ENGINEERING LABORATORY DESIGN INC.

HYDRAULIC DEMONSTRATION CHANNEL MODEL SET

INSTALLATION AND OPERATION INSTRUCTIONS

Engineering Laboratory Design, Inc.

PO Box 278, 2021 South Highway 61, Lake City, Minnesota 55041 USA
Voice: 651-345-4515 • 800-795-8536 • FAX: 651-345-5095
www.eldinc.com • eldinfo@eldinc.com

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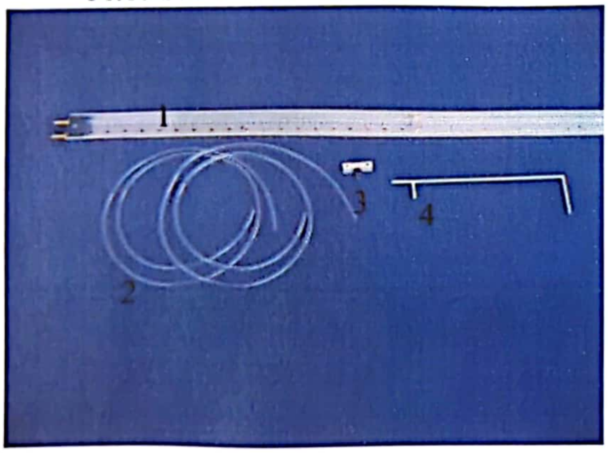
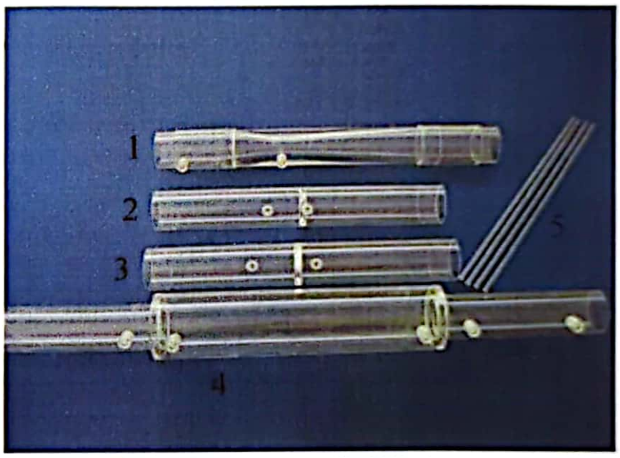
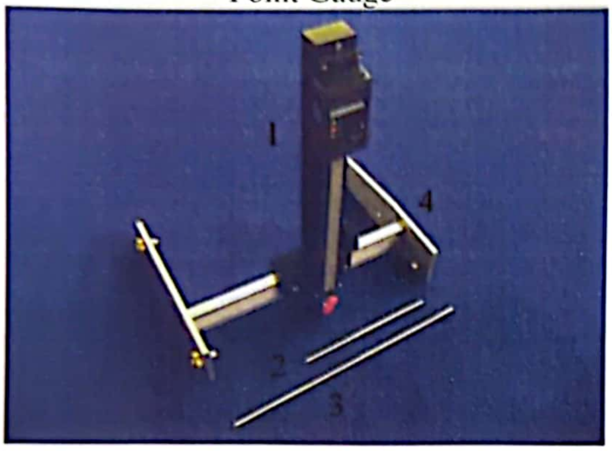
ENGINEERING LABORATORY DESIGN INC.
P.O. BOX 278
LAKE CITY, MN 55041-0278
(800) 795-8536
(651) 345-5096 FAX
www.eldinc.com

HYDRAULIC DEMONSTRATION CHANNEL

PACKING LIST

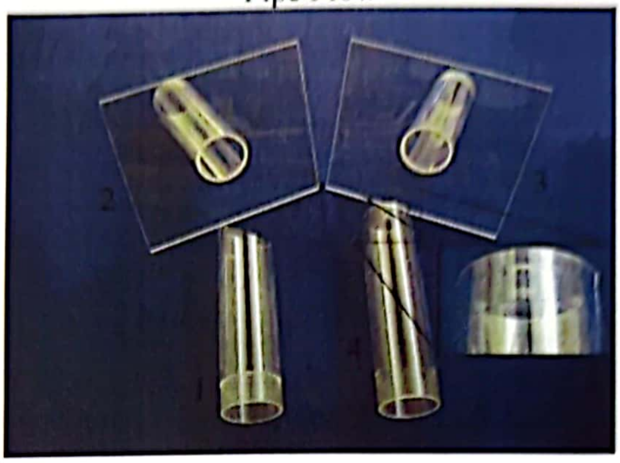
Pitot-Static Tube and Manometer	Tube Flow Meters
	
1. 48" Long Differential Manometer 2. Clear Tubing 3. Pitot-static Tube Clamp 4. Pitot-static Tube	1. Venturi Tube 2. Flow Nozzle 3. Pipe Orifice 4. Sudden Contraction/Expansion 5. Acrylic Manometer Tubes, 22" long (5)

Point Gauge



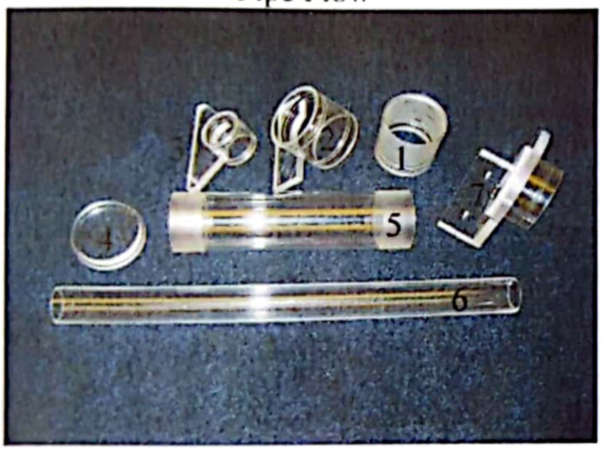
1. Point Gauge
2. 4.5" Point (A)
3. 9.5" Point (B)
4. Gauge Carriage

Pipe Flow



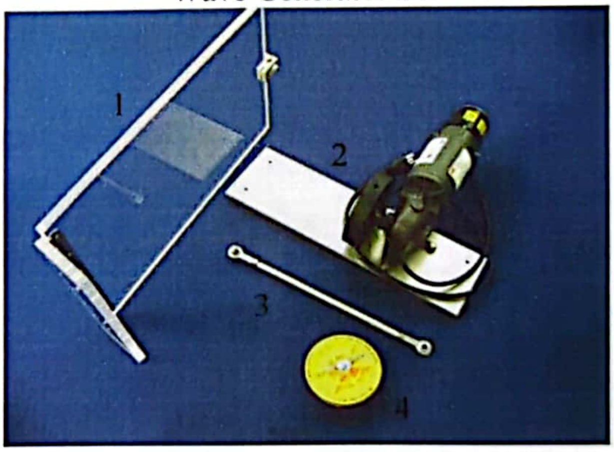
1. Hooded Inlet
2. Sharp Inlet
3. Rounded Inlet
4. Re-Entrant Inlet

Pipe Flow



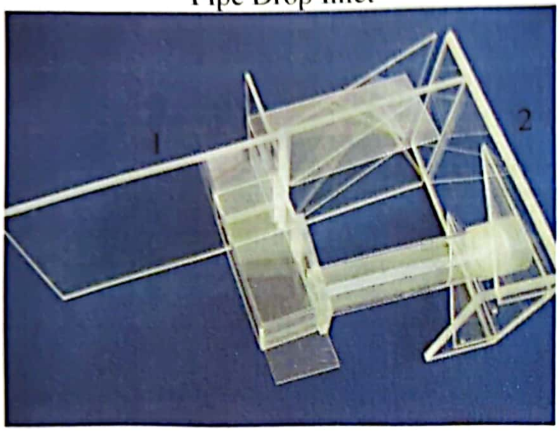
1. Headgate Bushing
2. Large Support (B Channel)
3. Small Support (A Channel)
4. Plug
5. 3 x 46-1/4 Tube (B Channel)
   3 x 11-5/8 Tube (A Channel)
6. 3 x 30 Tube (B Channel)
   1-3/4 x 22 Tube (A Channel)
7. Valve

Wave Generator Set



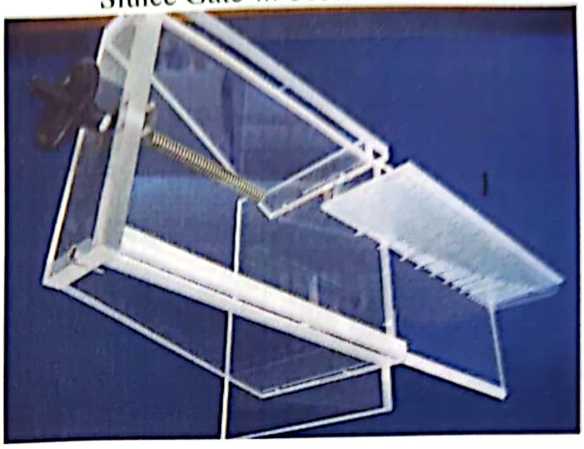
1. Hinged Plate
2. Motor Assembly
3. Connecting Rod
4. Plug

Pipe Drop Inlet



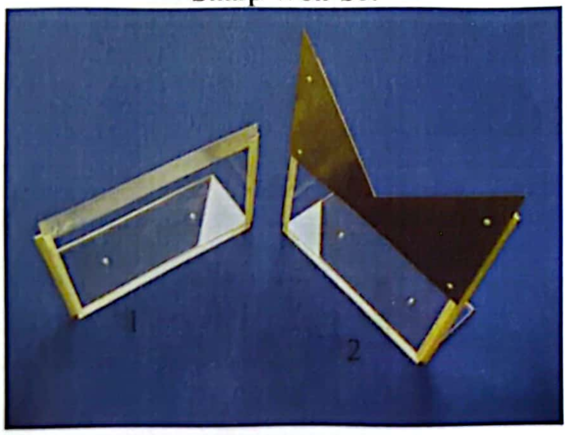
1. Pipe Drop Inlet Assembly
2. Headwall

Sluice Gate w/ Pressure Tubes



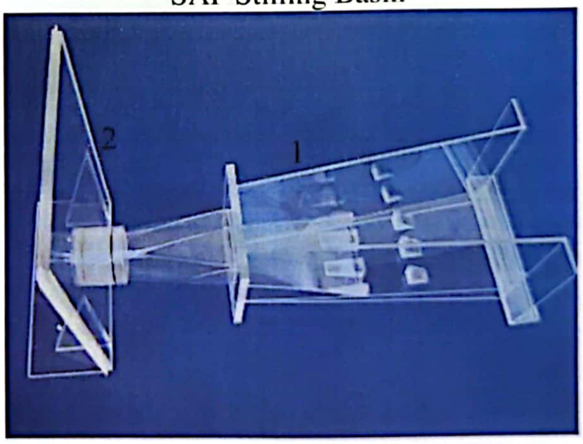
1. Sluice Gate Assembly

Sharp Weir Set



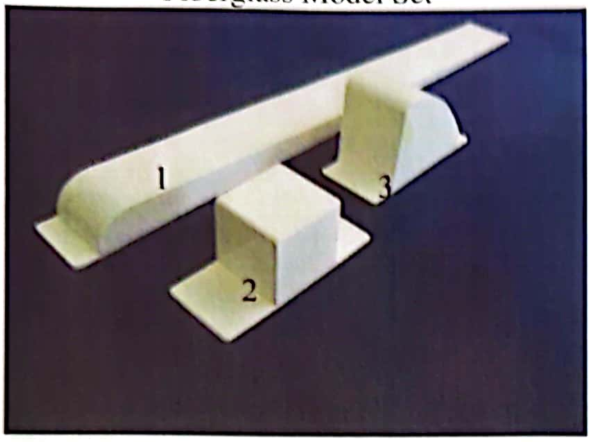
1. Sharp Crest Weir
2. V-Notch Weir

SAF Stilling Basin



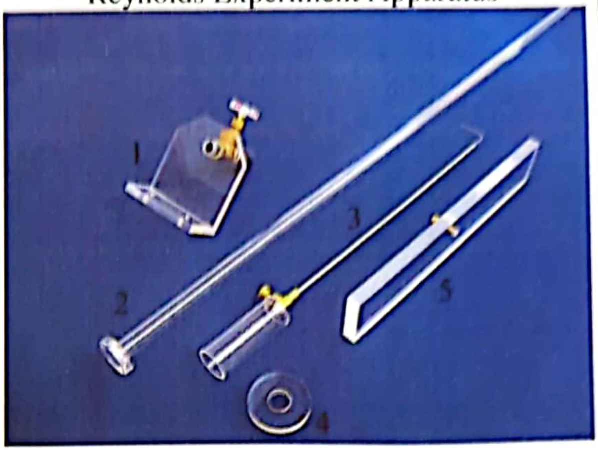
1. Stilling Basin Assembly
2. Headwall

Fiberglass Model Set



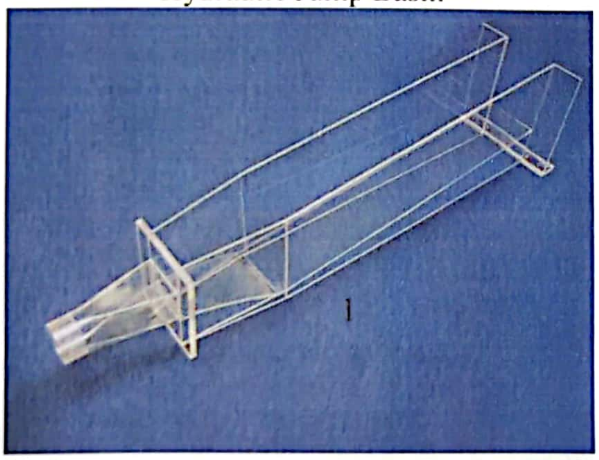
1. Inclined Slope
2. Broad Crest Weir
3. Spillway Section

Reynolds Experiment Apparatus



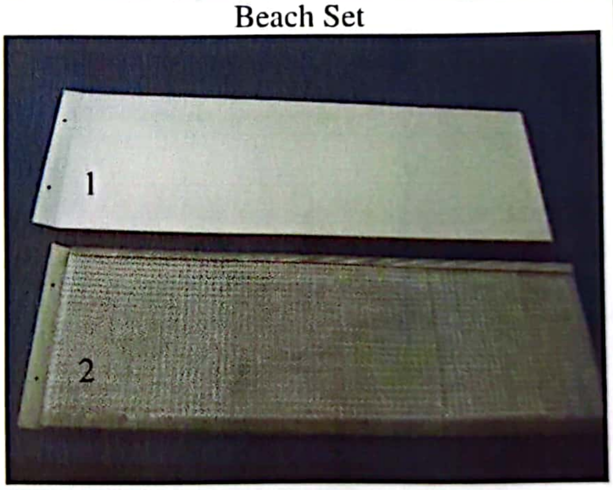
1. Valve
2. Tube
3. Dye Injector Assembly
4. Tube Bushing
5. Dye Injector Holder

Hydraulic Jump Basin



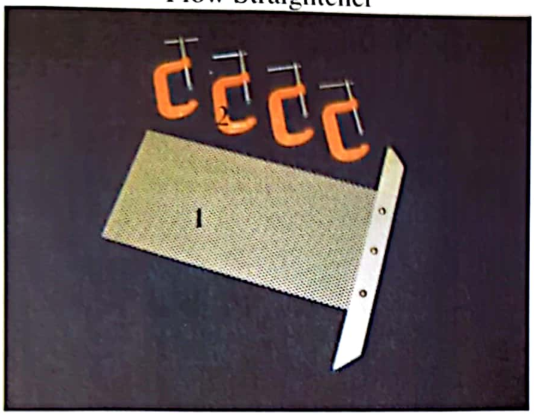
1. Hydraulic Jump Basin

Beach Set



1. Solid Beach
2. Porous Beach

Flow Straightener



1. Flow Straightener
2. C-Clamps (2)

Items pictured NOT included in this order:

- Pitot-static Tube Clamp
- Pitot-static Tube
- Tube Flow Meters
- Pipe Flow
- Wave Generator Set
- Pipe Drop Inlet
- Sluice Gate w/ Pressure Tubes
- Sharp Crest Weir
- Headwall
- Fiberglass Model Set
- Reynolds Experiment Apparatus
- Hydraulic Jump Basin
- Beach Set

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BROAD CREST WEIR MODEL

A broad crest weir is an obstruction placed in an open channel to measure flow. The discharge, Q, is directly related to the height of the upstream flow, H, or the critical depth over the weir, D, above the crest of the weir. The relationship is:

$$Q = \frac{2}{3} Hb\sqrt{\frac{2}{3} gH}\,(ft^3/s) = b\sqrt{gD^3}\ .$$

Where:

- Q: volume flow discharge (ft^3/s)
- g: gravitational acceleration, $32.2 ft/s^2$
- σ: submergence factor (ft)
- H: upstream head measurement from crest of model (ft)
- D: depth measurement of critical flow along length of model (ft) $\sim\frac{2}{3}H$
- b: width of model in spanwise direction (ft)

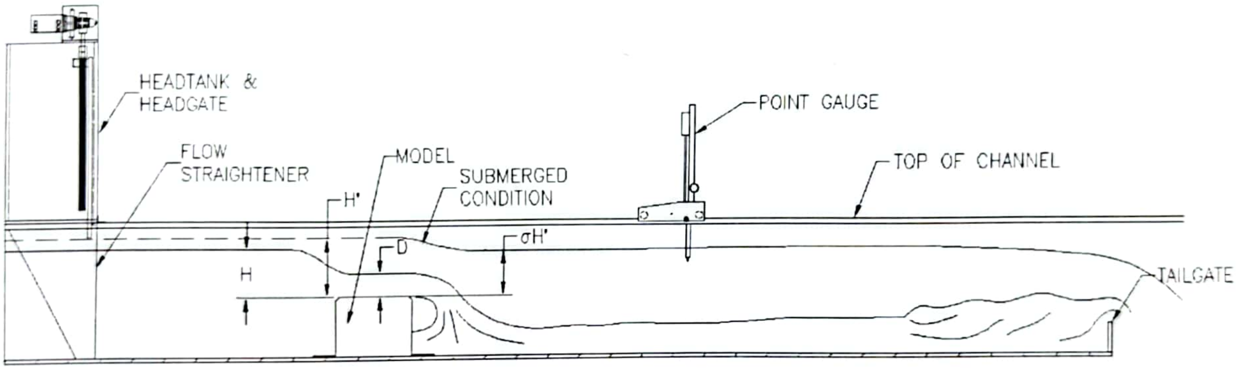

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise headgate to maximum opening.
   b. Lower tailgate completely.
   c. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   d. Set channel to zero slope.
   e. Install gauge carriage onto channel.
   f. Install point gauge onto carriage.
   g. Set channel valve(s) for maximum flow rate.
2. Mount the broad crest weir model midway in the channel using four (4) #10-24UNC-2A x 0.5" long Round Head Machine Screws (RHMS) at the flanges.
3. Establish a measurement 'zero', or datum, at the top of the model using the point gauge.
4. Start the pump(s).
5. Adjust flow rate for uniform flow over weir.

6. Measure and record the flow rate using the orifice meter(s) and manometer(s).
7. Measure and record 'H' and 'D' using the point gauge.
8. Set a new flow rate and repeat measurements. Repeat at several different flow rates.
9. Plot a head, H, vs. discharge, Q, curve.
10. Compare discharge curve to the above relationships.
11. Raise the tailgate, submerging the weir.
12. What effect does submergence have on the upstream level H'? At what depth H' is $\sigma \leq 0.80$ yielding 'free' discharge?

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FLOW NOZZLE METER MODEL

A flow nozzle is a method of flow metering in pipes, based on the Bernoulli equation. The flow rate, Q, is directly related to the pressure differential of the upstream section and the downstream section after the flow nozzle. Pressure ports are placed one (1) diameter upstream and one-half (1/2) diameter downstream from the upstream plane of the flow nozzle inlet. The flow rate relationship is as follows:

$$\Delta H = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \text{ (Bernoulli equation)} \qquad Q = V_2 C_d A_2 = V_1 A_1 \text{ (Continuity Equation)}$$

Combining:

$$Q = KA_2\sqrt{2g\Delta H} \ (\text{ft}^3/\text{s})$$

Where:

- Q: volumetric flow discharge (ft^3/s)
- C_d: Discharge coefficient (based on Re_d and β)
- K: Flow coefficient ($\frac{C_d}{\sqrt{1-\beta^4}}$)
- β: beta ratio $= \frac{\text{throat diameter}}{\text{upstream diameter}} = \frac{1.5"}{2.75"} = 0.545$
- A_2: area of flow nozzle (ft^2) (Fig. 1) $= 0.01227\text{ft}^2$
- g: gravitational acceleration, 32.2ft/s^2
- ΔH: measured height difference in pressure (manometer) tubing (ft fluid)

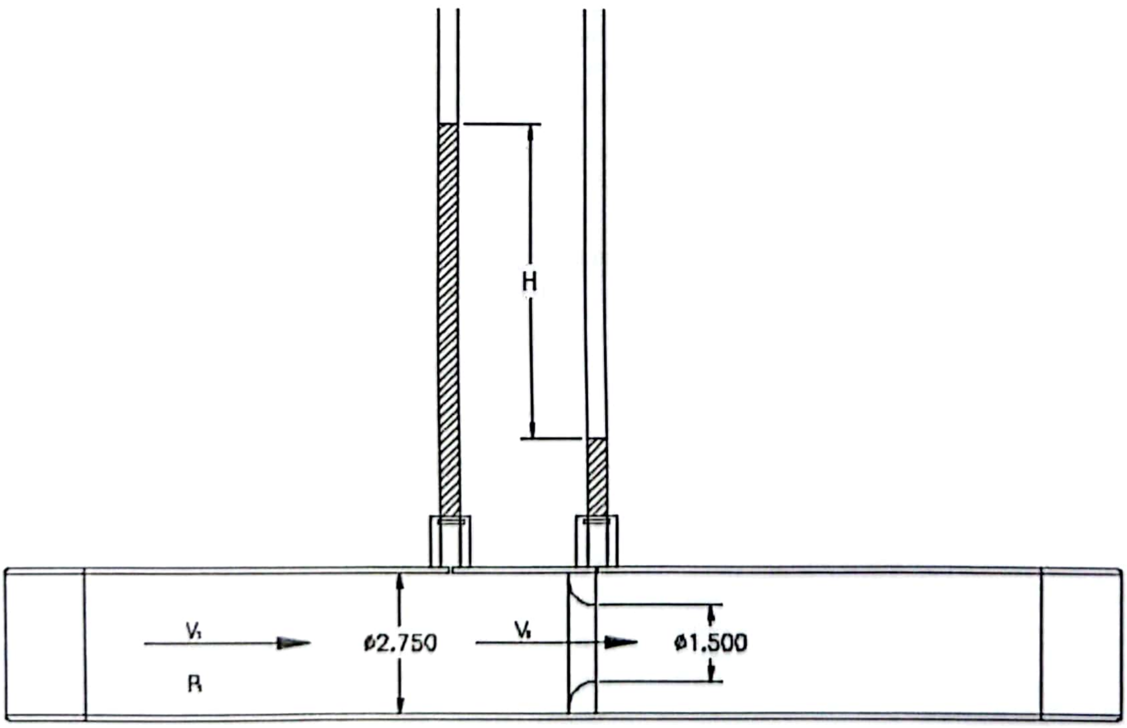

Figure 1: Detailed Flow Nozzle Meter Model Diagram

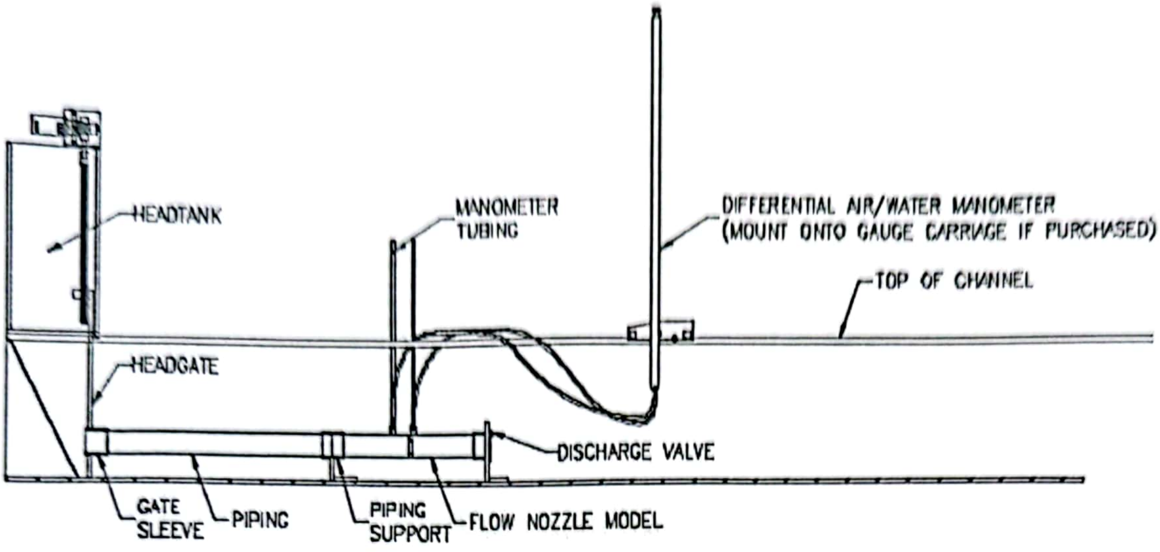

Figure 2: Flow Nozzle Meter Model Installation Diagram

Suggested Experimental Procedure

1. Initial settings (Fig. 2):
   a. Install piping sleeve into headgate by removing the plug and sliding the sleeve into the headgate.
   b. Lower the headgate to closed position.
   c. Lower tailgate completely.
   d. Set channel to 0% slope.
   e. Install gauge carriage onto channel.
   f. Set channel valve(s) for low flow rate.
2. Install pipe segment, pipe support, flow nozzle meter and discharge valve into headgate sleeve and onto channel floor. Secure discharge valve with two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS) at the flange. Engage all o-rings at pipe connections. Open the discharge valve fully.
3. Attach differential manometer to gauge carriage using provided bracket post. Connect flexible tubing to the flow nozzle meter and barbed, manometer fittings. Alternatively, install rigid manometer tubes into flow nozzle meter pressure port bosses.
4. Start pump(s) and regulate the discharge to give the minimum flow through the system. Close the discharge valve until the flow nozzle operates full.
5. Measure and record the difference in pressure through the flow nozzle meter. Measure and record the flow rate through the channel orifice meter(s).
6. Repeat the pressure measurement at a variety of flow rates.
7. Plot the flow rate, Q, vs. pressure difference, ΔH, on semi-log paper.
8. Determine the discharge coefficient.

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HYDRAULIC JUMP BASIN MODEL

The hydraulic jump basin model demonstrates the use of a stilling basin lacking energy dissipating devices. Energy reduction is obtained solely through the means of the hydraulic jump. Location of the jump is unstable and dependent completely on the height of the tail-water. Note the long length of the basin required for proper performance.

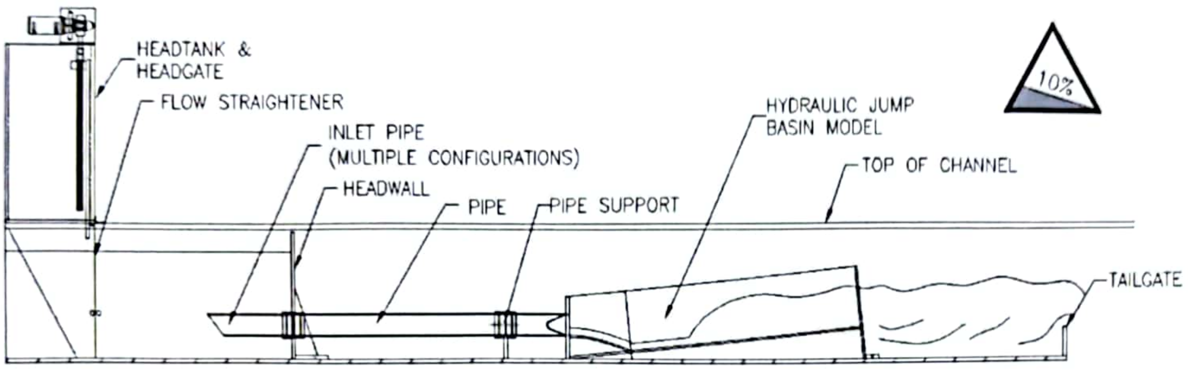

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
    a. Raise the headgate to fully open position.
    b. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
    c. Set channel to +10% slope.
    d. Lower tailgate completely.
    e. Set pump(s) for low flow rate.
2. Mount the head wall to the channel floor midway along the upstream channel segment using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS).
3. Install the hydraulic jump basin model, pipe segment and inlet models as shown. Mount the hydraulic jump basin model to the channel floor with two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS). Engage all o-rings at pipe connections. Any of the inlet models may be used.
4. Start the pump(s) and adjust flow rates until full pipe flow is established. Observe the discharge flow characteristics.
5. Raise the tailgate until a hydraulic jump forms in the basin.

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INCLINED SLOPE MODEL

An inclined slope is used to illustrate types of flow in open channels. The inclined slope model provides a point of control in the establishment of critical depth. The dimensionless Froude number is used to characterize flow regimes:

$$Fr = \frac{V}{\sqrt{g y_o}}$$

where:
- V: velocity of fluid (ft/s)
- g: gravitational acceleration, 32.2ft/s^2
- y_o: upstream head measurement from crest of model (ft)

The three (3) flow regime types (Fig. 1) are:

- Fr < 1.0 subcritical flow
- Fr = 1.0 critical flow
- Fr > 1.0 supercritical flow

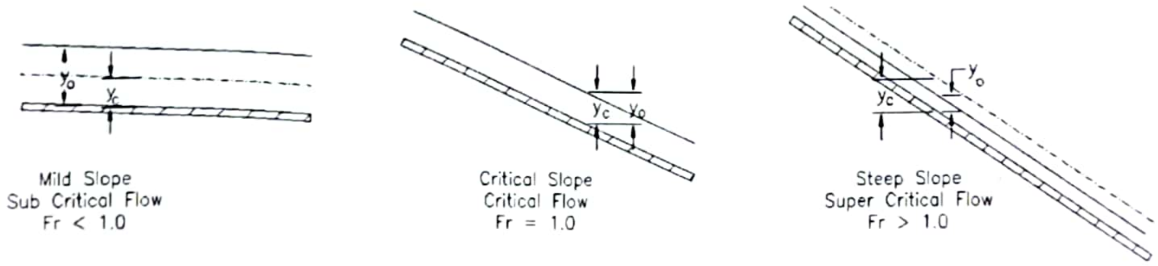

Figure 1 Various Types of Flow

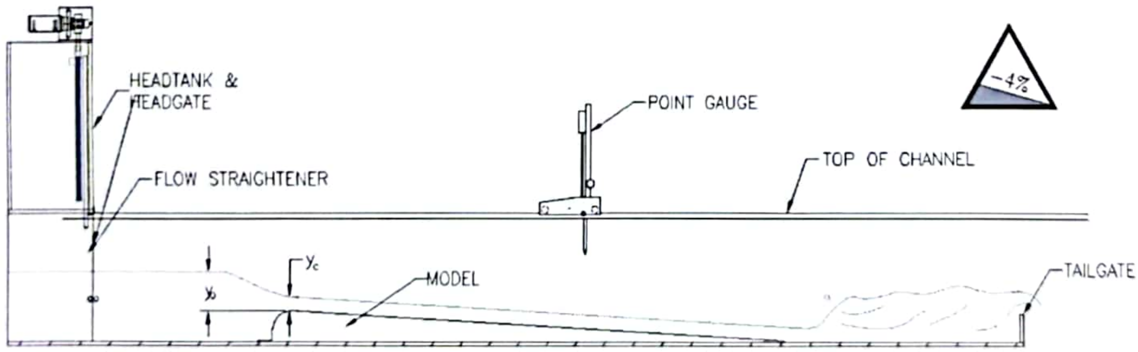

Figure 2 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 2):
   a. Raise headgate to maximum opening.
   b. Lower tailgate completely.
   c. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.

d. Set channel to -4% slope.
e. Install gauge carriage onto channel.
f. Install point gauge onto carriage.
g. Set channel valve(s) for maximum flow rate.

2. Mount the inclined slope model at the midpoint of the upstream channel using two (2) #10-24UNC-2A x 0.5" long Round Head Machine Screws (RHMS) at the upstream flange and two (2) #10-24UNC_2A x 0.5" long Flat head Machine Screw (FHMS) at the downstream end.
3. Establish a measurement 'zero', or datum, at the crest of the model using the point gauge.
4. Start the Pump(s) using greatest possible discharge.
5. Adjust the tailgate to give a uniform tranquil (sub critical) flow down channel.
6. Measure and record the flow rate using the orifice meter(s) and manometer(s).
7. Measure and record y_o and y_c using the point gauge.
8. Increase the slope until critical flow occurs over the entrance of the model. Critical flow is reached when the velocity down the slope is uniform without acceleration or deceleration. Also, note that waves caused by surface disturbances do not travel upstream.
9. Mark the point of critical depth on the channel sidewall for later reference.
10. Measure and record y_o and y_c using the point gauge (these values should be equal).
11. Increase the slope to show accelerated (super critical) flow down the channel.
12. Measure and record y_o and y_c using the point gauge.
13. Adjust the tailgate height to establish a hydraulic jump at the lower end of the slope.
14. Calculate the Froude number for each condition.

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PIPE DROP INLET MODEL

The pipe drop inlet model demonstrates the characteristics of a typical outflow structure used in a reservoir. The sloped face represents a 1:3 side slope of a reservoir fill. The vertical and longitudinal walls prevent vortex formation. As discharge begins weir flow exists, followed by a period of orifice flow, and finally, as sufficient head is available, the system is filled and full pipe flow is accomplished. In the zone between orifice and full pipe flow, periods of 'slug' flow occur. The flow in the tube alternates between open channel flow and full pipe flow. The head-discharge relationship of this structure makes it an excellent flow 'limiter'.

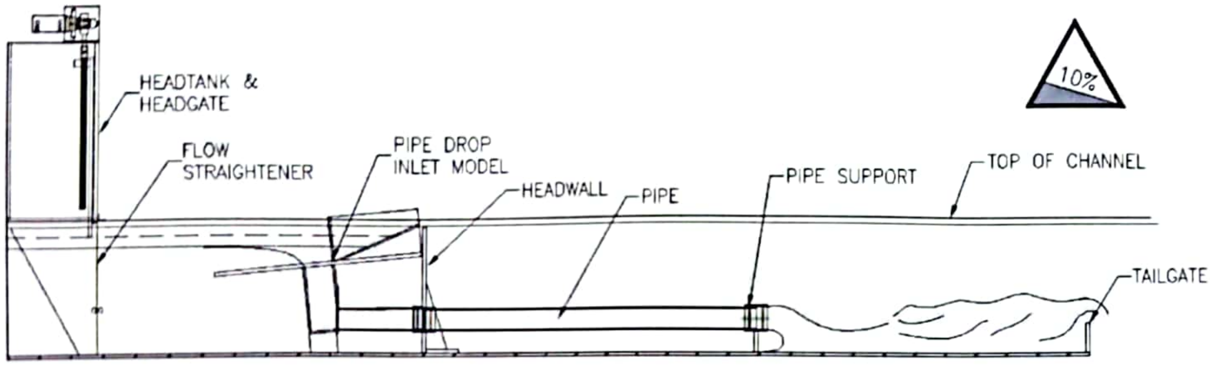

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise the headgate to fully open position.
   b. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   c. Set channel to +10% slope.
   d. Lower tailgate completely.
   e. Set pump(s) for low flow rate.
2. Mount the head wall to the channel floor midway along the length using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS).
3. Install the pipe drop inlet model, pipe segment and support as shown. Engage all o-rings at pipe connections.
4. Start the pump(s) and adjust flow rates while observing the multiple flow characteristics.
5. Optionally, mount either the SAF Basin or the Hydraulic Jump Basin at the end of the pipe system to fully demonstrate a complete flow conveying system.

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ORIFICE METER MODEL

An orifice plate is a method of flow metering in pipes, based on the Bernoulli equation. The flow rate, Q, is directly related to the pressure differential of the upstream section and the downstream section after the orifice plate. Pressure ports are placed one (1) diameter upstream and one-half (1/2) diameter downstream from the upstream face of the orifice plate. The flow rate relationship is:

$$\Delta H = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \text{ (Bernoulli equation)} \qquad Q = V_2 C_d A_2 = V_1 A_1 \text{ (Continuity Equation)}$$

combining:

$$Q = KA_2\sqrt{2g\Delta H} \ (ft^3/s)$$

where:

Q:	volumetric flow discharge (ft^3/s)
C_d:	Discharge coefficient (based on Re_d and β)
K:	Flow coefficient ($\frac{C_d}{\sqrt{1-\beta^4}}$)
β:	beta ratio $\frac{\text{throat diameter}}{\text{upstream diameter}} = \frac{1.5''}{2.75''} = 0.545$
A_2:	area of orifice (ft^2) (Fig. 1)= $0.01227 ft^2$
g:	gravitational acceleration, $32.2 ft/s^2$
ΔH:	measured height difference in pressure (manometer) tubing (ft fluid)

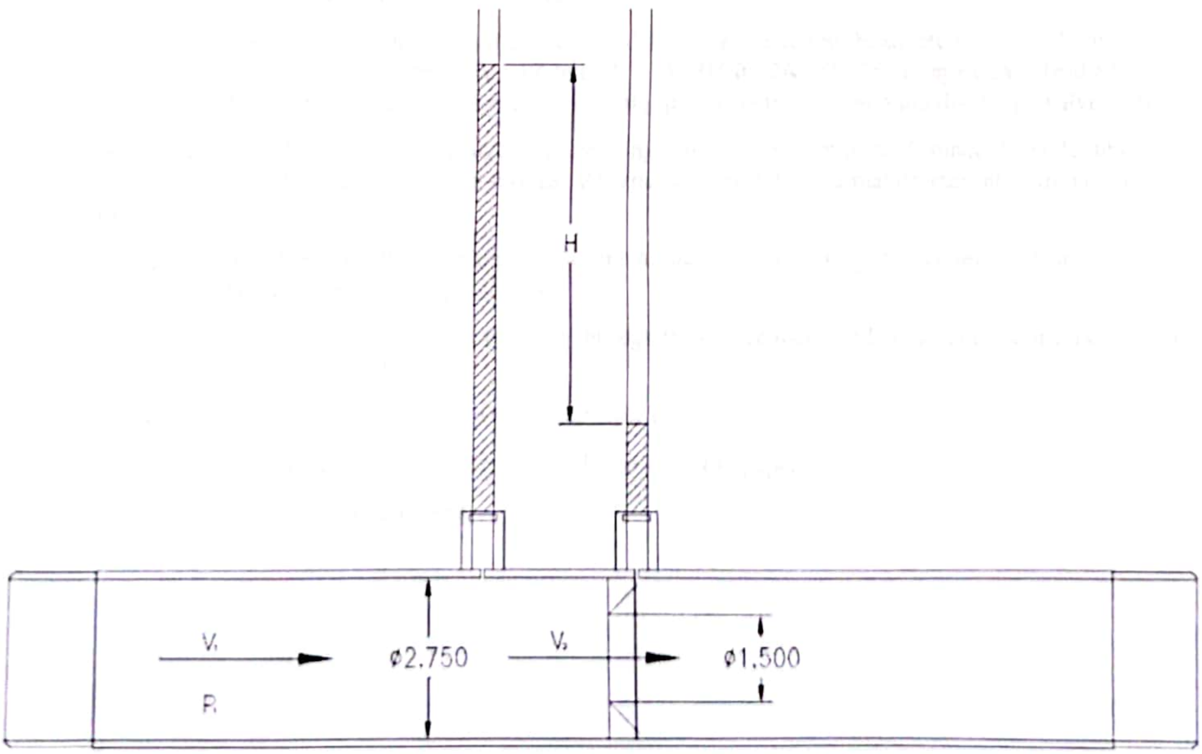

Figure 1 Orifice plate

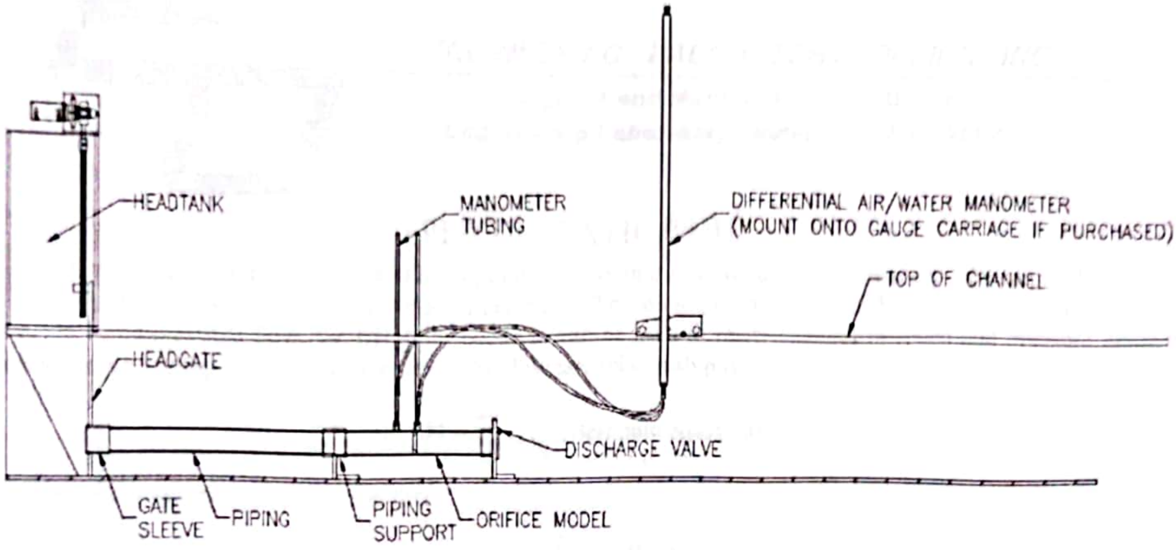

Figure 2 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 2):
   a. Install piping sleeve into headgate by removing the plug and sliding the sleeve into the headgate.
   b. Lower the headgate to closed position.
   c. Lower tailgate completely.
   d. Set channel to 0% slope.
   e. Install gauge carriage onto channel.
   f. Set channel valve(s) for low flow rate.
2. Install pipe segment, pipe support, orifice meter and discharge valve into headgate sleeve and onto channel floor. Secure discharge valve with two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS) at the flange. Engage all o-rings at pipe connections. Open the discharge valve fully.
3. Attach differential manometer to gauge carriage using provided bracket post. Connect flexible tubing to orifice meter and barbed, manometer fittings. Alternatively, install rigid manometer tubes into orifice meter pressure port bosses.
4. Start pump(s) and regulate the discharge to give the minimum flow through the system. Close the discharge valve until the orifice operates full.
5. Measure and record the difference in pressure through the orifice meter. Measure and record the flow rate through the channel orifice meter(s).
6. Repeat the pressure measurement at a variety of flow rates.
7. Plot the flow rate, Q, vs. pressure difference, ΔH, on semi-log paper.
8. Determine the discharge coefficient.

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PITOT-STATIC TUBE

A pitot-static tube is a method of measuring a point velocity in a fluid field. The pitot-static tube has an inner tube to measure the flow stagnation (total, impact) pressure. The static pressure is sensed by small holes in the outer tube. In incompressible flow, the Bernoulli equation can be used to relate changes in speed and pressure along a streamline, neglecting elevation differences. The flow rate relationship is:

$$\Delta H = \frac{V^2}{2g} - \frac{V_0^2}{2g} \text{ (Bernoulli equation)}$$

The stagnation speed, V_0, is zero; therefore:

$$V = \sqrt{2g\Delta H} \text{ (ft/s)}$$

where:

- V: point velocity (ft/s)
- g: gravitational acceleration, 32.2ft/s^2
- ΔH: measured height difference in pressure (manometer) tubing (ft)

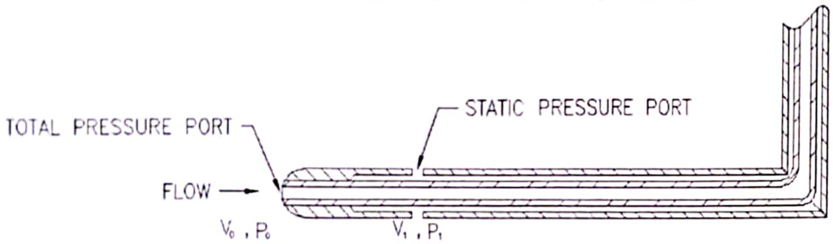

Figure 1 Pitot-Static Tube Geometry

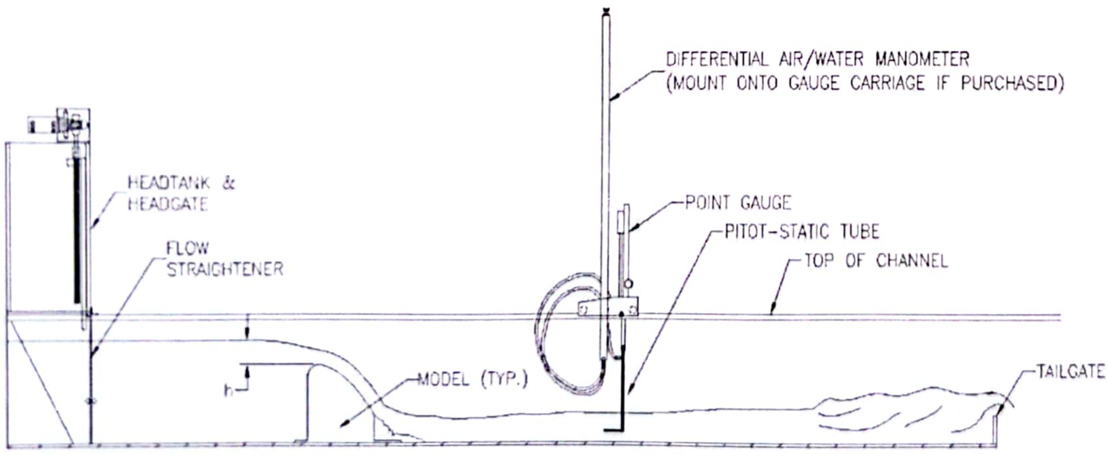

Figure 2 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 2):
   a. Arrange the channel with the desired model or flow conditions.
   b. Set channel to the desired slope.
   c. Install gauge carriage onto channel.
   d. Mount the point gauge onto the gauge carriage.
   e. Place the pitot-static tube bracket on the point rod.
   f. Clamp the pitot-static tube in the pitot-static tube bracket.
   g. Attach the differential manometer to the gauge carriage using the bracket post on the operator side of the gauge carriage.
   h. Connect the clear, plastic tube to the pitot-static tube.
   i. Lower the tubing outlet below the channel water height to induce a siphon.
   j. Connect the tubing to the differential manometer.
2. Start pump(s) and regulate the discharge to give the desired flowrate through the system.
3. Measure and record the difference in pressure developed by the pitot-static tube. Measure and record the flow rate through the channel orifice meter(s).
4. Repeat the pressure measurement at a variety of locations and/or flow rates.
5. Compare the flow rate determined from the point measurement and cross-sectional area to the orifice meter(s) measurement.
6. Plot the velocity profile for a given flowrate at a specific streamwise location. Compare the plot to predicted open channel flow field profiles.

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REYNOLDS EXPERIMENT APPARATUS MODEL

The Reynolds experiment apparatus model demonstrates the classic experiment of Osborne Reynolds (1842-1912) depicting the importance of the dimensionless Reynolds number on fluid mechanics. The defined Reynolds number is:

$$Re_D = \frac{\text{Inertia}}{\text{Viscous}} = \frac{\rho V D}{\mu}$$

where:

ρ: density of fluid $\rho_{water} = 62.3164 \frac{lb_m}{ft^3} = 998.213 \frac{kg}{m^3}$ at 20° C

V: Velocity of fluid $(\frac{ft}{s})$ or $(\frac{m}{s})$

D: Diameter of pipe (ft) or (m)

μ: viscosity of fluid $\mu_{water} = 20.92E\text{-}6 \frac{lb_f\, s}{ft^2} = 1.0E\text{-}3 \frac{kg}{m\, s}$ at 20° C

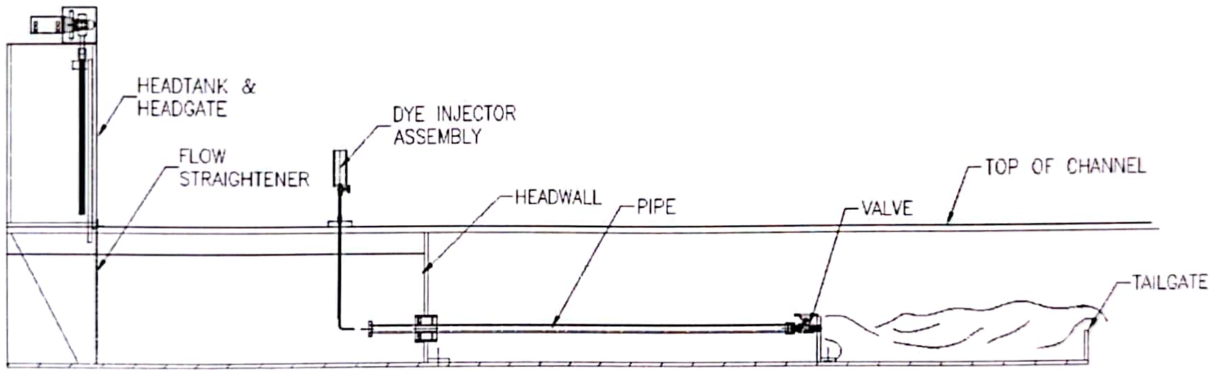

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise the headgate to fully open position.
   b. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   c. Set channel to 0% slope.
   d. Lower tailgate completely.
   e. Set pump(s) for low flow rate.
2. Mount the head wall to the channel floor midway along the upstream channel segment using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS).
3. Install the Reynolds apparatus model into the headwall as shown. Engage the o-ring at the pipe connection. Fit the valve and support at the downstream end of the tube. Secure the valve to the channel floor using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS).
4. Mount the dye well onto the channel top rail with the dye injector two (2) inches upstream of the tube inlet. Secure the dye well using the provided C-clamps. Adjust the dye injector tube to center on the tube inlet. Fill the dye reservoir with vegetable dye (food coloring).
5. Start the pump(s) and adjust flow rate(s) and the discharge valve until full, steady pipe flow is established.

6. Adjust the dye reservoir valve to produce a visible dye stream, observe the dye stream along the length of the tube as the fluid transitions from laminar flow into fully turbulent flow. Note the location of transition. Calculate the Reynolds number for the flow rate in the tube.

7. Repeat the experiment at different flow rates. Compare the Reynolds number to the location of transition.

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S.A.F. STILLING BASIN MODEL

The S.A.F. stilling basin model demonstrates the improved flow conditions and cost savings that can be obtained by using properly designed energy dissipation outlet structures while conveying of high energy flows from reservoirs to downstream channels, either natural or artificial. This type of structure offers good protection to erodible streambeds as well as an overall shorter length compared to other stilling basins. It should be emphasized that many varieties and combinations of stilling blocks may be used.

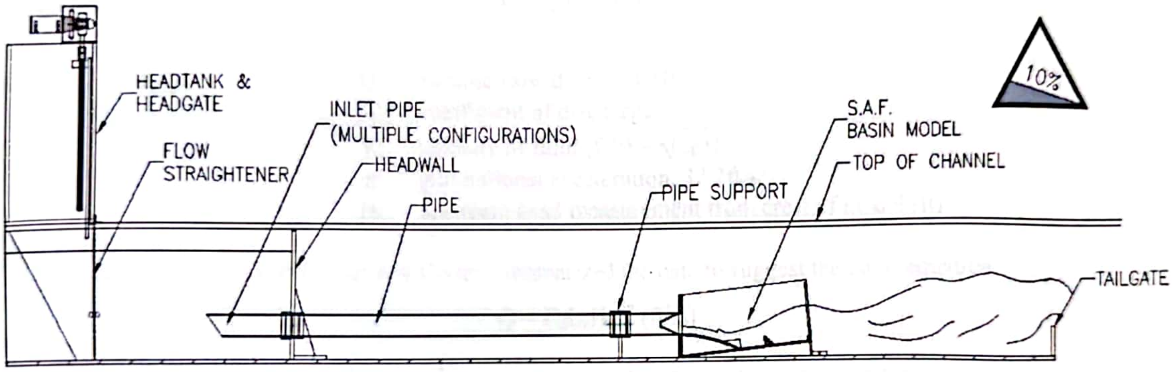

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise the headgate to fully open position.
   b. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   c. Set channel to +10% slope.
   d. Lower tailgate completely.
   e. Set pump(s) for low flow rate.
2. Mount the head wall to the channel floor midway along the upstream channel segment using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS).
3. Install the S.A.F. stilling basin model, pipe segment and inlet models as shown. Secure the S.A.F. stilling basin model to the channel floor using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS). Engage all o-rings at pipe connections. Any of the inlet models may be used.
4. Start the pump(s) and adjust flow rates until full pipe flow is established. Observe the discharge flow characteristics.
5. Raise the tailgate until proper stilling action is obtained and a hydraulic jump forms in the basin.
6. Vary the pump(s) flow rate(s) to illustrate the effectiveness of the S.A.F. stilling basin structure in a variety of conditions.

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SHARP CRESTED WEIR MODEL

A sharp crested weir is a method of open channel flow metering. The discharge, Q, is directly related to the height of the upstream flow, H, above the crest of the weir.

For a given weir of length L the discharge relationship is:

$$dQ = C_d VLh\,dh = (ft^3/s)$$

Integrating from 0 to H:

$$Q = \frac{2}{3} LC_d \sqrt{2g}\, H^{3/2}$$

where:

- Q: volume flow discharge (ft^3/s)
- C_d: coefficient of discharge
- V: velocity of fluid (ft/s) = $\sqrt{2gH}$
- g: gravitational acceleration, 32.2ft/s^2
- H: upstream head measurement from crest of model (ft)

Previous experimenters, Kindsvater and Carter, summarized the data to suggest the basic equation:

$$Q = C_d L_e H_e^{3/2}\ (ft^3/s)$$

where: $C_d = 3.22 + 0.40\frac{H}{P}$ and $L_e = L - 0.003$ ft and $H_e = H + 0.003$ ft

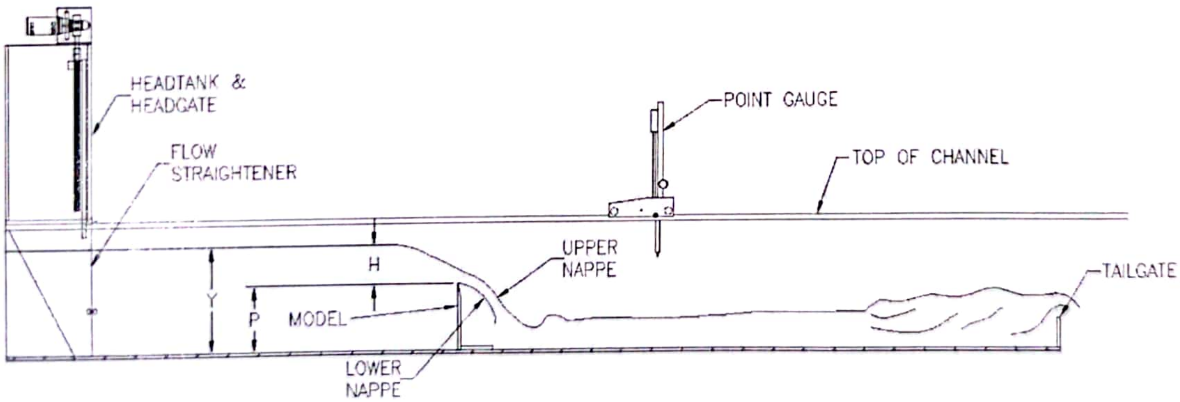

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise headgate to maximum opening.
   b. Lower tailgate completely.
   c. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   d. Set channel to zero slope.
   e. Install gauge carriage onto channel.
   f. Install point gauge onto carriage.
   g. Set channel valve(s) for low flow rate.

2. Mount the sharp crested weir model midway in the channel using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS) at the flanges.
3. Establish a measurement 'zero', or datum, at the top of the model using the point gauge.
4. Start the pump(s) and adjust the flow rate to obtain a minimum discharge over the weir with full aeration of the lower nappe.
5. Measure and record the flow rate using the orifice meter(s) and manometer(s).
6. Measure and record 'H' using the point gauge at a location far enough upstream so as not to be in the draw down area.
7. Set a new flow rate and repeat measurements. Repeat at several different flow rates.
8. Plot a head, H vs. discharge, Q curve on semi-log paper.
9. Compute the discharge coefficient and head term exponent from the discharge curve and compare to the above relationships.

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SLUICE GATE MODEL

A sluice gate is a vertical gate used to allow a controlled outlet of liquids. The model may be used to:

1. Illustrate the momentum theorem.
2. As a flow measuring device.

Momentum Theorem:

The force of water on the sluice gate may be computed from the momentum theorem, assuming one-dimensional flow and neglecting shear along the channel bed and the sidewalls. This may be compared with the force obtained from direct measurements of the pressure distribution on the sluice gate. Depths upstream and downstream of the sluice gate, the sluice gate opening, the channel width, and the heights of the various water columns in the manometer tubes connected to the upstream face of the sluice gate are all the data required.

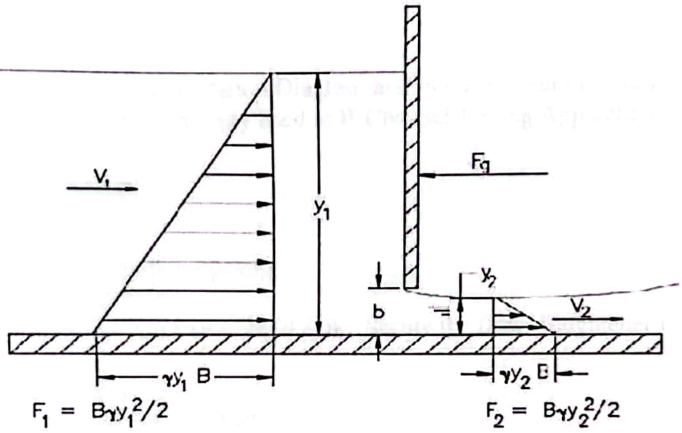

Figure 1: Momentum Theorem Diagram for Sluice Gate Model

Where: B = width of channel; y_1 = upstream height; y_2 = downstream height = bC_c
C_c = Contraction Coefficient; γ = specific weight of fluid; ρ = density of fluid
Fg = Force of water on sluicegate

From Figure 1, the continuity equation is

$$Q = V_1 y_1 B = V_2 y_2 B$$

For the assumptions mentioned above, the Bernoulli equation is valid. For a 0% slope bed:

$$(V_1^2 / 2g) + y_1 = (V_2^2 / 2g) + y_2$$

Combining these:

$$V_1 = \sqrt{\frac{2g(y_1 - y_2)}{(\frac{y_1}{y_2})^2 - 1}} \text{ (ft/sec)}$$

And

$$V_2 = V_1 (y_1/y_2) \text{ (ft/sec)}$$

The momentum theorem, based on the above assumptions is:

$$B\gamma y_1^2/2 - B\gamma y_2^2/2 - F_g = V_1 y_1 B\rho (V_2 - V_1)$$

Therefore:

$$F_g = \tfrac{1}{2}\gamma B (y_1^2 - y_2^2) - \rho Q (V_2 - V_1) \qquad \text{(Equation 1)}$$

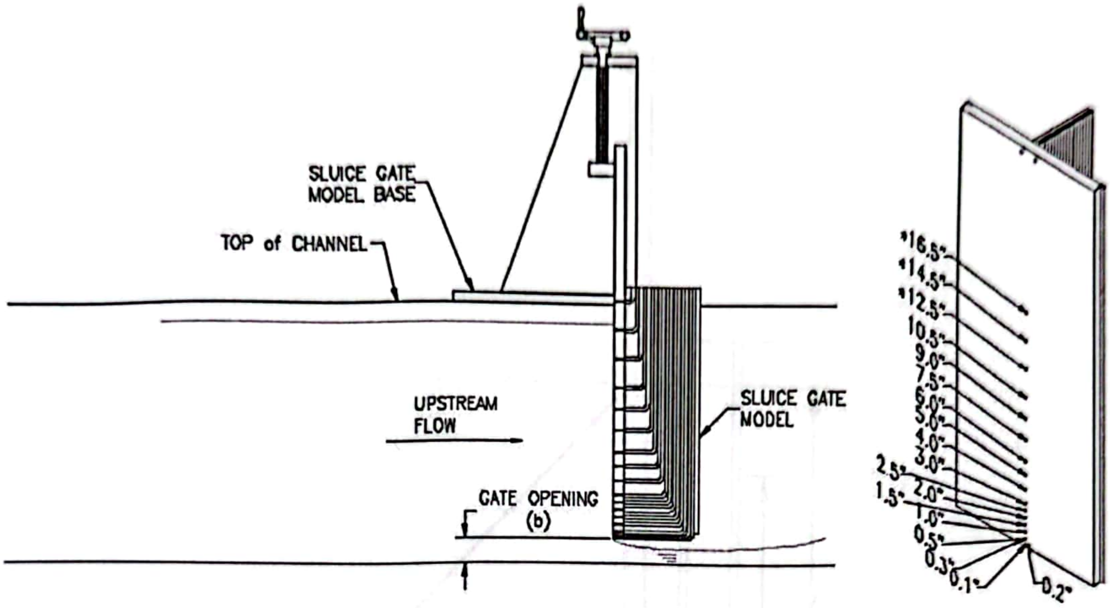

Figure 2: Sluice Gate Model Installation Diagram and Initial Pressure Locations in inches
(* Pressure Locations only used in B-Channel Testing Apparatus)

Suggested Experimental Procedure

1. Initial settings (Fig. 2):
   a. Raise headgate to maximum opening.
   b. Lower tailgate completely.
   c. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   d. Set channel to 0% slope.
   e. Install gauge carriage onto channel.
   f. Install point gauge onto carriage.
   g. Set channel valve(s) for low flow rate.
2. Install the sluice gate model mid way along channel section, at a position that the manometer tubes are clearly visible from the side. Secure with C clamps along the channel top aluminum support rails
3. Set the sluice model gate opening to a small height above the channel floor (b =~ 0.50").
4. Start the pump(s). Adjust the flow rate valves to set a given upstream water height in the channel. Mark the channel sidewall with the water height for later use using the point gauge.
5. Measure the pressure on the gate face by measuring and recording the height of each water column (h) (Fig 3) minus their initial height locations shown in (Fig 2).
6. Raise the gate to a larger opening (b).
7. Increase the Pump(s) flow rate until the upstream water height is at the same height as the point gauge in Step 4.
8. Measure the pressure on the gate face by measuring and recording the height of each water column (h) (Fig 3) minus their initial height locations shown in (Fig 2).
9. Determine the total force on the sluice gate by graphically plotting a load diagram and measuring the area, (Fig. 3).
10. Analytically determine the force on the gate by equating the hydrostatic and momentum forces on each side of the sluice gate using equation 1.

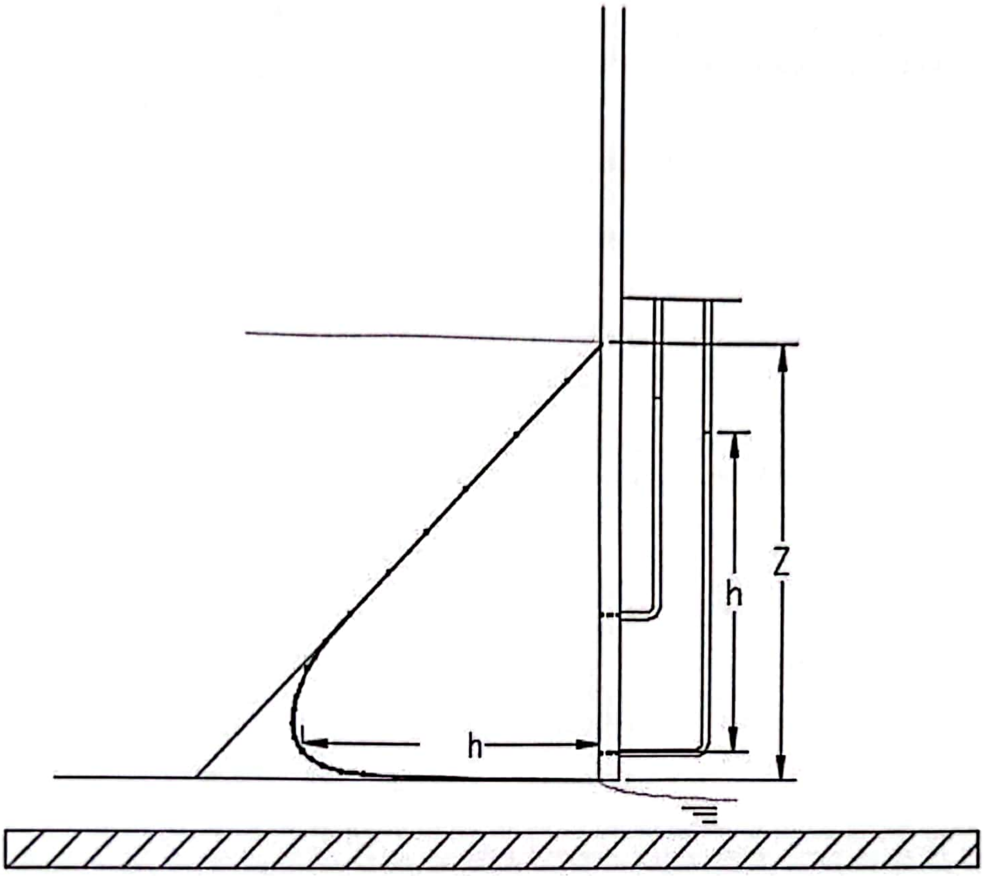

Figure 3: Sluice Gate Pressure Measurements

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SPILLWAY SECTION MODEL

A spillway is a method of channel control. The model is used to develop a head/discharge curve and a coefficient of discharge. The model represents a classical Waterways Experiment Station (WES) ogee type spillway. The flow rate relationship is:

$$Q = C_d h \sqrt{2gh}$$

where:

Q:	volume flow rate (ft^3/s)
C_d:	coefficient of discharge
g:	gravitational acceleration, $32.2 ft/s^2$
h:	head measurement from crest of model (ft)

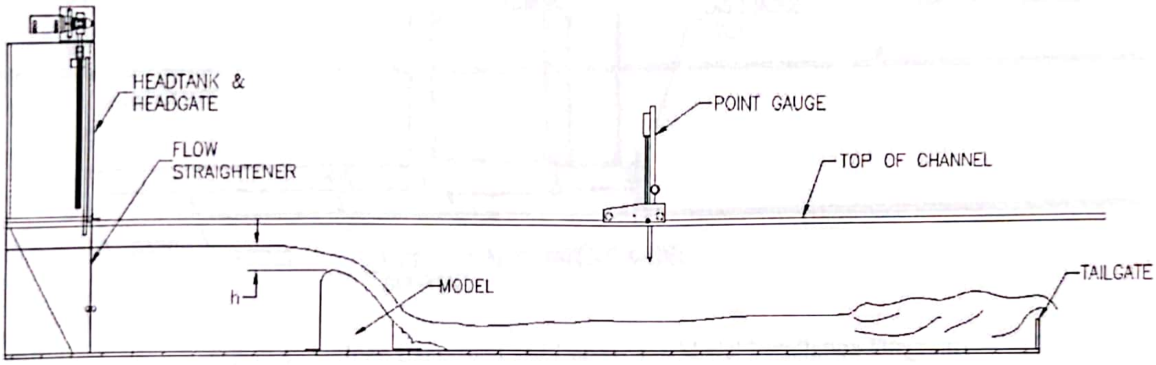

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise headgate to maximum opening.
   b. Lower tailgate completely.
   c. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   d. Set channel to 0% slope.
   e. Install gauge carriage onto channel.
   f. Install point gauge onto carriage.
   g. Set channel valve(s) for low flow rate.
2. Mount the spillway section model midway in the channel using four (4) #10-24UNC-2A x 0.5" long Round Head Machine Screws (RHMS) at the flanges.
3. Establish a measurement 'zero', or datum, at the crest of the model using the point gauge.
4. Start the pump(s).
5. Measure and record the flow rate using the orifice meter and manometers.
6. Measure and record 'h' using the point gauge at a location far enough upstream so as not to be in the draw down area.
7. Set a new flow rate and repeat measurements.
8. Plot a head, H vs. discharge, Q curve.
9. Determine the coefficient of discharge C_d and compare to the above relationship:

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SUDDEN EXPANSION AND CONTRACTION MODEL

The sudden expansion and contraction model demonstrates the effect of energy content of a sudden expansion and contraction in a conduit. Along with the rapid changes in momentum are associated turbulence and energy loss in the separation zone.

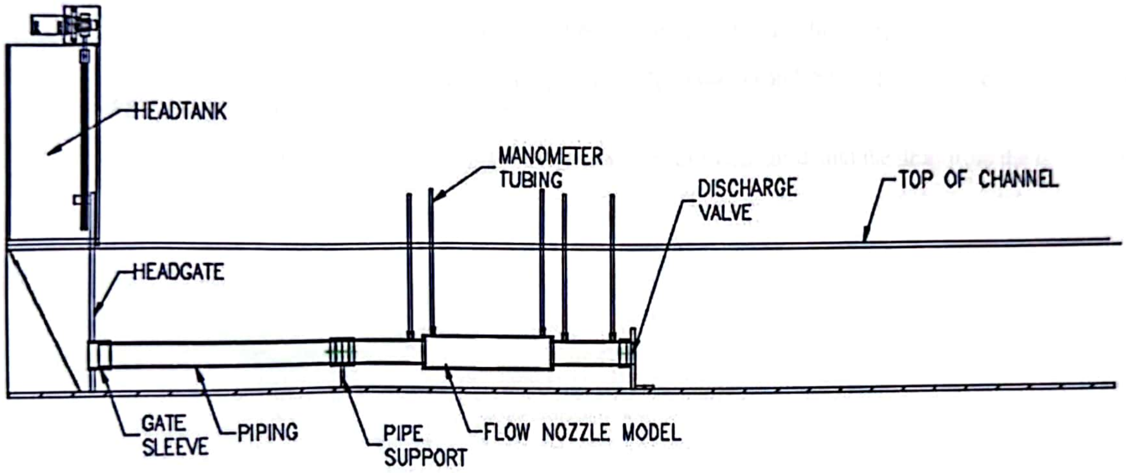

Figure 1: Sudden Expansion and Contraction Model Installation Diagram

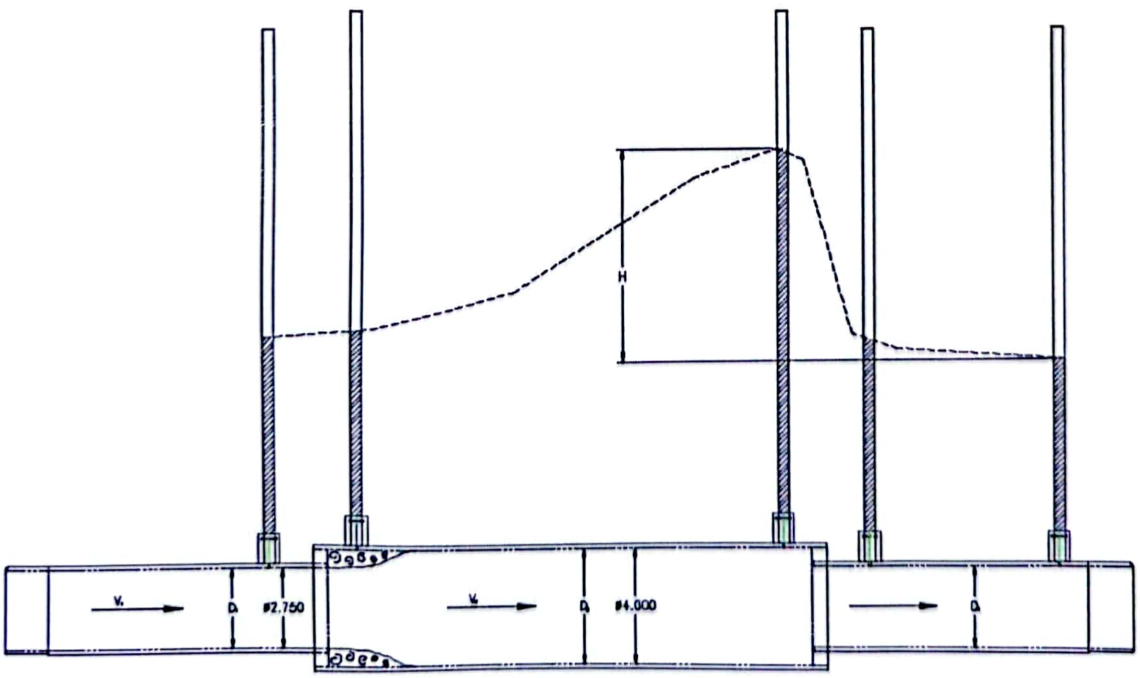

Figure 2: Detail of Sudden Expansion and Contraction Model

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Install piping sleeve into headgate by removing the plug and sliding the sleeve into the headgate.
   b. Lower the headgate to closed position.
   c. Lower tailgate completely.
   d. Set channel to zero slope.
   e. Set channel valve(s) for low flow rate.
2. Install pipe segment, pipe support, sudden expansion and contraction model and discharge valve into headgate sleeve and onto channel floor. Secure the discharge valve to the channel floor using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS). Engage all o-rings at pipe connections.
3. Open the discharge valve fully.
4. Insert rigid manometer tubes into pressure port bosses until o-rings are fully engaged.
5. Start pump(s). Adjust the discharge valve(s), on both the pump(s) and the model, until there is significant change in manometer tubing pressure levels.
6. Note the rise in pressure from the first upstream manometer to the third, and the drop from the third to the fourth (Fig. 2).

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VEE NOTCH WEIR MODEL

A vee notch weir is a method of open channel flow metering. The discharge, Q, is directly related to the height of the upstream flow, H, above the crest of the weir.

For a given vee notch weir (Fig. 2) of angle θ the discharge relationship is:

$$dQ = C_d X \sqrt{2gy}\, dy = (ft^3/s)$$

$$X = L\,\frac{H-y}{H} = 2(H-y)\tan(\frac{\theta}{2})$$

Substituting and integrating from 0 to H:

$$Q = \frac{8}{15} C_d \sqrt{2g}\ \tan(\frac{\theta}{2}) H^{5/2}$$

For θ = 90°, H=5.969", $Q = 2.5\ H^{5/2}\ (ft^3/s)$

where:

	Q:	volume flow discharge (ft^3/s)
	C_d:	coefficient of discharge
	X:	width of fluid over weir (ft)
	L:	Width of weir (ft)
	y:	depth from top of weir to fluid (ft)
	g:	gravitational acceleration, $32.2 ft/s^2$
	H:	upstream head measurement from weir notch (ft)

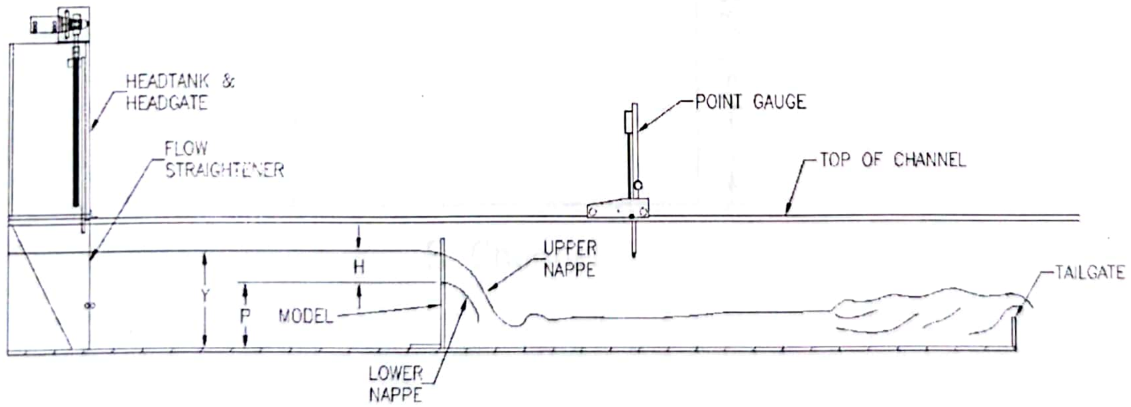

Figure 1 Installation

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise headgate to maximum opening.
   b. Lower tailgate completely.
   c. Install flow straightener at exit of head tank. Secure the flow straightener using the provided C-clamps.
   d. Set channel to 0% slope.
   e. Install gauge carriage onto channel.

f. Install point gauge onto carriage.
g. Set channel valve(s) for low flow rate.

2. Mount the vee notch weir model midway in the channel using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS) on the flange.
3. Establish a measurement 'zero', or datum, at the bottom of the vee of the model using the point gauge.
4. Start the pump(s) and adjust the flow rate to obtain a minimum discharge over the weir with full aeration of the lower nappe.
5. Measure and record the flow rate using the orifice meter(s) and manometer(s).
6. Measure and record 'H' using the point gauge at a location far enough upstream so as not to be in the draw down area.
7. Set a new flow rate and repeat measurements. Repeat at several different flow rates.
8. Plot a head, H, vs. discharge, Q, curve on semi-log paper.
9. Compute the discharge coefficient and head term exponent from the discharge curve and compare to the above relationships.

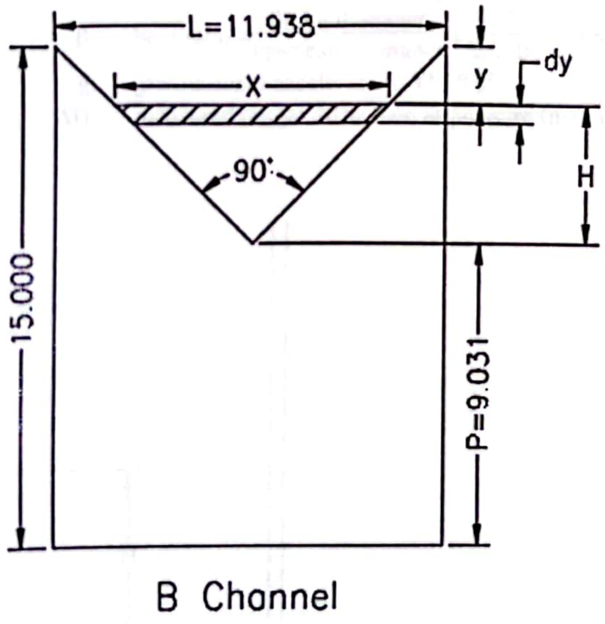

Figure 2 Weir

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VENTURI METER MODEL

A venture is a method of flow metering, based on the Bernoulli equation. The flow rate, Q, is directly related to the pressure differential of the upstream section and the throat of the venturi meter. The flow rate relationship is is expressed as follows:

$$\Delta H = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \text{ (Bernoulli equation)} \qquad Q = V_2 C_d A_2 = V_1 A_1 \text{ (Continuity Equation)}$$

Combining:

$$Q = K A_2 \sqrt{2g\Delta H} \text{ (ft}^3\text{/s)}$$

Where:

- Q: volumetric flow discharge (ft^3/s)
- C_d: discharge coefficient
- K: Discharge coefficient ($\frac{C_d}{\sqrt{1-\beta^4}}$)
- A_2: area of venturi throat (ft^2) (Fig. 1) = 0.0103 ft^2
- β: beta ratio $= \frac{\text{throat diameter}}{\text{upstream diameter}} = \frac{1.375''}{2.750''} = 0.50$
- g: gravitational acceleration, 32.2 ft/s^2
- ΔH: measured height difference in pressure (manometer) tubing (ft)

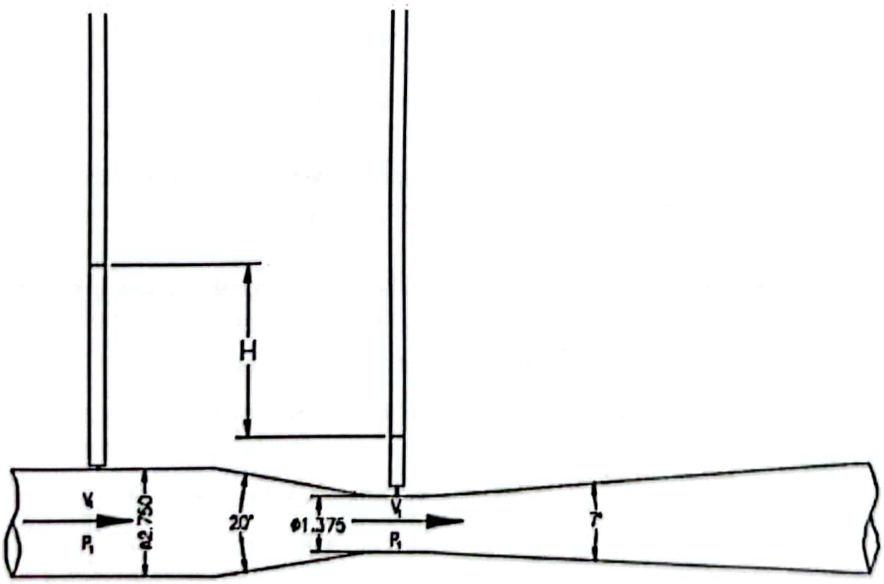

Figure 1: Detailed Diagram of Venturi Model

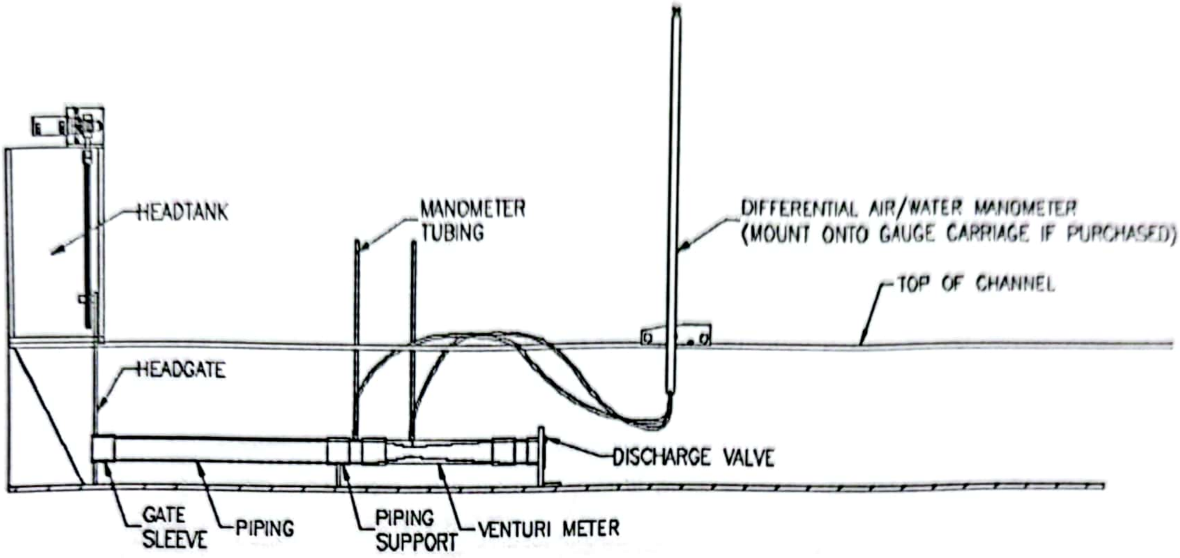

Figure 2: Venturi Meter Model Installation Diagram

Suggested Experimental Procedure

1. Initial settings (Fig. 2):
   a. Install piping sleeve into headgate by removing the plug and sliding the sleeve into the headgate.
   b. Lower the headgate to closed position.
   c. Lower tailgate completely.
   d. Set channel to 0% slope.
   e. Install gauge carriage onto channel.
   f. Set channel valve(s) for low flow rate.
2. Install pipe segment, pipe support, venturi and discharge valve into headgate sleeve and onto channel floor. Secure the discharge valve to the channel floor using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS). Engage all o-rings at pipe connections. Open the venturi discharge valve fully.
3. Attach differential manometer to gauge carriage using provided bracket post. Connect flexible tubing to venturi and barbed, manometer fittings. Alternatively, install rigid manometer tubes into venturi pressure port bosses.
4. Start pump(s) and regulate the discharge to give the minimum flow through the system. Close the discharge valve until the venturi operates full.
5. Flush air out of differential manometer and manometer tubing to insure accurate pressure readings.
6. Measure and record the difference in pressure through the venturi meter. Measure and record the flow rate through the channel orifice meter(s).
7. Repeat the pressure measurement at a variety of flow rates.
8. Plot the flow rate, Q, vs. pressure difference, ΔH, on semi-log paper.
9. Determine the discharge coefficient.

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WAVE GENERATOR MODEL

The wave generator model demonstrates the characteristics of waves and the effect of either a solid or porous beach on the waves.

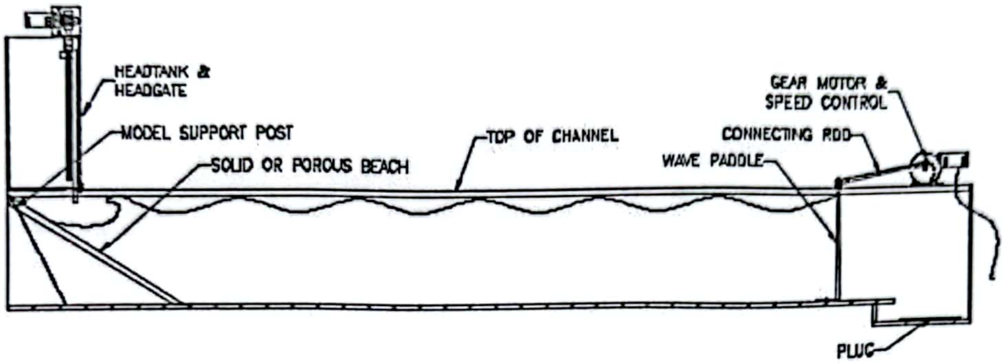

Figure 1: Wave Generator Model Installation Diagram

Suggested Experimental Procedure

1. Initial settings (Fig. 1):
   a. Raise the headgate to fully open position.
   b. Set channel to 0% slope.
   c. Raise the tailgate completely.
   d. Install the plug into channel drain under the tailgate.

2. Mount the wave paddle to the downstream floor of the channel using two (2) #10-24UNC-2A x 0.625" long Round Head Machine Screws (RHMS) into the last bolt location. Orient the base and paddle as shown.

3. Mount the motor and flywheel base plate assembly to the top of the channel, at the downstream end, using the thumbscrew. Orient the assembly as shown with the connecting rod parallel with the centerline of the channel.

4. Connect the wave paddle rod to the flywheel in any of the seven (7) threaded holes. Tighten fully and secure the lock nut.

5. Connect the wave generator motor to an 115V/1ϕ/60Hz grounded electric service.

6. Mount either the solid or permeable beaches at the upstream end of the channel. Place the top edge between the aluminum retaining posts and the perforated plate. Secure the base to the channel floor using two (2) #10-24UNC-2A x 0.25" long RHMS.

7. Start the pump(s) and fill the channel approximately 1/2 to 2/3 full or a desired depth. Close off the flow valves and stop the pump(s).

8. Wave frequency may be varied with the speed controller on the downstream end of the motor. Wave amplitude may be varied by changing the connecting rod position on the flywheel.

9. Drain the channel by opening the flow valves or removing the downstream plug.

10. Change out the beach and demonstrate wave variations due to beach permeability.