HYDRAULIC JUMP AND WEIR FLOW

Condition for formation of hydraulic jump

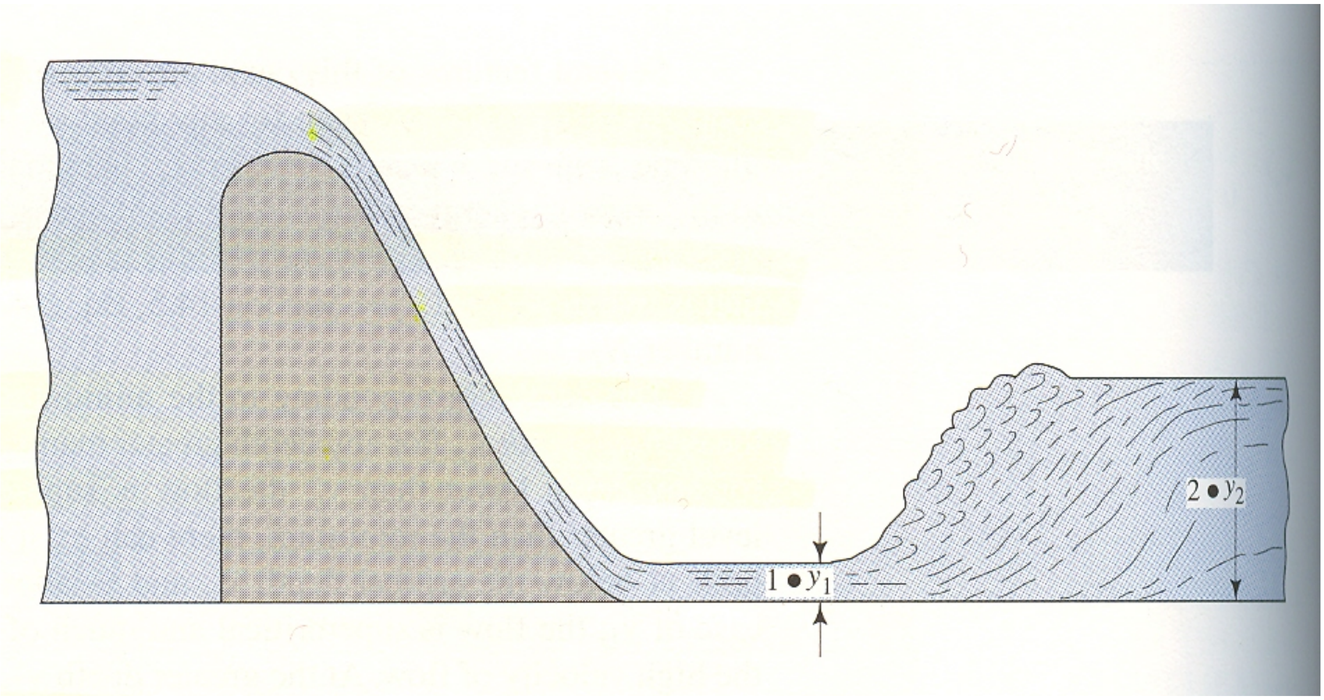
- When depth of ***flow is forced to change from a supercritical depth to a subcritical depth***

- Or Froude number decreases from greater than 1.0 to less than 1.0.

- Jump will not occur when Froude number is less than 1.0

- Jump does not occur from subcritical to supercritical flow – only vice versa.

Figure 14.3



y1 – supercritical flow
y2 – subcritical flow

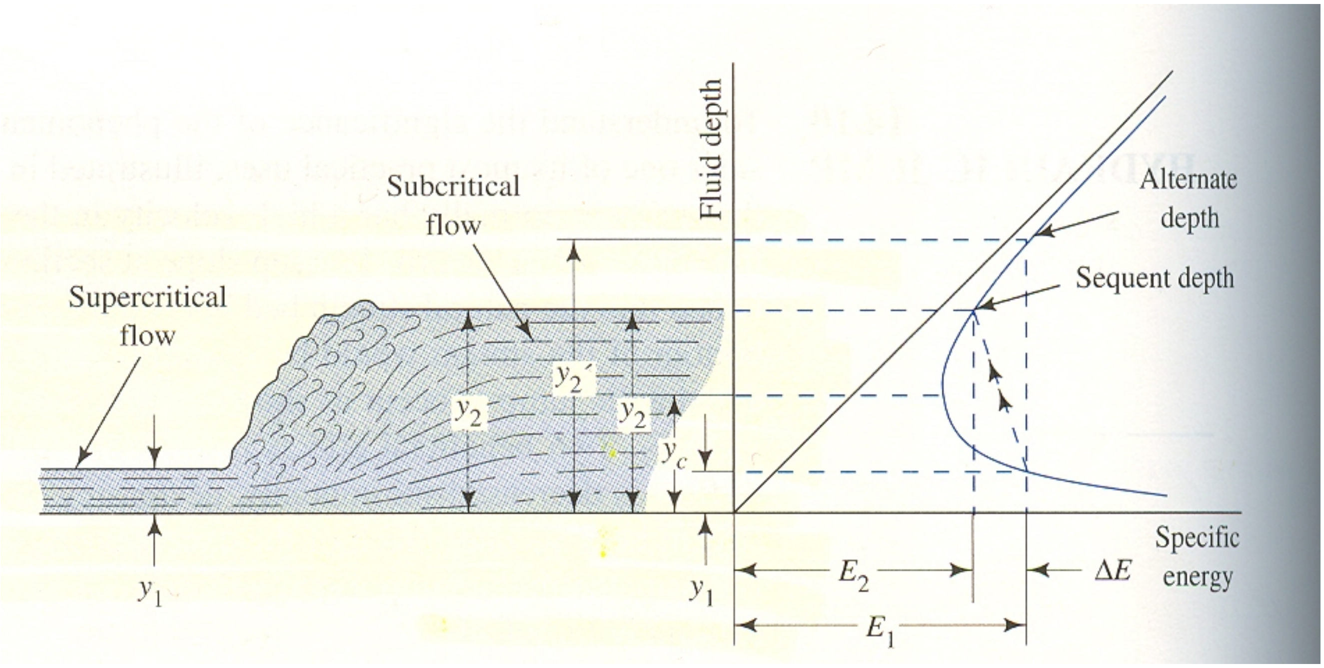
$$y_2 = (y_1 / 2)(\sqrt{1 + 8N_{F1}^2} - 1)$$

Where N_{F1} is the Froude number at section 1.

Note – subcritical depth y_2 only depends on y_1 and the Froude number.

Figure 14.4

Specific Energy conditions in the Hydraulic jump –



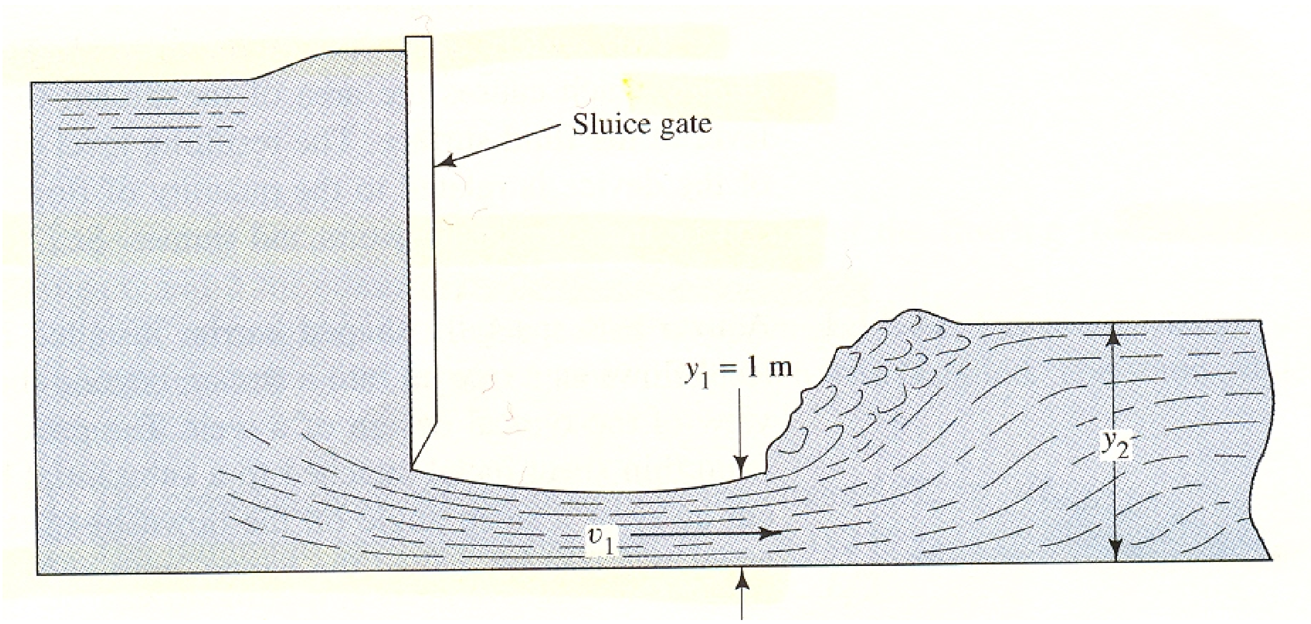
Loss of energy

$$E_1 - E_2 = (y_2 - y_1)^3 / 4y_1y_2$$

Theoretical depth after jump – **alternate depth**

Actual depth after jump – **sequent depth**

Length of jump – varies – but about 7 times the subcritical depth.



Problem 14.6

$Q = 18m^3/s$

Rectangular channel = 3m wide

Channel – unfinished form concrete
Hydraulic jump occurs where the depth is **1m = y1.**

Determine –

- Velocity before jump
- Depth after jump
- Velocity after jump
- Energy dissipated in the jump

Solution –

$y_1 = 1m$
$A_1 = 3 * 1 = 3m^2$

$\mathbf{V_1} = 18/3 = 6m/s$

$$N_F = \frac{v}{\sqrt{g y_h}}$$

$y_h = A/T$

For rectangular channel, $y_h = y$

Therefore **Nf = 1.92 > 1.0 (supercritical flow)**

Find y2 using the equation –

$$y_2 = (y_1 / 2)(\sqrt{1 + 8N_{F1}^2} - 1)$$

$\underline{\mathbf{y_2} = 2.26\ m}$

$\mathbf{v_2} = Q/A_2 = 18/(3*2.26) = 2.65\ m/s$

loss of energy is computed using –

$$E_1 - E_2 = (y_2 - y_1)^3 / 4y_1y_2$$

E1 – E2 = 0.22 m

Practical applications of hydraulic jumps:

- Dissipation of energy of water flowing over dams and weirs – to prevent possible erosion and scouring due to high velocities

- Raising water levels in canals to enhance irrigation practices and reduce pumping heads

- Reducing uplift pressure under the foundations of hydraulic structures

- Creating special flow conditions to meet certain special needs at control sections – gaging stations, flow measurement, flow regulation

You could also use it for thrills!!! (not recommended)

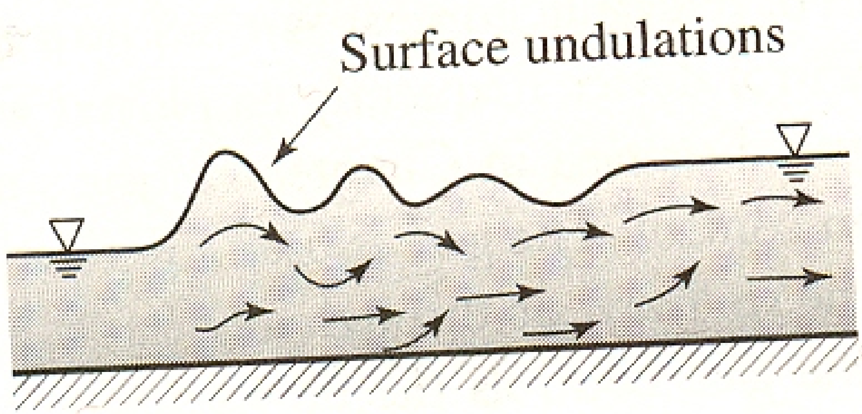
Types of hydraulic jumps

Classified based on **flow form, approach Froude number, and energy loss**.

$$N_F = \frac{v}{\sqrt{g y_h}}$$

(a) Undular jump (1 < Fn1<1.7)

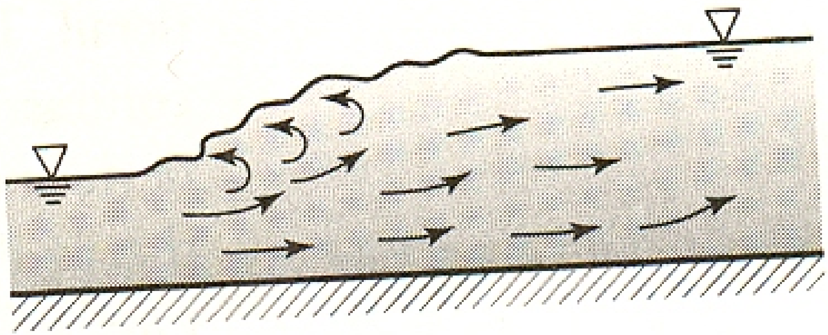
- Slight undulation
- Two conjugate depths are close
- Transition is not abrupt – slightly ruffled water surface



(a)

(b) Weak jump (1.7<Fn1<2.5)

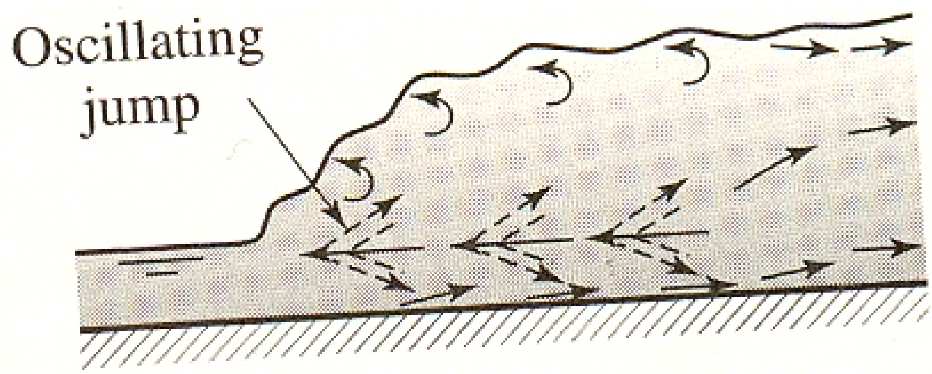
- Eddies and rollers are formed on the surface
- Energy loss is small
- The ratio of final depth to initial depth ~ between 2.0 and 3.1.



(b)

(c) Oscillating jump (2.5 <Fn1<4.5)

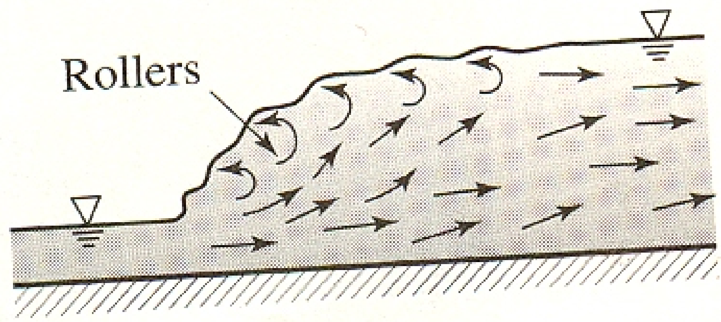
- Jet oscillates from top to bottom – generates surface waves that persist beyond the end of the jump
- Ratio final depth to initial depth ~ between 3.1 to 5.0
- To prevent destructive effects this type of jump should be avoided



(c)

(d)_Stable jump (4.5<Fn1<9)

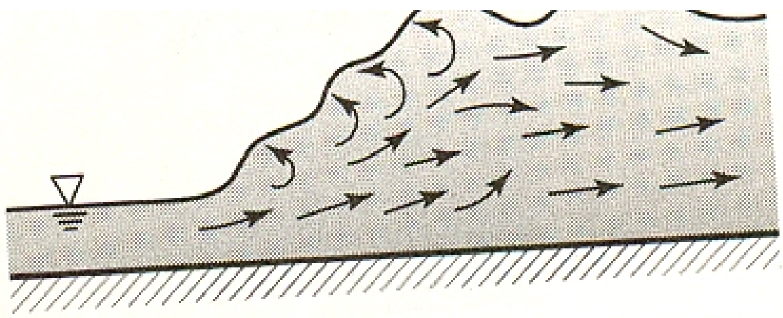
- Many advantages
- Position of jump fixed regardless of downstream conditions
- Good dissipation of energy
- Considerable rise in downstream water level
- Ratio of final to initial depth ~ between 5.9 and 12.0



(d)

(e) Strong or rough jump (Fn1 > 9)

- Jump becomes increasingly rough
- Fn1 should not be allowed to exceed 12 – otherwise required stilling basins will be large and massive
- Ability of jump to dissipate energy is massive
- Ratio of final to initial depth ~ over 12 and may exceed 20.



(e)

Uncontrolled Hydraulic jump – erosion !

http://www.rollanet.org/~conorw/cwome/article6&7.htm

- Taum Sauk reservoir on Proffit Mountain, Missouri.
- 80 feet dike
- 1.5 billion gallons (4,600 acre-feet) of water
- Water overtopped the dike

In 12 minutes after failure, 1.5 billion gallons of water roared down an un-named tributary of the East Fork and straight towards the upstream portion of Johnson's Shut-ins State Park.

Although the peak flow of the flood isn't known and may or may not be uncovered by the official investigation, the average flow was 280,000 cubic feet per second, larger than the average flow of the Mississippi River just upstream from its confluence with the Ohio River! The peak flow was likely larger.

The flow released during the failure stripped the upper slopes of Proffit Mountain down to bare bedrock. This picture shows the ~600 foot wide break, stripped area of Proffit Mountain, and the upper portions of the lower scour zone.

A large scour hole was formed by the hydraulic jump marking the transition between the upper steep portion and the lower, more gradual slopes of Proffit Mountain.

The hole is at least 20 feet deep and was likely much larger before the diminishing flows near the end of the flood filled much of it with debris.

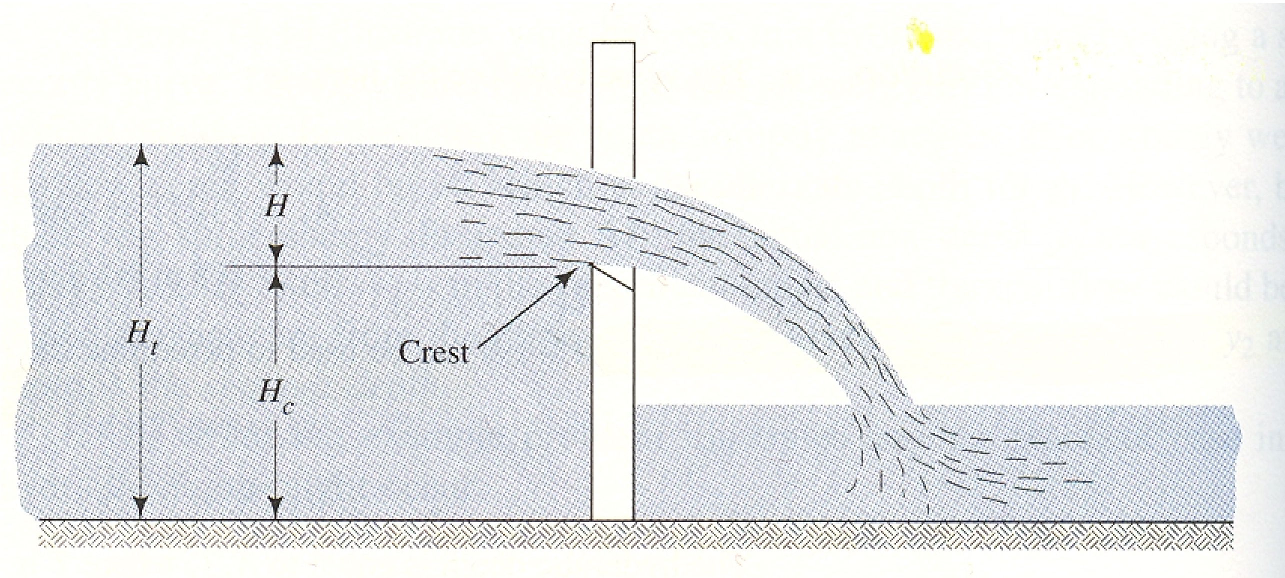
Weirs & Flumes

Devices that can be used to measure open channel flow

V notch weir in streamflow

Geometry of the section is used to measure the flow

Weirs –



- Sharp crested edge
- Water should flow over as a free jet (***nappe***) – aeration below the ***nappe***
- Water depth above the edge (H) should be measured at 4H from edge
- Various types of weirs

Rectangular weir –

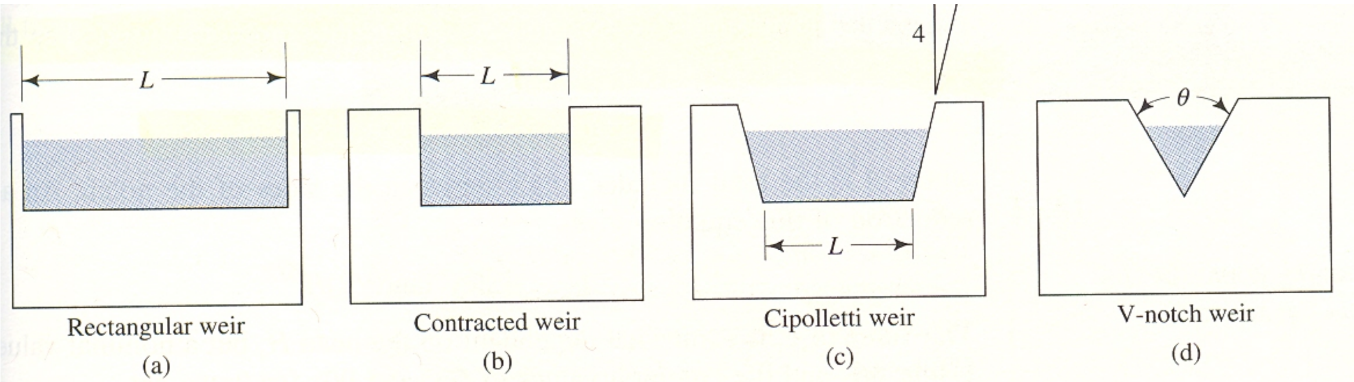


FIGURE 14.17 Notch geometry for weirs.

- Also called suppressed weir
- Crest length L
- Crest height above the bottom of channel $H_c \geq 3H_{max}$
- Minimum head above crest > 0.2 ft
- Max head above crest < L/3

$$Q = 3.33\,LH^{3/2}$$

Where Q ft^3/s and H is in ft.

Contracted weir –

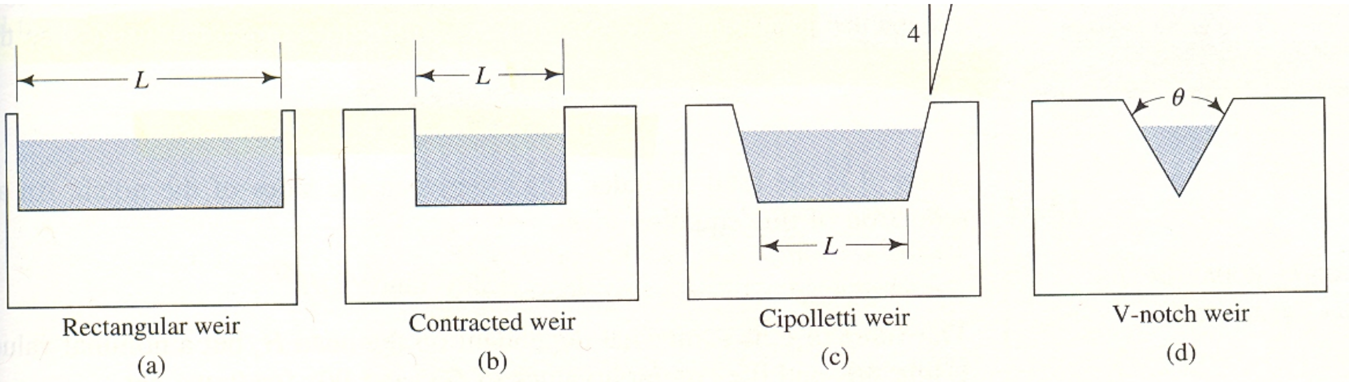


FIGURE 14.17 Notch geometry for weirs.

- Similar to rectangular but with sides extended inwards by at least $2H_{max}$
- Fluid contracts as it flows over the weir
- Crest height above the bottom of channel $H_c \geq 2H_{max}$
- Minimum head above crest > 0.2 ft
- Max head above crest < L/3

$$Q = 3.33(L - 0.2H)H^{3/2}$$

English units (ft).

Cipolletti weir –

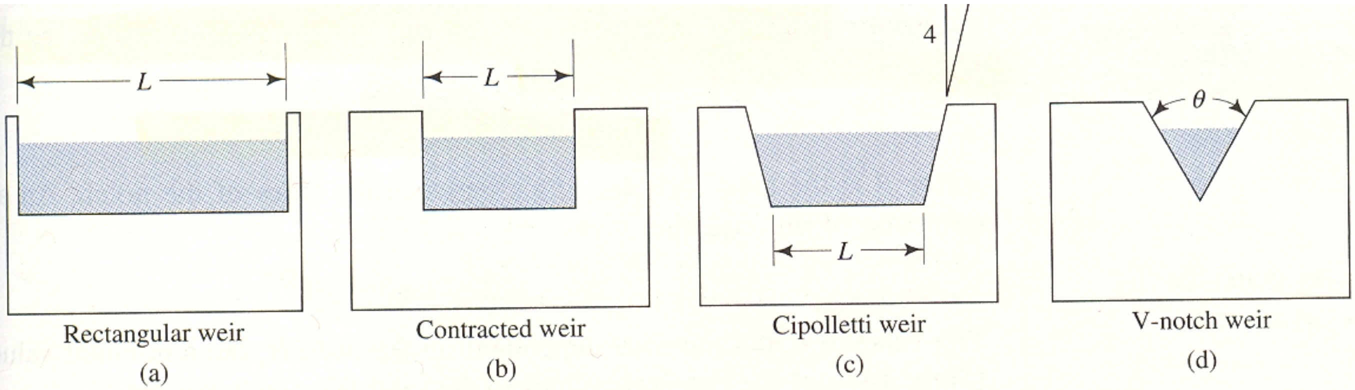


FIGURE 14.17 Notch geometry for weirs.

Similar to contracted rectangular weir but with sides sloped outwards.

$$Q = 3.367\, LH^{3/2}$$

<u>Triangular weir</u> –

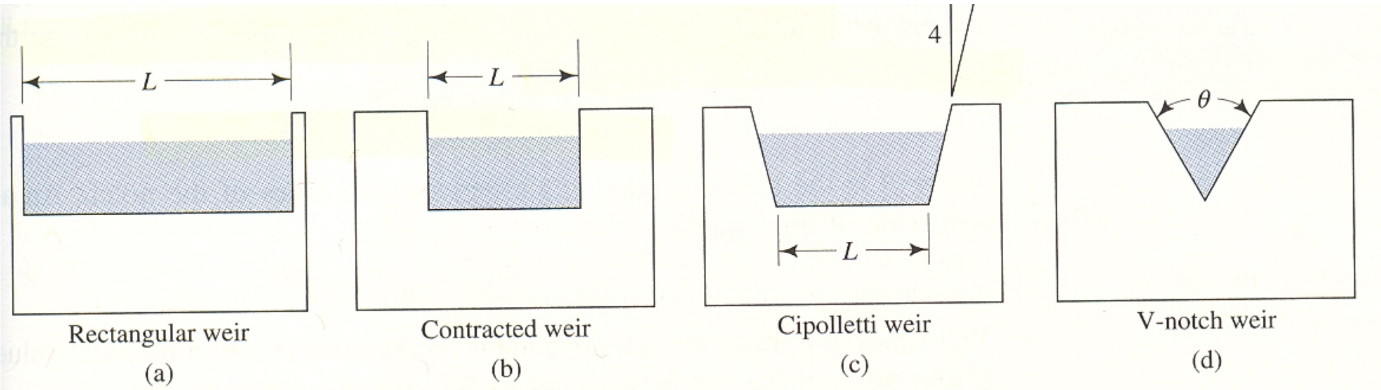


FIGURE 14.17 Notch geometry for weirs.

- Especially used for low flow rates – since a higher head can be generated compared to rectangular weirs
- Angle of the weir affects the discharge equations
- Angles – 35 to 120 degrees
- Typical angles used – 60 and 90 degrees

Generic equation for an angle –

$$Q = 4.28C\tan(\theta/2)H^{5/2}$$

C ~ 0.58.

Specific equation for 60 degree notch –

$$Q = 1.43H^{5/2}$$

Equation for 90 degree notch –

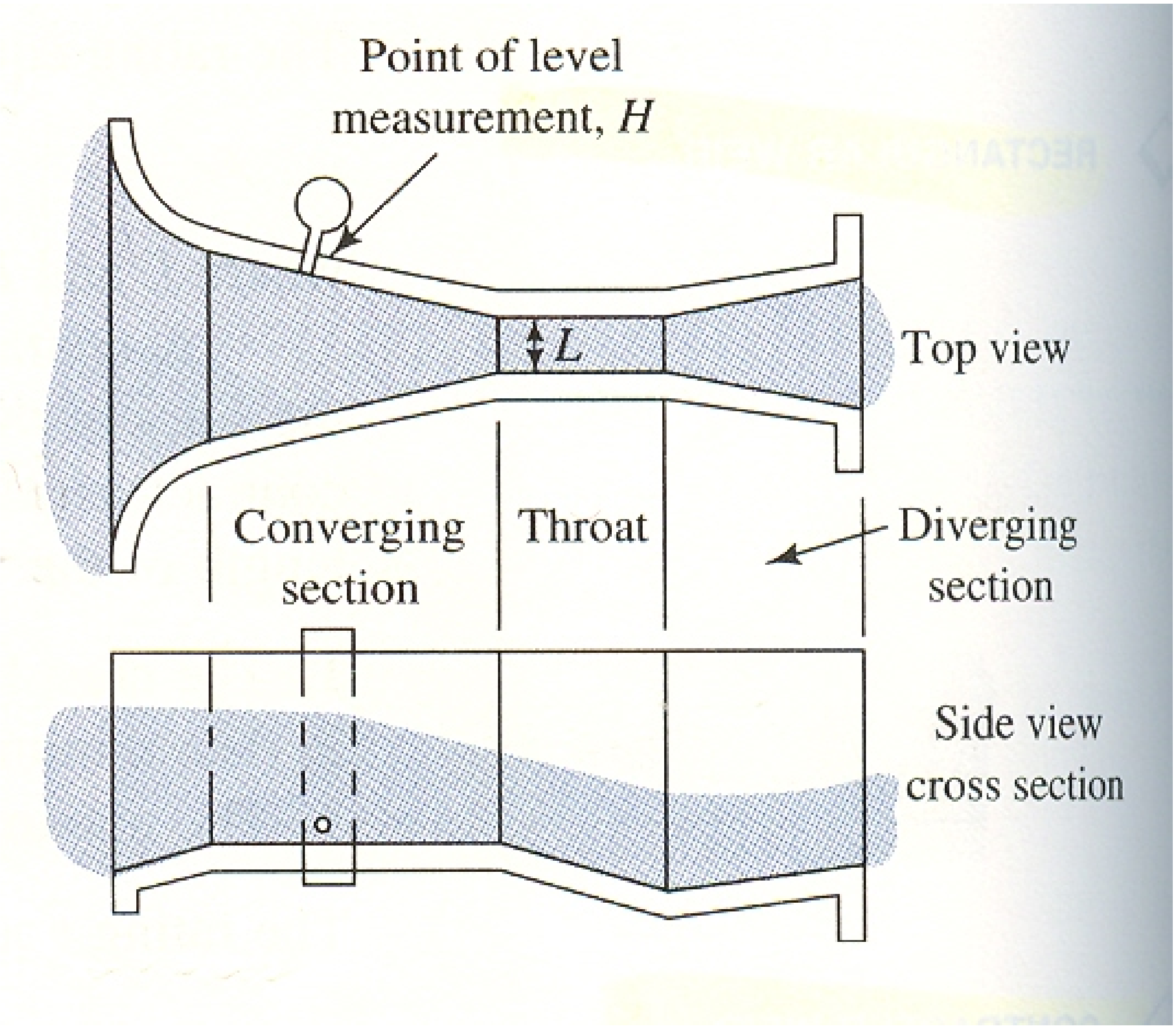
$$Q = 2.48H^{5/2}$$

Flumes –

- Designed so that flow achieves **critical depth** within the structure
- Definite relationship between depth and discharge at critical flow
- Various types of flumes have been created with specific equations for each

Parshall flume -

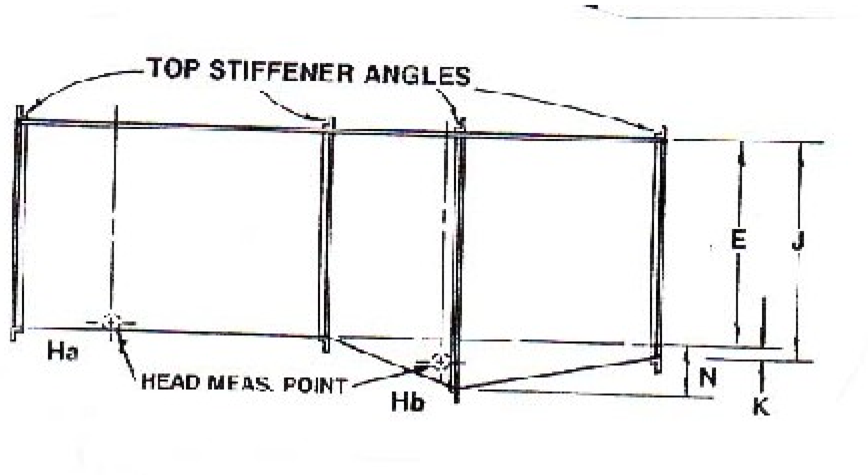
You size the flume based on throat width (6 inches in this case)

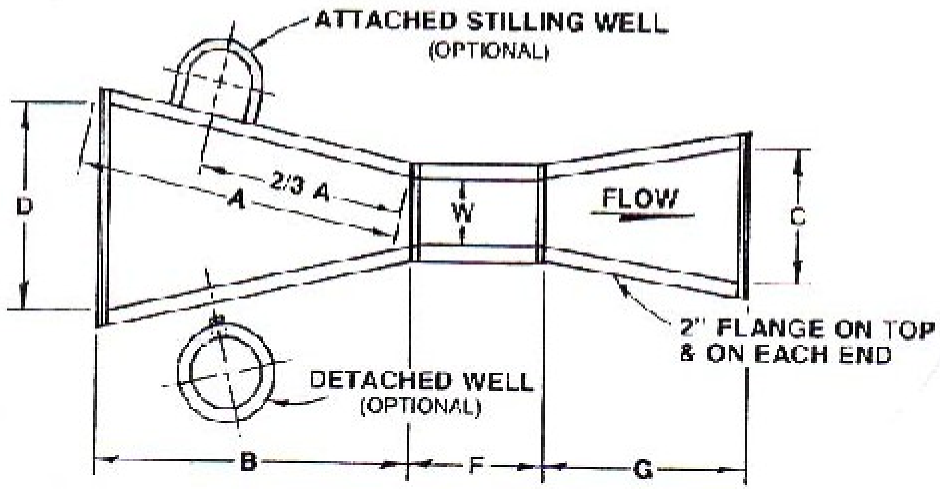

Point of level
measurement, H
L
Top view
Converging
section
Throat
Diverging
section
Side view
cross section

Throat Width L	Flow Range (ft^3/s) Min.	Max.	Equation (H and L in ft, Q in ft^3/s)
3 in	0.03	1.9	$Q = 0.992H^{1.547}$
6 in	0.05	3.9	$Q = 2.06H^{1.58}$
9 in	0.09	8.9	$Q = 3.07H^{1.53}$
1 ft	0.11	16.1	$Q = 4.00\,LH^n$, $n=1.55$
2 ft	0.42	33.1	$Q = 4.00\,LH^n$, $n=1.55$
4 ft	1.3	67.9	$Q = 4.00\,LH^n$, $n=1.58$
6 ft	2.6	103.5	$Q = 4.00\,LH^n$, $n=1.59$
8 ft	3.5	139.5	$Q = 4.00\,LH^n$, $n=1.61$
10 ft	6	200	$Q = (3.6875L + 2.5)H^{1.6}$
20 ft	10	1000	$Q = (3.6875L + 2.5)H^{1.6}$
30 ft	15	1500	$Q = (3.6875L + 2.5)H^{1.6}$
40 ft	20	2000	$Q = (3.6875L + 2.5)H^{1.6}$
50 ft	25	3000	$Q = (3.6875L + 2.5)H^{1.6}$

One of the suppliers of flumes –

http://www.globalw.com/products/flumes.html





PLAN VIEW

Table of Dimensions

Part #	W	A	2/3A	B	C	D	E	F	G	J	K	N	Price
01-006	1	14-9/32	9-17/32	14	3-21/32	6-19/32	9	3	8	9-1/4	3/4	1-1/8	$568
01-007	2	16-5/16	10-7/8	16	5-5/16	8-13/32	12	4-1/2	10	12-7/8	7/8	1-11/16	$746
01-008	3	18-3/8	12-1/4	18	7	10-3/16	24	6	12	25	1	2-1/4	$921
01-009	6	24-7/16	16-5/16	24	15-1/2	15-5/8	24	12	24	27	3	4-1/2	$1,550
01-010	9	34-5/8	23-1/8	34	15	22-5/8	30	24	18	33	3	4-1/2	$1,978
01-011	12	54	36	52-7/8	24	33-1/4	36	24	36	39	3	9	$3,561

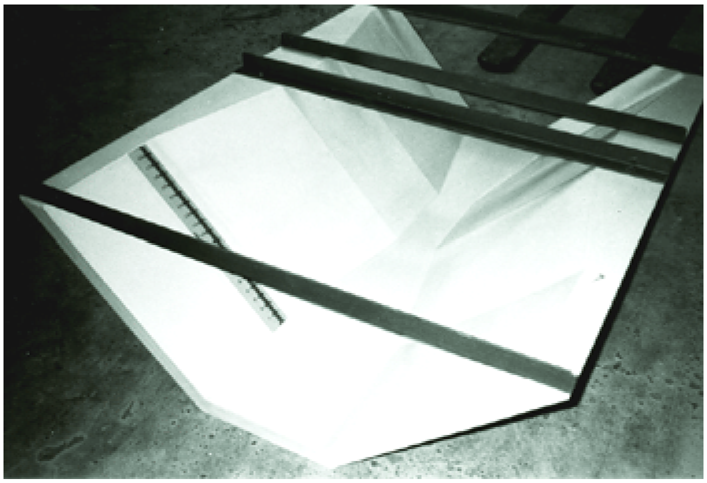
Prices listed are for United States and Canada only. Call or e-mail us for pricing in other countries.
Terms and Conditions

Table of Flow Data

Size	1"	2"	3"	6"	9"	12"
Min CFS	0.001	0.001	0.001	0.001	0.005	0.006
Min MGD	0.001	0.001	0.001	0.001	0.003	0.004
Max CFS	0.22	0.68	2.91	6.16	12.51	21.68

Max MGD	0.14	0.44	1.88	3.98	8.09	14.01
Complete Flow Table NOTE: Flow tables are only valid to the E (height) measurement of the Parshall Flume.	1" Table	2" Table	3" Table	6" Table	9" Table	12" Table

Tracom Flume types –



Trapezoidal

H-type flume

Cutthroat flume

Montana Flume