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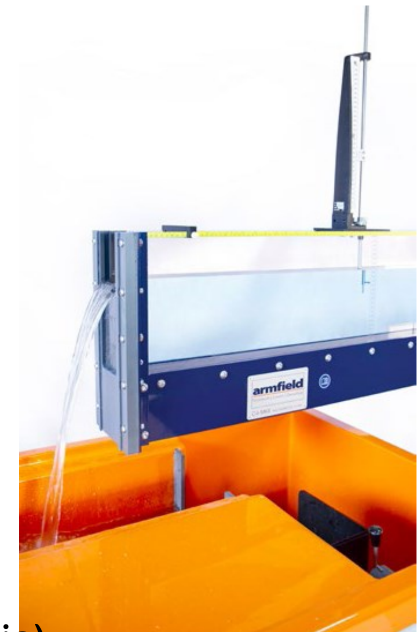


Department of Civil Engineering

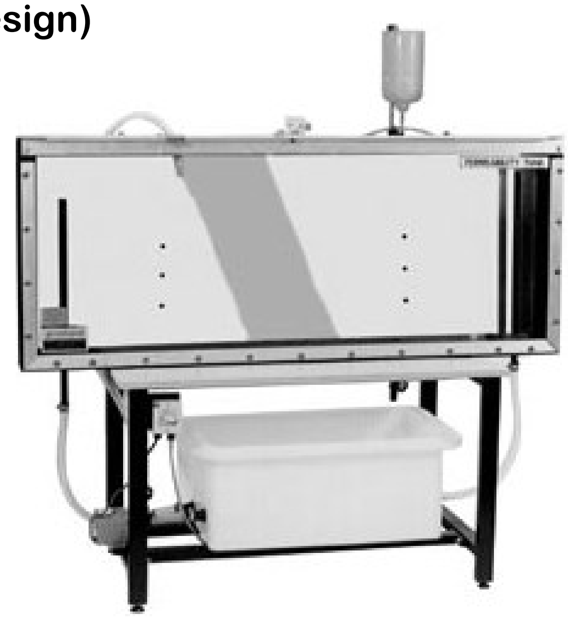
Hydraulics Lab Manual

Courses:

CE 332 (Engineering Hydrology and Hydraulic)

&

CE (438 Hydraulic Systems Design)



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Introduction

Hydraulics Lab: This lab serves the **elective** course CE 438 (Hydraulic Systems Design) & CE 332 (Engineering Hydrology and Hydraulic). In this lab, the students perform calculations of simulated rainfall intensity and uniformity variations with increasing of the disc aperture, understand about the generation of overland flow & flow through closed conduits. Furthermore, the students will perform experiments in order to develop the clear understanding of open channel flow phenomena and the formation of a hydraulic jump. Moreover, students perform few experiments related to flow under a sluice gate, flow over the broad crested weir, discharge beneath a sluice gate & seepage underneath a sheet pile wall.

1 EXPERIMENT

Hydraulics Lab

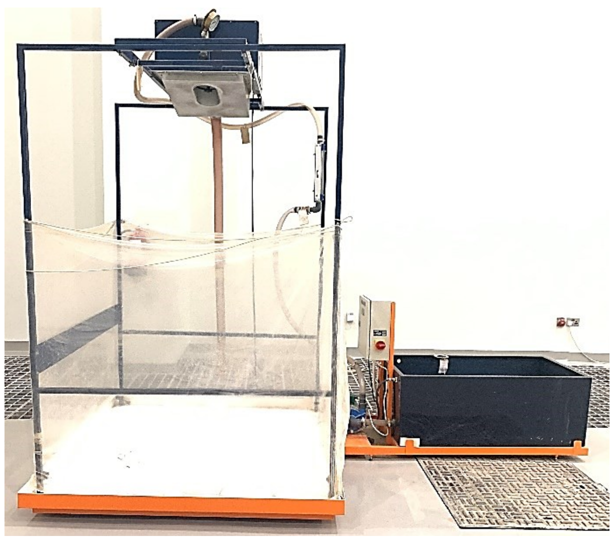
Calculations of Simulated Rainfall Intensity and Uniformity Variations with Increasing of the Disc Aperture

Objective:

- To assess the variation in intensity and uniformity of simulated rainfall with increasing disc aperture.

Apparatus:

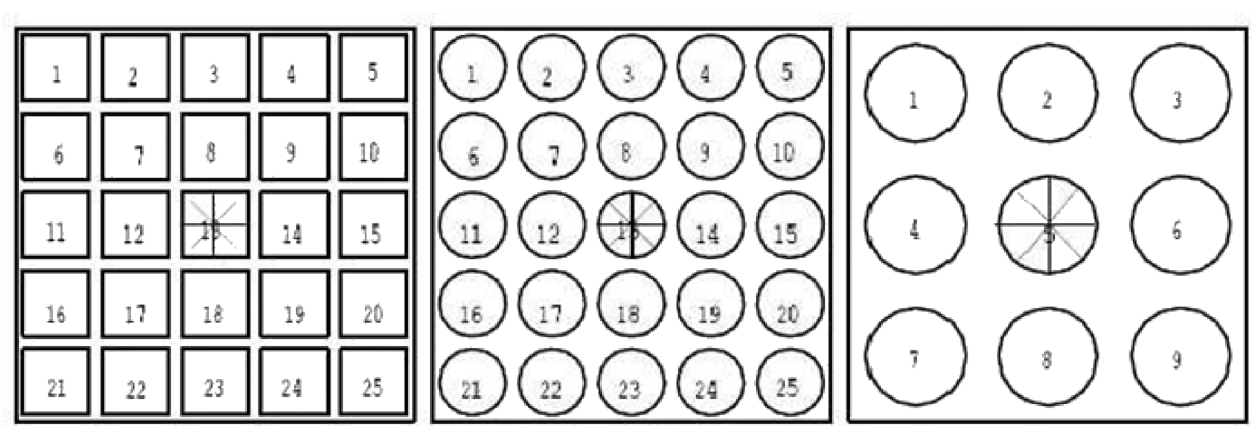
- ARMFIELD Rainfall Simulator (FEL3) is used for the experiment.



ARMFIELD Rainfall Simulator (FEL3)

- The equipment ARMFIELD Rainfall Simulator (FEL3) consists essentially of two units, the Rainfall Simulator and its service module which stands alongside. The service module comprises a glass fibre tank which is connected to the mains water supply via a ball-cock to maintain the level.
- Water is pumped from the tank to the rainfall simulator by a centrifugal pump and flexible PVC tube. The service module also carries the electrical control panel for the water pump and for the motor-driven spray head on the simulator.

- The simulator proper is made up of a metal framework supporting the spray head assembly, which may be either placed directly on the ground for field studies or fitted into a tray for indoor experiments. The framework is complete with spray-containing PVC curtains.
- Water from the supply unit is controlled by a flow control valve and measured with a flowmeter, both mounted on the simulator framework. Flow is supplied to a vertically orientated nozzle directed downwards and adjustable in height. Two nozzles are supplied for different water flow rates and pressure at the nozzle is indicated on a pressure gauge in the nozzle spray.
- Water from the nozzle is intercepted by a horizontal disc driven by an electric motor mounted above. The disc is made up of two circular plates each of which have three segmented apertures of 40° in it. If these discs are clamped together with the apertures aligned then an effective aperture of 40° results. The discs may be clamped in position to give apertures ranging from 5° to 40° in 5° steps, the aperture angle being read off a scale. The upper edges of the apertures are raised to stop water falling through the apertures from the top surface of the discs.
- Water from the nozzle which is intercepted by the disc is thrown off centrifugally into a collector and returned to the supply tank via a plastic tube.
- The speed of rotation of the disc system is controlled with a motor speed controller on the electrical control panel which also has a speed indicator.



Equipment Set Up:

- Position the centre of the test table directly below the nozzle using a plumbline.
- Place a grid of suitable containers upon the test table in a configuration similar to one
- shown above. Containers may be round or rectangular and of any convenient size. Small rain gauges or measuring cylinders are ideal. Number each container and
- clearly mark its position.
- Additional Equipment:-Wooden board approx. 0.6m x 0.6m; accurate measuring cylinders 500ml or 1000ml capacity; stop watch.

Theory:

- There is a close association between rainfall intensity and soil erosion - in general, the higher the intensity the greater the erosion.
- For a given Pressure-Flow-Disc speed combination the intensity of simulated rainfall is controlled by aperture size. Large disc apertures allow more "rain" to strike the test area increasing the intensity of the rainfall.

- Intensity (I) is usually expressed as a depth of water falling in unit time eg. 100mm/hr, and can be calculated using the equation:

$$I = Q * 600 / (A * t)$$

Where

Q = Volume of water in each container (ml)

A = Area of container (cm2)

t = Time (mins)

I = Intensity (mm/hr)

- The uniformity of distribution of simulated rainfall on the test area is important since lack of uniformity may give unreliable results. Uniformity may vary with pressure, disc speed and aperture size. A measure of uniformity is given by Christiansen's Coefficient (Cu) which is calculated from the following formula:

$$Cu = 100 * (1 - x)/(m * n)$$

Where:

  - m = mean of observed depths
  - n = number of observations
  - x = deviation of individual observed depth from the mean.

Initial values of variables to be used

  - Pressure Gauge = 0.4 bar
  - Disc Rotation Speed = 100 rev/min
  - Disc Aperture = 10°

Readings to be taken:

- Cover the collecting vessels with a wooden board and operate the simulator at the selected values until a steady state is attained. Remove the board and start the stop watch simultaneously. Allow rainfall to strike the target for the desired storm duration, eg. 10 mins. Cover the collectors with the wooden board and close down the simulator.

- The volume of water in each container is then measured with the measuring cylinder. Note the cross-sectional area of the collector.

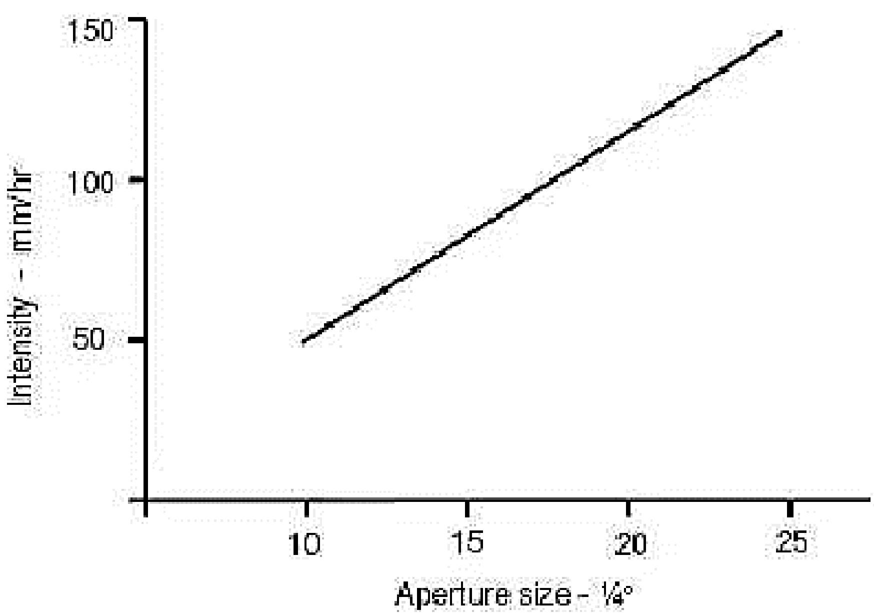
- Repeat the experiment for disc apertures of 15°, 20°, 25°, 30°.

Results:

- Construct a table of results similar to that shown below:

		Collected Volume (ml)				
Disc Aperture (°)		10	15	20	25	30
Container No,	1					
Total Volume (ml)						
Ave Intensity mm/hr						
Uniformity (Cu)						

- Plot a graph of intensity against aperture size:



- Students may wish to map the uniformity distribution and locate areas of greatest intensity and/or uniformity.

- Students may also wish to assess the effect of pressure and disc speeds on uniformity and intensity.

2 EXPERIMENT

Hydraulics Lab

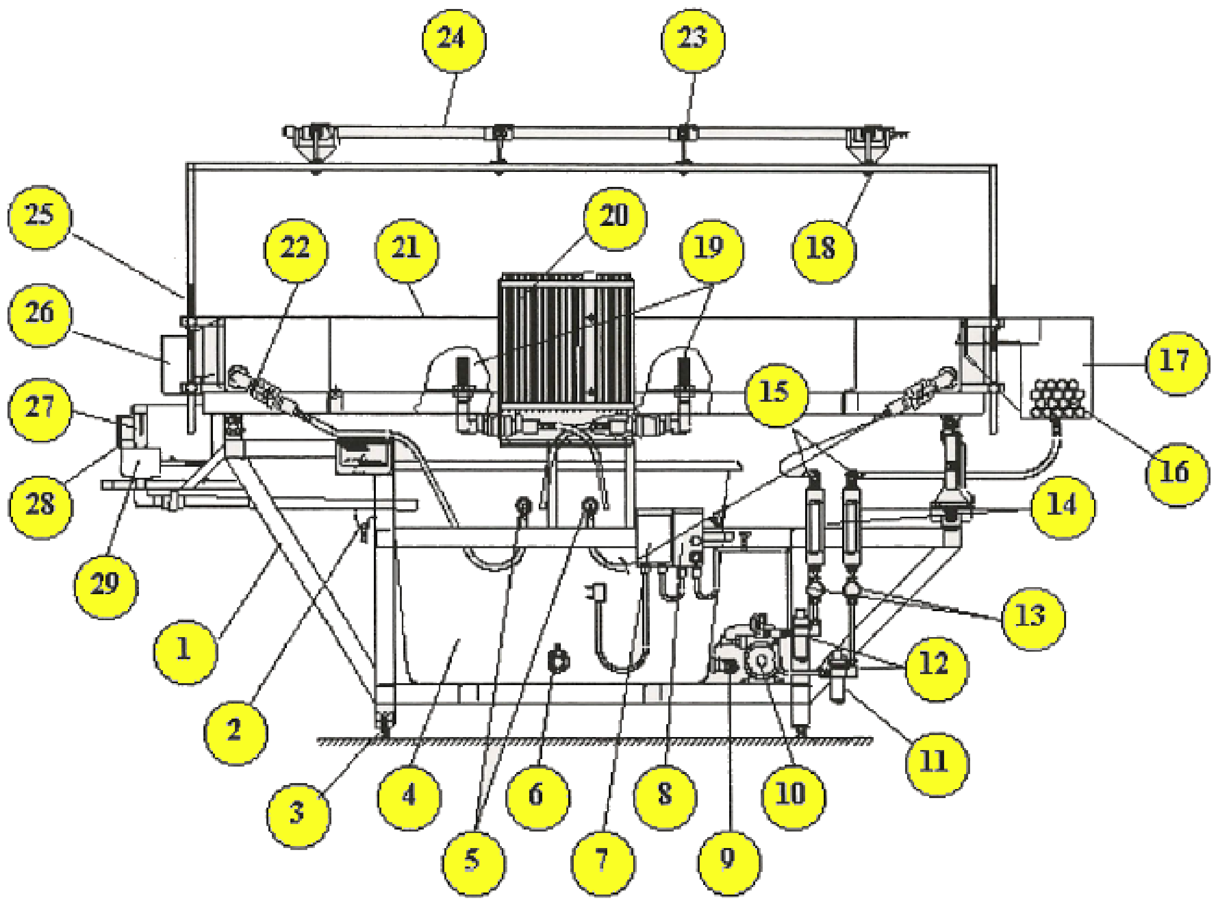
Generation of Overland Flow

Theory:

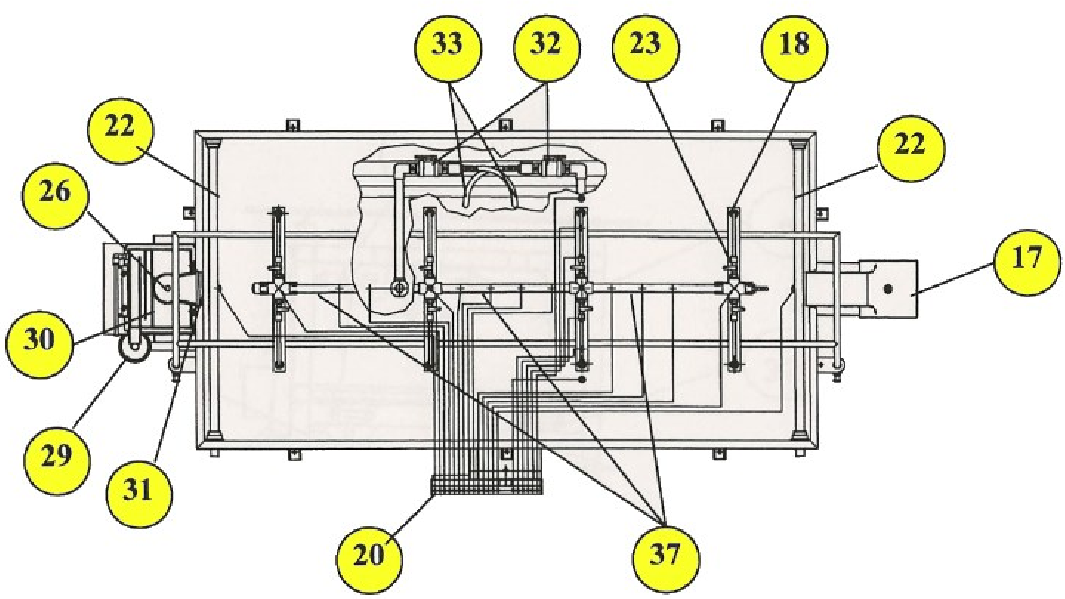
- Overland flow is the rainfall that fails to infiltrate the surface and subsequently travels over the ground until it reaches channel flow, infiltrates or evaporates. It is rarely seen, but may be important in a number of situations, for example, where ground conditions are saturated or frozen, or where the soil is highly compacted or very dry.
- Overland flow generally forms part of the quick flow element of the runoff process, and can vary considerably from catchment to catchment. The process of overland flow has important hydrological consequences, as it acts as a strong influence on the variation of streamflow with time in a catchment corresponding to a rainfall event.

Apparatus:

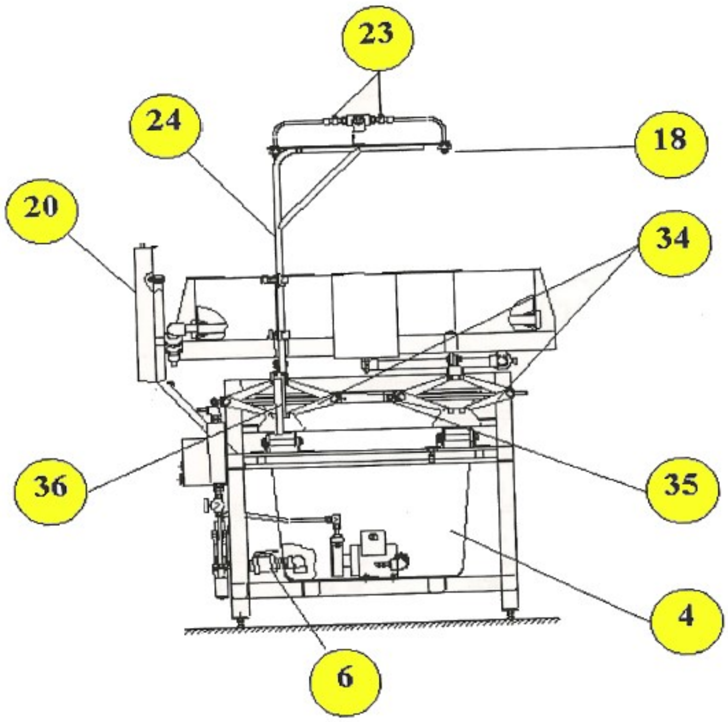
ARMFIELD Hydrology System S12-Mkll



Front View



Plan View



End View

Hydrology System S12-Mkll consists of a sand tank (21) that is mounted on a support frame (1) with the necessary services, features and with the following instrumentations:

Frame

- The frame incorporates an adjustable foot (3) on each leg to allow the equipment to be levelled. It is suggested that the top edge of the sand tank (21) be used as the datum when levelling the equipment.
- The frame incorporates a pair of scissor type jacks (34) at one end that allow the sand tank to be elevated. The jacks are linked so that the sand tank remains stable when raising or lowering. An indicator (36) shows the gradient of the sand tank. The jacking handle is simply inserted into the coupling (35) on the front jack and rotated clockwise to raise the sand tank or anticlockwise to lower the sand tank. The jacking handle should be removed after adjusting the elevation of the sand tank.

Water Feeds

- A sump tank (4) and centrifugal pump (10) mounted in the frame, beneath the sand tank, provide the water for the various demonstrations. Water exiting the sand tank from the various outlets returns to the sump tank under gravity for reuse if the equipment is self-contained. An overflow pipe (2) on the side of the side of the sump tank ensures that the tank cannot be overfilled. A drain valve (6) is connected to a tapping at the base of the sump tank.. Water from the pump passes through two parallel feed arrangements, each incorporating a filter (12), pressure regulator (11), feed flow control valve (13) and variable area flowmeter (14). The pressure regulator in each feed ensures that the flow is not affected by changes in the other feed provided that the regulator is adjusted to suit. The outlet from each feed is terminated with a self-sealing quick-release connector (15) that allows water to be fed to either end of the sand tank, the spray nozzles or the river inlet tank as required via the appropriate flexible connection. The self-sealing quick-release connectors allow rapid changes to the configuration without the need for tools.
- The electrical control box is mounted on the frame below the sand tank and incorporates a starter (7) for the pump and an Residual Current Device (RCD) (8) to protect the operator against electrical shock.
- The electrical control box is mounted on the frame below the sand tank and incorporates a starter (7) for the pump and an RCD (8) to protect the operator against electrical shock.

Sand Tank

- The shallow sand tank (21) is fabricated from stainless steel for corrosion resistance. An array of tapping points (37) in the sand tank floor is connected to a multi-tube manometer (20) that enables the water table surface (phreatic surface) to be determined. The level in each tube can be read by sliding the common scale along the track at the top of the manometer. Before using the manometer to measure water levels it is important to expel air from the flexible tubes connecting the manometer tubes to the tapping points. Each tapping (37) in the sand tank floor incorporates a filter mesh to retain the sand while allowing the water to flow. Two cylindrical wells (19) are also included in the sand tank floor. The wells are covered with stainless steel mesh to prevent the loss of sand.

- Valves and pipework beneath the sand tank allow the water draining from each well to return to the sump tank
- A perforated pipe (22), in the form of a French drain, is buried in the sand at each end of the sand tank. These allow water to be drained from the sand tank or admitted to the sand tank as required. Each French drain is connected through the side wall of the sand tank to a flexible tube terminated with a self-sealing quick-release connector.
- When it is required to drain water from the sand tank the flexible tube is connected to one of the quick-release connectors (5) on the side of the sump tank, allowing the water to return to the sump tank. The flow of water can be varied using the in-line valves (32). When it is required to admit water to the sand tank the flexible tube is connected to one of the water feeds via the quick-release connector (15).
- A deep cut-out (31) at the left-hand end of the sand tank allows water (and transported sediment) to leave the sand tank.

Outlet Collecting Tank

Water and sediment exiting the sand tank via the diffuser is deposited into the outlet collecting tank: (28) that is designed to measure the flow of water and collect any sediment washed from the sand tank. This tank is fabricated from clear acrylic and incorporates the following features:

- The water and sediment fall into the open area of the tank A vertical mesh screen (30), supported by perforated plates on either side, ensures that sediment is retained in the tank. The water flows through the mesh, along a stilling channel then over a narrow rectangular notch (31) before discharging into a funnel (29) that returns the water to the sump tank for re-use. The flowrate of the water is determined from the height of the water upstream of the notch using an inclined manometer that incorporates a scale calibrated directly in litres/min. The manometer is mounted directly on the side of the outlet collecting tank.
- Sediment falling into the tank is deposited in the bottom of the tank. The sand can be removed by lifting the tank clear from its support. If it is required to collect the sand for quantitative measurements then a piece of fine cloth or a small strainer can be positioned beneath the diffuser to collect the sediment. If this is changed at regular intervals then the rate of accumulation of the sediment can be determined.

Overhead Spray Nozzles

- Rainfall onto the catchment area is provided by two rows of four spray nozzles (18) above the tank, mounted on a support frame (24). The height of the spray nozzles above the sand tank can be varied to optimise the demonstration by adjusting the height of the support frame. This is achieved by withdrawing the spring-loaded plunger (25) at each end, raising or lowering the support frame to the required height, then re-locating the spring loaded plunger in the appropriate hole. One person at each end of the equipment should hold the support frame while performing the adjustment.
- An isolating valve (19) upstream of each nozzle allows the pattern to be changed as required. Since the flowrate through each nozzle is dependent on the pressure, if the appropriate pressure regulator (12) is adjusted to give the required flowrate then the flow through each nozzle will remain constant when other nozzles are turned on or off.
- The flexible tube from the arrangement of spray nozzles is connected to one of the water feeds, when required, using the self-sealing quick release connector (15). The height of the nozzles should be adjusted at the required flowrate to give adequate coverage over the surface of the sand without excessive spray over the sides of the sand tank as described above.

River Inlet Tank

- A river inlet tank (17) mounted at the right-hand end of the sand tank allows a stream of water to flow onto the surface of the sand, simulating the flow from a river upstream. The river inlet tank is fabricated from stainless steel and is bolted to the end wall of the sand tank adjacent to the shallow cut-out. Water enters at the base of the tank, flows upwards through a bed of glass marbles (16) to minimise any turbulence then flows sideways onto the surface of the sand through a rectangular section.
- An anti-erosion mat (small section of mesh) is supplied to reduce any local scour where the water enters the sand tank. This mat is buried just beneath the surface of the sand adjacent to the outlet of the river inlet tank.
- The flexible tube from the base of the sand tank is connected to one of the water feeds, when required, using the self-sealing quick release connector (15).

Procedure:

- Connect the flexible piping from the overhead spray nozzles to the quick release connector on the 3 l/min flow meter.
- Set the sand tank to a slope of between 3.5% and 4.5%. Mould the sand into a miniature drainage basin. This should include a central channel or valley leading to the deep cut-out at the foot of the tank. Include areas where overland flow would be expected to form, such as areas close to the water table and/or areas of flow convergence. Keep the topography simple to allow a clear drainage system to develop. Record the topography created, noting areas of high and low slope and elevation.
- Decide on the rainfall event to be simulated. The following options are all possible:
    - Prolonged low-intensity rainfall
    - Short high-intensity rainfall
    - Alternating intensity rainfall
    - Multiple rainfall events
- Observations of the sediment bed should be made throughout the simulation, noting the rainfall flow rate, outlet flow rate, and when and where the development of overland flow was seen.
- The development of source areas should also be recorded once overland flow has commenced.
- At the end of the rainfall event, observations should continue until the simulator has drained for 30-45 minutes.
- The experiment may be repeated with a variation in a single characteristic, such as rainfall intensity or topography, to determine the effects of these controls.

Results:

Description of catchment area and initial channel planform:

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Diagram of catchment area:

Time Since Start of Run (secs)	Rainfall Flow Rate (l/min)	Tank Outflow Rate (l/min)	Location and Direction of Overland Flow, including Source Areas (use references to diagram above)

Time Since Start of Run (secs)	Rainfall Flow Rate (l/min)	Tank Outflow Rate (l/min)	Location and Direction of Overland Flow, including Source Areas (use references to diagram above)

Conclusions:

- What conditions produced the best examples of overland flow?
- What factors may have contributed to its development?
- Did overland flow appear to produce significant surface erosion or channel planform change?
- Suggest ways in which overland flow could be reduced or prevented.

3 EXPERIMENT

Hydraulics Lab

Introduction to Flow through Closed Conduits

Objective:

To demonstrate visually the various phenomena and characteristics associated with water flowing through a closed conduit.

Method:

By operating the working section flooded to create a closed conduit and varying the height of the adjustable bed to change the cross sectional area.

Equipment Required:

- Armfield S16 Hydraulic Flow Demonstrator (S16-10 or S16-11)
- Armfield F1-10 Hydraulics Bench
- Stopwatch to measure flowrate when using the volumetric tank on F1-10

Armfield S16 Hydraulic Flow Demonstrator with Hydraulic Bench

Equipment Set Up:

Inlet valve and outlet control valves fully closed (no flow). Ensure that sluice gate (undershot weir) at inlet is fully raised and overshot weir at outlet is fully lowered.

Procedure:

- Raise middle Pitot tube until tip is 130mm above the bed then raise elevating section of bed until 110mm above the bed (Conduit reduces from 150 mm to 40 mm then returns to 150 mm).
- Locate upstream and downstream Pitot tubes 75mm above bed (mid height in each section). Ensure all three Pitot tubes point directly upstream.
- Confirm that level in all manometer tubes is the same with water stationary (Re-prime if levels are not the same).
- Switch on F1-10 and open F1-10 flow control valve fully.
- Gradually open inlet flow control valve on S16 to fill end tanks and working section until working section is full. Gradually open outlet control valve and open inlet control valve together to maintain level inside end tanks while allowing flow through working section.
- Increase flow until maximum is achieved without overflow operating (Outlet valve partially restricted to maintain working section full of water, inlet valve fully open).
- Allow flow to stabilise in working section and allow manometer levels to settle.
- Observe that static head at throat (contraction above elevating section of bed) is reduced below levels in inlet and outlet tanks. Also observe that total head at contraction is same as total head upstream (Bernoulli equation can be applied across a contraction).
- Observe that there is a small loss in total head between throat and outlet of working section because of frictional losses in the expansion (Bernoulli equation cannot be applied across an expansion without accounting for losses).
- Lower bed to mid height. Observe that static head at throat increases and frictional loss reduces because of reduced velocity.
- Lower bed to lowest position (0 mm on scale). Observe that piezometric and total head is constant at three positions in working section (minimal loss because of very low velocity).

- This simple demonstration illustrates how change in fluid velocity in a closed conduit affects the static and total head in the system. Frictional losses (especially significant where an expansion is involved) cause the static head and total head to reduce from inlet to outlet in the system (head is lost).

Conclusions:

- Changes in velocity and therefore velocity head cause the static head and the total head to change.
- Friction in the system (especially at an expansion) causes the total head and therefore the static head to fall slightly in the direction of flow due to losses in the system.
- Higher fluid velocity causes increased losses.

4 EXPERIMENT

Hydraulics Lab

Introduction of the Open Channel Flow by configuration of the Hydraulic Flow Simulator

Objectives:

- To correctly configure the Hydraulic Flow Simulator S16 for demonstrations involving water flowing through an open channel.
- To demonstrate visually the various phenomena associated with water flowing through an open channel.

Methods:

- Preparing the S16 in order to show the open channel flow phenomena.

Equipment Required:

- Armfield S16 Hydraulic Flow Demonstrator with:
    - Sharp Crested Weir, Broad Crested Weir models
- Armfield F1-10 Hydraulics Bench
- Wetting agent or surfactant to reduce surface tension in the water
- Stopwatch to measure flowrate when using the volumetric tank on F1-10

Equipment Set Up:

- Locate S16 at left hand side of F1-10 with outlet from channel and separate overflow above channel in top of F1-10.
- Fit outlet control valve to discharge end of channel and tighten all thumb nuts.
- Fit removable cover to top of working section and tighten all thumbnuts.

- Open outlet valve fully (discharge end of channel).
- Close inlet valve fully (above flowmeter).
- Close F1-10 flow control valve fully.
- Raise sluice gate (undershot weir) fully (inlet end of channel).
- Lower overshot outlet weir fully (discharge end of channel).
- Lower adjustable section of bed to its lowest position (0 mm on scale)
- Lower all three Pitot tubes flush with bed.
- A few drops of wetting agent or surfactant in the F1-10 and one drop in each manometer tube will reduce surface tension and aid priming.
- Start F1-10 pump.
- Open F1-10 flow control valve fully.
- Gradually open inlet valve to give steady flow along the bed of the working section (water will discharge into top of F1-10).
- Allow air bubbles to clear from flexible connection to F1-10.
- Armfield Instruction Manual
- Gradually close outlet control valve until fully closed to flood channel
- Gradually close inlet control valve and fully close valve when water level reaches overflow on inlet tank.
- Raise and lower elevating section of bed several times to displace any trapped air.
- Allow level to stabilize in end tanks then prime bed tappings.
- When fully primed all levels should coincide with levels in inlet tank and outlet tank.
- Open discharge valve to lower water level below roof of working section. Close outlet valve to leave working section filled to approximately 100 mm depth.
- Gradually open inlet valve to give a low steady flow and remove the discharge valve, ensuring that the Pitot tubes are kept submerged.
- Note: Cover in roof of working section can be removed for clearer viewing / insertion of models etc. however, care must be exercised not to flood the working section as water will spill from the opening if the water level rises too far.
- The equipment is ready to demonstrate flow in open channels.

Procedure:

- Ensure that all three Pitot tubes are located just clear of the bed.
- Confirm that level in all manometer tubes is the same with water stationary (Re-prime if levels are not the same).
- Switch on the F1-10 and open F1-10 flow control valve fully.
- Gradually open outlet control valve and inlet flow control valve alternately on S16 to maintain level inside depth of water in the working section.
- Gradually open discharge valve until fully open.
- Observe that water level falls until clear of roof of working section (when there is a continuous air space above the water between the inlet and discharge tanks the water is described as having a free surface / open channel flow). The difference in behaviour is dramatic and shown in the following demonstrations.
- With water flowing along the channel observe that three Total heads are relatively high because of high velocity and static heads vary slightly with levels along length of working section.
- Lower the sluice gate (undershot weir) to 15mm and observe the surface of the water and how the water level upstream of the weir rises.

5 EXPERIMENT

Hydraulics Lab

Introduction to Flow Under a Sluice Gate and the Formation of a Hydraulic Jump

Objective:

- To observe the flow patterns associated with the flow of water under a sluice gate (undershot weir) and the conditions required downstream to form a Hydraulic Jump.

Method:

- By using the elevating section of bed installed in the S16 Hydraulic Flow Demonstrator, and inducing a hydraulic jump.

Equipment Required:

- Armfield S16 Hydraulic Flow Demonstrator
- Armfield F1-10 Hydraulics Bench
- Stopwatch to measure flowrate when using the volumetric tank on F1-10

Equipment Set Up

- As described in Experiment 4.

Procedure:

- Ensure that outlet weir is fully lowered and outlet valve is fully open.
- Gradually close inlet valve to give typically 0.8 l/s on flowmeter.
- Gradually lower inlet weir (sluice gate) until tip is 10 mm above bed.

- Gradually raise outlet weir in 5 mm steps causing the water level at the downstream end to rise. At each step allow conditions to stabilise in working section and observe changes in Total and Static heads.
- At some point a hydraulic jump will form whereby the change from ‘fast’ flow to ‘slow’ flow necessitates a rapid dissipation of energy. Observe the differences in heads before and after the jump (High Total Head / Low Static head upstream because of the high velocity and Low Total Head / Higher Static head downstream because of the low velocity).
- Continue to raise the outlet weir in 5 mm steps. At each step allow conditions to stabilize in working section and observe that location of Hydraulic jump moves towards the sluice gate. Also observe changes in ‘total head’ and ‘static head’ at each station.
- At some point the hydraulic jump becomes suppressed and the sluice gate becomes flooded on the downstream side.
- Use the upstream Pitot tube to observe the velocity profile behind the sluice gate (High velocity near the bed reducing quickly with depth).

6 EXPERIMENT

Hydraulics Lab

Flow over the Broad Crested Weir

Objective:

- To determine the relationship between upstream head and flowrate for water flowing over a Broad Crested weir (long base weir).
- To calculate the discharge coefficient and to observe the flow patterns obtained.

Method:

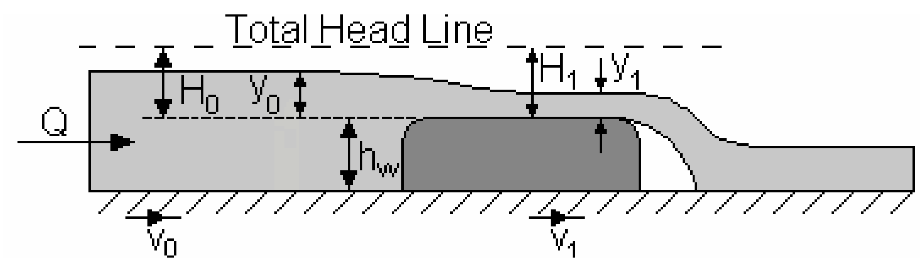
- By using the Broad Crested weir installed in the C4-MkII flume and operating the flume under a range of flow conditions.

Equipment Required:

- Armfield C4-MkII Flume
- Broad Crested Weir model
- Two Hook and Point Gauges, 300mm scale
- Armfield F1-10 Hydraulics Bench
- Stopwatch (for flow measurement using F1-10 volumetric tank)

C4MKII-Multi-Purpose-Teaching-Flume-and-bench

Theory:



From conservation of energy and ignoring losses:

$$H_0 = H_1 = y_0 + V^2_0/2g = y_1 + V^2_1/2g$$

Therefore,

$$V_1 = \sqrt{2g(H_0 + y_1)}$$

The Flow Rate Q is given by:

$$Q = y1\ v1\ b1$$

$$Q = \sqrt{2g(H_0 y_1{}^2 - y_1{}^3)}$$

Provided that the weir is not submerged (downstream water level is low), the flow over a Broad Crested Weir may be assumed to be critical as it passes over the weir. Hence:

$$H_0 y_1{}^2 - y_1{}^3 = Minimum$$

At maximum

$$\frac{dq}{dh} = 0 = 2H_0 y_1 - 3y_1{}^2$$

Therefore,

$$y_1 = \frac{2}{3} H_0$$

Therefore,

$$Q_{max} = b\sqrt{2g(\frac{4}{9}H_0{}^3 - \frac{8}{27}H_0{}^3)}$$

$$= 1.705\ bH_0{}^{3/2}$$

The actual flow over a Broad Crested weir will be less than the theoretical flow so a coefficient is introduced into the equation:

$$Q_{actual} = 1.705\ C_d\ b\ H_0{}^{3/2}$$

Where C_d is the coefficient of discharge.

i.e. $Q_{actual} = C_d * Q_{theoretical}$

The Coefficient of Discharge may therefore be determined as:

$$C_d = \frac{Actual\ Flow\ Rate}{Theoretical\ Flow\ Rate}$$

Equipment Set Up:

- Ensure the flume is level, with no stop logs installed at the discharge end of the channel.
- Measure and record the actual breadth b (m) of the broad crested weir.

- Install the weir in the flume with the rounded corner upstream. Ensure that the weir is secured using a mounting hook through the bed of the flume. For accurate results the gaps between the weir and the channel should be sealed on the upstream side using Plasticine.
- Position two hook and point level gauges on the channel sides, adjacent to the weir, each with the point fitted.
- The datum for all measurements will be the crest of the weir. Carefully adjust the level gauges to coincide with the top of the weir and record the datum readings.
- Using one level gauge carefully measure the height of the weir above the bed hw(m) taking care not to damage the surface of the weir.
- Position this level gauge above the weir near to the discharge end. Position the second level gauge some way upstream from the weir.

Procedure:

- Adjust the flow of water into the flume to obtain heads y_0, increasing in about 0.010m steps. For each step measure the flowrate Q_{actual}, the upstream depth of flow above the weir y_0 and the depth of flow over the weir y_1 (where the flow becomes parallel to the weir). The flowrate Q_{actual} can be determined using the direct reading flowmeter or the volumetric tank with a stopwatch. For accurate results the level gauge must be far enough upstream to be clear of the draw-down over the weir.
- At each setting also observe and sketch the flow patterns over the weir.
- Gradually increase the total depth of the water downstream of the weir by adding stop logs at the discharge end of the channel. For each step measure the flowrate Qactual, the upstream depth of flow y_0 and the depth of flow over the weir y_1. Observe and sketch the flow patterns over the weir.

Results:

Tabulate your readings and calculations as follows:

Breadth of Weir b =………..(m)

Height of weir h_w =………..(m)

y_0	y_1	Q_{actual}	H_0	$Q_{theoretical}$	C_d

Plot graphs of Q_{actual} against H_0 and C_d against H_0.

Conclusions:

- Does the magnitude of the flowrate affect the discharge coefficient Cd? Does Cd increase or decrease with increasing flowrate?
- What is the pattern of the water as it passes over the weir?
- Does the height of the weir affect the discharge coefficient?
- Would you expect the length of the weir crest to affect the discharge coefficient Cd?
- What is the effect of drowning the weir (increasing the downstream depth)? How does drowning affect the accuracy of the results?

7 EXPERIMENT

Hydraulics Lab

Discharge Beneath a Sluice Gate

Objective:

- To determine the relationship between upstream head and flowrate for water flowing under a sluice gate (undershot weir).
- To calculate the discharge coefficient and to observe the flow patterns obtained.

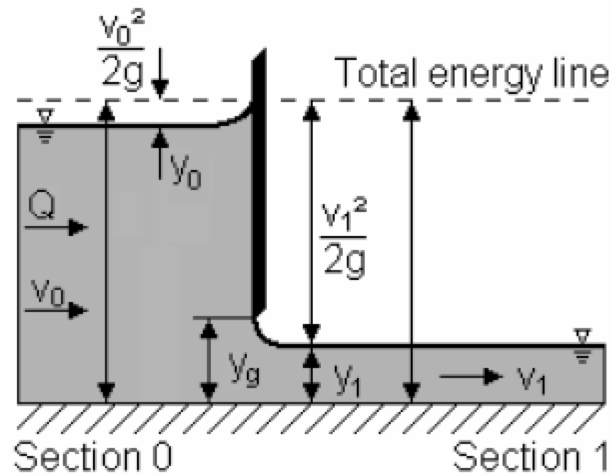
Method

- By using the adjustable undershot weir installed in the C4-MkII flume and operating the flume under a range of flow conditions.

Equipment Required

- Armfield C4-MkII Flume
- Adjustable Undershot Weir model
- Two Hook and Point Gauges, 300mm scale
- Armfield F1-10 Hydraulics Bench
- Stopwatch (for flow measurement using F1-10 volumetric tank)

Theory



For flow beneath a sharp edged undershot weir it can be shown that;

$$Q = C_d \; b \; y_g \sqrt{2 \, g \, y_o} \qquad \text{therefore:} \qquad C_d = \frac{Q}{b \; y_g \sqrt{2 \, g \, y_o}}$$

where:

Q	= Volume flowrate	($m^3.s^{-1}$)
	= Volume/time (using volumetric tank)	
C_d	= Discharge coefficient	(Dimensionless)
b	= Breadth of weir	(m)
y_g	= Height of weir opening above bed	(m)
y_0	= Upstream depth of flow	(m)
g	= Gravitational constant	($9.81 m \, s^{-2}$)

$$H_0 = y_0 \frac{V_0^{\;2}}{2\,g} = y_0 \frac{Q^2}{2\,g\,(y_0\,b)^2}$$

$$H_1 = y_1 \frac{V_1^{\;2}}{2\,g} = y_1 \frac{Q^2}{2\,g\,(y_1\,b)^2}$$

where:

H_0	= Total head upstream of weir	(m)
H_1	= Total head downstream of weir	(m)
y_1	= Downstream depth of flow	(m)
V_0	= Mean velocity upstream of weir	($m \, s^{-1}$)
V_1	= Mean velocity downstream of weir	($m \, s^{-1}$)

Equipment Set Up:

- Ensure the flume is level, with no stop logs installed at the discharge end of the channel.
- Measure and record the actual breadth b (m) of the undershot weir.
- Clamp the undershot weir assembly securely to the sides of the channel at a position approximately mid way along the flume with the sharp edge on the bottom of the weir facing upstream. For accurate results the gaps between the weir and the channel should be sealed on the upstream side using Plasticine.
- Position two hook and point level gauges on the channel sides, one upstream of the weir and one downstream of the weir, each with the point fitted.
- The datum for all measurements will be the bed of the flume. Carefully adjust the level gauges to coincide with the bed of the flume and record the datum readings.

Procedure:

- Adjust the knob on top of the weir to position the sharp edge of the weir 0.020m above the bed of the flume.
- Gradually open the flow control valve and admit water until y_o = 0.200m measured using the upstream level gauge. With y_o at this height, measure Q using the direct reading flowmeter or the volumetric tank with a stopwatch. Also measure y_1 using the downstream level gauge. Raise the weir in increments of 0.010m maintaining yo at the height of 0.200m by varying the flow of water. At each level of the weir record the values of Q and y_1.
- Repeat the procedure with a constant flow Q allowing y_o to vary. Record the values of y_0 and y_1.

Results:

- Tabulate your readings and calculations as follows:
- Breadth of weir, b = ……………..(m)

y_g	y_0	y_1	Q	C_d	H_0	H_1

- Plot graphs of Q against y_g for constant y_0 and y_0 against y_g for constant Q to show the characteristics of flow beneath the weir.
- Plot graphs of C_d against Q for constant y_0 and C_d against y_g for constant Q to show the changes in C_d of flow beneath the weir.

Conclusions:

- Comment on effects of y_o and Q on the discharge coefficient C_d for flow underneath the gate. Which factor has the greatest effect?
- Comments on any discrepancies between actual and expected results.
- Compare the values obtained for H_1 and H_0 and comment on any differences.

8 EXPERIMENT

Hydraulics Lab

Seepage Underneath a Sheet Pile Wall

Objectives:

- Seepage underneath a sheet pile wall is one of the seepage problems that are most common in practice. Sheet pile walls are used to reduce seepage under all types of dams, sea walls, dividing walls, lock walls, coffer-dams and similar structures. They are also used to reduce leakage from canals, rivers and the sub soils surrounding an excavation.
- It is also this type of seepage which most clearly illustrates the concept of a flow net where the flow net has a simple and intuitively clear pattern and fully defined boundary conditions.

Apparatus:

- S1 Drainage and Seepage Tank

Procedure:

Flow Line Visualization

- Prepare about ½ litre of fluorescein solution by slowly adding the chemical into water until the solution becomes a semi-transparent opal-like liquid of orange-greenish colour.
- Fill the tank with pure sand to a level of about 300mm above the bottom of the tank.
- Adjust the upstream overflow so that its top is about 100mm below the top of the tank and the downstream overflow so that its top is about 25mm above the surface of the sand bed.
- Adjust the impermeable screen at the middle of tank. Leave about 125 to 150mm of clearance between screen and bottom of the tank. Seal the contacts between the screen and tank walls with grease or other easily removable seal.
- Apply the seal on downstream side to prevent leakage in case screen moves under the final pressure difference.

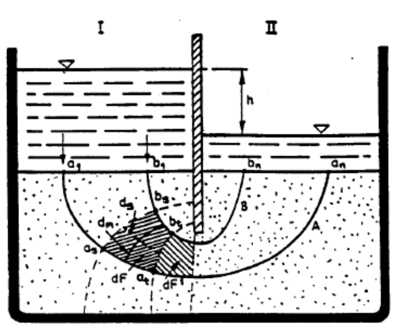
- Pour water slowly into the tank. Start with the downstream pool and transfer the input into the upstream after the lower pool is full. After overflow occurs both upstream and downstream reduce water input to the minimum needed to maintain constant water level in the upstream pool (in this case there will be a small continuous overflow from the upper pool). Smooth out any sharp irregularities of the sand bed which may have formed while filling the pool.
- Fix the bottle with dye on the stand in such a position that the liquid level is approximately at the same elevation as the water level in the upper pool.
- Then, depending on the desired number of flow lines (3 to 4 recommended), insert the corresponding number of dye-injection needles vertically about 6mm into the sand along one of the transparent walls of the upper pool. In order to obtain an approximately "square" flow net, the spacing between the needles should progressively increase in the upstream direction from the impermeable screen. The suggested needle distances from the screen for 4 flow lines, are approximately 50, 115, 230, 380mm. Tape the needles (or the tubes connecting them with the bottle) to the tank wall just above the water.
- After the dye-injection needles have been fixed, lift the bottle with dye and position it so that the liquid level is about 12mm above the water level in the upper pool. The position of the bottle should be adjusted according to the appearance of the flow lines. If lines are wide, the bottle is too high. If no dye appears or its flow is irregular, the bottle is too low. The formation of flow lines may require several minutes to an hour or two, depending on the permeability of the sand used.
- To stop the experiment, shut off the dye input by lowering dye container until dye surface is about 50mm below water level in pool. Let the flow lines wash away. Do not take out the needles before the dye input has been shut off as indicated. Otherwise dye will get into water in the pool while needles are being removed.

Flow Net Construction

- Trace the flow line pattern and the boundary conditions (the perimeter of the cross section of the body of sand in the tank) on tracing paper taped to the transparent wall of the tank. Use a felt marker to prevent erasing the contours which are to serve as a firm skeleton of the net when sketching in the completed net with a pencil later on.

- To obtain a square flow net, try first to fit the squares between one pair of the experimentally obtained flow lines. Proceed with the sketching of the equipotential lines from the upstream to the downstream boundary (ie. upstream sand surface to downstream sand surface) using care to obtain right angle intersections.
- On the first trial, a narrow residual rectangle will probably occur at the end.
- The correction can be made in two ways. The width of the "channel" formed by the two experimental flow lines can be either increased or reduced by drawing a parallel trial line close to one of the original lines.
- Using this corrected flow line instead of one of the experimental ones, a new set of squares is fitted into the "channel". If the new "channel" is wider than the original, the length of the residual rectangle will reduce eventually to zero.
- If it is narrower, the residual rectangle will eventually be lengthened until it approximates a square.
- Once the square net between one pair of flow lines has been established, the equipotential lines can be extended across the whole flow field so that they intersect all the experimental flow lines at right angles. Then flow lines are interpolated between the experimental ones so as to form, with the equipotential lines, a square network.
- Since the "channels" near the boundary flow lines need not be square at the first trial, the whole flow net may be adjusted. A way to avoid this is to set up a separate rectangular flow net in each of the two boundary "channels". This can be done by appropriately changing the position of some equipotential lines.

Seepage Rate



Background: The lines connecting points with equal potentials on different flow lines are called equipotential lines. Thus we see that the contours of the two bottoms represent two equipotential lines since they connect, respectively, points a_1 and b_1 having equal potentials, and points a_n and b_n also having equal potentials. Such a system of flow lines and equipotential lines is what is called the flow net. In each flow net, the flow lines and the equipotential lines intersect at right angles.

Naturally, pairs of points having equal potentials must also exist between the two pairs located at the beginning and the end of the flow lines. Examples of such pairs are represented by points as, b_s and at, b_t. The connecting lines a_s b_s and a_t b_t represent the equipotential lines between the pairs.

Therefore, Now consider that the same portion of the water that seeps out of basin I and into basin II in a given time will pass through an area dF bounded by the two flow lines (a_s a_t and b_s b_t) shown.

This seepage, Q, will be measured in gallons per unit of time per running foot (ie. per foot normal to the plane of the section). If we designate that portion of the seepage passing through dF as dq we get from Darcy's Law as follows:

$$d_q = K\ dm\ \frac{dh}{ds} \qquad \text{-------(a)}$$

where dh is the potential drop between the two equipotential lines, the only unknown in equation.

If we choose equipotential lines such that the area dF resembles a square, then the distance dm is approximately equal to ds, and above equation reduces to:

$$d_q = K\ dh \qquad \text{----- (b)}$$

For the subsequent "square" area dF' , the discharge is $d_{q'} = K\ dh'$ ----- (c)

However, we can get only as much water into dF' as has passed through dF. There is simply no other place from which the water could come. Nor is there any other place where the water from dF could go. Therefore we have :

$$d_q = d_{q'} \qquad \text{------ (d)}$$

which, from equations (c) and (d) gives: $dh = dh'$ ------ (e)

This is a very important result. It implies that the potential drop between two adjacent pairs of equipotential lines is the same if they share the same pair of adjacent flow lines and enclose an area similar to a square.

If a pair of flow lines is given, there is only one way to divide the strip between them into a sequence of "squares" (ie. tetragonals) whose four corners form right angles and whose mean distances between opposite faces are alike.

Therefore, if we succeed in dividing the strip between the two flow lines into a sequence of such "squares", we can use their number n for calculating the potential drop dh between two successive equipotential lines. Since all the values of dh must be the same according to equation (8) we have:

$$dh = \frac{h}{n} \qquad \text{------- (f)}$$

Knowing dh we can finally determine from equation (b), the discharge (per unit length) through the area between two flow lines.

Although it is advantageous to have a "square" flow net, it is also possible to determine dh from a rectangular net if all the rectangles between two flow lines have the same ratio . Denoting this ratio by c, equations (b) and (c) become respectively.

$$dq = K\ c\ dh \qquad \text{------- (g)}$$

In simple words.

- Students can find the pressure drop dh determined from equation (f).
- Then the seepage rate in each flow "channel" is determined using equation (b) in case of a square network, or equation (g) in case of a rectangular network.
- The total seepage flow rate per running foot underneath the steel pile is the sum of all the rates through the individual flow "channels".