# Hydraulic Engineering Lab

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## Specific Energy and Critical Flow

**Purpose:**

The purpose of this lab experiment is to analyze the energy relationships in the transition of flow from subcritical flow to supercritical flow in an open channel.

**Background:**

The sum of the depth of flow and the velocity head is the Specific Energy:

$$E = y + \frac{V^2}{2g} \tag{1}$$

Where E is the Specific Energy in units of distance [L], V is the velocity in [L/T] units, y is the depth of flow in [L] units, and g is the acceleration of gravity in [L/T$^2$]. Two assumptions are made to simplify the energy equation: Slope of the channel is zero (horizontal) and head loss is also zero. Since there is no head loss, the specific energy at any two given points is the same, i.e. (energy is conserved). If the continuity principle is applied (Q=VA), the total specific energy can be expressed in terms of total volumetric flow rate (Q) and wetted area (A):

$$E = y + \frac{V^2}{2g} = y + \frac{Q^2}{2gA^2} \tag{2}$$

For a rectangular channel the flow area (A) is equal to the depth of flow (y) times the channel width (b) giving:

$$E = y + \frac{V^2}{2g} = y + \frac{Q^2}{2gA^2} = y + \frac{Q^2}{2gb^2y^2} \tag{3}$$

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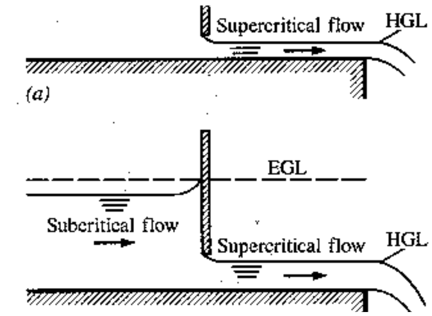
Since the total flow rate is constant, the magnitude of the specific energy at any two sections is solely a function of the depth at each section. Physically this means that for a low depth, the bulk of energy of flow is in the form of kinetic energy; whereas for greater depth, most of the energy is in the form of potential energy. The large depth and low kinetic energy is alternate to low depth and large kinetic energy. For the same value of specific energy, there are two different y values, called alternate depths. the large depth is alternate to the low depth. In the figure, it can be seen that at a point the specific energy is minimum and only a single depth occurs. At this point the flow is termed critical. The flow for which the depth is less than critical is termed supercritical flow, and the flow for which the depth is greater than critical is termed subcritical. Supercritical velocity is greater than critical velocity, and subcritical velocity is less than critical velocity.




Critical velocity is determined with the dimensionless Froude number. The Froude number is the ratio of inertial to gravity forces.

$$Fr = \frac{V}{\sqrt{gy}} \tag{4}$$

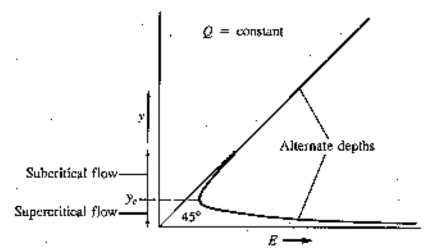



**Figure 4-12** Relation of depth versus specific energy

When the Froude number is greater than one the flow is supercritical.

**Hydraulic Jump**

When the flow is supercritical in an upstream section of the channel and is forced to become subcritical in a downstream section, a rather an abrupt change in depth usually occurs and considerable energy loss accompanies the process. This flow phenomenon, is defined as hydraulic jump is often considered in the design of open channels and spillways. The use of the hydraulic jump is to reduce the downstream velocity so that objectionable erosion of the river channel is prevented. If the channel is designed to carry water at supercritical velocities, the design must be certain that the flow will not become subcritical prematurely. If it did, overtopping of the channel walls would occur, thus failing to contain the flow of water.

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Quantitative analysis of a hydraulic jump differs in that, because of the high turbulence in the jump, energy is not conserved. However, since interactions with the channel sides are small, momentum is approximately conserved (i.e., the sum of the forces on the water must equal zero, if there are no significant external forces then the momentum must be constant). Since the shear stress forces on the side of the channel are small over the distance of concern, momentum is approximately conserved. The momentum balance leads to the following equation for the depths before and after a hydraulic jump.

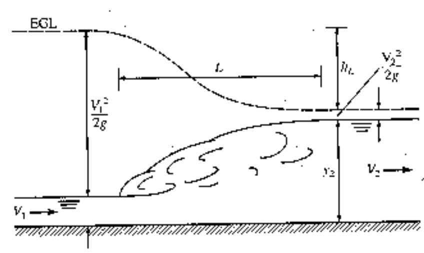
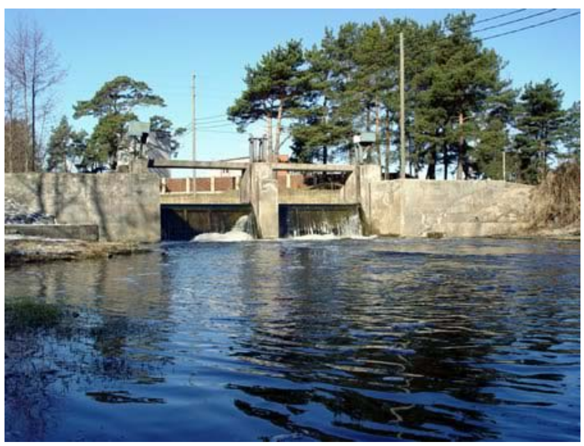


Figure 4-22 Definition sketch for the hydraulic jump

$$y_2 = \frac{y_1}{2}\left(\sqrt{1 + 8Fr^2} - 1\right) \tag{5}$$

**Underflow Gates**

Underflow gates are frequently employed in irrigation structures to control discharge. Underflow



gates are typically of two designs: the vertical lift gate (Sluice Gate) and the radial or tainter gate. The basic hydraulic principles are the same fo rthe two gate designs; the difference being that the circular gate is easire to manipulate than the vertical gate. For this reason tainter gates are normally employed in situations where the gate needs to be very large and heavy. The gate functions essentially as an orifice and lends itself to the same type of analysis. A major advantage of underflow gates is that they promote removal of silt from the upstream channel or reservoir. A disadvantage is that they can be deadly if one falls in upstream of the gate.

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Discharge from an underflow gate is calculated differently depending upon whether outflow from the gate is submerged or unsubmerged. How can one tell the difference? When is the flow sub and super critical?

**Critical Flow (first week's lab):**
**Note: Some years we combine both exercises below into one lab.**

i Adjust the tailgate of the channel so that it does not cause any obstruction at the outlet end. This is done by placing the tailgate into its lowest position. Adjust the channel for zero slope.

ii Open the sluice gate about 3/4 inches and turn the flow rate as high as you can without overflow.

iii Measure the alternate depths of flow before and after the gate. Record the flow rate. Also record depths needed to calculate flow rate from the sluice gate and spillway (broad crested weir on top) as an alternative to the flow gauges built into the flume.

iv Repeat the above for as you gradually raise the sluice gate.

v Remove the sluice gate and replace it with the spillway.

vi Adjust the flow rate to as low as can be measured.

vii Record flow rate and depth before and after the spillway.

viii Repeat 5 and 6 for several higher flow rates.

*Data Analysis*

**Sluice Gate Data:** Calculate the specific energy and Froude number for each measurement. Make a plot of specific energy versus depth of flow at constant discharge. Does your chart look like the one on the textbook? How much energy is lost going under the sluice gate?

**Spillway:** Estimate the change in specific energy going down the spillway. Does the fractional energy loss change with flow rate? Plot specific energy as a function of flow rate showing the data pairs taken at the same flow rate.

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**Hydraulic Jump (second week's lab):**

1) Adjust the tailgate of the channel so that it does not cause any obstruction at the outlet end. This is done by placing the tailgate into its lowest position. Adjust the channel for zero slope.

2) Open the sluice gate to a height of approximately 3/4 inch. Adjust the flow so the inlet reservoir has sufficient head to cause supercritical flow to exist along the entire length of the channel. Insure that no overflow occurs from the rear of the inlet reservoir.

3) By adjusting the tailgate, create a hydraulic jump in the center portion of the channel.

4) Record the flow rate as well as the water levels at the sluice gate/spillway needed to calculate the flow rate.

5) Keeping the flow rate constant, change the sluice gate opening and repeat step 1 through 4.

6) For 4 additional flow rates, create a hydraulic jumps in the central portion of the channel and measure the depth in front of and behind of the jump.

7) Repeat the experiment using the spillway.

*Data Analysis*

1) Draw the water level profiles and compute the average velocities at the cross sections on either side of the hydraulic jump for both the spillway and sluice gate.

2) Calculate the energy loss in the hydraulic jump. The energy loss is the difference in specific energy.

3) Plot the relationships between the ratio of the conjugate depths and corresponding Froude Number. The conjugate depths are the depths before and after the jump.

4) Calculate the critical depths. Do they fall within the expected ranges?

5) Is the hydraulic jump an efficient energy dissipater?