An ISO 9001 Company

INSTRUCTION MANUAL

C4-MKII

ISSUE 7

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MULTI-PURPOSE TEACHING FLUME

IMPORTANT SAFETY INFORMATION

All practical work areas and laboratories should be covered by local safety regulations **which must be followed at all times.**

It is the responsibility of the owner to ensure that all users are made aware of relevant local regulations, and that the apparatus is operated in accordance with those regulations. If requested then Armfield can supply a typical set of standard laboratory safety rules, but these are guidelines only and should be modified as required. Supervision of users should be provided whenever appropriate.

Your **Multi-Purpose Teaching Flume** has been designed to be safe in use when installed, operated and maintained in accordance with the instructions in this manual and with the instructions in the product manual supplied with the F1-10 Hydraulics Bench. As with any piece of sophisticated equipment, dangers may exist if the equipment is misused, mishandled or badly maintained.

Electrical Safety

The equipment described in this Instruction Manual operates using a service unit (the F1-10 Hydraulics Bench) that is powered by a mains voltage electrical supply.

- The flume involves the use of water so any supply must be properly protected to minimise the possibility of electric shock.
- The F1-10 Hydraulics Bench must be operated as described in the F1-10 product manual, and must be tested regularly to ensure that the integral electrical protection is working correctly.

Wet Environment

Use of the flume requires the presence of fast-moving water. During use it is probable that there will be some spillage and splashing.

- All users should be made aware that they may be splashed while operating the equipment, and should wear appropriate clothing and non-slip footwear.
- ‘Wet Floor’ warnings should be displayed where appropriate.
- Electrical devices in the vicinity of the flume must be suitable for use in wet environments or be properly protected from wetting.

Moving or Rotating Components

The C4-MKII Multi Purpose Teaching Flume has moving components.

- Before operating the jacking system ensure that no person or object can become trapped by the movement of the flume or the jacking mechanism.

The C4-67 Wave Generator has moving and rotating components.

- Ensure that the Wave Generator has been securely fixed to the top of the inlet tank on the flume before connecting the electrical supply.
- Do not remove any protective guards while the Wave Generator is in operation or connected to the electrical supply.
- When operating the apparatus ensure that long hair is tied back out of the way, and that clothing and jewellery cannot come into contact with any moving parts. Dangling items such as necklaces or neckties must be removed or secured so that they cannot become entangled in the equipment.
- Do not touch any moving components while the Wave Generator is in use, or insert any item into any moving or rotating section of the equipment.
- Ensure that the apparatus is switched off and disconnected from the electrical supply before handling the equipment or making adjustments to the stroke adjuster.

Heavy Equipment

This apparatus is heavy.

- The apparatus should be placed in a location that is sufficiently strong to support its weight, as described in the Installation section of the manual.
- The support pedestals may be bolted to the floor for additional stability.
- The flume should be assembled in place whenever possible. Where manual lifting is necessary, two or more people will be required for safety. All should be made aware of safe lifting techniques to avoid injury.
- Safety shoes and/or gloves should be worn when appropriate when moving the equipment.
- If the apparatus is to be repositioned after installation, the apparatus must be drained before it is moved and should be disassembled if possible.

Water Borne Hazards

The equipment described in this instruction manual involves the use of water, which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:-

- Any water contained within the product must not be allowed to stagnate, i.e. the water must be changed regularly.
- Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.
- Where practicable the water should be maintained at a temperature below 20°C. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.
- A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication "The Control of Legionellosis including Legionnaires Disease" - Health and Safety Series booklet HS (G) 70.

MULTI-PURPOSE TEACHING FLUME
C4-MKII

Contents

1 Introduction to the Equipment

When studying Hydraulics, the fundamental concepts of energy and momentum are sometimes difficult to grasp, particularly where free surface flow is concerned. The Armfield Multi-Purpose Teaching Flume has been developed to assist the student to overcome this difficulty. It provides a basic but nonetheless comprehensive facility for student experiments in open channel flow.

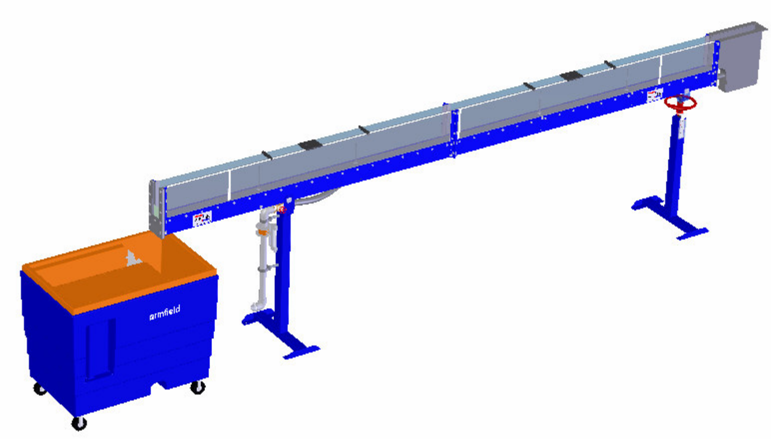
Although small in comparison with the majority of flumes, the dimensions of the working section have been sized so that the various phenomena may be clearly seen and reasonably accurate results may be obtained from measurements taken.

The C4-MkII flume is supplied with either a 2.5 metre long working section or a 5.0 metre long working section. Both versions of the flume can be fitted with an optional direct reading flowmeter for convenience in operation. A set of basic models is included with all versions of the flume. A range of optional models is also available to extend the experimental capabilities.

This manual covers all versions of the C4-MkII flume.

The flume requires the use of a standard Armfield Hydraulics Bench F1-10 (ordered separately) which stores water for recirculation making the unit self contained, except for the provision of an electrical supply. The construction of the flume allows for easy disassembly if at a later date it is required to move the unit to a different location.

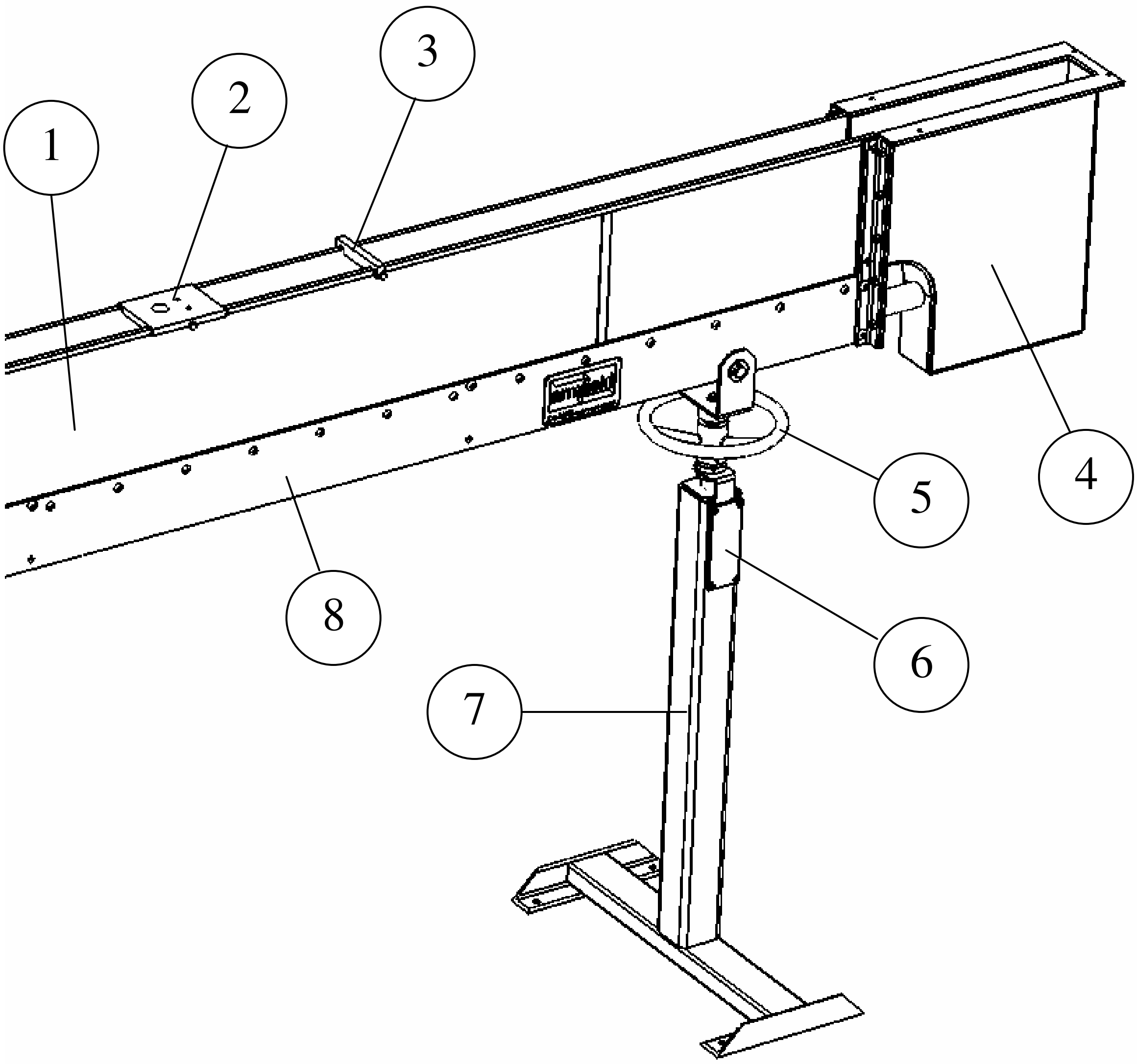
This manual includes experimental sheets detailing some of the demonstrations and exercises which can be performed using the flume and models. We wish to emphasise that these experiments do not exhaust the potential of the flume or the models. There are many further investigations that an imaginative user can devise and the user can construct alternative models for installation in the flume.



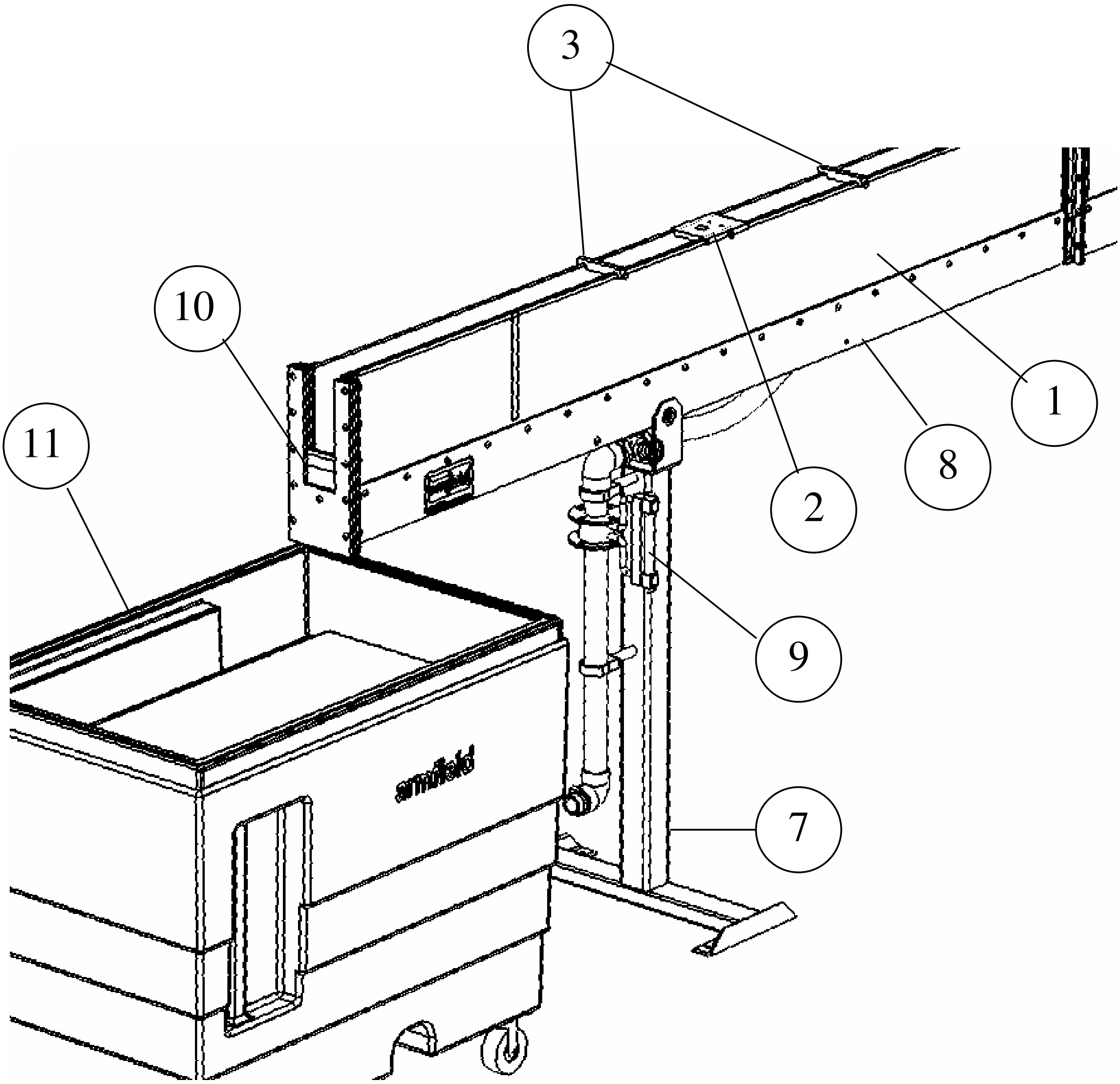
C4-MkII Multi-Purpose Teaching Flume

Shown with F1-10 Hydraulics Bench and optional flowmeter

1.1 Diagram 1: Inlet End of Flume



1.2 Diagram 2: Discharge End of Flume



2 Description

Numerical references refer to the drawings on pages 8 and 9.

2.1 Overview

The flume consists of a clear-sided rectangular working section supported on a frame, with an inlet tank at one end. The frame is supported on pedestals, and a jack allows the flume to be tilted. The flume is designed to be used with an Armfield F1-10 Hydraulics Bench, which provides a re-circulating water supply and a volumetric measuring facility.

2.2 Working Section

The working section of the channel (1), which is open at the top, consists of clear acrylic sides which are sealed to a bed (8) fabricated from painted aluminium alloy. The clear sides allow full visualisation of the flow conditions inside the working section. Spacers (3) across the top edges of the sides ensure that the flume sides remain rigid. The bed of the working section incorporates pressure tappings with isolating valves and model mounting points (See section 3.2 for further information). Two carriers (2), mounted across the top edges of the channel walls, allow hook and point level gauges to be used to measure the depth of water at any position along the length of the working section. See section 2.6.

2.3 Inlet Tank

Water enters the parallel working section via the inlet tank (4) that is constructed from PVC. The water pipe entering the inlet tank has diffused outlets and the water flows through a diffuser and a perforated plate to reduce any turbulence in the water and produce a smooth flow of water into the working section of the channel.

2.4 Overshot Weir

The level in the working section of the flume may be controlled by an overshot weir arrangement at the exit (10) consisting of stop logs in a slot. Stop logs are simply added or taken away to provide the required depth of water in the working section. Water exiting from the channel discharges into the moulded channel on top of the F1-10 Hydraulics Bench (11) where it returns by gravity to the sump tank via the volumetric measuring tank.

2.5 Optional Flowmeter

An optional shunt type flowmeter (9) can be supplied with the flume to provide a direct reading of the volume flowrate of the water passing through the working section of the flume. This provides a convenient means of setting up the various open channel demonstrations without the need for repeated timings using a stopwatch. When supplied this flowmeter is mounted on the pivot pedestal of the flume and consists of a variable area flowmeter which is shunted across an orifice plate with the scale calibrated to read the actual flow.

When the flowmeter is not fitted (or at low flowrate below 1.2 litres/second) the flowrate can be measured using the volumetric tank on the F1-10 Hydraulics Bench

2.6 Hook and Point Gauges

A pair of hook and point gauges enable the height of the water above the bed to be measured at two different locations. The gauges can be located along the length of the channel on carriers (2) that are located on top of the channel sides. A measuring scale attached along the top of the front channel side indicates the position of each gauge along the length of the channel. The gauges incorporate a scale with Vernier and a fine adjusting screw that allow accurate measurement of the water depth. Either the hook or the point may be clamped to the end of the vertical mast of the gauge to suit the operator – the point is used by observing the reflection on the surface of the water, the hook is used by observing the reflection through the water. The hook or point is correctly positioned when the tip and its reflection just touch. Measurements will not be accurate when a meniscus forms between the water surface and the tip.

2.7 Pedestals and Jack

The flume is supported on a pair of pedestals (7) which should be bolted to the floor for additional safety. The pedestal at the inlet end of the working section is fitted with a hand-operated jack. This jacking arrangement permits the slope of the channel bed to be manually adjusted. The jack is operated by a handwheel (5) and the mechanism incorporates a slope indicator (6) calibrated directly in units of % slope. For normal operation the slope should be set to 0% (bed of channel level).

2.8 The F1-10 Hydraulics Bench

The C4-MkII is designed for use with the F1-10 Hydraulics Bench. The F1-10 is not supplied as part of C4-MkII.

Water is drawn from a sump tank in the base of the F1-10 by a centrifugal pump. The water is delivered to the inlet tank of the flume via a flexible tube that is connected to the outlet in the moulded channel on the top of the F1-10. The flow of water through the working section is varied using the flow control valve on the side of the F1-10 Hydraulics Bench.

Having flowed along the working section of the flume the water falls by gravity into the moulded channel on the top of the F1-10. The water then flows into a volumetric tank before returning to the sump tank under gravity. The volumetric tank provides a means (and demonstration) of measuring the flow of water through the flume when not using the optional direct reading flowmeter.

Flowrates up to approximately 1.2 litre/sec can be measured using the volumetric tank and a stopwatch (not supplied). In normal operation the dump valve in the base of the volumetric tank should be open to allow the water to re-circulate. When measuring the flowrate the dump valve is dropped into the aperture and the flow is measured by timed volume collection. Using the sight glass (level scale) on the side of the F1-10 and a stopwatch.

At higher flowrate (above 1.2 litres/sec) it will be necessary to use the circular orifice plate supplied with the C4-MkII to measure the flowrate as the volumetric tank will remain flooded. To install the orifice plate lift the ball and weight from the aperture in the base of the volumetric tank then press the orifice plate into the aperture. At each flow setting allow the water level to stabilise in the volumetric tank (this may take several minutes after making a change in flowrate) then read the value from the upper scale on the F1-10 sight glass (level gauge). This reading in litres is used to find the actual flow rate by referring to the following table:

Flow Rate Reference Table (Only used with C4-MKII up to 1.6 l/s)

Scale Reading Litres	Flow Rate Litres/sec	Scale Reading Litres	Flow rate Litres/sec
0	1.41	12	1.78
1	1.44	13	1.81
2	1.48	14	1.84
3	1.51	15	1.86
4	1.54	16	1.89
5	1.57	17	1.92
6	1.60	18	1.94
7	1.63	19	1.97
8	1.66	20	2.00
9	1.69	21	2.02
10	1.72	22	2.05
11	1.75	23	2.07

Note that when using the C4-MKII Tilting Flume in conjunction with the F1-10 Hydraulics Bench the maximum flowrate available is approximately 1.6 litres/sec (approx 96 litres/min).

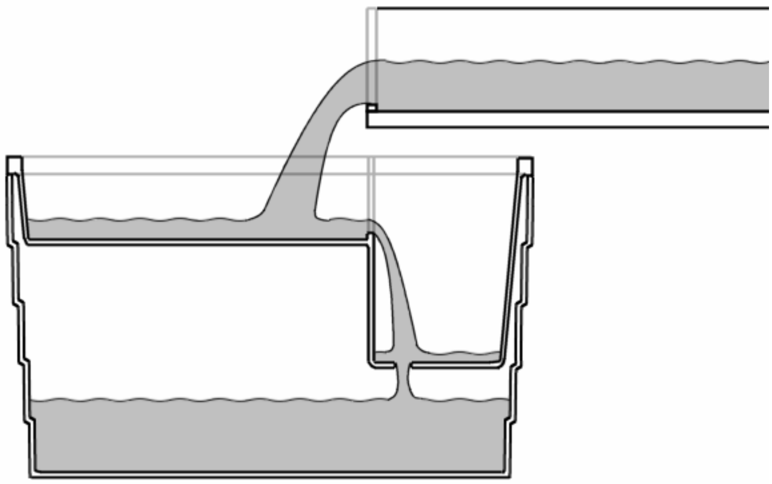
Additional information about the F1-10 Hydraulics Bench is provided in the separate product manual supplied with the F1-10. Refer to that manual for full information including installation and commissioning instructions.

3 Operation

Where necessary, refer to the drawings on pages 8 and 9.

3.1 Positioning the F1-10 Hydraulics Bench

The C4-MkII is designed for use with the F1-10 Hydraulics Bench. The flume discharges into the horizontal channel that is moulded into the top of the F1-10. The F1-10 must therefore be positioned to allow water discharging from the flume to enter the top channel with minimal splashing. Water should enter the channel just beyond the lip of the channel, without hitting the lip, remaining clear of the end wall of the channel, as shown:



As the flow rate and flume slope is altered, the angle of the water exiting the flume will change slightly. It may be necessary to move the F1-10 to allow for this, ensuring that the discharge flow always enters the channel centrally to prevent splashing on the sides of the channel. The F1-10 Hydraulics Bench is mounted on casters for ease of repositioning.

3.2 Connecting the F1-10 Hydraulics Bench

Disconnect any accessory that is already connected to the quick release connector on the F1-10 (connector located inside the top moulded channel on the F1-10). Ensure that the F1-10 is switched off and the flow control valve is closed then unscrew the quick release connector from the bed of the channel. Screw the adaptor, supplied with C4-MkII, onto the threaded outlet in the bed of the channel then connect the flexible tube from the C4-MkII to the union on top of the adaptor. The union incorporates a ‘O’ ring seal and only needs to be hand tight (do not use a tool to tighten the fitting).

To restore the F1-10 to normal use; unscrew the union to disconnect the flexible tube then unscrew the adaptor from the threaded outlet in the bed of the channel on F1-10. Screw the quick release connector onto the threaded outlet to allow the F1-10 to be used with any other accessories. It may be necessary to move the F1-10 slightly to the left to allow operation with some accessories but the castors on the F1-10 allow the unit to be easily repositioned.

3.3 Filling the F1-10 Hydraulics Bench with water

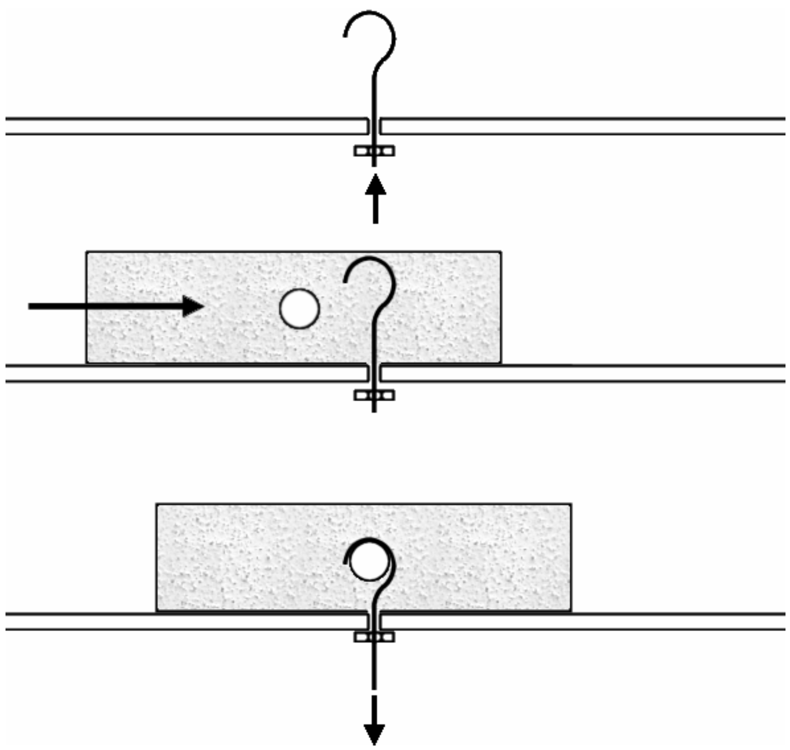
Place a filling hose in the volumetric tank of the F1-10. Fill the sump tank with clean cold water by lifting the dump valve in the base of the volumetric measuring tank and allowing the water to drain from the volumetric tank into the sump tank. (When lifted, a twist of 90° at the actuator will retain the dump valve in the open position.) When full ensure that the water level in the sump tank is just level with the outlet in the bottom of the volumetric tank.

A few drops of wetting agent (Teepol or similar) should be added to the water in the sump tank to reduce the effect of surface tension. Note that too much wetting agent will cause foaming.

3.4 Assembling and Installing Models

The bed-mounted models (with the exception of the Venturi flume, the false floor sections and the artificially roughened bed as described in later sections) are hooked in place via a retaining bar on the underside of the model using a clamping hook assembly. The rod incorporating the hook passes through a gland on the underside of the channel bed that incorporates a rubber 'O' ring seal to prevent water from leaking. Each gland should be adjusted so that the rod will move smoothly when pushed up or down but remain in position without leaking.

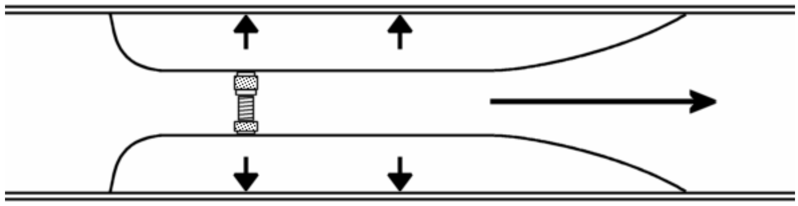
There are two hooks per 2.5 metre length of channel section. The diagrams below show how the model is retained in position. The appropriate hook is pushed upwards to clear the channel bed. The required model is placed over the hook and then slid along until its retaining bar is beneath the hook. The hook is then pulled downwards from beneath to secure the model. The model will be held in place until the hook is pushed up again.



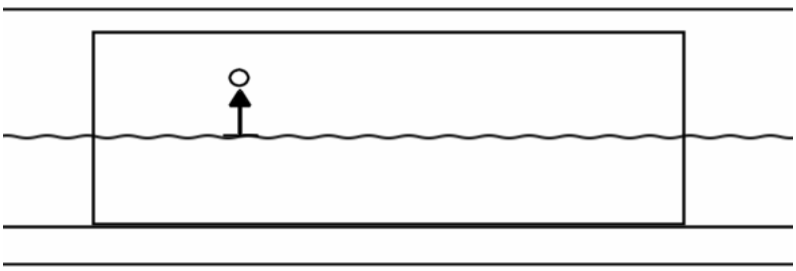
When not in use the model clamping rods can be inverted to minimise disturbance to the flow along the bed of the channel. To invert the rod unscrew the gland on the underside of the bed then pull the rod out from the gland from above. Re-insert the rod into the gland from below (taking care not to damage the ‘O’ ring in the gland) with the tip of the rod flush with the channel bed. Tighten the gland to retain the rod in position.

3.5 Assembling and Installing the Venturi Flume

The Venturi flume is held in place by a simple stretcher screw. This is placed between the two sections of the Venturi and adjusted to clamp them against the side walls of the channel.

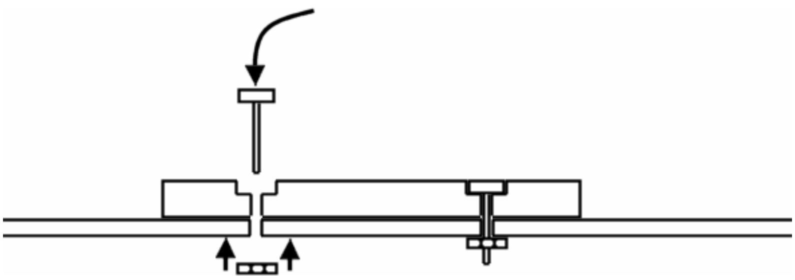


NOTE: The stretcher must be placed above the level of the water so as not to interfere with the flow:



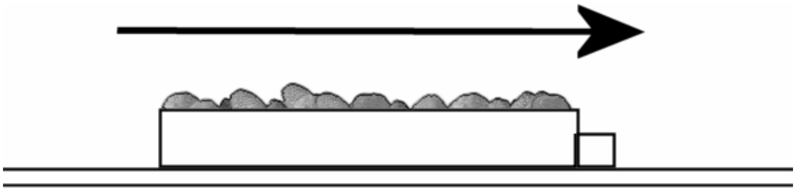
3.6 Installing the Optional False Floor Sections

The false floor sections are secured with the use of holes in the bed floor. The hooks are removed from the holes and pins are used instead. Each section of floor uses two pins which push through the floor section and into the two holes in each working section (one section if 2.5m, two sections if 5m). The end ramps simply slot into the required end of the floor. The raised floor support is held in compression between the floor and the channel bed.



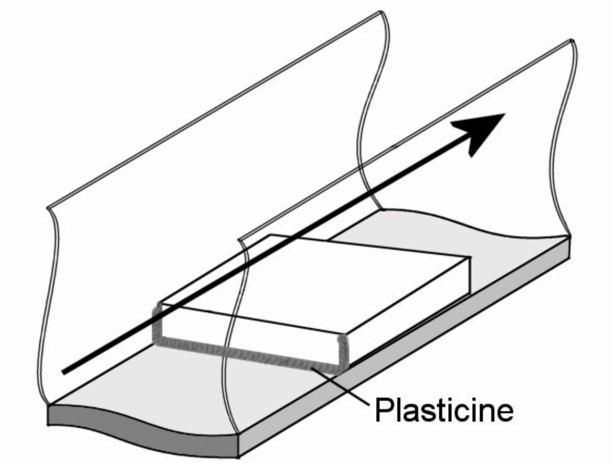
3.7 Installing the Optional Roughened Bed Sections

The artificially roughened (gravel) bed relies on its own weight to hold it onto the channel bed. It is aided by a bed end stop which is similar to the stretcher screw used on the Venturi flume except that it clamps between the channel side walls. This acts as a stop which prevents the gravel bed from sliding along the channel bed.



3.8 Sealing models into the flume

Plasticine is supplied with the flumes. This is used on the leading edge of the model and is placed between the side walls and bed of the channel and the sides of the model. This is to ensure that water flows over the model and not around or under it.

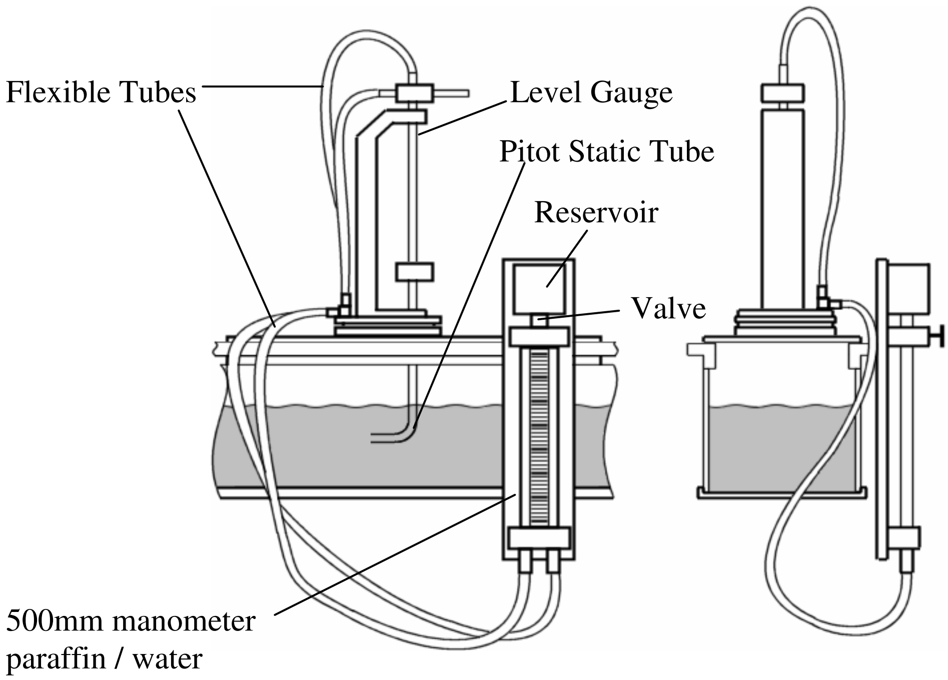


3.9 Use of Stop Logs to Vary Flume Flow Depth

The stop logs supplied slot into the discharge end of the channel. They may be used singly and in combination to raise the water level within the flume to different heights. Gaps between the logs may be sealed with Plasticine if required, but this is not usually necessary.

3.10 Installing the Optional Pitot Tube and Manometer Board (C4-61)

The Pitot tube and manometer board is an optional accessory (Armfield order code C4-61) and is used in conjunction with the C4-MkII Multi Purpose Teaching Flume to measure the local velocity of water flowing through the working section.



Partially fill the flume with water so that the head of the Pitot tube can be immersed when installed on the flume. The water in the flume should not be flowing during the priming procedure.

Before installing the Pitot tube and manometer on the flume it is necessary to prime them with water. Fill the manometer reservoir with water, ensuring that the valve at the base of the reservoir is closed. Position the manometer above the Pitot tube with the Pitot tube sloping uphill (cranked head at the top). Open the isolating valves at the base of the manometer.

Open the reservoir and allow water to flow through the flexible tubing until it flows through the static and total head holes in the Pitot tube. During this operation the reservoir must not be allowed to empty, thus letting air into the system. Ensure that there are no air bubbles in the assembly. Close the valve at the base of the reservoir on the manometer.

Set up the Pitot tube as shown in the diagram above with the head of the tube immersed under water. Ensure that the reservoir on the manometer is filled with water with the valve closed. Raise the manometer above the flume then open the valve and allow water to flow through the assembly. Ensure that no air remains in the pipework. Briefly raise the head of the Pitot tube above the level of the water in the flume and check that water flows from both the static and total head holes. Once again the reservoir on the manometer must not be allowed to empty during the priming operation.

If any air is trapped in the pipework the whole of the procedure should be repeated. It is essential that no air is present, otherwise reading obtained will be valueless.

Allow water to drain from the reservoir leaving a small amount in the base, then close the isolating valves at the base of the manometer. Fill the reservoir with paraffin (Kerosene, Specific Gravity = 0.784) then open each isolating valve in turn to half fill each manometer tube with paraffin. Take care to avoid slugs of paraffin/water in the manometer tubes. When both tubes are correctly filled to mid height close the isolating valve at the base of the reservoir.

Close the isolating valves at the base of the manometer until the equipment is ready for use.

3.11 Operating the Optional Pitot Tube and Manometer (C4-61)

The Pitot tube and manometer are used for measuring low velocities of water in the flume. If used with excessively high velocities, the paraffin will be pushed out of the manometer into the flexible tubing which may result in paraffin entering the flume.

DO NOT open the valve at the base of the reservoir during operation.

Open the flume inlet valve and allow water to flow slowly through the flume. Carefully open the isolating valves at the base of the manometer and note the difference in levels in the two limbs of the manometer.

The velocity of the water is calculated as follows:

For the Pitot tube $$v = k\sqrt{\frac{2(p_t - p_s)}{\rho_f}}$$

For the manometer $$(p_t - p_s) = g\,h\,(\rho_f - \rho_m)$$

where:

v	= Local velocity of water	($m\ s^{-1}$)
k	= Pitot tube coefficient (can be assumed to be unity)	(Dimensionless)
p_t	= Total pressure	($N\ m^{-2}$)
p_s	= Static pressure	($N\ m^{-2}$)
ρ_f	= Density of operating fluid, water	($kg\ m^{-3}$)
ρ_m	= Density of manometer fluid, paraffin	($kg\ m^{-3}$)
h	= Difference in levels in manometer	(m)
g	= Gravitational constant	($9.81 m\ s^{-2}$)

therefore:

$$v = \sqrt{\frac{2gh(1000-784)}{1000}}$$

$$v = \sqrt{4.24h} \qquad (m\ s^{-1})$$

For defining the position of the Pitot tube relative to the flume the following convention is used:

x_p	= distance along the flume (scale on side of flume)	(m)
y_p	= location across flume	(m)
z_p	= height above bed of flume (vertical level gauge)	(m)

These dimensions can be tabulated with the other results obtained.

This assembly can be used with many of the other accessories where velocities are required. The velocity profile in the flume can be obtained by moving the Pitot tube vertically and horizontally across the flume at different sections, noting the readings on the manometer at each position and converting these readings to a series of velocity profiles.

3.12 Installing the Optional Wave Generator (C4-67)

When required for use, the C4-67 Wave Generator should be mounted on top of the flow channel inlet tank with the vertical paddle at the entrance to the working section. The Wave Generator must be secured to the flange of the tank using the fixings supplied. Operation of the Wave Generator involves rotating and moving parts so extreme care must be taken when using the generator. Refer to the safety section of this instruction manual for specific notes regarding safe operation of the Wave Generator

The C4-67 Wave Generator consists of a vertical paddle that is moved backwards and forwards by a variable speed, variable stroke drive to produce water waves in the working section of the flow channel. The drive arrangement consists of a combined motor/gearbox with an eccentric crank wheel and connecting rod. The connecting rod can be connected to the crank wheel at different radii to change the stroke of the paddle and thereby change the amplitude of the waves. The speed of the drive motor is continuously adjustable to change the frequency of the waves via the speed controller mounted on a bracket at the side.

The stop logs should be installed at the discharge end of the flume to retain the water inside the working section when the C4-67 Wave Generator is operating.

The triangular sloping beach, supplied with the C4-67 Wave Generator, should be installed inside the working section of the flow channel at the opposite end to the Wave Generator (located against the stop logs). This absorbs the energy of the waves to minimise the effect of reflected waves. The beach consists of a plastic strip with a 25mm thick fibre mat bonded to it that allows water to flow through the material but resists the movement and absorbs the energy in the waves

3.13 Operating the Optional Wave Generator (C4-67)

Changing the depth of the water

The depth of the water should be adjusted to suit the required demonstration. The water level should be raised by opening the flow control valve with the F1-10 Hydraulics Bench switched on. The water level should be lowered by opening the flow control valve with the F1-10 Hydraulics Bench switched off.

If the required depth of water is not known then the channel should be filled initially to mid height then tested by operating the wave paddle. The level can then be adjusted up or down to suit the demonstration. Note that insufficient water will give waves of small amplitude and excessive depth may result in water spilling from the sides of the channel when waves are generated.

Setting the required amplitude of the waves (stroke of the paddle)

Before making any adjustments to the stroke of the paddle the drive motor must be switched off at the control console and the electrical supply must be disconnected.

Having checked that the electrical supply is disconnected the guard can be removed from the drive arrangement by unscrewing the fixings.

The connecting rod can be attached to the crank wheel at different radii to give different stroke lengths. To change the stroke length simply unscrew the pin that attaches the connecting rod to the crank wheel using a suitable wrench then screw the pin into the appropriate tapped hole. Ensure that the pin securing the connecting rod is tight using a wrench.

The guard must be replaced before reconnecting the electrical supply and operating the paddle.

When operating the equipment for the first time it is suggested that the shortest stroke is selected. If larger amplitude of wave is required then the above procedure should be repeated, moving the connecting rod to a larger radius on the crank wheel.

Setting the required frequency of the waves (speed of the drive motor)

Ensure that the guard is fitted to the drive arrangement and there are no obstructions to the movement of the paddle or connecting rod.

Check that the speed control knob is set to minimum (fully anticlockwise).

Turn on the on/off switch.

Gradually increase the speed of the motor by rotating the speed control knob clockwise until the required frequency of waves is achieved.

Warning: Excessive stroke, excessive frequency or overfilling of the flow channel may result in water spilling from the sides of the channel.

Typical demonstrations

Shallow water waves

The Wave Generator can be used to investigate the generation of regular water waves. As stated above, the depth of water, the amplitude of the waves and the frequency of the waves can be varied independently to suit the required demonstration.

Effectiveness of an energy absorbing beach

The sloping beach may be replaced with alternative structures or materials to suit the required demonstration. For example the effectiveness of a barrier constructed from small rocks could be investigated. Alternatively wedges of open cell foam with different density could be substituted to investigate the effectiveness of different types of foam.

4 Specifications

4.1 Overall Dimensions

C4-MKII-2.5M only

Height	-	1.50m
Length	-	3.4m
Width	-	0.62m

C4-MKII-5.0M only

Height	-	1.50m
Length	-	5.41m
Width	-	0.62m

C4-MKII-2.5M with F1-10

Height	-	1.50m
Length	-	3.66m
Width	-	0.90m

C4-MKII-5.0M with F1-10

Height	-	1.50m
Length	-	6.11 m
Width	-	0.90 m

4.2 Working Section Dimensions

Length of working section	-	2.5m or 5.0m (as ordered)
Width of working section	-	76mm
Depth of working section	-	250mm

4.3 Flume Slope

Max positive bed slope	-	+ 3.0 %
Max negative bed slope	-	- 1.0 %

4.4 Flow Rate

Operating flow range	-	0 – 1.6 litres/sec
Optional flowmeter range	-	0.5-2.5 litres/sec ± 2.5% FSD

4.5 Electrical Supply

The F1-10 Hydraulics Bench requires a mains electricity supply. Refer to the F1-10 product manual (supplied with the hydraulics bench) for details.

4.6 Water Supply and Drain

Water for the C4-MkII is provided by an F1-10 Hydraulics Bench. An initial fill of approximately 250 litres is required. Once the equipment has been installed and commissioned no permanent water supply or drain is required. A suitable drain and source of clean water will be required for draining and refilling the F1-10 after cleaning.

4.7 Hook and Point Gauges (2 supplied)

Range of scale	300 mm
Measurement accuracy	+/- 0.1 mm

4.8 Models Available for Use in the C4-MkII Flume

The following accessories are supplied as standard with the C4-MkII-2.5M and C4-MkII-5.0M flumes:

Sharp crested weir

Broad crested weir

Adjustable undershot weir (sluice gate)

Crump weir

Venturi flume (2 sections to line the vertical walls of the channel)

The following accessories are available as an option for use with the C4-MkII flume (all versions):

C4-61 Pitot tube and manometer board

C4-62 Culvert fitting, incorporates one square edge, one rounded edge

C4-63 Flow splitters, central wall with various nosepieces

C4-64 Free overflow spillway section, complete with ski jump, sloping apron and blended reverse curvature attachments

C4-65 Siphon spillway and air regulated siphon

C4-66 Model radial gate

C4-67 Wave generator and wave absorbing beach. Requires an electrical supply and therefore available in three versions:

C4-67-A	220/240 Volts, 1 Phase, 50 Hz
C4-67-B	120 Volts, 1 Phase, 60 Hz
C4-67-G	220/240 Volts, 1 Phase, 60 Hz

C4-68 False floor sections for gradually varied profiles, comprising: variable height laminated ramp, 2 parallel face sections with 2 end ramps and support piece to create raised false floor using 1 parallel face section

C4-69 Artificially roughened bed 2.5m long section (2 required for 5.0m flume).

5 Routine Maintenance

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

5.1 General

The F1-10 should be disconnected from the electrical supply when not in use.

Water should be drained from the C4-MkII when not in use.

5.2 RCD test for F1-10 Hydraulics Bench

Test the RCD by pressing the TEST button at least once a month. If the RCD button does not trip when the Test button is pressed then the equipment must not be used and should be checked by a competent electrician.

5.3 Test condition of water in F1-10 Hydraulics Bench

Check that the water in the sump tank is clean and suitable for use. The water should be changed regularly to avoid stagnation (refer to the notes on the COSHH REGULATIONS at the front of this instruction manual). The use of a corrosion inhibitor which includes a biocide/disinfectant will reduce the formation of algae or micro-organisms and allow water changes to be performed less frequently. The frequency of water changes will depend on usage, local conditions and whether or not a biocide is used. As most corrosion inhibitors for the treatment of water are used in closed systems, ensure that the inhibitor/biocide used is safe to handle and does not create a hazard to the health of operators handling models immersed in the treated water.

If it is necessary to change the water, drain all water from the channel then open the drain cock on the underside of the F1-10 Hydraulics Bench and allow the water to drain. A flexible tube connected to the cock will allow the water to be directed to a suitable drain.

Refill the sump tank as described in the Operation section or Installation Guide of this instruction manual, using clean water and add the correct amount of an appropriate corrosion inhibitor with biocide if required (must be suitable for use with aluminium alloy). The sump tank contains approximately 250 litres of water. Refer to the details supplied with the inhibitor used for information on dilution.

Switch on the pump with the flow control valve closed, then gradually open the valve to circulate the water through the C4-MkII channel and F1-10 to ensure that the inhibitor has dispersed thoroughly and coated all wetted surfaces with a protective film.

5.4 Check C4-MkII for leaks

The C4-MkII channel, F1-10 Hydraulics Bench and interconnecting pipework should be checked visually for drips or staining associated with leaks. Any leaks identified should be attended to immediately to minimise deterioration of the equipment. Refer to the notes on resealing (section 5.6.5) for further information.

5.5 Check condition of channel bed

The surface of the aluminium bed inside the channel section is treated with chlorinated rubber paint (Oxford Blue BS105) to provide corrosion resistance. It is important that this finish is maintained in perfect condition to prevent corrosion of the bed.

Inspect the bed thoroughly for any sign of damage to, or deterioration of, the paint finish, such as scratches, discoloration, peeling, blistering etc. Care should be taken to look for small indentations through the paint surface caused by instruments such as the point of a hook and point gauge. Small areas of damage can be touched up locally provided that care is taken to remove all traces of corrosion before repainting. The frequency of repainting will depend on usage but repainting of the whole bed must be undertaken if any deterioration is located, however small. If repainting is necessary refer to the notes on repainting (section 5.6.3) below for further information.

5.6 Full annual service

It is important to carry out a full service at regular intervals, at least annually or more frequently according to usage and local conditions. The full service must include the following:-

Note: As the channel will be out of use for several days while drained, cleaned, repainted etc. it is sensible to program the full service to coincide with an end of term shutdown etc.

5.6.1 Check for Leaks

Install the full set of stop logs at the discharge end of the channel. Operate the pump then open the flow control valve to fill the channel with water. Close the flow control valve then switch off the pump and allow the channel to stand for at least 24 hours. Check all joints, pipework etc. for leaks and mark any leaks for subsequent action.

5.6.2 Draining and Cleaning

Having inspected for any leakage all water should be drained from the channel and sump tank.

The channel and F1-10 Hydraulics Bench should be cleaned using warm water with household detergent then rinsed and dried. Particular attention should be paid to the clear acrylic walls of the channel if deposits are obscuring the view, taking care not to scratch the soft plastic. In order to restore visual clarity to scuffed, discoloured or surface crazed acrylic, an abrasive metal polish may be used.

After cleaning with warm soapy water, the painted bed should be checked for damage as described above. If repainting is necessary proceed as follows:

While the F1-10 is drained the centrifugal pump can be checked. Refer to the leaflet supplied by the pump manufacturer for service details.

5.6.3 Repainting the Channel Bed

If repainting is necessary the following steps should be carried out:

All existing paint on the bed should be completely removed and the surface degreased prior to painting.

The surface of the bed and the joints between the clear acrylic side walls and the bed must be fully dry prior to painting. A hair drier can be used to speed up this operation but care should be taken not to heat the plastic excessively. Within 4 hours of cleaning, the bed should be painted with one coat of an appropriate etch primer/undercoat. When the primer is dry, the bed should be painted with two top coats of chlorinated rubber paint, paying particular attention to the joints in the bed and internal corners.

The primer used should be a two pack etch primer/undercoat suitable for direct application to aluminium alloy and over-painting with chlorinated rubber paint. The dry film thickness of the primer should be 20 microns minimum.

The two top coats should be applied using chlorinated rubber paint. The dry film thickness of the top coats should be 80 microns minimum. The colour specification of the original paint is Oxford Blue, BS105.

The bed should be left for a minimum period of two days before refilling with water.

5.6.4 Check condition of external paintwork

Having checked/repainted the bed, any damage to external paintwork should be identified and touched up.

Any corrosion should be removed and the surface degreased.

The cleaned surface should be primed before painting. The two pack etch primer/undercoat used inside the flume can be used for the surfaces of the bed external to the working section. A two pack etch primer/undercoat suitable for use with mild steel should be used to coat the mild steel support pedestals.

The chlorinated rubber paint used for repainting the channel bed may be used for this application but a better finish will be obtained using polyurethane enamel paint.

The colour specification of the original paint is Oxford Blue, BS105

5.6.5 Resealing

Any leaks, which were identified while the channel and pipework were filled, should be resealed using an appropriate sealant. There are two types of sealant used in the construction of the channel, 'Silicone sealant' and 'Mastic sealant'.

Silicone sealant is supplied in a tube and is best used for internal clear acrylic joints to provide a smooth finish. The sealant cures at room temperature but remains flexible.

Mastic is supplied in strip form and is used for tank-to-bed and bed-to-bed joints. Clear acrylic joints have mastic between the acrylic and the support strip. The mastic is non-hardening.

Dripping leaks generally originate from the clear acrylic side butt joints adjacent to the flume bed. They may be made good by applying silicone sealant into the corner formed by the walls and the bed. Although leakage may not be evident, check the seal between the clear acrylic panels and the bed of the channel. Apply silicone sealant to the corner of the joint if any doubt exists.

All PVC and rubber hoses/sleeves must be checked and replaced if perished.

Despite appearing leak-tight, all joints should be checked for integrity and re-seated if necessary.

Leaks from threaded joints should be sealed by wrapping PTFE tape around the thread before refitting.

5.6.6 Lubrication

All moving parts should be lubricated using a general purpose grease. Special attention should be paid to the pivot, the jacking arrangement and the trunnions attaching the flume to the support pedestals.

Where usage is unusually heavy or local conditions are extreme increase the frequency of lubrication to every 6 months.

5.6.7 Check that channel section is straight and level

Refer to the Installation Guide at the end of this instruction manual for details on how to check that the channel section is straight and level before refilling the system.

5.6.8 Refilling

Refill the F1-10 Hydraulics Bench as described in the Operation section or Installation Guide of this manual.

5.6.9 Cleaning the Models

Models used in the channel should be checked for damage and repaired if necessary. All models should be washed in warm water to which household detergent has been added.

Many of the models use clear acrylic or rigid PVC in the construction and should not be cleaned using strong solvents such as acetone, trichloroethylene or tetrachloride which will soften the material and cause crazing of the clear acrylic.

In order to restore visual clarity to scuffed, discoloured or surface crazed acrylic, an abrasive metal polish may be used.

6 Laboratory Teaching Exercises

6.1 Index to Exercises

6.2 General Nomenclature

Name	Symbol	Units	Definition
Breadth of channel/weir etc	b	m	Measured
Gravitational constant	g	$m\ s^{-2}$	$9.81 m\ s^{-2}$
Difference in manometer readings	h	m	Calculated from manometer readings
Volumetric flowrate	Q	$m^3\ s^{-1}$	Measured or calculated
Hydraulic mean radius	R	m	
Temperature of water	T	°C	Measured
Local fluid velocity	v	$m\ s^{-1}$	
Mean fluid velocity	V	$m\ s^{-1}$	
Depth of fluid at any location	y	m	Measured
Density of fluid	ρ	$kg\ m^{-3}$	

6.3 Nomenclature for Free Surface Flow

Name	Symbol	Units	Definition
Velocity of gravity wave in still shallow water	c	ms^{-1}	(sometimes called celerity)
Coefficient of contraction	C_c	-	
Coefficient of discharge	C_d	-	
Coefficient of velocity	C_v	-	$0.95<C_v<1.0$
Specific energy head (total energy head measured relative to channel bed)	E	m	$E = y + V^2/2g$ **Note**: If the datum is the channel bed then $E = H$ ($z = 0$)
Force of a stream	F	N	$F = \rho gby^2/2 + \rho Q^2/by$
Height of water surface above a weir crest	y_c	m	
Total energy head or total head (height of energy line (e) above a datum)	H	m	$H = y + V^2/2g + z$
Loss of total head between specified sections	ΔH	m	
Pressure at height y above channel bed	p	Nm^2	Measured
Height of weir crest above channel bed	h	m	Measured
Height of water surface above the bed at position x	y_x	m	Measured
Critical depth	y_{crit}	m	Depth at which specific energy of flow is at a minimum.
Height of sluice gate opening	y_g	m	Measured
Height of siphon throat	y_t	m	Measured
Slope of energy line (for uniform flow assumed to be the same slope as the channel bed and the surface of the water)	S	°	$\sin\theta$

6.4 Exercise A: Sharp Crested Overshot Weir

Objective

To determine the relationship between upstream head and flowrate for water flowing over a Sharp Crested weir.

To calculate the discharge coefficient and to observe the flow patterns obtained.

Method

By using the Sharp Crested weir installed in the C4-MkII flume and comparing the flow characteristics under a range of flow conditions with the aeration pipe open and with the aeration pipe closed.

Equipment Required

Armfield C4-MkII Flume with:

Sharp Crested Weir model

Hook and Point Gauge, 300mm scale

Armfield F1-10 Hydraulics Bench

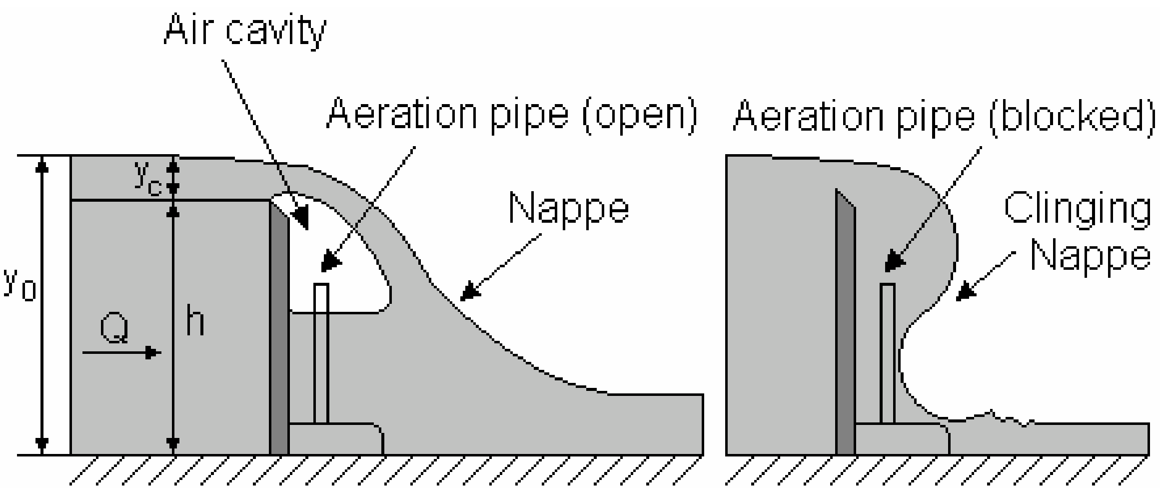
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



For a rectangular sharp crested weir:

$$Q = \frac{2}{3} C_d b \sqrt{2g}\, y_c^{\frac{3}{2}} \qquad \text{therefore:} \qquad C_d = \frac{Q}{\frac{2}{3} b \sqrt{2g}\, y_c^{\frac{3}{2}}}$$

where:

Q	= Volume flowrate	($m^3.s^{-1}$)
	= Volume/time (using volumetric tank)	
C_d	= Coefficient of discharge	(Dimensionless)
b	= Breadth of weir	(m)
y_c	= Height above crest of weir (upstream)	(m)
	= y_0 - h	
g	= Gravitational constant	($9.81ms^{-2}$)
h	= Height of weir crest above bed	(m)
y_0	= Upstream flow depth	(m)

When the rectangular weir extends across the whole width of the channel it is called a suppressed weir and the Rehbock formula can be applied to determine C_d as follows:

$$C_d = 0.602 + 0.083 \cdot \frac{y_c}{h}$$

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 sharp crested overshot weir (rectangular weir).

Install the weir in the flume with the sharp edge 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 a hook and point level gauge on the channel sides, above the weir, with the point fitted.

The datum for all measurements will be the top edge of the weir plate. Carefully adjust the level gauge to coincide with the top of the weir, taking care not to damage the edge of the weir, then record the datum reading. Alternatively, to avoid damage to the weir, open the flow control valve and admit water into the channel until it discharges over the weir then close the flow control valve to stop the flow of water. When water stops flowing over the weir adjust the level gauge to coincide with the surface of the water and record the datum reading.

Adjust the level gauge to measure the position of the bed relative to the top of the weir and record the height of the weir P (m). Reposition the level gauge some way upstream from the weir.

Procedure

Adjust the flow of water into the flume to obtain flow depths y_0, increasing in about 0.010m steps. For each step measure the flowrate Q and the depth y_0. The flowrate Q can be determined using the direct reading flowmeter (if fitted) 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 adjacent to the weir.

If the nappe tends to cling to the back face of the weir then the ventilation tubes are filled with water. Ventilate the nappe by inserting the end of a piece of hollow tube into the space behind the weir. The nappe should spring away from the weir.

Sketch the flow pattern as the water flows over the weir when the nappe is ventilated properly. Reduce the flowrate slightly then block the ventilation tubes and sketch the flow pattern with the nappe clinging to the weir. Measure the flowrate Q and the head H while the nappe is clinging to the weir.

Results

Tabulate your measurements and calculations as follows:

Breadth of Weir b =………..(m)

Height of weir h =………..(m)

y_c	Q	$y_c^{3/2}$	log y_c	log Q	C_d

Plot Q against y_c, log Q against log y_c and C_d against y_c.

From the straight-line graph of log Q against log h find the intercept log k on the log Q axis and the gradient m.

The relationship between Q and h is then $Q = k\ y_c^m$.

Calculate C_d for the condition when the nappe is not properly ventilated.

Calculate the C_d predicted by the Rehbock formula.

Conclusion

This should be a brief summary of any conclusions to be drawn from the experiment, e.g. graphs or experimentally obtained values to be studied and compared to the theoretical results. It should include any comparisons to make with previous experiments.

This section can suggest any other considerations a student should take into account when writing up the experiment, such as sources of error. It can also direct the student towards wider application of the results, such as possible commercial uses for the type of equipment under test.

6.5 Exercise B: 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

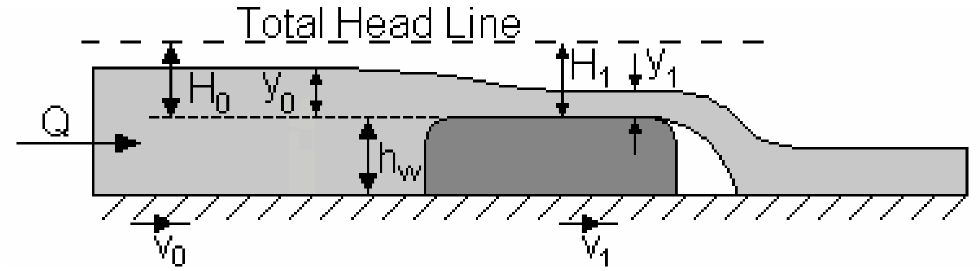
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



From conservation of energy and ignoring losses:

$$H_0 = H_1 = y_0 + \frac{v_0^2}{2g} = y_1 + \frac{v_1^2}{2g}$$

Therefore

$$v_1 = \sqrt{2g(H_0 - y_1)}$$

The flow rate Q is given by:

$$Q = y_1\, v_1\, b_1$$

$$= b\sqrt{2g\left(H_0 y_1^2 - y_1^3\right)}$$

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

$$H_0 y_1^2 - y_1^3 = \text{maximum}$$

At maximum

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

Therefore

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

Therefore

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

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

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

$$Q_{actual} = 1.704\, C_d\ b\, H_0^{\frac{3}{2}} \qquad \text{where } C_d \text{ is the coefficient of discharge.}$$

i.e. $Q_{actual} = C_d \times Q_{theoretical}$

The Coefficient of Discharge may therefore be determined as

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

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 h_w(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 Q_{actual}, 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.

Conclusion

Does the magnitude of the flowrate affect the discharge coefficient C_d? Does C_d 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 C_d?

What is the effect of drowning the weir (increasing the downstream depth)? How does drowning affect the accuracy of the results?

6.6 Exercise C: Crump Weir

Objective

To determine the relationship between upstream head and flowrate for water flowing over a Crump weir.

To determine the modular limit and to observe the flow patterns obtained.

Method

By using the Crump 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

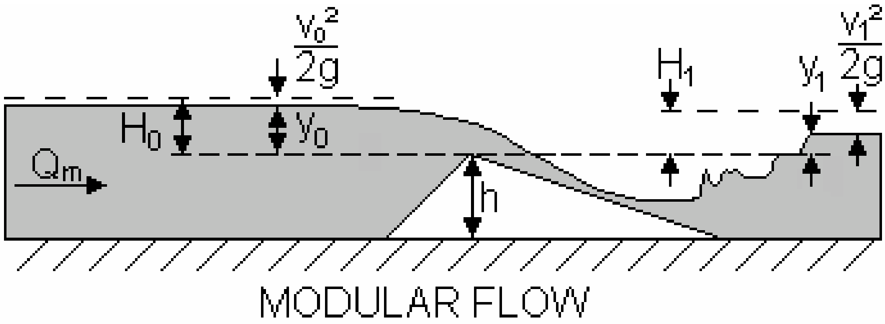
Stopwatch (for flow measurement using F1-10 volumetric tank)

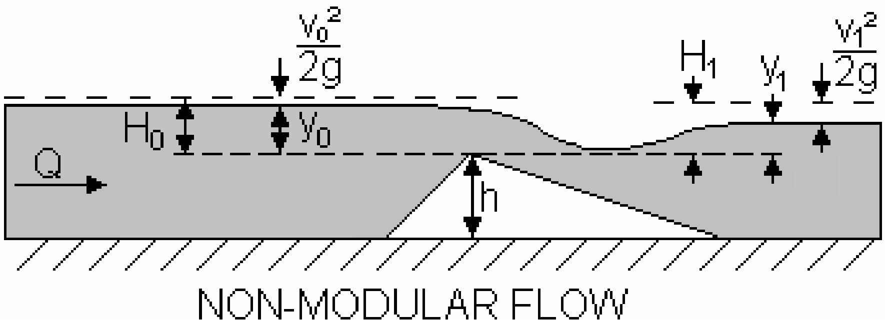
Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory





<u>For Modular Flow</u> (weir operates undrowned, downstream water level low)

$$Q_m = b\,C_d\,g^{\frac{1}{2}}\,H_0^{\frac{3}{2}} \quad \text{therefore:} \quad C_d = \frac{Q_m}{b\,g^{\frac{1}{2}}\,H_0^{\frac{3}{2}}}$$

where:

Q_m	= Modular volume flowrate	($m^3.s^{-1}$)
	= Volume/time (using volumetric tank)	
b	= Breadth of weir	(m)
g	= Gravitational constant	($9.81ms^{-2}$)
H_0	= Total head upstream of weir crest	(m)
	$= y_0 + \frac{V_0^2}{2g} = y_0 + \frac{Q_0^2}{2g A_0^2} = y_0 + \frac{Q_0^2}{2g(y_0 b)^2}$	
y_0	= Upstream depth of flow above weir	(m^2)
Q_0	= Upstream flow rate = Q_m for modular flow	(m^3/s)
h	= vertical height of weir	(m)
C_d	= Modular coefficient of discharge	(Dimensionless)

When the flow is modular the upstream head is not affected by changes in the downstream head. A single measurement of upstream head can therefore be taken to determine the volume flowrate over the weir.

For Non-Modular Flow (weir crest drowned, downstream water level high)

The weir ceases to act in modular fashion when:

$$\frac{H_1}{H_0} \geq 0.70$$

where:

H_1 = Total head downstream of weir crest (m)

$$= y_1 + \frac{V_1^{\,2}}{2\,g} = y_1 + \frac{Q_1^{\,2}}{2\,g\,A_1^{\,2}} = y_1 + \frac{Q_1^{\,2}}{2\,g\,(y_1\,b)^2}$$

Q_1 = downstream flow rate

H_0 = Total head upstream of weir crest (m)

$$= y_0 + \frac{V_0^{\,2}}{2\,g} = y_0 + \frac{Q_0^{\,2}}{2\,g\,A_0^{\,2}} = y_0 + \frac{Q_0^{\,2}}{2\,g\,(y_0\,b)^2}$$

Q_0 = upstream flow rate

When the flow is not modular the upstream head is affected by changes in the downstream head. A single measurement of upstream head is no longer adequate to determine the actual flowrate.

A reduction factor can be used to correct for non-modular flow where:

$$f = \frac{Q}{Q_m}$$

(Dimensionless)

where Q is measured using timed volume collection or flowmeter and Q_m calculated from

$$Q_m = b\,C_d\,g^{\frac{1}{2}}\,H_0^{\frac{3}{2}}$$

using the upstream flow head and the value of C_d determined during modular flow.

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) and the vertical height h_w (m) of the Crump weir.

For accuracy of measurement install the weir in the flume at least 0.4m downstream of the working section inlet (i.e. at a distance that is at least five times the maximum height of the weir), with the short face of the weir facing the inlet tank. Ensure that the weir is secured using a mounting hook through the bed of the flume. 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, each with the point fitted. The upstream depth measurement gauge must be at least 0.16m upstream of the weir. The downstream gauge should be positioned close to the working section outlet.

The datum for all measurements will be the bed of the channel. Carefully adjust each level gauge in turn to coincide with the bed of the channel and record the datum readings.

Procedure

Open the flow control valve and allow the water to flow into the flume then adjust the valve to obtain a depth y_0 of 0.070m upstream of the weir. Maintain this level whilst measuring the downstream depth of flow y_1 and the flowrate Q. For accurate results the upstream level gauge must be far enough upstream to be clear of the draw-down over the weir. Similarly the downstream level gauge must be in clear water after the level has stabilised.

Repeat this for 0.010m increments of y_0, recording the measurements of y_0, y_1 and Q and noting any variation in the flow patterns over the weir.

Add stop logs one at a time at the discharge end of the flume. When the levels have stabilised record the measurements of y_0, y_1 and Q. Observe the changes in the flow patterns over the weir.

Results

Tabulate your readings and calculations as follows:

Breadth of Weir b =...........(m)

y_0	y_1	Q	H_0	H_1	Q_m	C_d	f

Determine the average coefficient of discharge for modular flow conditions.

Plot values of f against $\frac{H_1}{H_0}$ then determine the modular limit – the value of $\frac{H_1}{H_0}$ where f ceases to be unity.

Conclusion

How does your value for the modular limit compare with the recognised value of approximately 0.7?

How does the value of f change when the weir is drowned?

How are the flow patterns affected when flow over the weir changes from modular to non-modular flow?

6.7 Exercise D: 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

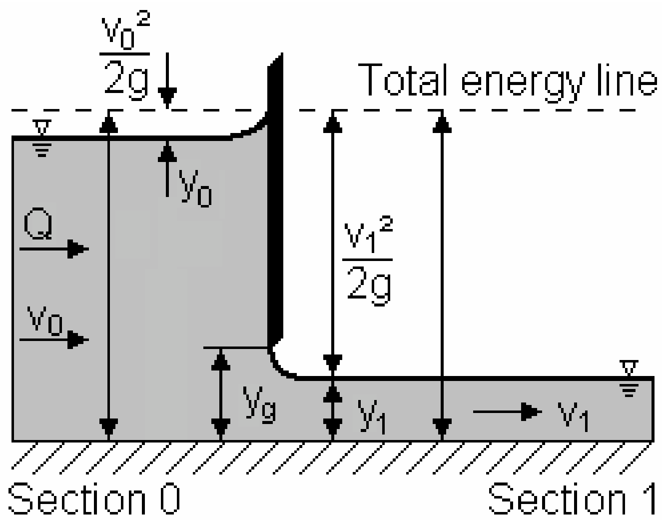
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

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	($9.81 m \, s^{-2}$)

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

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

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 y_o 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_o	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.

Conclusion

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.

6.8 Exercise E: Force on a Sluice Gate

Objective

To determine the relationship between upstream head and thrust on a sluice gate (undershot weir) for water flowing under the sluice gate.

Method

By using the adjustable undershot weir installed in the C4-MkII flume.

Equipment Required

Armfield C4-MkII Flume

Adjustable Undershot Weir model

Two Hook and Point Gauges, 300mm scale

Armfield F1-10 Hydraulics Bench

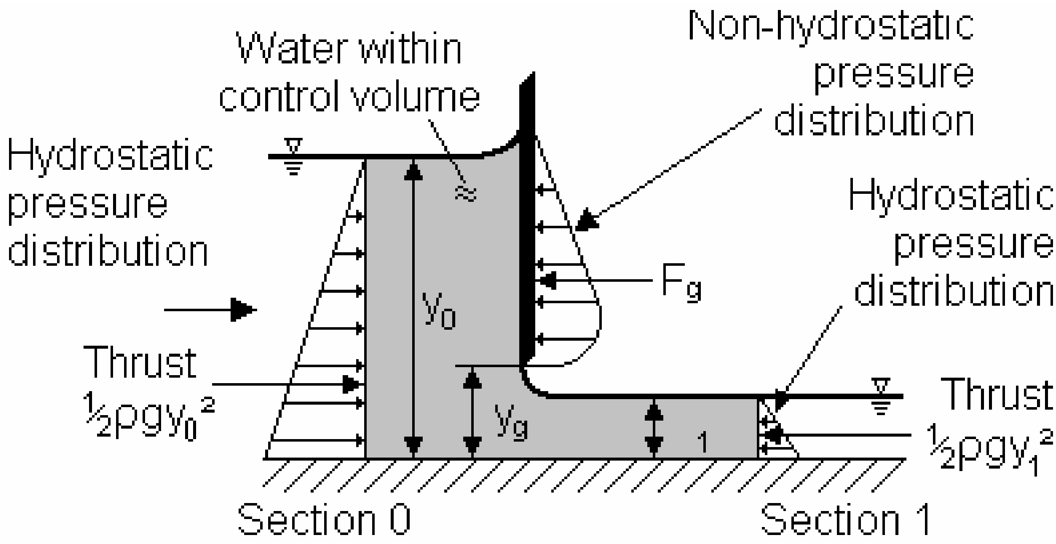
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



It can be shown that the resultant force on the gate is given by the equation:

$$F_g = \frac{1}{2}\rho\, g\, y_1^2\left[\frac{y_o^2}{y_1^2} - 1\right] - \frac{\rho\, Q}{b\, y_1}\left[1 - \frac{y_1}{y_o}\right]$$

The gate thrust for a hydrostatic pressure distribution is given by the equation:

$$F_H = \frac{1}{2}\rho\, g\,(y_o - y_g)^2$$

where:

F_g	= Resultant gate thrust	(N)
F_H	= Resultant hydrostatic thrust	(N)
Q	= Volume flowrate	($m^3\ s^{-1}$)
	= Volume/time (using volumetric tank)	
ρ	= Density of fluid	(kgm^{-3})
g	= Gravitational constant	($9.81m\ s^{-2}$)
b	= Breadth of gate	(m)
y_g	= Height of gate opening above bed	(m)
y_0	= Upstream depth of flow	(m)
y_1	= Downstream depth of flow	(m)

Equipment Set Up

Note: To save time, the measurements obtained in experiment D can be used to perform the calculations in this experiment. If results are not available proceed as follows:

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 gate 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 y_o 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**	F_g	F_H	$\frac{F_g}{F_H}$	$\frac{y_g}{y_0}$

Plot a graph of the ratio $\frac{F_g}{F_H}$ against the ratio $\frac{y_g}{y_0}$.

Conclusion

Compare your calculated values for F_g and F_H and comment on any differences.

What is the effect of flow rate on the results obtained?

Comment on the graph obtained.

6.9 Exercise F: The Specific Energy Equation

Objective

To determine the relationship between the specific energy and upstream head for water flowing under an undershot weir.

Method

By using the adjustable undershot weir installed in the C4-MkII flume.

Equipment Required

Armfield C4-MkII Flume

Adjustable Undershot Weir model

Two Hook and Point Gauges, 300mm scale

Armfield F1-10 Hydraulics Bench

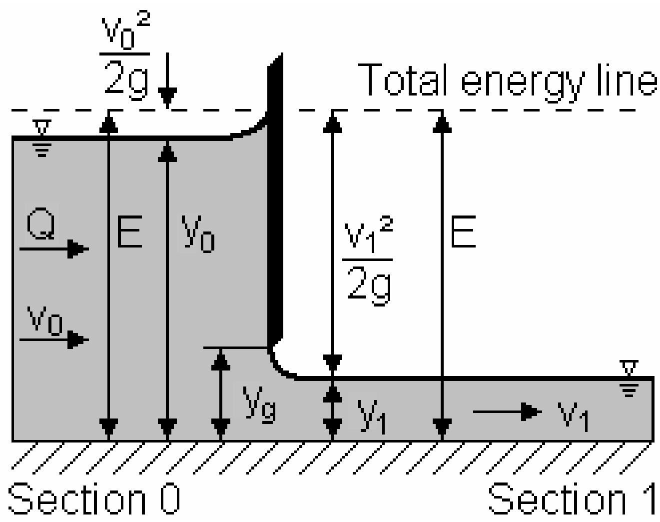
Stopwatch (for flow measurement using F1-10 volumetric tank)

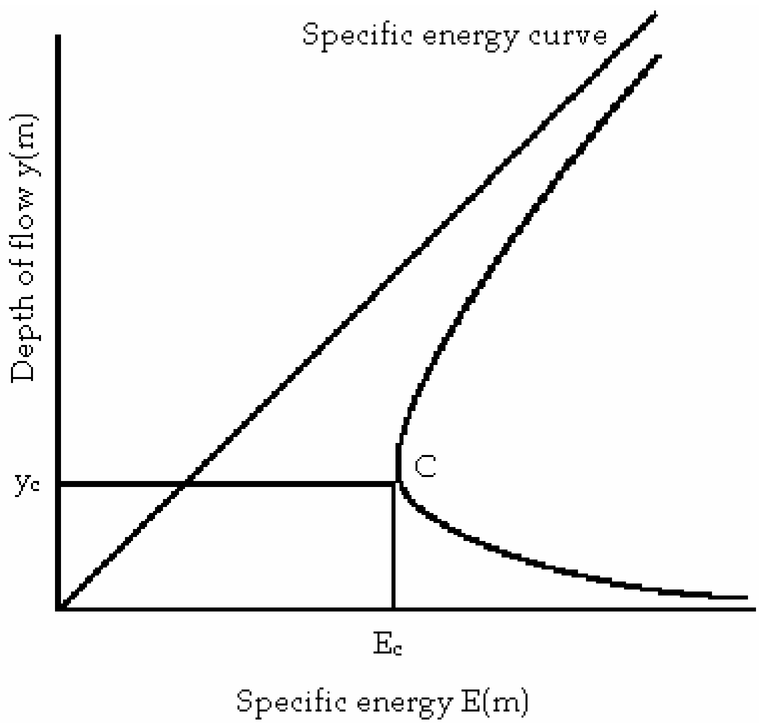
Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory





The depth and velocity of a given flow at any section of an open channel adapt themselves to the energy available at that section. For a constant discharge this energy reaches a minimum value at the 'critical' depth. This parameter is fundamental to a complete understanding of free flow behaviour because the response of a stream to energy (and force) depends on whether the actual depth is greater than or less than the critical depth.

In an open channel it is convenient to use the bed as the datum and to compare the specific energy at different sections where the specific energy is defined as the sum of the potential energy (the depth of flow) and the kinetic energy (the velocity head):

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

Considering unit width of channel the equation becomes:

$$E = y + \frac{Q^2}{2\,g\,y^2}$$

where:

E	= Specific energy	(m)
y	= Depth of flow	(m)
Q	= Volume flowrate	(m^3s^{-1})
	= Volume/time (using volumetric tank)	
g	= Gravitational constant	(ms^{-2})

Note: When the datum coincides with the bed E = H

A plot of specific energy against depth of flow gives a curve called the specific energy curve shown below. The shape of the curve shows that for a given specific energy there are two possible depths called the alternate depths. At point C on the curve the specific energy is a minimum with only one corresponding depth called the critical depth y_c.

Flow at depths greater than critical is described as ‘slow’, ‘subcritical’ or ‘tranquil’.

Flow at depths less than critical is described as ‘fast’, ‘supercritical’ or ‘shooting’.

A family of such curves will exist for different flowrates through the channel.

When considering a rectangular channel of unit width, where the streamlines are parallel, it can be shown that:

$$y_c = \sqrt[3]{\frac{Q^2}{g}} \quad \text{and} \quad E_c = E_{min} = \frac{3}{2}\,y_c$$

where:

E_c	= Minimum specific energy	(m)
y_c	= Critical depth	(m)

When the slope of a channel is just sufficient to maintain a given flowrate at a uniform and critical depth the slope is called the critical slope S_c. It should be noted that the surface of the water may appear wavy when the flow is near to the critical state because a small change in specific energy is accompanied by a large change in depth of flow – predicted by the shape of the specific energy curve.

Equipment Set Up

Ensure the flume is level, with no stop logs installed at the discharge end of the channel.

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 gate 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 0.010m 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 and record Q using the direct reading flowmeter or the volumetric tank with a stopwatch. Also measure and record y_1 using the downstream level gauge.

Raise the weir in increments of 0.010m, allowing the upstream and downstream levels to stabilise, then measure and record the depths of flow y_0 and y_1.

Increase the flowrate Q slightly, lower the weir until y_0 = 0.200m. Measure and record Q then repeat the above measurements by gradually raising the weir.

Tilt the channel slightly, water flowing downhill, and gradually adjust the combination of flowrate and height of weir until critical depth exists along the length of the channel.

Results

Tabulate your readings and calculations as follows:

y_0	y_1	Q	E_0	E_1	E

Calculate E_0 and E_1 for each value of Q.

Plot E_0 against y_0 and E_1 against y_1 to establish the shape of the curve on either side of the minimum energy point.

Plot your calculated values for E_c on the same axes.

On your graph draw a line through the critical point on each curve to show the critical state (tranquil flow above the line, shooting flow below the line).

Conclusion

How is the critical depth y_c affected by the flowrate Q?

How do your calculated values for E_c agree with the corresponding minimum energy points on your plotted curves?

Was it easy to find the combination to give critical depth in the sloping channel?

How did you know that critical depth had been achieved?

6.10 Exercise G: The Hydraulic Jump

Objective

To investigate the characteristics of a standing wave (the hydraulic jump) produced when water flows beneath an undershot weir and to observe the flow patterns obtained.

Method

By using the adjustable undershot weir installed in the C4-MkII flume.

Equipment Required

Armfield C4-MkII Flume

Adjustable Undershot Weir model

Two Hook and Point Gauges, 300mm scale

Armfield F1-10 Hydraulics Bench

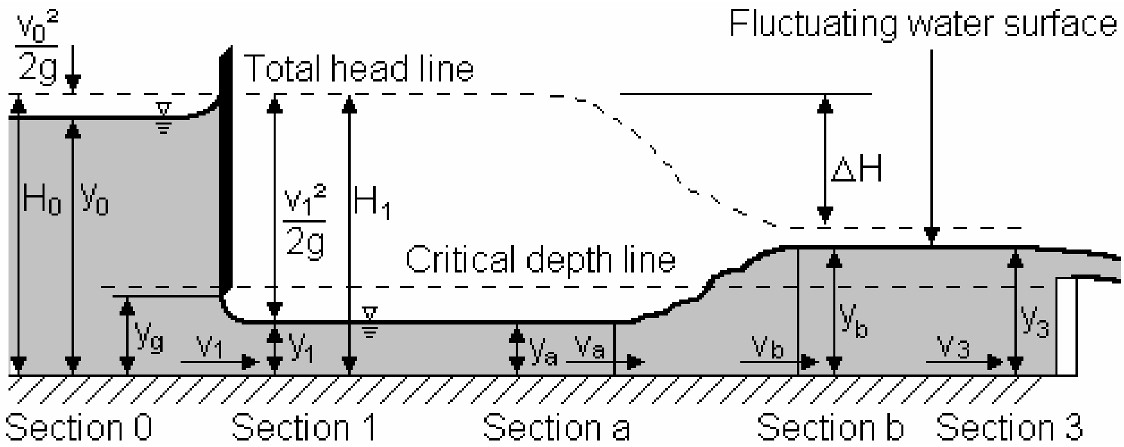
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



When water flowing rapidly changes to slower tranquil flow a hydraulic jump or standing wave is produced. This phenomenon can be seen where water shooting under a sluice gate mixes with deeper water downstream. It occurs when a depth less than critical changes to a depth which is greater than critical and must be accompanied by a loss of energy.

An undular jump occurs when the change in depth is small. The surface of the water undulates in a series of oscillations which gradually decay to a region of smooth tranquil flow

A direct jump occurs when the change in depth is great. The large amount of energy loss results in a zone of extremely turbulent water before it settles to smooth tranquil flow.

By considering the forces acting within the fluid on either side of a hydraulic jump of unit width it can be shown that:

$$\Delta H = y_a + \frac{V_a^2}{2g} - \left(y_b + \frac{V_b^2}{2g} \right)$$

where:

ΔH	= Total head loss across jump (energy dissipated)	(m)
V_a	= Mean velocity before hydraulic jump	($m\ s^{-1}$)
y_a	= Depth of flow before hydraulic jump	(m)
V_b	= Mean velocity after hydraulic jump	($m\ s^{-1}$)
y_b	= Depth of flow after hydraulic jump	(m)

Because the working section is short $y_a \approx y_1$ and $y_b \approx y_3$

Therefore simplifying the above equation:

$$\Delta H = \frac{(y_3 - y_1)^3}{4\, y_1\, y_3}$$

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 close to the upstream end of the flume with the sharp edge on the bottom of the gate 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, 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. Place one stop log at the discharge end of the flume.

Gradually open the flow control valve and adjust the flow until an undular jump is created with small ripples decaying towards the discharge end of the flume. Observe and sketch the flow pattern.

Increase the height of water upstream of the weir by increasing the flowrate and increase the height of the stop logs to create a hydraulic jump in the centre of the working section. Observe and sketch the flow pattern.

Move one level gauge to the region of rapid flow just upstream of the jump (section a). Move the second level gauge to the region of tranquil flow just after the jump (section b). Measure and record the values of y_1, y_3, y_g and Q. Repeat this for other flowrates Q (upstream head) and heights of the gate y_g.

Results

Tabulate your readings and calculations as follows:

Breadth of gate, b =…………(m)

$\mathbf{y_g}$	$\mathbf{y_1}$	$\mathbf{y_3}$	**Q**	$\mathbf{H_b}$	ΔH

Calculate v_1 and plot $\frac{v_1^2}{gy_1}$ against $\frac{y_3}{y_1}$

Calculate $\frac{\Delta H}{y_1}$ and plot $\frac{\Delta H}{y_1}$ against $\frac{y_3}{y_1}$

Calculate y_c and verify $y_1 < y_c < y_3$.

Conclusion

Verify the force of the stream on either side of the jump is the same and that the specific energy curve predicts a loss equal to $\frac{\Delta H}{y_c}$.

Suggest an application where the loss of energy in hydraulic jump would be desirable. How is the energy dissipated?

6.11 Exercise H: Flow Through a Venturi Flume

Objective

To determine the relationship between upstream head and flowrate for water flowing through a Venturi flume.

To calculate the discharge coefficient and to observe the flow patterns obtained.

Method

By using the Venturi flume installed in the C4-MkII flume.

Equipment Required

Armfield C4-MkII Flume

Venturi flume assembly with spreader bar

Two Hook and Point Gauges, 300mm scale

Armfield F1-10 Hydraulics Bench

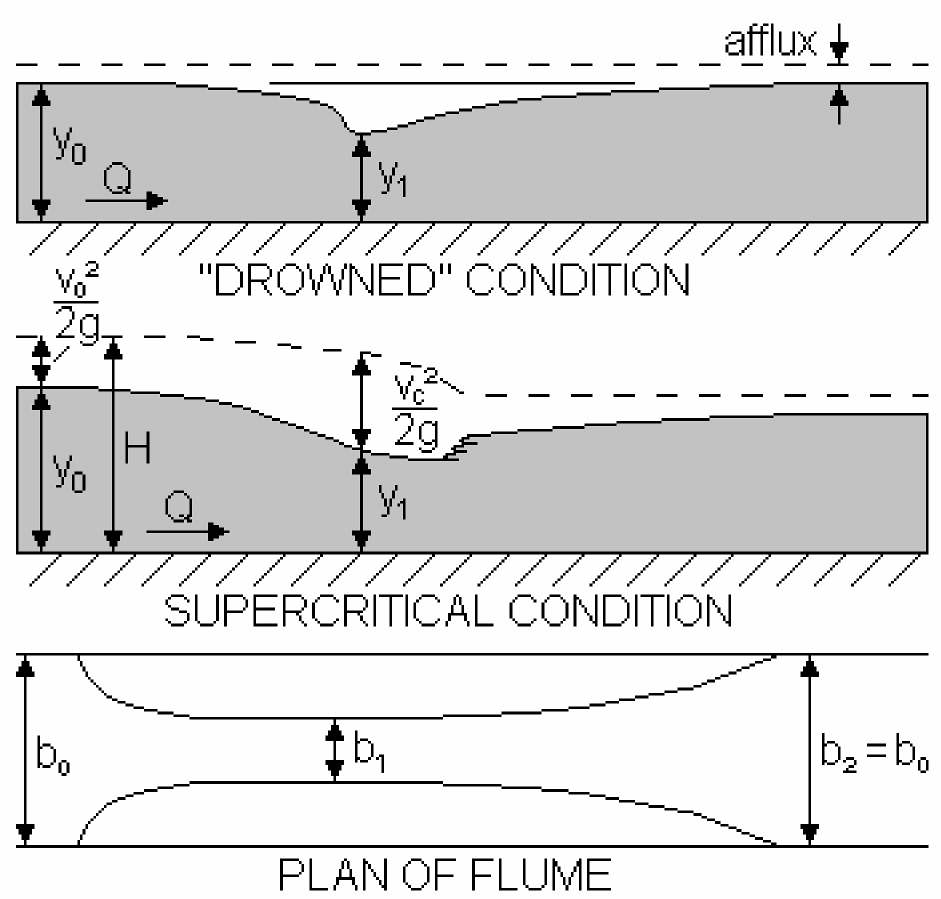
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



Widening or narrowing the width of a channel has the same effect as raising or lowering the bed of the channel. Therefore the throat created by a Venturi flume has the same characteristics as the Broad Crested Weir (Exercise B) and the discharge is given by:

$$Q = \frac{2\sqrt{2g}}{3\sqrt{3}}.b.H^{\frac{3}{2}} = 1.704\, b_1\, H_0^{\frac{3}{2}}$$

Equipment Set Up

Ensure the flume is level, with no stop logs installed at the end of the flume.

Form the Venturi Flume mid way along the flume by fixing an asymmetrical throat insert to each wall. Then measure and note the throat width (b_1). For accurate results seal any gaps between the Venturi Flume and the flume sides (at the upstream end), using Plasticine.

Procedure

Open the flow control valve and admit water into the working section.

Maintaining a constant flow, measure and note y_0, y_1 and Q. Increasing the flow in stages, measure and note the above for each stage. Add stop logs as required to observe the drowned and standing wave flow conditions.

Results

Throat width: …………mm

Breadth Of Weir b (m)	Upstream Flow Depth y_0 (m)	Throat Flow Depth y_1 (m)	Flow Rate (l/s)	Flow Rate Q (m^3/s)	Head H_0 (m)	Head H_1 (m)	$H_0 - H_1$ (m)

Plot Q against (H_0-H_1), Q against H_0, and Q against H_1

Determine Cd.

Conclusion

Comment on the effects of narrowing the channel. Is it the same as raising the bed?

What factors influence the efficiency of the Venturi Flume?

6.12 Exercise J: Flow Through a Culvert

Objective

To determine the characteristics and observe the flow patterns obtained for water flowing through a Culvert.

Method

By using the culvert block assembly installed in the C4-MkII flume, and operating the flume at different heads upstream and downstream.

Equipment Required

Armfield C4-MkII Flume

Culvert block assembly, C4-62 (optional accessory)

Two Hook and Point Gauges, 300mm scale

Armfield F1-10 Hydraulics Bench

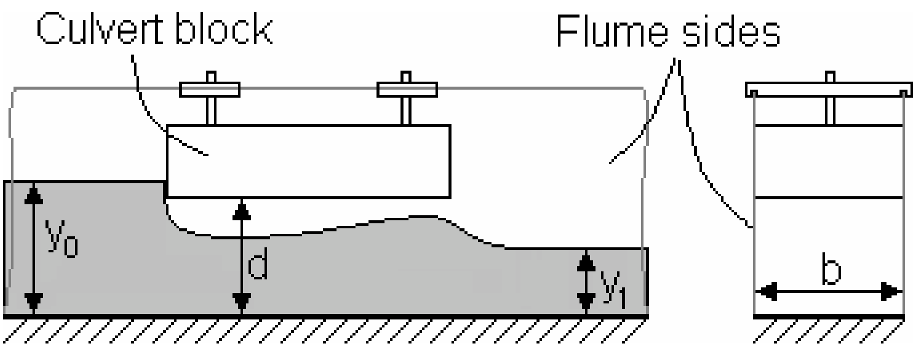
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



The culvert is a covered channel of comparatively short length which is typically installed to drain water through an embankment. The culvert acts as on open channel, as long as the section is partly full, and is normally used in this condition. However, under flood conditions the inlet or outlet may become submerged and a variety of flow patterns can exist. A culvert will run full, like a pipe, when the outlet is submerged or when the upstream level is sufficiently high.

The objective is to view the range of patterns which can exist, to determine the head/discharge characteristics and to determine the conditions necessary for the culvert to run full.

The performance of a culvert is defined by the ratio $\frac{y_0}{d}$ (typical values are in the range 1.2 to 1.5 depending on geometry and conditions).

where:

y_0	=	Depth of flow upstream of the culvert at the point where the culvert runs full	(m)
d	=	Height of the culvert	(m)

Equipment Set Up

Ensure the flume is level, with no stop logs installed at the discharge end of the channel. Clamp the culvert block securely to the sides of the channel at a position approximately mid way along the flume with the rounded edge of the culvert facing upstream. For accurate results the gaps between the block and the channel should be sealed on the upstream side using Plasticine. Measure and record the actual breadth b (m) and the height d (m) of the culvert created.

Position two hook and point level gauges on the channel sides, one upstream of the culvert and one downstream of the culvert, each with the point fitted. Record the distance x (m) between the gauges to allow level measurements to be corrected for inclination of the bed. 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

Gradually open the flow control valve and admit the water into the flume. By altering the flow, gradually increase the depth of water upstream of the culvert until the culvert runs full. Observe and sketch the changing profile of the water flow as it passes through the culvert. When running full, measure and record the depth of flow y_0 upstream of the culvert, the flow depth y_1 downstream and the corresponding flowrate Q.

Drain the culvert, add one stop log at the discharge end of the channel then repeat the above observations and record y_0, y_1 and Q when the culvert runs full.

Repeat the procedure adding stop logs at the discharge end until the culvert remains full with no flow.

Remove the stop logs, drain the culvert then incline the channel bed slightly (flow downhill). Gradually increase the flowrate until the channel runs full as before then record y_0, y_1, Q and S (slope of the bed).

Repeat the procedure for increasing slope of the channel bed.

If time permits repeat the above experiment for a different height of culvert by adjusting the vertical position of the culvert block. The change in flow profile when the square corner is positioned upstream could also be investigated.

Results

Tabulate your readings and calculations as follows:

Breadth of culvert, b =…………(m)

Height of culvert, d =………….(m)

$\mathbf{y_0}$	$\mathbf{y_1}$	**Q**	**S**	$\mathbf{y_0/d}$

Conclusion

How many different profiles did you observe as flow through the culvert changes from partial to full flow?

What is your value for $\frac{y_0}{d}$ when the exit is not submerged?

How does this ratio change when the exit becomes submerged?

How does the slope affect the performance of the culvert?

Are there any similarities between the culvert and the undershot weir and if so under what conditions of flow do they occur?

6.13 Exercise K: Flow Around Flow Splitters

Objective

To observe the flow patterns obtained for water flowing around splitters with different profiles.

Method

By operating the C4-MkII with different profiles of flow splitter installed in the flume.

Equipment Required

Armfield C4-MkII Flume

Two Hook and Point Gauges, 300mm scale

Flow splitters, C4-63 (optional accessory)

Armfield F1-10 Hydraulics Bench

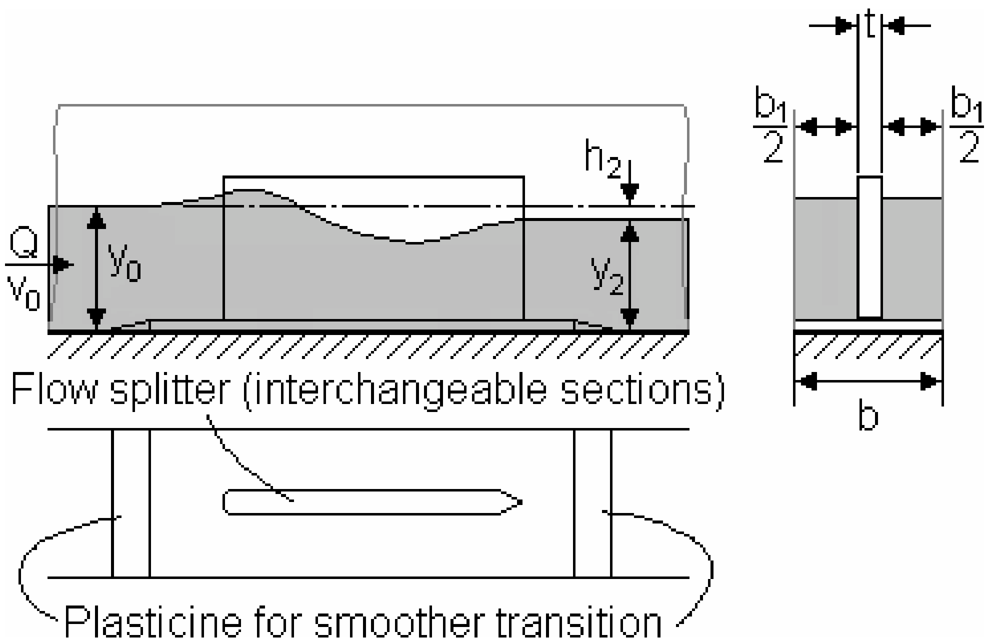
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



The flow splitter represents an obstruction in an open channel, typically the pier of a bridge, the support structure on the top of a dam spillway etc. The effect of the obstruction is similar to a constriction but the flow is split into two streams instead of one.

The obstruction causes a disturbance to the flow and turbulence is created where the two streams mix resulting in head loss. This head loss also produces a force on the object known as form drag.

The magnitude of the losses and forces depends on the shape of the obstruction and the degree of narrowing of the channel.

The objective is to view the disturbances caused by the splitter and to determine the headloss/discharge characteristics.

The performance of an obstruction can be defined by the d'Aubuisson formula which states:

$$Q = K_A b_1\, y_2 \left(2\, g\, h_2 + v_0{}^2\right)^{\frac{1}{2}}$$

where:

Q	= Volume flowrate	(m^3s^{-1})
K_A	= Coefficient of contraction	(Dimensionless)
b_1	= Remaining width of channel at obstruction	(m)
y_2	= Depth of flow downstream of obstruction	(m)
h_2	= Height of backwater = y_0-y_2	(m)
v_0	= Mean upstream velocity	(m)
g	= Gravitational constant	($9.81m\ s^{-2}$)

Equipment Set Up

Ensure the flume is level, with no stop logs installed at the discharge end of the channel. Measure the width of the channel b_0 (m) and the thickness of the splitter t (m).

Position the model flow splitter mid way along the channel with the rounded end upstream. Use Plasticine to form a smooth transition at each end of the base plate.

Position two hook and point level gauges on the channel sides, one upstream of the splitter and one downstream of the splitter, 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

Gradually open the flow control valve and allow water to flow along the channel. Add stop logs at the discharge end of the channel to provide a head of water which does not totally submerge the model. Increase the flow in stages, ensuring that the model is not submerged and at each stage observe and sketch the flow pattern around the model then measure and record y_0, y_2 and Q.

Repeat the above procedure with the pointed end of the flow splitter facing upstream.

Results

Tabulate your readings and calculations as follows:

Breadth of channel, b_0 =…………(m)

Thickness of splitter, t =…………(m)

$b_2 = b_0 - t$ =…………(m)

y_0	y_2	Q	v_0	K_A

Conclusion

Comment on the flow pattern surrounding the splitter and how it changes with increasing fluid velocity.

What is your value for K_a? Does the value change with increasing velocity?

What is the effect of changing the orientation (round nose/pointed nose upstream) of the splitter?

6.14 Exercise L: Flow Over a Dam Spillway

Objective

To observe the flow patterns associated with the flow of water over a dam spillway

Method

By operating the C4-MkII flume with the dam spillway fitted, using with different shapes of spillway toe.

Equipment Required

Armfield C4-MkII Flume

Two Hook and Point Gauges, 300mm scale

Dam spillway C4-64 with different toes (optional accessory):

- Blended Reverse Curvature Toe
- Ski Jump
- Sloping Apron

Armfield F1-10 Hydraulics Bench

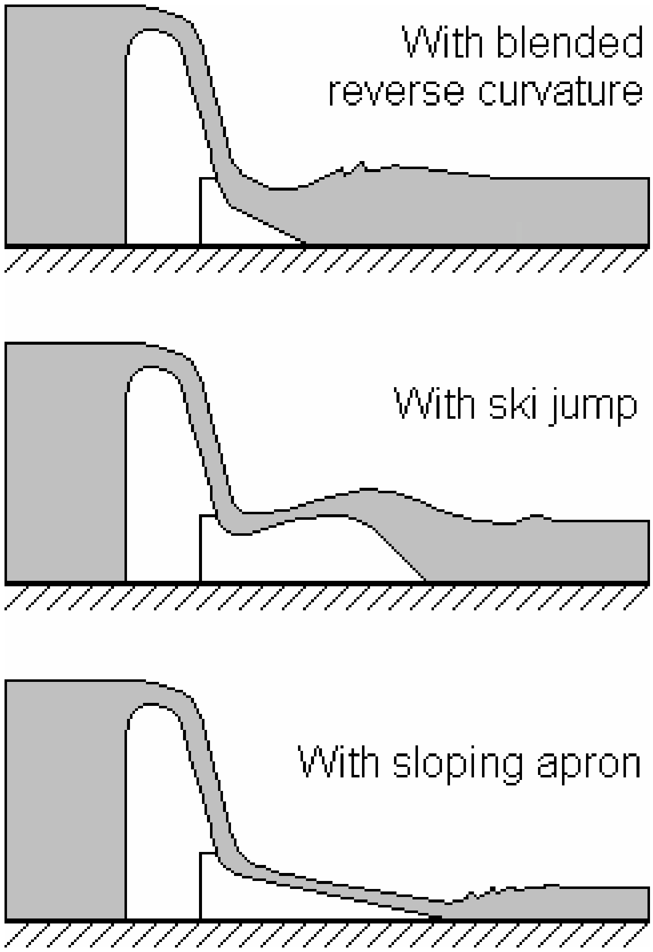
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



The dam spillway model may be fitted with three different shapes of toe. The flow pattern over each type may be studied through observation as the flume is operated.

Equipment Set Up

Ensure the flume is level, with no stop logs installed at the discharge end of the channel. Place the dam spillway in the flume towards the inlet end of the working section with the crest facing upstream and the blended reverse curvature toe located beneath the lip. Ensure that the spillway is secured using a mounting hook through the bed of the flume. For accurate results the gaps between the spillway 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 spillway, the second downstream, 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

The flow over each version of the dam spillway should be varied in stages, by adjusting the flow control valve, and at each stage the flow pattern should be observed and sketched and the flowrate, upstream and downstream water levels recorded.

Note: When using the ski jump it should be retained using the stretcher screw provided.

The downstream depth of water should then be varied in stages, by adding stop logs at the discharge end of the channel, to investigate the effect on the flow patterns. Observe and sketch the modified flow pattern at each stage as the downstream depth is increased.

Results

Upstream and downstream flow levels should be noted with each sketch of the flow pattern.

Conclusion

Compare the various flow characteristics and relate these to problems which may occur in everyday practice, e.g. erosion of the structure, scouring of the river bed, foaming of the water etc.

Comment on the different methods of dissipating the kinetic energy of the water. Which method is the most effective?

6.15 Exercise M: Flow Through a Siphon Spillway

Objective

To determine the relationship between upstream head and flowrate through a siphon spillway in the “blackwater” fully primed condition.

To calculate the discharge coefficient and to observe the operation of the siphon as it primes and de-primes.

Method

By operating the C4-MkII flume with the siphon spillway fitted.

Equipment Required

Armfield C4-MkII Flume

Two Hook and Point Gauges, 300mm scale

Siphon spillway, C4-65 (optional accessory)

Armfield F1-10 Hydraulics Bench

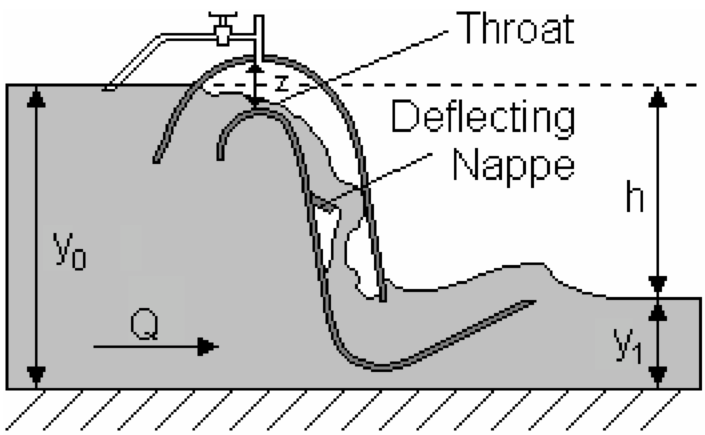
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



The traditional siphon spillway is shown in the above diagram and consists of a weir with a crest which is covered by a hood to create a barrel. In normal operation the inlet and outlet are both submerged so that air cannot enter the barrel from the outside atmosphere.

No flow of water can occur until the upstream level rises above the crest. Flow then spills over in much the same way as a normal weir. As the level rises further the velocity increases and the falling nappe, assisted by a deflector in the down-leg, entrains and removes air from inside the barrel. As the barrel becomes sealed, air cannot enter from outside so the pressure falls - increasing the flow rate until the barrel is running full of water. At this stage the siphon is said to be primed and the flow condition is called "blackwater flow" because no air is entrained in the water. (Entrained air gives the water a milky appearance.)

During priming the discharge increases rapidly from zero to full capacity. Any further rise in the upstream level has little effect on the flowrate through the siphon, only increasing it slightly.

Provided that the flow through the siphon is in excess of the flow into the channel, the upstream level will continue to fall, even when the level falls below the top of the crest. The siphon will stop acting when the level falls below the hood and air enters the barrel. The accompanying fall in flowrate through the siphon will cause the upstream level to rise again and the siphon will prime again. This cycle will continue until the flowrate upstream reduces.

To achieve closer control of the level upstream a siphon breaker (breather tube) can be fitted to the top of the hood above the crest. By positioning the free end of the tube just above the crest of the weir the change in level between the primed and de-primed condition can be minimised.

When running full (fully primed) the theoretical discharge through a siphon can be calculated using the equation:

$$Q = C_d \ A_t \ \sqrt{h}$$

Therefore: $$C_d = \frac{Q}{A_t \cdot h^{\frac{1}{2}}}$$

where:

Q	= Volume flowrate	(m^3s^{-1})
	= Volume/time (using volumetric tank)	
A_t	= Area of throat in siphon	(m^2)
	= Breadth b x Height z	
h	= Height difference between upstream and downstream water levels	(m)
	= $(y_0 - y_1)$	
C_d	= Coefficient of discharge	(Dimensionless)

Equipment Set Up

Ensure the flume is level, with no stop logs installed at the discharge end of the channel. Measure and record the dimensions - breadth b (m) and height z (m) of the throat above the crest inside the siphon.

Place the siphon in the flume with the upper leg facing upstream. Ensure that the siphon is secured using a mounting hook through the bed of the flume. For accurate results the gaps between the siphon and the channel should be sealed on the upstream side using Plasticine. Close the valve on the siphon breaker tube at the top of the hood on the siphon.

Position two hook and point level gauges on the channel sides, one upstream of the siphon, the second downstream, 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.

Gradually open the flow control valve and allow the channel upstream of the siphon to fill with water. Reduce the flowrate as the water level reaches the crest of the siphon tube then gradually increase the flow again.

Note: It takes a little time for the siphon to prime and increasing the flow too quickly will result in water flooding over the top of the siphon and possibly over the sides of the channel.

Allow the upstream and downstream channels to fill so that both the siphon inlet and outlet are submerged. If the outlet is not submerged add stop logs at the exit from the channel until the outlet just remains submerged.

If necessary adjust the flow control valve so that the upstream water level falls slowly when the siphon has fully primed.

Procedure

Observe the level changes upstream and the operation of the siphon as it primes and de-primes in a continuous cycle. Observe that the water level falls below the crest and does not de-prime until the hood is exposed and air enters the barrel.

Position the end of the siphon breaker (breather tube) so that it is just above the level of the crest then open the valve on the tube. Observe that the siphon action breaks when the end of the tube is exposed to the air resulting in a much smaller change in the upstream level.

Close the valve on the siphon breaker. When the siphon is primed increase the flow by adjusting the flow control valve so that the upstream level remains constant. When conditions are stable measure the upstream level y_0 and the downstream level y_1 using the level gauges then measure the volume flowrate Q using the direct reading flowmeter or volumetric tank with a stopwatch. Measure the pressure at each of the tappings P1 to P5.

With the siphon still fully primed, gradually raise the tailwater level by increasing the number of stop logs. When each change has stabilised measure y_0, y_1, Q and P1 to P5.

Results

Tabulate your readings and calculations as follows:

Breadth of throat, b……………(m)

Height of throat, z……………..(m)

Area of throat, A_t ……...…..….(m^2)

y_0	y_1	h	Q	C_d	P_1	P_2	P_3	P_4	P_5

Calculate the coefficient of discharge C_d.

Conclusion

What are the advantages and disadvantages of siphon spillways ("blackwater" siphons)?

What is the function of the deflecting nappe?

6.16 Exercise N: Flow Through an Air Regulated Siphon

Objective

To determine the relationship between upstream head and flowrate through an air regulated siphon.

To calculate the discharge coefficient and to observe the operation of the siphon as it primes and de-primes.

Method

By operating the C4-MkII flume with the air regulated siphon fitted.

Equipment Required

Armfield C4-MkII Flume

Two Hook and Point Gauges, 300mm scale

Air regulated siphon, C4-65 (optional accessory)

Armfield F1-10 Hydraulics Bench

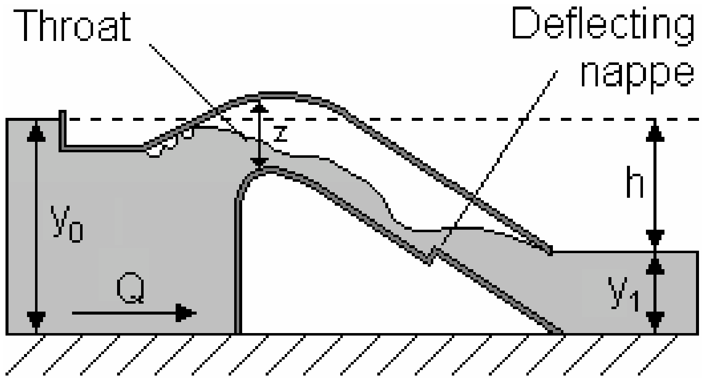
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory

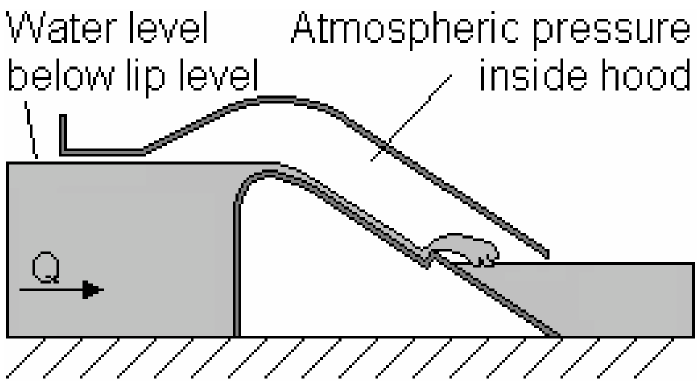


The air-regulated siphon is a more recent development than the traditional siphon demonstrated in experiment M. It will automatically adjust its discharge over a wide range while maintaining a relatively constant water level upstream. This is achieved by the siphon passing a mixture of air and water continuously. The upstream level is more stable and not prone to hunting.

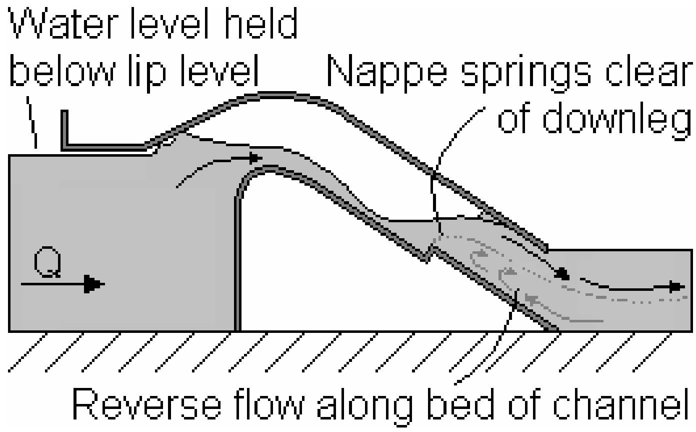
The shape of the air-regulated siphon is similar to the blackwater siphon and relies on the barrel being enclosed and sealed by the upstream and downstream water levels. However, the main difference is that the inlet to the hood or upstream lip is set at a level above the crest. A step is also included in the down-leg to promote turbulence and air entrainment.

The air-regulated siphon has five distinct phases as shown in the diagrams below:

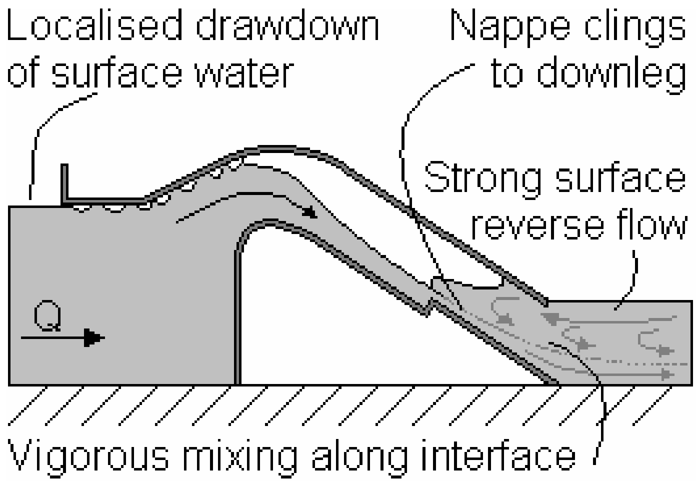
Phase 1: Weiring flow



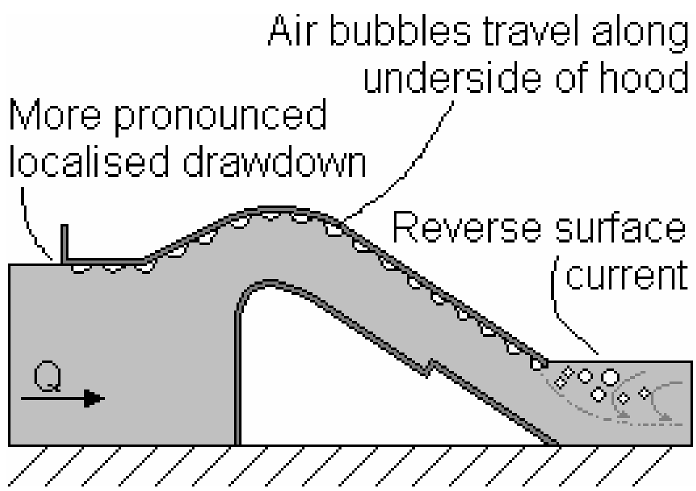
Phase 2: Deflected nappe



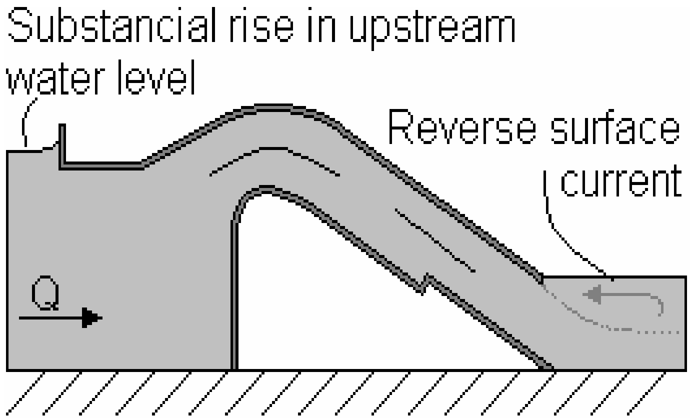
Phase 3: Depressed nappe



Phase 4: Air Partialised



Phase 5: "Blackwater" flow



The transition from one phase to another is quite gradual and there is no distinct or abrupt change over point.

When running full (Phase 5 – blackwater flow) the theoretical discharge through the air-regulated siphon is the same as the blackwater siphon and can be calculated using the equation:

$$Q = C_d \; A_t \; \sqrt{h}$$

Therefore: $$C_d = \frac{Q}{A_t \; h^{\frac{1}{2}}}$$

where:

Q	= Volume flowrate	(m^3s^{-1})
	= Volume/time (using volumetric tank)	
A_t	= Area of throat in siphon	(m^2)
	= Breadth b x Height z	
h	= Height difference between upstream and downstream water levels	(m)
	= $(y_0 - y_1)$	
C_d	= Coefficient of discharge	(Dimensionless)

Equipment Set Up

Ensure the flume is level, with no stop logs installed at the discharge end of the channel. Measure and record the dimensions - breadth b (m) and height z (m) of the throat above the crest inside the siphon.

Place the siphon in the flume towards the inlet end of the working section with the upper lip facing upstream. Ensure that the siphon is secured using a mounting hook through the bed of the flume. For accurate results the gaps between the siphon 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 siphon, the second downstream, 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

Gradually open the flow control valve and allow the channel upstream of the siphon to fill with water. Reduce the flowrate as the water level reaches the crest of the siphon tube then gradually increase the flow again.

Open the inlet valve and gradually increase the flow to the siphon taking great care not to overload the siphon. It takes a little time for the siphon to prime and increasing the flow too quickly will cause the flow to flood over the top of the siphon. Gradually allow the downstream channel to fill with water so that the siphon outlet is submerged. Add stop logs if necessary until the hood at the outlet of the siphon is just submerged.

Adjust the flow control valve to a very low flow and observe the free weiring flow. Increase the flowrate so that the upstream water level rises and seals the inlet.

Observe the priming action and deflected nappe flow as air is drawn in through the inlet and evacuated through the outlet. Increase the flow and observe the gradual change to the depressed nappe flow. At certain flows the siphon may alternate between deflected nappe and depressed nappe flow.

Increase the flow further and observe the air partialised and “blackwater” flow conditions. Because of the increased flow the downstream water level will have risen above the original priming level. To ensure a vigorous air flow, gradually lower the tailwater level by removing stop logs as the flow increases but make sure the outlet is always drowned.

While operating in the blackwater condition measure the upstream level y_0 and the downstream level y_1 using the level gauges then measure the volume flowrate Q using the direct reading flowmeter or volumetric tank with a stopwatch.

Observe the effect of different tailwater levels on the initial priming action and on air regulation for the different flow phases.

Results

Tabulate your readings and calculations as follows:

Breadth of throat, b =…………(m)

Height of throat, z =…………(m)

Area of throat A_t =………....(m^2)

y_0	y_1	h	Q	C_d

Calculate the coefficient of discharge C_d for the "blackwater" flow condition.

Plot the stage discharge characteristics.

Conclusion

What is the function of the deflecting nappe in the conduit?

6.17 Exercise P: Flow Under a Radial Gate

Objective

To determine the relationship between upstream head and flowrate beneath a radial gate (Tainter Gate) under different operating conditions.

To calculate the discharge coefficient in each condition.

Method

By using the radial gate assembly installed in the C4-MkII flume.

Equipment Required

Armfield C4-MkII Flume

Two Hook and Point Gauges, 300mm scale

Radial gate assembly, C4-66 (optional accessory)

Armfield F1-10 Hydraulics Bench

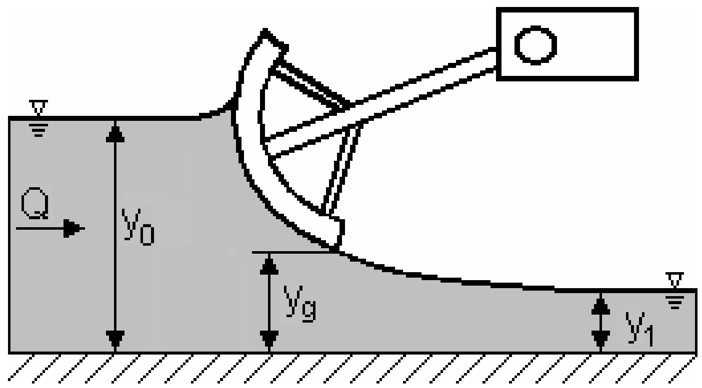
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



For an underflow gate with free discharge:

$$Q = C_d \ A \sqrt{2 \, g \, y_0}$$

where:

Q	= Volume flowrate	(m^3s^{-1})
	= Volume/time (using volumetric tank)	
C_d	= Overall coefficient of discharge	(Dimensionless)
A	= Area of the opening	(m^2)
	= b breadth x height of gate opening y_a	
y_0	= Upstream depth of flow	(m)
g	= Gravitational constant	(ms^{-2})

Note: If the downstream side is submerged then y_o is replaced with (y_o-y_1) in the above equation.

Equipment Set Up

Clamp the radial gate assembly securely to the sides of the channel then level the flume. Adjust the screw on the top of the gate to create a small gap between the bottom of the gate and the bed of the channel. Gradually open the flow control valve and allow the flow to stabilise without the water flowing over the gate.

Procedure

With the flow constant, measure and note the values of Q, y_g and y_0. Raise the gate in increments, measuring and noting the values of Q, y_g and y_0 for each step.

The procedure should be repeated with a varying flow and constant y_0 thus obtaining a further set of results.

Stop logs can be added at the discharge end of the channel to submerge the discharge side of the gate. Measurements should include the downstream level in the flume.

Results

Tabulate your readings and calculations as follows:

Breadth of gate b, =…………(m)

y_0	y_1	y_g	Q	A	C_d

Plot C_d against $\frac{y_1}{y_0}$ for constant Q.

Plot C_d against $\frac{y_1}{y_0}$ for constant y_0.

Conclusion

Comment on the effects of y_0 and Q on the discharge underneath the gate. Which factor has the greatest effect?

Comment on discrepancies between actual and expected results.

6.18 Exercise Q: Flow Over False Floor Sections

Objective

To observe the flow patterns associated with the flow of water over different bed profiles.

Method

By using false floor sections installed in the C4-MkII flume.

Equipment Required

Armfield C4-MkII Flume

Two Hook and Point Gauges, 300mm scale

False floor sections, C4-68 (optional accessory)

Armfield F1-10 Hydraulics Bench

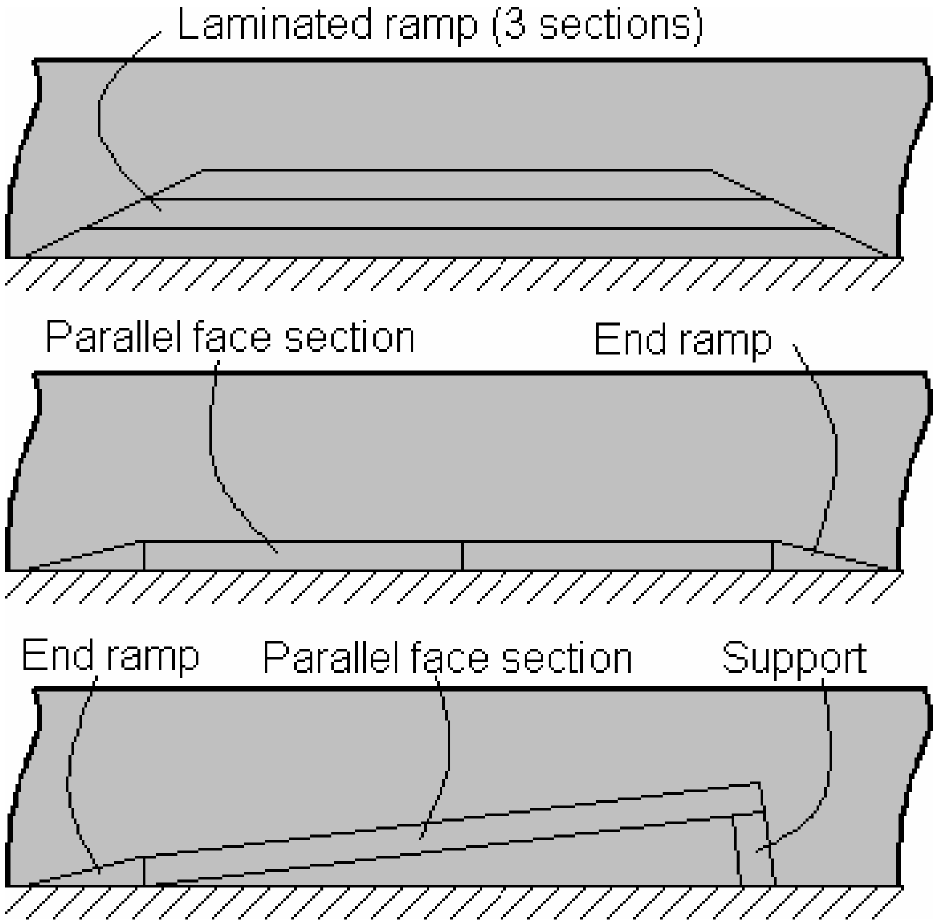
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Equipment Set Up and Procedure



The above diagrams show the correct assembly of the three different arrangements of the floor sections. Set up the laminated ramp in the flume ensuring that the flume is level. Open the flow control valve and allow the water to enter the flume. By adjusting the valve, the depth of water can be varied in stages. At each stage the flow pattern of the water should be observed and noted.

The critical depth can be determined as a separate experiment if required.

Since the ramp is fabricated in three sections the above procedure can be repeated with the different profiles.

Close the flow control valve, allow the water to drain from the flume then replace the laminated ramp with the false floor. Repeat the above.

Close the flow control valve, allow the water to drain from the flume then replace the false floor with the raised floor. Repeat the above.

Results and Conclusions

Compare the flow patterns obtained with each of the different floor sections.

Is there any similarity with the flow patterns obtained when using the Broad Crested Weir?

6.19 Exercise R: Flow Over a Gravel Bed

Objective

To determine the effect of a roughened bed on the depth of water at different flowrates and to obtain appropriate coefficients to satisfy the Manning Formula.

Method

By using the artificially roughened bed installed in the C4-MkII flume.

Equipment Required

Armfield C4-MkII Flume

Two Hook and Point Gauges, 300mm scale

Artificially roughened bed, C4-66 (optional accessory)

Armfield F1-10 Hydraulics Bench

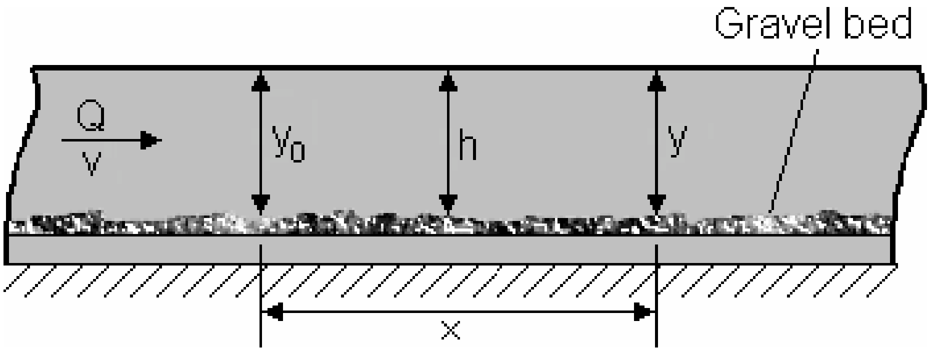
Stopwatch (for flow measurement using F1-10 volumetric tank)

Optional Equipment

Direct reading flowmeter

C4-61 Pitot tube and manometer (for velocity measurement)

Theory



For uniform flow over a gravel bed, the Manning formula states that:

$$v = \left(\frac{1}{n}\right) R^{2/3} S^{1/2}$$

where:

n	= Coefficient of roughness	(Dimensionless)
v	= mean fluid velocity	(m/s)
R	= Hydraulic mean radius	(m)
	= Flow area A / Wetted perimeter P	
S	= Slope of energy line	(m)
	= $\sin\theta = (y_0 - y_1) / x$	
	where	
	x = distance between level measurements	
	y_0 = upstream flow depth	
	y_1 = downstream flow depth	

Note: For simplicity the slope S can be assumed to be the slope of the water surface, if the small change in velocity head between inlet and outlet is ignored. When using the flume with the bed inclined, the slope of the bed must be added to calculations of S, when using the hook and point gauges with the bed as a datum.

The actual fluid velocity can be calculated as:

$v = Q / A$

where

v	= mean fluid velocity	(m/s)
Q	= Volume flow rate	(m^3/s)
h	= Average depth of flow above gravel bed	(m)
	= $(y_0 + y_1) / 2$	
A	= Area of flow	(m^2)
	= Breadth of channel b x Depth of flow h	

Equipment Set Up

Ensure that the flume is horizontal with no stop logs installed at the discharge end. Line the bottom of the flume with the gravel bed section(s).

Procedure

Using the surface of the bed as a datum, measure and record the datum height. Measure the distance x between the two depth measurement points.

Open the flow control valve and allow water into the flume. Once a small head of flowing water has been set, do not adjust the control valve again so that the flow rate is maintained at a constant value through the experiment.

Measure and record the flow rate Q, and the depths y_0 and y_1 above the roughened bed at each end.

Add stop logs one at a time, repeating the measurements after adding each stop log.

The procedure should be repeated at different fixed flow rates, and then repeated while increasing the flume slope in stages, taking measurements after each step change.

Results

Tabulate your readings and calculations as follows:

Breadth of bed b, =…………(m)

y_0	y_1	x	Q	v	S	R	n

Conclusion

Does the value of n obtained correspond with the expected value?

Comment on the results.

7 Installation Guide

The F1-10 Hydraulics Bench should be commissioned before installation of the C4-MkII. Refer to the product manual supplied with the F1-10 for information on installation and commissioning the Hydraulics bench.

Before operating the C4-MkII, it must be unpacked, assembled and installed as described in this Installation Guide. Safe use of the equipment depends on following the correct installation procedure.

Refer to diagrams on pages 8 and 9 of the C4-MkII Instruction Manual.

Note:

Two versions of the Multi Purpose Teaching Flume are available as follows:

C4-2.5m with a 2.5 metre long working section

C4-5.0m with a 5.0 metre long working section

The channel for the 2.5 metre version is supplied in one complete section with the inlet tank fitted to it and the flexible pipework installed.

The channel for the 5.0 metre version is supplied in two sections, one with the inlet tank and flexible pipework fitted and the second with the discharge arrangement fitted. It will be necessary to fix the two sections together before mounting the channel on the support pedestals as described below.

The floor should be firm and level (preferably concrete). The apparatus is stable but for added safety the flume should be secured to the floor using the set of 8 masonry bolts provided, where possible.

For safety during assembly, a pair of trestles approximately 1 metre high will be required to support the channel section while the support pedestals are attached.

1. Carefully unpack the flume section(s), jacking pedestal, bearing pedestal and other associated parts. The parts should be laid out on the floor then inspected for damage and checked against the advice note for any missing parts. Note that the channel section(s) is fragile until assembled onto the pedestals.

2. Locate the parts at the proposed site – it would be difficult to move the complete flume once assembled.

3. If installing the 5.0 metre long version the two sections must be fixed together before attempting to lift the channel into place. Position the two sections of channel in line, on the floor, with the mating flanges together. Lightly smear the faces of the mating flanges with the sealing compound (Seelastik) supplied, then fix the flanges together using the 6 nuts and bolts supplied. Ensure that the two flanges are aligned correctly then insert the dowels into the pre-drilled holes before tightening the nuts and bolts evenly. It is very important that the inside surfaces of the two channel beds and clear acrylic side walls are straight and level to prevent disturbances to the water flowing along the channel. It is also important that the tops of the clear acrylic sides are flush to ensure smooth travel of the

instrument carrier. When the joint is tight carefully remove any excess sealant from the inside of the channel to provide a smooth transition between the sections.

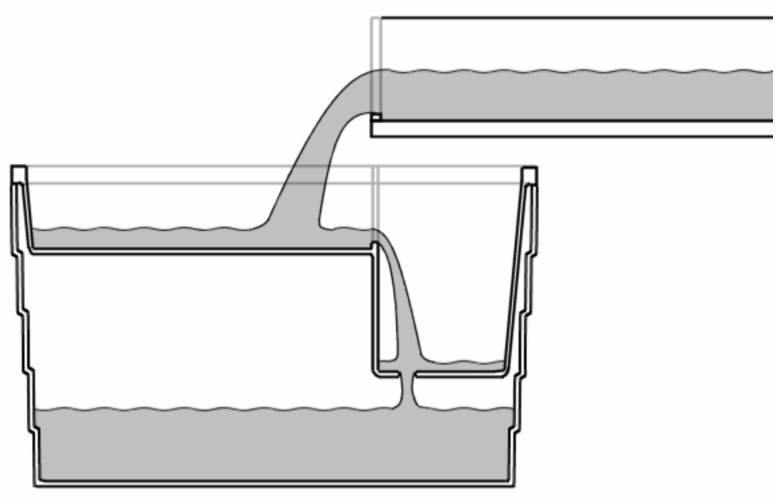
4. Place the spacers provided at equidistant points along the top of the clear acrylic sides. Two spacers are supplied with the 2.5m version, four spacers are supplied with the 5.0m version.

5. Carefully lift the channel section onto the temporary trestles in the required position.

6. Position the bearing pedestal (incorporating the flowmeter if supplied) adjacent to the locating holes in the channel support towards the downstream end (outlet) of the channel section. Apply a smear of grease to the pivot pin then lift the channel into position on the pedestal. Slide the pivot pin into position then retain the pivot pin using a split pin at each end. Ensure that the flume can pivot freely at this end.

7. Position the jacking pedestal (incorporating the jacking handwheel) adjacent to the locating holes in the channel support at the upstream (inlet) end of the channel section. Adjust the height of the actuator to suit and apply a smear of grease to the pivot pin, then lift the channel into position on the pedestal. Slide the pivot pin into position then retain the pivot pin using a split pin at each end. The temporary trestles can now be removed.

8. Position the F1-10 at the downstream end of the channel (adjacent to the pivot pedestal) with the end of the flow channel above the moulded channel on the top of the F1-10 as shown in the diagram below:



When correctly positioned, the end of the flow channel should be just inside the moulded channel (not above the volumetric tank) and aligned with the centre line of the moulded channel.

9. When the position of the C4-MkII and F1-10 have been confirmed the two pedestals of the C4-MkII should be bolted to the floor using the 8 masonry bolts supplied (4 bolts on each pedestal). When bolted to the floor it is unlikely that the flume will fall over even if accidentally subjected to a severe side impact.

10. If a 5.0M long working section is installed; Install the flexible tube underneath the discharge section of the channel and connect the tube to the pipework underneath the inlet section of flume using the jubilee clip provided.

11. Connect the flexible tube running along the underside of the channel (connected to the inlet tank) to the stub pipe at the bearing pedestal using the jubilee clip provided.

12. Attach the flexible tube to the stub pipe at the base of the bearing pedestal (below the flowmeter if fitted) and secure the tube using the jubilee clip provided.

13. Disconnect any accessory that is already connected to the quick release connector on the F1-10 (connector located inside the top moulded channel on the F1-10). Ensure that the F1-10 is switched off and the flow control valve is closed then unscrew the quick release connector from the bed of the channel. Screw the adaptor, supplied with C4-MkII, onto the threaded outlet in the bed of the channel then connect the flexible tube from the C4-MkII to the union on top of the adaptor. The union incorporates a 'O' ring seal and only needs to be hand tight (do not use a tool to tighten the fitting).

14. Install the stilling baffle inside the inlet tank. Ensure that the diffuser (open cell foam) is correctly positioned inside the perforated plate to match the contour of the inlet tank where it meets the bed of the channel. The action of the stilling baffle is to reduce the turbulence of the water entering the inlet tank and produce a smooth flow of water into the working section of the channel.

15. Loosely attach the slope indicator pointer and scale to the jacking pedestal. Place a spirit level on the bed of the channel and adjust the jack to level the channel. Adjust the position of the scale to read zero against the pointer. Tighten the fixings on the scale. Note: The scale will provide an approximate indication of the bed slope. A more precise technique is described later in this guide using a hook and point gauge in conjunction with the water surface.

16. Place the various accessories in a safe place where they will not be damaged.

17. Check that all packaging has been removed from the F1-10 Hydraulics Bench (if newly installed) and C4-MkII Flow Channel and all flexible tubes and nuts/bolts are securely tightened.

18. Check that the drain valve on the underside of the F1-10 is closed. Check that the cock below each tapping in the bed of the channel is closed. Check that the gland securing each model mounting hook is tightened. (When not in use the hooks are up-ended and the non-hook end is pushed from under the channel through the gland until the tip is flush with the bed so as not to impede the water flow). Take care not to damage the rubber 'O' ring seals inside the glands when fitting or removing the mounting hooks.

19. Place a filling hose in the volumetric tank of the F1-10. Fill the sump tank with clean cold water by lifting the dump valve in the base of the volumetric measuring tank and allowing the water to drain from the volumetric tank into the sump tank. (When lifted, a twist of 90° at the actuator will retain the dump valve in the open position.) When full ensure that the water level in the sump tank is just level with the outlet in the bottom of the volumetric tank.

20. A few drops of wetting agent should be added to the water in the sump tank to minimise the effects of surface tension.

Note: If too much wetting agent is added foaming will occur and it will be necessary to replace the water.

A few drops of wetting agent may be introduced to the sight tube (level gauge), on the side of the F1-10, via the overflow tube at the top. This will reduce the meniscus, making readings clearer.

21. Ensure that the stilling baffle is correctly positioned in the volumetric tank of the F1-10 such that the top edge is alongside the exit of the open channel in the moulded top.

22. Close the flow control valve on the front of the F1-10 then connect the mains lead from the F1-10 to the electrical supply.

23. Switch on the RCD on the side of the F1-10, then press the TEST button to check that the RCD is operating correctly. The RCD must trip. If the RCD does not trip or it trips before pressing the test button then it must be checked by a competent electrician before the equipment is used. Switch on the RCD again.

24. Operate the pump ON/OFF switch and confirm that the pump functions. Slowly open the flow control valve and check that water is delivered to the inlet end of the channel.

Allow the water to flow along the working section of the flow channel and discharge into the volumetric tank of the F1-10. Allow circulation to occur for several minutes to remove air from the system. Adjust the position of the F1-10 if necessary to minimise splashing as the water discharges into the top of the F1-10.

25. Release the actuator of the dump valve to close the valve in the bottom of the volumetric tank. Fill the volumetric tank until water runs into the sump tank through the overflow. Now check that the sight tube (level gauge) is full and no air bubbles are present. Repeat this filling several times, ensuring that the sight tube is free from air bubbles.

26. Close the flow control valve and allow water to drain from the volumetric tank until the surface is level with the step in the bottom of the tank. A few drops of wetting agent smeared onto the step will enable an accurate level to be achieved.

Slacken the securing screws at the top and bottom of the sight tube scale and position the scale so that the meniscus of the fluid in the tube is level with the black datum line engraved between the large and small scales. This will ensure that the scale is positioned accurately for volumetric measurements using either of the ranges.

Note: All volumetric readings should be taken with the stilling baffle installed, since calibration has been effected in this condition.

27. Place the stop logs in the slot at the discharge end of the channel to allow the channel to fill with water to the maximum level.

Ensure that the flow control valve is closed, switch on the pump then slowly open the flow control valve and allow the channel to fill with water. When the channel is full, close the flow control valve and switch off the pump. It is suggested that the channel is left standing in this condition for at least one hour to allow any leaks to become visible. Check the channel and pipework for leaks and tighten the appropriate fittings as necessary.

28. The accuracy of the zero setting on the slope indicator can be checked as follows: Attach a hook and point gauge to a carrier and install a point in the end of the rod. Locate the carrier on the top of the channel sides and position it at one end of the channel. Adjust the gauge to indicate the height of the water then transfer the gauge to the opposite end of the channel. The water level will be the same if the channel is level. Adjust the handwheel on the jack, if necessary, to obtain the same reading at both ends of the channel. The position of the scale can then be adjusted to read zero against the pointer.

29. Remove the stop logs one at a time and allow the channel to drain. Ensure that the flow control valve is closed and the pump is switched off.

Note: After use always allow the water to drain down into the sump tank of the F1-10. The flow control valve can be opened to allow water to drain from the pipework to the sump via the pump.

The basic operation of the C4 - MkII has been confirmed.

Refer to the Operational Procedures section in the C4-MkII product manual for further information.

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