OPENCHANNELFLOW

CUTTHROAT FLUME

USER'S MANUAL

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INTRODUCTION TO THE CUTTHROAT FLUME

In the 1960's researchers at the Utah Water Research Laboratory at Utah State University began investigations into what would become the Cutthroat flume. The goal of the researchers was to develop a flume that overcame the limitations of the Parshall flume in flat gradient applications.

Although originally developed to measure irrigation flow, Cutthroat flumes are now used to for:

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

In addition to these flow measurement applications, Cutthroat flume are frequently used in wastewater treatment plants for proportional flow splitting.

DEVELOPMENT

Prior to the development of the Cutthroat flume, flow on flat gradients presented a problem. The drop though the Parshall flume mean that the flume had to either be elevated above the floor of the channel – creating upstream ponding and overtopping issues – or using that the flume had to be used in a submerged manner (creating measurement and accuracy issues).

Funded by the U.S. Department of the Interior, Office of Water Resources Research, Drs. Skogerboe, Hyatt, Anderson, and Eggleston at the Utah Water Research Laboratory extensively researched issues related to the problem:

» Flow conditions in flat-bodied Trapezoidal flumes (Robinson et al 1960), (Hyatt 1965)

» Inlet convergence ratios (Ackers and Harrison 1963)

» Submerged flow in open channel flow measurement structures (Skogerboe, Hyatt, Eggleston 1967)

» Flume discharge in flat-bodied Trapezoidal flumes (Hyatt 1965)

Ultimately this research lead to the development of two different styles of Cutthroat flumes: Rectangular (with flat, vertical sidewalls like a Parshall flume) and Trapezoidal (with outward sloping sidewalls like a Trapezoidal flume). Of the two, the Rectangular Cutthroat flume is most commonly used.

Rectangular Cutthroat flumes are available in four different lengths (18, 36, 54, and 108-inches L) and four throat widths for each length. Trapezoidal Cutthroat flumes come in three different throat widths.

Rectangular Cutthroat flumes have a distinct advantage over similar flumes in that, for a given length, intermediate throat widths can be developed without the need to laboratory or field rate the new flume size.

Trapezoidal Cutthroat flumes have one given length and three different throat widths (V, 6-inch, and 12-inch).

For the purposes of this User's Manual, the discussion below will be for Rectangular Cutthroat flumes unless otherwise indicated.

FUNCTION

Sub-critical flumes like the Cutthroat 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 Cutthroat flume accomplishes this restriction by contracting the side walls of the – while keeping a constant floor elevation.

DESIGN

When viewed from above, the Cutthroat flume has an hourglass shape. As flow enters the flume it is accelerated in the short, uniformly converging (inlet) section. Upon reaching the throat – the narrowest portion of the flume – the flow immediately expands into the diverging (outlet) section. Unlike many other flumes, the Cutthroat flume lacks an extended throat – hence the name “Cutthroat”.

The converging (inlet) section of a Cutthroat flume is 1/3 the length of the flume, with the flat sidewalls contracting at a uniform 3:1 ratio.

The diverging (outlet) section of a Cutthroat flume is 2/3 the length of the flume, with the flat sidewalls expanding at a uniform 6:1 ratio.

The floor of a Cutthroat flume is flat from inlet to outlet, making the flume well suited for low gradient installations.

This layout is the same for both Rectangular and Trapezoidal Cutthroat flumes.

STANDARDS

Like the Trapezoidal flume, the dimensions for the Cutthroat flume are not subject to a

national standard, but are instead presented in various academic journals.

» Skogerboe, G., Bennett, R., Walker, W., Generalized Discharge Relations for Cutthroat Flumes, Journal of the Irrigation and Drainage Division, Vol. 98, No. IR4, December 1972

» Bennett, R., Cutthroat Flume Discharge Relations, Water Management Technical Paper No. 16, Colorado State University, AER71-72RSB6, March 1972

ACCURACY

The Cutthroat flume was developed to provide accurate flow measurement with a precision of +/-3% under free-flow conditions.

This accuracy is to be expected when the ratio of flow depth (at the point of measurement) to flume length.

For greatest accuracy, the ratio of flow depth to flume length should be 0.1 and 0.4. Above 0.4 and higher approach velocities and rapid changes in the water surface introduce inaccuracies.

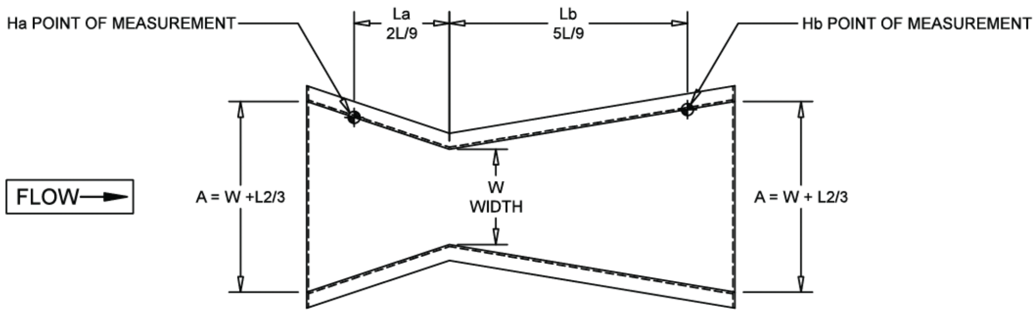
DIMENSIONS

The master dimensions for Rectangular Cutthroat flumes are found in Figure 1.

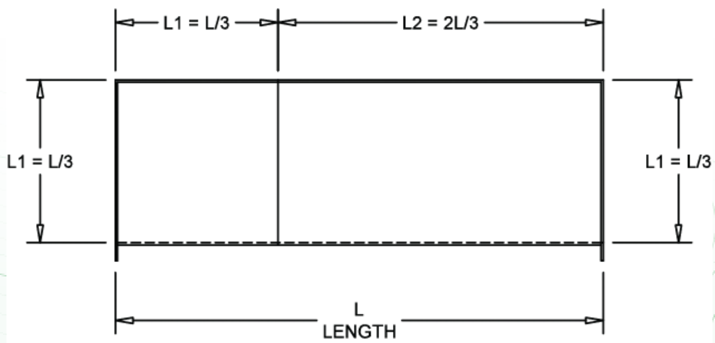
DIMENSIONAL TOLERANCES

In general, the dimensions of a Cutthroat flume must be within +/-2% of nominal.

Wider than that and the equation for the actual dimensions should be developed *(assuming the deviations are constant and the throat width is between two standard sizes).*



PLAN VIEW



ELEVATION VIEW

L (LENGTH)	W (WIDTH)	A	La	Lb	L1	L2
18" [45.72 CM]	1" [2.54 CM]	5" [12.7 CM]	4" [10.16 CM]	10" [25.4 CM]	6" [15.24 CM]	1' [30.48 CM]
	2" [5.08 CM]	6" [15.24 CM]	4" [10.16 CM]	10" [25.4 CM]	6" [15.24 CM]	1' [30.48 CM]
	4" [10.16 CM]	8" [20.32 CM]	4" [10.16 CM]	10" [25.4 CM]	6" [15.24 CM]	1' [30.48 CM]
	8" [20.32 CM]	1" [30.48 CM]	4" [10.16 CM]	10" [25.4 CM]	6" [15.24 CM]	1' [30.48 CM]
36" [91.44 CM]	2" [5.08 CM]	10" [25.4 CM]	8" [20.32 CM]	1'-8" [50.8 CM]	1' [30.48 CM]	2' [60.96 CM]
	4" [10.16 CM]	1' [30.48 CM]	8" [20.32 CM]	1'-8" [50.8 CM]	1' [30.48 CM]	2' [60.96 CM]
	8" [20.32 CM]	1'-4" [40.64 CM]	8" [20.32 CM]	1'-8" [50.8 CM]	1' [30.48 CM]	2' [60.96 CM]
	1'-4" [40.64 CM]	2' [60.96 CM]	8" [20.32 CM]	1'-8" [50.8 CM]	1' [30.48 CM]	2' [60.96 CM]
54" [137.2 CM]	3" [7.62 CM]	1'-3" [38.1 CM]	1' [30.48 CM]	2'-6" [76.2 CM]	1'-6" [45.72 CM]	3' [91.44 CM]
	6' [15.24 CM]	1'-6" [45.72 CM]	1' [30.48 CM]	2'-6" [76.2 CM]	1'-6" [45.72 CM]	3' [91.44 CM]
	1' [30.48 CM]	2' [60.96 CM]	1' [30.48 CM]	2'-6" [76.2 CM]	1'-6" [45.72 CM]	3' [91.44 CM]
	2' [60.96 CM]	3' [91.44 CM]	1' [30.48 CM]	2'-6" [76.2 CM]	1'-6" [45.72 CM]	3' [91.44 CM]
108" [274.3 CM]	1' [30.48 CM]	3' [91.44 CM]	2' [60.96 CM]	5' [152.4 CM]	3' [91.44 CM]	6' [182.9 CM]
	2' [60.96 CM]	4' [121.9 CM]	2' [60.96 CM]	5' [152.4 CM]	3' [91.44 CM]	6' [182.9 CM]
	4' [121.9 CM]	6' [182.9 CM]	2' [60.96 CM]	5' [152.4 CM]	3' [91.44 CM]	6' [182.9 CM]
	6' [182.9 CM]	8' [243.8 CM]	2' [60.96 CM]	5' [152.4 CM]	3' [91.44 CM]	6' [182.9 CM]

Figure 1 – Rectangular Cutthroat Flume Master Dimensions

POINTS OF MEASUREMENT

The primary, free-flow, point of measurement, Ha, is located in the converging section of the flume a distance of 2L/9 upstream of the throat (L = flume length).

The secondary point of measurement, Hb, used to determine the submergence of a Cutthroat flume is located in near the outlet of the flume, 5L/9 downstream of the throat.

As the floor of the Cutthroat flume is flat, there is no need to adjust the Hb elevation when calculating the submergence ratio.

FLOW EQUATIONS

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

$$Q = KW^{1.025} H_a^{\,n} = CH_a^{\,n}$$

Q = free flow rate (cfs / m3/s)

K = flume discharge constant (varies by flume size / units)

C = flume discharge constant (varies by flume length / throat width / units)

W = throat wodth

H_a = depth at the point of measurement (feet / meters)

n = discharge exponent (depends upon flume size)

Equation 1 – Cutthroat Flume Free-Flow Equation

A unique advantage of the Cutthroat flume over other short-throated flumes is the ability to develop flow equations for intermediate throat widths. So long as the flume is of a standard length and converges / diverges as the stand ratios, the rating can be developed without the need for laboratory investigation.

SIZE	C (CFS)	C (M3/s)	N
18-inch x 1-inch	0.494	1479.9	2.15
18-inch x 2-inch	0.947	344.8	2.15
18-inch x 4-inch	1.9975	719.2	2.15
18-inch x 8-inch	4.030	1,467	2.15
36-inch x 2-inch	0.719	181.2	1.84
36-inch x 4-inch	1.459	367.6	1.84
36-inch x 8-inc	2.970	748.3	1.84
36-inch x 16-inch	6.040	1,522	1.84
54-inch x 3-inch	0.96	209.7	1.72
54-inch x 6-inch	1.96	428.2	1.72
54-inch x 12-inch	3.980	869.5	1.72
54-inch x 24-inch	8.01	1,750	1.72
108-inch x 12-inch	3.50	632.2	1.56
108-inch x 24-inch	7.11	1,284	1.56
108-inch x 48-inch	14.49	2,618	1.56
108-inch x 72-inch	22.0	3.974	1.56

Table 1 – Rectangular Cutthroat Flume Free-Flow Discharge Values

SUBMERGED FLOW

As a Cutthroat 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 Cutthroat flumes, as the flume gets large, so does the submergence transition.

18-inchs L	60%
36-inchs L	65%
54-inchs L	70%
108-inchs L	80%

Table 2 – Submergence Transitions (St) Values for Rectangular Cutthroat Flumes

WHERE TO INSTALL A CUTTHROAT FLUME

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

UPSTREAM OF THE FLUME

» Flow entering the Cutthroat 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.

  • ASTM D1941 indicates that 10 to 20 times the throat width will usually meet the necessary inlet conditions.

» 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).

» 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 nonturbulent.

» While corrections can be made for improper installations or flume settlement, they should be avoided where at all possible.

» Cutthroat 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 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

- Cutthroat flumes must set so that the floor of the flume is level from front-to-back and from side-to-side.
- The shorter converging section of the flume is set upstream.
- When Cutthroat 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 Cutthroat 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 Cutthroat 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 Cutthroat 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 CUTTHROAT 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 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 point of measurement must be set upstream.
- The floor of the flume 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.

DIMENSIONAL BRACING

Most Cutthroat 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

Cutthroat 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 THE CUTTHROAT FLUME

For a Cutthroat 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

- 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.

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