the Parshall flume can be expressed as:

$$Q = KH_a^{\,n}$$

Q = free flow rate (cfs / m3/s)
K = flume discharge constant (varies by flume size / units)
H_a = depth at the point of measurement (feet / meters)
n = discharge exponent (depends upon flume size)

Equation 1 – Parshall Flume Free-Flow Equation

Throat Width	K (cfs)	K (m3/s)	N
1-inch	0.338	0.0479	1.55
2-inches	0.676	0.0959	1.55
3-inches	0.992	0.141	1.55
6-inches	2.06	0.264	1.58
9-inches	3.07	0.393	1.53
1-foot	4	0.624	1.522
1.5-feet	6	0.887	1.538
2-feet	8	1.135	1.55
3-feet	12	1.612	1.566
4-feet	16	2.062	1.578
5-feet	20	2.5	1.587
6-feet	24	2.919	1.595
7-feet	28	3.337	1.601
8-feet	32	3.736	1.607
10-feet	39.28	4.709	1.6
12-feet	46.75	5.590	1.6
15-feet	57.81	6.912	1.6
20-feet	76.25	9.117	1.6
25-feet	94.69	11.32	1.6
30-feet	113.13	13.53	1.6
40-feet	150	17.94	1.6
50-feet	186.88	22.35	1.6

Table 1 – Parshall Flume Free-Flow Discharge Values

SUBMERGED FLOW

As a Parshall flume becomes submerged – where downstream conditions reduce the flow out of the flume – corrections must be made to the flow equation.

In order to determine when these corrections should be made (and the degree to which the flume is submerged), the submergence ratio must be calculated.

The submergence ratio is the ratio of the downstream depth at the secondary point of measurement, Hb, to the depth at the primary point of measurement, Ha.

$$S = \frac{H_b}{H_a}$$

Equation 2 – Submergence Ratio Equation

SUBMERGENCE TRANSITION

The transition from free, unrestricted flow to submerged to one of backwater / slowed velocity discharge is known as the submergence transition (St). For Parshall flumes, as the flume gets large, so does the submergence transition.

1 to 3-inch	50%
6-inches	60%
1 to 8-foot	70%
10 to 50-foot	80%

Table 2 – Submergence Transitions (St) Values for Parshall Flumes

Above the submergence transitions for a given flume's size, the flow must be corrected for the effects of submergence.

WHERE TO INSTALL A PARSHALL FLUME

When selecting a site in which to install a Parshall flume, there are several points to consider:

UPSTREAM OF THE FLUME

- *Flow entering the Parshall flume MUST be sub-critical.*
- *The Froude number (Fr) for flow entering a flume should not exceed 0.5 and should never exceed 0.99.*
    - *Surface turbulence may be encountered for Froude numbers above 0.5.*
    - *For a flume to accurately measure flow, that flow must be sub-critical (Fr<0.99).*
- *If the approaching flow is critical (Fr = 1.0) or supercritical (Fr > 1.0), then a hydraulic jump must be formed at least 30 times the maximum anticipated head upstream of the entrance to the flume.*
- *The flow entering the flume should be smooth, tranquil, and well distributed across the channel.*
- *If the flow is super-critical approaching the flume a hydraulic jump must be formed well upstream of the flume or upstream energy absorbers and tranquilizing racks must be used).*
- *Should a hydraulic jump need to be formed to slow the flow, it should be forced to occur at least 30 Ha upstream of the flume.*
- *The approaching channel should be straight so that the velocity profile is uniform. Surging, turbulent, or unbalanced flows must be conditioned before the flow enters the flume.*
- *Any bends, dips, elbows, or flow junctions upstream of the flume must be sufficiently far upstream so that the flow has is well distributed and non-turbulent.*
- *EPA recommendations for upstream channel runs are conservatively the same as for long throated flume – 25 throat widths. While ASTM D1941 indicates that 10 to 20 times the throat with usually will meet the necessary inlet conditions.*
- *While corrections can be made for improper installations or flume settlement, they should be avoided where at all possible.*
- *Parshall flumes have been successfully used in applications where the flow rises up a uniform vertical column and then enters the flume.*

- *Where the channel is wider than the inlet of the Parshall flume, wing walls should be formed to smoothly direct the flow into the flume. The inlet wing walls should be of a constant radius and should end tangent to the inlet walls of the flume.*
- *When connecting to inlet piping, observations have shown that the pipe should be straight and without bends for at least 15 pipe diameters.*
- *The upstream channel should be clear of vegetative growth.*
- *Open channel (non-full pipe) flow must be present under all flow conditions.*

FLUME LOCATION

- *The flume must be able to be set so that the flat converging section is level from front-to-back and from side-to-side.*
- *When Parshall flumes are installed in earthen channels and furrows, care should be taken to ensure that a stable bottom elevation is present and that the elevation does not change during dry / wet seasons or low-flow periods.*
- *The flume must be centered in the flow stream.*
- *Where a Parshall flume must be set above the floor of a channel, a 1:4 (rise:run) slope should be formed into the flume. Slopes greater than this should be avoided as they can cause turbulence as the flow separates at the junction of the ramp and the inlet of the flume.*
- *All of the flow must go through the flume – there should be no bypass.*

DOWNSTREAM OF THE FLUME

- *For a Parshall flume to operate under free-flow conditions, the downstream channel must be of a sufficient size / configuration so that flow does not back up into the flume – slowing discharge out of the flume.*
- *When flow out of the Parshall flume is returning to a channel or pipe, the EPA recommends that the channel be straight and unobstructed for 5-20 throat widths – although flow spilling freely off the end of the flume can eliminate this requirement.*
- *To transition the flow out of a Parshall flume, wing walls should be used. These walls can be flat or perpendicular to the flume (to save space or money) or they can extend from the flume's discharge at some angle or radius sufficient to transition the flow as desired. Transitions to earthen or natural channels should be as gradual as practical to minimize downstream scour.*

- *The downstream channel should be armored (riprap) or otherwise protected so that scour does not occur.*
- *The downstream channel must be clear of vegetative growth or the collection of debris so that flow does not back up in to the flume.*

HOW TO INSTALL A PARSHALL FLUME

Once a site has been selected, the flume must then be installed correctly:

- *The flume should be set so that it is centered in the flow stream.*
- *The upstream floor of the flume should be set high enough so that the flume does not operate under submerged flow conditions.*
- *The outlet of the flume should be set at or above (ideally) the invert of the outlet channel / pipe to help transition solids out of the flume.*
- *The flat floor of the converging section must be set upstream.*
- *The flat floor must be level from front-to-back and from side-to-side (using a level on the floor - not the top - of the flume)*
- *The flume must be braced internally (plywood and lumber are typically used) during installation to ensure that distortion does not occur.*
- *The flume must not float out of its intended final position during installation.*

BRACING THE FLUME

Most Parshall flumes ship with dimensional bracing (angle or tube) at the top of the flume. The bracing should be left on the flume until the installation has been completed.

If the flume is set in concrete, the bracing may be removed once the installation has been completed.

For installations where the flume is free-standing or otherwise not set in concrete, the bracing should be left in place.

If the bracing is removed, verify the dimensional accuracy of the flume after the removal.

CONNECTION JOINTS

Parshall flumes supplied with bulkheads, or transition sections must remain sealed between the joints.

While these joints may be sealed initially at the factory, a final visual inspection of all joints should be done before installation. Where required, apply one or two continuous beads of silicone on all seating surfaces before proceeding with the installation.

HOW TO MAINTAIN A PARSHALL FLUME

For a Parshall flume to accurately measure flow, it must be periodically inspected and maintained. This inspection should be done six (6) months after installation and each following year.

The inspection should include the channel in which the flume is installed, the flow entering / exiting the flume, and the flume itself.

CHANNEL INSPECTION

- The upstream channel banks should be clear of vegetation or debris that could affect the flow profile entering the flume (upstream) or restrict flow out of the flume (downstream).
- Inspect the upstream channel to make sure that flow is not bypassing the flume.
- Inspect the downstream channel to make sure that scouring is not occurring.
- Any hydraulic jump should be at least 30 times the maximum head (Hmax) upstream of the flume.

FLOW INSPECTION

- *Flow entering the flume should be tranquil and well distributed.*
- *Turbulence, poor velocity profile, or surging should not be present.*
- *The Froude (Fr) number should, ideally, be 0.5.*
- *As the Froude number increases so does surface turbulence.*
- *Flumes accelerate sub-critical flow (Fr < 1) to a supercritical state (Fr 1>) .*
- *Flumes experiencing flows greater than unit (Fr = 1) will not accurately measure flow.*

FLUME INSPECTION

- *Flumes must be level from front-to-back and from side-to-side.*
- *Earthen installations are particularly susceptible to settling due to wet / dry and freeze / thaw cycles.*
- *Flow surfaces are to be kept clean of surface buildup or algal growth. Scrubbing or a mild detergent can be used.*
- *Galvanized flumes should be checked for corrosion.*
- *Any corrosion should be removed and then cold galvanization applied to the area.*