# Internal Training

**Training Course:** **Water Distribution Management**

**Training Module P4:** **Flow Measurement**

**Version:** **01 July 2022**

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**Training Course:** **Water Distribution Management**

**Training Module P4:** **Flow Measurement**

## 1. Outline of the training module

### 1.1 Background of the training

The ultimate mission of a waterworks system is to properly purify the raw water and to provide customers with a constant supply of hygienic, safe, and necessary amounts of water at the appropriate water pressure.

Since water utilities are in the business of collecting fees for the water they supply to customers, accurately measuring the amount of water produced and supplied is an essential management task.

There are four objectives of flow measurement:

**[Measurement for water distribution management]**

In order to provide an equal and adequate water supply to all water supply areas, operators are required to interrelate the operation of each facility from intake to distribution, and to distribute water volumes and operate facilities in a safe and economical manner.

These target values for water volume allocation and facility operation must be determined in response to changes in seasonal and social conditions, and the previously forecasted and determined planned values are revised and replaced by new planned values according to the water volume allocated on the day of the event, etc.

Therefore, flow measurement, together with water quality testing, is one of the most important tasks in the operation of a water utility.

**[Measurement for facility control]**

At a water treatment plant, the operating conditions of various facilities must be determined according to the amount of conducted raw water. Measurements of raw water intake and filtered water volume are essential for determining the amount of coagulant, chlorine, etc. to be injected.

In addition, the measured inflow rate of the distribution reservoir and the measured volume of water transmitted by the pump are important data for ensuring proper water distribution pressure.

**[Measurement of data indispensable for waterworks management]**

In order for a water utility to ensure its credibility, the data it publishes must be accurate.

Indicators such as effective rate water use, revenue water ratio, operation rate, and load factor are indicators of the current status of waterworks management, and flow measurement is a fundamental part of this process.

**[Storage of data]**

Data measured at various points in the water supply facility must be properly and continuously recorded. Data storage is extremely important in order to identify problems with past water supply projects and areas for improvement in the future.

### 1.2 Purpose of this training

The training aims to provide staff who will be working in water supply service by KUKL with the basic knowledge required for meter reading, production control in the WTPs and the distribution network management.

### 1.3 Target person

- Chief of meter reading (Technical/Administrative)
- Persons newly appointed Level 5 Senior Assistant (Technical)
- Persons newly appointed Level 6 Assistant Officer (Technical)

### 1.4 Timetable

**[Session 1: Lecture]**

- Definition of flow rate
- International standard for water meters
- Water meter accuracy control
- Types and functions of water meters for domestic use
- Types and functions of typical flow meters
- Flow Measuring Weir
- Parshall Flume

**[Session 2: Practice of Flow Measurement]**

- Setting and Installation of ultrasonic flow meter
- Accuracy testing of customer meter

**[Session 3: Achievement test]**

**Table 1.1 Training Timetable**

| Session | Activity | Estimated time | Venue |
|---|---|---|---|
| 1 | Lecture | 120 min | Mahankalchaur Seminar Room |
| | Q&A | 10 min | |
| | Lunch break | 60 min | |
| 2 | Practice of Flow Measurement | 90 min | Mahankalchaur Training Yard |
| | Coffee Break | 20 min | |
| 3 | Achievement test | 30 min | Mahankalchaur Seminar Room |
| | Total | 330 min | |

## 2. Definition of flow rate

### 2.1 How to express the flow rate

Flow rate is the volume or mass of fluid passing through an area per unit time.

There are two types of flow measurement methods: “Volumetric Flow”, which measures water volume, and “Mass Flow”, which measures mass of water.

The volumetric flow rate is the flow rate indexed to the change in volume per unit, while mass flow rate is the flow rate indexed to the change in mass per unit. The difference between the two concepts is as follows:

In general, "Volumetric Flow Rate" is used in many cases, but when measuring vapor or gas, it is sometimes expressed as "Mass Flow Rate" since the volume changes with temperature and pressure.

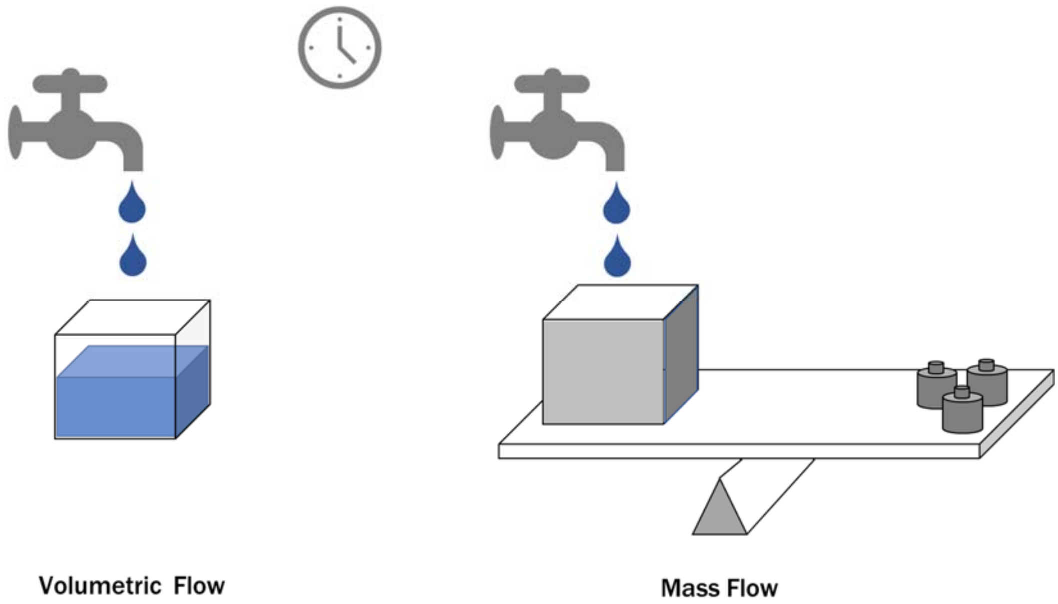



**Figure 2.1 Volumetric Flow and Mass Flow**

### 2.1.1 Volumetric Flow

Volumetric flow rate is a method of determining flow rate from the volume passing through a surface per unit time.

Generally, when we speak of flow rate, we mean volumetric flow rate, expressed in Q ($m^3$/s, L/s etc.).

$Q = A \times V$ A: Fluid passing area ($m^2$)

V: Average velocity of flow perpendicular to the area (m/s)

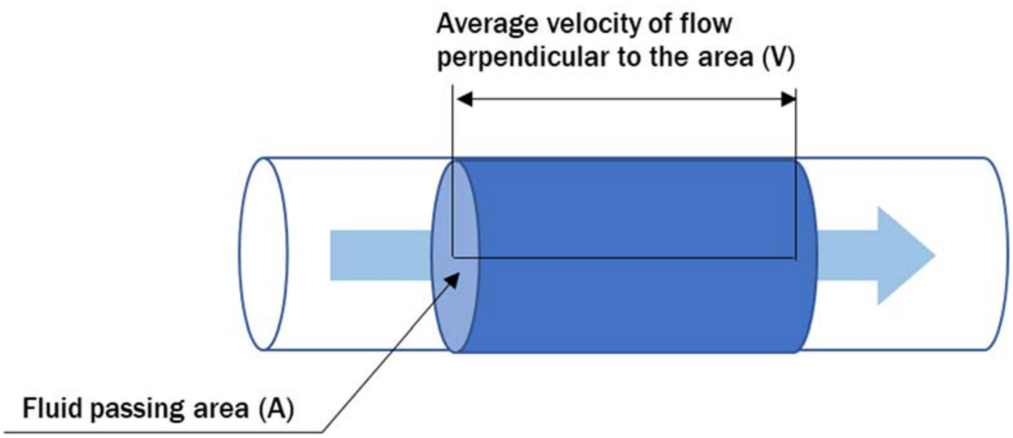



**Figure 2.2 Flow and Flowrate**

### 2.1.2 Unit of volume

In the International System of Units (SI), the unit of "$m^3$ (cubic meter)" is often used.

Note that $cm^3$ is a cubic centimeter (synonymous with cc) and is not an auxiliary unit to $m^3$.

1,000 cc can be expressed as 1 liter (L), and 1 $m^3$ is equivalent to 1,000 L.

**Table 2.1 Conversion table of volume**

| | $m^3$ | L | cc | Gallon (US) |
|---|---|---|---|---|
| $m^3$ | 1 | 1000 | 1,000,000 | 264.17205 |
| L | 0.001 | 1 | 1,000 | 0.26417205 |
| cc | 0.000001 | 0.001 | 1 | 0.00026417 |
| Gallon (US) | 0.003785411784 | 3.785411784 | 3785.411784 | 1 |

### 2.1.3 How to express the water flow

**[Instantaneous Flow]**

Instantaneous flow rate indicates the amount of flow per unit time.

For example, the instantaneous flow rate when 10 liters flow per minute is 10 L/min, and the instantaneous flow rate when 1 liter flows per second is 1 L/sec.

**[Totalized Flow]**

The totalized flow rate indicates the cumulative value of the flowed charge from the start of the measurement. For example, if water is stored in a tank for 1 hour at an instantaneous flow rate of 100 L/min, the totalized flow rate would be 100 L/min x 60 min = 6000 L = 6 $m^3$.

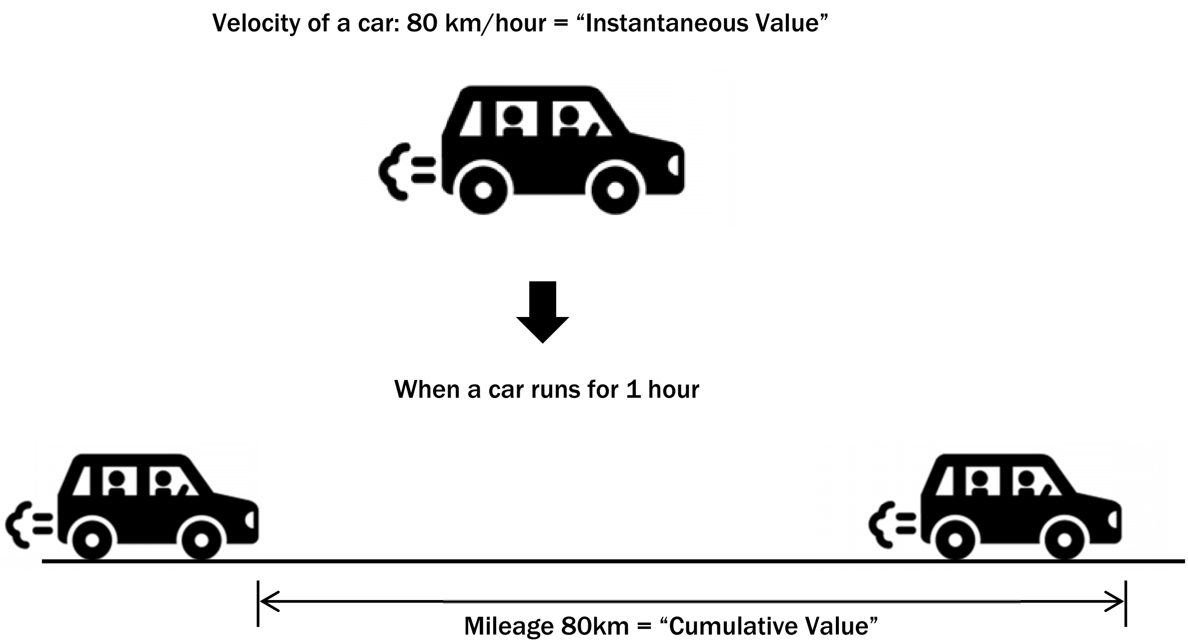



**Figure 2.3 Difference between “Instantaneous flow” and “Totalized flow”**

The units and conversion table for flow rates used in the water supply sector are shown below:

**Table 2.2 Various flow units**

| Unit | Way of reading |
|---|---|
| $m^3/h$ | Cubic meter per hour |
| $m^3/min$ | Cubic meter per minute |
| $m^3/sec$ | Cubic meter per second |
| L/h | Liter per hour |
| L/min | Liter per minute |
| L/sec | Liter per second |
| mL/h | Mili liter per hour |
| mL/min | Mili liter per minute |
| mL/sec | Mili liter per second |

**Table 2.3 Conversion table of flow unit**

| | L/sec | L/min | L/h | $m^3$/h |
|---|---|---|---|---|
| L/sec | 1 | 60 | 3,600 | 3.6 |
| L/min | 0.016667 | 1 | 60 | 0.06 |
| L/h | 0.000278 | 0.016667 | 1 | 0.001 |
| $m^3$/h | 0.2778 | 16.668 | 1,000 | 1 |

## 3. International Standards for Water Meters

In the field of measuring instruments, international unification of technical standards for measuring instruments is being promoted by international organizations such as OIML (International Organization of Legal Metrology) and ISO (International Organization for Standardization) in response to globalization and borderless economic activities.

### 3.1 OIML (International Organization of Legal Metrology)

International harmonization of units of measurement alone will not eliminate technical barriers to international trade in measuring instruments. It is necessary to harmonize internationally the technical standards and conformity assessment procedures of national measuring instruments.

The OIML Convention (Convention establishing an International Organization of Legal Metrology) was concluded in Paris, France, in 1955 with the participation of 22 countries, with the aim of facilitating international trade in measuring instruments through harmonization of the legal metrology regulations of member countries.

The International Bureau of Legal Metrology (BIML) is located in Paris. (http://www.oiml.org/)

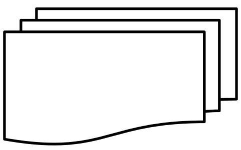
The main activities of the OIML are the formulation and publication of International Recommendations (R) and International Documents (D) and the issuance of OIML Certificates.

International Recommendations are model regulations for measuring instruments. The OIML produces International Recommendations for measuring instruments used in the fields of commerce, health, safety, and the environment.

It administers the OIML Certificate System, which provides a mechanism for OIML member countries to mutually accept and utilize OIML certificates issued by other member countries under a voluntary system introduced in 1991.

Currently, 59 types of international recommendations for measuring instruments are covered by this system. For manufacturers and importers/exporters, it helps to reduce the cost of administrative procedures and testing when importing and exporting measuring instruments.

The water meter-related standards are OIML 49-1, 49-2, and 49-3.



**OIML 49-1 Part1: Metrological and Technical Requirements**
**OIML 49-2 Part2: Test Methods**
**OIML 49-3 Part3: Report Format**

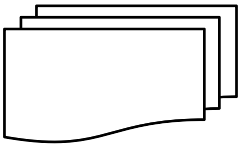
### 3.2 ISO (International Organization for Standardization)

ISO is a private organization with headquarters in Switzerland, which defines "ISO Standards" and has 163 member countries that have published more than 21,600 international standards.

One representative standardization body per country is a member, and Nepal is represented by the following as a member body.

ISO standards are "standards that unify standards on an international scale," which can be paraphrased as "standards that create global standards.

For water meters, it consists of ISO-4064-1, 4064-2, and 4064-3, each in accordance with OIML-49.



ISO 4064-1 Part1: Specification
ISO 4064-2 Part2: Installation Requirements
ISO 4906-3 Part3: Test Methods and Equipment

### 3.3 Nepal Bureau of Standards & Metrology (NBSM)

NBSM is the National Standard Body in Nepal. It is a government organization under the Ministry of Industry. It is also the national enquiry point / nodal point for WTO (TBTs & NTMs) and focal point for National Authority on Disarmament Affairs (NADA).

**[Vision]**

- To provide efficient and timely service.
- To satisfy the customer's need for quality goods and services.
- To raise awareness in the field of standardization & metrology.

**[Objectives]**

- Harmonious development of standardization, marking and quality certification.
- Harmonious development of scientific and legal metrology.
- To facilitate development of production and exports.

The main activities of NBSM are to:

- formulate national standards.
- operate the product certification mark.
- provide testing facilities and technical services in the fields of SMQC.
- work as the third-party guaranteeing agency.
- provide service for lot certification and pre-shipment inspection, as well as laboratory recognition and
- launching of consumer awareness programmes on quality.
- Provide laboratory services for testing of various commodities.
- Involve in environment protection.

Additional activities include legal metrology and calibration services for weighing and measuring devices. Initiation on industrial and scientific metrology is in progress.

Nepal Bureau of Standards and Metrology (NBSM)
http://nbsm.gov.np/

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Among the national standards stipulated by the Nepalese government, those related to water supply facilities are as follows:

NS 40:2049 High density polythene pipe (Second Amendment) (third revision)

NS 139:2043 Colour code for the identification of pipelines

NS 199: 2046 Galvanized Mild Steel Pipe for Water Supply - Second Amendment

NS 206: 2046 PVC Pipe for Drinking Water Supply - First Amendment

NS 223: 2047 Methods of Test for Water

NS 246:2048 Cast iron pipe, vertically cast

NS 254:2048 Cast iron pipe, centrifugally cast

NS 383:2054 Cast Iron Pipe Fittings

NS 402: 2054 Injection Moulded High Density HDPE Fittings for Potable Water

Part 1 – General requirements

Part 2 – Specific requirements for 900 Bends

Part 3 – Specific requirements for 900 Tees

Part 4 – Specific requirements for Reducer

Part 5 – Specific requirements for Ferrule Reducer

Part 6 – Specifications of pipe end

Part 7 – Specifications of sandwich flanges

NS 428: 2075 Water Meter (Domestic) - first revision

NS 432: 2059 Characteristics of Pipe Distributed Drinking Water

NS 570 Chlorinated Polyvinyl Chloride (CPVC) Pipes for Potable Hot and Cold Water Distribution Supplies – Specification

NS/ISO 2507 - 2:1995:2064 Part 2: Test condition for unplasticized poly vinyl chloride) (PVC - U) or chlorinated poly( vinyl chloride ) ( PVC - C ) pipes and fittings and for high impact resistance poly( vinyl chloride ) ( PVC - HI ) pipes

# 4. Water Meter Accuracy Control

## 4.1 Instrumental error (relative error)

Instrumental error of a water meter is the value indicated by the measuring instrument minus the true value to be indicated, expressed as a percentage according to the following formula:

$$E(\%) = \frac{V_i - V_a}{V_a} \times 100$$

$V_i$ : is the indicated volume

$V_a$ : is the actual volume (Volume of water metered and rectified in the reference tank)

The instrumental error described here is the denominator of the true water volume and can be calculated when metered in a reference tank with a valid certificate.

When a water test meter is used to check the accuracy of a customer's meter, it is not exactly meant to measure the real error.

Since the test meter has its instrumental error, the accuracy check using the test meter is solely intended to determine whether there is an abnormality in the accuracy of customer's meter.

According to ISO 4064, testing of instrumental error of meters is required to be performed at least at each of the following flow points

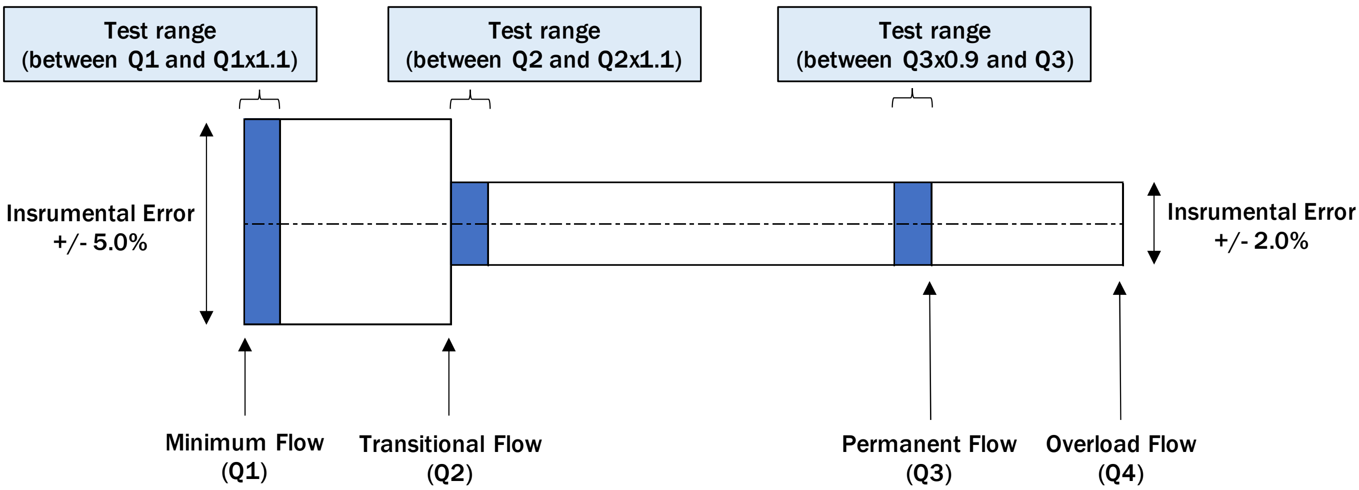



**Figure 4.1 Flow range of meter inspection (3 points)**

## 4.2 Classification of Meter Performance Classes

The former ISO standard specified the metering range and tolerance for each class of water meter.

Subsequently, a revision of the ISO standard in 2004 specified the performance of water meters in terms of flow range (R).

Flow Range: $R=Q_3/Q_1$

$Q_3$: Permanent Flow Rate (Maximum flow rate that can be accurately metered)

$Q_1$ : Minimum Flow Rate (Minimum flow rate that can be accurately metered)

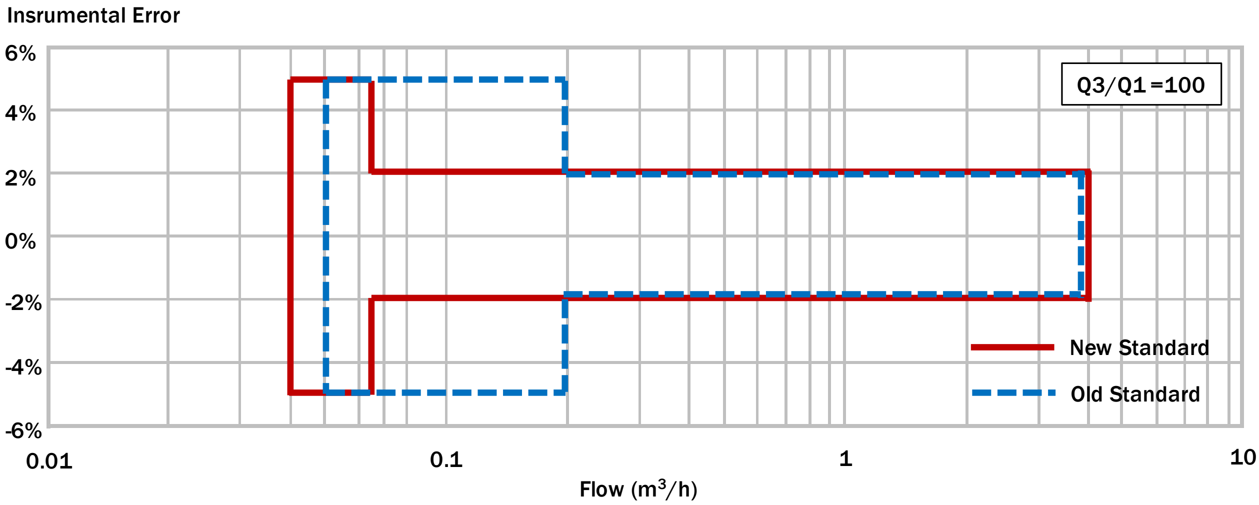



**Figure 4.2 Reform of required performance of water meter**

The instrumental errors of a typical water meter are described below.

The values and units in the table below are determined by the diameter and class of the meter.

Water meters are tested for "instrumental error (%)" at these flow rates, and only products that pass will be shipped from the manufacturer.

### (1) ISO-4064:2003 (Old Standard)

**Table 4.1 Meter of Class B by Old ISO Standard**

| Symbol | Meaning | Nominal Diameter | |
|---|---|---|---|
| | | DN15 | DN20 |
| $Q_{min}$ | Smallest flow rate | 30 L/h | 50 L/h |
| $Q_t$ | Transitional flow rate | 120 L/h | 200 L/h |
| $Q_n$ | Nominal flow rate | 1.5 $m^3/h$ | 2.5 $m^3/h$ |
| $Q_{max}$ | Maximum flow rate | 3.0 $m^3/h$ | 5.0 $m^3/h$ |

**Table 4.2 Meter of Class C by Old ISO Standard**

| Symbol | Meaning | Nominal Diameter | |
|---|---|---|---|
| | | DN15 | DN20 |
| $Q_{min}$ | Smallest flow rate | 15.0 L/h | 25.0 L/h |
| $Q_t$ | Transitional flow rate | 22.5 L/h | 37.5 L/h |
| $Q_n$ | Nominal flow rate | 1.5 $m^3/h$ | 2.5 $m^3/h$ |
| $Q_{max}$ | Maximum flow rate | 3.0 $m^3/h$ | 5.0 $m^3/h$ |

**Table 4.3 Meter of Class D by Old ISO Standard**

| Symbol | Meaning | Nominal Diameter | |
|---|---|---|---|
| | | DN15 | DN20 |
| $Q_{min}$ | Smallest flow rate | 11.25 L/h | 18.75 L/h |
| $Q_t$ | Transitional flow rate | 17.25 L/h | 28.75 L/h |
| $Q_n$ | Nominal flow rate | 1.5 $m^3/h$ | 2.5 $m^3/h$ |
| $Q_{max}$ | Maximum flow rate | 3.0 $m^3/h$ | 5.0 $m^3/h$ |

### (2) ISO-4064:2014 (New Standard)

**Table 4.4 Meter of R100 by New ISO Standard**

| Symbol | Meaning | Nominal Diameter | |
|---|---|---|---|
| | | DN15 | DN20 |
| $Q_1$ | Minimum flow rate | 25.0 L/h | 40.0 L/h |
| $Q_2$ | Transitional flow rate | 40.0 L/h | 64.0 L/h |
| $Q_3$ | Permanent flow rate | 2.5 $m^3/h$ | 4.0 $m^3/h$ |
| $Q_4$ | Overload flow rate | 3.125 $m^3/h$ | 5.0 $m^3/h$ |

**Table 4.5 Meter of R160 by New ISO Standard**

| Symbol | Meaning | Nominal Diameter | |
|---|---|---|---|
| | | DN15 | DN20 |
| $Q_1$ | Minimum flow rate | 15.625 L/h | 25.0 L/h |
| $Q_2$ | Transitional flow rate | 25 L/h | 40.0 L/h |
| $Q_3$ | Permanent flow rate | 2.5 $m^3$/h | 4.0 $m^3$/h |
| $Q_4$ | Overload flow rate | 3.125 $m^3$/h | 5.0 $m^3$/h |

**Table 4.6 Meter of R200 by New ISO Standard**

| Symbol | Meaning | Nominal Diameter | |
|---|---|---|---|
| | | DN15 | DN20 |
| $Q_1$ | Minimum flow rate | 12.5 L/h | 20.0 L/h |
| $Q_2$ | Transitional flow rate | 20 L/h | 32.0 L/h |
| $Q_3$ | Permanent flow rate | 2.5 $m^3$/h | 4.0 $m^3$/h |
| $Q_4$ | Overload flow rate | 3.125 $m^3$/h | 5.0 $m^3$/h |

## 4.3 Instrumental error curve and low flow rate beyond the measurable limit

The relation between Instrumental Error (%) and Flow Range is shown below.

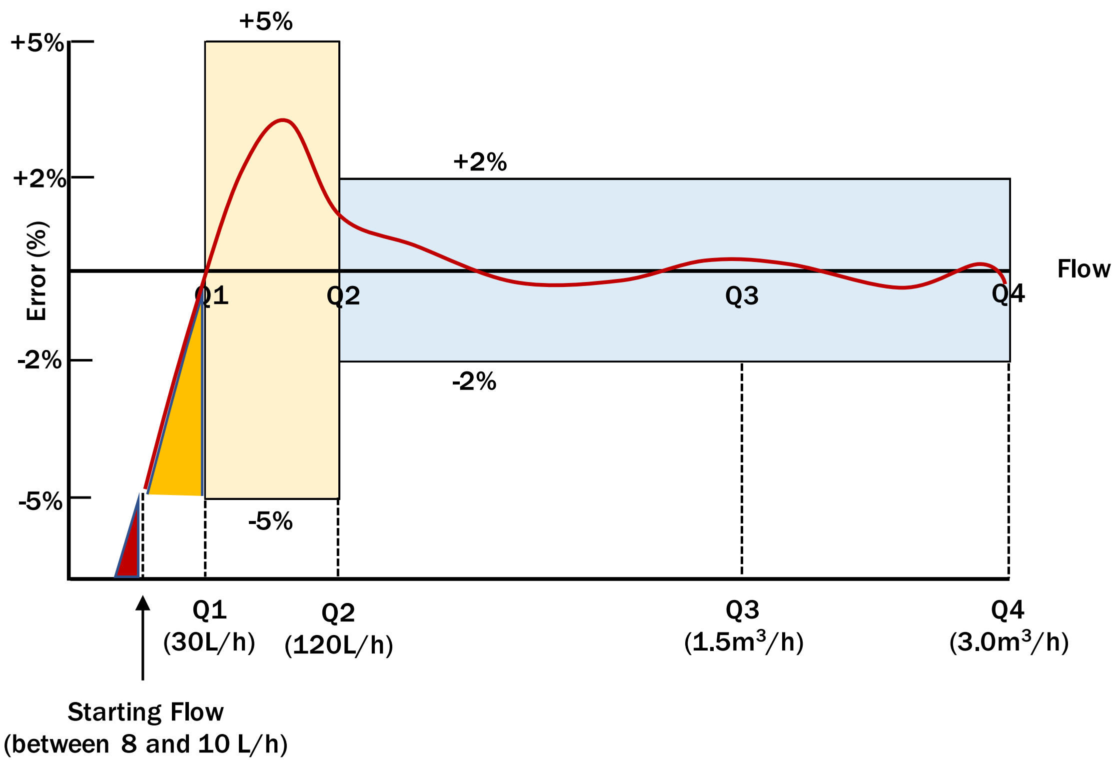



**Figure 4.3 Instrumental curve of water meter (DN15mm、Class B)**

For Class B meters in the Old ISO Standard, if the flow range is within ±5.0% error for $Q_1$ through $Q_2$ and ±2.0% error for $Q_2$ through $Q_4$, the meter is accepted as a shipping product.

Looking at this instrumental error curve and understanding that the flow range below $Q_1$ (the orange area in the above figure) is the dead flow range of the meter would be a big mistake.

If the product is from a reliable manufacturer, the meter will operate and measure the flow rate, although it cannot guarantee an accuracy of ±5.0% in the flow range of less than 30 L/h.

All meters have a Starting Flow Value, the flow rate that starts the metering process, which is often 8 to 10 L/h for Class B DN15mm, but this value increases with age.

Thus, the true value of low flow rate beyond the measurable limit is in the flow range that is smaller than this Starting Flow (the red area in the figure above).

### 4.4 Terms for understanding instrumental error

The terms used to test the meters are organized as follows:

**[Tolerance]**

The range of allowable instrumental error that determines whether a water meter passes or fails as a water meter. There are two types of tolerances: “Verification Tolerance” and “Tolerance for device in use”.

**[Verification Tolerance]**

This is the numerical value of the allowable instrumental error as an acceptable range for passing or failing a water meter verification test.

$Q_1$ ($Q_{min}$) ≦ Q < $Q_2$ ($Q_t$) : ±5%

$Q_2$ ($Q_t$) ≦ Q ≦ $Q_4$ ($Q_{max}$) : ±2% (Water of 30°C)

**Table 4.7 Definition of Term Q**

| Symbol | Name | Meaning |
|---|---|---|
| $Q_1$ | Minimum flow rate | Lowest flow rate at which the meter is to operate within the maximum permissible errors |
| $Q_2$ | Transitional flow rate | Flow rate between the permanent flow rate and the minimum flow rate that divides the flow rate range into two zones, the upper flow rate zone and the lower flow rate zone, each characterized by its own maximum permissible errors |
| $Q_3$ | Permanent flow rate | Highest flow rate within the rated operating conditions at which the meter is to operate within the maximum permissible errors |
| $Q_4$ | Overload flow rate | Highest flow rate at which the meter is to operate for a short period of time within the maximum permissible errors, while maintaining its metrological performance when it is subsequently operating within the rated operating conditions |

**[Tolerance applicable for devices in use”]**

The allowable instrumental error of a meter in service during the validity period of a verified water meter. For meters in use, errors up to twice the verification tolerance are allowed.

## 5. Types and functions of water meters for domestic use

There are two types of household water meters: those that measure flow velocity and those that measure volume.

### 5.1 Flow Velocimetry Type

Among flow velocimetry types, the impeller (turbine) type is the most common and is divided into single-jet and multi jet types.

In the single-jet type, the box itself also serves as the weighing chamber, while the multi-jet type has a separate structure for the rotating impeller and the weighing chamber.

The multi-jet type meter refers to a structure in which multiple nozzles provide a jet water flow to the impeller, and is often employed mainly in tangential-flow impeller types of 20 mm or larger.

The axial-flow impeller type is called the Woltman type. The blades are screwed together in a twisted manner, and are classified into vertical and horizontal types according to the position of the axis of rotation.

The Woltman type is used for meters with relatively large water usage (e.g., industry and hotel) and is suitable for a wide range of metering from small to large flow rates.

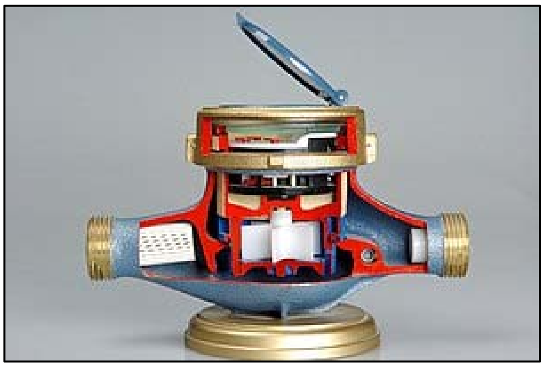



**Figure 5.1 Exploded View of Velocimetry Type Water Meter**

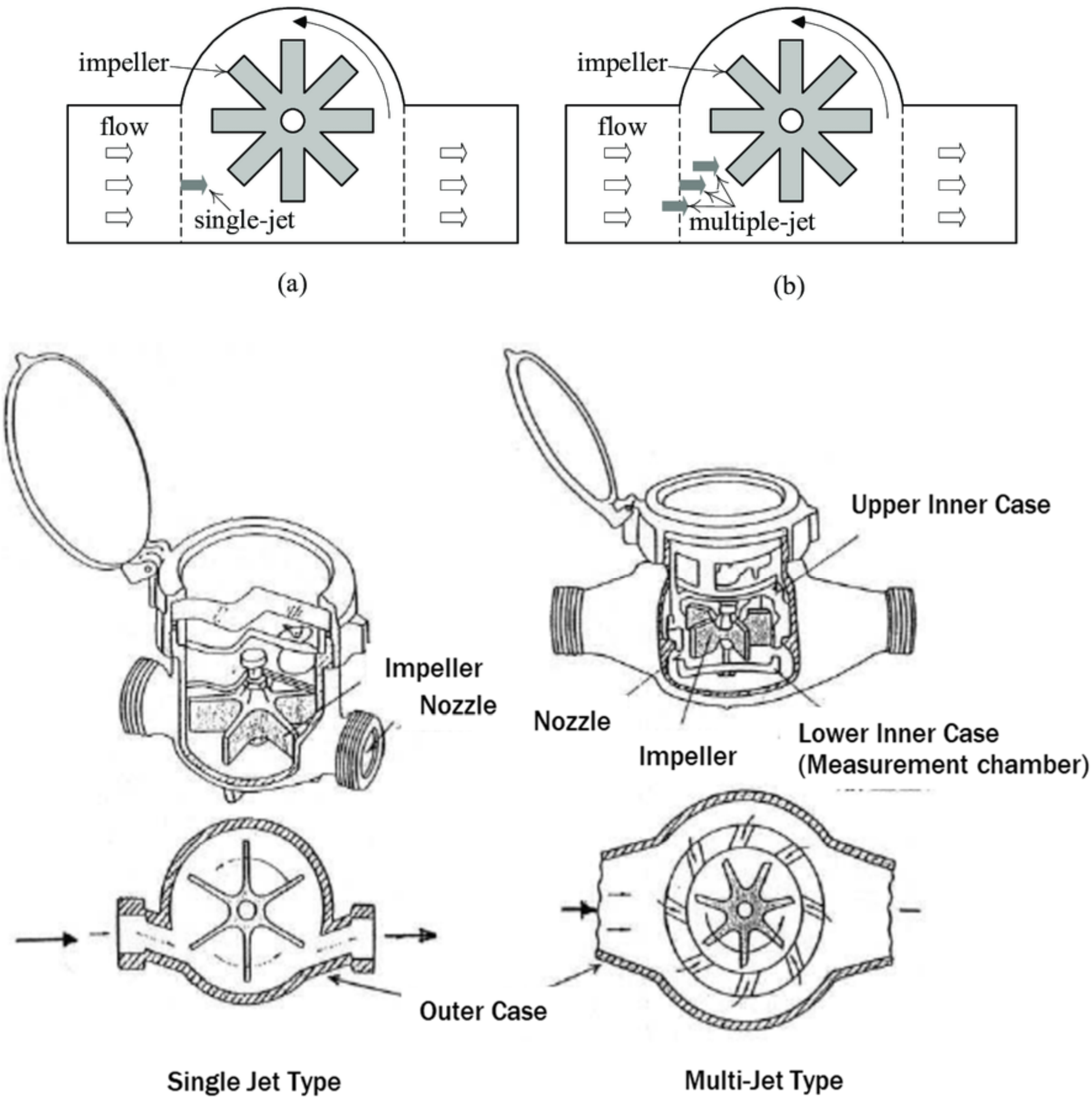



**Figure 5.2 Mechanism of Velocimetry Type Water Meter**

**[Advantage of velocimetry type]**

- It is generally less expensive than the volumetric type.
- Easily accommodates large flow rates and diameters.

**[Disadvantage of velocimetry type]**

- The meter must be installed horizontally to avoid unbalanced rotation of the impeller.
- Wear of rotating parts reduces accuracy.
- Accuracy is inferior to the volumetric type.

### 5.2 Volumetric Type Water Meter (Positive Displacement Flow Meters)


Unlike a velicimetry type water meter, a volumetric water meter measures the volume of the actual fluid passing through the water meter. The most vivid metaphor is like the kind of revolving door in front of a large supermarket or hotel.

It can only be rotated in a fixed direction. Every time a certain angle is turned, the fluid passes through the water meter to the other side. Therefore, volumetric water meters are more accurate than velocimetry type meters. The velocimetry type meter will have an error of ±2% depending on the fluid velocity, while the volumetric water meter error can be controlled to ±0.5% or lower.

In terms of use, volumetric water meters are generally used in precision industrial enterprises or test places because of their accurate measurement results; and velocity water meters are generally used for normal domestic, industrial or commercial water use.

In terms of price, volumetric water meters are generally much more expensive than velocimetry meters (single jet, multi jet, woltman type).

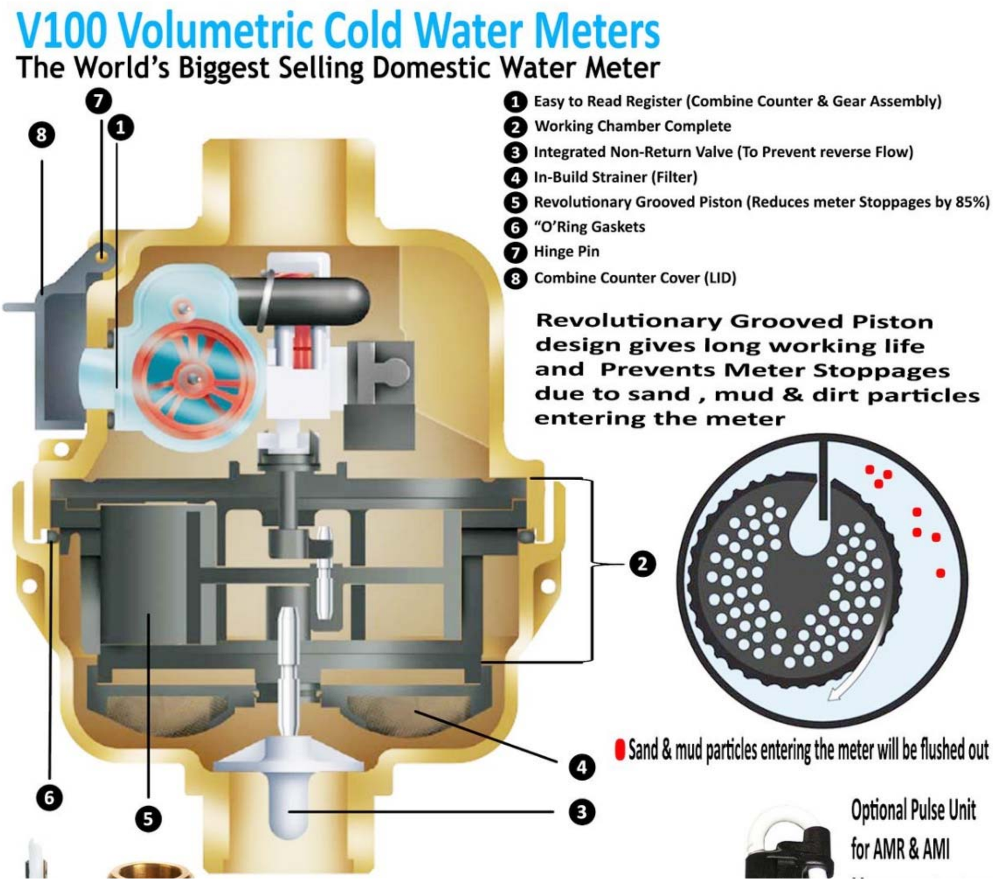



**Figure 5.3 General View of Volumetric Meter**

A volumetric meter is a device fitted into a closed conduit, which consists of chambers of known volume and a mechanism driven by the flow, whereby these chambers are successively filled with water and then emptied.

A cylindrical piston is placed inside the meter which when moved by the water, it rotates around a pinion in the middle of the measuring chamber whose volume is known. The chamber has one inlet and one outlet hole. The water to be measured enters the chamber through the inlet hole and its pressure pushes the piston to rotation thereby displacing a volume of water through the outlet hole which is exactly the same as the known volume of the meters measuring chamber. Every rotational cycle of the piston discharge a fixed volume of water to the body of meter.

The number of rotation of the piston is totalized through a reduction gear, to totalize in the counters of the register, when the volume of water is registered.

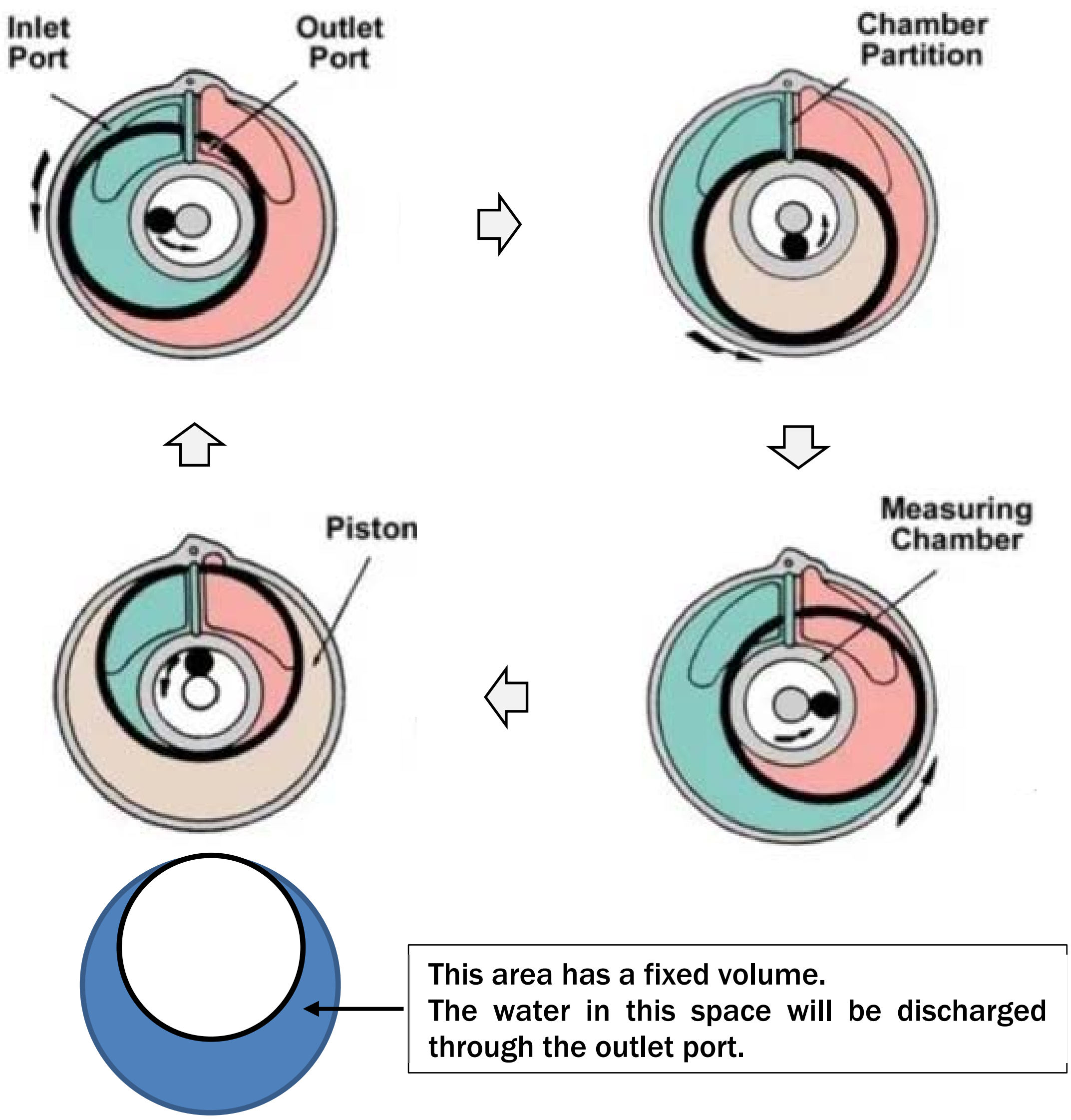



**Figure 5.4 How the oscillating piston works**

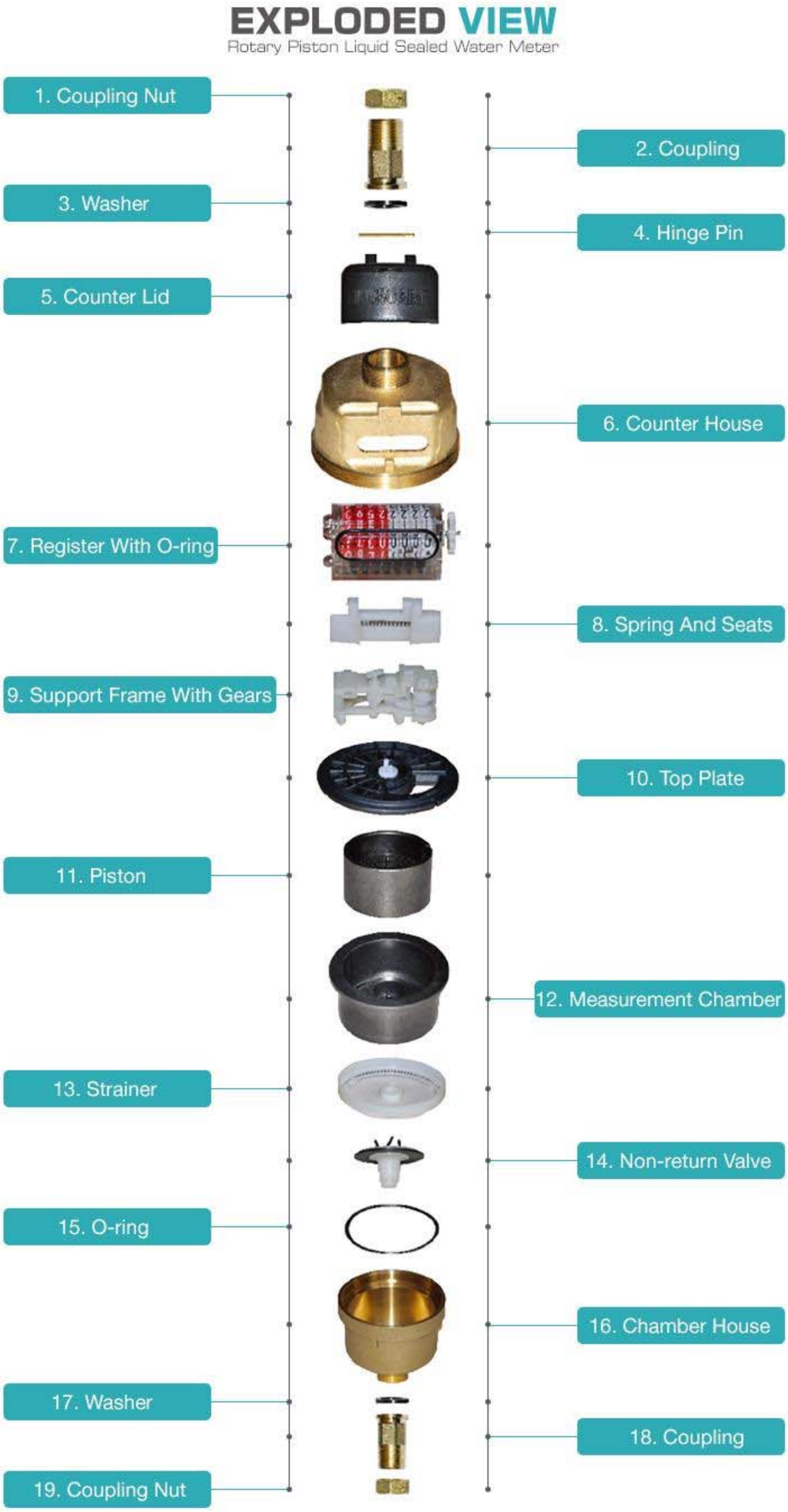



**Figure 5.5 Exploded View of Oscillating Piston Meter**

**[Advantage of Volumetric Meter]**

- Highly durable and longer service life than velocimetry type.
- Maintains metering accuracy and working characteristics over a long-time period.
- Accuracy not affected by the upstream conditions. It requires very little straight upstream piping.
- Suitable for high viscosity fluids
- Little sensitive to uneven flow distribution across the area of the pipe, it does not matter the flow is pulsing.
- Read out directly in volumetric units

**[Disadvantage of Volumetric Meter]**

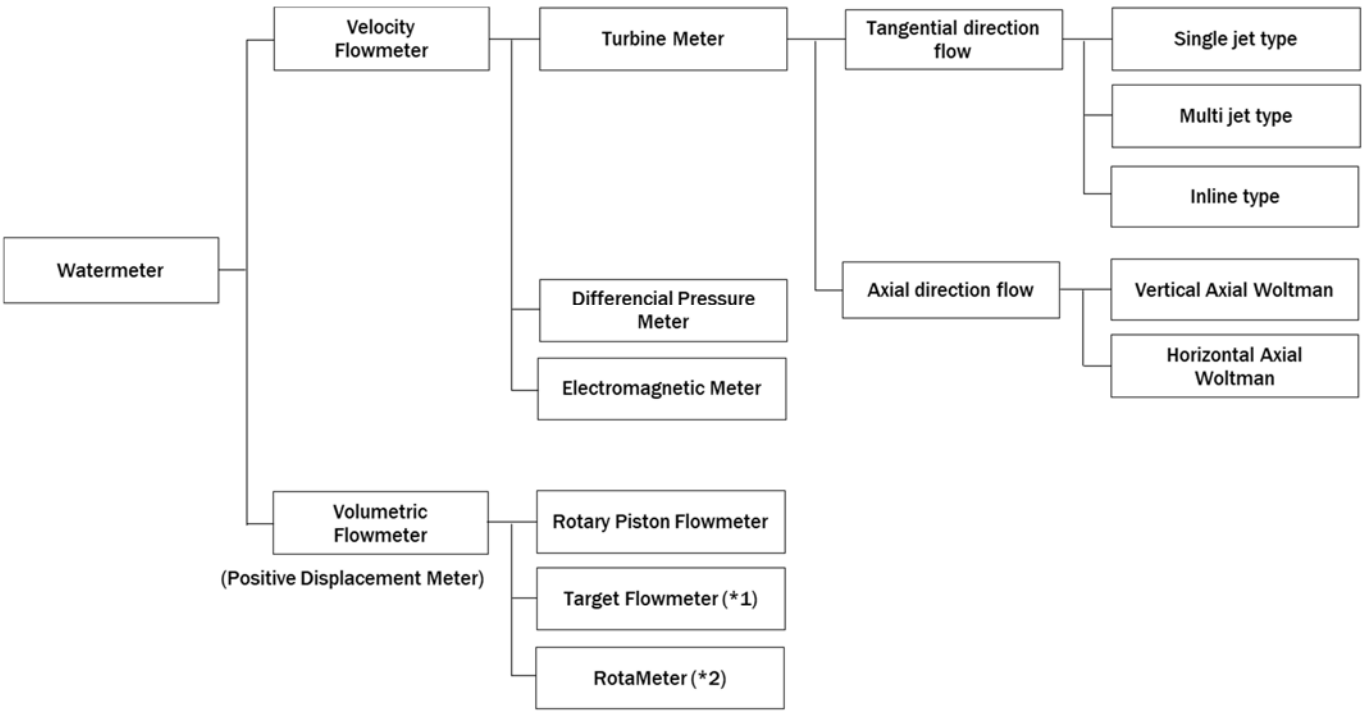
- More expensive than typical velocimetly type.
- Sudden change in flow may damage the moving parts due to inertia
- Moving parts subjected to wear and construction material susceptible to corrosion.
- Not suitable for sticky, abrasive liquids
- It may cause pulsation in flow

## 6. Types and function of typical flow maters

There are a wide variety of flow meter types. The type of flow meter is determined according to the nature of the measurement target and the installation location. The appropriate type of flowmeter should be then selected based on a comparison of specifications and cost according to the required measurement accuracy.

This section describes the types of flow meters most heavily used in water supply facilities and pipe networks.

### 6.1 Classification of Flow Meter




*1 Target flow meters, also known as drag force flow meters, insert a target (drag element), usually a flat disc or a sphere with an extension rod, into the flow field. They then measure the drag force on the inserted target and convert it to the flow velocity.

*2 A Rotameter is a form of variable area flow meter which has a simplistic operation whereby a liquid or gas passes through a tapered tube. In order for this gas to pass through the tube it must first raise a float held within the tube.

**Figure 6.1 Classification Diagram of Flow Meter**

## 6.2 Differential Pressure Flow Meter

As shown below, when the flow is constricted in the middle of a pipe, the fluid pressure drops. Since the extent of the drop is related to the fluid density and flow velocity, the flow rate can be calculated by measuring the pressure difference between the upstream and downstream sides.

This flow rate is the volumetric flow rate; if you want to know the mass flow rate, multiply it by the density.

**[Advantage of Differential Pressure Flow Meter]**

- A wide range of fluids can be measured, including liquids, gases, and the above.
- No moving parts, making it less prone to breakdowns, especially the orifice plate, which is inexpensive.
- The aperture structure and aperture range are defined by international standards, and actual flow calibration is not required.

**[Disadvantage of Differential Pressure Flow Meter]**

- The maximum and minimum flow range that can be measured is about 3:1, so the measurement range is narrow.
- Accuracy as low as 2-3% of full scale.
- The pipe that takes out the differential pressure is easily clogged.
- Long straight pipe sections are needed upstream and downstream.
- Large pressure loss due to flow throttling.

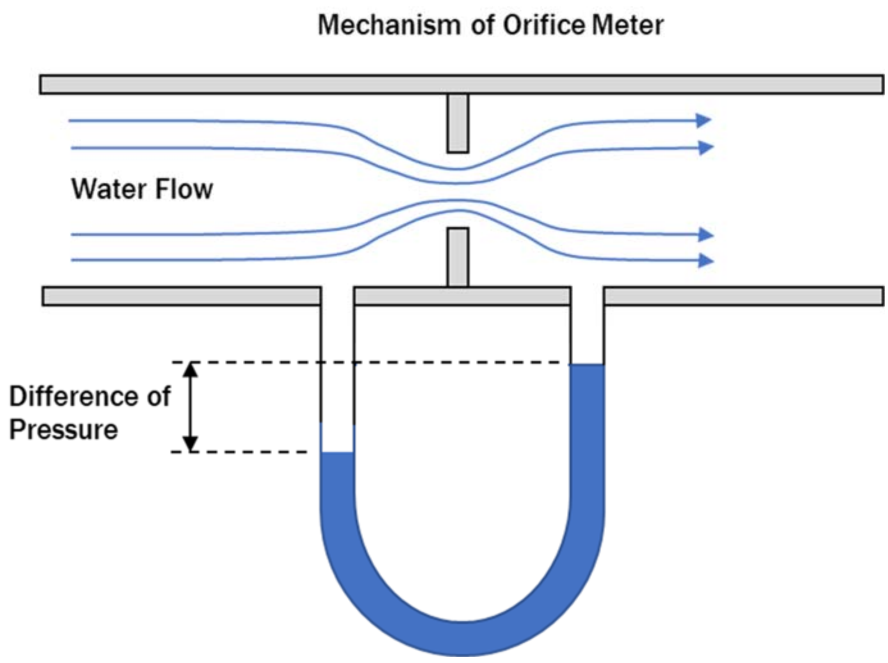



**Figure 6.2 Simple Mechanism of Differential Pressure Flow Meter**

Venturi Meter

Orifice Meter

**Figure 6.3 Example of Differential Pressure Flow Meter**

### 6.3 Turbine Flow Meter

A turbine meter is a device that is placed in the flow and calculates the flow rate from the number of rotations of the impeller, utilizing the fact that the rotation speed of the impeller, which has an axis parallel to the flow, is proportional to the flow velocity.

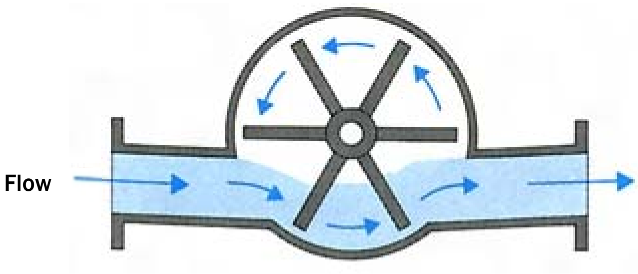
Counting the number of rotations can be done by embedding magnets in the tips of the blades or in the axis of rotation, so that the electrical pulses signal can be taken out as a signal and converted into flow rate.

In the case of a domestic meter, the tip of the impeller, which has a structure similar to a waterwheel, catches the water flow, whereas a turbine meter with a larger bore catches the flow with its entire propeller, which is similar to a windmill.

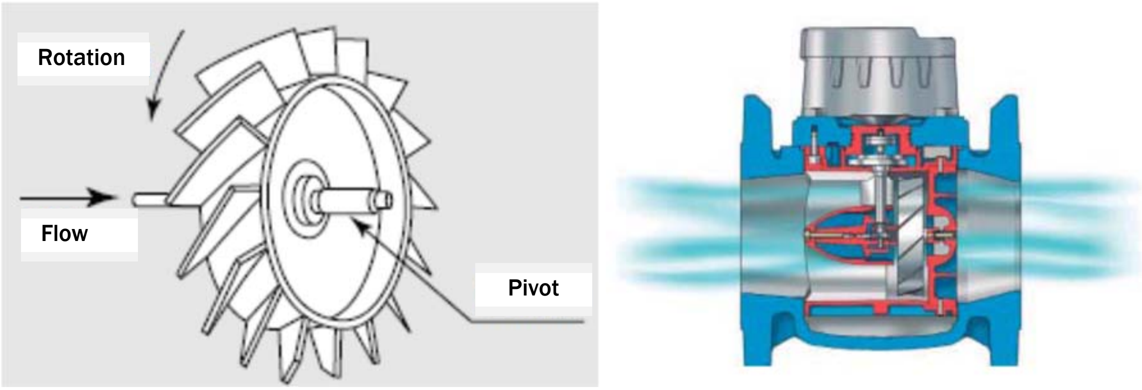
The type of waterwheel structure applies water flow in the direction in which the blades rotate and is called a "Tangential Flow Type".

On the other hand, the type of wind turbine structure in which the flow strikes the impeller at right angles to the impeller is called an "Axial-Flow Type".

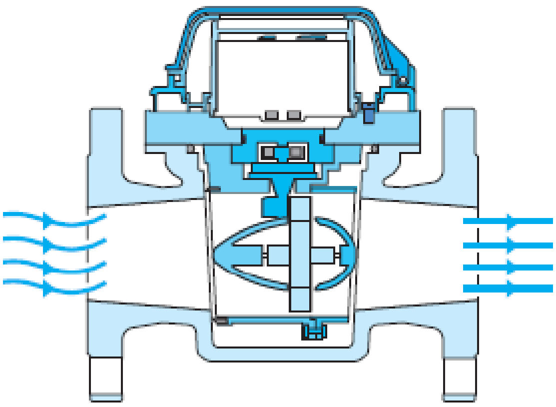
There are mechanical, optical, and magnetic methods of transmitting impeller movement; the inexpensive mechanical type is also called a mechanical meter.



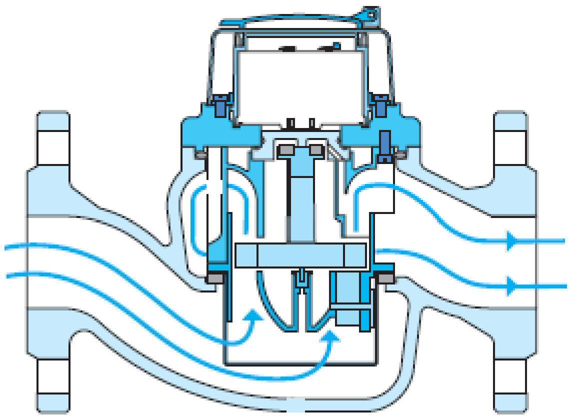

Tangential Direction Flow Type




Axial Flow Woltman Type



Axial Flow (Horizontal)



Axial Flow (Vertical)

**Figure 6.4 Mechanism of Turbine Flow Meter**

### 6.4 Electromagnetic Flow Meter

The electromagnetic flowmeter uses Faraday's law of electromagnetic induction as its measuring principle.

Faraday's law of electromagnetic induction states that "when a conductive object moves in a magnetic field, an electromotive force is generated within that object.

The flowmeter is equipped with a magnetic coil that generates a magnetic field and electrodes that capture the electromotive force.

According to Faraday's law of electromagnetic induction, when a conductive liquid moves in a geomagnetic field, an electromotive force proportional to the

"pipe inner diameter x magnetic flux density x average flow velocity"

In other words, the velocity of the liquid moving in the magnetic flux band is converted into electricity.

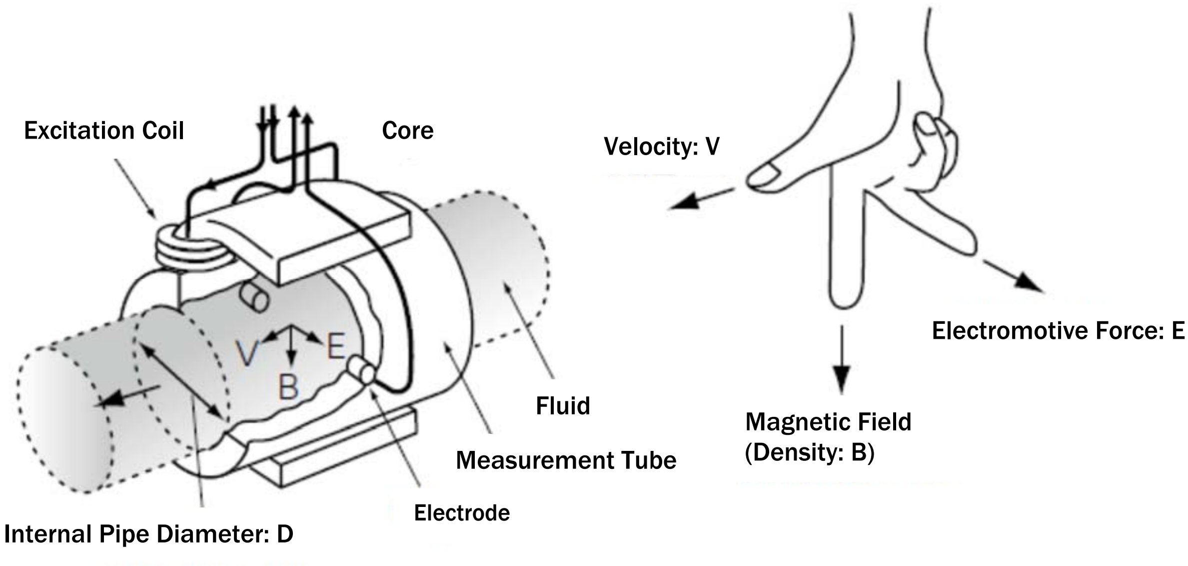



**Figure 6.5 Faraday's Law and the Mechanism of Electromagnetic Flowmeters**

As the flow rate changes, the electromotive force (voltage) supplemented by the electrodes changes as follows:

The higher the flow velocity, the greater the energy of water movement and the greater the voltage generated.

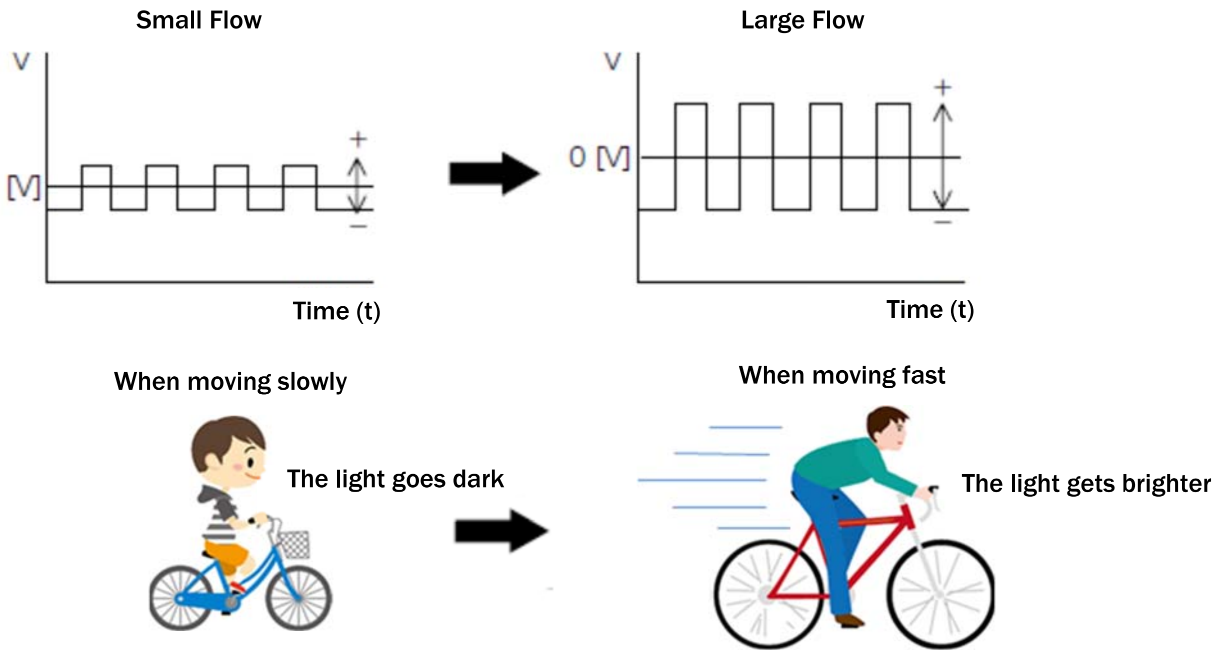



**Figure 6.6 Relation between flow rate (velocity) change and electromotive force**

**[Advantage of Electromagnetic Flow Meter]**

- Not affected by temperature, pressure, density, or viscosity of the liquid.
- Capable of detecting liquids containing air bubbles and other contaminants.
- Low pressure loss.
- Good responsiveness and accuracy.
- Easy maintenance due to no moving parts.

**[Disadvantage]**

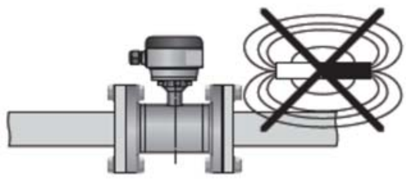
- Gases and liquids with no conductivity cannot be measured.
- Straight pipe sections are required upstream and downstream.

**[Installation Notes]**

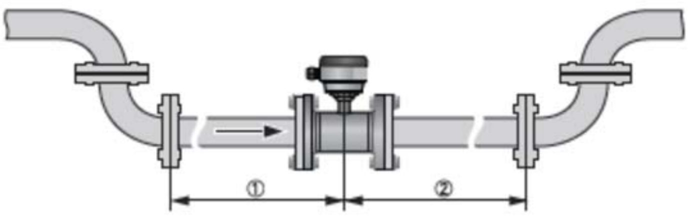
- Do not install in areas where air tends to accumulate, downhill slopes, or just before the outlet of a conduit where there is not full flow.
- Average flow velocity should be in the range of 2 to 4 m/sec
- If the average flow velocity is less than 1 m/sec, the electromotive force (EMF) will be small, and the accuracy will be poor.
- If the average flow velocity is greater than 6 m/sec, the risk of damaging the lining inside the pipe is higher.
- If the same size as the pipe diameter causes the flow velocity to be reduced, the reducers should be installed in the front and back to maintain the proper velocity range.

❶ Avoid places where there are vibration.

❷ Avoid places where there are magnetic forces in the vicinity.

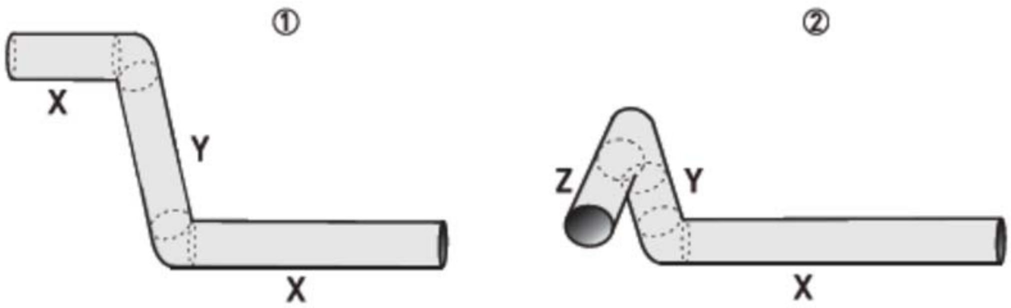


❸ Required straight length for sections upstream and downstream of meter



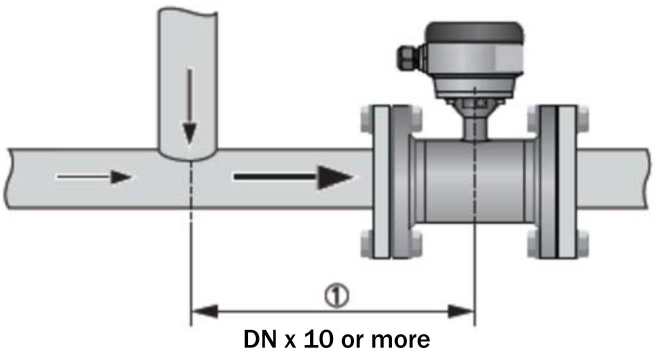

①Refer to the required dimension for Bends
②DN x 2 or more

❹ Required straight length for sections with multiple bends

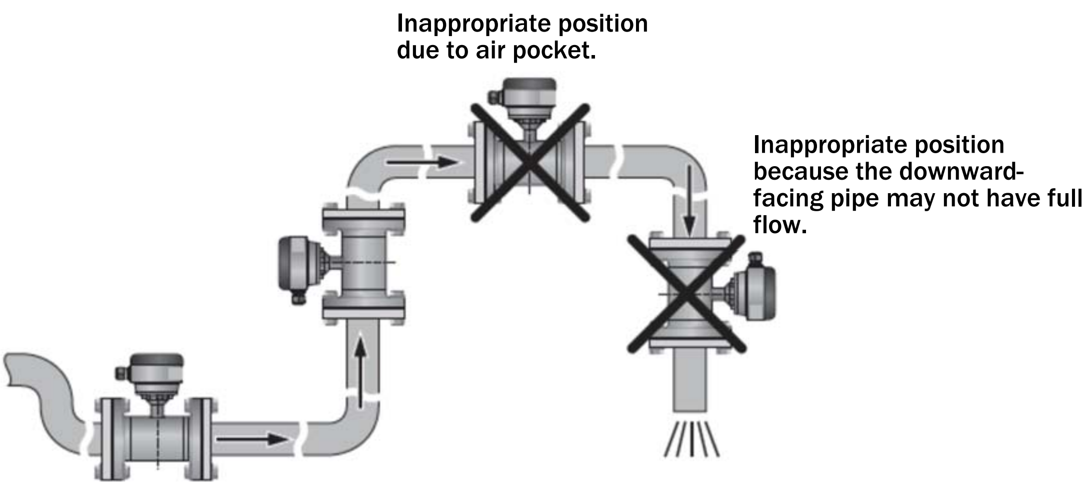


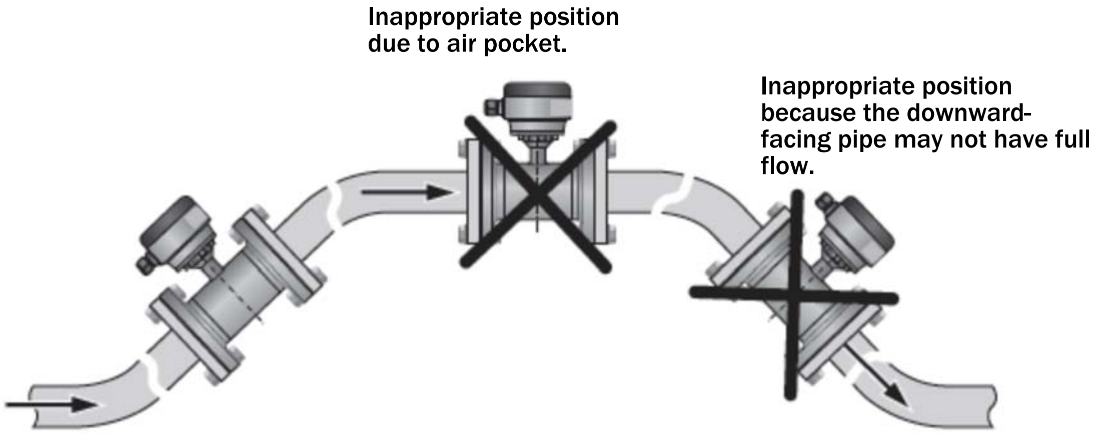

① 2 dimensions = X/Y
② 3 dimensions = X/Y/Z
**Inlet length: using bends in 2 dimensions: DN x 5 or more, when having bends in 3 dimensions: DN x 10 or more**

❺ T Joint

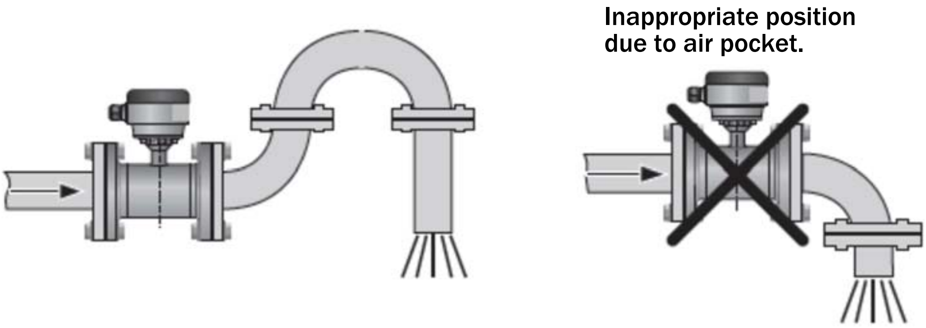



❻ Bends



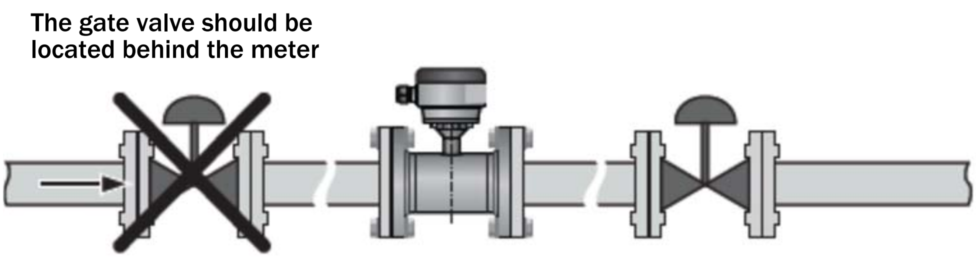



❼ Opening discharge




❽ Prohibited installation in front of pump


❾ Prohibited installation behind of valve



**[Understanding of accuracy]**

The accuracy (really inaccuracy) of mass flow instruments is specified in one of two ways, either accuracy as a percentage of full scale (% FS), or accuracy as a percentage of reading (% RD).

In selecting a flowmeter, it is important to compare product specifications based on a thorough understanding of “what needs to be measured” and “at what flow range will be needed”.

**Table 6.1 Type of meter accuracy**

| | RS (Reading-scale) | FS (Full-scale) |
|---|---|---|
| Meaning | The accuracy is expressed as "+/-**% RS" as a percentage error rate of the indicated value in any flow range.<br>The error will always be the same percentage of the actual flow. | The maximum measurement value (full scale) is determined, and the percentage error with respect to that maximum value is indicated by "+/-**% FS".<br>The error will have a fixed value no matter where the flow is in the flow range. |
| Detail | Within the flow range where accuracy is guaranteed, the error rate is always the same, so even measurements with minute flow rates or large flow rate changes can be detected stably. | The smaller the flow rate, the greater the relative error.<br>For example, for a flowmeter capable of measuring up to 100 $m^3/h$ and +/-1% F.S, the calculation is as follows:<br>$100m^3/h \times 0.01 = 1.0m^3/h$ (error 1%)<br>$50m^3/h \times 0.02 = 1.0m^3/h$ (error 2%)<br>$10m^3/h \times 0.10 = 1.0m^3/h$ (error 10%) |

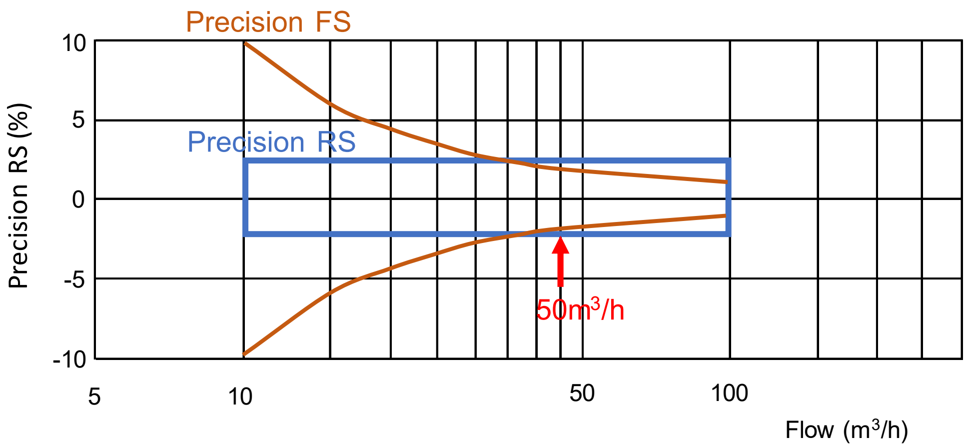



**Figure 6.7 Difference between RS and FS**

## 6.5 Ultrasonic Flow Meter

### 6.5.1 Characteristics of ultrasonic flow meter

An ultrasonic flow meter is a device that uses the fact that the speed at which ultrasonic waves propagate through a liquid varies according to the flow velocity of the fluid to produce an output proportional to the flow rate in the pipe.

Ultrasonic waves are characterized by their slow transit speed and short wavelength compared to radio waves.

**Table 6.2 Difference between ultrasonic wave and radio wave**

| | Ultrasonic Wave (Sound) | Radio Wave |
|---|---|---|
| physical phenomenon | Acoustic vibration | Electromagnetic field vibration |
| Transit speed | | |
| In the air | 343 m/sec (20℃) | 300,000 km/sec |
| In the water | 1,480 m/sec | 240,000 km/sec |
| In a solid body (Iron) | 5,180 m/sec | No transit |
| In a vacuum | No transit | 300,000 km/sec |

When the distance to an object is extremely large, such as to a broadcast tower tens of kilometers away or to a celestial body, radio waves are used for radar and communications because the fast transit speed is practical.

However, at short distances, such as pipe diameter, the arrival time of radio waves is extremely short, making it difficult to detect differences in transit time. For this reason, ultrasonic waves with slow transit times are practical for flow meters.

The range of "sound that the human ear can hear" is said to be from about 20 Hz (low tones) to 20,000 Hz (high tones). Sounds that exceeds this range, that is, low sounds below about 20 Hz and high sounds above about 20,000 Hz, are called "ultrasonic".

Sound" including ultrasonic waves propagates through gases, liquids, and solids as a medium and does not propagate in a vacuum.

In addition, the ease of transit differs depending on the material. Transit efficiency tends to increase in the order of GAS < LIQUID < SOLID, and the speed also tends to increase. The speed of sound in air is about 340 m/sec, while in water it is about 1,500 m/sec.

### 6.5.2 Advantage and disadvantage

**[Advantage]**

- Not affected by temperature, pressure, or viscosity of the liquid.
- Applicable to any liquid, conductive or not, through which ultrasonic waves can pass.
- Low pressure losses.
- A single flowmeter can measure a wide range of flow rates.
- In the case of the clamp-on type, which can detect from the outside of the pipe, pipe cutting work is not required.
- The sensor is installed symmetrically along the flow direction so that flow in the opposite direction can also be measured.
- Fast response time and can follow pulsating flow.

**[Disadvantage]**

- Bubbles, foreign matter, etc. in the liquid will cause errors.
- Rust and deterioration conditions on the inner surface of the pipe affect measurement accuracy.
- Certain straight sections are needed upstream and downstream.
- The measurement accuracy of the clamp-on type is about 2 to 3% of full scale.

### 6.5.3 Measuring principle of ultrasonic flowmeters

The most common ultrasonic flowmeter system currently in the market is the type that measures the transit time difference.

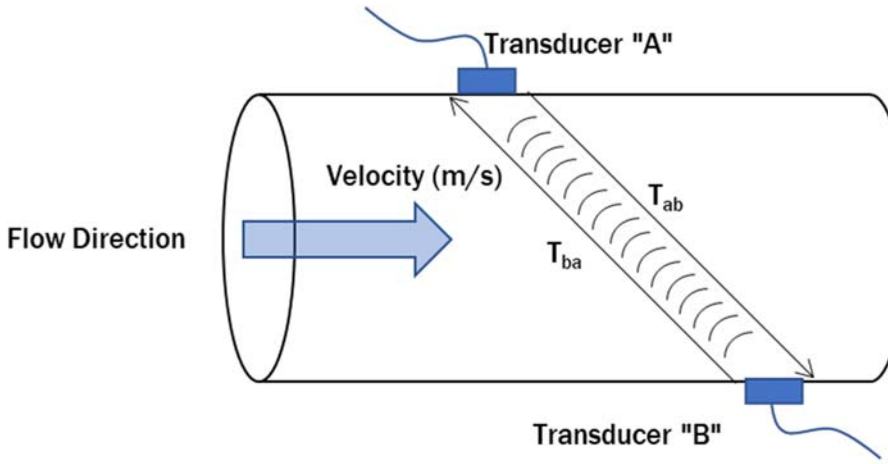



**Figure 6.8 Principle of ultrasonic flow meter**

Transducers are placed on the pipe at predetermined positions and alternately transmit and receive ultrasound waves.

When the flow is stopped, the time for ultrasonic waves to propagate from upstream A to downstream B ($T_{ab}$) is equal to the time for ultrasonic waves to propagate from B to A ($T_{ba}$).

When the water flows in the pipe, ultrasonic waves transmitted from A to B propagate faster than when there is no flow, because they are in the forward direction of the flow.

Conversely, when ultrasonic waves are transmitted from B to A, the transit time is slower than when there is no flow, because the ultrasonic waves go against the flow.

The ultrasonic flowmeter detects this difference in transit time and calculates the fluid flow velocity using a principle formula. The calculated value is the average flow velocity, which is multiplied by the cross-sectional area inside the pipe to calculate the flow rate.

If the flow velocity is "V", the transit time from upstream to downstream and from downstream to upstream is $T_{ab}$ and $T_{ba}$, the transit path length is "L", the sound velocity in the fluid is "C", and the angle between the flow path and the ultrasonic propagation path is "θ", the transit time can be expressed by the following equation:

$$T_{ab} = \frac{L}{C + V\cos\theta} \qquad T_{ba} = \frac{L}{C - V\cos\theta}$$

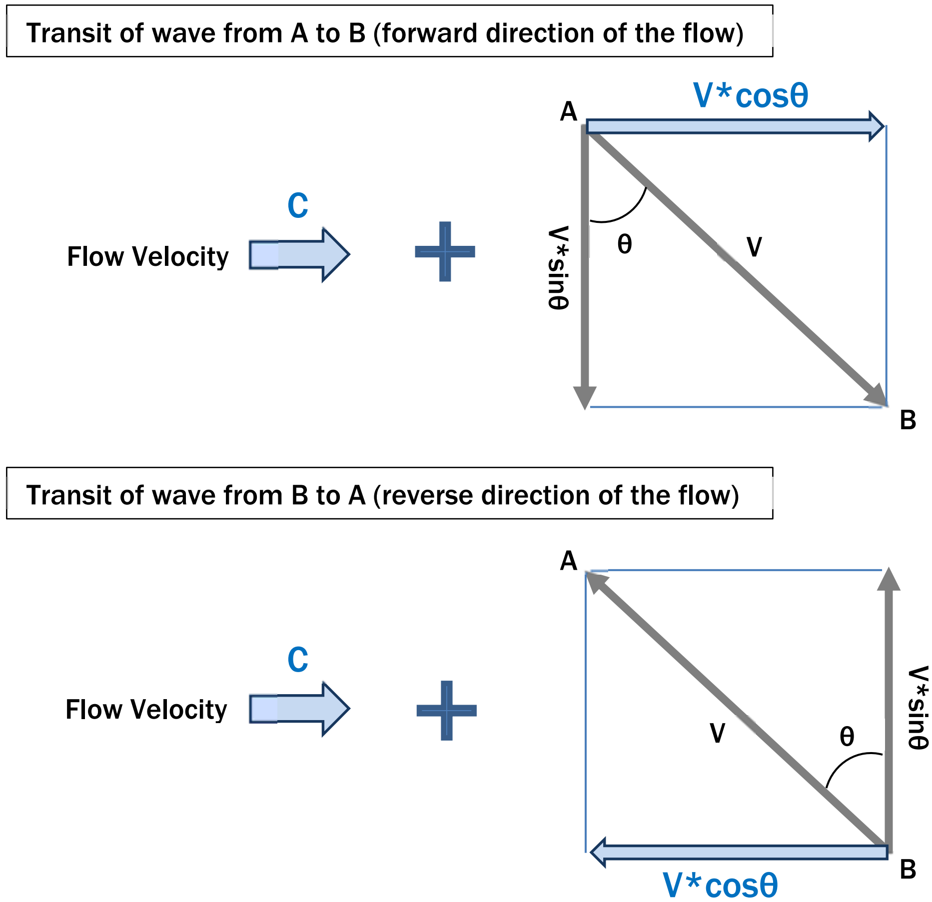



**Figure 6.9 Synthesis of fluid velocity and ultrasonic velocity**

$$T_{ab} = \frac{L}{C + V\cos\theta} \qquad T_{ba} = \frac{L}{C - V\cos\theta}$$

**Deformation**

$$\frac{1}{T_{ab}} = \frac{C + V\cos\theta}{L} \qquad \frac{1}{T_{ba}} = \frac{C - V\cos\theta}{L}$$

$$\frac{1}{T_{ab}} - \frac{1}{T_{ba}} = \frac{C + V\cos\theta}{L} - \frac{C - V\cos\theta}{L} = \frac{2V\cos\theta}{L}$$

Finally, the following equation is obtained.

$$V = \frac{L}{2\cos\theta}\left(\frac{1}{T_{ab}} - \frac{1}{T_{ba}}\right)$$

Using this formula, the flow velocity can be calculated by determining the distance between the sensors and the angle of incidence of the ultrasonic waves and measuring the propagation time of the ultrasonic waves. This velocity is the average velocity in the pipe.

Furthermore, if the pipe bore diameter D is known, the flow rate Q can be calculated as follows:

$$Q = \frac{3.14 * D^2}{4} * V$$

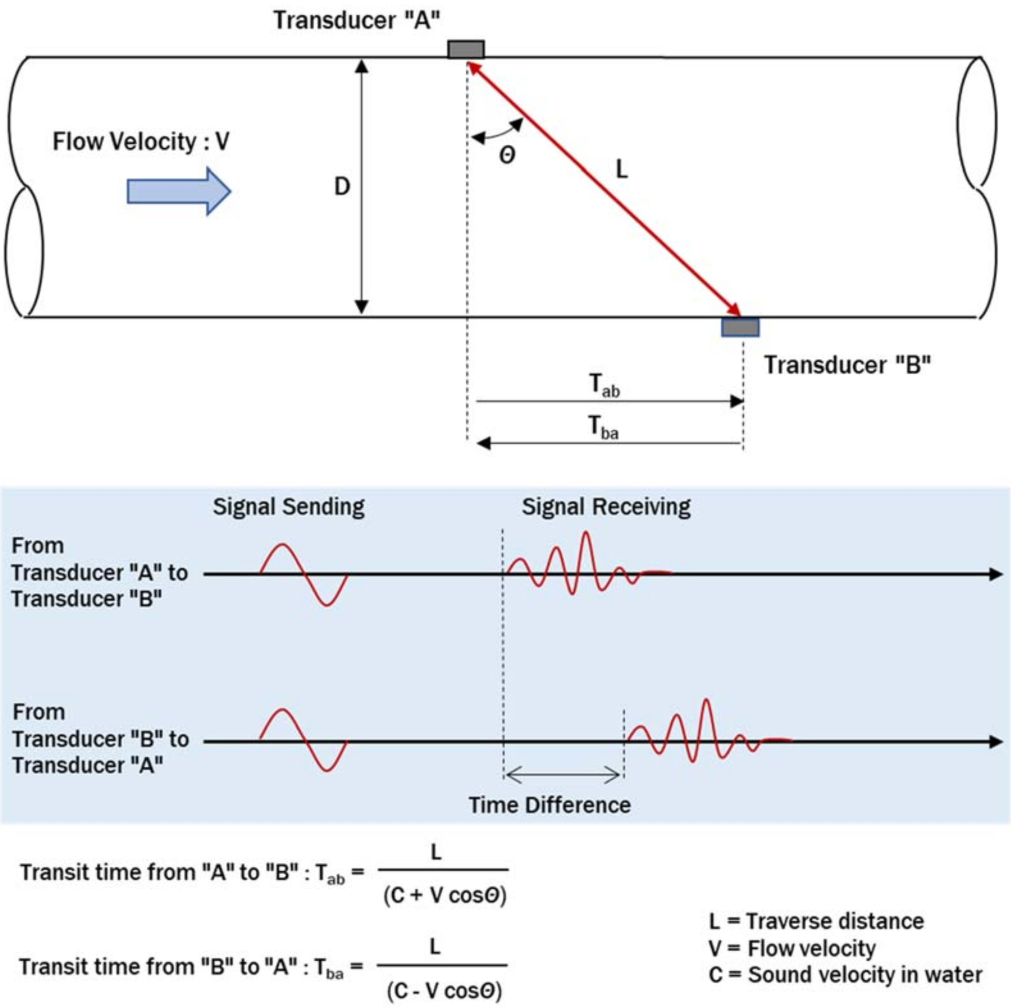



**Figure 6.10 Calculation of transit time (ΔT)**

In reality, because of the friction between the wall and the water in the pipe, the flow velocity is slower closer to the wall and faster toward the center.

However, there is a slight error between them because the flow velocity measured by ultrasonic flowmeters is the average flow velocity on the path along which ultrasonic waves propagate (called linear average velocity) and not the average velocity over a plane.

Therefore, the above equation is a simplification and is not strictly speaking correct, since the flow velocity V to be converted to flow rate must be the average velocity over the entire pipe cross section.

In the actual computer circuit of the flowmeter, the detected flow velocity value is corrected to the average velocity over the surface by a "flow correction factor" and then multiplied by the cross-sectional area to obtain the flow rate.

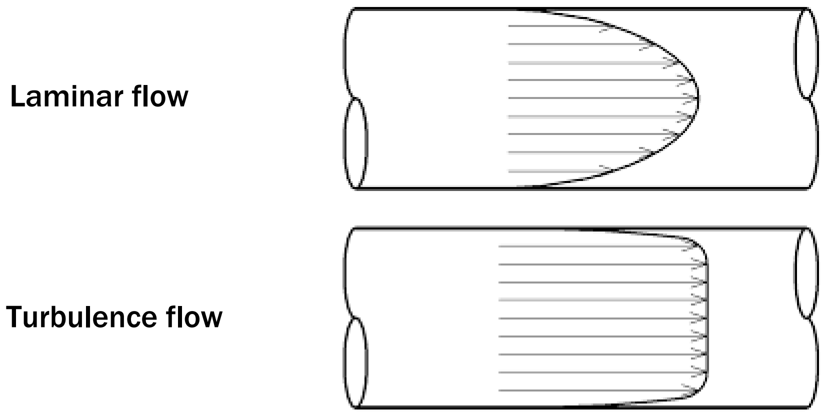



**Figure 6.11 Distribution of flow velocity in the pipe**

### 6.5.4 How to install the transducer

**[V Method (2 traverses mode)]**

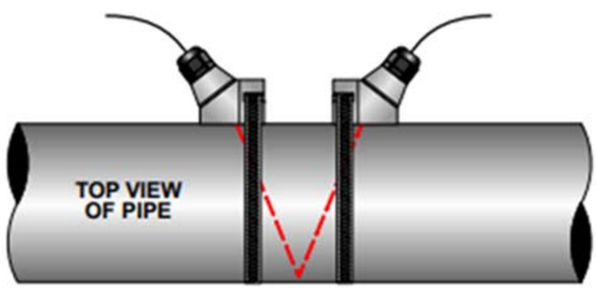



**Figure 6.12 Transducer setting in the V method (2 travers mode)**

This is the most basic and simplest installation method and is also called “2 travers mode” or “Reflection mode”.

The transducer (sensor) can be fixed to one guide rail and mounted on the pipe body, making it easy to set the distance between sensors accurately.

In the case of plastic resin pipes, large diameter pipes, and pipes with treated mortar lining on the inner surface, the V method may not be able to receive signals well. Normally, the V method is selected, but in the following cases, the Z method or other methods should be applied.

- When mounting space is tight
- When the turbidity of the liquid is high
- When the receiving signal intensity is weak
- When scale is thickly adhered to the inner surface of piping

In the case of Tokyo Keiki UFP-20, each transducer and its corresponding applicable aperture are as follows:

**Table 6.3 Type of transducer of UFP-20 (Tokyo Keiki)**

| Type | Model No | Applicable diameter |
|---|---|---|
| Small | UP50AST | DN 13 mm -DN 50mm |
| Middle | UP10AST | DN 65 mm – DN 500mm |
| Large | UP04AST | DN 300 mm – DN 5000mm |

**[Z method (1 travers mode)]**

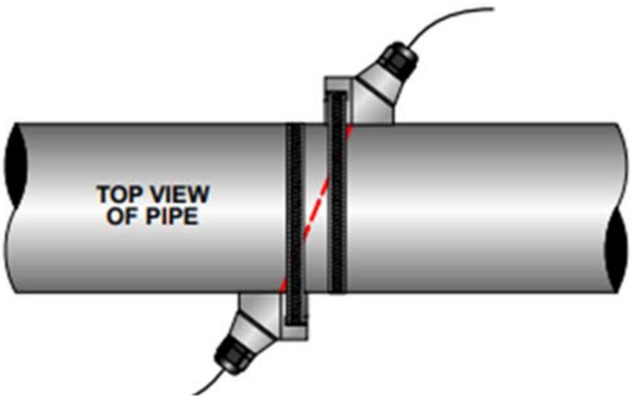



**Figure 6.13 Transducer setting in the Z method (1 traverse mode)**

This is also called “1 traverse mode” or “Direct mode”.

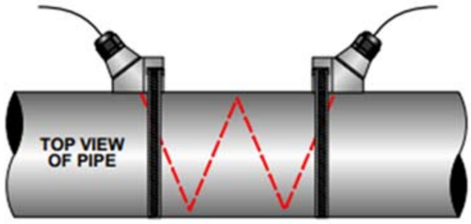
The ultrasonic wave propagation path can be shortened, which is effective for flow measurement under fluid and pipe conditions where ultrasonic wave propagation conditions are not favorable.

Since plastic synthetic resins tend to attenuate ultrasonic propagation more easily than metals, it is recommended that the Z method be used if the material of the pipe to be measured is plastic synthetic resin.

The Z method is also used when there is no space for installation, because the Z method requires only half the straight pipe length compared to the V method.

**[W Method (4 traverses mode)]**

Some flowmeters have a method of measuring by overlapping several V's, which is called the W measurement method. If the piping has a small bore and the V method is less accurate due to a short propagation path, the W method should be used to check if measurement is possible.




**[Internal dissolution type]**

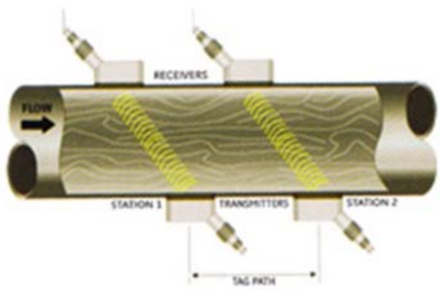
While the method of installing the transducer on the outside of the pipe is simple, the ultrasonic wave attenuates as it passes through the pipe wall and inner lining, affecting the strength of the receiving signal.

For this reason, it is much more accurate to measure only the fluid in the pipe directly.

A method that applies this theory is a flowmeter in which the transducer is embedded in the pipe wall from the beginning, and is used for medium to large diameter pipes such as water supply pipes and water distribution mains.

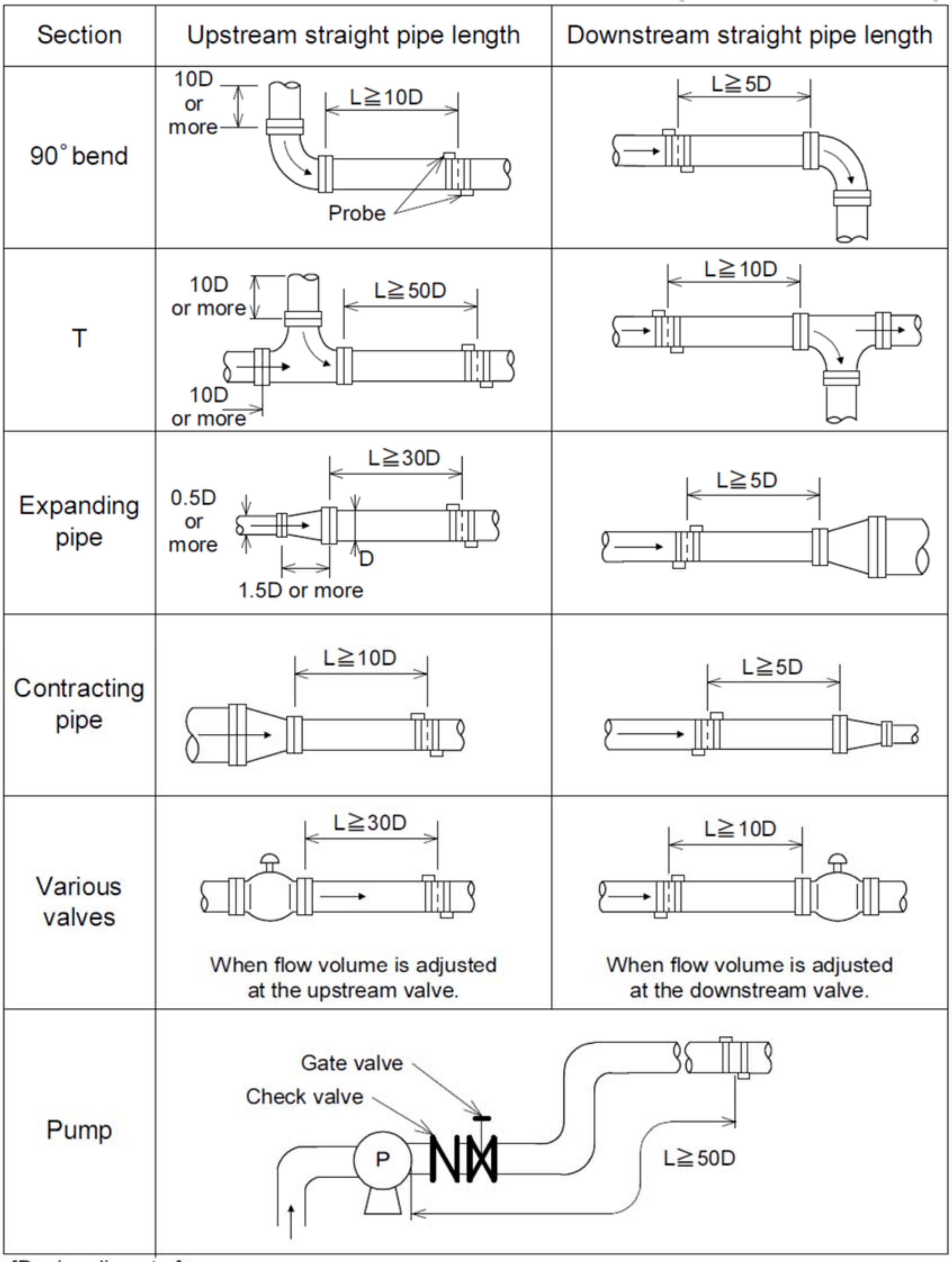
**[Correlative labeling method]**

Two sets of transmitting and receiving sensors are used to measure the flow rate, one set of sensors that only transmit ultrasonic signals and the other set of sensors that only receive them.




Apply a cross-correlation function to the received intensity of the first set of sensors and the received intensity of the second set of sensors, and calculate the time when the waveform patterns of each sensor match. From this time and the sensor interval, measure the flow rate.

### Table 6.4 Required straight section for flow measurement with an ultrasonic flowmeter

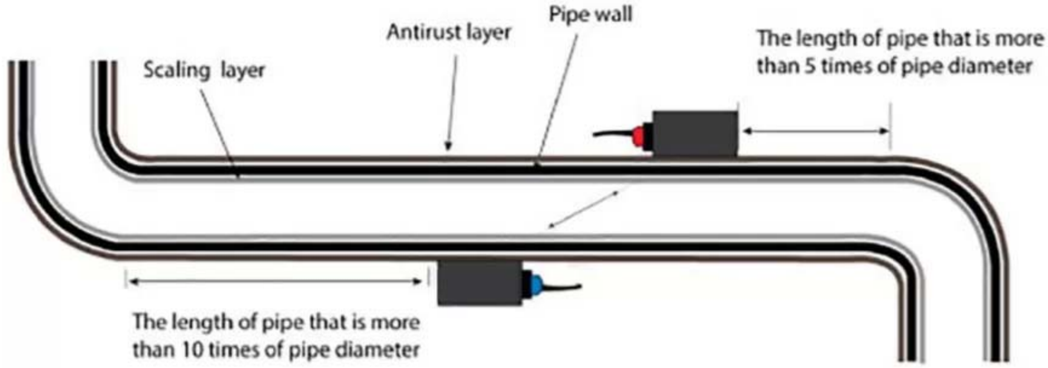


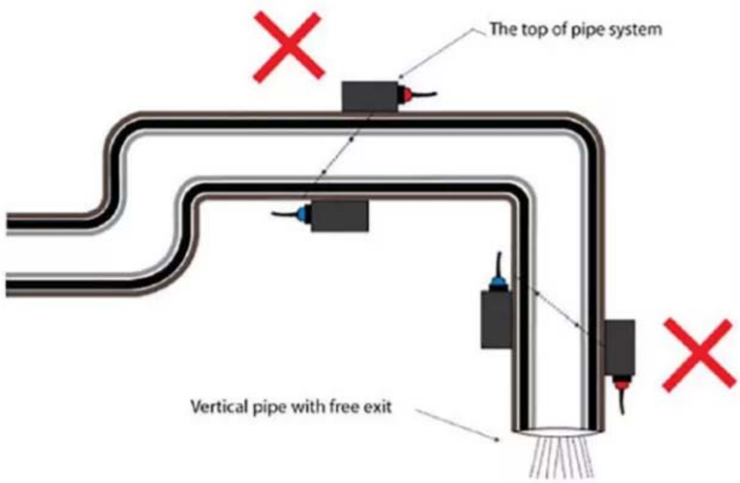

[D: pipe diameter]

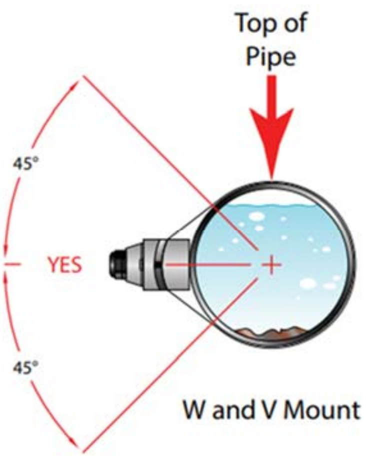
Source: JIS JEMIS-032

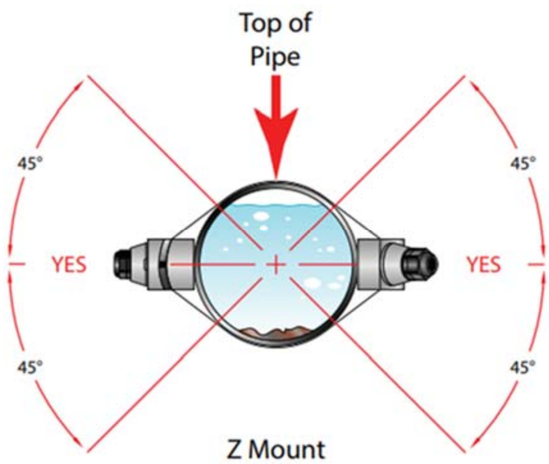
**[Installation Notes]**

- Position where air tends to accumulate, downhill slopes, or just before the discharge end of a pipe. Do not install in locations where there is not full flow.

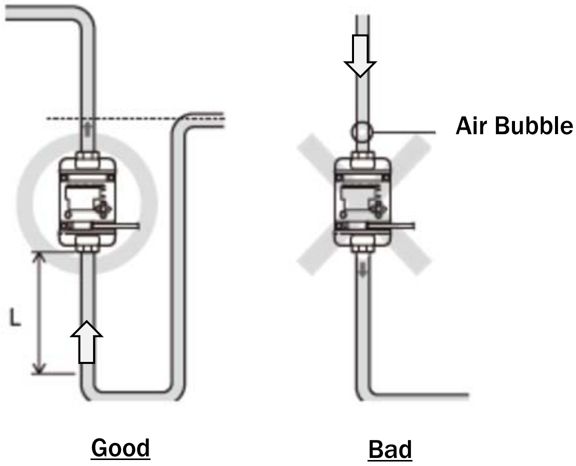


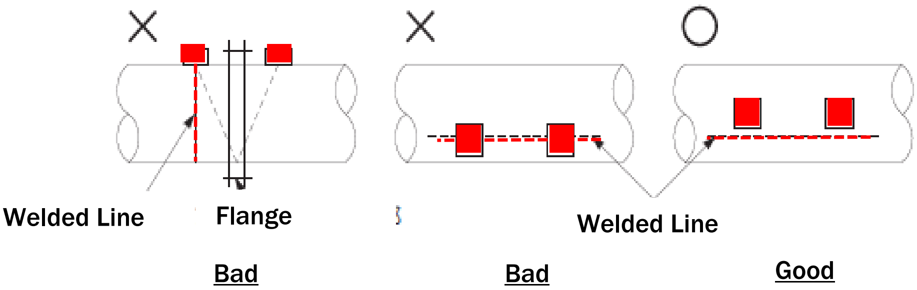



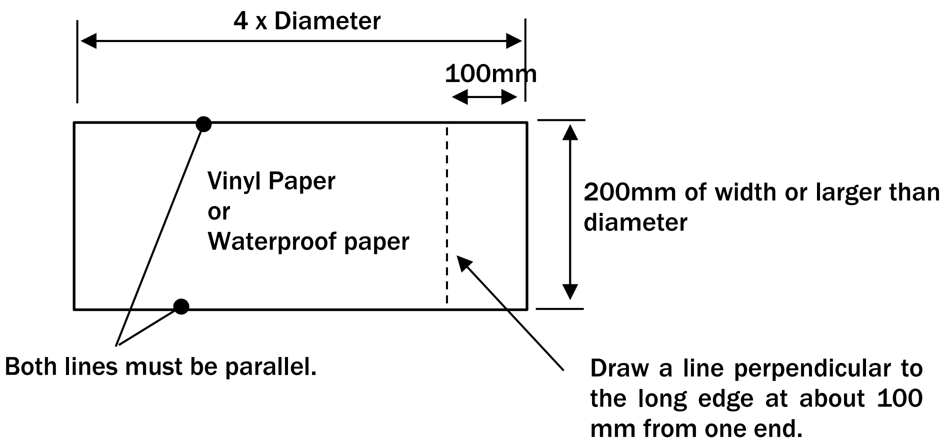
- Pipe through which water flows from the bottom to the top



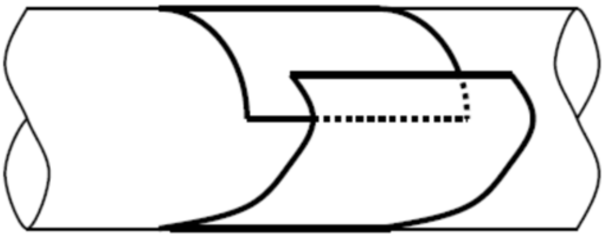

- Transducers should not be installed in seams or welds.



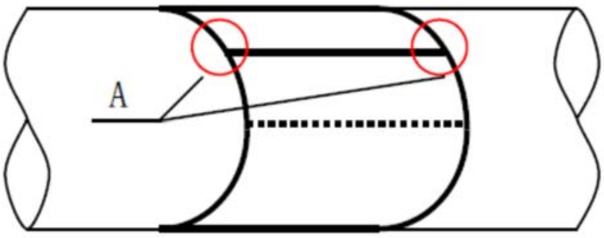

- The position of the transducer should be accurately measured, and it should be carefully fixed. Especially in the case of the Z method, the following gauge paper must be used to determine the correct position.



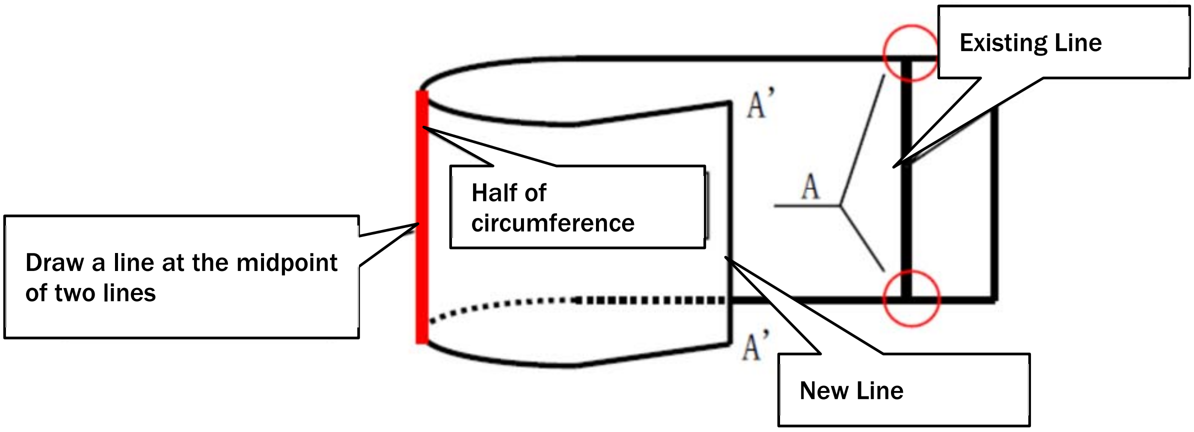
1. Wrap the gauge sheet tightly around the tube.



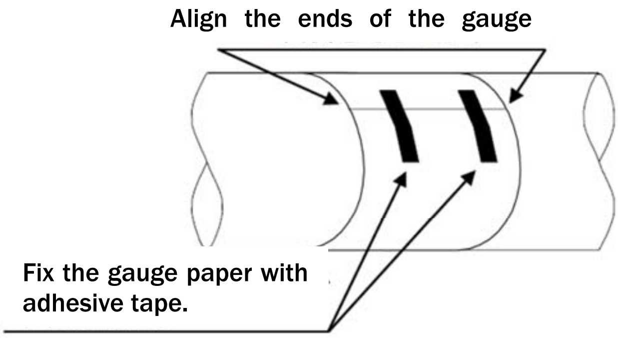
2. Mark the overlap with the line previously drawn 10 cm from the edge of paper.




3. Draw the line between overlapped marks, and fold the gauge paper so that the two lines meet and draw a line at the midpoint of each line.



4. Wrap the gauge paper with the lines drawn around the tube again.




5. Extend the fold line of the gauge sheet outward from ① and the other side from ②, respectively.

Next, draw a line in the direction of the pipe axis. Next, draw a line for the sensor installation interval. In the following figure, the line is drawn based on ①.

After the lines have been cleaned, remove the gage sheet. Remove the gauge sheet after the lines have been scratched.

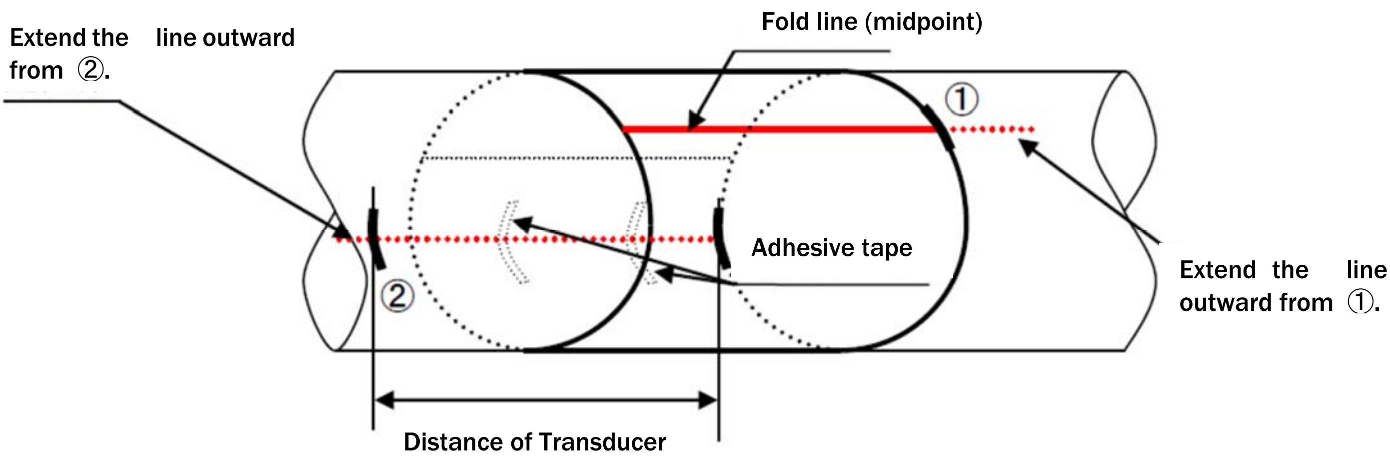



**Figure 6.14 How to determine the sensor position using gauge paper**

### 6.5.5 Accuracy of ultrasonic flow meter

Widely used in the water supply field, ultrasonic flowmeters, called clamp-on types, are particularly economical in measuring flow in large-diameter pipelines.

The characteristics of ultrasonic flowmeters are shown below, but the measurement accuracy is about 2 to 3% at full scale because obstructions such as tube thickness and refraction by air bubbles in the liquid affect the accuracy.

- The price of the equipment is constant regardless of the caliber. (Required sensors vary by pipe diameter.)
- Can be measured and repaired without stopping the flow.
- Completely non-contact with fluid.

In using ultrasonic flowmeters, it is necessary to fully understand their versatility and characteristics, and to learn the correct measurement method.

#### (1) Comparison of different flowmeter specifications

The following is a list of flow meters owned by the KUKL Tripureshwor branch and provided by the JICA project team, along with their functions, features, and usage.

**Table 6.5 Comparison of different flowmeter specifications**

| | TransPort@PT878<br>(GE Panametrics) | UFP-20<br>(Tokyo Keiki) |
|---|---|---|
| Applicable pipe diameter | [In case of transducer No 402]<br>DN50mm to DN7500mm | DN13mm to DN5000mm |
| Transducer | [No 402: Mid-size pipe]<br>DN50mm to DN7500mm | Small type: DN13mm to 50mm<br>Medium type: DN65mm to 500mm<br>Large type: DN300mm to 5000mm |
| Velocity range | - 12.2 m/sec to +12.2 m/sec | - 30 m/sec to +30 m/sec |
| Nominal accuracy | [DN150mm and less]<br>- +/- 2% to 5% of reading typical<br>[More than DN150mm]<br>- +/- 1% to 2% of reading typical | [DN13mm to DN90mm]<br>- Velocity ≧ 1 m/sec<br>+/-2.0% of reading typical<br>- Velocity < 1 m/sec<br>±0.02 m/sec<br>[DN100mm to DN250mm]<br>- Velocity ≧ 1 m/sec<br>+/-1.5% of reading typical<br>- Velocity < 1 m/sec<br>±0.015 m/sec<br>[DN300mm to DN5000mm]<br>- Velocity ≧ 1 m/sec<br>+/-1.0% of reading typical<br>- Velocity < 1 m/sec<br>±0.01 m/sec |
| Power supply | [Internal Battery]<br>Rechargeable batteries<br>DC6.0V 3.0Ah Ni-MH<br>Standard operation time: 9 – 11 hours of continuous operation is typical.<br>[AC Adaptor]<br>Output: DV12V 5A<br>Input: AC100 – 250V 50/60Hz 0.38A | [Internal Battery]<br>Rechargeable batteries<br>DC6.0V 4.0Ah Ni-MH<br>Standard operation time: 8 hours<br>Rapid charging time: 4 hours<br>[AC Adaptor]<br>Output: DV12V 5A<br>Input: AC90 – 264V 47/63Hz 1.5A (AC90V)<br>[DC input] |

| | TransPort@PT878 (GE Panametrics) | UFP-20 (Tokyo Keiki) |
|---|---|---|
| | | 10 – 30V |
| Waterproof grade | Main: IP67 (IEC 60529)<br>Transducer: IP66 (IEC 60529)<br>Submersion is not allowed. | Main: IP65 (IEC 60529)<br>Transducer: IP65 (IEC 60529)<br>Submersion is not allowed. |
| Thickness gauge | Optional | Included in a default package.<br>Range 1 – 100mm/Accuracy +/-0.1mm<br>Or<br>+/-1.5% R.D. which is larger in case of steel |
| Data recording | Internal memory.<br>Internal logged data transferred through USB memory as CSV format. | Internal memory.<br>Internal logged data transferred through USB memory as CSV format. |
| Minimum logging Interval | 10 seconds | 5 seconds |
| Zero calibration | Manual | Manual |

### (2) Understanding of Accuracy

Ultrasonic flowmeters have different notations of guaranteed error depending on the velocity range of the fluid being measured.

The following accuracy is guaranteed for the Tokyo Keiki UFP-20. It should be noted that the error is usually stable for flow velocities above 2 m/sec, but for slower velocities, the error increases as the velocity slows.

**Table 6.6 Guaranteed accuracy of UFP-20(Tokyo Keiki)**

| Diameter | Velocity | Accuracy |
|---|---|---|
| DN13mm to 90mm | 1 m/sec or higher | +/-2.0% on reading value |
| | Less than 1 m/sec | +/-0.02 m/sec |
| DN100mm to 250mm | 1 m/sec or higher | +/-1.5% of reading value |
| | Less than 1 m/sec | +/-0.0015 m/sec |
| DN300mm to 5000mm | 1 m/sec or higher | +/-1.0% of reading value |
| | Less than 1 m/sec | +/-0.01 m/sec |

**[Example of calculation of error]**

In case of DN 50mm

The error E (%) for a flow velocity of 2m/sec

$$E = \pm 2.0\%$$

The accuracy for a flow velocity of 0.8 m/sec is ±0.02m/sec, then

$$\pm 0.02 = 0.8 \times E/100$$

$$E = \pm 0.02 \times 100/0.8 = \pm 2.5\ (\%)$$

The accuracy for a flow velocity of 0.5 m/sec is ±0.02m/sec, then

$$\pm 0.02 = 0.5 \times E/100$$

$$E = \pm 0.02 \times 100/0.5 = \pm 4\ (\%)$$

### 1) Effect of pipe inside diameter error on accuracy

If the input pipe inner diameter differs from the actual dimensions, a 1% error in the input pipe inner diameter will result in an error of approximately 3% when converted to flow rate.

**Table 6.7 Effect of pipe inside diameter error on accuracy**

| | Inside Diameter | | |
|---|---|---|---|
| | 99mm (Area: 0.007694m$^2$) | 100mm (Area: 0.007850m$^2$) | 101mm (Area: 0.008008m$^2$) |
| V=0.5m/sec | 0.003847 m$^3$/sec | 0.003925 m$^3$/sec | 0.004004 m$^3$/sec |
| Proportion | 0.98 | 1.00 | 1.03 |

The following example shows the flow rate error for a 1 mm difference in the bore diameter value.

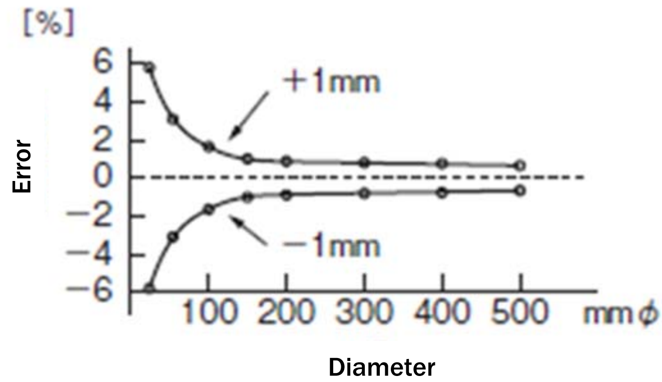
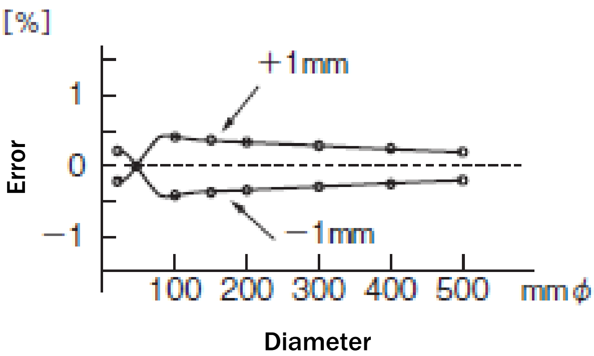



**Figure 6.15 Effect of an error of 1mm in pipe inner diameter on flow rate error**

### 2) Effect of transducer mounting spacing error

If the position of the transformer is inaccurate, an error of +/- 1 mm in mounting spacing, as an approximate guide, will result in a flow error of 1% or less.



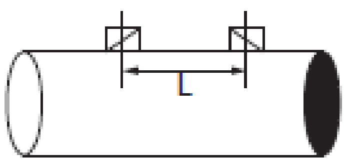




**Figure 6.16 Effect of 1mm transducer spacing error on flow rate error**

## 7. Flow Measuring Weir

All of the flow measurement devices we have studied so far use machines to measure flow rates and velocities. Various components are used in these products, and their functions deteriorate as they age, so they must be replaced periodically over a span of 10 or 15 years.

On the other hand, there are cases where flow measurement does not require strict accuracy. For example, in pumping tests after drilling wells or measuring water intake at water treatment plants, equipment that is inexpensive and can be used over a long period of time is suitable.

The most typical facility is called a Flow Measuring Weir.

### 7.1 Mechanism of Flow Measuring Weir

In a facility like the one shown below, where water is collected and allowed to drain from the overflow outlet, it is easy to imagine the following relationship between water level and flow rate, unless there is a velocity that pushes the water toward the overflow outlet.

- As flows increase, water levels would also increase.
- There may be some relationship between water level and flow rate.
- If the relationship between water level and flow rate is known, it may be possible to determine the flow rate by measuring the water level, even if the average flow rate is not known.

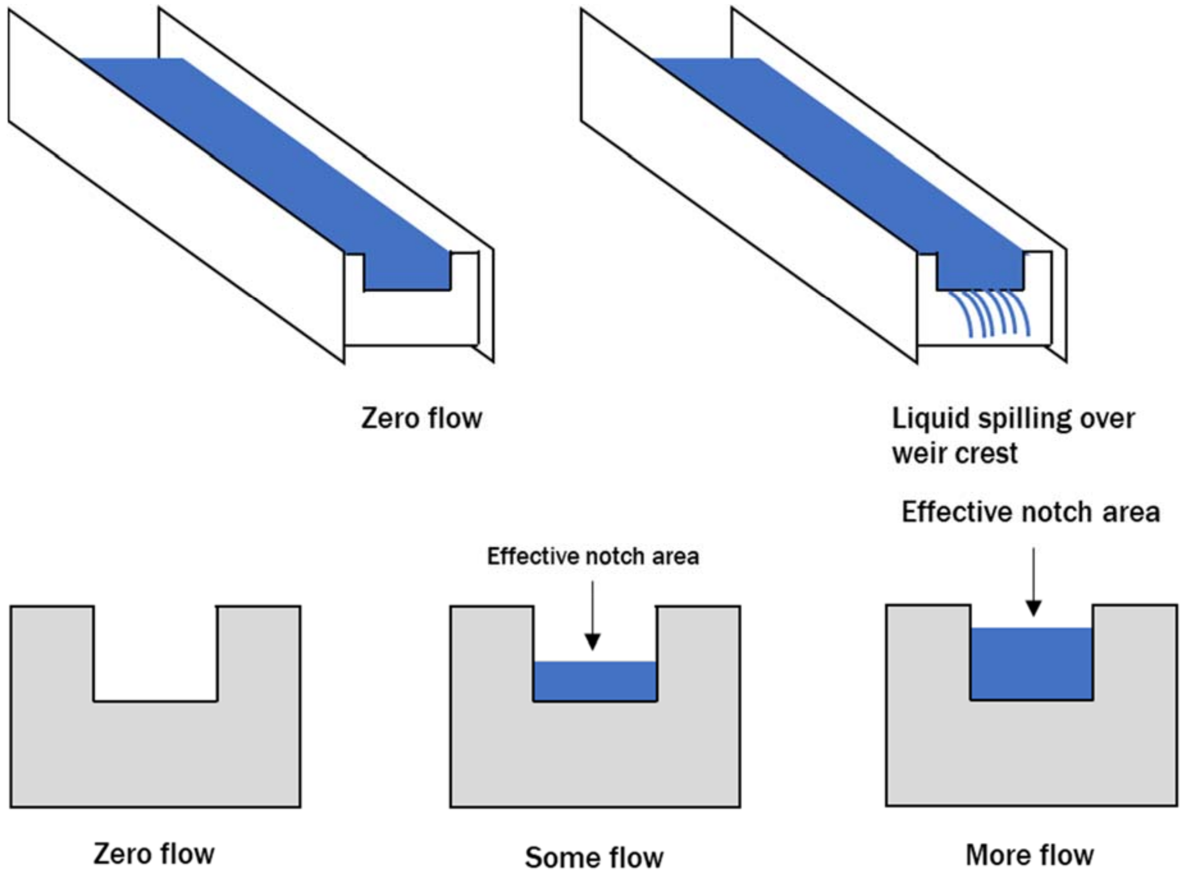



**Figure 7.1 Image of Flow Measuring Weir**

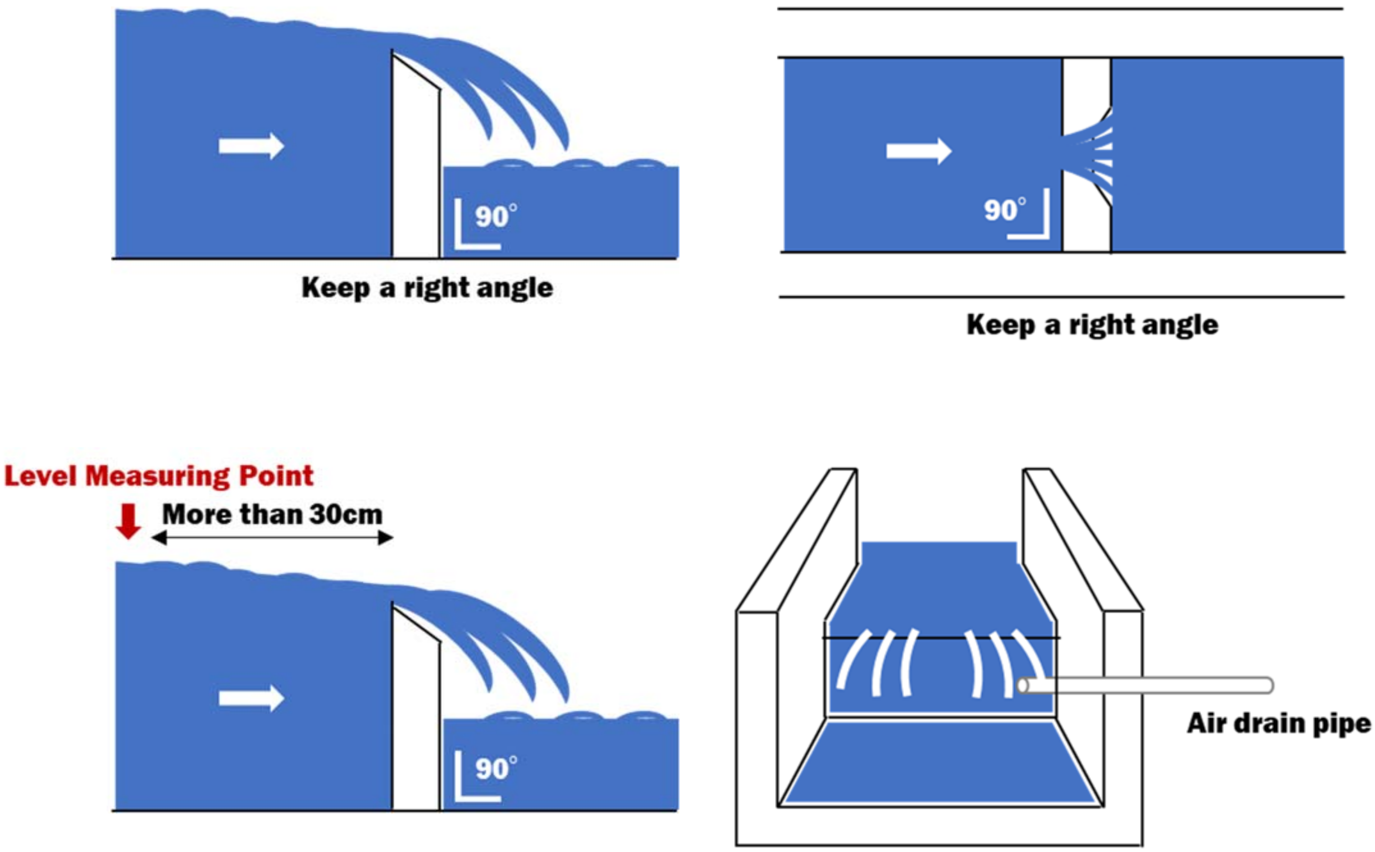



**Figure 7.2 Weir Installation Guide**

### 7.2 Precautions for Weir Installation

a. If the air supply downstream of the crest is inadequate, the weir will not function properly, so the rectangular weir should be replaced with a triangular weir, or a vinyl pipe for air ventilation should be passed downstream of the crest of the suppressed rectangular weir.

b. In order to minimize as much as possible the effect of the velocity of the pushing flow, the notch depth must be at least 15 cm for a contracted rectangular type and 30 cm for a suppressed rectangular type.

c. If the notch is not sufficiently higher than the highest water level downstream, the weir will be underwater when the flow is high. (Empirically, it should be at least 15 cm higher.)

d. To reduce the measurement error for contracted rectangular weir, keep sufficient width between the sidewall of channel and the sideline of notch close to the wall. (Empirically, at least 1.5 times the maximum overflow water level)

e. There is a risk of flooding at unexpected locations due to the increased water level upstream of the weir. The notch height and overflow depth should be considered to reduce the impact on the upstream side.

f. In wastewater mixed with solids, such as sewage, sediment accumulates upstream of the weir plate. As a result, measurement accuracy cannot be maintained without frequent trash removal.

g. Since a weir is a type of water storage facility, the flow data collected is averaged from instantaneous flow data. On the other hand, since they have a higher water storage capacity than flumes, they are less susceptible to approaching flow velocities.

h. Do not measure the water depth just above the notch because the water level drops near the notch. Water lever should be measured at a distance of 30 cm upstream from the weir plate where the water level is stable.

i. Since wave run-up can cause errors in water level measurement, the possibility of installing a rectification plate should be considered.

**[Weir Plate]**

The weir plate shall be perpendicular to the upstream inner surface line and the top edge of the weir plate, as shown below. The edge must be sharp and not have the slightest rounding.

It also stipulates that the slope shall be approximately 45° downstream from the weir top edge.

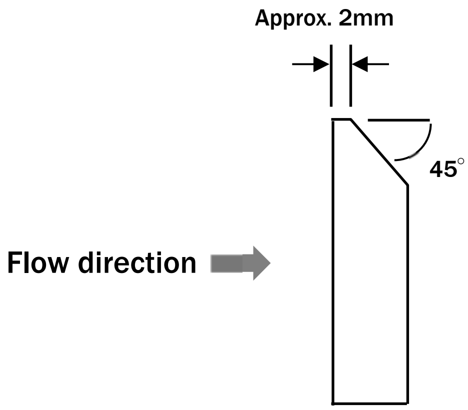



**Figure 7.3 Detail of the weir plate**

### 7.3 Name of each part

**[Nappe]**

The overflowing stream in a weir

**[Crest of weir]**

The edge or top surface of a weir with which the flowing liquid comes in Contact.

**[Contracted Weir]**

Weirs having sides sharp-edged, so that the nappe is contracted in width or having end contractions, either one end or two ends.

**[Suppressed weir or full-width weir]**

Weirs having its length "b" being equal to the width of the channel "B" so that the nappe suffers no end contractions.

**[Drop-down curve]**

The downward curvature of the liquid surface before the weir.

**[Head, H]**

The distance between the liquid surface and the crest of the weir measured before the drop-down curve.

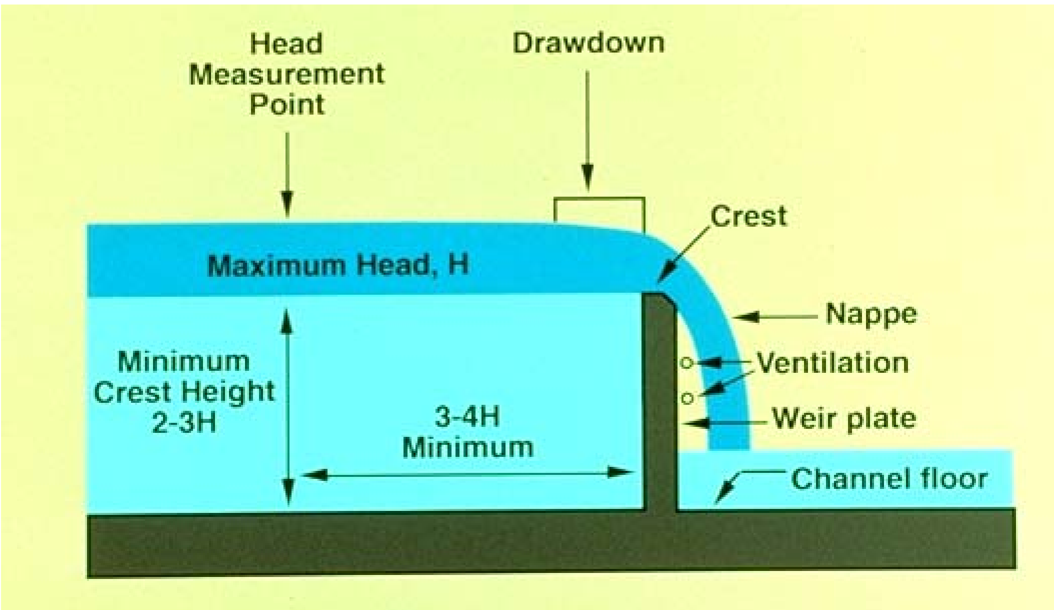



**Figure 7.4 Name of each part of weir**

## 7.4 Standard of weir and weir type

**[ISO 1438:2017/Hydrometry - Open channel flow measurement using thin-plate weirs]**

It defines the requirements for the use of rectangular and triangular (V-notch) thin-plate weirs for the measurement of flow of clear water in open channels under free flow conditions. It includes the requirements for the use of full-width rectangular thin-plate weirs in submerged (drowned) flow conditions.

**[ISO 9826:1992/Measurement of liquid flow in open channels — Parshall and SANIIRI flumes]**

This specifies methods of liquid flow measurement in open channels (particularly in irrigation canals) under steady or slowly varying flow conditions. The flumes used are designed to operate under both free-flow and submergence conditions.

**[JIS B8302/Measurement methods of pump discharge]**

**[JIS K0094/Sampling methods for industrial water and industrial wastewater]**

**[IS 6966-1/Hydraulic design of barrages and weirs]**

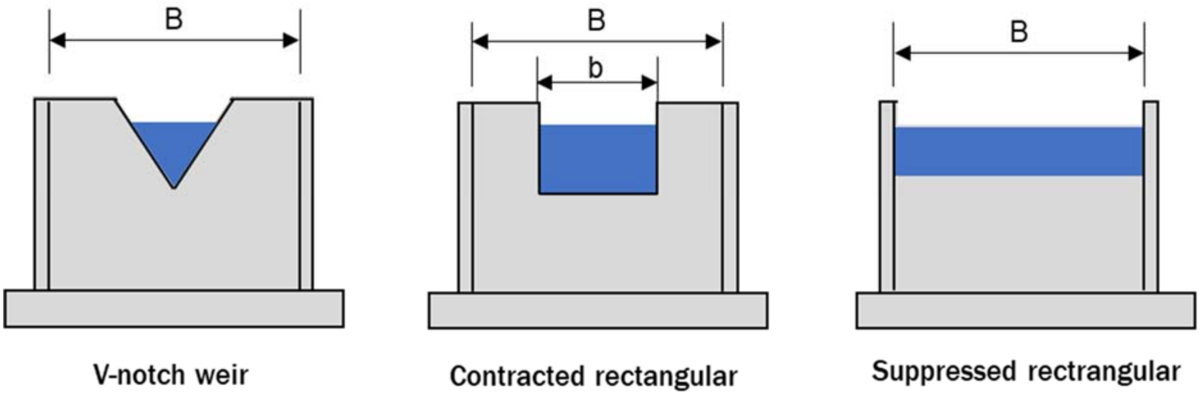
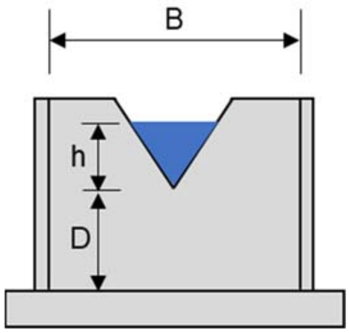
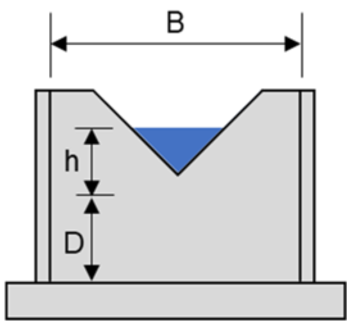
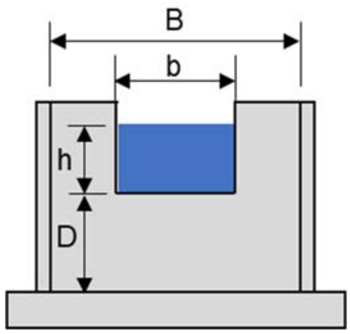
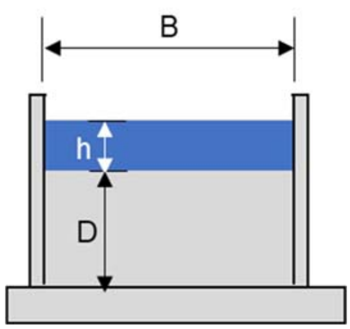



**Figure 7.5 Type of weir**

### Table 7.1 Flow Calculation Formula by type of weir

| | JIS B8322 | | |
|---|---|---|---|
| | | Foumula | Applicable range |
| V-notch Weir (60° ) |   | $Q = 0.577 * K * h^{2.5}$<br>$K = 83 + (1.978 / (B * R)^{0.5})$<br>$R = B * 0.1 * h * (h/\nu)^{0.5}$<br>$\nu = 10^{-6}$ ($m^2$/sec) --- Water | B = 0.44 to 1.0 (m)<br>h = 0.04 to 0.12 (m)<br>D = 0.1 to 0.13 (m) |
| V-notch Weir (90° ) |   | $Q = K * h^{2.5}$<br>$K = 81.2 + (0.24/h) + (8.4 + (12/(D^{0.5})) * (h/B - 0.09)^{0.5}$ | B = 0.5 to 1.2 (m)<br>h = 0.07 to 0.26 (m) < B/3<br>D = 0.1 to 0.75 (m) |
| Contracted Rectangular Weir |   | $Q = K * b * h^{1.5}$<br>$K = 107.1 + (0.177/h) + (14.2h/D) - 25.7 \{ (B-b)*h/(D*B) \}^{0.5} + 2.04 (B/D)^{0.5}$ | B = 0.5 to 6.3 (m)<br>b = 0.15 to 5.0 (m)<br>D = 0.15 to 3.5 (m)<br>$bD/B^2$ = more than 0.06<br>h = 0.03 to $0.45*b^{0.5}$ (m) |
| Suppressed Rectangular Weir |   | $Q = K * B * h^{1.5}$<br>$K = 107.1 + \{ (0.177/h) + (14.2h/D) \} * (1 + \varepsilon)$<br>$D \leqq 1: \varepsilon = 0$<br>$D > 1: \varepsilon = 0.55 * (D - 1)$ | B = more than 0.5 (m)<br>D = 0.3 to 2.5 (m)<br>h = 0.03 to D (m) < 0.8 (m)<br>h = less than B/4 |

## 7.5 Example of Contracted Rectangular Weir

### 7.5.1 Flow Calculation Formula

The formula for the contracted rectangular weir is as follows

$$Q = K * b * h^{3/2}$$

$$K = 107.1 + \left( \frac{0.177}{h} + 14.2 \frac{h}{D} \right) - 25.7 \sqrt{\frac{(B - b)\, h}{D * B}} + 2.04 \sqrt{\frac{B}{D}}$$

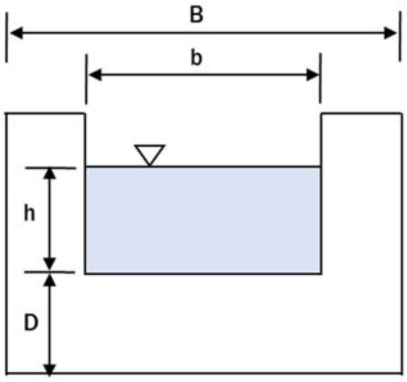
Q: Flow Rate ($m^3$/min)

B: Width of channel

b: Width of weir crest (m)

D: Distance from the channel bottom to the crest line (m)

h: Overflow Head (m)




B: Width of channel (m)

b: Width of weir crest (m)

D: Hight from the bottom of channel to the top of weir crest (m)

**Figure 7.6 Section of contracted rectangular weir**

### 7.5.1 Mahankalchaur WTP

The following example shows the use of "Contracted Rectangular Weir" in the mixing chamber of the Mahankalchaur WTP:

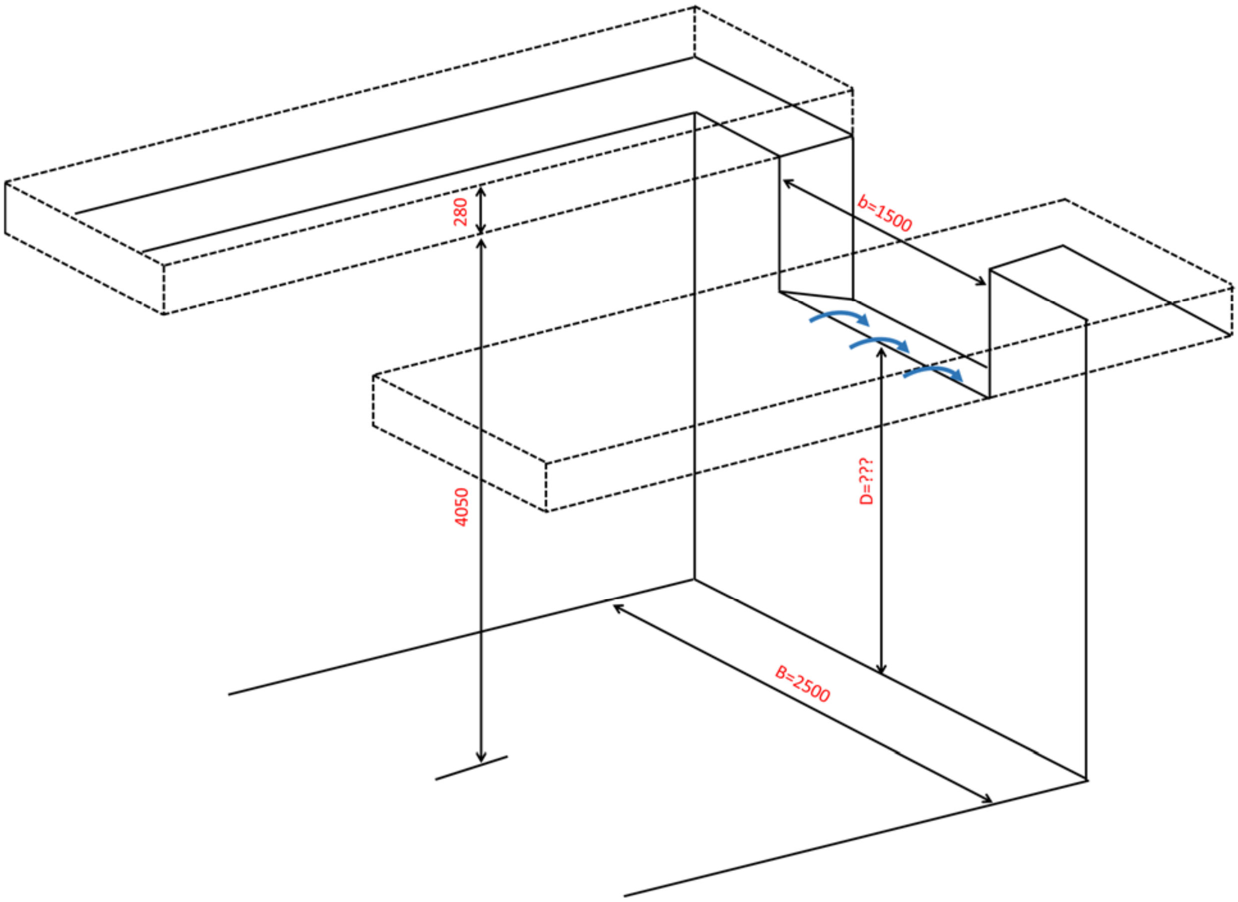



**Figure 7.7 Detail of the contracted rectangular weir in Mahankalchaur WTP**

**Table 7.2 Dimension of the contracted rectangular weir**

| Part | Dimension in the As-built drawing | Required condition | Result |
|---|---|---|---|
| B | 2.5 m | 0.5 ～ 6.3m | OK |
| b | 1.5 m | 0.15 ～ 5 m | OK |
| D | 3.5 m | 0.15 ～ 3.5 m | OK |

The following table shows the relationship between "Overflow Head" and "Flow Rates" using the dimensions in the drawing.

## Table 7.3 Flow calculation chart by overflow head in Mahankalchaur WTP

| Contracted Rectangular Weir at Mixing Chamber of Bode WTP | | |
|---|---|---|
| Width of channel (B) | 2.50 | m |
| Width of weir plate (b) | 1.50 | m |
| Distance from the weir top to the bottom of channel (D) | 3.50 | m |
| Distance from the upper slab top to the weir top | 0.73 | m |

This data should be checked by Mahankalchaur WTP Staff.

| Distance from the upper slub to the water surface (m) | Overflow Head (m) | Flow Coeficient (K) | Inlet Flow $m^3/min$ | Inlet Flow $m^3/hour$ |
|---|---|---|---|---|
| 0.540 | 0.190 | 106.73946 | 13.260 | 795.606 |
| 0.539 | 0.191 | 106.72869 | 13.364 | 801.814 |
| 0.538 | 0.192 | 106.71799 | 13.467 | 808.038 |
| 0.537 | 0.193 | 106.70737 | 13.571 | 814.278 |
| 0.536 | 0.194 | 106.69682 | 13.676 | 820.534 |
| 0.535 | 0.195 | 106.68635 | 13.780 | 826.805 |
| 0.534 | 0.196 | 106.67595 | 13.885 | 833.092 |
| 0.533 | 0.197 | 106.66563 | 13.990 | 839.395 |
| 0.532 | 0.198 | 106.65537 | 14.095 | 845.713 |
| 0.531 | 0.199 | 106.64518 | 14.201 | 852.047 |
| 0.530 | 0.200 | 106.63507 | 14.307 | 858.396 |
| 0.529 | 0.201 | 106.62502 | 14.413 | 864.760 |
| 0.528 | 0.202 | 106.61504 | 14.519 | 871.140 |
| 0.527 | 0.203 | 106.60513 | 14.626 | 877.535 |
| 0.526 | 0.204 | 106.59528 | 14.732 | 883.946 |
| 0.525 | 0.205 | 106.58550 | 14.840 | 890.372 |
| 0.524 | 0.206 | 106.57578 | 14.947 | 896.813 |
| 0.523 | 0.207 | 106.56613 | 15.054 | 903.269 |
| 0.522 | 0.208 | 106.55654 | 15.162 | 909.741 |
| 0.521 | 0.209 | 106.54701 | 15.270 | 916.227 |
| 0.520 | 0.210 | 106.53754 | 15.379 | 922.729 |
| 0.519 | 0.211 | 106.52814 | 15.487 | 929.246 |
| 0.518 | 0.212 | 106.51879 | 15.596 | 935.777 |
| 0.517 | 0.213 | 106.50951 | 15.705 | 942.324 |
| 0.516 | 0.214 | 106.50028 | 15.815 | 948.886 |
| 0.515 | 0.215 | 106.49111 | 15.924 | 955.462 |
| 0.514 | 0.216 | 106.48200 | 16.034 | 962.054 |
| 0.513 | 0.217 | 106.47294 | 16.144 | 968.660 |
| 0.512 | 0.218 | 106.46394 | 16.255 | 975.281 |
| 0.511 | 0.219 | 106.45500 | 16.365 | 981.917 |
| 0.510 | 0.220 | 106.44611 | 16.476 | 988.568 |
| 0.509 | 0.221 | 106.43728 | 16.587 | 995.233 |
| 0.508 | 0.222 | 106.42850 | 16.699 | 1001.913 |
| 0.507 | 0.223 | 106.41977 | 16.810 | 1008.607 |
| 0.506 | 0.224 | 106.41109 | 16.922 | 1015.316 |
| 0.505 | 0.225 | 106.40247 | 17.034 | 1022.040 |
| 0.504 | 0.226 | 106.39390 | 17.146 | 1028.779 |
| 0.503 | 0.227 | 106.38538 | 17.259 | 1035.531 |
| 0.502 | 0.228 | 106.37691 | 17.372 | 1042.299 |
| 0.501 | 0.229 | 106.36849 | 17.485 | 1049.080 |
| 0.500 | 0.230 | 106.36012 | 17.598 | 1055.876 |
| 0.499 | 0.231 | 106.35179 | 17.711 | 1062.687 |

### 7.5.2 Bode WTP

The following example shows the use of "Contracted Rectangular Weir" in the mixing chamber of the Bode WTP:

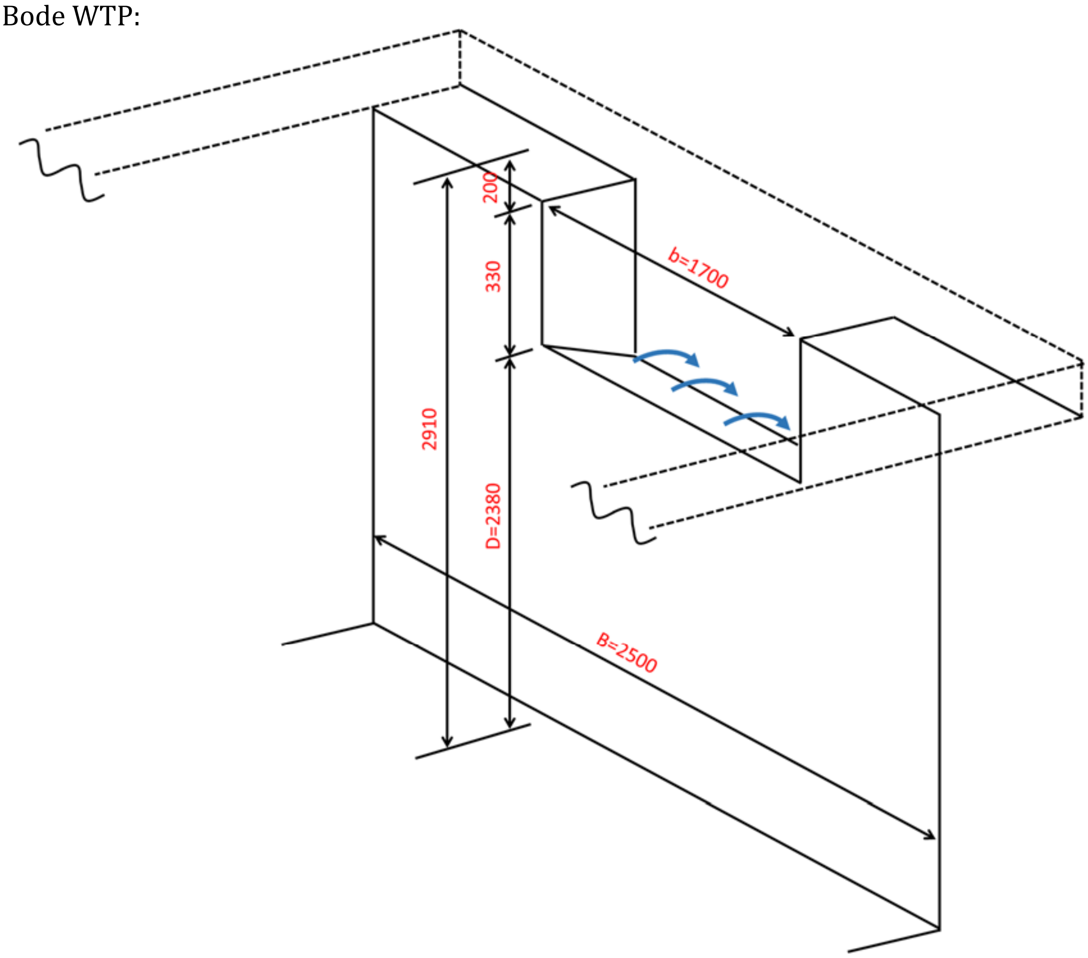



**Figure 7.8 Detail of the contracted rectangular weir in Bode WTP**

**Table 7.4 Dimension of the contracted rectangular weir in Bode WTP**

| Part | Dimension in the As-built drawing | Required condition | Result |
|---|---|---|---|
| B | More than 5 m | 0.5 ～ 6.3m | OK |
| b | 1.70 m | 0.15 ～ 5 m | OK |
| D | 2.38 m | 0.15 ～ 3.5 m | OK |

The following table shows the relationship between "Overflow Head" and "Flow Rates" using the dimensions in the drawing.

# Table 7.5 Flow calculation chart by overflow head in Bode WTP

| Contracted Rectangular Weir at Mixing Chamber of Bode WTP | | |
|---|---|---|
| Width of channel (B) | 2.50 | m |
| Width of weir plate (b) | 1.70 | m |
| Distance from the weir top to the bottom of channel (D) | 2.38 | m |
| Distance from the upper slab top to the weir top | 0.53 | m |

| Distance from the upper slub to the water surface | Overflow Head | Flow Coeficient (K) | Inlet Flow | |
|---|---|---|---|---|
| (m) | (m) | | $m^3$/min | $m^3$/hour |
| 0.470 | 0.060 | 110.19046 | 2.753 | 165.185 |
| 0.469 | 0.061 | 110.12891 | 2.821 | 169.237 |
| 0.468 | 0.062 | 110.06908 | 2.889 | 173.322 |
| 0.467 | 0.063 | 110.01088 | 2.957 | 177.438 |
| 0.466 | 0.064 | 109.95425 | 3.026 | 181.586 |
| 0.465 | 0.065 | 109.89912 | 3.096 | 185.765 |
| 0.464 | 0.066 | 109.84541 | 3.166 | 189.976 |
| 0.463 | 0.067 | 109.79308 | 3.237 | 194.217 |
| 0.462 | 0.068 | 109.74206 | 3.308 | 198.489 |
| 0.461 | 0.069 | 109.69230 | 3.380 | 202.792 |
| 0.460 | 0.070 | 109.64375 | 3.452 | 207.124 |
| 0.459 | 0.071 | 109.59636 | 3.525 | 211.487 |
| 0.458 | 0.072 | 109.55008 | 3.598 | 215.880 |
| 0.457 | 0.073 | 109.50487 | 3.672 | 220.302 |
| 0.456 | 0.074 | 109.46069 | 3.746 | 224.753 |
| 0.455 | 0.075 | 109.41750 | 3.821 | 229.234 |
| 0.454 | 0.076 | 109.37526 | 3.896 | 233.744 |
| 0.453 | 0.077 | 109.33395 | 3.971 | 238.282 |
| 0.452 | 0.078 | 109.29352 | 4.047 | 242.849 |
| 0.451 | 0.079 | 109.25394 | 4.124 | 247.445 |
| 0.450 | 0.080 | 109.21519 | 4.201 | 252.068 |
| 0.449 | 0.081 | 109.17724 | 4.279 | 256.720 |
| 0.448 | 0.082 | 109.14005 | 4.357 | 261.400 |
| 0.447 | 0.083 | 109.10361 | 4.435 | 266.107 |
| 0.446 | 0.084 | 109.06788 | 4.514 | 270.842 |
| 0.445 | 0.085 | 109.03285 | 4.593 | 275.604 |
| 0.444 | 0.086 | 108.99849 | 4.673 | 280.394 |
| 0.443 | 0.087 | 108.96477 | 4.754 | 285.210 |
| 0.442 | 0.088 | 108.93169 | 4.834 | 290.054 |
| 0.441 | 0.089 | 108.89922 | 4.915 | 294.924 |
| 0.440 | 0.090 | 108.86734 | 4.997 | 299.821 |
| 0.439 | 0.091 | 108.83603 | 5.079 | 304.744 |
| 0.438 | 0.092 | 108.80528 | 5.162 | 309.693 |
| 0.437 | 0.093 | 108.77507 | 5.244 | 314.669 |
| 0.436 | 0.094 | 108.74538 | 5.328 | 319.671 |
| 0.435 | 0.095 | 108.71619 | 5.412 | 324.698 |
| 0.434 | 0.096 | 108.68750 | 5.496 | 329.751 |
| 0.433 | 0.097 | 108.65930 | 5.581 | 334.830 |
| 0.432 | 0.098 | 108.63155 | 5.666 | 339.935 |
| 0.431 | 0.099 | 108.60426 | 5.751 | 345.064 |
| 0.430 | 0.100 | 108.57741 | 5.837 | 350.219 |
| 0.429 | 0.101 | 108.55099 | 5.923 | 355.399 |

### 7.6 Various water level measurement methods

The overflow level of a weir is determined as follows:

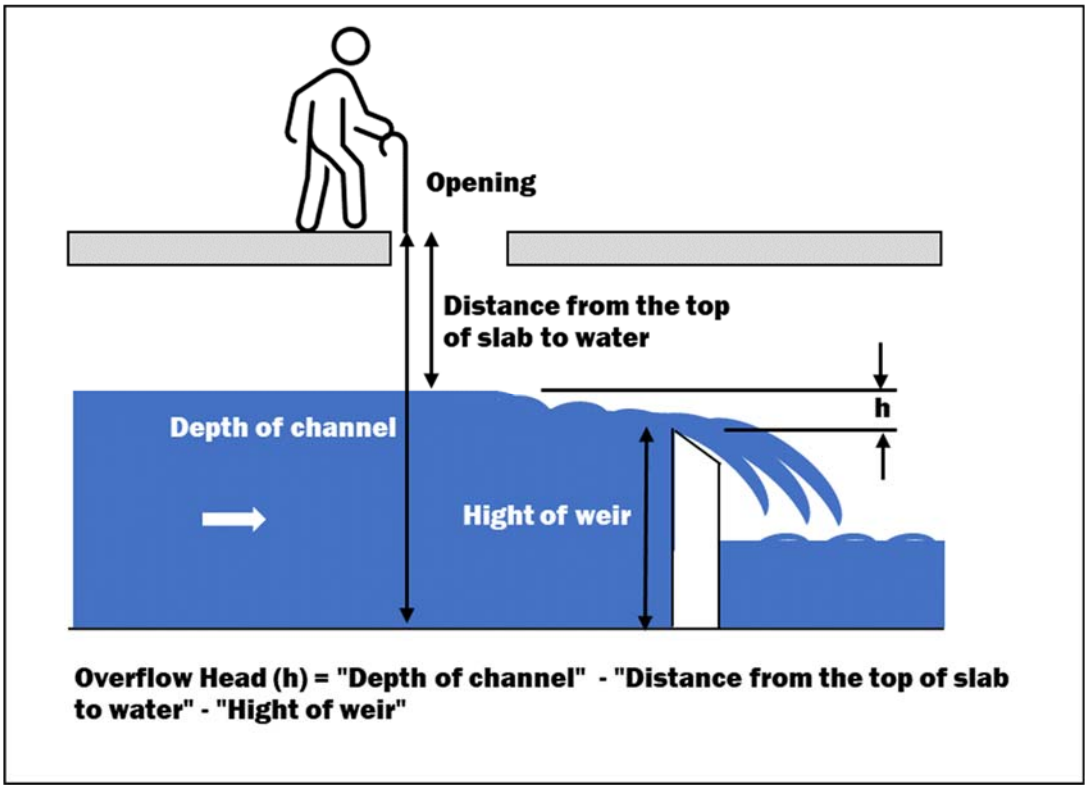



**Figure 7.7 How to know the overflow head**

Manual measurement using a steel ruler as shown in the figure above is the simplest but time-consuming method. Therefore, it is common to use a water level gauge for simple and accurate measurement.

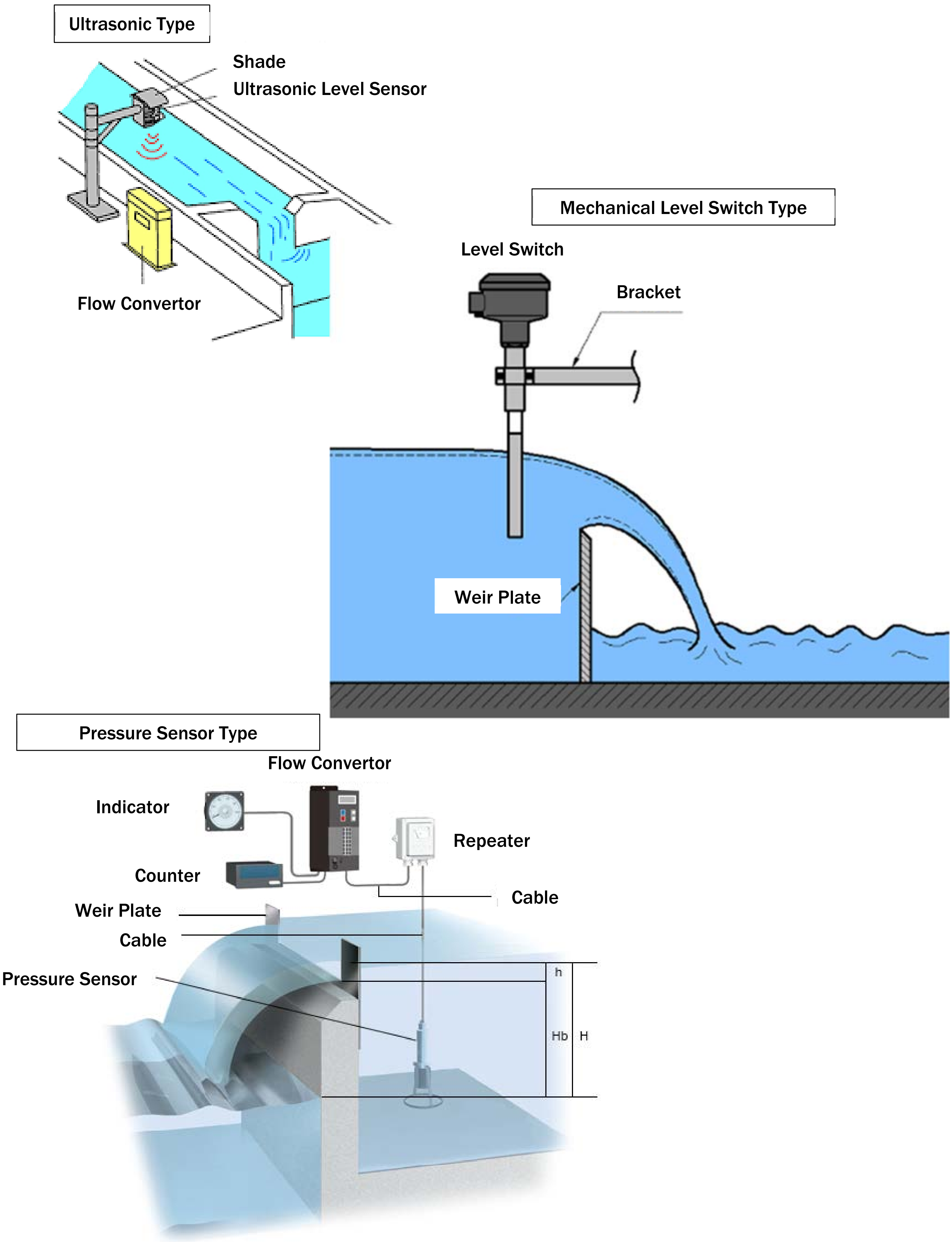



**Figure 7.8 Various methods of water level measurement**

## 8. Parshall Flume

In addition to the conventional flow measuring weir that uses the difference in water head, there is another method for measuring the flow rate of an open channel called a flume.

In this method, a narrow throat is installed in the middle of the open channel to create a forced change in water level before and after the throat.

When a flume with the shape shown below is installed in the middle of a rectangular channel, the flow entering the flume will have its velocity increase in the constriction section, and a critical flow will occur in the narrowing section called the throat section.

In this condition, the water level upstream of the throat (Ha) and the flow rate Q have a constant relationship (Q=C*Han), so the flow rate can be calculated by measuring the upstream water level only.

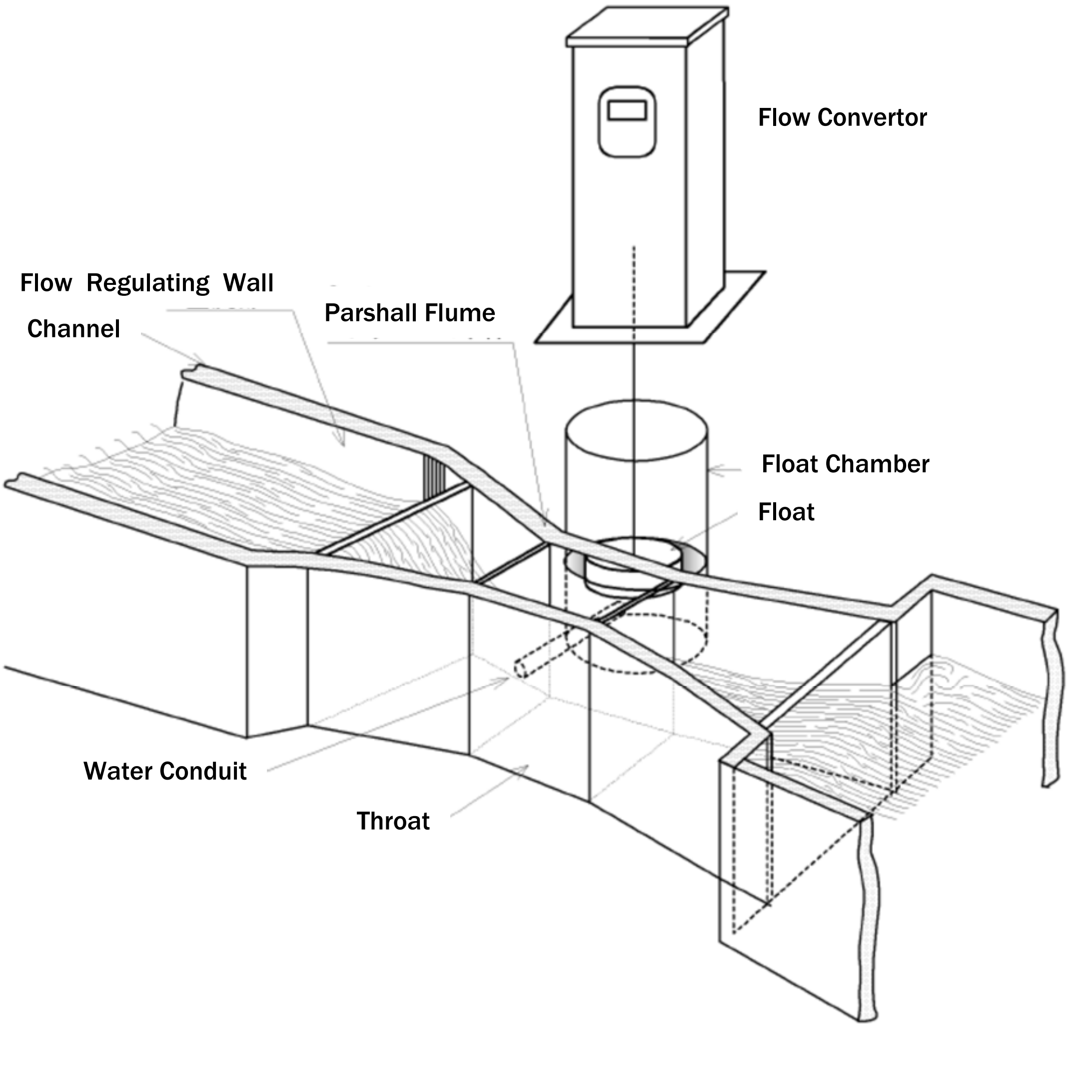



**Figure 8.1 Example of a Parshall Flume**

**[Characteristics of Parshall Flume]**

a. Compared to the weir type, the water head loss is only about 1/4 of that of the weir type, making it suitable for measurement in waterways where a large drop-off cannot be taken.

b. Often used in agricultural water, water supply and sewage, etc., because solids in the fluid do not easily settle or accumulate.

c. Flumes can be made of metal plates, cast-in-place concrete, or integrally molded FRP. To improve measurement accuracy, it is necessary to accurately manufacture the dimensions of each part of the flume.

## 9. Achievement Test

| No | Question | Yes | No |
|---|---|---|---|
| 1 | Flow rate is the volume of fluid passing through an area per unit time. | ☐ | ☐ |
| 2 | In the water supply field, “Mass Flow” is generally used. | ☐ | ☐ |
| 3 | The volume of 1 $m^3$ of water is equal to 100 L. | ☐ | ☐ |
| 4 | If 1 L of water flows per second, it reaches 3.6 $m^3$ in 1 hour. | ☐ | ☐ |
| 5 | It took 5 hours for the tank with a capacity of 1200 $m^3$ to fill up. The average water inflow is calculated as 4 $m^3$/min. | ☐ | ☐ |
| 6 | Required performance for water meters are determined by international standards. | ☐ | ☐ |
| 7 | Accuracy testing of water meters may be performed at any flow range you like. | ☐ | ☐ |
| 8 | Guaranteed error of water meters depends on flow range. | ☐ | ☐ |
| 9 | The R value, which indicates the performance of the water meter, means the range of flow rates that can be accurately metered. | ☐ | ☐ |
| 10 | In water meters, small flow rates have wider tolerances than large flow rates. | ☐ | ☐ |
| 11 | In water meters, the error always remains the same even if the flow rate changes. | ☐ | ☐ |
| 12 | In general, meters with larger R-values are also more expensive. | ☐ | ☐ |
| 13 | Errors of water meters in use are allowed up to twice the verification tolerance. | ☐ | ☐ |
| 14 | Types of domestic (residential) water meters can be divided into two types: those that convert flow velocity into volume and those that directly measure volume. | ☐ | ☐ |
| 15 | Volumetric meters are less accurate than velocimetry meters. | ☐ | ☐ |
| 16 | Velocimetry meter can be installed on the inclined section. | ☐ | ☐ |
| 17 | Volumetric meters can be installed vertically | ☐ | ☐ |
| 18 | A venturi meter is a flowmeter that converts the pressure difference inside a pipe into a flow rate. | ☐ | ☐ |
| 19 | A flowmeter that uses Faraday's law of electromagnetic induction is called an ultrasonic flowmeter. | ☐ | ☐ |
| 20 | Electromagnetic flowmeter is less affected by debris and turbulence in the fluid. | ☐ | ☐ |
| 21 | Bends may be installed just before the flow meter. | ☐ | ☐ |
| 22 | As a general rule, there should be an appropriate linear length in front of and behind the flowmeter. | ☐ | ☐ |
| 23 | An ultrasonic flow meter can measure flow rate without cutting the pipe | ☐ | ☐ |
| 24 | Ultrasonic flow meters can measure pipes of any material. | ☐ | ☐ |
| 25 | Even if the transducers of ultrasonic flow meter are not precisely positioned, the measurement error is small. | ☐ | ☐ |
| 26 | The Z method is the easiest to measure with an ultrasonic flowmeter. | ☐ | ☐ |
| 27 | In ultrasonic flowmeters, the smaller the flow velocity, the smaller the error. | ☐ | ☐ |

| No | Question | Yes | No |
|---|---|---|---|
| 28 | If the flow velocity is extremely slow, it may not be measurable with an ultrasonic flowmeter. | ☐ | ☐ |
| 29 | An ultrasonic flow meters may also be installed on vertical (upward) pipes. | ☐ | ☐ |
| 30 | The velocity of the fluid in the pipe is the same at any position in the pipe. | ☐ | ☐ |
| 31 | Generally, the flow velocity is slower in the center of the pipe. | ☐ | ☐ |
| 32 | There are RS and FS accuracy designations for Flow meters. | ☐ | ☐ |
| 33 | When selecting a flow meter, any type can be used as long as it is inexpensive. | ☐ | ☐ |
| 34 | The diameter of the flowmeter must be determined according to the expected flow velocity and flow rate. | ☐ | ☐ |
| 35 | A flow meter may be installed immediately after the gate valve. | ☐ | ☐ |
| 36 | Water treatment plants do not need to measure inflow water volume daily to operate. | ☐ | ☐ |
| 37 | The amount of chemicals to be injected at a water treatment plant can be determined without measuring the flow rate. | ☐ | ☐ |
| 38 | Flow rate is not particularly important in the operating record of a water treatment plant. | ☐ | ☐ |
| 39 | The true error of a water meter can only be confirmed by testing with a reference tank. | ☐ | ☐ |
| 40 | Water meter errors verified using a test meter are true errors | ☐ | ☐ |
| 41 | The larger the R value representing the performance of the water meter, the wider the flow range over which accuracy is guaranteed. | ☐ | ☐ |
| 42 | Water meters can always measure even minute flow rates. | ☐ | ☐ |
| 43 | In countries with metering laws, the replacement time of water meters is strictly regulated. | ☐ | ☐ |
| 44 | Turbine flowmeter converts the flow velocity determined from the rotation speed of the internal propeller into flow rate. | ☐ | ☐ |
| 45 | Filters should be installed in the inflow area because debris can enter the water meter and cause it to malfunction. | ☐ | ☐ |
| 46 | If the error for a flow velocity of 0.5 m/sec is +/-0.02 m/sec, the error E can be expressed as +/-4(%). | ☐ | ☐ |
| 47 | If the error for a flow velocity of 0.8 m/sec is +/-0.02 m/sec, the error E can be expressed as +/-4 (%). | ☐ | ☐ |
| 48 | “Class C” and “Class D”of flow meter performance classifications are based on new ISO standards. | ☐ | ☐ |
| 49 | In order to calculate non-revenue water ratio, it is necessary to record the amount of water used by all customers. | ☐ | ☐ |
| 50 | If a customer's water meter cannot be read, no further metering is required. | ☐ | ☐ |