Welcome to GUNT

In this catalogue, we present a comprehensive overview of our innovative demonstration and experimental units.

GUNT units are used for:
- education in technical professions
- training and education of technical personnel in trade and industry
- studies in engineering disciplines

Imprint
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We would like to thank Prof. Dr.-Ing. Bernhard Haber of the Bochum University of Applied Sciences, Department of Civil Engineering, Institute of Water and Environment, Centre for Hydraulic Engineering and Fluid Mechanics, for his kind and professional support on the topic of open-channel flow.

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Fluid mechanics at GUNT

Fluid mechanics plays a fundamental and key role in engineering education. Lectures and laboratory exercises on fluid mechanics are part of the standard curriculum for a wide range of engineering disciplines, such as mechanical and plant engineering, energy and process engineering, environmental engineering, shipbuilding, civil engineering, agriculture, food technology etc. The fundamental principles of fluid mechanics are also an indispensable part of the teaching programme in vocational education and training for many technical professions.

The graphic below illustrates the structure of the GUNT programme for product sector 4. The field of general fluid mechanics is covered in catalogue 4. Catalogue 4b details the subject of hydraulic engineering and catalogue 4a deals with fluid machinery.

What can GUNT do for you...

...to support and enrich your lectures and lessons?
We provide demonstration, experiment and research equipment for virtually all topics related to the field of fluid mechanics.

You know – as a lecturer and academic in colleges and universities – and we know – as a developer and manufacturer – that well thought out and clear experiments result in a stable and sustainable foundation of knowledge in students.

We see ourselves as partner to our customers:
Further development of our devices relies on your feedback.

GUNT devices allow application of learned theory:
• properly conceived experiments
• visualisation of processes
• design and functionality of systems

We are driven by your feedback:
Tell us your opinion!
We are constantly reviewing our product range for permanent improvement!

Your success is our AIM!

More than 40 years of experience in developing GUNT equipment

We are a C P L A N

DO
CHECK
Teaching and learning systems for the field of hydraulics for civil engineering

Fluid mechanics plays a key role in many fields of engineering. For engineers it is therefore crucial to understand the basic principles of fluid mechanics. Structures for supplying water, drainage systems and the protection against water all fall within the scope of civil engineering. Certain areas from the overall field of fluid mechanics are of secondary importance in the civil engineering curriculum, such as the basic principles of compressible flow. To take this fact into account, in addition to our catalogue 4 “Fluid mechanics” we have compiled a self-contained catalogue 4b “Hydraulics for civil engineering”. The teaching and experimentation systems specifically consider the training needs of civil engineering.

Catalogue 4b is divided into two sections. The first section contains general principles of fluid mechanics that are relevant to multiple disciplines, such as basic equations, such as the continuity and Bernoulli equations, pipe flow and turbomachines. The second section covers the specific topics for civil engineering with a focus on hydraulic engineering. This section looks at open-channel flow, open-channel sediment transport and flow through porous media.

The subsections are preceded by information pages containing basic knowledge. These pages explain the technical and physical relationships in a way that is simple to understand, making it easy to jump into each subject area. The corresponding GUNT devices then facilitate the practical demonstration and investigation of the relationships.

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## Fundamentals of fluid mechanics

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Hydrostatics is the study of fluids at rest. The experimental units from GUNT cover the basic principles of the following topics from the field of hydrostatics: hydrostatic pressure, buoyancy, surface tension, capillarity/adhesion.

**Hydrostatic pressure**
The pressure in fluids at rest does not depend on the direction. It is linearly dependent on the amount of fluid over the element being studied, or the diving depth respectively.
The hydrostatic pressure for incompressible fluids that are not subject to gravity is calculated according to Pascal’s law.

**Pascal’s law**
The effect of a force $F$ on a motionless liquid generates a pressure $p$ within the liquid, which at any point acts equally in all directions. The pressure always acts perpendicular to the boundary surface $A$ of the liquid.
All force and pressure processes in liquids are based on this law.

**Hydrostatic paradox**
The hydrostatic pressure generates a force $F$ on the area $A$. If these areas are equal, this force only depends on the level $h$; the shape of the vessel is irrelevant.

**Communicating vessels**
Communicating vessels are tubes that are open at the top and interconnected at the bottom. Regardless of the shape and size of the tubes, the level of the fluid in them is the same.
Applications include water levels, locks and drain traps in sewers.

**Stability of floating bodies**
In order to be able to assess whether a body floats stably or could capsize, it is necessary to determine its metacentre $M$. The location of the metacentre depends on the centre of gravity of the displaced water $A$ and the angle of heel. The body floats stably when the metacentre $M$ is located above the centre of gravity $S$. Then the restoring moment $M_d$ has a ‘righting’ effect.
The distance between the centre of gravity and the metacentre is known as the metacentric height $z$.

**Capillarity**
Liquids in capillaries rise or fall due to molecular forces between the liquid and the wall or between the liquid and air. The height of rise in the capillary depends on the surface tension and the diameter of the capillary.
In wetting liquids (e.g. water) the surface level in the capillary rises. In non-wetting liquids (e.g. mercury) the level falls.
### HM 115 Hydrostatics trainer

#### Description
- **basic experiments in hydrostatics**
- **wide range of experiments**
- **closed water circuit with tank and pump**

Hydrostatics is the study of fluids at rest. Phenomena occurring as a result of hydrostatic pressure are analysed and the force effects determined. Hydrostatic aspects play a crucial role in various areas of engineering, such as in plumbing and domestic engineering, in pump manufacturing, in aerospace and in shipping (buoyancy, load on the sides of a ship).

The HM 115 trainer can be used to conduct experiments in the field of hydrostatics, such as ground pressure measurement or demonstrating Boyle's law. Determining the centre of pressure completes the range of experiments. Furthermore, experimental units for studying capillarity and buoyancy are included. The hydrostatic pressure and surface tension are measured. Additionally, one experiment uses a Pitot tube and a tube for static pressure to study the pressure components in a flowing fluid.

#### Learning objectives/experiments
- study of buoyancy on a variety of bodies
- study of the density of liquids
- hydrostatic pressure, Pascal's law
- communicating vessels
- determination of the centre of pressure
- study of surface tensions
- demonstration of capillarity
- Boyle's law
- study of static and dynamic pressure component in flowing fluid
- familiarisation with various methods of pressure measurement

To make the functions and processes visible, the tanks and the experimental units use a transparent design. Tanks and pipes are made entirely of plastic.

Various pressure gauges are available for measuring pressure and differential pressure of the liquid fluid, such as a Pitot tube, tube for static pressure, pressure sensor with digital display, twin tube manometers or a differential pressure manometer. A diaphragm manometer and a Bourdon tube manometer indicate the pressure of the gaseous fluid.

The trainer has its own air and water supply. The closed water circuit includes a supply tank with submersible pump. A compressor is included to generate positive and negative pressures for the experiments with air.

#### Specification
- **wide range of accessories included**: compressor for generating positive and negative pressures, bottom pressure apparatus, two areometers
- **1 experimental unit**: each: measuring the buoyancy force, investigation of the hydrostatic pressure in liquids, measuring the surface tension, communicating vessels, capillarity
- **5** Pitot tube for determining the total pressure and tube for static pressure
- **6** instruments: pressure sensor with digital display, differential pressure manometer, twin tube manometers, diaphragm manometer, Bourdon tube manometer

#### Technical data
- **Pump**
  - power consumption: 250W
  - max. flow rate: 9m³/h
  - max. head: 7,6m
- **Compressor**
  - power: 65W
  - pressure at inlet: 240mbar
  - pressure at outlet: 2bar
- **3 tanks**
  - height: 500mm
  - Ø 100mm, Ø 133mm, Ø 200mm
- **Supply tank for water**: approx. 50L
- **2 areometers with different measuring ranges**
- **Measuring ranges**
  - pressure: 2...1...1.5bar
  - differential pressure: 0...0.2bar
  - differential: 0.0 0.4bar
  - density: 1x 0.8...1.9g/cm³, 1x 1...1.2g/cm³
- **230V, 50Hz, 1 phase**
  - 230V, 60Hz, 1 phase
  - 120V, 60Hz, 1 phase
- **UL/Csa optional**
- **LxWxH**: 1760x820x1940mm
- **Weight**: approx. 270kg
- **Scope of delivery**
  - **1 trainer**
  - **1 compressor**
  - **1 bottom pressure device**
  - **2 areometers**
  - **1 wedge-shaped tank**
  - **1 experimental unit**: each: surface tension, hydrostatic pressure in fluids, buoyancy force, capillarity, communicating vessels
  - **1 set of instructional material**

#### Image: Description of the trainer and a diagram with labels and numbers indicating the parts of the trainer.
The HM 150.06 unit can be used to study the stability of a floating body and to determine the metacentre graphically. In addition, the buoyancy of the floating body can also be determined. The experiment is easy to set up and is particularly suitable for practical work in small groups.

The experiment is conducted in a tank filled with water. A transparent body with a rectangular frame cross-section is used as the floating body. Clamped weights that can be moved horizontally and vertically make it possible to adjust the centre of gravity and the heel.

The position of the clamped weights can be read on scales. A clinometer indicates the heel.

The accessory HM 150.39 is available as an optional extra for further experiments with different frame shapes.

Learning objectives/experiments
- study and determination of
  - buoyancy, centre of buoyancy
  - centre of gravity, metacentre, stability
  - heel

HM 150.06
Stability of floating bodies

Description
- stability of a floating body
- determining the metacentre
- other floating bodies with different shapes of frame optionally available, HM 150.39

In hydrostatics, the metacentre is an important point to be considered when assessing the stability of floating bodies. Stability refers to the ability of a ship to right itself from a heeled position. The metacentre is the intersection of the buoyancy vector and the vessel’s axis of symmetry at a certain heel.

The HM 150.06 unit can be used to study the stability of a floating body and to determine the metacentre graphically. In addition, the buoyancy of the floating body can also be determined. The experiment is easy to set up and is particularly suitable for practical work in small groups.

The experiment is conducted in a tank filled with water. A transparent body with a rectangular frame cross-section is used as the floating body. Clamped weights that can be moved horizontally and vertically make it possible to adjust the centre of gravity and the heel.

The position of the clamped weights can be read on scales. A clinometer indicates the heel.

The accessory HM 150.39 is available as an optional extra for further experiments with different frame shapes.

Learning objectives/experiments
- study and determination of
  - buoyancy, centre of buoyancy
  - centre of gravity, metacentre, stability
  - heel

HM 150.06
Stability of floating bodies

Specification
1. investigating the stability of a floating body and determining the metacentre
2. transparent floating body with rectangular frame cross-section
3. one horizontally movable clamped weight for adjusting the heel
4. one vertically movable clamped weight for adjusting the centre of gravity
5. clinometer with scale for displaying the heel
6. other floating bodies with different shapes of frame available as accessories: HM 150.39

Technical data
Floating body
- LxWxH: 300x130x190mm
- mast height: 400mm

Horizontal scale: 180mm
Vertical scale: 400mm
Height scale of the floating body: 120mm
Clinometer scale: ±30°

Weights
- floating body without clamped weights: approx. 2.7kg
- vertical clamped weight: 575g
- horizontal clamped weight: 196g

Tank for water: 50L
- LxWxH: 660x450x220mm (tank)
- Weight: approx. 6kg

Scope of delivery
1. experimental unit
2. set of instructional material
**HM 150.39**  
Floating bodies for HM 150.06

### Description
- **stability of floating bodies with different frame shapes**

The HM 150.39 accessory includes two transparent floating bodies with different frame shapes (hard chine and round bilge). The floating bodies are used together with HM 150.06 and extend this device’s range of experiments.

### Learning objectives/experiments
- comparison of two different frame shapes: hard chine and round bilge

### Specification
1. determination of the metacentre of 2 floating bodies with different frame shapes: hard chine and round bilge
2. each floating body fitted with a horizontally movable clamped weight for adjusting the heel
3. each floating body fitted with a vertically movable clamped weight for adjusting the centre of gravity
4. each floating body fitted with a clinometer with scale for displaying the heel
5. for use with HM 150.06

### Technical data

#### Hard chine frame
- LxWxH: 300x200x140mm
- mast height: 200mm

#### Round bilge frame
- LxWxH: 300x200x100mm
- mast height: 240mm

#### Horizontal scale: 180mm  
Vertical scale: 240mm  
Height scale of the floating body: 120mm  
Clinometer scale: ±30°

#### Weights
- floating body without clamped weights  
  - hard chine: approx. 2.9kg  
  - round bilge: approx. 2.4kg  
- vertical clamped weight: 575g  
- horizontal clamped weight: 196g

- LxWxH: 330x220x290mm (hard chine)  
- LxWxH: 330x220x280mm (round bilge)
- Total weight: approx. 7kg

### Scope of delivery
- 2 floating bodies  
- 1 manual

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On our website you will find all you need to know, including all the latest news.
Basic knowledge
Fundamentals of hydrodynamics

Hydrodynamics is concerned with the study and description of fluids in motion. The main emphasis is the teaching of the conservation laws of mass, energy and momentum.

Flowing fluids possess kinetic energy. This energy can be converted into potential energy (pressure, height) and vice versa.

Typical keywords include Bernoulli’s equation, continuity equation and conservation of momentum. For ease of understanding, it is mostly steady states of incompressible fluids that are considered.

Other topics within hydrodynamics
  • pipe flow (laminar/turbulent)
  • methods of flow rate measurement
  • open-channel flow
  • flow around bodies
  • turbomachines
  • flow of compressible fluids

Flow from a tank
The flow from a tank can be regarded as both steady and transient. In the steady case the fill level, and thus the width of the jet, remains constant (e.g. discharge under a weir). The outlet velocity \( v \) only depends on the head \( h \) and is calculated according to Torricelli’s law.

\[
v = \sqrt{2gh}
\]

\( v \) velocity, \( g \) gravitational acceleration, \( h \) distance between discharge and water level

When the tank is emptying during the discharge process, it is in what is referred to as the transient state.

Venturi nozzle
The velocity of the flowing fluid is at its greatest at the narrowest cross-section (continuity equation \( A \cdot v = \text{const} \)). Bernoulli discovered that a part of the pressure energy is converted into kinetic energy. When velocity increases it therefore results in a drop in pressure, so that the lowest pressure occurs in the narrowest cross-section. Bernoulli’s equation states that the energy of a frictionlessly flowing, incompressible fluid is constant.

Applications include water jet pumps, carburettors, flow measurement

Jet forces
If the flow velocity changes then the momentum of a fluid changes according to the magnitude and/or direction. This results in forces that, for example, could drive a free jet turbine or a water vehicle.

These forces can be easily demonstrated and measured when the jet hits the wall and is deflected.

Vortex formation
Vortices occur when, within a fluid, a portion of the fluid flows more quickly than the rest of the fluid. This results in a velocity gradient within the fluid. Energy is dissipated in vortices.

Free vortices (potential vortex, e.g. whirlpool) are formed during discharge from a tank, for example. With free vortices all fluid particles move in concentric circular paths without rotating around their own axis. Free vortices are formed solely by hydrodynamic forces.

Forced vortices are rotational and are formed by external forces, such as a stirrer.

Pressure in a flowing fluid
The energy of the flowing fluid is determined by pressure, velocity and density. The total pressure is made up of a static and a dynamic component. The dynamic component grows quadratically as the flow velocity increases. A flowing fluid can contain potential, kinetic and pressure energy. In the ideal case the total energy is conserved. In this case, the proportions may vary, so for example pressure energy is converted into kinetic energy.
## Experimental units on the fundamentals of hydrodynamics

### Continuity equation, Bernoulli

**HM 150.07**
Bernoulli’s principle

- investigation and verification of Bernoulli’s law
- recording pressure distribution in the venturi nozzle
- six tube manometers for displaying the static pressure and a single tube manometer for displaying the total pressure

### Laminar and turbulent flow

**HM 150.18**
Osborne Reynolds experiment

- representation of laminar and turbulent flow and the transition zone
- determining the critical Reynolds number
- visualisation of flow conditions using ink as a contrast medium

### Discharge from openings

**HM 150.09**
Horizontal flow from a tank

- visualising the trajectory of a water jet with HM 150.09
- investigations on the outlet jet (diameter, velocity) with HM 150.12
- determination of the contraction coefficient in two experimental units

**HM 150.12**
Vertical flow from a tank

- visualising the trajectory of a water jet

### Visualisation of streamlines

**HM 150.10**
Visualisation of streamlines

- visualisation of streamlines using ink as a contrast medium
- various models included: drag bodies and changes in cross-section
- influence of sources and sinks

**HM 150.21**
Visualisation of streamlines in an open channel

- demonstration of flow phenomena in open channels
- incident flow and flow around various weirs and drag bodies
- visualisation of streamlines using ink as a contrast medium

### Jet force

**HM 150.08**
Measurement of jet forces

- investigation of jet forces and demonstration of the momentum equation
- four different shaped deflectors: flat surface, oblique surface, semi-circular surface, conical surface
- influence of mass flow and deflection
**HM 150.18 Osborne Reynolds experiment**

**Description**

- Visualisation of laminar and turbulent flow
- Determining the critical Reynolds number
- Traditional experiment based on the model of the British physicist Osborne Reynolds

The Osborne Reynolds experiment is used to display laminar and turbulent flows. During the experiment it is possible to observe the transition from laminar to turbulent flow after a limiting velocity. The Reynolds number is used to assess whether a flow is laminar or turbulent.

With HM 150.18 the streamlines during laminar or turbulent flow are displayed in colour with the aid of an injected contrast medium (ink). The experimental results can be used to determine the critical Reynolds number.

The experimental unit consists of a transparent pipe section through which water flows, with flow-optimised inlet. A valve can be used to adjust the flow rate in the pipe section. Ink is injected into the flowing water. A layer of glass beads in the water tank ensures an even and low-turbulence flow.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

**Learning objectives/experiments**

- Visualisation of laminar flow
- Visualisation of the transition zone
- Visualisation of turbulent flow
- Determination of the critical Reynolds number

**Specification**

1. Visualisation of laminar and turbulent flow in the Osborne Reynolds experiment
2. Water as flowing medium and ink as contrast medium
3. Vertical glass pipe section
4. Water tank with glass beads to stabilise the flow
5. Flow rate in the pipe section can be adjusted via a valve
6. Flow rate determined by HM 150 base module
7. Water supply using HM 150 base module or via laboratory supply

**Technical data**

- **Water tank**
  - Capacity: 2200mL
- **Pipe section**
  - Length: 675mm
  - Ø, inner: 10mm
- **Tank for ink**
  - Capacity: approx. 250mL

**Required for operation**

- HM 150 (closed water circuit) or water connection, drain

**Scope of delivery**

1. Experimental unit
2. Bag of glass beads
3. Ink (1L)
4. Set of instructional material

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Flow conditions from left to right: laminar flow, transition from laminar to turbulent flow, turbulent flow.
Fundamentals of fluid mechanics
Hydrodynamics

HM 150.07
Bernoulli’s principle

Description
- Investigation and verification of Bernoulli’s principle
- Static pressures and total pressure distribution along the Venturi nozzle
- Determination of the flow coefficient at different flow rates

Bernoulli’s principle describes the relationship between the flow velocity of a fluid and its pressure. An increase in velocity leads to a reduction in pressure in a flowing fluid, and vice versa. The total pressure of the fluid remains constant. Bernoulli’s equation is also known as the principle of conservation of energy of the flow.

The experimental unit includes a pipe section with a transparent Venturi nozzle and a movable Pitot tube for measuring the total pressure. The Pitot tube is located within the Venturi nozzle, where it is displaced axially. The position of the Pitot tube can be observed through the Venturi nozzle’s transparent front panel.

The Venturi nozzle is equipped with pressure measuring points to determine the static pressures. The pressures are displayed on the six tube manometers. The total pressure is measured by the Pitot tube and displayed on another single tube manometer.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

Learning objectives/experiments
- Energy conversion in divergent/convergent pipe flow
- Recording the pressure curve in a Venturi nozzle
- Recording the velocity curve in a Venturi nozzle
- Determining the flow coefficient
- Recognising friction effects

 Specification
1. Familiarisation with Bernoulli’s principle
2. Venturi nozzle with transparent front panel and measuring points for measuring the static pressures
3. Axially movable Pitot tube for determining the total pressure at various points within the Venturi nozzle
4. 6 tube manometers for displaying the static pressures
5. Single tube manometer for displaying the total pressure
6. Flow rate determined by HM 150 base module
7. Water supply using HM 150 base module or via laboratory supply

Technical data
Venturi nozzle
- A: 84…338mm²
- Angle at the inlet: 10.5°
- Angle at the outlet: 4°

Pitot tube
- Moveable range: 0…200mm
- Ø 4mm

Pipes and pipe connectors: PVC

Measuring ranges
- Pressure: 0…290mmWC (static pressure)
  0…370mmWC (total pressure)

LxWxH: 1100x680x900mm
Weight: approx. 28kg

Required for operation
HM 150 (closed water circuit) or water connection, drain

Scope of delivery
1. Experimental unit.
1. Set of instructional material
HM 150.08
Measurement of jet forces

Description
- Investigation of jet forces on deflectors
- Demonstration of the principle of linear momentum
- Four interchangeable deflectors with different deflection angles

During deceleration, acceleration and deflection of a flowing fluid, there is a change of velocity and thus a change in momentum. Changes in momentum result in forces. In practice, the motive forces are used to convert kinetic energy into work done, for example in a Pelton turbine.

In HM 150.08 jet forces are generated and studied with the aid of a water jet that acts on and is diverted by an interchangeable deflector.

The experimental unit includes a transparent tank, a nozzle, four interchangeable deflectors with different deflection angles and a weight-loaded scale. The force of the water jet is adjusted via the flow rate.

Experiments study the influence of flow velocity and flow rate as well as of different deflection angles. The jet forces generated by the water jet are measured on the weight-loaded scale. The forces are calculated using the momentum equation and compared with the measurements.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

Learning objectives/experiments
- Demonstration of the principle of linear momentum
- Study of the jet forces
- Influence of flow rate and flow velocity
- Influence of different deflection angles

Specification
1. Investigation of jet forces and demonstration of the principle of linear momentum
2. Tank made of transparent material for observing the experiments
3. Nozzle for generating the water jet
4. Jet force can be adjusted via flow rate
5. Four different shaped deflectors: flat surface, oblique surface, semi-circular surface, conical surface
6. Measurement of the jet forces via the weight-loaded scale
7. Flow rate determined by HM 150 base module
8. Water supply using HM 150 base module or via laboratory supply

Technical data
- Tank
  - Ø inner: 200mm
  - Height: 340mm
- Nozzle
  - Ø 10mm
- Deflector
  - Flat surface: 90°
  - Oblique surface: 45°/135°
  - Semi-circular surface: 180°
  - Conical surface: 135°
- Weights
  - 4x 0.2N
  - 3x 0.3N
  - 2x 1N
  - 2x 2N
  - 2x 5N
- LxWxH: 400x400x880mm
- Weight: approx. 23kg

Required for operation
- HM 150 (closed water circuit) or water connection, drain

Scope of delivery
- 1 experimental unit
- 1 set of weights
- 4 deflectors
- 1 set of instructional material
**HM 150.21**

**Visualisation of streamlines in an open channel**

**Description**

- Flow around various drag bodies
- Incident flow of different weirs
- Ink as contrast medium for visualising the streamlines

HM 150.21 can be used to visualise flow around drag bodies and flow phenomena in open channels.

Either a drag body or weir is fixed in the experimental flume. The streamlines are made visible by injecting a contrast medium. The experimental flume is made of transparent material so that the streamlines and the formation of vortices can easily be observed. The water level in the experimental flume can be adjusted via a sluice gate at the inlet and via a weir at the outlet.

**Learning objectives/experiments**

- How differently shaped weirs affect the flow
- Visualisation of streamlines for flow incident to a weir
- Visualisation of streamlines when flowing around various drag bodies

There are two weirs and four different drag bodies available for the experiments. A stabiliser ensures an even and non-vortical flow of water. The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

**Specification**

1. Visualisation of streamlines during incident flow and flow around various weirs and drag bodies
2. Transparent experimental flume
3. Incident flow demonstrated on two weirs
4. Demonstration of flow around four different drag bodies
5. Contrast medium: ink
6. Distributor for contrast medium with seven nozzles
7. Water level in the experimental flume adjustable via sluice gate at the water inlet and weir at the water outlet
8. Flow straightener for even, non-vortical water inlet
9. Water supply using HM 150 base module or via laboratory supply

**Technical data**

**Experimental flume**

- LxWxH: 625x20x150mm
- Contrast medium: ink
- Injection of the contrast medium
  - 7 nozzles
- Tank for water: 12.5L
- Tank for ink: 200mL
- Drag bodies
  - Small cylinder: Ø 35mm
  - Large cylinder: Ø 60mm
  - Streamlined body
  - Guide vane profile
- Weirs
  - Broad-crested weir
  - Sharp-crested weir
- LxWxH: 895x640x890mm
- Weight: approx. 24kg

**Required for operation**

- HM 150 (closed water circuit) or water connection, drain

**Scope of delivery**

- 1 experimental flume
- 1 set of drag bodies and weirs
- 1 ink (1L)
- 1 set of tools
- 1 set of instructional material
**HM 150.10**  
Visualisation of streamlines

**Description**
- visualisation of streamlines  
- ink as a contrast medium  
- various models included: drag bodies and changes in cross-section  
- sources and sinks, individually or in combination

The laminar, two-dimensional flow in HM 150.10 is a good approximation of the flow of ideal fluids: the potential flow.

HM 150.10 can be used to visualise streamline fields for flows around drag bodies and flow through changes in cross-section. The streamlines are displayed in colour by injecting a contrast medium (ink). Sources and sinks are generated via four water connections in the bottom plate. The streamlines can be clearly observed through the glass plate during flow around and flow through.

The water flow rate and the quantity of contrast medium injected can be adjusted by valves. The water connections are also activated by valves and can be combined as required. Individual models can be cut out of a rubber plate that is included.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

**Learning objectives/experiments**
- visualisation of streamlines in flow around drag bodies  
- flow through changes in cross-section  
- influence of sources and sinks

**HM 150.10**  
Visualisation of streamlines

**Specification**
1. visualisation of streamlines  
2. water as flowing medium and ink as contrast medium  
3. upper glass plate, hinged for interchanging models  
4. bottom plate with water connections for generating sources/sinks  
5. sources/sinks can be combined as required  
6. different drag bodies and changes in cross-section included  
7. rubber plate for creating your own models included  
8. flow velocity, water supply and water drain in sources/sinks as well as dosage of the contrast medium can be adjusted by using valves  
9. water supply using HM 150 base module or via laboratory supply

**Technical data**

- Flow chamber contains two plates  
- distance between the plates: 2mm  
- upper plate made of glass  
- bottom glass plate with four water connections for sources/sinks  
- size experiment area: LxW: 400x280mm  
- 10 drag bodies and changes in cross-section  
- Rubber plate for your own models  
- LxH: 300x400mm  
- thickness: 2mm  
- Injection of the contrast medium (ink)  
- 15 holes  
- Tank for contrast medium: 500mL  
- LxWxH: 640x520x520mm  
- Weight: approx. 24kg

**Required for operation**
HM 150 (closed water circuit) or water connection, drain

**Scope of delivery**
1. experimental unit  
2. set of models  
3. rubber plate  
4. ink (2x 30mL)  
5. set of hoses  
6. set of instructional material
**Description**

- visualisation of the trajectory of the outlet jet
- study of openings with different diameters and contours
- determination of the contraction coefficient

Hydrodynamics considers the relationship between the trajectory, the outlet contour and the outlet velocity during flow from tanks. These considerations have practical applications in hydraulic engineering or in the design of bottom outlets in dams, for example.

HM 150.09 allows a user to study and visualise the profile of a water jet. Additionally, the contraction coefficient can be determined as a characteristic for different contours.

The experimental unit includes a transparent tank, a point gauge and a panel for visualising the jet paths. An interchangeable insert is installed in the tank’s water outlet to facilitate the investigation of various openings. Four inserts with different diameters and contours are provided along with the unit.

To visualise the trajectory, the issued water jet is measured via a point gauge that consists of movable rods. The rods are positioned depending on the profile of the water jet. This results in a trajectory that is transferred to the panel. The tank contains an adjustable overflow and a scale. In this way, a precise adjustment and accurate reading of the fill level are possible. The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

**Learning objectives/experiments**

- recording the trajectory of the water jet at different outlet velocities
- study of how the level in the tank affects the outlet velocity
- determination of the contraction coefficient for different contours and diameters
- comparison of the actual and theoretical outlet velocity

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**Specification**

1. study of horizontal flows from tanks
2. determining the contraction coefficient for different outlet contours and diameters
3. tank with adjustable overflow and scale
4. four interchangeable inserts with different diameters and contours
5. point gauge with eight movable rods for visualisation of the jet path
6. white panel for recording the trajectory
7. flow rate determined by HM 150 base module
8. water supply using HM 150 base module or via laboratory supply

**Technical data**

**Tank**
- height: 510mm
- Ø 190mm
- contents: approx. 13.5L

**Inserts with rounded contour**
- 1x Ø 4mm
- 1x Ø 8mm

**Inserts with square contour**
- 1x Ø 4mm
- 1x Ø 8mm

**Point gauge, 8 movable rods**
- length: 350mm

**HM 150 (closed water circuit) or water connection, drain**

**Scope of delivery**
- 1 experimental unit
- 4 inserts
- 1 set of instructional material
**HM 150.12**

**Vertical flow from a tank**

**Description**

- determination of the diameter and velocity of the outlet jet
- study of openings with different inlet and outlet contours
- determining the contraction coefficient

Pressure losses in the flow from tanks are essentially the result of two processes: the jet deflection upon entry into the opening and the wall friction in the opening. As a result of the pressure losses the real discharge is smaller than the theoretical flow rate.

HM 150.12 determines these losses at different flow rates. Different diameters as well as inlet and outlet contours of the openings can be studied. Additionally, the contraction coefficient can be determined as a characteristic for different contours.

The experimental unit includes a transparent tank, a measuring device as well as a Pitot tube and twin tube manometers. An interchangeable insert is installed in the tank’s water outlet to facilitate the investigation of various openings. Five inserts with different diameters, inlet contours and outlet contours are provided along with the unit.

The issued water jet is measured using a measuring device. A Pitot tube detects the total pressure of the flow. The pressure difference (read on the manometer) is used to determine the velocity.

The tank is fitted with an adjustable overflow and a measuring point for static pressure. In this way, the level can be precisely adjusted and read on the manometer. The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

**Learning objectives/experiments**

- study of the outlet jet (diameter, velocity)
- determination of pressure losses and contraction coefficient for different outlet contours
- determination of flow rate at different discharge heads

**Specification**

(1) study of pressure losses in vertical flows from tanks
(2) determining the contraction coefficient for different contours and diameters
(3) tank with adjustable overflow
(4) 5 interchangeable inserts with different contours
(5) measuring device for determining the jet diameter
(6) Pitot tube for determining the total pressure
(7) pressure display on twin tube manometers
(8) flow rate determined by HM 150 base module
(9) water supply using HM 150 base module or via laboratory supply

**Technical data**

**Tank**

- capacity: approx. 13L
- overflow height: max. 400mm
- max. flow rate: 14L/min

**Inserts**

- Inner diameters: \(d_1=\) inlet, \(d_2=\) outlet
  - 1x cylindrical hole, \(d=12\)mm
  - 1x outlet from the insert: cone \(d_1=24\)mm, \(d_2=12\)mm
  - 1x inlet to the insert: orifice plate \(d_1=24\)mm, \(d_2=12\)mm
  - 1x inlet to the insert: cone \(d_1=30\)mm, \(d_2=12\)mm
  - 1x inlet to the insert: rounded, \(d=12\)mm

**Measuring ranges**

- pressure: 500mmWC
- jet radius: 0…10mm

**LxWxH**: 400x400x830mm

**Weight**: approx. 18kg

**Required for operation**

HM 150 (closed water circuit) or water connection, drain

**Scope of delivery**

- 1 experimental unit
- 5 inserts
- 1 set of hoses
- 1 set of instructional material
Steady flow of incompressible fluids

Fluid mechanics is concerned with the study of forces and movements of liquids and gases. Both substances are continua whose elements can easily move against each other. They are grouped together under the term 'fluid'.

Liquids are incompressible. In technical fields of application of fluid mechanics, incompressibility is also assumed for gases as long as the flow velocity remains below Mach 0.3. Based on air at 20°C this limiting value corresponds to a velocity of approximately 100 m/s and the change in density is roughly 4%. It is therefore broadly possible to treat liquid and gas flows with common fundamental principles in fluid mechanics.

Incompressible flow

Steady flow: the velocity of a fluid particle changes with the position: \( \mathbf{v} = \mathbf{f}(s) \).

Transient flow: the velocity of a fluid particle changes with the time and the position: \( \mathbf{v} = \mathbf{f}(s, t) \).

Transient flows occur during discharge processes, during startup and shutdown processes of turbomachines or in the case of fluid oscillations and water hammer processes.

Steady and transient flow

Learning objectives

Flow in pipe systems

Velocity profile in fully developed flow
- laminar (left)
- turbulent (right)

Pressure losses in straight pipes

Pressure losses in pipe fittings
- enlargement/constriction/change of direction
- pipe bends
- segment bends / pipe angles

Losses in single-strand and multi-strand pipe systems

Flow rate metrology: representation of the common industry measuring methods

Cavitation

1. formation of the vapour bubble,
2. collapse of the vapour bubble,
3. jet of water hits the surface and leads to material destruction

Discharge processes

- Flows from tanks
  - how the discharge cross-section and the shape affect the jet cross-section
  - vertical discharge / horizontal discharge

Flow in valves

Special emphasis on technical issues
- constructions
- valve characteristics
- \( K_\text{vs} \) values

Open-channel flow

- subcritical and supercritical flow
- control structures
- discharge measurement

For the field of steady flow of incompressible fluids we have tried to capture the many learning objectives found in the literature around the world within the list of learning objectives defined above. Of course, variations in some sub-fields are possible. For example, we could argue whether or not industrial flow rate metrology should be covered here.

GUNT provides a programme that allows to work through all of the items listed in the learning objectives in educational laboratory experiments.
HM 150.01
Pipe friction for laminar / turbulent flow

Description
- pipe friction losses in laminar and turbulent flow
- determining the critical Reynolds number

During flow through pipes, pressure losses occur due to internal friction and friction between the fluid and the wall. When calculating pressure losses, we need to know the friction factor, a dimensionless number. The friction factor is determined with the aid of the Reynolds number, which describes the ratio of inertia forces to friction forces.

HM 150.01 enables the study of the relationship between pressure loss due to fluid friction and velocity in the pipe flow. Additionally, the pipe friction factor is determined.

The experimental unit includes a small diameter pipe section in which the laminar and turbulent flow is generated. The Reynolds number and the pipe friction factor are determined from the flow rate and pressure loss. In turbulent flow, the pipe is supplied directly from the water supply. The constant pressure at the water supply required for laminar flow is provided by a standpipe on the overflow. Valves can be used to adjust the flow rate.

The pressures in laminar flow are measured with twin tube manometers. In turbulent flow, the pressure is read on a dial-gauge manometer.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

Learning objectives/experiments
- measurements of the pressure loss in laminar flow
- measurements of the pressure loss in turbulent flow
- determining the critical Reynolds number
- determining the pipe friction factor
- comparing the actual pipe friction factor with the theoretical friction factor

HM 150.01
Pipe friction for laminar / turbulent flow

Specification
1) investigation of the pipe friction in laminar or turbulent flow
2) transparent tank with overflow ensures constant water inlet pressure in the pipe section for experiments with laminar flow
3) flow rate adjustment via valves
4) twin tube manometers for measurements in laminar flow
5) dial-gauge manometer for measurements in turbulent flow
6) flow rate determined by HM 150 base module or via laboratory supply

Technical data
Pipe section
- length: 400mm
- Ø, inner: 3mm

Tank: approx. 2L

Measuring ranges
- differential pressure:
  - 2x 370mmWC
  - 1x 0...0.4bar

LxWxH: 850x680x930mm
Weight: approx. 23kg

Required for operation
HM 150 (closed water circuit) or water connection, drain

Scope of delivery
1) experimental unit
2) set of accessories
3) set of instructional material
HM 150.11
Losses in a pipe system

Description

- Pressure losses in the piping system
- Pressure measurement without interaction via annular chambers
- Transparent measuring objects for determining flow rate

Pressure losses occur during the flow of real fluids due to friction and turbulence (vortices). Pressure losses in pipes, piping elements, fittings and measuring instruments [e.g. flow meter, velocity meter] cause pressure losses and must therefore be taken into account when designing piping systems.

HM 150.11 allows to study the pressure losses in pipes, piping elements and shut-off devices. In addition, the differential pressure method is presented for determining flow rate.

HM 150.11 allows to study the pressure losses in piping elements, shut-off devices and measuring objects for determining flow rate separately. The pressure losses can be transferred to a measurement object (i.e. annular chamber) and provide excellent insight into the inner structure. The pressure measuring points in the piping system are designed as annular chambers. This creates a largely interference-free pressure measurement.

The experimental unit contains six different pipe sections capable of being shut off individually. The pipe sections are equipped with piping elements such as bends, elbows and branches. In one pipe section, different shut-off devices and measuring objects are installed to determine the flow rate. The measuring objects are made of transparent material and provide excellent insight into the inner structure. The pressure measuring points in the pipe system are designed as annular chambers. This creates a largely interference-free pressure measurement.

The experiments measure the pressure losses in pipes, piping elements and fittings, such as branches and bends. The opening characteristic of the shut-off devices are also recorded. The pressures are measured with twin tube manometers.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

Learning objectives/experiments

- Pressure losses in pipes, piping elements and fittings
- How the flow velocity affects the pressure loss
- Determining resistance coefficients
- Open characteristics of angle seat valve and gate valve
- Familiarisation with various measuring objects for determining flow rate:
  - Venturi nozzle
  - Orifice plate flow meter and measuring nozzle

Specifications

- Measuring ranges:
  - Pressure: 0…0.1 bar
  - Pressure difference: 0…1000 mm WC
- Technical data:
  - Pipe sections
    - Inner diameter: d
    - Straight: d=20x1.5mm, length: 800 mm, PVC
    - Sudden contraction: d=32x1.8-20x1.5mm, PVC
    - Sudden enlargement: d=20x1.5-32x1.8mm, PVC
    - With 2x Y-piece 45° and 2x T-piece
    - With 2x 90° elbow/bend: d=20x1.5mm, PVC and 2x 45° elbow: d=20x1.5mm, PVC
    - 2x twin tube manometers: 0…1000mm WC
- Measuring range
  - Pressure: 0…0.1 bar
  - Pressure difference: 0…1000 mm WC
- Weight: approx. 58 kg

Scope of delivery

- 1 set of instructional material
- 1 set of tools
- 1 set of hoses
- 1 orifice plate flow meter or measuring nozzle
- 1 Venturi nozzle
- 1 experimental unit
- 2 shut-off devices (angle seat valve, gate valve)
- 2x twin tube manometers
- 2x 90° elbow/bend: d=20x1.5mm, PVC
- 2x 45° elbow: d=20x1.5mm, PVC
- 2x Y-piece 45° and 2x T-piece
- 2x 90° elbow/bend: d=20x1.5mm, PVC and 2x 45° elbow: d=20x1.5mm, PVC
- 2x twin tube manometers: 0…1000mm WC
HM 164
Open channel and closed channel flow

Description
- flow processes in the open channel: gate, sill and various weirs
- flow processes in the closed channel: pipe flow
- closed water circuit with tank and pump

HM 164 is used to demonstrate different flow processes at different control structures in the open channel. In the closed channel, pressure components in a pipe are determined.

The trainer includes a transparent experimental flume with upper limit, a height-adjustable sill and a closed water circuit. The water level in the experimental section is set with an adjustable plate weir at the water outlet. With a simple alteration, the experimental flume can be used as an open or closed channel.

The water level must be low when investigating the open-channel flow. To conduct the experiment, a weir is attached to the bottom of the channel or the height-adjustable sill is used. Furthermore, the discharge under a gate can also be demonstrated. Various weirs, which can be exchanged quickly and safely, are available as control structures.

When studying the closed channel, the water level needs to be high enough that the entire experimental section is flowed through. In this case the sill is used to change the cross-section flowed through.

The static pressures and the total pressure over the cross-section are detected by measuring tubes. The pressure difference is used to calculate the flow velocity.

Learning objectives/experiments
- open channel
  - flow over control structures: broad-crested weir, narrow-crested weir, ogee-crested weir, ski jump spillway, sill
  - discharge under a gate
  - hydraulic jump
- closed channel
  - pipe flow with constant and variable flow cross-section
  - measurement of static pressure and total pressure
  - calculation of the flow velocity

Technical data

Experimental section
- length: 1,1m
- cross-section WxH: 40x300mm

Supply tank: 70L

Pump
- power consumption: 250W
- max. flow rate: 150L/min
- max. head: 7,6m
230V, 50Hz, 1 phase
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 1900x800x1350mm
Empty weight: approx. 150kg

Scope of delivery
- 1 trainer
- 1 set of control structures
- 1 plate weir
- 1 set of tools
- 1 set of instructional material
HM 111
Pipe networks

Description

- structure of various pipe networks
- pressure losses at various piping elements and pipe networks
- closed water circuit with tank and pump

An important task in the construction of pipelines is to determine the pressure and flow rate in complex piping systems. In practice, the calculation of the total pressure losses serves as a foundation for the design of suitable drive units for heating and air conditioning systems, drinking water supply systems and parts of wastewater systems. Knowledge of pressure losses is also used to optimise operation.

HM 111 enables the construction and investigation of various pipe networks, such as parallel and series connections of pipes, their branching and merging, and the study of individual pipes. In analogy to Kirchhoff's laws of electricity, it is possible to conduct nodal analysis.

The five pre-installed pipe sections on the top of the trainer are connected to pipe networks using the piping elements. Tank, pipes, piping elements and valves and fittings are made entirely of plastic. The individual pipe sections are shut off by ball valves. During the experiments, the pressure losses in various pipes and piping elements are recorded and evaluated.

Two manometers for different measuring ranges are included to measure differential pressure. The flow rate is measured volumetrically.

The trainer has its own water supply. The closed water circuit includes a supply tank with submersible pump.

Learning objectives/experiments

- recording the calibration curve for pipe sections: pressure loss over flow rate
- pipe sections connected in parallel
- pipe sections connected in series
- combined series and parallel connection
- investigation of a closed circular pipeline
- differential pressure measurement
- pressure losses at various piping elements

Different pipe networks constructed from pipe sections: 1 calibration of pipe sections, 2 doubling, 3 series connection, 4 parallel and series connection, 5 closed circular pipeline, 6 parallel connection.

Specification

1. investigation of different pipe networks
2. five pre-installed pipe sections with different diameters
3. panel for piping elements
4. construction of pipe networks from pipe sections and various piping elements
5. calibration of pipe sections
6. parallel and series connection of pipe sections
7. construction of a closed circular pipeline
8. differential pressure measurement with twin tube manometers and differential pressure manometer
9. flow rate measurement with measuring tank (can be shut off), stopwatch and level indicator

Technical data

Pump
- power consumption: 250W
- max. flow rate: 9m³/h
- max. head: 7,6m

Pipe network, max. flow rate: 4,8m³/h
Pipe sections, length 700mm each
- 1 x Ø 25x1,9mm
- 2 x Ø 20x1,5mm
- 2 x Ø 16x1,2mm

Tank for water: 180L
Tank for flow rate measurement
- small measuring range: 10L
- large measuring range: 40L

Stopwatch: 1/100s

Measuring ranges
- differential pressure:
  - 1 x 0...1bar
  - 1 x 0...100mbar

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
UL/CJB optional
LxWxH: 1550x800x1600mm
Weight: approx. 117kg

Scope of delivery

1 trainer
1 stopwatch
1 set of instructional material
Experimental units from the field of turbomachinery

One important field of fluid mechanics concerns turbomachines, these are divided into driving machines and driven machines (power engines and machines). Turbines are driving machines, while pumps are classic driven machines.

The experimental units presented here are all powered by water. They serve as an introduction into the subject of turbomachinery.

**Driving machines**

- HM 150.19 Operating principle of a Pelton turbine
  - model of an impulse turbine
  - transparent front panel for observing the operating area
  - adjustable nozzle needle for setting different nozzle cross-sections

- HM 150.20 Operating principle of a Francis turbine
  - model of a reaction turbine
  - transparent front panel for observing the operating area
  - adjustable guide vanes for setting different angles of incidence

**Driven machines**

- HM 150.04 Centrifugal pump
  - studying a centrifugal pump and recording a typical pump characteristic curve
  - determining the pump efficiency
  - studying how speed affects flow rate and head

- HM 150.16 Series and parallel configuration of pumps
  - studying pumps individually, connected in series and in parallel
  - recording pump characteristic curves and determining the operating point
  - determining the hydraulic power of pumps
HM 150.19
Operating principle of a Pelton turbine

Description
- model of an impulse turbine
- transparent operating area
- adjustable nozzle cross-section
- loading by band brake

Water turbines are turbomachines utilising water power. The Pelton turbine is a type of impulse turbine; such turbines convert the pressure energy of water into kinetic energy entirely in the distributor. During the conversion, the water jet is accelerated in a nozzle and directed onto the blades of the Pelton wheel tangentially. The water jet is redirected by approximately 180° in the blades. The impulse of the water jet is transmitted to the Pelton wheel.

HM 150.19 is a model of a Pelton turbine demonstrating the function of an impulse turbine.

The experimental unit consists of the Pelton wheel, a needle nozzle used as distributor, a band brake for loading the turbine and a housing with a transparent front panel. The transparent cover enables to observe the water flow, the Pelton wheel and the nozzle during operation. The nozzle cross-section and thus the flow rate are modified by adjusting the nozzle needle.

The turbine torque is determined by force measurement on a band brake and is read on spring balances. For measuring the rotational speed, a non-contact speed sensor, e.g. HM 082, is required. A manometer shows the water pressure at the turbine inlet.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

Learning objectives/experiments
- design and function of a Pelton turbine
- determination of torque, power and efficiency
- graphical representation of characteristic curves for torque, power and efficiency

HM 150.19
Operating principle of a Pelton turbine

Specification
(1) function of a Pelton turbine
(2) transparent front panel for observing the operating area
(3) loading the turbine by use of the band brake
(4) adjustable nozzle needle for setting different nozzle cross-sections
(5) marking on brake drum for non-contact speed measurement
(6) instruments: spring balances for determining the torque, manometer shows pressure at turbine inlet
(7) flow rate: determination by base module HM 150
(8) water supply using base module HM 150 or via laboratory supply

Technical data
Pelton turbine
- output: 5W at 500min⁻¹, approx. 30L/min, H=2m
- Pelton wheel
  - 14 blades
  - blade width: 33,5mm
  - external Ø: 132mm
Needle nozzle
- jet diameter: 10mm
Measuring ranges
- force: 2x 0...10N
- pressure: 0...1bar

LwWW: 400x400x620mm
Weight: approx. 15kg

Required for operation
HM 150 (closed water circuit) or water connection, drain

Scope of delivery
1 experimental unit
1 set of instructional material

Learning objectives/experiments
- design and function of a Pelton turbine
- determination of torque, power and efficiency
- graphical representation of characteristic curves for torque, power and efficiency

HM 150.19
Operating principle of a Pelton turbine

Turbine output curves at different positions of the nozzle needle:
1: Q=31,6L/min, 2: Q=18,8L/min, 3: Q=11,5L/min; n speed, P turbine output

1 spring balance, 2 manometer, 3 adjustment of the nozzle cross-section, 4 needle nozzle, 5 Pelton wheel, 6 adjustment of the band brake
Operating principle of a Francis turbine

**HM 150.20**

**Description**
- model of a reaction turbine
- transparent operating area
- turbine with adjustable guide vanes
- loading by band brake

Water turbines are turbomachines utilising water power. The Francis turbine is a type of reaction turbine which converts the pressure energy of the water into kinetic energy in the distributor and in the rotor. The water is fed into the distributor by means of a spiral housing. The flowing water is accelerated in the distributor by the adjustable guide vanes and directed onto the blades. The redirection and further acceleration of the water in the rotor generates an impulse which is transmitted to the rotor.

HM 150.20 is the model of a Francis turbine demonstrating the function of a reaction turbine. The experimental unit consists of the rotor, the distributor with adjustable guide vanes, a band brake for loading the turbine and a housing with a transparent cover allowing the water flow, the rotor and the guide vanes during operation. The angle of attack and thus the power of the rotor are modified by adjusting the guide vanes.

The turbine torque is determined by force measurement on a band brake and is read on spring balances. For measuring the rotational speed, a non-contact speed sensor, e.g. HM 082, is required. A manometer shows the water pressure at the turbine inlet.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

**Learning objectives/experiments**
- design and function of a Francis turbine
- determination of torque, power and efficiency
- graphical representation of characteristic curves for torque, power and efficiency

**Specification**
- function of a Francis turbine
- transparent front panel for observing the operating area
- loading the turbine by use of the band brake
- adjustable guide vanes for setting different angles of attack
- marking on brake drum for non-contact speed measurement
- instruments: spring balances for determining the torque, manometer shows pressure at turbine inlet
- flow determination by base module HM 150
- water supply using the base module HM 150 or via lab supply

**Technical data**
- Turbine:
  - output: 12W at n=1100min⁻¹, approx. 40L/min, H=8m
- rotor:
  - 7 blades
  - blade width: 5mm
  - external Ø: 50mm
- guide vanes:
  - 6 vanes, adjustable (20 stages)

Measuring ranges:
- force: 2x 0…10N
- pressure: 0…1,0bar

LxWxH: 400x400x630mm
Weight: approx. 17kg

**Required for operation**
- HM 150 (closed water circuit) or water connection, drain

**Scope of delivery**
- 1 experimental unit
- 1 set of instructional material
HM 150.04 Centrifugal pump

The illustration shows HM 150.04 together with HM 150.

**Description**

- characteristic curve of a centrifugal pump
- variable speed via frequency converter

Centrifugal pumps are turbomachines that are used for conveying fluids. The HM 150.04 unit can be used to study a centrifugal pump and to record a typical pump characteristic curve.

The experimental unit includes a self-priming centrifugal pump, a ball valve on the outlet side and manometers on the inlet and outlet side. It is driven by an asynchronous motor. The speed is infinitely adjustable by using a frequency converter. A ball valve is used to adjust the head.

In experiments, the operating behaviour of the pump as a function of the flow rate is studied and displayed in characteristic curves. The motor’s speed and electrical power are displayed digitally. Pressures on the inlet and outlet side are displayed on two manometers.

**Learning objectives/experiments**

- familiarisation with operating behaviour and characteristics of a centrifugal pump through experiments
- recording the pump characteristic curve at a constant pump speed
  - measuring the inlet and outlet pressure
  - determining the flow rate
- recording the pump characteristics for different speeds
- power and efficiency curves
  - measuring the electrical drive power
  - determining the hydraulic power
  - calculating the efficiency

**Specification**

| [1] investigation of a centrifugal pump |
| [2] drive with variable speed via frequency converter |
| [3] ball valve to adjust the head |
| [4] manometers on the inlet and outlet side of the pump |
| [5] digital display of speed and power |
| [6] flow rate determined by base module HM 150 |
| [7] water supply using base module HM 150 |

**Technical data**

Centrifugal pump, self-priming
- max. flow rate: 3000L/h
- max. head: 36,9m

Asynchronous motor
- nominal power: 370W

Measuring ranges
- pressure (outlet side): -1…5bar
- pressure (inlet side): -1…1.5bar
- speed: 0…3000min⁻¹
- power: 0…1000W

**Required for operation**

HM 150 (closed water circuit)

**Scope of delivery**

1 experimental unit
1 set of instructional material
HM 150.16
Series and parallel configuration of pumps

Description
- series and parallel configuration of pumps
- determining pump characteristic curves

In complex systems, pumps can be connected in series or in parallel. In series operation the heads are added together and in parallel operation, the flow rates of the pumps are added. Series and parallel configuration of pumps behave similar to series and parallel configuration of electric resistances in electric circuits. The pump correlates with the electric resistance, the flow correlates with the electric current and the head with the voltage.

With HM 150.16 pumps are studied individually, in series and in parallel configuration.

The experimental unit contains two identical centrifugal pumps and an intake tank with overflow. The overflow ensures a constant suction head in the tank, regardless of the water supply. Ball valves in the pipes allow easy switching between series and parallel operation.

Pressures at inlet and outlet of the two pumps are displayed on manometers.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

Learning objectives/experiments
- investigation of pumps in series and parallel configuration
- determining the head
- recording the pump characteristics
- determining the hydraulic power
- determining the operating point

HM 150.16
Series and parallel configuration of pumps

Specification
- investigation of series and parallel configuration of pumps
- two identical centrifugal pumps
- transparent tank as intake tank
- overflow in the tank ensures constant suction head
- ball valves used to switch between series and parallel operation
- manometers at inlet and outlet of each pump
- flow rate determined by base module HM 150
- water supply via HM 150 or via laboratory supply

Technical data
- 2x centrifugal pump
  - power consumption: 370W
  - max. flow rate: 21L/min
  - max. head: 12m
- Tank: 13L
- Pipes and pipe connections: PVC
- Measuring ranges
  - pressure (inlet): 2x -1…1,5bar
  - pressure (outlet): 3x 0…2,5bar
  - 230V, 50Hz, 1 phase
  - 230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
  - UL/CSA optional
  - LxWxH: 1110x650x500mm
  - Weight: approx. 62kg

Required for operation
- HM 150 (closed water circuit) or water connection, drain

Scope of delivery
- 1 experimental unit
- 1 set of instructional material
Introduction into the fundamentals of fluid mechanics

### Steady flow in pipes
- **HM 150.11** Losses in a pipe system
- **HM 150.01** Pipe friction for laminar / turbulent flow
- **HM 150.29** Energy losses in piping elements

### Laminar / turbulent flow, Reynolds number
- **HM 150.18** Osborne Reynolds experiment
- **HM 150.01** Pipe friction for laminar / turbulent flow

### Determining the metacentre
- **HM 150.06** Stability of floating bodies

### Steady open-channel flow
- **HM 150.21** Visualisation of streamlines in an open channel
- **HM 150.03** Plate weirs for HM 150

### Bernoulli’s principle / flow rate measurement
- **HM 150.13** Methods of flow measurement
- **HM 150.11** Losses in a pipe system
- **HM 150.07** Bernoulli’s principle

### Transient flow
- **HM 150.15** Hydraulic ram – pumping using water hammer

### Flow around bodies
- **HM 150.10** Visualisation of streamlines
- **HM 150.21** Visualisation of streamlines in an open channel

### Free/forced vortex formation
- **HM 150.14** Vortex formation

### Steady open-channel flow
- **HM 150.21** Visualisation of streamlines in an open channel

### Flow from tanks
- **HM 150.09** Horizontal flow from a tank
- **HM 150.12** Vertical flow from a tank

### Turbomachines
- **HM 150.04** Centrifugal pump
- **HM 150.08** Measurement of jet forces

### Jet forces
- **HM 150.04** Centrifugal pump
- **HM 150.16** Series and parallel connected pumps
- **HM 150.19** Operating principle of a Pelton turbine
- **HM 150.20** Operating principle of a Francis turbine

### Flow from tanks
- **HM 150.09** Horizontal flow from a tank
- **HM 150.12** Vertical flow from a tank

### Free/forced vortex formation
- **HM 150.14** Vortex formation

GUNT devices from the HM 150 series demonstrate phenomena and facilitate simple experiments on the following topics of fluid mechanics:
- steady flow in pipes
- laminar/turbulent flow, Reynolds number
- continuity equation, Bernoulli’s principle
- steady flow in pipes
- laminar/turbulent flow, Reynolds number
- flow from tanks
- free/forced vortex formation
- open-channel flow
- flow around bodies
- transient flow at a hydraulic ram
- turbomachines
- jet forces

The HM 150 base module provides a closed water circuit to supply the separate experimental units. The experimental unit is connected to the base module for the water supply via a hose. The flow rate is measured volumetrically. All devices are designed so that they can be placed securely and stably on the base module.
**HM 150**

**Base module for experiments in fluid mechanics**

**Description**

- Water supply for experimental units for fluid mechanics
- Volumetric flow rate measurement for large and small flow rates
- Comprehensive range of accessories allows a complete course in the fundamentals of fluid mechanics

The HM 150 series of devices permits a varied experimental cross-section in the fundamentals of fluid mechanics. The base module HM 150 provides the basic equipment for individual experiments: the supply of water in the closed circuit; the determination of volumetric flow rate and the positioning of the experimental unit on the working surface of the base module and the collection of dripping water.

The closed water circuit consists of the underlying storage tank with a powerful submersible pump and the measuring tank arranged above, in which the returning water is collected.

The measuring tank is stepped, for larger and smaller volumetric flow rates. A measuring beaker is used for very small volumetric flow rates. The volumetric flow rates are measured using a stopwatch.

The top work surface enables the various experimental units to be easily and safely positioned. A small flume is integrated in the work surface, in which experiments with weirs (HM 150.03) are conducted.

**Technical data**

- **Pump**
  - Power consumption: 250W
  - Max. flow rate: 150L/min
  - Max. head: 7.6m

- **Storage tank, capacity:** 180L

- **Measuring tank**
  - At large volumetric flow rates: 40L
  - At small volumetric flow rates: 10L

- **Flume**
  - LxWxH: 530x150x180mm

- **Measuring beaker with scale for very small volumetric flow rates**
  - Capacity: 2L

- **Stopwatch**
  - Measuring range: 0...9h 59min 59sec
  - 230V, 50Hz, 1 phase
  - 230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
  - UL/CSA optional
  - LxWxH: 1230x770x1070mm
  - Weight: approx. 85kg

**Specification**

1. Base module for supplying experimental units in fluid mechanics
2. Closed water circuit with storage tank, submersible pump and measuring tank
3. Measuring tank divided in two for volumetric flow rate measurements
4. Measuring beaker with scale for very small volumetric flow rates
5. Measurement of volumetric flow rates by using a stopwatch
6. Work surface with integrated flume for experiments with weirs
7. Work surface with inside edge for safe placement of the accessory and for collecting the dripping water
8. Storage tank, measuring tank and work surface made of GRP

**Scope of delivery**

1. Base module
2. Stopwatch
3. Measuring cup
4. Set of accessories
5. Manual
Transient flow in pipes and surge chambers

**Transient flow**
Flows in which flow conditions vary over time at an observation point are known as transient. An exception is changes caused by turbulence. For flows with a free surface a transient flow can be recognised by the variation in the water level over time.

Transient flows occur during all startup and shutdown processes of turbomachines, in equipment and pipelines as well as during discharge processes from containers with variable liquid level; similarly in fluid vibrations (surge chambers), with water hammer processes in pipes and in open channels (positive and negative surges/hydropeaking).

In practice, the understanding of transient flow conditions is useful for commercial designs of pipelines (reserve in water hammer) in water distribution systems, process plants and hydroelectric power stations.

GUNT provides you with illustrative experimental units for studying transient flows in pipelines, representing water hammer, and showing how surge chambers work as safety elements in hydroelectric power stations.

We demonstrate the useful effect of water hammer for pumping water by the operating principle of a hydraulic ram.

**Water hammer in pipes**
A common phenomenon of transient flow is the occurrence of water hammer in pipes. Fluctuations of pressure and flow rate can significantly exceed or fall below the designed pressure for a pipeline.

Water hammer is caused by:
- closing or opening shut-off elements in the pipeline
- startup and shutdown pumps and turbines
- re-commissioning systems
- change in the feed water level

**Effects of water hammer**
Water hammer causes damage to the affected system. Pipes can burst, pipe brackets may be damaged. Additionally, valves, pumps, mountings and other components of the pipe system (e.g. heat exchangers) are at risk. In drinking water pipelines a water hammer can lead to dirty water being drawn in from outside. Since damage to pipelines is not necessarily immediately visible (e.g. a damaged flange), it is necessary to deal with the potential occurrence of water hammer when planning a pipeline.

**Reducing water hammer**
At smaller nominal diameters, installing an expansion tank or the choice of valves affects the emergence of water hammer. Valves and gate valves are less affected than shut-off valves and butterfly valves due to longer closing times. Safety valves can protect pipelines from damage caused by water hammer.

Water hammer in pipes with large nominal diameters and large head are mitigated or avoided by slowly operating the slide gate and using surge chambers at the entrance of the pressure pipes (similar to equalisation basins).

**Principle of a surge chamber**
Hydroelectric power stations use surge chambers to reduce pressure fluctuations. The water moving through the pressure pipe is deflected when valves in the surge chamber are closed. The water level can then oscillate up and down until it returns to rest. The kinetic energy of the flowing water in the pressure tube is therefore converted into potential energy of the increased water level in the surge chamber and not into destructive pressure energy.

The table shows an abstract from a common university curriculum. GUNT devices cover this content to the greatest extent.

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<th>Curriculum for the field of transient flow</th>
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<td>Water hammer: investigation of water hammer and pressure waves in pipes, displaying vibrations in the water hammer, determining the speed of sound in water, determining reflection time, measuring water hammer (Joukowsky shock), how flow rate/closing velocity of valves affect water hammer</td>
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</table>
In structures such as hydropower plants, or in systems for supplying water, changes in flow rate result in pressure fluctuations. For example during startup and shutdown of hydraulic machines or by opening and closing shut-off elements. There is a distinction to be made between rapid pressure changes that propagate with the sound velocity (water hammer) and slow pressure changes caused by mass oscillations.

Pipeline systems use air vessels or surge chambers to dampen water hammer and mass oscillations.

HM 156 is used to generate and visualise water hammer in pipes and to demonstrate how a surge chamber works. The trainer contains a pipe section with a ball valve and a surge chamber and a second pipe section with a solenoid valve.

In the first experiment a water hammer is produced by rapidly closing the ball valve. The sudden deceleration of the water mass releases kinetic energy, which is converted into potential energy in the surge chamber. The resulting pressure oscillations are measured by a pressure sensor behind the surge chamber and displayed in the software as a pressure curve. The oscillation can also be seen as pendulum movement of the water level in the surge chamber.

In the second experiment a rapid closing of the solenoid valve in the second pipe section produces a strong water hammer. The water's kinetic energy is converted into pressure energy. The water hammer and the subsequent oscillations are detected by two pressure sensors in the pipe section and displayed in the software as a pressure curve.

The water is supplied and the flow rate measured by the supply unit.
HM 143

Transient drainage processes in storage reservoirs

Learning objectives/experiments
- demonstrating transient drainage processes in two rainwater retention basins located one behind the other
- demonstrating transient drainage processes in two storage lakes located one behind the other
- recording oscillations of the water level in a surge chamber after water hammer
- recording and displaying water level fluctuations

Description
- investigation of transient drainage processes in storage reservoirs
- simulation of rainwater retention basin and storage lakes
- transparent surge chamber for observing oscillations after a water hammer
- GUNT software for displaying the water levels

The drainage processes from reservoirs are realised by pipelines, tunnels or other means. A surge chamber prevents water hammer in pipes and fittings in the event of rapid changes in flow rate.

HM 143 is used to demonstrate transient drainage processes from storage reservoirs and how a surge chamber works. The trainer includes a basin with adjustable weir and a second, depth-adjustable weir, connected with overflow and drainage line. A surge chamber is installed in the drainage line.

The main purpose of the rainwater retention basin is to delay the drainage process by temporary intermediate storage. Storage lakes are used in applications such as water supply, energy conversion, or in flood protection. The water rises before it is fed over an overflow.

In the experiment "storage lakes", the transient drainage processes are shown in two long-term storage reservoirs. In this experiment the weir is used as a free overfall weir.

In the "surge chamber" experiment a water hammer is produced by rapidly closing a gate in the drainage line. The oscillation can be seen as pendulum movement of the water level in the surge chamber.

The water levels in the basins and at the surge chamber are detected by pressure sensors and displayed using the GUNT software.

HM 143

Transient drainage processes in storage reservoirs

Specification
(1) transient drainage processes in storage reservoirs
(2) functioning of a surge chamber
(3) "rainwater retention basin" experiment: basin A and basin B as short-term storage reservoirs, rectangular weir as gate
(4) "storage lakes" experiment: basin A and basin B are used as long-term storage reservoirs, rectangular weir as overflow weir
(5) "surge chamber" experiment: transparent pipe as surge chamber in drainage line of basin B
(6) gate in the drainage line for generating water hammer
(7) pressure sensors at both basins and the surge chamber capture the water level fluctuations
(8) representation of the variation in the water levels with GUNT software
(9) GUNT software for data acquisition via USB under Windows 7, 8, 10

Technical data
Basin A: LxWxH: 900x900x300mm
- material: stainless steel
- rectangular weir according to Rehbock, adjustable
  - as gate, opening: 0...200mm
  - as weir, weir height: 0...200mm
- overflowed width: 50mm
Basin B: LxWxH: 900x900x300mm
- material: stainless steel
- overflow: 200mm
Surge chamber
- material: PMMA
- Ø inner: 60mm
- height: 1900mm

Measuring ranges
- pressure: 2x 0...100mbar, 1x 0...200mbar
- flow rate: 300...1300L/h

Required for operation
- water connection: 3000L/h
- PC with Windows

Scope of delivery
1 trainer
1 GUNT software CD + USB cable
1 set of instructional material
## Introduction

**Overview**

Hydraulic engineering

## Open-channel flow

### Basic knowledge

- **Overview**
  - An overview of GUNT experimental flumes
  - Technical details for GUNT experimental flumes
  - Structural features
  - GUNT experimental flumes Laboratory design
  - Setup of GUNT experimental flumes using the example of HM 162
- **Overview**
  - GUNT experimental flumes are being used all around the world
  - HM 160 Experimental flume 86 x 300 mm
  - Experimental flume 86 x 300 mm
  - HM 162 Experimental flume 309 x 450 mm
  - HM 163 Experimental flume 409 x 500 mm
  - HM 162 / HM 163 Experimental flume A few impressions
  - HM 161 Experimental flume 600 x 800 mm
  - HM 161 Experimental flume A few impressions
  - HM 161 Experimental flume 600 x 800 mm
  - Open-channel flow in the lab
  - GUNT experimental flumes Instrumentation
  - GUNT experimental flumes Wave generator
  - GUNT experimental flumes Sediment transport
  - Accessories for experimental flumes HM 160, HM 161, HM 162 and HM 163

## Sediment transport

### Basic knowledge

- **Overview**
  - Fundamentals of sediment transport
  - Sediment transport in running waters
  - Open-channel sediment transport
  - Sediment transport in river courses
  - Separation in sedimentation tanks

## Seepage flow

### Basic knowledge

- **Overview**
  - Experimental units
  - Seepage flow, groundwater flow and filtration
  - Potential flow
  - Studies in hydrology
  - Groundwater flow
  - Visualisation of seepage flows
  - Advanced hydrological investigations
  - Hydrographs after precipitation
  - Cake and depth filtration
Hydraulic engineering

Structural measures, technical interventions and construction in the area of groundwater, surface water and the coast are all referred to as hydraulic engineering. The basic principles of hydraulic engineering are taught in hydromechanics and hydrology.

Hydromechanics is divided into hydrostatics, flow in pipes, flow in open channels and flow in groundwater. This catalogue covers hydrostatics and pipe flow in the section on the fundamentals of fluid mechanics.

Hydrology is concerned with the natural distribution of water over and under the ground. Some processes from hydrology are demonstrated in the subsections of sediment transport and seepage flow.

**Open-channel flow**

The forces and phenomena in running waters are covered in the open-channel flow subsection. What happens if – in addition to water – sediment and/or solids are also transported in the running water, as is usually the case in nature? Questions on this topic are tackled in the subsection on sediment transport. The seepage flow subsection deals with issues of how water is transported in soil.

**Sediment transport**

This subsection investigates the transport of sediments in flowing watercourses. When talking about sediment transport, we distinguish between suspended matter and bed-load transport.

Rivers primarily involve bed-load transport. When sediment is removed, this is called erosion or scouring. Siltation occurs when sediment is deposited. Sediment transport can be influenced by hydraulic engineering measures.

Suspended load transport is a topic in the field of wastewater treatment plants and upstream of barrages and dams. In wastewater treatment plants, the sedimentation of suspended matter is desired, whereas in the case of dams it causes problems.

The GUNT units for bed-load transport study, for example, changes in the bed surface of a river and the formation of bed forms. It is possible to observe the formation and migration of dunes. Furthermore, erosion and siltation at bridge piers are also considered.

**Seepage flow**

Seepage flows and groundwater flows are water movements in a permeable subsoil (sand, gravel, etc.). In hydraulic engineering it is the seepage through earth dams or the seepage under barrages in particular that are of importance.

The GUNT units demonstrate and study the relationship between precipitation, seepage and groundwater flow. The influence of wells on the groundwater level and the storage capacity of soils during these processes is considered.
In nature, watercourses represent “open-channel flow”. For centuries, humans have been making structural interventions to watercourses: irrigation systems, flood protection and utilisation of rivers for navigation and power generation.

Famous examples are ancient water systems (aqueducts) or agricultural irrigation channels extending over very large distances: the “Levada” in Portugal (below).
Open-channel flow are widely spread. Typical examples include rivers and canals, drainage channels, gutters, water rides at amusement parks or sewerage. The driving force of this normally turbulent flow is gravity. Open-channel flows are characterised by their free surface. Compared to pipe flows, open-channel flows have one more degree of freedom as a result of the free surface.

There are essentially two types of open-channel flow:
- **uniform flow** (the discharge depth (water depth) remains equal; acceleration = deceleration)
- **non-uniform flow** (the discharge depth is changed by acceleration or deceleration)

The discharge can be either **subcritical**, **critical** or **supercritical**.

**Typical flume profiles**

In most cases an approximation of the respective cross-section of an open-channel flow can be illustrated with only a few geometric profiles. Circular, semi-circular, square, trapezoidal and combinations of these profiles are perfectly suited to making the flume easier to model and calculate mathematically. It is often important to determine the discharge $Q$ and the discharge depth $h$ at defined locations. Typical variables for calculations are the flow area $A$ (or the area of flow), the wetted perimeter $P$ and the hydraulic radius $R$.

In the case of a **rectangular cross-section**, these variables are defined as follows:
- flow area $A = bh$
- wetted perimeter $P = b + 2h$
- hydraulic radius $R = A/P = bh/(b+2h)$

In wide, shallow flumes the hydraulic radius $R$ therefore corresponds to the discharge depth $h$.

In the case of artificial flumes, such as ducts, the hydraulically efficient profile is an important variable – an optimum profile design saves materials and costs:
- given discharge $Q$ + energy grade line $J$: determine minimum flow area $A$
- given discharge $Q$ + flow area $A$: determine minimum energy grade line $J$.

**Optimal hydraulic flume cross-section**

In the case of the smallest wetted perimeter, based on the given area, we refer to the optimal hydraulic cross-section.

In addition to being able to install different models, they also allow the user to change the slope and the flume bottom, affecting the surface and roughness. A large number of experiments on uniform and non-uniform open-channel flow, including measurement of flow velocity $v$ and discharge depth $h$, is possible.
Basic knowledge
Open-channel flow

Uniform discharge in a rectangular flume

In uniform open-channel flow the discharge depth $h$ remains equal, i.e. parallel to the bottom. This also means that the flow velocity $v$ remains constant.

The discharge depth $h$ can also be described as a pressure head ($h$ component of the specific energy). These energy heads are often applied in the form of what are known as grade lines. In the energy grade line $J$ the most significant component in many cases is the discharge depth $h$. In uniform open-channel flow the energy grade line $J$ is equal to the bottom slope $J_s$ and thus equal to the discharge depth $h$. In uniform open-channel flow the normal discharge prevails, i.e. the bottom slope $J_s$ balances out the friction losses in the discharge $Q$. The energy grade line, water surface profile and bottom slope are all parallel.

Flow formulae

Flow formulae describe the relationship between the discharge $Q$ and the discharge depth $h$ at a given shape of cross-section and roughness characteristic. The shape of cross-section is taken into account in the hydraulic radius; the discharge depth $h$ comes into play via the energy grade line $J$.

Commonly used formulae for general flumes are:
- Darcy-Weisbach
- Manning-Strickler (also Gauckler-Manning-Strickler).

Flow formulae are based on empirical values.

Steady discharge

When considering energy head on the control volume we can resort to Bernoulli's equation and the continuity equation.

Continuity equation:

$$ Q = \text{const} = AV = bhv $$

Bernoulli's equation (general conservation of energy):

$$ \frac{1}{2}mv^2 + mgh = \text{const} $$

Expressed with energy head we get:

$$ \frac{v^2}{2g} + h_1 + z_1 = \frac{v^2}{2g} + h_2 + z_2 + hv $$

With $v = \frac{Q}{bh}$ from the continuity equation we get:

$$ \frac{1}{2} \frac{Q^2}{gh^3} + h_1 + (z_1 - z_2) = \frac{1}{2} \frac{Q^2}{gh^2} + h_2 + hv $$

For normal discharge:

$h_1 = h_2$, thus $h_v = z_1 - z_2$
Non-uniform discharge in a rectangular flume

In many cases the discharge \( Q \) in a flume is not uniform. We distinguish between gradually and rapidly varying discharge.

- Gradually varying discharge: the discharge depth \( h \) varies, the discharge \( Q \) or type of flow itself is (initially) subcritical. Gradually varying discharge occurs for example during flow over weirs. In many cases the discharge is subcritical.
- Rapidly varying discharge occurs for example during flow over slopes. In small slopes with considerable surface roughness, gradually varying discharge occurs for example during flow over weirs. In many cases the discharge is supercritical.

Subcritical discharge has a large discharge depth \( h \) at smaller flow velocity \( v \). In supercritical discharge the opposite is true: small discharge depth \( h \) and large flow velocity \( v \).

The flow transition from subcritical to supercritical discharge occurs with a continuous change of discharge depth \( h \), flow velocity \( v \), and specific energy \( E \), for example with an increase in the slope.

The flow transition from supercritical to subcritical discharge, on the other hand, always occurs with an abrupt change in the discharge depth \( h \) and a loss of specific energy \( \Delta E \), such as in a hydraulic jump.

Considerations of the energy head at the control volume result in a third-order equation for the discharge depth \( h \). The discharge depth \( h \) depends on the specific energy \( E \) and the discharge \( Q \). A specific energy diagram shows the discharge depth \( h \) graphically as a function of the specific energy \( E \) at constant discharge \( Q \). The minimum specific energy \( E_{\text{min}} \) only has one possible discharge depth, which is known as the critical depth \( h_c \). Critical discharge prevails at the critical depth \( h_c \).

For all other specific energies there are two alternative depths that are relevant from a physics point of view (see diagram with hydraulic jump). The correct one of the two discharge depths has to be calculated in each case (is there subcritical or supercritical discharge?). The maximum discharge \( Q \) at a given specific energy \( E \) can also be determined.

The third important equation after Bernoulli and the conservation of mass is the momentum equation. The equilibrium of forces is established at the control volume. In many cases, the influence of the weight and the friction force is negligible. Therefore only the forces acting on the flow areas come into play: the static pressure force and the dynamic motive force. The specific force \( F \) is the sum of these two forces and is determined by the momentum equation.

The specific force can also be represented in a diagram. The specific force diagram plots the discharge depth \( h \) over specific force \( F \) at constant discharge \( Q \). Similar to the specific energy diagram, there is the minimum specific force \( F_{\text{min}} \) at critical discharge \( Q \). For all other specific forces there are two sequent depths.

Specific energy and momentum diagrams:
- \( E \): specific energy
- \( Q \): discharge
- \( h \): discharge depth
- \( h_c \): critical discharge depth
- \( h_s \): subcritical discharge depth
- \( E_s \): subcritical specific energy
- \( E_c \): critical specific energy
- \( F \): specific force
- \( F_{\text{min}} \): minimum specific force
- \( h_s \): sequent subcritical discharge depth
- \( h_s' \): alternative subcritical discharge depth
- \( h_s'' \): alternative supercritical discharge depth
- \( h_c \): critical depth
- \( h_s \): sequent subcritical depth for specific energy \( E \)
- \( h_s' \): sequent supercritical depth for specific energy \( E \)
- \( h_{s''} \): alternative supercritical discharge depth
- \( \Delta E \): loss of specific energy

Graphic representations:
- Energy heads of a control volume
- Relationship between discharge \( Q \), specific energy \( E \) and discharge depth \( h \)
- Specific energy diagram
- Specific energy loss in the hydraulic jump
- Specific force diagram
- Forces occurring at a control volume

Formulas:
- \( E = v^2 / 2g \) velocity head
- \( v = Q / (L \cdot h) \) specific energy
- \( Q = \text{const} \) constant discharge
- \( L \): length of the flume
- \( h \): discharge depth
- \( E_{\text{min}} \): minimum specific energy
- \( F \): specific force
- \( F_{\text{min}} \): minimum specific force
- \( F_1 \): force of the water on the flow areas
- \( F_2 \): weight
- \( F_R \): friction force
- \( L \): length of the flume
- \( h_1 \): discharge depth
- \( h_s \): subcritical discharge depth
- \( h_c \): critical depth
- \( h_s' \): alternative subcritical discharge depth
- \( h_s'' \): alternative supercritical discharge depth
- \( h_s' \): sequent subcritical discharge depth for specific energy \( E_s \)
- \( h_s'' \): sequent supercritical discharge depth for specific energy \( E_c \)
- \( \Delta E \): loss of specific energy
Basic knowledge

Open-channel flow

Determining the loss of specific energy in a hydraulic jump

At the hydraulic jump a supercritical discharge $Q$ becomes subcritical again. The discharge depth $h$ rises rapidly and increases after the hydraulic jump. Energy is dissipated at the hydraulic jump due to the resulting turbulence. However, the momentum is retained, which means that there are two sequent depths $h$ for the same specific force $F$. The ratio of the sequent depths $h_1$ and $h_2$ is described by the following formula:

$$h_2 = \frac{1}{2} \sqrt{8F \frac{v^2}{g} + 1 - 1}$$

or

$$h_2 = \frac{h_1}{2} \sqrt{\frac{h_1^2}{4} + 4h_1 - \frac{v^2}{2g}}$$

Using the given specific energy diagram and an analogue specific force diagram, it is a simple matter to determine the resulting specific energy loss $\Delta E$ graphically.

The discharge depth $h_1$ is entered in the specific energy diagram and the specific force diagram (points 1 and 2). To determine the discharge depth $h_2$ after the hydraulic jump, the sequent depth to $h_1$ is determined graphically in the specific force diagram (point 3). The specific forces $F_1$ in point 2 and $F_2$ in point 3 are equal (conservation of momentum). Then the discharge depth $h_2$ is entered in the specific energy diagram (point 4). The specific energy loss $\Delta E$ that occurs in the hydraulic jump is equal to the difference between the specific energies.

The resulting specific energy loss $\Delta E$ can also be calculated using the following formula:

$$\Delta E = E_1 - E_2 = \left( h_1 + \frac{v_1^2}{2g} \right) - \left( h_2 + \frac{v_2^2}{2g} \right)$$

Froude number and critical discharge

Subcritical discharge
Disturbances in the discharge behaviour are noticeable upstream. The flow velocity $v$ is less than the propagation velocity $c$ of a surface wave. Subcritical discharge usually has a large discharge depth $h$ at low flow velocity $v$.

Critical discharge
Disturbances in the discharge behaviour are not noticeable upstream. The flow velocity $v$ is equal to the propagation velocity $c$ of a surface wave.

Supercritical discharge
Disturbances in the discharge behaviour are not noticeable upstream. The flow velocity $v$ is greater than the propagation velocity $c$ of a surface wave. The Froude number describes the ratio of flow velocity $v$ to propagation velocity $c$ of a surface wave and therefore serves as a measure of subcritical or supercritical discharge. The same Froude number means a dynamically similar open-channel flow.

$$Fr < 1: \text{subcritical}$$

$$Fr = 1: \text{critical}$$

$$Fr > 1: \text{supercritical}$$

Open-channel flow has many similarities with compressible flow. In both cases there is a dimensionless number (Froude or Mach) that characterises the flow. Many of the differences between subcritical and supercritical discharge have analogies in subsonic and supersonic flow.
Basic knowledge

Open-channel flow

Froude number and critical discharge

At the minimum specific energy \( E_{\text{min}} \), the discharge depth \( h \) corresponds to the critical depth \( h_c \). At this point, the Froude number is \( F_r = 1 \), there is a prevailing critical discharge and the propagation velocity \( c \) is equal to the flow velocity \( v \). Also, at this point the specific force \( F \) in the flume is minimal.

Examples where critical depths (critical discharge) may occur:
1. Critical depth near free overfall,
2. Change in the bottom slope,
3. Flow over a broad-crested weir,
4. Hydraulic jump

Illustration of the hydraulic jump at different Froude numbers

<table>
<thead>
<tr>
<th>Type of flow</th>
<th>Discharge depth</th>
<th>Flow velocity</th>
<th>Slope</th>
<th>Froude number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcritical discharge</td>
<td>( h &gt; h_c )</td>
<td>( v &lt; v_c )</td>
<td>( J &lt; J_{\text{crit}} )</td>
<td>( F_r &lt; 1 )</td>
</tr>
<tr>
<td>Critical discharge</td>
<td>( h = h_c )</td>
<td>( v = v_c )</td>
<td>( J = J_{\text{crit}} )</td>
<td>( F_r = 1 )</td>
</tr>
<tr>
<td>Supercritical discharge</td>
<td>( h &lt; h_c )</td>
<td>( v &gt; v_c )</td>
<td>( J &gt; J_{\text{crit}} )</td>
<td>( F_r &gt; 1 )</td>
</tr>
<tr>
<td>For rectangular flume</td>
<td>( h_c = \sqrt{\frac{Q^2}{gb^2}} )</td>
<td>( v_c = \sqrt{gh_c} )</td>
<td></td>
<td>( F_r = \frac{v}{\sqrt{gh}} )</td>
</tr>
</tbody>
</table>

1. Undulating jump
2. Weak jump
3. Oscillating jump
4. Steady jump
5. Strong jump
Basic knowledge

Open-channel flow

Positive and negative surges in open channels

The phenomena of positive and negative surges in an open channel describe waves caused by a sudden change in the discharge. In pipes, there is the similar phenomenon with water hammers. The sudden change of the discharge may occur for example, when opening and closing a gate or switching off turbines. The positive surge wave is formed steeply (propagation velocity of the wave increases with increasing water depth), while the negative surge wave is rather flat.

As a first approximation, positive and negative surge heights are equal in size and can be calculated using the continuity equation. In the case of a sudden opening (left illustration) we refer to a discharge surge and fill surge, and in the case of closure (right illustration) we refer to backwater surge and downstream negative surge.

Positive and negative surge waves on sudden operation of a gate

Positive surge wave

Open-channel flow in the lab

Aalto University
Finland

University of Southampton
United Kingdom

Federal Waterways Engineering and Research Institute
Germany
Open-channel flow

Basic knowledge

Energy dissipation

Supercritical flow often also has a high flow energy, which is composed of the kinetic energy necessary for further flow and excess energy. The excess energy can lead to erosion of the bottom, amongst other things. Therefore it is important to dissipate this excess energy. This can be realised in the hydraulic jump mentioned above (naturally occurring or intentional in a stilling basin) or in specially designed overfalls (stepped, ski jump style). A spillway fitted with a ski jump results in a free jet that sprays into the air and that has dissipated its energy after hitting the bottom (see photo below left).

Excess energy can be found at the following locations:
- at cross-sectional constrictions, e.g. weirs, gates
- in spillways chutes / steep slopes
- upon change in the discharge depth due to obstacles

Stilling basins have the following functions:
- stabilisation of the hydraulic jump at a defined location (depending on discharge depth \( h \) and / or backwater conditions in the downstream water, the position of the hydraulic jump may vary)
- in addition to the hydraulic jump, further energy dissipation through structural elements such as baffle blocks, sills
- protection of the flume bottom against erosion and scour formation (funnel or kettle-shaped deepening in the flume bottom)
- conversion of the water’s excess energy (kinetic and potential) into thermal and sound energy; good energy conversion occurs at Froude numbers from 4 to 8.

It is important that the hydraulic jump does not migrate out of the stilling basin into the downstream water, where it may cause scour. A slight backwater is recommended to avoid this from happening. The ratio of the actual discharge depth \( h \) to the theoretically required discharge depth \( \text{req. } h \) can be used as a measure of the backwater in the stilling basin.

The stilling basin can be made more efficient through various design measures. It is possible to widen the flow cross-section or to use what are known as chute blocks.

In GUNT experimental flumes, chute blocks and sills can be installed on the bottom of the stilling basin. These energy dissipation elements support the energy conversion and dissipate excess energy more quickly.
Open-channel flow

Basic knowledge

Control structures

Control structures are common elements in flumes and are used for the following purposes:
- raising the water level, for example creating a sufficient navigable depth for ships, use of hydropower, erosion protection due to lower flow velocity
- controlling the discharge
- measuring the discharge

Typical control structures are weirs or gates. The difference between the two is whether the water flows over (weir) or under the structure (gate). There are fixed or movable control structures. Gates are usually movable; they can regulate the water level and discharge. Possible movements are: lifting, retracting, rotating, tilting, rolling or combinations of these. Weirs can be constructed as a fixed or movable weir. Fixed weirs cannot regulate the water level, offering the advantage that they do not contain any moving parts prone to failure and requiring intensive maintenance. A special form of the fixed weir is the siphon weir (see page 92).

There is a flow transition from subcritical to supercritical flow over the crest is exceeded, there is submerged overfall. In the case of free overfall, the upstream water remains unaffected by the downstream water. The weir acts like a submerged weir and in many cases is completely under water. In the case of free overfall, weirs remove any connection between the water level in the upstream water and the water level in the downstream water. As soon as the downstream water has accumulated to the weir crest to the extent that the critical depth over the crest is exceeded, there is submerged overfall.

Real control structures consist of the following components:
- damming body (generates increase of water level), can be fixed, movable or a combination of both
- stilling basin: energy dissipation of the discharge
- bed pitching in the upstream and downstream water, structural connection (weir sidewalls)
- structures for ecological consistency

We can essentially distinguish between three different types of weir:
- sharp-crested
- ogee-crested/rounded (free-overfall weir)
- broad-crested

Sharp-crested weirs are preferred for measuring weirs. Ogee-crested weirs are often found being used as a retaining weir and flood overflow. Broad-crested weirs are often used as a sill and overflowed structure. These three weir types are all considered in the GUNT experimental flumes.

Real control structures consist of the following components:

Weirs can be constructed as a fixed or movable weir. Fixed weirs cannot regulate the water level, offering the advantage that they do not contain any moving parts prone to failure and requiring intensive maintenance. A special form of the fixed weir is the siphon weir (see page 92).

There is a flow transition from subcritical to supercritical

Control structures: flow over fixed weirs

Fixed weirs are often used to retain a river. The weir itself consists of a massive damming body. The applied moments of the water pressure is compensated by the weight of the dam wall. For this reason, weirs are normally constructed so that the outer contours roughly correspond to a triangle. The weir downstream sides can be designed to improve flow, in order to achieve the largest possible discharge. A hydraulically good discharge profile is the WES profile, which was developed at the Waterways Experimental Station in Vicksburg, Massachusetts, USA, by the US Army. The WES profile design does not assume a design discharge. Usually discharges smaller than the design discharge flow over the weir. The weir is therefore optimised for a slightly smaller discharge. For discharges that are smaller than or equal to the "chosen design discharge", the discharge profile remains stable and nappe separations can be avoided. With the design discharge, small negative pressures occur at the downstream side of the weir, but these do not represent a danger to the weir.
Basic knowledge

Open-channel flow

Control structures: types of overfall at the weir

There are two types of overfall: sharp-crested overfall and hydrodynamic overfall. In both types of overfall, the overfall condition can be free or submerged.

In the case of sharp-crested overfall, it is important that the nappe is aerated so that it falls freely. Lack of aeration may result in disturbances and thus to reduced discharge.

In hydrodynamic overfall at a fixed weir, it is important that nappe separations (reduced discharge) and excessive negative pressures (risk of cavitation) are avoided.

Control structures: calculation of discharge at the weir

Calculating the discharge plays a key role in flow over control structures. To calculate the discharge we use the Poleni equation. For a weir with free overfall:

\[ Q = \frac{g}{2} \cdot \mu \cdot b \cdot h_o \cdot \sqrt{2gh_o} \]

\( \mu \) is a factor that takes into account the weir geometry (see table), \( b \) is the weir’s crest width, \( h_o \) the weir head.

In submerged overfall the equation is supplemented with a reducing factor that is taken from appropriate diagrams.

From the Bernoulli equation we can see that the specific energy \( E \) can be calculated from the kinetic energy (velocity of approaching flow \( v_u \)) and the discharge depth \( h_u \) in the upstream water. In many cases \( v_u \) is relatively small and is ignored.

In the GUNT experimental flumes, the models studied are approached normally, i.e. perpendicular to the flow direction. The weirs considered all belong to the group of fixed weirs.

In practice there are also lateral weirs, which are used as flood spillways. Lateral weirs are installed parallel to the flow direction. Lateral weirs are also fixed weirs.

Discharge coefficient \( \mu \) for weirs with different shaped crests

<table>
<thead>
<tr>
<th>Design of the weir crest</th>
<th>( \mu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>broad, sharp-crested, horizontal</td>
<td>0.49…0.51</td>
</tr>
<tr>
<td>broad, well-rounded edges, horizontal</td>
<td>0.50…0.55</td>
</tr>
<tr>
<td>broad, fully-rounded weir crest, realised by a shifted weir flap</td>
<td>0.65…0.73</td>
</tr>
<tr>
<td>sharp-crested, nappe aerated</td>
<td>≈ 0.64</td>
</tr>
<tr>
<td>ogee-crested, vertical upstream and inclined downstream face</td>
<td>0.73…0.75</td>
</tr>
<tr>
<td>roof-shaped, rounded weir crest</td>
<td>0.75…0.79</td>
</tr>
</tbody>
</table>

Control structures: ogee-crested weirs

Fixed ogee-crested weirs are the preferred weir to be used as a retaining weir and flood overflow. They usually have a spillway for optimum flow, such as the WES profile.

On the ogee-crested weir HM 162.34 from GUNT the pressure distribution is measured along the weir downstream side and displayed directly on eight tube manometers.

Hydrodynamic overfall on the ogee-crested weir, pressure distribution on the weir crest at different discharge

1 nappe lying on the crest, 2 weir downstream side roughly corresponds to the contour of the free nappe, 3 nappe lifts off where appropriate; \( Q \) discharge, \( Q_b \) design discharge

Pressure distribution on the ogee-crested weir HM 162.34
Basic knowledge
Open-channel flow

Control structures: sharp-crested weirs

There is also free and submerged overfall in the case of a sharp-crested weir. For the optimal discharge at a sharp-crested weir, it is important that the nappe is aerated. Ambient pressure prevails at the top and bottom of the aerated nappe.

Typical variables include the height of weir $W$, the weir head $h_w$, above the weir crest in the upstream water and the discharge depth $h_d$ in the downstream water. Together with the width of the weir $b$ these variables are entered into the Poleni equation (p. 88) to calculate the discharge. Some variables are included indirectly in coefficients or reducing factors.

Aerated free overfall at a sharp-crested weir

- $h_u$: upstream water discharge depth,
- $W$: height of weir,
- $h_d$: downstream water discharge depth,
- $v_u$: velocity in the upstream water,
- $v_1$: velocity in the nappe.

Submerged overfall

- $h_u$: upstream water discharge depth,
- $W$: height of weir,
- $h_d$: downstream water discharge depth,
- $v_u$: upstream water flow velocity,
- $h_c$: critical depth.

Control structures: broad-crested weirs

Broad-crested weirs are overflowed structures that are used in rivers where there is little variation in the discharge and only a rather small top water level is desired. They can also be the foundation for a movable control structure.

Broad-crested weirs are characterised by a short section of almost uniform discharge with critical depth occurs on the weir crest (see illustration). In this section, there is a hydrostatic pressure distribution. The streamlines extend almost horizontally. These conditions apply as long as the ratio of weir head to weir length $h_o/L$ is between 0.08 and 0.5. Broad-crested weirs with these dimensions can also be used as a measuring weir.

Once $h_o/L < 0.08$, friction losses can no longer be ignored and the weir body is too long to be used as a measuring weir. At $h_o/L > 0.5$, i.e. short weir bodies, the streamlines do not run horizontally and the pressure distribution is not hydrostatic, so that we cannot use the calculation approaches presented in this brochure.

For ecological reasons, a broad-crested weir is rarely used as a sill in rivers. Instead, a ramp is built so that fish and other aquatic creatures can swim upstream.

GUNT experimental flumes facilitate the investigation of various broad-crested weirs and the their respective discharges $Q$. 

Control structures: sharp-crested weirs

- $h_w$: weir head above the weir crest in the upstream water,
- $h_d$: downstream water discharge depth,
- $v_1$: velocity in the nappe,
- $h_o$: weir head,
- $v_2$: velocity in the upstream water,
- $vu$: velocity in the upstream water,
Basic knowledge

Open-channel flow

Control structures: siphon weir

The siphon weir is a fixed weir. The illustrations below show the hydraulic principle of the syphon when used as a flood overflow.

When the water level of the storage lake rises just above the weir crest of the damming body, the siphon comes into play, soon resulting in free overfall. If there is a slight increase in water level, i.e. a slight increase in discharge, the nappe deflector directs the water jet to the siphon hood. This leads to an evacuation in the siphon duct, resulting in the discharge pressure in the pipe with full flow. This discharge pressure has a high discharge capacity, which only increases a little with rising water level.

If the water level of the storage lake falls again so that it is below the edge of the inlet lip, air is sucked into the siphon and the siphon vented. This abruptly stops the flow of water.

The discharge can be interrupted at any time by an additional device for venting. GUNT siphon weirs have air vents to allow a comparison of the function and discharge capacity of the siphon weir with and without venting.

Siphon weirs can only be adjusted to a limited extent and cannot be overloaded. In the past they were often incorporated as spillways in dams on the basis of their high specific discharge capacity.

Control structures: flow under gates

Discharge under a sluice gate

1 Free discharge, 2 submerged discharge; hu upstream water discharge depth, a gate opening, h1 downstream water discharge depth, ZS top water level, Zh highest water level

Discharge under a radial gate

hd upstream water discharge depth, hu downstream water discharge depth, a gate opening

Gates may be subject to either free or submerged discharge, in a similar way to flow over weirs. Discharge leads to jet contraction, also called “vena contracta” (minimum discharge depth h_1).

Free discharge prevails as long as the discharge passes under the gate without disturbance and the downstream water does not form a backwater to the gate. In free discharge, there is supercritical discharge directly downstream of the gate.

In a similar way to the flow over weirs, the free discharge Q is calculated from Bernoulli’s equation, the momentum equation and the continuity equation giving

\[ Q = \mu ba \frac{1}{2}gh_u \]

where \( \mu \) = discharge coefficient, \( b \) = gate width, \( a \) = gate opening.

Gates are movable control structures, i.e. the gate opening \( a \) and thus the discharge \( Q \) is altered and adjusted to actual needs. In practice, there are therefore characteristic diagrams which show the discharge \( Q \) (upstream and downstream water discharge depth \( h_u \) and \( h_d \) and gate opening \( a \) are given).

One type of gate commonly used in practice is the circular radial gate used to control discharge. It can be rotated about a bearing point. The radial gate is often placed on the weir crest of a control structure. Flow does not just go under the radial gate, but can also go over into a flume (radial weir).

GUNT experimental flumes allow the installation and investigation of a flat sluice gate and a radial gate.
Culverts are crossing structures in running waters and allow the passage of water. They may be pipes that are laid under a road, allowing the flume to cross. The culvert may be flowed through partially or in full, depending on the discharge occurring. A partially filled culvert with free surface is treated in the same way as an open channel. By contrast, a full flow through culvert and a culvert in which the inlet is completely submerged are classed as control structures. These result in a limiting of the discharge. There may also be a combination of these two states, so that the culvert is sometimes fully flowed through and sometimes partially filled.

For various reasons, culverts are not ideal from a hydraulic point of view: they cause flow losses, are vulnerable to blockages (rubbish, sediments), can cause silt at the inlet and outlet and – in the event of floods – are often too small. Furthermore, they are difficult for aquatic creatures to pass through. Bridges are a much better alternative from a hydraulic point of view, but of course much more expensive.

**Local losses in flumes**

Local losses result from changes in cross-section (construction, sills, flow-measuring flumes), changes in direction and obstacles. Obstacles in flumes include piers for bridges or weirs. Piers constrain the flow cross-section possibly leading to back eddies or backwaters. From a hydraulic point of view, there are four general cases for piers which class the discharge behaviour as without obstacles, i.e., as normal discharge. The four general cases are:

- subcritical discharge with little or considerable reduction of cross-section
- supercritical discharge with little or considerable reduction of cross-section

A non-negligible backwater and possibly a flow transition in front of the pier occurs when the specific energy $E$ of the undisturbed discharge $Q$ is less than the minimum required specific energy $E_{\text{min}}$ that guarantees the complete discharge $Q$. As the flow width $b_{\text{rest}}$ of the flume through the obstacles decreases, $E_{\text{min}}$ increases (see illustrations).

For rectangular flumes with a broad cross-section we get

$$E_{\text{min}} = 1.53 \sqrt{\frac{Q^2}{gb_{\text{rest}}}}$$

Piers with a rectangular profile, with a rounded profile and a tapering profile are studied in GUNT experimental flumes.
Methods of discharge measurement

The two most common methods of determining the discharge of a flume are flow-measuring flumes and measuring weirs. In both methods, there is a fixed relationship between discharge depth \( h \) and discharge \( Q \).

Flow-measuring flumes

Venturi flumes are specially shaped flumes with defined lateral contraction, sometimes also with a shaped bottom. The contraction dams up the discharge \( Q \). The backed-up water ensures that subcritical discharge occurs in the flume. The contraction is where acceleration (including flow transition) from subcritical to supercritical discharge takes place. Critical discharge is present at the narrowest cross-section. This results in a hydraulic jump in the expansion section of the venturi flume. The discharge \( Q \) is calculated from the discharge depth \( h_u \) in the upstream water.

The GUNT venturi flumes have a flat bottom.

To prevent distortions to the measurement in the venturi flume, it is essential that discharge is free. The discharge depth \( h_u \) in the upstream water should not be affected by the downstream water.

Parshall flumes are venturi flumes with a profiled bottom. The ratios of constriction and enlargement are defined. Parshall flumes are commercially available as a complete component including a discharge curve (discharge \( Q \) as a function of the discharge depth \( h_u \) in the upstream water). They are widely used in North America.

Parshall flumes

A plan view of venturi or Parshall flume, B side view of a Parshall flume; 1 narrowest cross-section, 2 hydraulic jump; \( h_u \) upstream water discharge depth, \( Q \) discharge

Parshall flumes

Trapezoidal flumes are another type of flow-measuring flumes. The flow cross-section is triangular or trapezoidal with smooth walls. In contrast to Parshall flumes, they often have a smaller pressure head loss for the same discharge and are more suitable for small discharges.

Flow-measuring flumes are mainly used in wastewater treatment plants because they are well suited for contaminated water. They can be easily maintained.

Measuring weirs

Measuring weirs are usually sharp-crested weirs. They have a simple design, require little space and are relatively easy to construct.

Measuring weirs are used in order to determine the discharge \( Q \). The quantity is measured by detecting the weir head \( h_o \) upstream of the weir. There must be a minimum distance of \( 3h_o \) between the measuring point and the weir. To convert the weir head \( h_o \) into the discharge \( Q \), there are approximation formulae that take into account the geometry of the measuring weir and the discharge coefficient according to Poleni.

Measuring weirs always have free overfall.

Sharp-crested weirs in the form of plate weirs exist with different geometries, such as:

- **rectangular weir according to Rehbock**: Use at relatively uniform discharge of more than 50 m³/h, but reduced accuracy in the lower part of the measuring range. The rectangular weir requires guaranteed aeration.

- **v-notch weir according to Thomson**: Use with varying discharges (0,75...240 m³/h); high measuring accuracy for smaller discharges.

- **trapezoidal weir according to Cipoletti**: Use at relatively uniform discharges greater than 125 m³/h.

Flow over typical measuring weirs in side and plan view

1 rectangular weir without contraction, 2 v-notch weir according to Thomson, 3 trapezoidal weir according to Cipoletti

\[ h_u, v, W \]
Basic knowledge
Open-channel flow

Transient flow: flow-induced vibrations

Jetties or drilling platforms usually stand in the water on piles. Flowing water exerts forces on the part of the piles that is located under water, possibly causing vibrations. We distinguish between vortex-induced and flow-induced vibrations. It is important to deal with these forces and the stresses caused by them, since they can lead to component failure.

The vibrations are caused by the interaction between the moving fluid and the pile. For example, flow around a pile can lead to the formation of a Karman vortex street. The detachment of these vortices causes a change in the flow direction. In the worst case the vortex shedding frequency corresponds to the natural frequency of the pile.

The GUNT model HM 162.61 “Vibrating piles” enables the observation of a single vibrating pile. Furthermore, there are two parallel piles that stand transverse to the direction of flow, and which are made to vibrate by the flow. The distance between the piles can be varied. If the distance is too small, there will be coupled vibrations between the two piles.

Sediment transport

In addition to the flowing water, almost all flumes include sediment transport that affects the flow behaviour. Sediment transport consists of suspended-load transport and bed-load transport. Suspended matter are solids that are suspended in the water and that have no contact with the bottom. Bed load on the other hand, consists of solids that are moved along the bottom. When studying the flow behaviour in flumes, it is bed-load transport that is the predominant component. Sediment that is deposited (siltation) or removed (erosion and/or scour) may, for example, change the flow cross-section or the water surface profiles. Sediment transport also results in a modified bed structure (formation of ripples or dunes, change of roughness).

In the case of normal discharge, in addition to the equations detailed above, it is also necessary to consider the transport balance on the control volume – is the same amount of sediment that leaves the control volume, also fed back in?

The GUNT experimental flumes use sand to demonstrate sediment transport. In addition to the sediment feeder at the inlet of the experimental flume, a sediment trap is integrated at the end of the experimental flume. Depending on the flow velocity, ripples can occur or a wandering dune may be observed. Together with other models, it is possible to observe siltation against a weir or scour formation at the stilling basin.

Essentially, the topic of sediment transport is studied in depth in several independent trainers, for example HM 140 or HM 168.
Basic knowledge

Open-channel flow

Transonic flow: waves

The free surface of the water is “deformed” by the wind (waves). In nature, there is a wide variety of waves (long or short wavelengths, breaking or smooth, etc.) Natural waves are irregular, for example a flat wave follows a high wave (amplitude). Aside from wind-induced waves, there are also surface waves caused by a disturbance, positive and negative surge waves and tsunami waves, which are caused by an increase in the water, such as during an earthquake.

Waves carry energy, but no mass. When a wave reaches shallow water, such as near the beach, it is slowed down. The wave trough is slowed more than the wave crest. Therefore, the wave crest overtakes the trough and the waves break.

The study of the formation and effect of waves is an important field in maritime navigation, coastal protection and in the design of offshore systems (wind farms, drilling platforms). In coastal protection in particular, it is a matter of reducing the destructive power of waves and the washing away of sediment.

The GUNT wave generator produces periodic, harmonic waves in the GUNT experimental flumes. For example, we can observe wave reflection at the end of a flume. Together with the various beach simulations, it is possible to observe and compare the behaviour of the same waves on different beds.

The run-up on piers, for example in a harbour basin or as part of an offshore system, can be observed with the HM 162.46 piers accessory.

Periodic wave

Δh amplitude, h average depth, c propagation velocity of the wave, λ wavelength
An overview of GUNT experimental flumes

GUNT experimental flumes and their accessories open up a wide range of experiments and demonstrations on the topics of open-channel flow, running waters, hydraulic engineering and coastal protection. They form the expandable foundation for custom investigations and research work. Experimental flumes from GUNT have been successfully put to use around the world for many years.

For each of the experimental flumes, there is a variety of models for discharge control, such as weirs, sills, stilling basins, as well as wave generators, beach elements and bridge piers. Technical solutions for sediment feed and removal are also available.

In addition, we can also provide specially adapted instrumentation such as water level gauges, pitotstatic tubes, tube manometers and velocity meters.

GUNT provides four experimental flumes with different cross-sections, depending on the purpose of use and the local conditions:

- HM 160 (86x300 mm)
- HM 162 (309x450 mm)
- HM 163 (409x500 mm)
- HM 161 (600x800 mm)

The experimental flumes have different lengths of experimental section to choose from:

- HM 160 with experimental sections of 2.5m or 5m
- HM 162 and HM 163 with experimental sections of 5m, 7.5m, 10m or 12.5m
- HM 161 with an experimental section of 16m

As a result, the length of the experimental section can be adjusted to the individual requirements of the laboratory.

The HM 160 flume is perfectly suited as an introduction to the topic of open-channel flow and the demonstration of many of the basic principles. This flume is compact and required little space.

The HM 162 and HM 163 experimental flumes can be supplied in four different lengths. The “short” experimental flume, with an experimental section of 5m, can easily be set up even in smaller laboratories. As the length of the experimental section increases, the observation section upstream and downstream of obstacles increases.

The largest GUNT experimental flume HM 161 – with a cross-section of 600x800 mm and a 16m long experimental section – offers a large number of possibilities for your own research projects.
Technical details for GUNT experimental flumes
The closed water circuit

All experimental flumes can be operated independently of the laboratory water supply and have a closed water circuit with water tanks, pump and flow meter. To protect against overfilling of the experimental section, level switches turn off the pump when the maximum level in the inlet or outlet element is exceeded.

In all experimental flumes, the inlet element is designed for optimum flow so that the flow is less turbulent as it enters the experimental section.

The water enters from below through a flow straightener. A damping plate calms the water further. The damping plate floats on the water and is mounted on a guide.

The outlet element of all experimental flumes contains a plate weir. The plate weir included in HM 160 consists of six elements that can be removed, so that six damming heights are available to choose from. If all elements are removed, it corresponds to free discharge without a weir. The plate weir included in HM 161, HM 162 and HM 163 is mounted to rotate around a fixed point and can thus be lowered completely. As such, any desired top water level can be set (see illustrations).

Methods for adjusting the flow rate in the inlet to the experimental section
All experimental flumes allow adjusting the flow rate. The speed of the pump used in HM 161, HM 162 and HM 163 is infinitely adjustable by using a frequency converter until the desired flow rate is achieved. In HM 160, a valve is used to adjust the flow rate. The flow rate in HM 160 is measured by a rotameter, while HM 161, HM 162 and HM 163 are both equipped with an electromagnetic flow meter.

The pump
The centrifugal pump is separated from the experimental section in the experimental flumes HM 162, HM 163 and HM 161 and is mounted on its own foundation. It is connected to the piping to the inlet element via a hose. This ensures that there is no transmission of vibrations between the experimental section and the pump. In the small experimental flume HM 160 the vibrations that occur are negligible, so the pump is integrated in one of the experimental flume’s supports.

Pump (HM 162) with shut-off valve with manual actuation in the delivery side for adjusting the flow rate (above the pump). The pump’s delivery line also contains the hose and the electromagnetic flow meter. The shut-off valve is only needed for wave experiments.

Principle of the plate weir with elements
1 removable element

Plate weir 1 with full damming height in different positions to adjust the top water level in the outlet of the experimental section.
Technical details for GUNT experimental flumes

### Structural features

#### Rigidity against deformation

The experimental section of HM 162 and HM 163 is available in several lengths. The components used are essentially the same (modular design). In order to realise different lengths with the modular design, while maintaining inclination adjustment, the experimental flume is supported by an auxiliary carrier with two supports. In the version with long experimental section, the inevitable deformations are absorbed by the supports. The individual adjustability of the elements enables precise alignment of the experimental section.

The elements of the self-supporting experimental section in HM 161 are mounted on four supports, so that there is only ever a minimal deformation.

In all experimental flumes, the bottom of the experimental section is made of stainless steel. Tempered glass is used for the side walls of the experimental section. It is scratch resistant, does not age and does not deform. The water tank, inlet and outlet elements are made of corrosion-resistant GRP (glass reinforced plastic) or steel. The piping is PVC. The models used in the experimental flumes consist of aluminium, stainless steel, PVC or Plexiglas.

#### Inclination adjustment

All experimental flumes can be inclined, which means that the slope is adjustable. The current slope can be read directly on a scale (HM 160, HM 162, HM 163) or a digital display (HM 161).

Inclination adjustment in HM 160 is manual and electrical in HM 161.

In HM 162 and HM 163 the inclination can be adjusted either manually or electrically. With an experimental section above 7.5m we recommend electrical inclination adjustment HM 162.57 / HM 163.57.

#### Materials used

In all experimental flumes, the bottom of the experimental section is made of stainless steel. Tempered glass is used for the side walls of the experimental section. It is scratch resistant, does not age and does not deform. The water tank, inlet and outlet elements are made of corrosion-resistant GRP (glass reinforced plastic) or steel. The piping is PVC. The models used in the experimental flumes consist of aluminium, stainless steel, PVC or Plexiglas.

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<th>1</th>
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<tr>
<td>welded frame</td>
<td>bottom element of an element of the experimental section</td>
<td>diagonal rib</td>
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![Diagram of experimental section components]
The following table lists the space requirements of all GUNT experimental flumes including the water tank. GUNT will gladly undertake the precise laboratory planning for you to set up the experimental flumes.

A lifting device is recommended when placing larger models in the experimental sections of HM 161.

Installation requirements
This section provides some tips for planning a laboratory in which an experimental flume is going to be set up:
- the laboratory should be on the ground floor
- the floor must have sufficient load capacity
- the floor and the skirting area of the walls should be water-resistant
- the transportation routes to and within the laboratory must be spacious
- the water supply and drains must be big enough for larger amounts of water
- the two larger experimental flumes HM 162, HM 163, and HM 161 require three-phase alternating current

An example of laboratory planning
The drawing below shows the planning for a laboratory that contains the experimental flume HM 162 (10 m long experimental section), a few other GUNT units on fluid mechanics and workstations for the students.

In this case the models for HM 162 are stored on tables. A small cabinet in the corner contains tools and can be used to store instruction manuals.
Setup of GUNT experimental flumes using the example of HM162

The carrier (bottom left) is assembled from separate elements (left) and placed on the flume supports using a forklift (right). The flume supports are bolted into the floor (centre).

The experimental section element is placed on the carrier with a forklift, aligned and installed.

The inlet element is raised onto the carrier, aligned and connected to the experimental section.

Then the experimental flume is sealed.

Last but not least is work on the wiring (left). Then the water tank is aligned and connected to the pipeline system (right).

Once installation is complete the system is commissioned; this photo shows the process with the broad-crested weir.

GUNT experimental flumes are set up and commissioned by experienced staff on site. This ensures that you can focus on your experiments right from the word go.

This fully assembled experimental flume is located at the Universiti Teknologi PETRONAS (UTP) in Ipoh, Malaysia.
GUNT experimental flumes are being used all around the world

Below is a selection of customers who are using a GUNT experimental flume. There is at least one GUNT experimental flume in each of these countries, often there are several flumes in use at other colleges and universities within the country.

Satisfied customers...

In Malaysia with HM 162

In Spain with HM 160

In Bangladesh with HM 161

In Indonesia with HM 162

Africa
- École Nationale Supérieure d’Hydraulique (ENS-H; HM 162), Algeria
- Instituto Superior Politécnico de Tecnologias e Ciências (ISPTEC; HM 163), Angola
- University of Asmara (HM 160), Eritrea
- Haramaya University (HM 162), Ethiopia
- École Nationale d’Ingénieurs (HM 160), Mali
- Rivers State University of Science and Technology (HM 160), Nigeria

America
- Centro Universitario Luterano de Palmas (CEULP/ULBRA; HM 160), Brasil
- Concordia University (HM 162), Canada
- Universidad Central de Chile (HM 162), Chile
- UCR Universidad de Costa Rica (HM 162), Costa Rica
- Escuela Superior Politécnica del Litoral (ESPE; HM 162), Ecuador
- Instituto Tecnológico Agropecuario No. 10 de Torreón (008.161BL), Mexico
- Universitas Bandar Lampung (HM 162), Indonesia
- Qom University (HM 162), Iran
- University of Technology (HM 160), Iraq
- University Teknologi PETRONAS (HM 162), Malaysia
- Far Eastern University (HM 160), Philippines
- Taif University (HM 162), Saudi Arabia
- Institute of Technology University of MonaSuwa (ITUM; HM 160), Sri Lanka
- Burapha University (HM 161), Thailand
- American University of Sharjah (HM 160), UAE
- Flinders University (HM 160), Australia

Asia
- Herat University (HM 162), Afghanistan
- Military Institute of Science & Technology (MIST; HM 161), Bangladesh
- Instituto Technology Brunel (ITB; HM 162), Brunei
- City University of Hong Kong (HM 162), China
- Indian Institute of Technology of Roorkee (IITI (HM 162), India
- Universitas Bandar Lampung (HM 162), Indonesia
- Qom University (HM 162), Iran
- University of Technology (HM 160), Iraq
- University Teknologi PETRONAS (HM 162), Malaysia
- Far Eastern University (HM 160), Philippines
- Taif University (HM 162), Saudi Arabia
- Institute of Technology University of MonaSuwa (ITUM; HM 160), Sri Lanka
- Burapha University (HM 161), Thailand
- American University of Sharjah (HM 160), UAE
- Flinders University (HM 160), Australia

Europe
- University of Cyprus (HM 162), Cyprus
- Aalto University (HM 161), Finland
- Centre de Formation Hydraulique de EDF (HM 163), France
- Bundesanstalt für Wasserbau (HM 163), Germany
- Rezekne Higher Education Institution (HM 160), Latvia
- Warsaw Agricultural University (HM 162), Poland
- Politécnico de Vizag (HM 162), Portugal
- Moscow State Construction University (MGSU; HM 162), Russia
- Slovak University of Technology (STU; HM 163), Slovakia
- Universidad de la Laguna (ULL; HM 162), Spain
- Okay University (HM 160), Turkey
- University of Southampton (HM 161), UK
- ... and many more
**HM 160 Experimental flume 86 x 300 mm**

HM 160 is the smallest experimental flume in the GUNT range that can be used to give excellent demonstrations of all open-channel flow phenomena. Thanks to its small size and the closed water circuit, HM 160 can easily be set up and used in classrooms.

Used together with the comprehensive selection of additional accessories a wide range of topics within the field of open-channel flow can be demonstrated and investigated. These accessories include control structures, discharge measurement, losses due to changes in cross-section, waves and sediment transport. Additional accessories allow measuring the discharge depth and flow velocity.

The experimental flume HM 160 is available with two experimental sections of different lengths: 2.5 m or 5 m with an additional extension element HM 160.10 – see diagram.

Models available as accessories

| Control structures          | HM 160.29 Sluice gate                             |
|                           | HM 160.40 Radial gate                             |
|                           | HM 160.30 Set of plate weirs, four types          |
|                           | HM 160.31 Broad-crested weir                      |
|                           | HM 160.33 Crump weir                              |
|                           | HM 160.34 Ogee-crested weir with pressure measurement |
|                           | HM 160.36 Siphon weir                             |
|                           | HM 160.32 Ogee-crested weir with two weir outlets (expandable with HM 160.35 Elements for energy dissipation) |
| Discharge measurement      | HM 160.51 Venturi flume                           |
| Change in cross-section    | HM 160.77 Flume bottom with pebble stones         |
|                           | HM 160.44 Sill                                    |
|                           | HM 160.45 Culvert                                 |
|                           | HM 160.46 Set of piers, seven profiles            |
| Other                     | HM 160.41 Wave generator                          |
|                           | HM 160.42 Plain beach                             |
|                           | HM 160.72 Sediment trap                           |
|                           | HM 160.73 Sediment feeder                         |
|                           | HM 160.61 Vibrating piles                         |

Measuring instruments available as accessories

| HM 160.52 Level gauge / HM 160.91 Digital level gauge |
| HM 160.53 Ten tube manometers                          |
| HM 160.50 Pitotstatic tube                            |
| HM 160.64 Velocity meter                              |
Hydraulic engineering
Open-channel flow

HM 160
Experimental flume 86x300mm

The illustration shows HM 160 together with the ogee-crested weir HM 160.32 and the level gauge HM 160.52.

Description
- basic principles of open-channel flow
- experimental section with transparent side walls, lengths of 2.5m and 5m available
- homogeneous flow through carefully designed inlet element
- models from all fields of hydraulic engineering available as accessories

Hydraulic engineering is concerned with artificial waterways, the regulation of rivers and with barrages, amongst other things. By using experimental flumes in the laboratory, it is possible to teach the necessary basic principles.

The experimental flume HM 160 has a closed water circuit. The cross-section of the experimental section is 86x300mm. The experimental section is 2.5m long and can be increased to 5m with the extension element HM 160.10. The side walls of the experimental section are made of tempered glass, which allows excellent observation of the experiments. All components that come into contact with water are made of corrosion-resistant materials (stainless steel, glass reinforced plastic). The inlet element is designed so that the flow enters the experimental section with very little turbulence.

The inclination of the experimental flume can be finely adjusted to allow simulation of slope and to create a uniform flow at a constant discharge depth.

A wide selection of models, such as weirs, piers, flow-measuring flumes or a wave generator are available as accessories and ensure a comprehensive programme of experiments. Most models are quickly and safely bolted to the bottom of the experimental section.

Learning objectives/experiments
- together with optionally available models
  - uniform and non-uniform discharge
  - flow formulae
  - flow transition (hydraulic jump)
  - energy dissipation (hydraulic jump, stilling basin)
  - flow over control structures: weirs (sharp-crested, broad-crested, ogee-crested), discharge under gates
  - flow-measuring flumes
  - local losses due to obstacles
  - transient flow: waves
  - vibrating piles
  - sediment transport

Specification
1) basic principles of open-channel flow
2) experimental flume with experimental section, inlet and outlet element and closed water circuit
3) length of the experimental section 2.5m or 5m (with extension element HM 160.10)
4) smoothly adjustable inclination of the experimental section
5) experimental section with 10 evenly spaced threaded holes on the bottom for installing models or for water level measurement using pressure
6) side walls of the experimental section are made of tempered glass for excellent observation of the experiments
7) all surfaces in contact with water are made of corrosion-resistant materials
8) flow-optimised inlet element for low-turbulence entry into the experimental section
9) closed water circuit with water tank, pump, rotameter and manual flow adjustment
10) models from all fields of hydraulic engineering available as accessories

Technical data
Experimental section
- length: 2.5m or 5m (with 1x HM 160.10)
- flow cross-section WxH: 86x300mm
- inclination adjustment: -0.5...+3%
- experimental section with 10 evenly spaced threaded holes on the bottom for installing models or for water level measurement using pressure
- side walls of the experimental section are made of tempered glass for excellent observation of the experiments
- all surfaces in contact with water are made of corrosion-resistant materials
- flow-optimised inlet element for low-turbulence entry into the experimental section
- closed water circuit with water tank, pump, rotameter and manual flow adjustment
- models from all fields of hydraulic engineering available as accessories

Tank: 280L
Pump
- power consumption: 1.02kW
- max. flow rate: 22.5m³/h
- max. head: 13.7m

Measuring ranges
- flow rate: 0...10m³/h
- 230V, 50Hz, 1 phase
- 230V, 60Hz, 1 phase: 220V, 60Hz, 1 phase
- UL/CSA optional
- LWNet: 4300x160x1350mm (experimental section 2.5m)

Weight: approx. 244kg

Scope of delivery
1 experimental flume
1 set of instructional material

G.U.N.T. Gerätebau GmbH, Hanskampring 15-17, D-22885 Barsbüttel, Telefon (040) 67 08 54-0, Fax (040) 67 08 54-42, Email sales@gunt.de, Web www.gunt.de

We reserve the right to modify our products without any notifications.
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**HM 162 / HM 163**

**Experimental flume 309 x 450mm / 409 x 500mm**

**HM 162 and HM 163 – used worldwide by satisfied customers**

The length of the experimental section is between 5m and – with further HM 16x.10 extension elements – a maximum of 12.5m. The closed water circuit contains two water tanks and a powerful pump. Depending on the desired length, additional water tanks HM 16x.20 are required (see drawings).

Used together with the comprehensive selection of additional accessories a wide range of topics within the field of open-channel flow can be demonstrated and investigated. These accessories include control structures, discharge measurement, losses due to changes in cross-section, waves and sediment transport.

The length of the experimental section is between 5m and – with further HM 16x.10 extension elements – a maximum of 12,5m. The closed water circuit contains two water tanks and a powerful pump. Depending on the desired length, additional water tanks HM 16x.20 are required (see drawings).
**HM 162**

**Experimental flume 309x450mm**

The illustration shows HM 162 (7.5m experimental section) with the wave generator HM 162.41 and the level gauge HM 162.52.

**Description**

- experiments ranging from fundamental principles to research projects
- experimental section with transparent side walls, lengths between 5m and 12.5m available
- homogeneous flow through carefully designed inlet element
- models from all fields of hydraulic engineering available as accessories

Hydraulic engineering is a crucial part of engineering. How do we achieve the necessary river depth for ships? How does open-channel flow change during flooding? How far upstream do measures such as control structures have an effect? How can the discharge at barrages be calculated? By using experimental flumes in laboratories it is possible to teach the basic knowledge required to understand the answers to these questions and to develop possible solutions.

The experimental flume HM 162 with a closed water circuit has a cross-section of 309x450mm. The length of the experimental section is between 5m and – with further extension elements HM 162.10 – a maximum of 12.5m.

The side walls of the experimental section are made of tempered glass, which allows excellent observation of the experiments. All components that come into contact with water are made of corrosion-resistant materials (stainless steel, glass reinforced plastic). The inlet element is designed so that the flow enters the experimental section with very little turbulence.

The inclination of the experimental flume can be finely adjusted to allow simulation of slope and to create a uniform flow at a constant discharge depth.

A wide selection of models, such as weirs, piers, flow-measuring flumes or a wave generator are available as accessories and ensure a comprehensive programme of experiments. Most models are quickly and safely bolted to the bottom of the experimental section.

**Learning objectives/experiments**

- together with optionally available models
  - flow formulae
  - flow transition (hydraulic jump)
  - energy dissipation (hydraulic jump, stilling basin)
  - flow over control structures: weirs (sharp-crested, broad-crested, ogee-crested)
  - flow over control structures: discharge under gates
  - flow-measuring flumes
  - local losses due to obstacles
  - transient flow, waves
  - vibrating piles
  - sediment transport

**Specification**

1. basic principles of open-channel flow
2. experimental flume with experimental section, inlet and outlet element and closed water circuit
3. length of the experimental section 5m, up to 12.5m possible with additional extension elements HM 162.10
4. smoothly adjustable inclination of the experimental section
5. experimental section with 20 evenly spaced threaded holes on the bottom for installing models or for water level measurement using pressure
6. side walls of the experimental section are made of tempered glass for excellent observation of the experiments
7. experimental section with guide rails for the optionally available instrument carrier HM 162.59
8. all surfaces in contact with water are made of corrosion-resistant materials
9. flow-optimised inlet element for low-turbulence entry into the experimental section
10. closed water circuit with 2 water tanks, pump, electromagnetic flow sensor and flow control
11. models from all fields of hydraulic engineering available as accessories

**Technical data**

**Experimental section**

- possible lengths: 5m-7.5m-10m-12.5m
- flow cross-section: WAH 309x450mm
- inclination adjustment: ±0.5…+2.5%
- possible lengths: 5m-7.5m-10m-12.5m
- empty weight: approx. 1500kg
- LxWxH: 9170x1000x2200mm (experimental section 5m)

**Pump**

- power consumption: 4kW
- max. flow rate: 192m³/h
- max. head: 16.1m
- speed: 1450min⁻¹

**Measuring ranges**

- flow rate: 0.4…130m³/h
- 400V: 50Hz, 3 phases
- 400V: 60Hz, 3 phases
- 230V: 60Hz, 3 phases
- UL/CBA optional

**Overfall at ogee-crested weir with ski jump spillway HM 162.32.**

**Scope of delivery**

1. experimental flume
2. set of tools
3. set of instructional material
Open-channel flow

Hydraulic engineering

Learning objectives/experiments

- together with optionally available models
  - uniform and non-uniform discharge
  - flow formulae
  - flow transition (hydraulic jump)
  - energy dissipation (hydraulic jump, stilling basin)
  - flow over control structures: weirs (sharp-crested, broad-crested, ogee-crested)
  - flow over control structures: discharge under gates
  - flow-measuring flumes
  - local losses due to obstacles
  - transient flow, waves
  - vibrating piles
  - sediment transport

Description

- experimental range from fundamentals up to research projects
- experimental section with transparent side walls, lengths between 5m and 12.5m available
- homogeneous flow realised with carefully designed inlet element
- models from all subjects of hydraulic engineering available.

Hydraulic engineering is an important part of technology. How do you establish the required depth of water for ships? How do you calculate the discharge at barrages or dams? Experiments in laboratories enable to teach the fundamentals required to understand the answers to these questions and to develop possible solutions.

The experimental flume HM 163 has a cross-section of 409x500mm and includes a closed water circuit. The length of the experimental section is between 5m and 12.5m when using additional extension elements HM 163.10. The side walls of the experimental sections are made from hardened glass allowing optimal observation of the experiments.

All components in contact with water are made of corrosion-resistant materials (stainless steel, glass fiber reinforced plastic). The inlet element is designed in a way to ensure low turbulent flow inlet into the experimental section.

The experimental flume can be inclined continuously to simulate a slope and to continuously to simulate a slope and to simulate a slope and to simulate a slope.

A large variety of models, i.e. weirs, pilnars, flow-measuring flumes or a wave generator, are available as accessories and enable an extensive range of experiments. Most of these models are screwed quickly and safely to the bottom of the experimental section.

HM 163
Experimental flume 409x500mm

Technical data

- Experimental section
  - possible length: 5m-7.5m-10m-12.5m
  - flow cross-section: BxH: 409x500mm
  - inclination adjustment: ±5…±2.5%

- 3 tanks
  - made of glass fiber reinforced plastic
  - 1100L each

- Pump
  - power consumption: 7.5kW
  - max. flow rate: 120m³/h
  - max. head: 30m
  - speed: 2800min⁻¹

- Measuring ranges
  - flow rate: 5.4…190m³/h

- Specifiction

- maximum head: 30m
- maximum flow rate: 120m³/h
- maximum speed: 2800min⁻¹

Scope of delivery

- 1 experimental flume
- 1 set of tools
- 1 set of instructional material

Specifications

[1] fundamentals of open channel flow
[2] experimental flume with experimental section, inlet and outlet elements and closed water circuit
[3] length of the experimental section 5m, can be extended up to 12.5m by using additional extension elements HM 163.10
[4] experimental section can be inclined continuously
[5] experimental section with 20 evenly spaced threaded holes on the bottom for installing models or for water level measurement using pressure
[6] side walls of the experimental section made of hardened glass to ensure optimal observation of the experiments
[7] experimental section fitted with guide rails for the optionally available instrument carrier HM 163.59
[8] all contact surfaces with water made of corrosion-resistant material
[9] inlet element optimised for low turbulent inlet flow into the experimental section
[10] closed water circuit with 3 water tanks, pump, electromagnetic flow sensor and flow control
[11] models from all subjects of hydraulic engineering available as accessory
**HM 163**  
Experimental flume 409x500mm

Optional accessories

Control structures  
070.16329 HM 163.29 Sluice gate  
070.16340 HM 163.40 Radial gate  
070.16330 HM 163.30 Set of plate weirs, four types  
070.16331 HM 163.31 Broad-crested weir  
070.16333 HM 163.33 Grump weir  
070.16336 HM 163.36 Siphon weir  
070.16338 HM 163.38 Rake  
070.16334 HM 163.34 Ogee-crested weir with pressure measurement  
070.16332 HM 163.32 Ogee-crested weir with two weir outlets  
070.16335 HM 163.35 Elements for energy dissipation  

Change in cross-section  
070.16344 HM 163.44 Sill  
070.16345 HM 163.45 Culvert  
070.16346 HM 163.46 Set of piers, seven profiles  
070.16377 HM 163.77 Flume bottom with pebble stones  

Flow-measuring flumes  
070.16351 HM 163.51 Venturi flume  
070.16355 HM 163.55 Parshall flume  
070.16363 HM 163.63 Trapezoidal flume  

Other experiments  
070.16361 HM 163.61 Vibrating piles  
070.16371 HM 163.71 Closed sediment circuit  
070.16372 HM 163.72 Sediment trap  
070.16373 HM 163.73 Sediment feeder  
070.16341 HM 163.41 Wave generator  
070.16380 HM 163.80 Set of beaches  

Measuring instruments  
070.16352 HM 163.52 Level gauge  
070.16391 HM 163.91 Digital level gauge  
070.16364 HM 163.64 Velocity meter  
070.16350 HM 163.50 Pitotstatic tube  
070.16353 HM 163.53 Ten tube manometers  
070.16313 HM 163.13 Electronic pressure measurement, 10x 0…50mbar  
070.16359 HM 163.59 Instrument carrier  

Other accessories  
070.16212 HM 162.12 System for data acquisition and automation  
070.16257 HM 162.57 Electrical inclination adjustment  
070.16310 HM 163.10 Extension element of the experimental flume, 2.5m  
070.16320 HM 163.20 Water tank  
070.16314 HM 163.14 Gallery  
070.16315 HM 163.15 Extension element of the gallery

---

**Installation and commissioning**

Guaranteed trouble-free by professional GUNT staff

Have your new equipment commissioned by trained expert personnel. Our highly qualified staff will gladly assist you.

Commissioning of the equipment includes the following services:

- setup of equipment in the laboratory
- connection to the laboratory’s supply systems
- commissioning the equipment
- testing the equipment
HM 162/HM 163 Experimental flume
A few impressions

Glimpse into the water tank
Siphon weir in action
Culvert
Ogee-crested weir with a sill
Rake
Aerated plate weir side view
Radial gate

Demonstrations for the customer
Operating the sluice gate
HM 161 Experimental flume 600 x 800 mm

HM 161 has an experimental section of 16 m and a cross-section of 600 x 800 mm, making it the largest experimental flume in the GUNT range. Thanks to its large size, HM 161 is ideal for your own research projects. The results of experiments are very close to what happens in nature. The water forces occurring in this experimental flume are impressive.

Used together with the comprehensive selection of additional accessories a wide range of topics within the field of open-channel flow can be demonstrated and investigated. These accessories include control structures, discharge measurement, losses due to changes in cross-section, waves and sediment transport. Additional accessories allow measuring the discharge depth and flow velocity.

Element of the experimental section during on-site assembly. The elements are delivered ready for installation. Frames and beams are welded and painted. Tempered glass is used.

---

Front view
1. outlet element,
2. sediment trap HM 161.72,
3. water tank,
4. platform for sediment feeder (HM 161.73),
5. inlet element,
6. gallery

Rear view with jacking supports
1. piping,
2. motorised jacking support (flume inclination adjustment),
3. water tank,
4. flow meter,
5. switch cabinet,
6. fixed support,
7. pump,
8. outlet element,
9. sediment trap (HM 161.72),
10. inlet element,
11. gallery

Plain view
1. gallery,
2. platform for sediment feeder (HM 161.73),
3. inlet element,
4. experimental section,
5. jacking supports,
6. rails for instrument carrier,
7. fixed support,
8. sediment trap HM 161.72,
9. outlet element
Experimental flume HM 161 with sediment transport. The sediment feeder HM 161.73 sits on the inlet element. At the end of the experimental section, the sediment trap HM 161.72 separates the sediment.

Side view during discharge over the ogee-crested weir HM 161.34

Hydraulic jump

Plan view during discharge over the ogee-crested weir HM 161.34

Discharge in the active siphon weir HM 161.36

View towards the inlet element

Positive surge wave
The experimental flume HM 161 is the largest within the GUNT product range. The flumes can be achieved in the experimental flume, and the length of the experimental section, are the perfect conditions for designing your own projects. These projects can be very close approximations of reality.

The experimental section is 16m long and has a cross-section of 600x800mm. The side walls of the experimental section are made of tempered glass, which allows excellent observation of the experiments. All components that come into contact with water are made of corrosion resistant materials (stainless steel, glass reinforced plastic). The inlet element is designed so that the flow enters the experimental section with very little turbulence. The closed water circuit consists of a series of water tanks and two powerful pumps. The tanks are included in the system in such a way that they also serve as a gallery which you can stand on. The user can thus comfortably reach any part of the experimental section.

The experimental flume has a motorised inclination adjustment to allow simulation of slope and to create a uniform flow at a constant discharge depth. The experimental flume is equipped with a comprehensive range of functions for measurement, control and operation that are controlled by a PLC. Two freely positionable touch panels display the measured values and operating states and can be used to control the system. At the same time, the measured values can be transmitted directly to a PC under Windows 7, 8.1, 10 via a USB connection.

A wide selection of models, such as weirs, planks, flow-measuring flumes or a wave generator made available as accessories and ensure a comprehensive programme of experiments. Most models are quickly installed and safely bolted to the bottom of the experimental section.
Open-channel flow in the lab

A wide range of typical models allows the user to design a broad and individual programme of experiments with GUNT experimental flumes. The programme of experiments shown in this catalogue for HM 162 applies, in principle, for all GUNT experimental flumes.

The models of the other GUNT experimental flumes are similar.

The appropriate instrumentation for measuring the discharge depth and the flow velocity is also available as additional accessories.
GUNT experimental flumes
Instrumentation

Instrument carrier for HM 162, HM 163 and HM 161

The experimental flumes HM 162, HM 163 and HM 161 extend above the side wall guide rails. An instrument carrier can be placed on the rails and moved. The different instruments are mounted on the instrument carrier, for example a level gauge or a pitotstatic tube. Using the carrier, the instruments can be moved to nearly every point of the flow. The carrier can be locked during the measurements with fixing devices. The position of the carrier along the experimental section is read on a scale (see photo). On the carrier itself is another scale, used to determine the position transverse to the direction of flow.

In the small experimental flume HM 160 no instrument carrier is necessary. The instruments are placed directly on the top of the experimental section and clamped in place.

Flow velocity

GUNT offers two methods of measuring the flow rate in all experimental flumes: the traditional pitotstatic tube or a digital velocity meter. The pitotstatic tube HM 16x.50 measures the static pressure and the total pressure at any point of the flow. A digital pressure gauge displays the difference between the two pressures. The pressure difference corresponds to the dynamic pressure, from which the flow velocity can be calculated.

The core element of the velocity meter HM 16x.64 is an impeller that is rotated by the flow. The speed of the impeller is proportional to the flow velocity. The flow velocity is read directly from the digital display.

Discharge depth

To measure the discharge depth, the level gauge HM 16x.52 or HM 16x.31 with digital display is used. The tip of the probe is moved to the surface of the water from above.

Pressure measurement

All experimental flumes are equipped with pressure measuring points in the flume bottom. The pressure measuring points are evenly distributed over the length of the experimental section. To read these pressures, the pressure measuring points are connected to the optional manometer panel HM 16x.53 via hoses. This allows directly reading a profile of discharge depth over the entire length of the experimental section on the manometer panel.

Measuring methods in your laboratory

Of course, you can also use your own laboratory measuring methods to determine the flow velocity, such as PIV (Particle Image Velocimetry) or LDA (Laser Doppler Anemometry) and ultrasound to determine the discharge depth.

Example of a pressure measurement along the experimental section

A broad-crested weir (HM 162.31) and a sluice gate (HM 162.29) have been inserted in the 5m long experimental section of HM 162. The elements of the experimental section of HM 162 each contain ten pressure measuring points, which are uniformly distributed over the length of the 2.5m element. The pressure at these measuring points is called the pressure head and corresponds to the discharge depth. The pressure heads are displayed on the manometer panel HM 162.53. When the experimental section is inclined, i.e. open-channel flow with a slope, it is more accurate to measure the discharge depth via the pressure head than via a level gauge.

The manometer panel HM 162.53 contains ten tubes. Depending on the length of the experimental section, we can either represent selected points on a panel or use multiple panels to show all pressures.

In the experimental flume HM 161, 48 pressure measuring points are evenly distributed over the experimental section with 16m length. The manometer panel HM 161.53 contains 20 tubes.

Automated operation and data acquisition for HM 162/HM 163 and HM 161

Automated operation and data acquisition for HM 162/HM 163 and HM 161

Using HM 162/163, the experimental flume HM 162 or HM 163 can be operated by a PC. Flow rate, inclination adjustment and frequency of the wave generator HM 162.41/HM 163.41 are set by the GUNT software. Measured values are recorded and saved. The software detects automatically if the electronic pressure measurement HM 162.13 is also used. In this case, both softwares are operated in HM 162.12 including the selection of the corresponding windows.

HM 161 includes a control with PLC via two touch panels and a GUNT software for acquisition of the measured values.
GUNT experimental flumes
Wave generator

The wave generator HM 16x.41 is available as an accessory for all experimental flumes and generates periodic, harmonic waves with different wavelengths and/or wave heights.

An electric motor drives a crank disk, which is connected to a plate via a driving rod. The plate performs a harmonious stroke movement. The speed of the crank disk, in other words the frequency, with which the plate is moved back and forth can be adjusted, therefore affecting the wavelength of the generated waves. Furthermore, the stroke is finely adjustable, so that the wave height (amplitude) can be varied.

The speed of the crank disk is either set on the switch cabinet (HM 162, HM 163, HM 161) or on a control unit that is part of the wave generator (HM 160).

GUNT’s policy is simple:
high quality hardware and clearly developed instructional material ensure successful teaching and learning about an experimental unit.

The core of this material are detailed reference experiments that we have carried out. The description of the experiment contains the actual experimental setup right through to the interpretation of the results and findings. A group of experienced engineers develops and maintains the instructional material.

Nevertheless, we are here to help should any questions remain unanswered, either by phone or – if necessary – on site.
Flows in rivers, canals and coastal areas are often associated with sediment transport. Bed-load transport is the main transport mechanism. During bed-load transport, solids are moved along the flume bottom.

The described accessories for the GUNT experimental flumes consider bed-load transport only. The used sediment is sand with a grain size of 1...2 mm. The sediment is introduced at the inlet of the experimental section. At the end of the experimental section, a sediment trap separates the sediment.

The purpose of the sediment trap is to separate sediment from the flow to prevent sediment from entering the pump or the flow meter. The flow near the bottom of the flume contains the sediment.

The sediment trap HM 160.72 is inserted in the water tank after the outlet element. It consists of a fine mesh screen and serves to collect the sediment.

For the larger experimental flumes HM 162, HM 163 and HM 161, the sediment trap HM 162.72/HM 163.72/HM 161.72 is permanently mounted between the experimental section and the outlet element. The flow near the bottom is fed into this sediment trap. In the trap, the sediment sinks to the bottom and accumulates. The sediment-free water continues to flow into the outlet element. The sediment is removed manually from the trap and delivered back to the feed.

The sediment is added manually with a shovel or a bucket included in the scope of delivery of the sediment trap HM 16x.72. Alternatively, the sediment feeder HM 16x.73 can be used. This feeder essentially consists of a vibrating conveyor, via which sediment is introduced into the experimental section. The feeder is mounted above the inlet of the experimental section.

For HM 162/HM 163/HM 161, there is an alternative system to the sediment trap HM 16x.72: the closed sediment circuit HM 16x.71.

The sediment trap HM 160.72 is inserted in the water tank after the outlet element. It consists of a fine mesh screen and serves to collect the sediment.
## Accessories for experimental flumes

**HM160, HM161, HM162 and HM163**

### Control structures

- **Sluice gate**
  - HM160.29: Sluice gate
  - HM161.29: Sluice gate
  - HM162.29: Sluice gate
  - HM163.29: Sluice gate

- **Radial gate**
  - HM160.40: Radial gate
  - HM161.40: Radial gate
  - HM162.40: Radial gate
  - HM163.40: Radial gate

- **Sharp-crested weirs/plate weirs** (Rehbock, Cipoletti, Thomson: rectangular weir without contraction)
  - HM160.30: Set of plate weirs, four types
  - HM161.30: Set of plate weirs, four types
  - HM162.30: Set of plate weirs, four types
  - HM163.30: Set of plate weirs, four types

- **Broad-crested weir**
  - HM160.31: Broad-crested weir
  - HM161.31: Broad-crested weir
  - HM162.31: Broad-crested weir
  - HM163.31: Broad-crested weir

- **Sill**
  - HM160.44: Sill
  - HM161.44: Sill
  - HM162.44: Sill
  - HM163.44: Sill

- **Crump weir**
  - HM160.33: Crump weir
  - HM161.33: Crump weir
  - HM162.33: Crump weir
  - HM163.33: Crump weir

The pictures show accessories for HM162. The accessories for the other experimental flumes are similar.
## Hydraulic engineering

**Open-channel flow**

### Control structures

<table>
<thead>
<tr>
<th>Accessories for experimental flumes HM 160, HM 161, HM 162 and HM 163</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ogee-crested weir</td>
</tr>
<tr>
<td>HM 160.32 Ogee-crested weir with two weir outlets</td>
</tr>
<tr>
<td>HM 161.32 Ogee-crested weir with two weir outlets</td>
</tr>
<tr>
<td>HM 162.32 Ogee-crested weir with two weir outlets</td>
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<tr>
<td>HM 163.32 Ogee-crested weir with two weir outlets</td>
</tr>
</tbody>
</table>

Optional expansion for the ogee-crested weir:

**Energy dissipation elements**

(including chute block and sills)

<table>
<thead>
<tr>
<th>Energy dissipation elements</th>
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</thead>
<tbody>
<tr>
<td>HM 160.35 Elements for energy dissipation</td>
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<tr>
<td>HM 161.35 Elements for energy dissipation</td>
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<tr>
<td>HM 162.35 Elements for energy dissipation</td>
</tr>
<tr>
<td>HM 163.35 Elements for energy dissipation</td>
</tr>
</tbody>
</table>

### Siphon weir

| HM 160.36 Siphon weir |
| HM 161.36 Siphon weir |
| HM 162.36 Siphon weir |
| HM 163.36 Siphon weir |

### Rake

| HM 161.38 Rake |
| HM 162.38 Rake |
| HM 163.38 Rake |

The pictures show accessories for HM 162. The accessories for the other experimental flumes are similar.
Accessories for experimental flumes HM 160, HM 161, HM 162 and HM 163

Discharge measurement

<table>
<thead>
<tr>
<th>Sharp-crested weirs / plate weirs (Rafelski, Cipollazzi, Thomson; rectangular weir without contraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM 160.30</td>
</tr>
<tr>
<td>Set of plate weirs, four types</td>
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<tr>
<td>HM 161.30</td>
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<tr>
<td>Set of plate weirs, four types</td>
</tr>
<tr>
<td>HM 162.30</td>
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<tr>
<td>Set of plate weirs, four types</td>
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<tr>
<td>HM 163.30</td>
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<tr>
<td>Set of plate weirs, four types</td>
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<table>
<thead>
<tr>
<th>Venturi flume</th>
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</thead>
<tbody>
<tr>
<td>HM 160.51</td>
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<tr>
<td>Venturi flume</td>
</tr>
<tr>
<td>HM 161.51</td>
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<tr>
<td>Venturi flume</td>
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<tr>
<td>HM 162.51</td>
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<tr>
<td>Venturi flume</td>
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<tr>
<td>HM 163.51</td>
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<td>Venturi flume</td>
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<table>
<thead>
<tr>
<th>Parshall flume</th>
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<tbody>
<tr>
<td>HM 161.55</td>
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<tr>
<td>Parshall flume</td>
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<tr>
<td>HM 162.55</td>
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<tr>
<td>Parshall flume</td>
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<tr>
<td>HM 163.55</td>
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<tr>
<td>Parshall flume</td>
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Discharge measurement

<table>
<thead>
<tr>
<th>Trapezoidal flume</th>
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<tbody>
<tr>
<td>HM 161.63</td>
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<tr>
<td>Trapezoidal flume</td>
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<tr>
<td>HM 162.63</td>
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<tr>
<td>Trapezoidal flume</td>
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<tr>
<td>HM 163.63</td>
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<tr>
<td>Trapezoidal flume</td>
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</tbody>
</table>

Change in cross-section

<table>
<thead>
<tr>
<th>Sill</th>
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</thead>
<tbody>
<tr>
<td>HM 160.44</td>
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<tr>
<td>Sill</td>
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<tr>
<td>HM 161.44</td>
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<tr>
<td>Sill</td>
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<td>HM 162.44</td>
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<td>Sill</td>
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<tr>
<td>HM 163.44</td>
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<tr>
<td>Sill</td>
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</tbody>
</table>

Flume bottom with pebble stones

| HM 160.77 Flume bottom with pebble stones |
| HM 161.77 Flume bottom with pebble stones |
| HM 162.77 Flume bottom with pebble stones |
| HM 163.77 Flume bottom with pebble stones |

The pictures show accessories for HM 162. The accessories for the other experimental flumes are similar.
Accessories for experimental flumes
HM 160, HM 161, HM 162 and HM 163

Change in cross-section

<table>
<thead>
<tr>
<th>Change in cross-section</th>
<th>Crump weir</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM 160.33 Crump weir</td>
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<tr>
<td>HM 161.33 Crump weir</td>
<td></td>
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<tr>
<td>HM 162.33 Crump weir</td>
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<tr>
<td>HM 163.33 Crump weir</td>
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</tbody>
</table>

Piers

7 profiles: rectangular, square, circular; rounded (one end or both ends); pointed-nosed (one end or both ends)

<table>
<thead>
<tr>
<th>Piers</th>
<th>Set of piers, seven profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM 160.46</td>
<td>HM 160.46</td>
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<tr>
<td>HM 161.46</td>
<td>HM 161.46</td>
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<tr>
<td>HM 162.46</td>
<td>HM 162.46</td>
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<td>HM 163.46</td>
<td>HM 163.46</td>
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Culvert

<table>
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<th>Culvert</th>
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<tbody>
<tr>
<td>HM 160.45 Culvert</td>
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<tr>
<td>HM 161.45 Culvert</td>
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<tr>
<td>HM 162.45 Culvert</td>
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<tr>
<td>HM 163.45 Culvert</td>
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Other: waves with beaches

<table>
<thead>
<tr>
<th>Wave generator</th>
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<tbody>
<tr>
<td>HM 160.41 Wave generator</td>
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<tr>
<td>HM 161.41 Wave generator</td>
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<tr>
<td>HM 162.41 Wave Generator</td>
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<td>HM 163.41 Wave generator</td>
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Plain beach

<table>
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<tr>
<th>Plain beach</th>
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<tbody>
<tr>
<td>HM 160.42 Plain beach</td>
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Set of beaches

3 beaches: plain, rough, permeable

<table>
<thead>
<tr>
<th>Set of beaches</th>
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<tbody>
<tr>
<td>HM 160.80 Set of beaches</td>
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<tr>
<td>HM 161.80 Set of beaches</td>
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<tr>
<td>HM 162.80 Set of beaches</td>
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<tr>
<td>HM 163.80 Set of beaches</td>
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</tbody>
</table>

The pictures show accessories for HM 162. The accessories for the other experimental flumes are similar.
Accessories for experimental flumes HM160, HM161, HM162 and HM163

Other: sediment transport

<table>
<thead>
<tr>
<th>Sediment trap</th>
<th>HM160.72</th>
<th>Sediment trap</th>
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<tbody>
<tr>
<td></td>
<td>HM161.72</td>
<td>Sediment trap</td>
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<td></td>
<td>HM162.72</td>
<td>Sediment trap</td>
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<td>HM163.72</td>
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<table>
<thead>
<tr>
<th>Sediment feeder</th>
<th>HM160.73</th>
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<td>HM161.73</td>
<td>Sediment feeder</td>
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<td>HM162.73</td>
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<td>HM163.73</td>
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<table>
<thead>
<tr>
<th>Closed sediment circuit</th>
<th>HM161.71</th>
<th>Closed sediment circuit</th>
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<tbody>
<tr>
<td></td>
<td>HM162.71</td>
<td>Closed sediment circuit</td>
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<td></td>
<td>HM163.71</td>
<td>Closed sediment circuit</td>
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</tbody>
</table>

Other: flow-induced vibrations

<table>
<thead>
<tr>
<th>Vibrating piles</th>
<th>HM160.61</th>
<th>Vibrating piles</th>
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<tbody>
<tr>
<td></td>
<td>HM161.61</td>
<td>Vibrating piles</td>
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<tr>
<td></td>
<td>HM162.61</td>
<td>Vibrating piles</td>
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<td></td>
<td>HM163.61</td>
<td>Vibrating piles</td>
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</table>

<table>
<thead>
<tr>
<th>Measuring instruments</th>
<th>Pressure measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HM160.53 Ten tube manometers</td>
</tr>
<tr>
<td></td>
<td>HM161.53 20 tube manometers</td>
</tr>
<tr>
<td></td>
<td>HM162.53 Ten tube manometers</td>
</tr>
<tr>
<td></td>
<td>HM163.53 Ten tube manometers</td>
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</tbody>
</table>

The pictures show accessories for HM 162. The accessories for the other experimental flumes are similar.
Accessories for experimental flumes
HM 160, HM 161, HM 162 and HM 163

**Measuring instruments**

<table>
<thead>
<tr>
<th>Level gauge (analogue or with digital display)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM 160.52 Level gauge</td>
</tr>
<tr>
<td>HM 160.91 Digital level gauge</td>
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<tr>
<td>HM 161.52 Level gauge</td>
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<tr>
<td>HM 161.91 Digital level gauge</td>
</tr>
<tr>
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<tr>
<td>HM 162.91 Digital level gauge</td>
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<td>HM 163.52 Level gauge</td>
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<th>Velocity measurement (via pitotstatic tube)</th>
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<td>HM 161.50 Pitotstatic tube</td>
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<td>HM 162.50 Pitotstatic tube</td>
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<td>HM 163.50 Pitotstatic tube</td>
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<thead>
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<th>Velocity measurement (via velocity meter)</th>
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<td>HM 161.64 Velocity meter</td>
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<td>HM 162.64 Velocity meter</td>
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<td>HM 163.64 Velocity meter</td>
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</tbody>
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<thead>
<tr>
<th>Instrument carrier (accessory required for the level gauge and the velocity measurement)</th>
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<tbody>
<tr>
<td>HM 161.59 Instrument carrier</td>
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<td>HM 162.59 Instrument carrier</td>
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<td>HM 163.59 Instrument carrier</td>
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</tbody>
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The pictures show accessories for HM 162. The accessories for the other experimental flumes are similar.
Accessories for experimental flumes
HM 160, HM 161, HM 162 and HM 163

Other accessories

Data acquisition and automation

- in HM 161 included
- HM 162.12 System for data acquisition and automation

Electrical inclination adjustment

- Recommended for experimental sections larger than 7.5m
- HM 162.57 Electrical inclination adjustment
- HM 163.57 Electrical inclination adjustment

Experimental flume extension element, 2.5m

- For longer experimental sections
- HM 160.10 Extension element of the experimental flume
- HM 162.10 Extension element of the experimental flume
- HM 163.10 Extension element of the experimental flume

Water tank, 1100L

- HM 162.20 Water tank
- HM 163.20 Water tank

Other accessories

- HM 162.14 Gallery
- HM 162.15 Extension element of the gallery
- HM 163.14 Gallery
- HM 163.15 Extension element of the gallery

The pictures show accessories for HM 162. The accessories for the other experimental flumes are similar.
Flows in rivers, canals and coastal areas are often associated with sediment transport. Sediment transport consists of suspended load transport and bed-load transport.

Bed-load transport takes place in the area near the bottom and is therefore a very important factor in the shaping of the river bed. In natural running waters, erosion and sedimentation processes are constantly alternating and characterise the bed load balance of the water route.

When studying the flow behaviour in flumes, it is bed-load transport that is the predominant component. Sediment that is deposited (siltation) or removed (erosion and/or scour formation) may, for example, change the flow rates through a cross-section or the water surface profiles. Sediment transport can also result in a modified bed structure (formation of ripples or dunes, change of roughness).

Sediment that is transported as suspended matter is only relevant for the transport balance when it is deposited, thus contributing, for example, to a change of the flow rates through a cross-section or to the water surface profiles. Sediment transport can also result in a modified bed structure (formation of ripples or dunes, change of roughness).

To assess the discharge behaviour of a flume in the case of normal discharge, in addition to the commonly known equations on conservation of energy, conservation of momentum and conservation of mass, it is also necessary to consider the transport balance on the control volume – i.e., the same amount of sediment that leaves the control volume, also fed back in? Transport formulae are empirical formulae, such as Meyer-Peter & Müller.

The GUNT trainers that cover this field of study are mainly concerned with bed-load transport.
Basic knowledge

**Fundamentals of sediment transport**

**Types of sediment transport**

A sediment grain in a flow is subject to different forces acting on it. The form of sediment transport that occurs is decided according to the size, mass and shape of the grain and according to the acting flow force. The illustration below shows all the relevant forces:

The flow force $F_F$ is the force resulting from vertically acting lift force $F_{FL}$ and the horizontal acting drag force $F_{FD}$. In order for the sediment grain to leave the flume bottom (for saltation or as suspended matter), the lift force must be greater than that of the opposing weight $F_G$ of the sediment grain.

The flow force acting on small grains is smaller than on a larger grain, due to the distribution of flow velocity $v$ between flume bottom and the surface of the water. Therefore, for the larger grain the weight $F_G$ is greater and prevents suspended load transport.

Large grains (e.g. stones) roll or slide across the bottom, while small sand grains become suspended matter. Sediment grains that are larger than sand, such as fine gravel, can also be subject to saltation.

**Rolling**

The sediment remains in constant contact with the bottom. Normally it is large sediment grains that roll, such as stones.

**Saltation**

The sediment grain, e.g. a small pebble, is torn from the bottom by the flow and thus briefly leaves the bottom. The flow drags it along before it is deposited on the bottom again. It appears as though the particle is jumping.

**Suspension**

Suspended matter is solids that are suspended in the water and that have no contact with the bottom. The main factors are:
- discharge
- slope
- bed structure
- amount of available solids

**Bed load** consists of solids that are moved along the bottom. The main factors are:
- discharge
- slope
- bed structure
- amount of available solids
Basic knowledge
Fundamentals of sediment transport

Bed form

The processes that wind causes in a (sand) desert are similar to the processes in running waters.

As soon as the flow velocity is a bit higher than the critical velocity at which the sediment is set in motion, we start to see unevenness at flume bottom, which is known as the bed form. This unevenness can reach heights of about 1/3 of the flow depth. There are essentially three basic forms of bed forms: ripples, dunes and antidunes.

Current ripples are caused by processes in the boundary layer, so that the minimum discharge depth is approximately three times the ripple height. The maximum sand grain diameter for the formation of ripples is approximately 0.6 mm. Ripples are 3.5 cm high on average and have a wavelength of 4.80 cm. They are so small that their influence on the flow does not reach the surface.

Dunes are large ripples and can be described as large, often regular hills. Their height depends on the discharge depth. They also affect the flow up to the surface. Ripples and dunes can occur overlayed.

Ripples and dunes move in the direction of flow. The rarer antidunes move against the flow direction. Antidunes occur in supercritical discharge and form wavy bed forms.

Types of ripple
There are current ripples (explained on this page) and wave ripples, which are caused by the surface waves in the shallow water region. Asymmetric ripples are caused by a flow interfering with surface waves.

Formation and movement of current ripples

When the critical flow velocity for the movement of sand has been reached, the grains begin to move. They form small clusters (hills). The hills work like irregularities on the sediment surface. These irregularities are only a few grains thick and affect the flow in the boundary layer. The streamlines above a hill are closer together; the flow velocity is higher (Bernoulli effect, see illustration of erosion in the trough). The higher flow velocity can cause other grains on the upstream side of the hill to roll or jump and accumulate on the top. If too many grains have been piled up, the situation becomes unstable and they slide down the downstream side of the hill. The downstream side is steeper than the upstream side.

At the top of the hill the streamline lying on the sand surface, so to speak, is detached from the surface and then bounces back onto the sand surface (see illustration of the emergence of counterflows on the downstream side). The area below this streamline is called the separation zone. In this zone a separation eddy can form, causing a small counterflow. Turbulence and erosion are also present, so that valleys between the ripples form or deepen. These valleys are called troughs. Some of the eroded grains deposit at the bottom of the downstream side, while others are carried away by the fluid and/or deposited on the upstream side.

The sand grains on the top of the sediment layer are continuously transported onwards, so that the ripples move in the flow direction and appear to wander.

1 top of the ripple, 2 downstream side of the ripple, 3 upstream side of the ripple; L wavelength, R ripple height

Black arrows turbulence in the water, white arrows direction of motion of the sand

Erosion in the trough
1 detachment of the streamline at the top, 2 impact point; black lines streamlines

Emergence of counterflows at the downstream side
separation zone with vortex
Basic knowledge
Fundamentals of sediment transport

Sediment transport at bridge piers

Structures such as bridge piers can change the flume bottom of a watercourse in the long term. The flow conditions altered by the structure can cause scour formation on the flume bottom in the immediate vicinity of the structure. Scour can occur even if there is no actual sediment transport in the watercourse. In this case we refer to clear-water scour.

There are two main causes of scour formation at structures: contraction scour and local erosion. In local erosion, the flow is deflected locally by the structure. Highly turbulent vortex systems form in the immediate vicinity of the structure, leading to increased local velocities (see illustrations). This increases the erosion rate of the sediment. In the case of contraction scour, the reduction of the flow cross-section through the structure, for example a bridge pier, causes higher flow velocities. The increased flow velocities induce increased bottom shear stress, i.e. an increased carrying capacity. The erosion at the base or foundation of the pier can have fatal consequences, potentially leading to the collapse of the structure. It is therefore important to understand the mechanisms of scour formation, in order to be able to predict the probable scour depth and to take appropriate protective measures.

During scour formation there are two largely independent vortex systems that occur: the horseshoe vortex system and the wake vortex system (see illustration of clear-water scour formation at a cylindrical pier). In this case, the horseshoe vortex system is the decisive system in scour formation. Horseshoe vortices are caused by the downward flow at the upstream side of the structure. The downward flow occurs due to the pressure drop (see red arrows in the top illustration and the pressure distribution in the bottom side view). Wake vortices occur during the separation of the boundary layer around the sides of the cylinder flowed around (black arrows in the top illustration).

For cylindrical piers, the (clear-water) scour is at its largest on the upstream side, while rectangular piers have the greatest scour formation on the sides.

Fluvial obstacle mark

Scour formation also leads to siltation, also known as silt accumulation, downstream of the obstacle. Both phenomena are grouped under the term fluvial obstacle mark.

The illustrations below show the fluvial obstacle mark on the pier if upstream bed-load transport is taking place in the watercourse.
Sediment transport in running waters

Sediment transport in running waters (suspended load transport or bed-load transport) can be demonstrated and studied with four GUNT units. For balancing a watercourse it is usually only the bed-load transport that transports or deposits sediment in a control volume that is relevant. Suspended matter passes the control volume and therefore is not part of the transport balance.

Suspended load transport is only relevant to the transport balance if the flow velocity is very small, so that suspended matter can settle out. Suspended load transport is demonstrated with HM 142.

Bed-load transport is demonstrated in HM 166, HM 140 and HM 168. The GUNT experimental flumes HM 160 – HM 163 are also suitable for bed-load transport.

### Suspended load transport

**HM 142**
Separation in sedimentation tanks

In many watercourses fine sediment is in suspension as suspended matter. This suspended matter is not usually taken into account in the transport balance. At very slow flow velocities, it is possible that suspended matter settles. In storage lakes or dams this can lead to undesired siltation. In wastewater treatment plants on the other hand, there are sedimentation tanks where sedimentation is desirable and is used as a separation process for the treatment of wastewater.

- separation of a suspension in the transparent sedimentation tank
- factors affecting the separation process
  - flow velocity
  - concentration of the sediment
- visualisation of the flow conditions with ink

### Bed-load transport

**HM 166**
Fundamentals of sediment transport

- water is delivered in a circulating channel by a paddle
- deepening along a straight section of the channel as the experimental section
- experimental section with transparent side walls, LxWxH: 660x50x150 mm
- variable-speed paddle produces flows at a velocity between 0...1 m/s
- start conditions for sediment transport
- demonstration of ripple and dune formation on the river bed
- fluvial obstacle mark of bridge piers (scour formation and siltation)

**HM 168**
Sediment transport in river courses

- stainless steel experimental flume
- dimensions of the experimental section, LxWxH: 5x0,8x0,25 m
- closed water circuit with pump, inlet and outlet elements
- discharge measurement can be adjusted in two areas:
  - low discharge: 0...2 m³/h (e.g. to observe meanders)
  - discharge up to 70 m³/h (e.g. observe ripple formation)
- open-channel bed-load transport
- scour formation
- ripple formation
- observation of scour formation
- fluvial obstacle marks on structures:
  - various bridge piers
  - island

**HM 140**
Open-channel sediment transport

- inclining experimental section with transparent side walls
- length of the experimental section: 1600 mm
- flow cross-section W x H: 300 x 86 mm
- inclination adjustment: -1...+3%
- discharge measurement can be adjusted by valve
- closed water circuit with pump, inlet and outlet element
- open-channel bed-load transport
- observing bed forms: ripples, dunes, antidunes
- sediment transport at structures:
  - bridge piers
  - sluice gate
- also:
  - basic principles of open-channel flow without sediment transport

Dune migration: the sediment migrates upwards through the flow on the upstream side to remain lying downstream.

Erosion and siltation in the river bed
HM 166
Fundamentals of sediment transport

Description
- sediment transport in open channels
- circulating flow channel with transparent side walls as open channel
- observing ripple formation and fluvial obstacle marks

In many real open channels there is sediment transport that affects the flow behaviour. Normally the key component is bed-load transport. HM 166 uses sand to demonstrate important phenomena of bed-load transport in the area near the bottom. The transparent experimental section allows observation of the formation of ripples in the river bed.

HM 166 consists of a circulating, oval, transparent flow channel. A deepening for holding the sediment in the longitudinal side of the channel forms the experimental section. The other longitudinal side contains a paddle wheel that produces the flow. A flow straightener at the inlet to the experimental section ensures low-turbulence flow.

The speed of the paddle can be adjusted in order to study how the flow velocity affects the bed-load transport. Flow velocities can be generated in the region of critical discharge (without sediment). The paddle is driven by an electric motor and a belt drive. Motor and speed adjustment are located under the base plate and are water resistant.

The fluvial obstacle mark, i.e. scour formation and siltation at bridge piers, is observed at three different pier models, which are inserted into the experimental section.

Learning objectives/experiments
- observation of
  - starting conditions for bed-load transport
  - how flow velocity affects bed-load transport
  - ripple and dune formation on the river bed
  - fluvial obstacle mark of bridge piers (scour formation and siltation)
  - secondary flows in channel bends
- additionally with fine sand
  - observation of solid matter flows
  - how sediment size and density affect sediment transport

Specification
[1] experimental unit for bed-load transport in open channels
[2] transparent, circular, oval flow channel as open channel
[3] variable-speed paddle to generate the flow velocity
[4] experimental section with transparent deepening for holding the sediment
[5] low-turbulence flow at the inlet to the experimental section thanks to a flow straightener
[6] paddle driven via electric motor and belt drive
[7] three different bridge piers for observing fluvial obstacle marks on piers

Technical data
Experimental section
- length: 660mm
- cross-section WxH: 50x200mm
- deepening: 50mm
Flow channel
- height: 150mm
- width: 50…72mm
Paddle
- 12 blades
- Ø 330mm
- speed at the paddle: 5,2…70min⁻¹
Measuring ranges
- flow velocity: approx. 0…1m/s

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 1030x410x560mm
Weight: approx. 42kg

Scope of delivery
1 experimental unit
3 piers
1 sand (5kg, 1…2mm grain size)
1 set of accessories
1 set of instructional material
Open-channel sediment transport

**HM 140**

**Description**

- Flow in an inclinable flume with and without bed-load transport
- Subcritical and supercritical flow
- Siltation and scour formation at a bridge pier or sluice gate

HM 140 uses sand as an example to demonstrate important phenomena of bed-load transport in the area near the bottom. Open-channel flow without sediment transport is also possible. Discharge can be subcritical or supercritical.

The core element of the HM 140 experimental flume with closed water circuit is the inclining experimental section. The side walls of the experimental section are made of tempered glass, which allows excellent observation of the experiments. All components that come into contact with water are made of corrosion-resistant materials (stainless steel, glass reinforced plastic). The flume is designed so that the flow enters the experimental section with very little turbulence and no sediment can flow back. The tank after the water outlet contains a sediment trap for coarse sand.

The inclination of the experimental flume can be finely adjusted to produce slope and to create a uniform flow at a constant discharge depth.

In addition to bed-load transport, in open channels, some models can also be used to observe fluvial obstacle marks, namely scour formation and siltation at structures. A rounded-nosed pier or sluice gate can be inserted into the experimental section.

The discharge is measured via a measuring weir in the water outlet and a level gauge.

A contrast medium can be injected to visualise the flow conditions.

**Learning objectives/experiments**

- Bed-load transport in open channels
- Subcritical and supercritical flow
- Formation of ripples, dunes and antidunes
- How flow velocity affects bed-load transport
- Fluvial obstacle mark (siltation/scour formation)
- Bridge pier
- Sluice gate
- Visualisation of the flow
- Open-channel flow without sediment transport
- Subcritical and supercritical flow
- Control structure: sluice gate
- Discharge measurement on the sharp-crested weir

**Specification**

1. Investigation of open-channel flow with and without bed-load transport
2. Experimental flume, consisting of experimental section, inlet element, water outlet and closed water circuit
3. Smoothly adjustable inclination of the experimental section
4. Side walls of the experimental section are made of tempered glass for excellent observation of the experiments
5. All surfaces in contact with water are made of corrosion-resistant materials
6. Flow-optimised inlet element for low-turbulence entry to the experimental section
7. Closed water circuit with water tank with sediment trap for coarse sand, pump and manual flow rate adjustment
8. Sluice gate and bridge pier for experiments with and without sediment transport
9. Visualisation of the flow using a contrast medium
10. Discharge measurement via measuring weir in the water drain
11. Level gauge for measuring the discharge depth

**Technical data**

- **Experimental section**
  - Length: 1600mm
  - Flow cross-section WxH: 86x300mm
  - Inclination adjustment: -1°…+3°
  - Tank: 280L
- **Pump**
  - Power consumption: 1.02kW
  - Max. flow rate: 22.5m³/h
  - Max. head: 13.7m
  - Sediment trap filter element
  - Aperture size: 0.3mm (49mesh)

- **Sediment transport**
  - 230V, 50Hz, 1 phase
  - 230V, 60Hz, 1 phase
  - 120V, 60Hz, 1 phase
- **UL/CSA optional**
  - LxWxH: 3450x650x1200mm
  - Weight: approx. 215kg

**Scope of delivery**

1. Experimental flume
2. Sluice gate
3. Rounded-nosed pier
4. Measuring weir
5. System for flow visualisation
6. Level gauge
7. Tool for smoothing sand
8. Set of instructional material

**Required for operation**

- Sediment: sand (1…2mm grain size)
Sediment transport in river courses

Description

- open-channel bed-load transport
- observing the formation of meanders
- observing fluvial obstacle marks on structures
- movable point gauge for profile measurement in the sediment

HM 168 demonstrates important phenomena of bed-load transport in the area near the bottom at subcritical discharge. The large dimensions of the experimental section enable the modelling of river courses with and without structures.

The core element of the HM 168 experimental flume is the stainless steel experimental section. A sediment layer up to 10cm high covering an area of 5x0.8m allows bed-load transport to be studied.

Profile measurement in the sediment along the bottom and the determination of the discharge depth at each point on the experimental section is done via a movable instrument carrier and a point gauge. The discharge is measured via an electromagnetic flow meter.

In addition to bed-load transport in open channels without structures, some models can also be used to observe fluvial obstacle marks, namely scour formation and siltation at structures. A bridge pier, a plate weir or an island can be inserted into the experimental section. You can also design your own models using deflection plates and angular steel.

Learning objectives/experiments

- bed-load transport in open channels
- how flow velocity affects bed-load transport
- ripple formation on the river bed
- observing the formation of meanders
- fluvial obstacle marks on structures
  - bridge pier with rectangular profile
  - rounded-nosed bridge pier
  - pointed-nosed bridge pier
- island (round or rectangular)

HM 168

Specification

1. open-channel bed-load transport
2. experimental flume with experimental section, inlet element, outlet element, closed water circuit, 1 set of models
3. closed water circuit with water tank with sediment trap, pump, and electromagnetic flow meter
4. experimental section with grooves for plate weirs to realise different flow conditions
5. measurement of profiles along the bottom with moveable instrument carrier and point gauge
6. inlet element with plate weir to protect against sediment flowing back
7. models supplied 3 bridge piers, 2 islands, set of deflection plates (for your own model ideas)
8. sediment trap with filter element for sand
9. experimental section, inlet and outlet element made of stainless steel

Technical data

Experimental flume
- stainless steel
- dimensions of the experimental section: 5000x800x250mm

Pump
- power consumption: 2.2kW
- max. head: 11.5m
- max. flow rate: 74m³/h

Storage tank, content: approx. 1000L

Sediment trap filter element
- aperture size: 0.3mm (49mesh)

Flow meter
- measuring range: 80m³/h

400V, 50Hz, 3 phases
400V, 60Hz, 3 phases; 230V, 60Hz, 3 phases
UL/CSA optional

LxWxH: 6250x1000x1300mm

Empty weight: approx. 680kg

Required for operation

- sediment: sand (1…2mm grain size), approx. 1m³

Scope of delivery

1. experimental flume
2. inlet element, 2 valve, 3 sensor for flow rate, 4 pump, 5 controls, 6 water tank, 7 outlet element with sediment trap, 8 experimental section
Separation in sedimentation tanks

Description

- transparent sedimentation tank for observation of the separation process
- illumination for optimum visualisation of the flow conditions
- possible to use lamellas in the sedimentation tank

In sedimentation tanks, solids are separated out from suspensions under the influence of gravity. In this process the density of the solid particles must be greater than that of the liquid. HM 142 makes it possible to investigate the separation of solids from a suspension in a sedimentation tank.

First a concentrated suspension is prepared in a tank, comprising water and the solid to be separated. A pump transports the concentrated suspension to the sedimentation tank. Upstream of the sedimentation tank the suspension is mixed with fresh water. The raw water generated in this way flows into the sedimentation tank via an inlet weir. A stirring machine is located upstream of the inlet weir. This prevents solids sedimenting before entering the sedimentation tank. The treated water first flows under a baffle and then over a weir to the outlet weir. This prevents solids sedimenting in this way flows into the sedimentation tank.

A lamella unit can be inserted into the experimental section. This makes it possible to study how lamellas affect the separation process. The flow through the lamellas occurs from bottom to top. Above the lamellas is an outlet channel. The side walls of the outlet channel are designed as a serrated weir.

Learning objectives/experiments

- basic principle for the separation of solids from suspensions in a sedimentation tank
- determine the hydraulic loading rate
- influence of the following parameters on the separation process:
  - concentration of solids
  - flow rate
  - flow velocity in the inlet
  - water level in the sedimentation tank
- investigation of the flow conditions
- how lamellas affect the sedimentation process

The height of the weir on the outlet side is adjustable and allows the water level in the sedimentation tank to be changed. The water level above the inlet weir can also be adjusted. This affects the flow velocity over the inlet weir.

The flow rates of the concentrated suspension and the fresh water are adjusted via valves. This means the mixing ratio, and thus the concentration of solids in the inlet to the sedimentation tank, can be adjusted. An electromagnetic flow rate sensor measures the flow rate in the inlet of the sedimentation tank. Flow rate and speed of the stirring machine are displayed digitally. The sedimentation tank is equipped with lighting to better observe the flow conditions.

HM 142
Separation in sedimentation tanks

Specification

1. separation of suspensions by sedimentation in the sedimentation tank
2. transparent sedimentation tank with lighting for visualisation of the flow conditions
3. stirring machine in the inlet area of the sedimentation tank
4. lamella unit can optionally be inserted into the sedimentation tank
5. tank with pump and stirring machine to create and transport a concentrated suspension
6. mixture of the concentrated suspension with fresh water gives the raw water to be studied
7. adjustment of the concentration of solids via valves for fresh water flow rate and suspension flow rate
8. adjustable water level in the sedimentation tank and adjustable flow velocity in the inlet
9. electromagnetic flow rate sensor for raw water
10. Imhoff cones for determining settleable substances of a water sample

Technical data

Sedimentation tank (experimental section)
- LxWxH: 900x110x300mm
- max. filling capacity: approx. 25L
- material: plexiglass

Lamella unit
- angle of inclination of lamellas: 60°
- number of lamellas: 16

Suspension tank
- capacity: approx. 85L
- material: stainless steel

Pump
- max. flow rate: 75L/h

Stirring machines (max. speed)
- suspension tank: 800min⁻¹
- sedimentation tank: 500min⁻¹

Measuring ranges
- flow rate: 30–600L/h
- 230V, 50Hz, 1 phase
- 230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
- UL/CSA optional
- LxWxH: 2300x790x1540mm
- Weight: approx. 200kg

Required for operation
- water connection, drain

Scope of delivery
- trainer
- set of accessories
- packing unit of solids
- set of instructional material
In hydrology, seepage flow refers to the flow of a fluid (water) in permeable soil layers such as sand. The fluid fills the pores in the unsaturated bottom layer and moves into the deeper layers as a result of the effect of gravity. The soil has to be permeable so that the seepage water is not stored.

The permeability of the soil is described by the permeability coefficient $k_f$ in m/s and is dependent on the grain size and the useful pore space. In less permeable soils the seepage water can be stored temporarily. If the seepage water encounters an impermeable soil layer or impermeable rock, seepage will no longer take place and the seepage water accumulates permanently. Such underground water accumulations are known as groundwater.

We talk about groundwater when the water resource is available all year round. It is called accumulated water if the water resource only occurs for part of the year, for example after the snow melts or after heavy precipitation over compressed soil layers.

Groundwater is a natural commodity that is used for drinking and mineral water. Furthermore, it represents an important buffer in the total water cycle.

Different types of groundwater

1. Water-unsaturated, aerated soil layer
2. Water-saturated soil layer, all pores are filled with water
3. Impermeable soil layer (rock)
4. Less permeable soil layer
5. Water-saturated soil layer (groundwater)

The effect of seepage flows when flowing through dams or flowing around structures in the water is a key factor in civil engineering. For example, the hydrostatic pressure that forms in the accumulated water can exert stress on structures to a large degree, such as the buoyancy in deep structures (underground garage).

Incident flow from wells or drainage facilities can also be described by the physical principles of seepage flow.

Seepage flows must not be ignored in the preservation of groundwater, in order to avoid contamination by construction, fertilizers, chemicals or mineral oils.

In engineering, flow processes such as those that occur in seepage flows are used in filter technology. In this case, fluid flows through a pore space for the purposes of cleaning or separation of media.
Flow processes in soils

The flow processes take place in the water-saturated soil layers, the groundwater and accumulated water, as well as above the groundwater, in the seepage water. The cause of water movements in the soil are differences in potential. In this case, the water always moves from points of higher potential, i.e. higher potential energy, to points with lower potential. The water moves until an equilibrium between the potentials is established.

Precipitation, groundwater extraction and evapotranspiration (evaporation from the free surface and release of water vapour from plants) constantly disrupt a potential equilibrium. Soil water is rarely in a static state of equilibrium. The movement of water also depends on the permeability of the soil being flowed through.

The permeability is described by the coefficient of permeability \( k_f \) in m/s and is dependent on the grain size and the useful pore space.

<table>
<thead>
<tr>
<th>( k_f ) in m/s</th>
<th>Soil layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10^{-8}</td>
<td>very slightly permeable</td>
</tr>
<tr>
<td>10^{-8} to 10^{-6}</td>
<td>slightly permeable</td>
</tr>
<tr>
<td>&gt; 10^{-6} to 10^{-4}</td>
<td>permeable</td>
</tr>
<tr>
<td>&gt; 10^{-4} to 10^{-2}</td>
<td>highly permeable</td>
</tr>
<tr>
<td>&gt; 10^{-2}</td>
<td>very highly permeable</td>
</tr>
</tbody>
</table>

Mathematical determination of flow processes

Due to the inhomogeneity of the soil flowed through, it is extremely difficult to accurately determine the flow processes. Therefore idealised conditions are assumed when calculating the flow processes. For the majority of the problems that occur, Darcy’s law is sufficiently accurate. According to Darcy, the filtration velocity \( v \) is proportional to the specific energy \( \Delta h \) that is removed over the length \( L \). The dimensionless variable \( \Delta h/L \) is denoted as the hydraulic gradient \( i \). Darcy’s law is:

\[
v = k_f \frac{\Delta h}{L} = k_f i
\]

The application of Darcy’s law assumes a homogeneous substrate for the entire flow area, in which there is generally a laminar flow with Reynolds numbers 1...10.

Seepage velocity as a function of soil capacity in water-unsaturated soils

<table>
<thead>
<tr>
<th>( v )</th>
<th>Soil layer</th>
<th>Grain size</th>
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</thead>
<tbody>
<tr>
<td>5 m/year</td>
<td>gravel</td>
<td>2...63 mm</td>
</tr>
<tr>
<td>2...4 m/year</td>
<td>sand</td>
<td>0,063...2 mm</td>
</tr>
<tr>
<td>1 m/year</td>
<td>silt</td>
<td>0,002...0,063 mm</td>
</tr>
<tr>
<td>several cm/year</td>
<td>clay</td>
<td>&lt; 0,002 mm</td>
</tr>
</tbody>
</table>

Reynolds number:

\[
Re = \frac{d \cdot v}{\nu} < 10
\]

Graphical determination of flow processes

The analysis of seepage flow through a dam, a ditch for excavation or under a weir, as well as the determination of groundwater flow in sinks and sources can be done via drawings using a flow net, also known as a potential net. Darcy’s law is again used as a basis for determining the flow net. The evaluation determines seepage flow rate, pressure distribution on the structure being observed and other safety considerations.

Structure of a flow net

The streamlines in a flow net are drawn in two dimensions. The potential lines connect the points with the same potential, in this case the same water levels. The streamlines run perpendicular to the potential lines, because the water flows on the shortest route from the higher potential to the low potential.

Groundwater flow around a sheet pile

Seepage flows cannot be directly observed, since they take place in the non-visible porous medium. All of these processes can only be made “visible” by using laboratory models or with suitable measurement devices.
Experimental units
Seepage flow, groundwater flow and filtration

Basic experiments

HM 152
Potential flow
- simulation of two-dimensional, inviscid potential flow in a Hele-Shaw cell
- visualisation of streamlines using a contrast medium
- influence of sources and sinks on the streamlines

Flow pattern with a source

Flow pattern with a sink

HM 167
Groundwater flow
- groundwater levels over time with one and more outlets
- various models allow the study of water inrush into dikes and excavation ditches
- lowering of groundwater in excavation ditches

Groundwater level over time in a sand bed with one outlet
A water supply, B water drain; blue arrows flow direction

CE 116
Cake and depth filtration
- seepage flow in a filter
- different suspensions and filter medium layers
- application of Darcy’s law to determine the filtration velocity

Depth filtration

Cake filtration

HM 169
Visualisation of seepage flows
- groundwater levels over time with one and more outlets
- various models allow the study of water inrush into dikes and excavation ditches
- lowering of groundwater in excavation ditches

Flow net under a sheet pile

Relationship between precipitation, seepage and groundwater flow

HM 141
Hydrographs after precipitation
- precipitation-drain relationship
- precipitation time, lag time and measurement time can be adjusted via separate timers
- effect of rainwater retention basin

L/h

HM 165
Studies in hydrology
- precipitation-drain relationship
- seepage flows and groundwater flows in soils
- supply and drain over a large area (groundwater)
- lowering of groundwater via wells and drainage

Groundwater level over time in a sand bed with two wells
A water supply, B water drain through wells; blue arrows flow direction

HM 145
Advanced hydrological investigations
- precipitation-drain relationship
- seepage flows and groundwater flows in soils
- supply and drain (groundwater and running waters) over a large area and at individual points
- lowering of groundwater via wells and drainage
- sediment transport and obstacles in running waters
- GUNT software for data acquisition of the water supplies and drains and the amount of sediment as a function of time

Software screenshot:
Water drain for persistent rain with saturation of the soil
A precipitation, B drain
Potential flow

Sources and sinks are generated via eight water connections in the bottom glass plate. The streamlines are displayed on the glass plate by injecting a contrast medium (ink).

In experiments the flow around bodies is demonstrated by inserting models into the parallel flow. Interchangeable models such as a cylinder, guide vane profile or nozzle contour are included.

To model the flow without models, it is possible to overlay parallel flow, sources, sinks and dipoles as required. This allows the demonstration of the formation of Rankine half-bodies.

The water flow rate and the quantity of contrast medium injected can be adjusted by using valves. The water connections are also activated by valves and can be combined as required.

**Learning objectives/experiments**

- Visualisation of streamlines in:
  - Flow around drag bodies: cylinder, guide vane profile, square, rectangle
  - Flow through models: nozzle contour, sudden contraction or enlargement
  - Flow separation, flow with 90° deflection
- Modelling the flow around bodies by overlaying parallel flow and sources and/or sinks
- Formation of Rankine half-bodies
- Demonstration of a dipole
- Analogy between potential flow and other physical systems which are described by the Laplace equation

**Description**

- Two-dimensional, inviscid potential flow
- Visualisation of streamlines
- Flow around different models: drag bodies and changes in cross-section
- Modelling the flow around bodies by overlaying the parallel flow and sources and/or sinks
- Sources and sinks, individually or in combination

The laminar, two-dimensional flow in HM 152 is a good approximation of the flow of ideal fluids, the potential flow. All physical systems described with the Laplace equation can be demonstrated with potential flow. This includes current and thermal flows as well as magnetic flux.

The core element of the HM 152 trainer is a classic Hele-Shaw cell with additional water connections for sources and sinks. The laminar, two-dimensional flow is achieved by water flowing at low velocity in a narrow gap between two parallel glass plates. The parallel flow generated in this way is non-vertical and can be regarded as potential flow.

**Specification**

- Demonstration of potential flow in a Hele-Shaw cell for visualising streamlines
- Flow around supplied models: cylinder, square, rectangle, guide vane profile, various models for changes in cross-section
- Modelling the flow around contours without models by overlaying parallel flow with sources or sinks
- Water as flowing medium and ink as contrast medium
- Hele-Shaw cell made of two glass plates arranged in parallel with narrow gap
- Upper glass plate, hinged for swapping models
- Bottom glass plate with cross-shaped water connections for generating sources/sinks, can be combined as required
- Grid in the bottom glass panel for optimal observation of the streamlines
- Flow velocity, water inlet and water outlet in sources/sinks as well as dosage of the contrast medium can be adjusted by using valves

**Technical data**

- 2 glass plates, LxW: 910x585mm
- Distance between the plates: 5mm
- Bottom glass plate with eight water connections for sources/sinks
- 6 drag bodies
- 2 changes in cross-section
- Material: rubber
- Thickness: 5mm
- Injection of the contrast medium (ink)
- 19 nozzles

**Required for operation**

- Water connection 30L/h, drain

**Scope of delivery**

- 1 trainer
- 1 set of models
- 1 ink (1L)
- 1 set of instructional material
**HM 165**

**Studies in hydrology**

**Description**

- precipitation-drain relationship
- seepage flows and groundwater flows in soils
- supply and drain over a large area

In civil engineering, studies in hydrology are conducted in connection with the design, construction and operation of hydraulic engineering systems and water management functions. These studies focus on topics such as seepage and flow of water in the soil and the use of groundwater resources.

HM 165 can be used to study seepage and groundwater flows after precipitation. Variable precipitation density and areas and different groundwater supply and drain possibilities allow a wide variety of experiments.

**Learning objectives/experiments**

- investigating transient processes
  - effect of rainfall of varying duration on the discharge
  - storage capacity of a soil

- investigating steady processes
  - investigating seepage flow
  - effects of wells on the groundwater level over time

HM 165 contains a closed water circuit with storage tank and pump. The core element is a sand-filled, stainless steel experiment tank with inclination adjustment. To study precipitation, a precipitation device is available. The precipitation device consists of two groups of four nozzles. Water can flow in (groundwater) or out (drainage) via two chambers on the side. The experiment tank is separated from the chambers by fine mesh screens. To study the lowering of groundwater, two wells with open seam tubes are available. Water supply and water drain can be opened and closed, thus allowing a wide variety of experimental conditions.

At the bottom of the experiment tank there are measuring connections to detect groundwater levels, which are displayed on 19 tube manometers. The water supply is controlled by a valve and read on a flow meter. The water drain is determined by a measuring weir.

**Specification**

1. investigation of precipitation-discharge relationships, storage capacity of soils, seepage flows and groundwater flows
2. closed water circuit
3. inclined stainless steel experiment tank contains 19 measuring connections to detect groundwater levels, transparent splash guard and screens for separating the chambers
4. 2 wells with open seam tubes in the experiment tank
5. precipitation device with 8 nozzles, adjustable
6. water supplies and drains can be selected individually
7. transparent measuring tank (flow)
8. instruments: tube manometers (groundwater), flow meter (supply) and measuring weir in the measuring tank (drain)

**Technical data**

**Experiment tank**

- area: 2x 1m², depth: 0,2m
- max. sand filling: 0,3m³
- inclination adjustment: -2,5…5%

**Precipitation device**

- 8 nozzles, switchable in 2 groups of 4 nozzles
- flow rate per nozzle: 1…4,7L/min, square spray pattern

**Pump**

- power consumption: 0,55kW
- max. flow rate: 2000L/h

**Storage tank, stainless steel: content 180L**

**Measuring ranges**

- pressure: 19x 0…300mmWC
- flow rate:
  - 1x 150…1700L/h (water supply)
  - 1x 0…1700L/h (water drain)

230V: 50Hz, 1 phase
230V: 60Hz, 1 phase
120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 2400x1100x1800mm
Empty weight: approx. 310kg

**Required for operation**

- sand (1…2mm grain size)

**Scope of delivery**

1. trainer
2. set of instructional material
HM 167

Groundwater flow

Specification

1. Investigation of groundwater flows
2. Stainless steel tank as experimental section to be filled with coarse sand
3. Water supply via 2 open-seam tubes
4. Water drain via 2 wells with open-seam tubes in the experimental section
5. Water feeds and discharges can be adjusted separately via valves
6. 19 measuring connections with filters to detect the groundwater levels, arranged orthogonal to the tank bottom
7. 2 different models for excavation pits
8. 1 model for structure with waterproof bottom
9. Groundwater levels displayed on the 19 tube manometers

Technical data

Tank
- Material: stainless steel
- Content, LxWxH: 1000x615x350mm
- 19 measuring connections at the bottom of the tank

Plastic models
- Excavation pit, LxWxH: 610x464x150mm
- Excavation pit, LxWxH: 256x464x150mm
- Structure with waterproof bottom ØxH: 180x150mm, inner tube ØxH: 40x330mm

Measuring ranges
- Pressure: 19x 0…300 mm WC

Weight: approx. 125 kg

Required for operation
- Water connection, drain
- Sand (1…2 mm grain size)

Scope of delivery
- 1 trainer
- 3 models
- 1 set of hoses
- 1 set of instructional material

Description

- Investigation of groundwater flows
- Demonstration of lowering of groundwater
- Investigation of excavation pits

Groundwater flows consist, among other things, of the extraction of groundwater from wells and excavation pits. An understanding of the hydrological principles of groundwater flow is useful when designing reliable structures such as excavation pits or drainage systems.

HM 167 allows three-dimensional investigations of groundwater flows. The trainer consists of a tank with a sand filling. Various models can be placed in the sand bed.

The water is supplied to the tank via two horizontal open-seam tubes that can be activated separately via valves. This results in various experiment possibilities with flowing groundwater. The investigation of various extractions is facilitated by two wells with open-seam tubes, which are also activated individually via valves. Three different models allow the study of excavation pits.

At the bottom of the tank there are orthogonally arranged measuring connections to detect groundwater levels. Groundwater levels are displayed on 19 tube manometers.

Learning objectives/experiments

- Determining the groundwater level
- Lowering of groundwater level via two wells
- Groundwater flow on excavation pits
- Groundwater studies under concentric load on the substrate

Arrangement of the measuring points and wells:
1. Water inlet via open-seam tube, 2 measuring points, 3 water drain via open-seam tube (well), blue: water inlet, red: water drain

Groundwater level over time with one well: 1 water inlet via open-seam tube, 2 sand bed, 3 well with open-seam tube. Diagram: blue: groundwater level over time, red: well, 14-15 measuring points on the bottom in the sand bed.
HM 169
Visualisation of seepage flows

Description
- visualisation of two-dimensional seepage and groundwater flows
- investigation of the water pressure on structures
- closed water circuit

A descriptive method in the study of seepage and groundwater flow is the visualisation of the streamlines and their graphical representation as a flow net. The flow net provides information about the seepage of water in dams and sheet piles.

HM 169 can be used to visualise streamlines in seepage and groundwater flow on different models using a contrast medium. Furthermore, the effects of water pressure on different structures are displayed as pressure curves.

The trainer consists of a transparent tank with a sand filling. Various models can be placed in the sand bed to demonstrate typical structures. The experimental section is separated from the feed and discharge chambers by fine mesh screens. A valve is used to adjust the water supply. Using a contrast medium it is possible to make streamlines visible, as they occur in seepage and groundwater flow. A tempered glass viewing window allows for optimal observation of the experiments.

Various models allow an extensive range of experiments, such as pressure distribution on retaining walls or seepage and groundwater flow under sheet piles. The "foundation" and "retaining wall" models are equipped with tubes to show the pressures on the models.

In the experimental section there are measuring connections to detect groundwater levels. Groundwater levels are displayed on 14 tube manometers.

HM 169 contains a closed water circuit with storage tank and pump.

Learning objectives/experiments
- determining flow nets in permeable media graphically
- streamlines under a sheet pile
- streamlines through an earth dam
- drainage at an open ditch
- determining the pressure curve at a foundation
- determining the pressure curve at a retaining wall
- groundwater levels over time in various models

Specification
[1] visualisation of two-dimensional seepage flows and investigation of water pressure at various models
[2] closed water circuit
[3] fluoresceine as a contrast medium
[4] experimental section with tempered glass viewing window
[5] fine-mesh screen to separate the experimental section from the feed and discharge chamber
[6] height-adjustable overflows in the feed and discharge to adjust the water levels
[7] 14 measuring connections with filters to detect the groundwater levels in the experimental section
[8] "sheet pile" model for visualisation of streamlines
[9] "retaining wall" and "foundation" models for demonstration of the water pressure
[10] instruments: tube manometers, tubes on the "foundation" and "retaining wall" models

Technical data
- Experimental section
  - usable volume: 82L
  - LxWxH: 1480x104x630mm
- Pump
  - max. flow rate: 4m³/h
  - max. head: 4m
- Tank for contrast medium: 0,5L
- Storage tank, stainless steel: 96L
- Models
  - "sheet pile"
  - "retaining wall"
  - "foundation"
- Measuring ranges
  - pressure: 14x 20…650mmWC
  - 230V, 50Hz, 1 phase
  - 230V, 60Hz, 1 phase
  - 120V, 60Hz, 1 phase
  - UL/CSA optional
  - LxWxH: 1900x800x1870mm
- Weight: approx. 230kg

Required for operation
- sand (1…2mm grain size)

Scope of delivery
- 1 trainer
- 1 set of models
- 1 contrast medium, 1L
- 1 set of instructional material
Advanced hydrological investigations

Description

- Seepage flows and groundwater flows in soils
- Supply and drain (groundwater and running waters) over a large area and at individual points
- Sediment transport and obstacles in running waters

HM 145 can be used to study seepage and groundwater flows after precipitation. Furthermore, sediment transport in courses of rivers is also presented in the context of flow obstacles. Variable precipitation density and areas and different groundwater supply and drain possibilities allow a wide variety of experiments.

HM 145 contains a closed water circuit, with storage tank and pump. The core element is a sand-filled, stainless steel experiment tank with inclination adjustment. To study precipitation, a precipitation device is available, which is equipped with a timer to define the times of precipitation. The precipitation device consists of two groups of four nozzles. Water can flow in (groundwater) or out (drainage) via two chambers on the side. The experiment tank is separated from the chambers by fine mesh screens. To study the lowering of groundwater, two wells with open seam tubes are available. By means of a small weir in the supply and drain, a course of a river can be generated. Different water levels can be generated. Water supply and water drain can be opened and closed, thus allowing a wide variety of experimental conditions. In addition, three different models make it possible to study the flow around obstacles and the resulting sediment transport in the river bed.

At the bottom of the experiment tank there are measuring connections to detect groundwater levels, which are displayed on 19 tube manometers. Two flow meters with different measuring ranges indicate the supply to the experiment tank. A measuring tank at the drain contains a measuring weir for determining the water level and a force sensor for determining the amount of sediment.

The measured values are indicated at the trainer. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included.

Learning objectives/experiments

- Investigating transient processes
  - Effect of rainfall of varying duration on the discharge
  - Storage capacity of a soil
- Investigating steady processes
  - Seepage flow
  - Effects of wells on the groundwater level over time
- Flow behavior of rivers, obstacles in the river bed, sediment transport in rivers

HM 145

Advanced hydrological investigations

Specification

1. Investigation of precipitation-discharge relationships, storage capacity of soils, seepage flows, groundwater flows and sediment transport.
2. Closed water circuit.
3. Inclinable stainless steel experiment tank contains 19 measuring connections to detect groundwater levels, transparent splash guard and screens for separating the chambers.
4. 2 wells with open seam tubes in the experiment tank.
5. Precipitation device with 8 nozzles, adjustable.
6. Precipitation time can be adjusted via timer.
7. Water supplies and drains can be selected individually.
8. Transparent measuring tank (flow) and force sensor (determining the amount of sediment).
9. 3 models for pillars: round, square, oval.
10. Instruments: tube manometers (groundwater), flow meter (5x at the supply) and measuring weir in the measuring tank (1x at the drain).
11. GUNT software for data acquisition via USB under Windows 7, 8, 10.

Technical data

Experiment tank, inclination adjustment: -1...5%
- Area: 2 x 1 m² - depth: 0.2 m, max. sand filling: 0.3 m³
Precipitation device
- 8 nozzles, switchable in 4 groups of 2 nozzles.
- Flow rate: 1...4.7 L/min, square spray pattern.
Pump
- Power consumption: 0.55 kW.
- Max. flow rate: 1500 L/h.
Storage tank, stainless steel: 290 L.

Measuring ranges
- Pressure: 1 Bar 0...300 mm WC.
- Flow rate:
  - 0...100 L/h, 0...300 L/h (water drain).
  - 0...1000 L/h, 0...320 L/h (water supply).
- Sediment mass: 0...5 kg.

230V, 50Hz, 1 phase.
230V, 60Hz, 1 phase.
120V, 60Hz, 1 phase.
UK/USA optional.
LwWft: 2300x1100x1950 mm.
Empty weight: approx. 350 kg.

Required for operation
- Sediment: sand (gran size: 1...2 mm).
- PC with Windows recommended.

Scope of delivery
- 1 trainer
- 1 set of models
- 1 GUNT software CD + USB cable
- 1 set of instructional material.
### Description

**HM 141** produces precipitation of varying duration and intensity. The storage capacity of soils with different saturation is also examined. Using various drainage methods, it is possible to demonstrate the correlations between precipitation and seepage.

The trainer includes a tank with a sand filling, which is flowed through by water. The water is supplied to the tank via a precipitation device with two nozzles that can be adjusted separately via valves. To study different drainages, the water is drained either via a drainage pipe or a drain chamber, which is separated from the experimental section by a screen.

The draining water is distributed over 17 transparent chambers. This creates a profile over time of the water drain. The water levels are measured and plotted in a hydrograph.

Drip pans can be used to demonstrate the lag of the drainage through rainwater retention basins. The water supply is controlled by a valve and read on a flow meter. The timed discharges are adjusted via electronic timers.

Hydrographs are an important tool for the representation of hydrological data such as precipitation, groundwater levels or discharges.

### Learning objectives/experiments

- Effect of precipitation of varying duration or intensity on soils with different saturation
- Record hydrographs after precipitation
- Influence of rainwater retention basin on the hydrograph
- Precipitation, lag time and measurement time can be adjusted via separate timers

### Specification

1. Investigation of the effect of precipitation on soils
2. Stainless steel experimental tank with transparent splash guard
3. Precipitation device with two nozzles, adjustable precipitation area and quantity
4. Precipitation time can be adjusted via solenoid valve with timer
5. Distribution to 17 chambers by timer
6. Mobile sled distributes draining water to 17 chambers in the measuring tank
7. Drain water either via removable drain chamber with fine-mesh screen or via drainage pipe
8. Separate flushing connection for pipelines
9. Drip pans as rainwater retention basins
10. Rotameter (inlet), indicator of precipitation time, lag time and measurement time

### Technical data

**Experimental section**
- Volume: 1500x600x200mm
- Max. sand height: 185mm

**Precipitation device**
- 2 nozzles, individually adjustable
- Flow rate: 1…6,7L/min, square spray pattern
- Precipitation: max. 320L/h

**Measuring tank with 17 chambers**
- Volume: 17x0,9L

**Timers**
- Precipitation: max. 99min59s
- Lag time until start of measurements: max. 99min59s
- Measurement time per chamber: max. 99min59s

4 drip pans: 305x215x55mm
Steel scale: 200mm

**Measuring ranges**
- Flow rate: 30…320L/h

**Required for operation**
- Water connection, drain
- Sand (grain size: 1…2mm)

**Scope of delivery**
- Trainer
- Set of accessories
- Set of instructional material
CE 116
Cake and depth filtration

Description
- cake and depth filtration with different suspensions and filter medium layers

With CE 116 the processes in depth filtration and cake filtration can be observed and investigated. The suspension (water and diatomite as the solid) flows from the hopper into the top of the filter element, where the solids are separated off.

The filtrate flows through a flow meter into the drain. The filter element has a porous filter medium at the bottom. In cake filtration, the filter medium provides the foundation for build-up of the filter cake. In depth filtration, the filter medium supports the bulk solids (filter medium layer; gravel). Twin tube manometers measure the pressure loss over the filter element.

To register the filtrate quantity, the balance CE 116.01 is recommended.

Learning objectives/experiments
- fundamentals of filtration: Darcy’s equation
- depth filtration with different bulk solids and suspensions
- cake filtration with different suspensions
- identification of characteristic filtration values

Specification
1. fundamentals of cake and depth filtration
2. filter element with sintered filter medium on its bottom to capture the particles
3. pressure loss measurement with twin tube manometers
4. height-adjustable filter hopper made of DURAN glass
5. flow meter with needle valve for adjustment

Technical data
- Filter element:
  - filter chamber height: 85mm
  - Ø inner: approx. 37mm
  - cross-sectional area: approx. 11cm²
  - tube material: DURAN glass
- Filter medium, sintered filter SIKA 100
  - pore size: 100μm
  - thickness: 2mm
  - material: sintered metal

Measuring ranges
- flow rate: 40...360mL/min
- pressure: 2x 0...500mmWC
- temperature: -10...100°C
- measuring cup
  - 1x 1000mL, graduation: 10mL
  - 1x 100mL, graduation: 2mL

LxWxH: 450x410x1040mm
Weight: approx. 30kg

Required for operation
- drain

Scope of delivery
1. experimental unit
2. measuring cups
3. stopwatch
4. thermometer
5. sand (1kg 1...2mm)
6. packing unit of diatomite (2kg)
7. set of instructional material

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**Optimal evaluation and analysis of conducted experiments**

The GUNT software always has comprehensive online help explaining the functions and application.

The GUNT software is developed and maintained in-house by a group of experienced engineers.

**Product overview**

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