Equipment for Engineering Education

Instruction Manual

HM 164 Adjustable Bed Flow Channel

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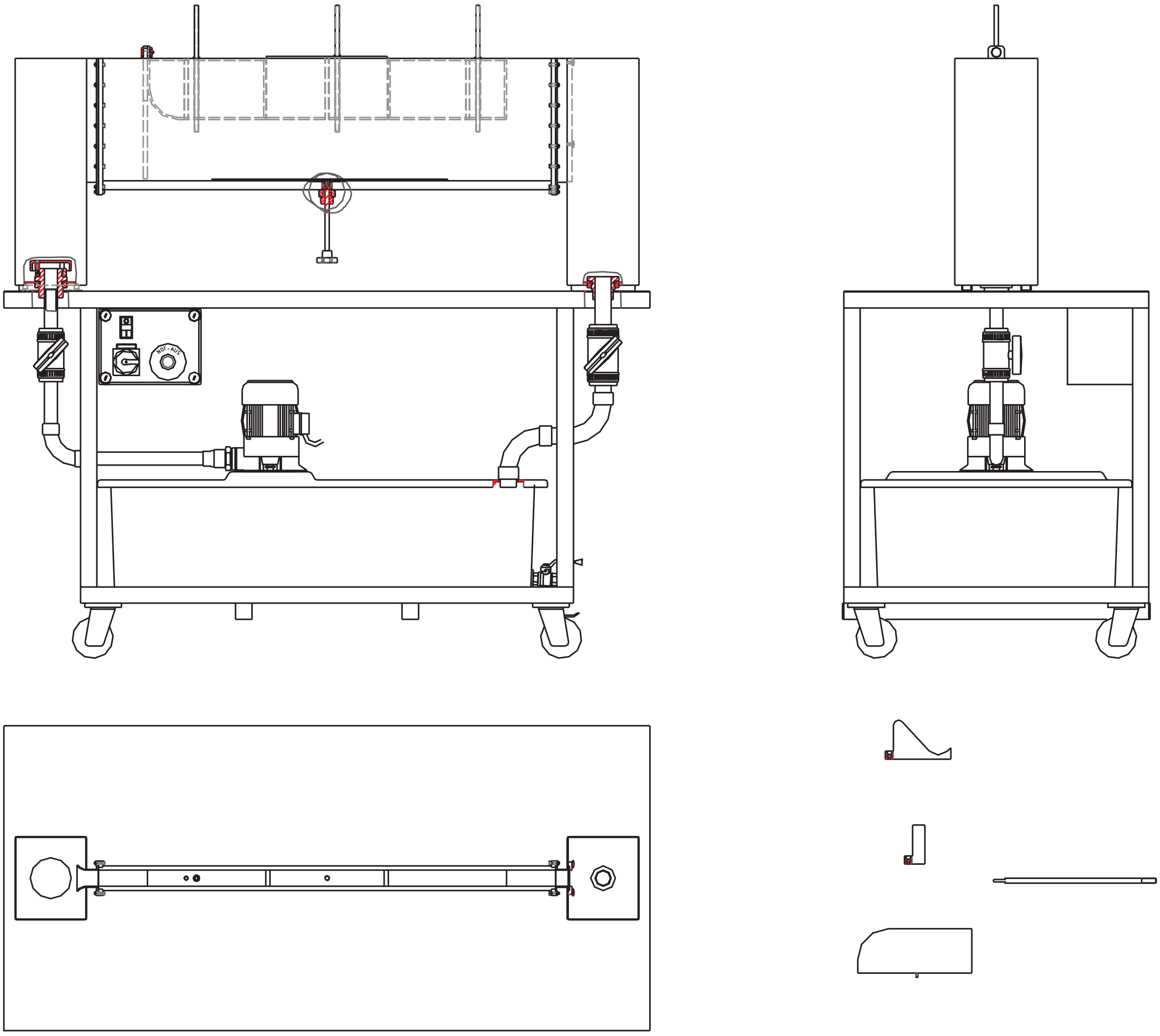
HM 164 **ADJUSTABLE BED FLOW CHANNEL**



Instruction Manual

Please read and follow the safety regulations before the first installation!

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Inhaltsverzeichnis

1 Introduction

The **HM 164 Adjustable Bed Flow Channel** experimental arrangement represents an expansion of the G.U.N.T. „Fluid Mechanics“ product range. The experimental setup is a closed unit. Installation on a laboratory trolley eases use in seminar rooms and laboratories. Only a mains electricity supply is necessary for operation.

The HM 164 unit enables experiments to be performed on open flumes, for example the investigation of flow processes on different weir structures.

By means of straightforward modifications it is also possible to set up a closed flume. In this way basic experiments on pipe flow or on flow processes in a culvert can also be made on the unit. In addition, it is also possible to establish different flow conditions in the closed flume by changing the cross-section for the flow. In this way a large range of experiments can be performed with a unit of straightforward design.

Open flume:

- Flow over weir structures
- Flow over a wide crested weir
- Flow underneath an undershoot weir
- Transition from subcritical flow to supercritical flow („hydraulic jump“)
- Critical water depth and its effect on the upstream water
- Observation of surface waves near critical water depth
- Supercritical / subcritical flow

Closed flume (Culvert):

- Measurements of static pressure and total pressure in a pipe flow (closed flume with full flow)
- Flow through a closed flume with constant cross-section
- Flow through a closed flume with changing cross-section

2 Unit Description

2.1 Unit Layout

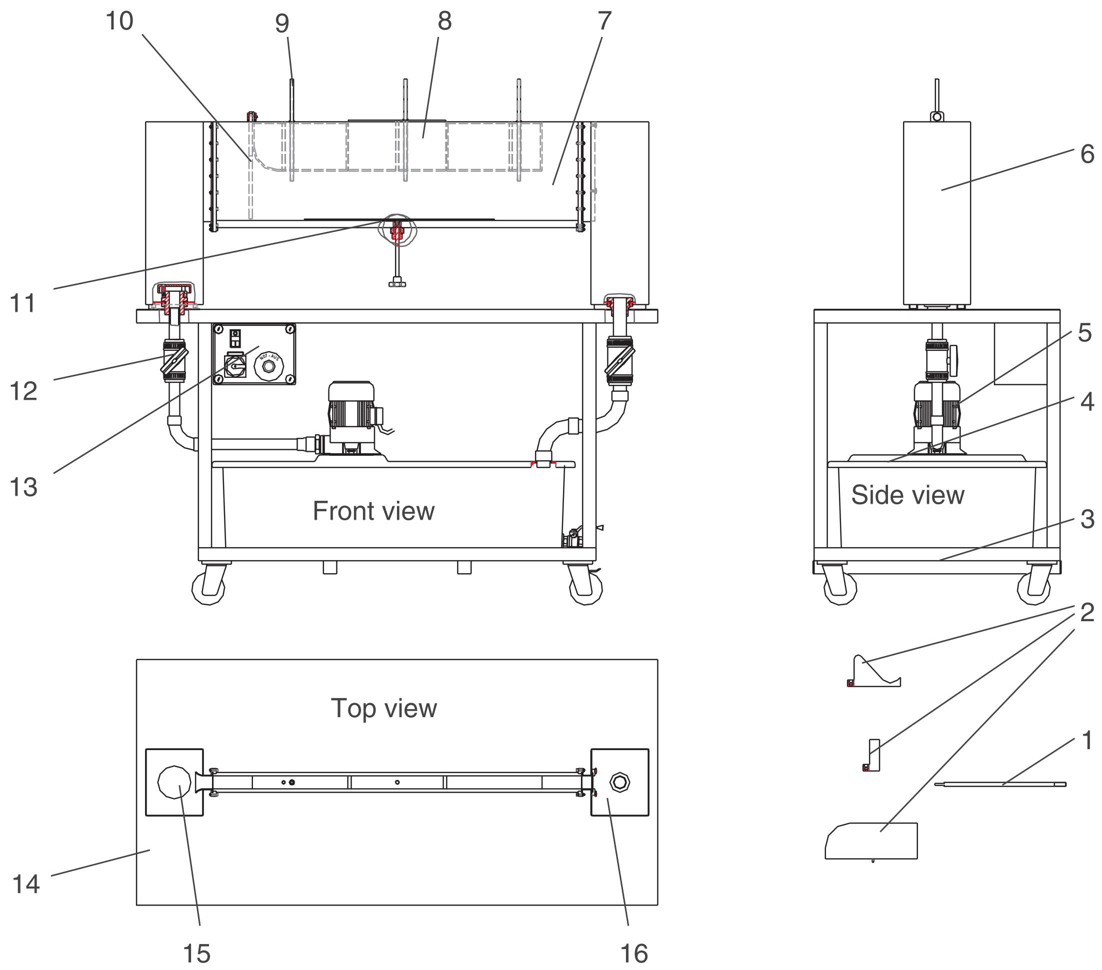


Fig. 2.1 HM 164 Experimental Setup

1	ModelLifter	9	Measuring Tubes
2	Different weir models	10	Vertically adjustable Weir Plate
3	Labortory Trolley	11	Height adjustable Channel bed (Ramp)
4	Supply Tank	12	Regulator Valve
5	Pump	13	Switch Box (Pump)
6	Flow Channel	14	Work surface
7	Experimental section	15	Inlet Flow Channel
8	Insert	16	Outlet Flow Channel

The HM 164 Adjustable Bed Flow Channel experimental setup is fitted to a **laboratory trolley** (3). The water supply comprising **pump** (5), **supply tank** (4) and pipework is fitted in the bottom of the trolley. The **flow channel** (6) in which the experiments are performed is fitted to the top of the trolley. On a **work surface** (14), e.g., experiment documentation can be stored.

The **experimental section** (7) of the channel comprises a flume made of transparent plastic. The top of the flume is partially covered, or can be converted to a closed flume (culvert) using an **insert** (8). Total pressure and static pressure of the flow in the closed flume can be measured using **measuring tubes** (9). At the inlet to the channel there is a vertically adjustable **weir plate** (10) („sluice gate“).

Once the insert (8) is removed, other **weir models** (2) can be inserted in the cut-out. For this purpose the **model lifter (**1) supplied must be used.

Part of the channel bed has been designed as a **height adjustable ramp** (11). In this way, for example, the cross-section for the flow in the closed flume can be changed.

The flow rate through the flow channel is adjusted at a **regulator valve** (12), once the pump has been started on the **switch box** (13) for the system.

The **inlet to the channel** (15) is equipped with a streamlined water inlet. At the **outlet** (16) there is a height adjustable weir for damming the water in the channel.

2.2 Function

2.2.1 Experimental Section

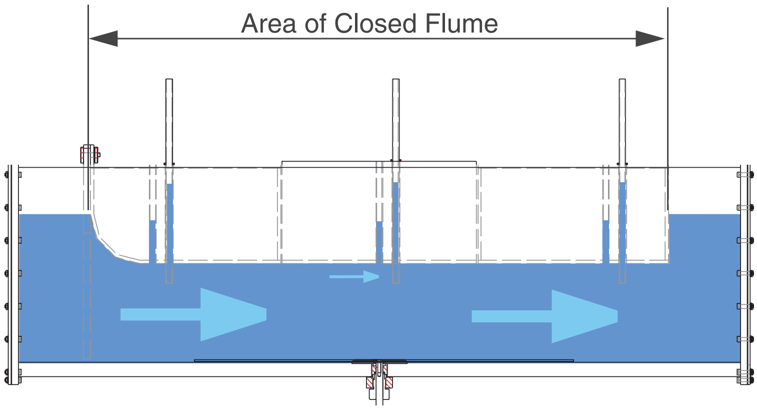


Fig. 2.2 Experimental Section as Closed Flume

If the water level is high enough and the insert fitted (cf. item 8 in Fig. 2.1) the flow channel can be operated as a closed flume (Fig. 2.2).

Fig. 2.3: The water level in the experimental section is adjusted using a vertically adjustable overflow weir (a). This overflow weir is in the outlet area (b) of the experimental section.

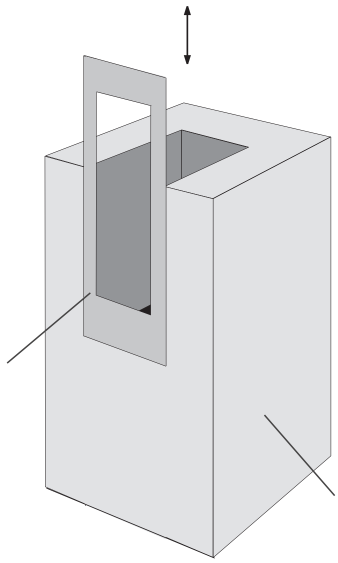


Fig. 2.3 Adjusting the Water Level

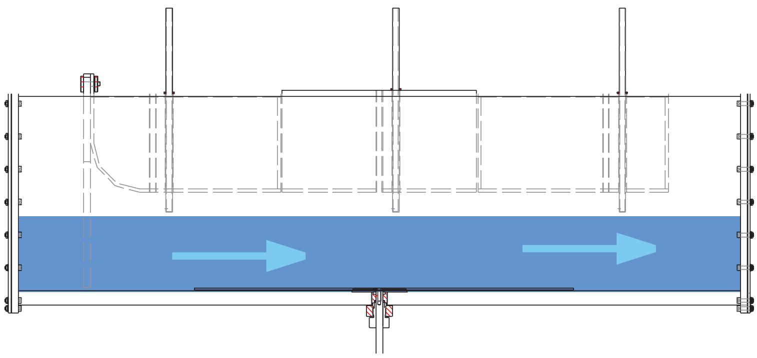


Fig. 2.4 Experimental Section as Open Flume

With a low water level the channel is operated as an open flume.

Fig. 2.5: By removing the insert (item 8 in Fig. 2.1) a cut-out in the experimental section is revealed using which the weir models supplied can be placed in the channel.

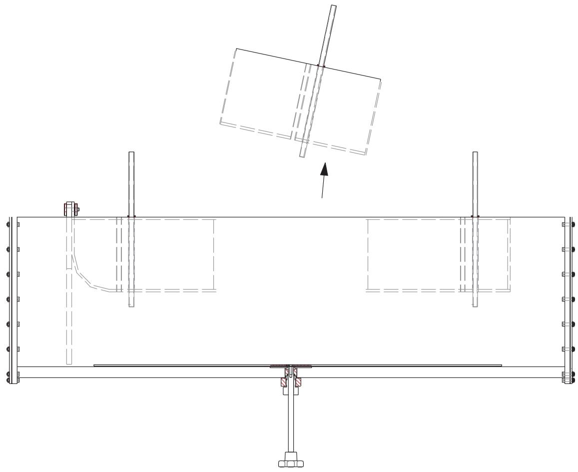
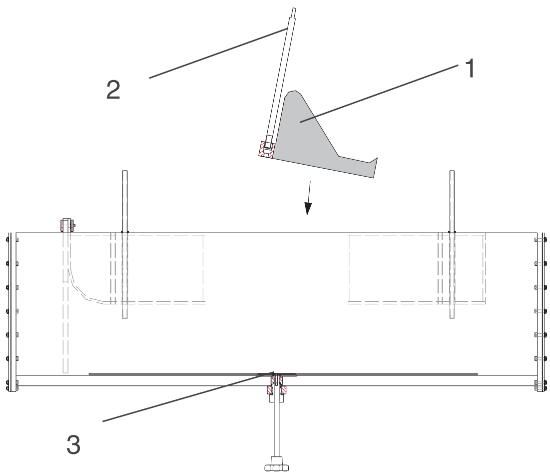


Fig. 2.5 Removing the Insert

Fig. 2.6: To insert a weir structure (1) the model holder (2) must be used. The model holder has a thread on one end using which the holder is bolted to the structure. On the other end there is a hexagonal head using which the bolt in the model can be bolted to the base of the channel. There is a hole with a thread (3) in the base of the channel for fitting the models.



Note! There is only one bolt for fitting the weir models. The bolt is to be fitted in the weir structure **prior to fitting**!

Fig. 2.6 Inserting a Weir Structure

With a weir body fitted, the channel should only be used as an open flume (Fig. 2.7).

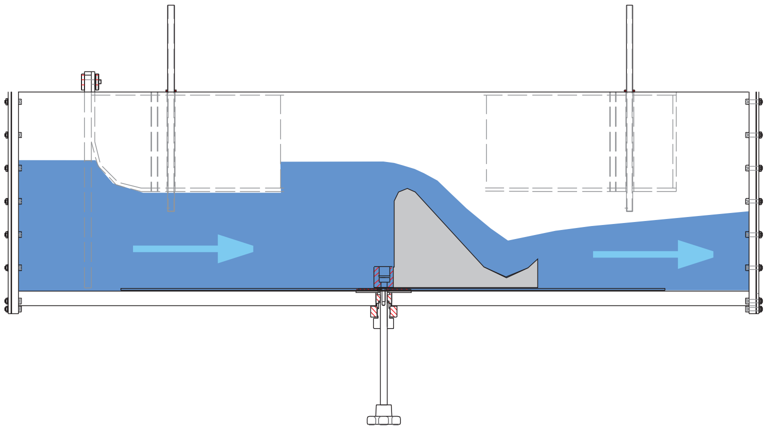


Fig. 2.7 Weir Structure Inserted

2.2.2 Changing the Cross-Section for the Flow

The channel bed on this flow channel **is height adjustable** (Fig. 2.8). If the rod (1) is moved upwards, a ramp is formed (2).

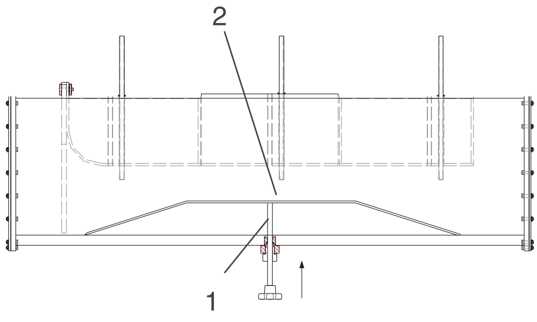


Fig. 2.8 Height Adjustment of Channel Bed

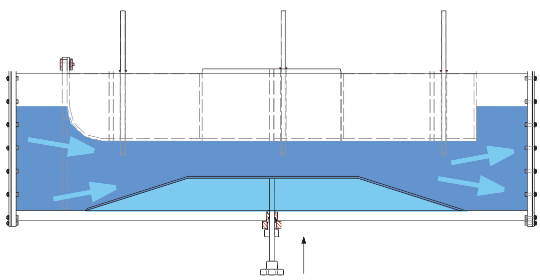


Fig. 2.9 Closed Flume with Changing Cross-Sectio

With the flume closed there is thus a convergent inlet area and a divergent outlet area (Fig. 2.9).

2.2.3 Channel Inlet with Undershoot Weir

In the area of the channel inlet there is a weir plate (Fig. 2.10). The weir plate (1) is secured in the required position with a knurled bolt (2). In this way clear demonstrations on the flow behaviour of an undershoot weir can be made using the experimental section.

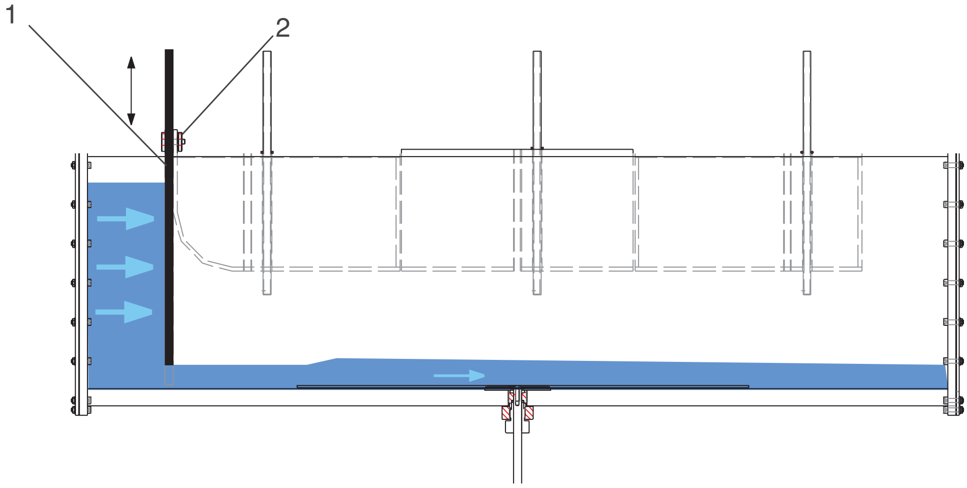
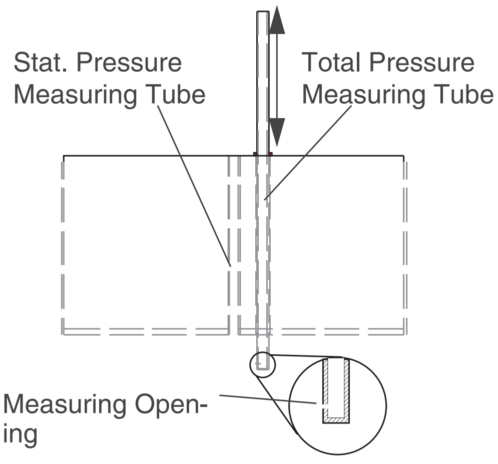


Fig. 2.10 Experimental Section with Weir Plate Slid into Place

2.2.4 Measuring Tubes



The top cover of the closed flume is divided into 3 segments. Each of these segments contains 2 measuring tubes:

– One measuring tube is used to measure the total pressure. This measuring tube can be moved vertically. It has a measuring opening that must be aligned **against** the flow (by turning the tube)

– The other measuring tube is used to measure the static pressure. This measuring tube ends flush at the segment

If the experimental section is used as a closed flume, the water rises up the measuring tubes. The height difference Δh that can be read on the two tubes for a segment is a measure of the dynamic pressure content of the flow (Fig. 2.11).

The speed u of the flow can be calculated if Δh is

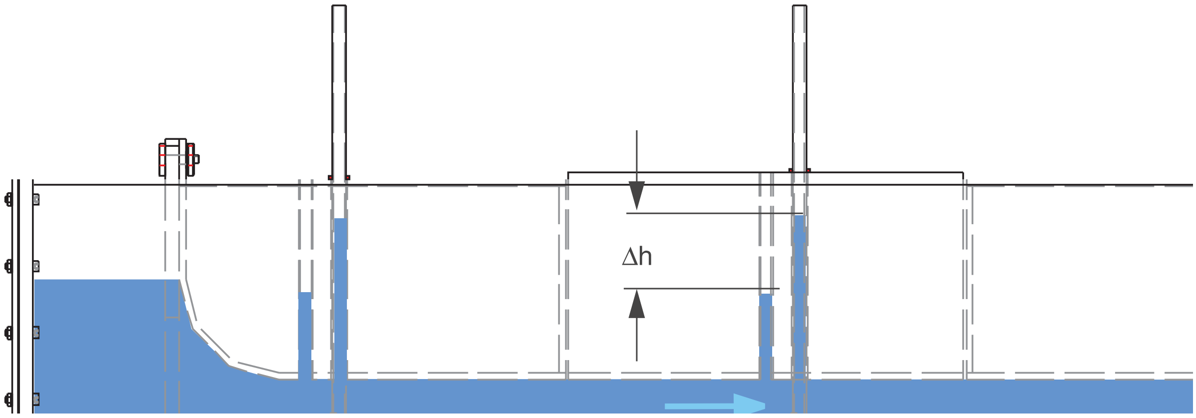


Fig. 2.11 Dynamic Pressure Content as a Measure of the Speed of the Flow

known using the equation

$$u = \sqrt{2 \cdot g \cdot \Delta h} \qquad (2.1)$$

Here Δh is to be in m.

(g = acceleration due to gravity = 9.81 m/s^2)

Attention! The measuring opening on the „total pressure“ tube must be aligned to face exactly into the flow. The measuring opening is correctly positioned when the water rising up the tube reaches a maximum height.

2.3 Commissioning

- Place laboratory trolley on a flat surface and secure against rolling away using the locking castors
- Connect unit to mains electricity supply
- Fill supply tank for the system with water to approx. 5 cm below the top edge
- Switch on pump on the switch box for the system, for this purpose unlock the emergency stop switch, place master switch in „ON“ position and operate On/Off switch for the pump
- Adjust required flow rate in the experimental section at the regulator valve (item 11 in Fig. 2.1)
- Set up experimental section for required experiment, e.g., establish water level in the flume using overflow weir at the end of the channel

In this way commissioning is complete and the experiments can be commenced.

2.4 Taking Out of Operation

- Switch off system
- Leave experimental section to run dry, for this purpose lift up overflow weir at the end of the channel, if fitted
- Isolate unit from the mains

2.5 Maintenance/Care

Due to the usage of corrosion resistant materials the system is maintenance-free. If the system is not to be used for an extended period, the water should be completely drained.

3 Safety

3.1 Health Hazards

DANGER! Electric shock! Always unplug from the mains when working on electrical components.

- Repairs only by trained and authorised personnel!
- In the case of obvious damage (e.g. damaged electrical cable), do not place the system in operation in any circumstances! If the system is already in operation, switch off immediately!
- Always ensure that the electrical parts of the system do not come into contact with water!

3.2 Hazards for Unit and Function

- Never operate pump in the supply tank without water!
- Prior to commissioning the system, all persons who operate the system should be briefed on the function and usage of the system!
- The experimental section made of Plexiglas must not be cleaned with hot water or with agents that contain abrasive materials!
- The rod that is used to adjust the ramp in the experimental section is sealed with a **shaft seal** (1). Should leaks occur during the operation of the experimental section, the shaft seal can be readjusted by screwing in the **knurled bolt**(2)! (Fig. 3.1)

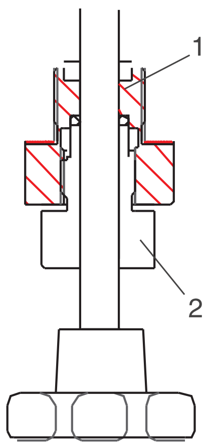


Fig. 3.1 Ramp Sealing

4 Theory

The theoretical principles that are covered with this system are divided into 2 areas:

- **The theory of the open flume** and
- **The theory of the closed flume**

The theory of the open flume covers predominantly the so-called **dam** or **weir systems.** In general it can be stated that in this area hydraulic structures are covered that man uses to adapt river areas to his needs.

The theory of the closed flume on the other hand addresses more tasks from drainage. In a closed flume the laws of **pipe flow** apply.

4.1 Pipe Flow in the Closed Flume

On the entry of the water from a tank or open flume into a pipe, the water suffers a loss of energy. This can be due to the flow of water changing its direction, the constriction of the flow, or the flow opening out again on mixing with dead water surrounding it. The energy loss on the inlet to a pipe is termed the **inlet loss.**

The inlet losses are countered in practice by appropriately rounding the inlets on pipes.

If the outlet from the closed flume takes place under water, an **outlet loss** is produced similar to the inlet loss.

If the outlet of the water from the closed flume takes place in undammed water of the same or lower water level, there is no outlet loss.

This experimental setup makes it possible to perform measurements on the total pressure, the static pressure and the resulting calculation of the dynamic pressure content in a closed flume. The measurements can be performed at constant cross-section or with changing flow cross-section. The changing flow cross-section is established using a ramp; this produces a **convergent inlet area**, a **constricted middle section** and a **divergent outlet area** in the closed flume (Fig. 4.1 and 4.2).

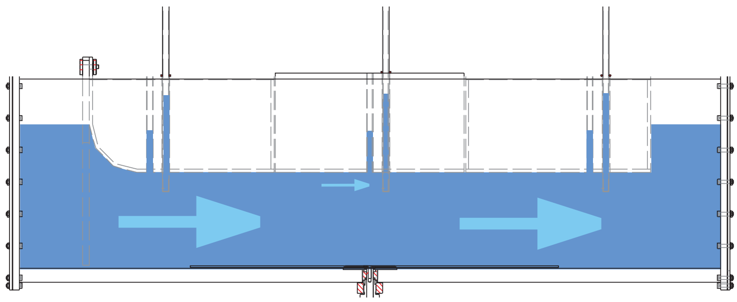


Fig. 4.1 Closed Flume with Constant Flow Cross-Section

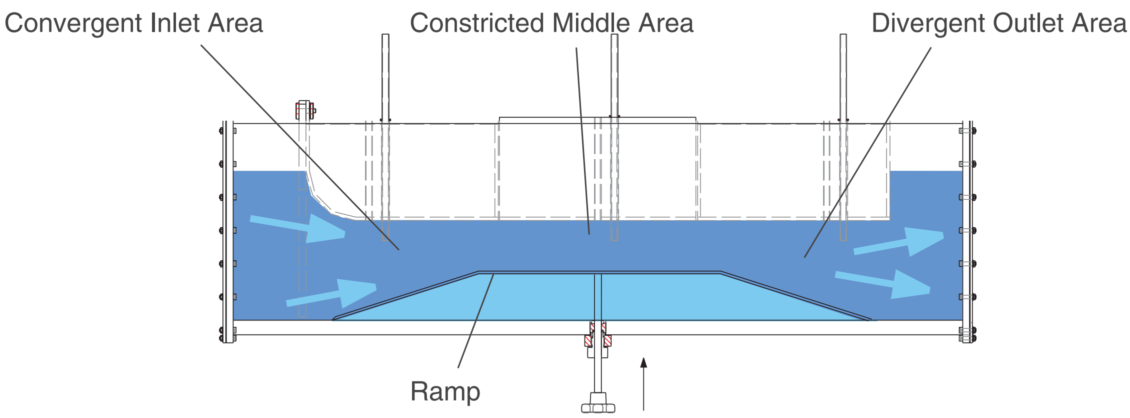


Fig. 4.2 Closed Flume with Changing Flow Cross-Section

4.2 General Information on Weir and Dam Systems

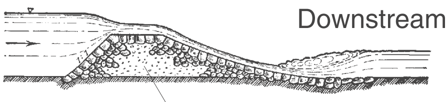


Abb.: 4.3 Weir System

All structures in the bed of a water channel that are fitted with the intention of artificially raising the water level upstream are termed weir or dam systems. **Upstream** is the term used for the section of water between the dam system and the feed, the section after the dam system is called **downstream**.

A dam that is predominantly used to raise the upstream water level is termed a weir. If such a structure is built to store water and to even out drainage, then it is a retaining dam or a storage dam.

Purpose of Dam Systems

- Increase of the depth of water in the natural course a river

This is predominantly of benefit to ship navigation so that even in times of low water there is still sufficient depth of water in the river. In addition a reduction in the flow speed of the water is achieved that saves energy on a journey upriver.

However also on the extraction of water an increase in the depth of water is necessary to achieve a hydraulically favourable outlet cross-section (small width, large depth).

- Combination of the natural river gradient at one point

This usage is important in those locations where the natural gradient of the river is to be used to obtain energy (hydroelectric power stations, turbines), or a high level take off point for artificial irrigation is to be created.

- Reduction in the fluctuation of the water level

If water is drawn off in artificial channels (e.g. for irrigation purposes), fluctuations in the natural water level should be kept away from irrigation channels to ensure that the amount of water drawn is as constant as possible. For this purpose mostly moving weirs or weir structures arranged inclined to the flow are used.

- Protection against high water levels

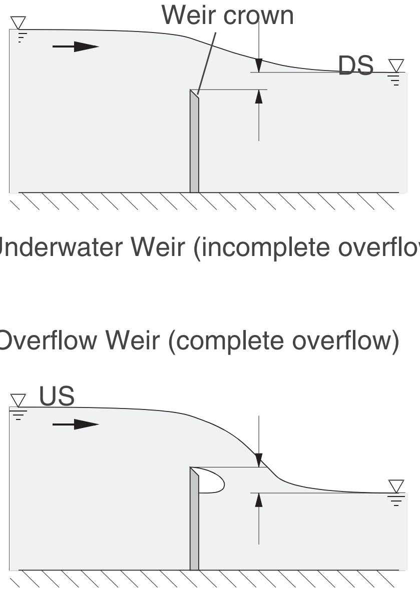
By means of retaining dams and storage dams it is possible to even out the fluctuation of the supply of water over the seasons and to store surplus water (e.g. in reservoirs). In this way effective protection against high water levels is achieved.

Forms of Weir

Weirs are differentiated in various ways. First a differentiation can be made between the physical construction of **fixed** weirs and **moving** weirs.

Fixed weirs are significantly cheaper and can be used where a possible increased height backup of water (on high water) upstream does not cause any damage to the environment. Moving weirs must be used everywhere where the upstream water level is to be exactly and variably regulated, and also a certain water level is not to permitted to be exceeded at the maximum high water level. An example for a fixed weir is the wide crested weir supplied. An example for a moving weir is the undershoot weir supplied.

A further important division among weirs is differentiation by the height of the weir crest with respect to the downstream water level. A differentiation is made between **overflow weirs** and **underwater weirs**.



Underwater Weir (incomplete overflow)

Overflow Weir (complete overflow)

Abb.: 4.4

One and the same weir can take on both weir types depending on the amount of water flowing. In the case of a low water flow rate, the weir acts as an overflow weir, in the case of high water flow rate, however, it acts as an underwater weir because with increasing water flow rate the depth of water downstream can increase much more quickly than upstream.

On an overflow weir the term **complete overflow** is also used, in the case of an underwater weir, **incomplete overflow** (Fig. 4.4).

4.3 General Information on the Flow Processes of Water

4.3.1 Flow Forms

A differentiation is made between two basic types on movement of water:

- Subcritical flow and
- Supercritical flow

In an outlet through which there is a flow, the flow speed of the water v_{water} is always less than the wave speed v_{wave}. This means that in a flowing section the water flows more slowly than a wave can propagate.

The wave speed v_{wave} is as per Fig. 4.5 dependent on the acceleration due to gravity g and the depth of the water t:

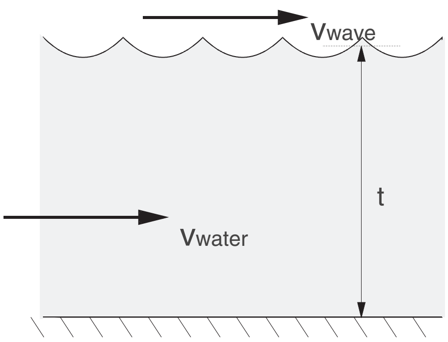


Abb.: 4.5

$$v_{Wave} = \sqrt{g \cdot t} \tag{4.1}$$

In the case of a supercritical drain flow the relationships are completely reversed: The wave speed is always smaller than the flow speed of the water. This means that the wave here can never move upstream, but only downstream!

The transition from subcritical flow to supercritical flow is termed the **hydraulic jump**.

4.3.2 Critical Water Depth

The **critical water depth** is closely related to the flow forms described in Section 4.3.1. In an open flume one criterion for the critical water depth is that the water speed v_{water} is exactly the same as the wave speed v_{wave}. The critical water depth t_{crit} in an open flume can be determined using the equation

$$t_{crit} = \sqrt[3]{\frac{Q^2}{b^2 \cdot g}} \quad (4.2)$$

Here g is the acceleration due to gravity (9.81 m/s^2), Q the flow rate in m^3/s and b the width of the weir (or of the flume) in m.

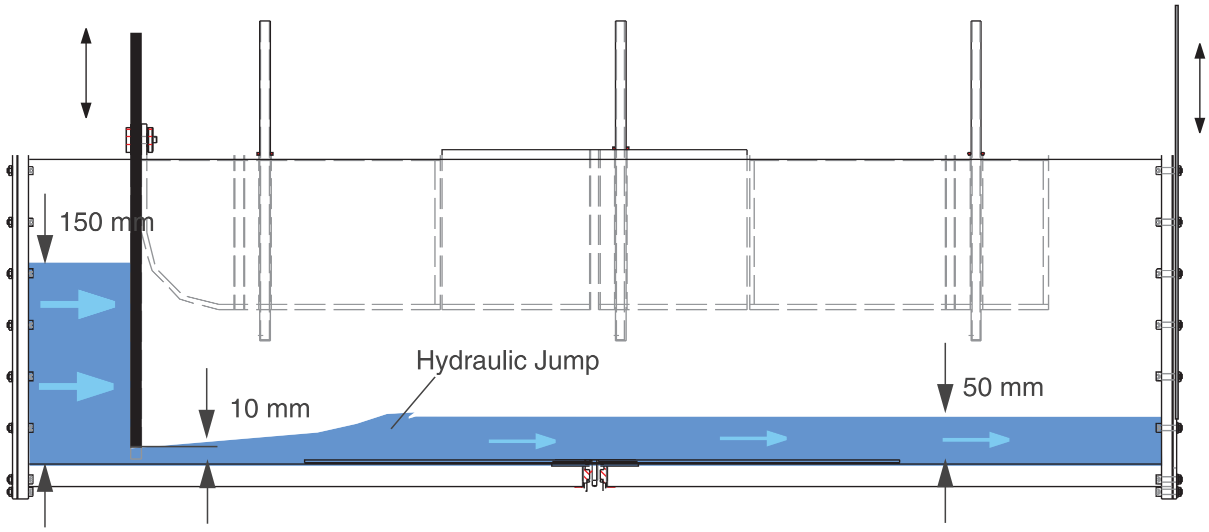
5 Experiments

The HM 164 is designed predominantly for the demonstration of flow processes.

The experiments described here are examples that are also intended to act as suggestions for your own further experiments.

5.1 Adjustable Undershoot Weir

Experimental Setup:



The water levels shown were set in the experimental section. The amount of feed water was regulated (cf. item 12 in Fig. 2.1). The backup, i.e. the water of height 50 mm, was set up using the overflow weir at the channel outlet (cf. Sec. 2.1.1, Fig. 2.3). In this experimental arrangement it is already possible to observe the hydraulic jump.

The theoretical amount of water flowing out can be determined using the equation

$$Q = \sqrt{\frac{h^2 \cdot h_0 \cdot b^2 \cdot 2 \cdot g}{1 + (h / h_0)}} \qquad (5.1)$$

Here b is the weir or channel width in m, h the height of the gap underneath the undershoot weir in m and h_0 the height of the water upstream in m (acceleration due to gravity g= 9.81 m/sý).

b = 0.04 m

h = 0.01 m

h_0 = 0.15 m

If the values are placed in the equation, an outlet flow is found of

$$Q = \sqrt{\frac{0{,}01\,m^2 \cdot 0{,}15\,m \cdot 0{,}04\,m^2 \cdot 19{,}62\,m/s^2}{1 + (0{,}01\,m / 0{,}15\,m)}}$$

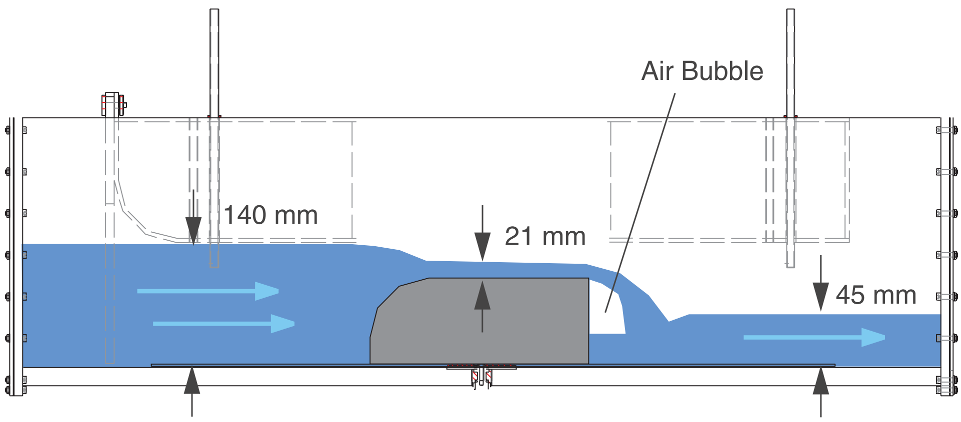
$Q = 0{,}000594\ m^3/s$, this corresponds to

$Q = 35{,}7\ l/min$

5.2 Different Weir Structures

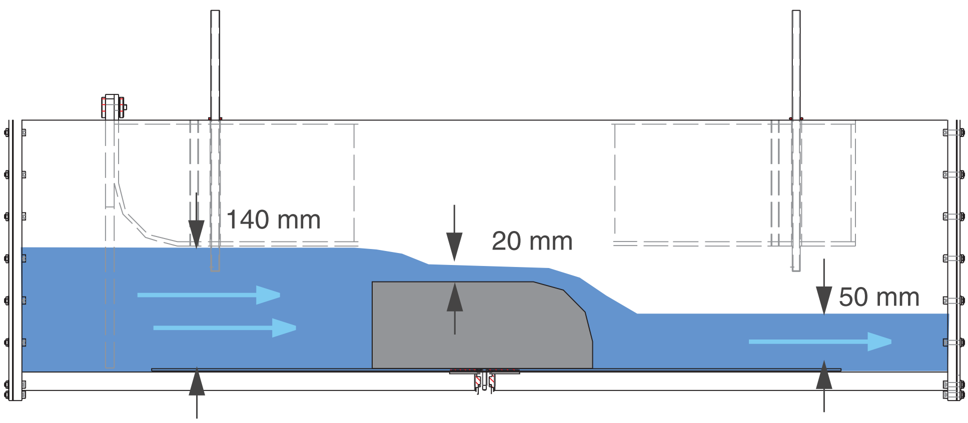
In the following experiments the water was **not** dammed at the outlet of the channel, otherwise the water levels are set as shown in the figures.

Underwater weir, sharp edged:



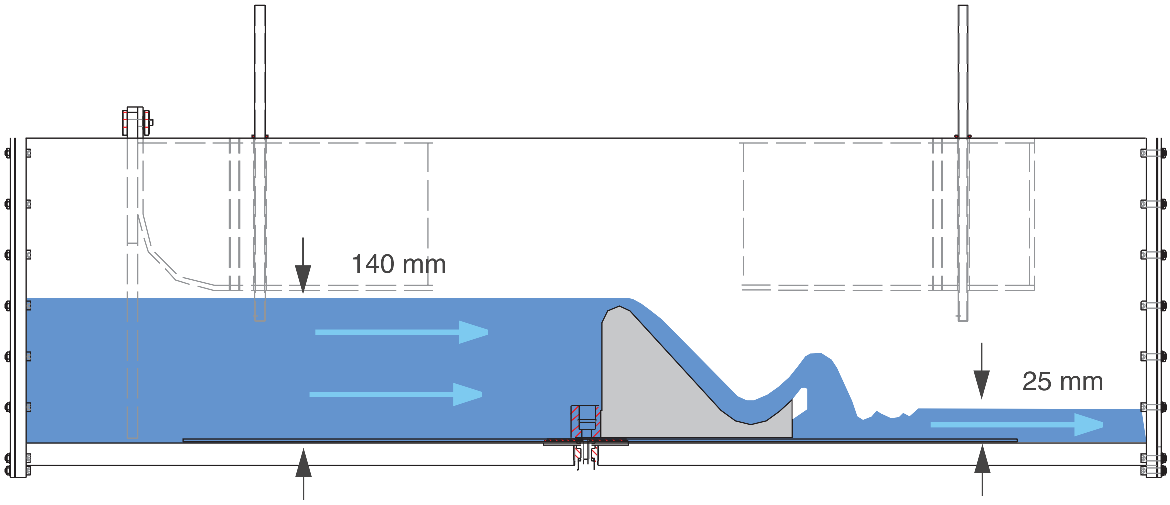
On such sharp-edged, complete overflow as is present here, a characteristic air bubble forms at the weir.

Underwater weir, rounded



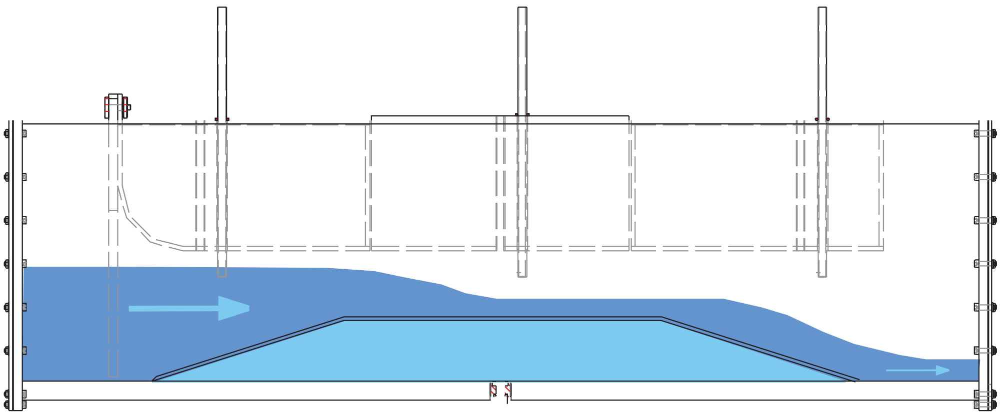
Experiment with same feed. There is a completely different flow over the weir structure.

Overflow with „Ski Jump“



In practice, such weirs are used after long sections of gradient where the direct impact of the flow over an extended period would cause serious damage, e.g., due to erosion.

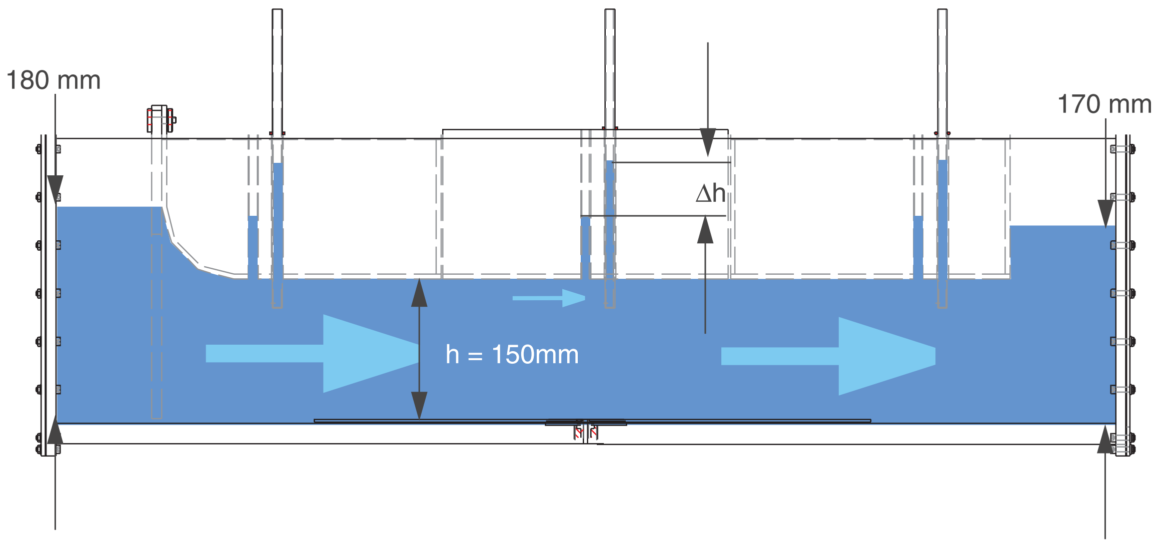
The models supplied enable a large number of experiments to be performed on the flow behaviour at weir structures. Suggestions for experiments can be found in the appropriate specialist literature. The height adjustable underwater weir built into the experimental section can also be used for experiments in the open flume:



5.3 Closed Flume

In the experiments on the closed flume the water is **not** dammed at the outlet. The experiment was performed at full flow rate.

Culvert with constant cross-section



At all 3 measuring points a Δh of 5mm was measured in the culvert. Using Equation 2.1 the speed u of the flow can be determined from this value:

$$u = \sqrt{2 \cdot 9{,}81 m/s^2 \cdot 0{,}005 m} = 0{,}313 \ m/s$$

For a known cross-section for the flow A ($A = w \times h$), the flow rate is found from the speed:

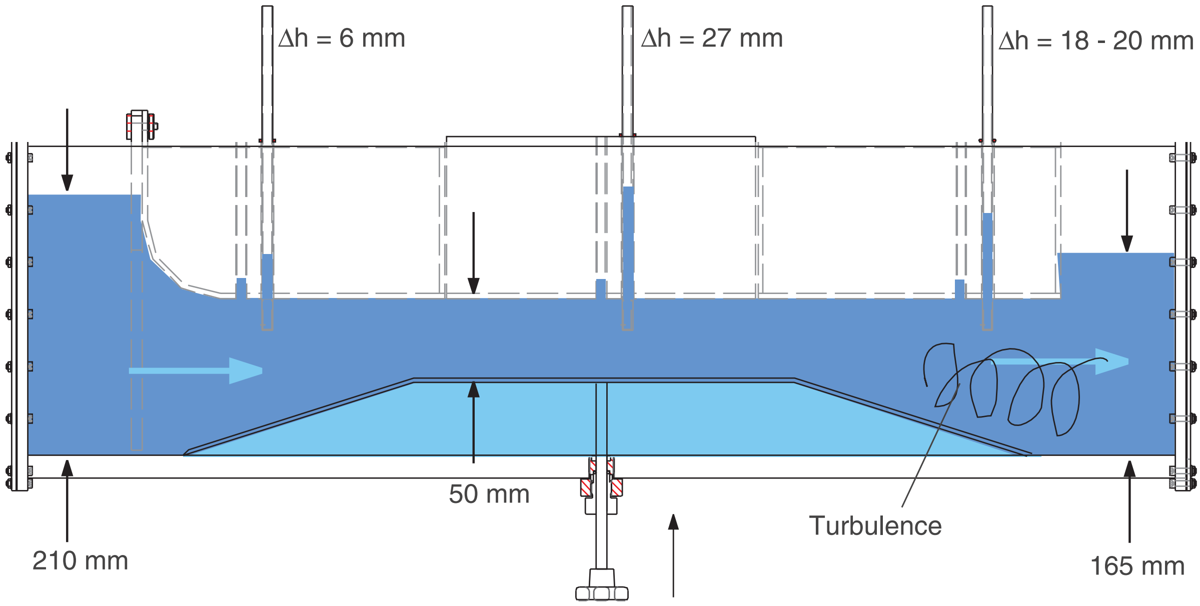
$$\dot{V} = u \cdot A \qquad (5.2)$$

with b= const.= 0.04m and h= 0.15m

$$\dot{V} = 0{,}313 \tfrac{m}{s} \cdot 0{,}006 m^2 = 0{,}001878 \tfrac{m^3}{s} = 112{,}7 \tfrac{l}{min}$$

Culvert with changing cross-section

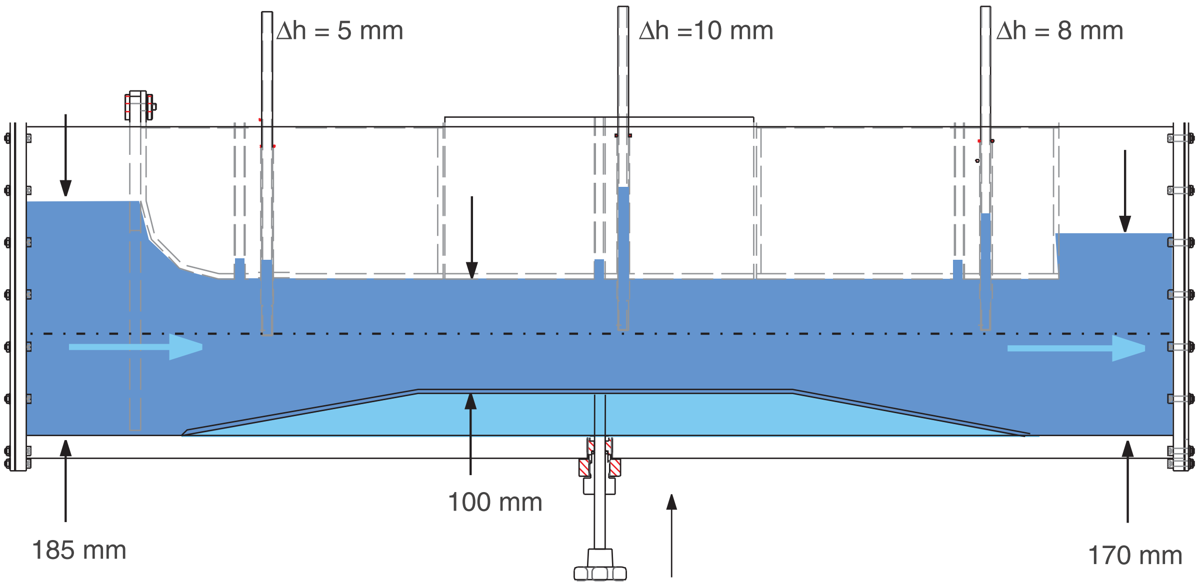
Two experiments were performed (full flow rate, outlet not dammed):



The ramp in the experimental section is raised until the central area is constricted to 50 mm. Then flow conditions as shown in the figure are produced. After Bernoulli different pressure heads are then found at the measuring tubes, as at constant flow rate different speeds are measured in the different sections of the experimental section (convergent inlet, constricted middle section and divergent outlet).

At the „divergent outlet“ measuring tube there was a fluctuating indication for this experimental setup. In such a case the measuring tube should be moved to an area in which the fluctuations are at a minimum.

For the second experiment the middle section was constricted to a height of 100mm instead of 50mm as before. The vertically adjustable measuring tube was set to the „middle“ of the flow for this experiment.



Using this experimental setup the law of continuity can be checked, for example using the equation

$$\dot{V} = \text{konst.} = u_1 \cdot A_1 = u_2 \cdot A_2 = u_3 \cdot A_3 \qquad (5.3)$$

Here u is the speed in the cross-section A containing the flow, subscripts:

1 = convergent inlet

2 = constricted middle section

3 = divergent outlet

To determine A, a suitable scale should be used.

6 Appendix

6.1 Technical Data

Dimensions

LxWxH	1585 x 750 x 1500	mm

Weight

approx.	100	kg

Supply Tank

Capacity	approx. 180	l

Pump

Max. Pump Capacity	120	l/min

Experimental Section

Material	Transparent Plastic	
LxWxH (without insert)	1100 x 40 x 300	mm

6.2 Items Supplied

- 1 experimental setup, fitted to laboratory trolley complete and ready for use
- 3 additional weir models
- 1 model holder
- 1 instruction manual