



APPLICATION NOTE

SEEPAGE MEASUREMENT IN AN OPEN CHANNEL THROUGH A WEIR

1 Introduction

Seepage of water through, around or under a dam is expected in all embankment dams and even in concrete dams. The quantity of seepage, the seepage path and the velocity of seepage water are of great concern in analyzing the structural behavior of a dam (refer application note AN-9602 - earth and rockfill dams). The **quantity of seepage** is important for the following reasons:

- Large quantity of seepage around a dam (through the abutments), under a dam (through the foundation) and in some cases, through the dam itself, may dissolve some of the chemical constituents of the rock or soil material present at those locations. Larger the seepage, greater is the dissolution. This in turn provides an enlarged seepage path which results in even greater seepage. Dams founded on certain evaporites like gypsum are specially effected by this problem.
- Large quantity of water moving through, around or under a dam result in completely saturated soils and rock in the seepage areas, excessive hydrostatic uplift pressure, as well as softening and weakening of the soil and rock.
- Excessive quantity of seepage may in extreme cases, compromise the storage capability of the reservoir.

The **location** of the seepage paths is of concern because:

- If the majority of the seepage water is confined to only a few discrete seepage paths and the velocity of the seepage is sufficiently high, then progressive erosion of particles of soil may occur resulting in a piping type failure of the dam.
- Seepage water in sufficient quantity in a few paths may result in concentrated dissolution in those areas.

The **velocity of movement** of seepage water is important because:

- The greater the velocity, the greater the chance of particles being eroded way in the seepage path. Larger velocity can result in increasingly larger particles being moved and piping failure is more likely to occur.

Embankment dams should as a consequence have **provision** for:

- Determination of seepage source
- Reliable measurement of seepage quantity
- Evaluation of water quality of seepage flow, in relation to the materials transported with the flow
- Indication of pore pressure in embankment, foundation and the abutments

Seepage monitoring is probably the single most important form of performance observation for an embankment dam. Some quantity of seepage is unavoidable and if not properly channeled, is a threat to the dam. Both the quality and quantity of seepage are of importance.

The quantity of seepage entering a seepage collection system is normally directly related to the level of the water in the reservoir. Some of the methods used for measuring seepage are as follows:

1.1 Calibrated catch container

For a relatively low flow rate, the simplest method for monitoring the rate of seepage, is by using a calibrated catch container. To use a catch container, the drain water should either be directed through a pipe with an open end or through a channel constructed with an overhang and a vertical drop. The calibrated catch container is then placed in position to catch the water

and the time required to do so is measured with a stop watch. The catch container should preferably be made of stainless steel or some suitable plastic material which does not corrode easily.

1.2 Flow Meter

Seepage water collected in a toe drain or drain trench of a dam is taken through open channels or pipes for discharge into the downstream of the dam. The quantity of this flow can be determined by measuring the velocity of the water. There are many methods of measuring the velocity of water. Some use the pitot tube principle for this purpose. Others use propeller type rotary devices or electromagnetic sensors or acoustic velocity meters for measurement of the velocity. In case the seepage water is directed through a pipe, an easy method of determining the flow is to mount a suitable orifice plate in the pipe and measure the pressure drop across it by a differential pressure transmitter. The Encardio-rite model EDPT-12 differential pressure transmitter can be used for measuring the pressure drop. The Encardio-rite model ECON-90B can be used for the indication of the flow rate and totalizing the quantity of flow.

1.3 Parshall Flumes

A flume is a specially shaped open channel flow section, somewhat like a venturi. The flow is constricted by a converging section over the crest of the flume. This produces a differential head which can be related to the discharge. Just downstream of the crest is a downward sloping floor which accelerates the flowing water, essentially preventing the deposition of any sediments which could reduce the measurement accuracy. The downward sloping floor also yields the capability of accurate measurement of flow with no submergence (free flow) moderate submergence or even with considerable submergence downstream.

The Parshall flume is a particular kind of venturi flume named after its principal developer Ralph L Parshall. Under free flow conditions, the discharge depends solely on the width of the throat W and the water head H_a (refer figure 1). Depending upon a flow rate varying from $28 \text{ cm}^3/\text{second}$ to $85 \text{ m}^3/\text{second}$, the width of the throat W varies from 25 mm to 15 m. Under submerged flow conditions, unless the backwater level H_b exceeds a certain percentage of H_a , the flow rate is not much effected by the submergence.

Another kind of flume often used is a trapezoidal flume. Several kind of these are commercially available. They are usually supplied as a precast unit of molded hard plastic. For flow varying from $28 \text{ cm}^3/\text{second}$ to 20 litre/second, the throat width varies from 5 cm to 30 cm.

For further details on flumes, refer to the references at the end of this application note.

1.4 Weir

The weir is one of the oldest, simplest and the most reliable device used to measure the quantity of flow of water. The weir normally used is the rectangular or 90° V-notch type. In case of a low flow rate, a V-notch weir with an angle of less than 90° may be used. Sometimes, a trapezoidal weir is used. In some rare cases a parabolic or circular weir is used (refer IS: 9117-1979).

The discharge over a thin plate weir is a function of the water head on the weir, the size and shape of the discharge area and an experimentally determined discharge coefficient which takes into account the head of the water over the weir, the geometry of the approach channel and the weir and the physical properties of water and characteristics of flow.

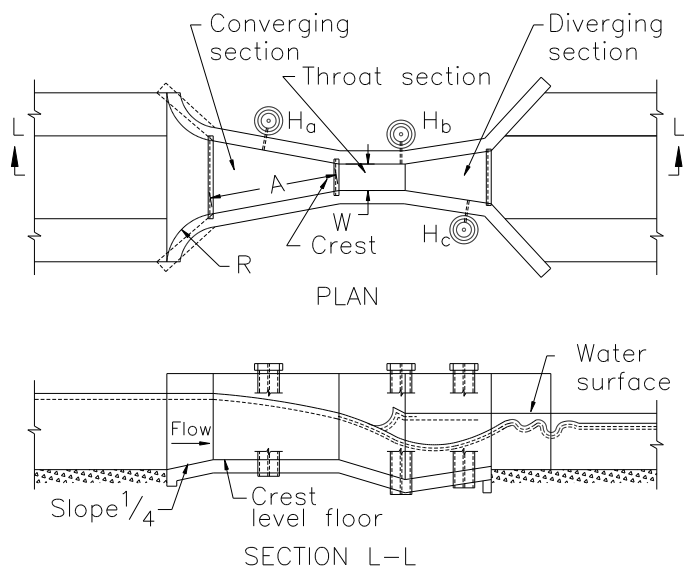


Figure 1 Parshall flume - plan and elevation

For a rectangular or a trapezoidal weir, the bottom edge of the opening is called the crest and the side edges are called sides or weir ends. The sheet of water leaving the weir crest or the V-notch is called the nappe. A weir operates best when it discharges into the atmosphere. Unlike a Parshall flume, a submerged or partially submerged weir results in inaccuracies. For a weir, a free flow condition is better than partially submerged flow. A weir is known as sharp crested in case the weir crest or notch is cut with a sharp upstream corner into a relatively thin plate and the flowing water springs past the bulkhead or wall on which the weir is mounted, without touching it. In case the flowing water touches the wall or the bulkhead, the weir is classified as broad crested. Only a sharp crested weir is recommended. If a rectangular weir is placed in a flume, with the sides of the flume acting as the ends of the weir, there are no horizontal side contractions and the nappe is of the same width as the flume. This type of weir is called a suppressed weir. If the weir is partially submerged or broad crested, the accuracy of flow measurement is reduced. In general, a rectangular suppressed weir or a 90° V-notch weir provides the most accurate measurement. A trapezoidal weir with a slope of 1:4 (Cipolletti weir), also provides good accuracy. This is because, its discharge occurs essentially like a suppressed weir due to the end contractions getting compensated by the outward slope of the weir sides.

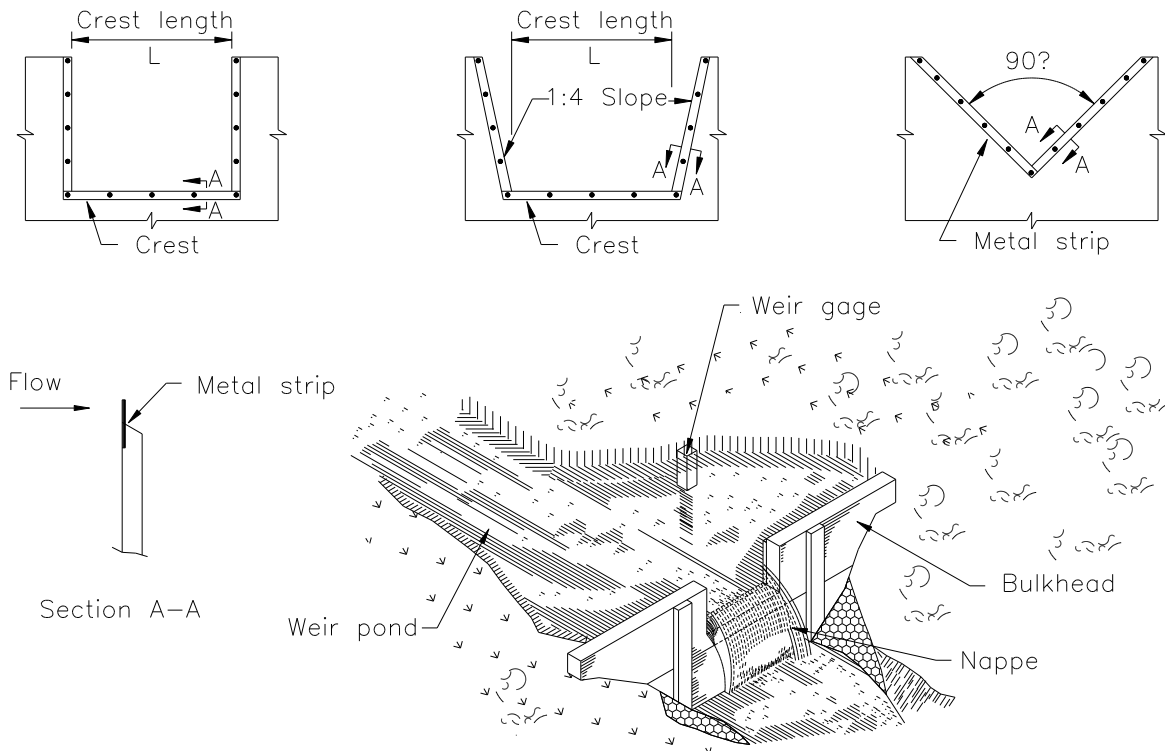


Figure 2 Standard contracted weir

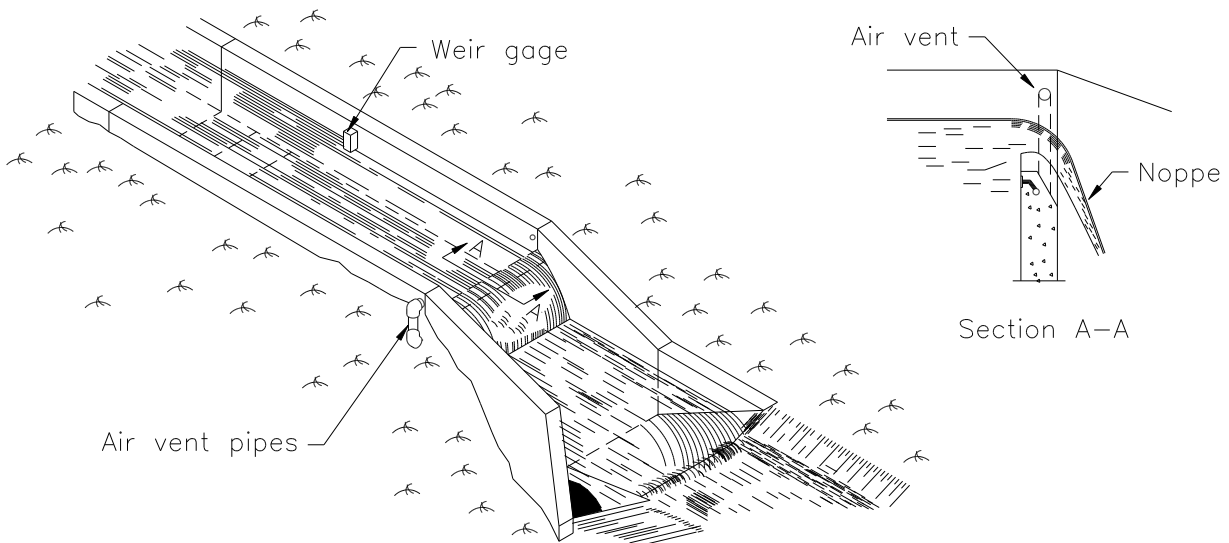


Figure 3 Standard suppressed weir

2 Standard contracted rectangular weir

In a standard contracted rectangular weir, the crest and the sides of the weir are sufficiently far away from the bottom and sides of the channel such that full contraction is developed.

2.1 Conditions for accurate measurement of flow

- The upstream face of the bulkhead and the weir plate should be smooth and in a vertical plane perpendicular to the axis of the channel.
- The entire crest should be a level plane surface that forms a sharp right-angled edge where it intersects the upstream face. The thickness of the crest, measured in the direction of flow, should be between 0.8-2.0 mm. Both sides of a rectangular weir should be vertical and of the same thickness as the crest.
- The upstream corner of the notch must be sharp. The sides and crest should be machined or filed perpendicular to the upstream face. They should be free from any burr or scratch and should also not have any scratch marks produced by abrasive cloth or paper. A knife-edge is not desirable and should be avoided because it is difficult to maintain and does not allow the nappe to develop properly.
- The downstream edges of the notch should be chamfered as the plate is thicker than the prescribed crest width. This chamfer should be at an angle of 45° or more with the surface of the crest.
- The distance from the bottom of the approach channel (weir pool) to the crest should preferably be at least twice the depth of water above the crest, but not less than 30 cm.
- The distance from the sides of the weir to the sides of the approach channel should preferably be at least twice the depth of water above the crest, but not less than 30 cm.
- The overflow sheet (nappe) should touch only the upstream edges of the crest and the sides.
- The maximum downstream pool level should be at least 6 cm below crest elevation.
- The head on the weir should be taken as the difference in elevation between the crest and the water surface at a point upstream from the weir. This distance should be at least four times the maximum water head over the crest.

The cross-sectional area of the approach channel should be at least eight times that of the nappe. The upstream cross section should be uniform for a distance of 15 to 20 times the depth of nappe. If the approach channel is smaller than that defined by this criteria, the velocity of approach may be too high and the gauge may show a low reading.

2.2 Flow measurement formula

Flow through any infinitesimal section of width dy is:

$$\begin{aligned} dQ &= \text{area} \times \text{velocity} \\ &= b \, dy \, [2g(h-y)]^{1/2} \end{aligned}$$

$$\text{or } Q = \int_0^h b \, [2g(h-y)]^{1/2} \, dy$$

$$\text{let } z = h-y$$

$$dz = -dy$$

$$\begin{aligned} Q &= \int_h^0 b \, [2g z]^{1/2} \, dz \\ &= -\frac{2}{3} (2g)^{1/2} b \, [z^{3/2}]_h^0 \end{aligned}$$

$$\text{or } Q = \frac{2}{3} (2g)^{1/2} b \, h^{3/2}$$

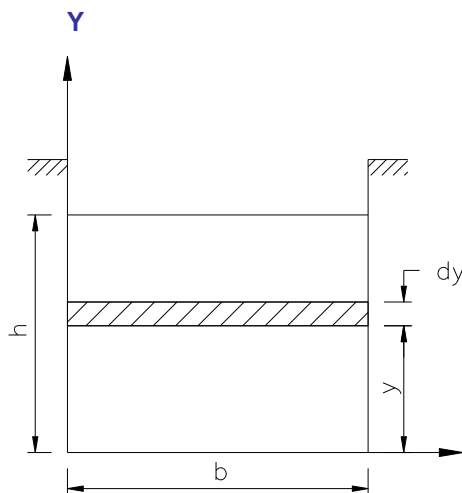


Figure 4

In actual practice, to determine the correct flow rate, the term on the right hand side has to be multiplied by a coefficient of discharge C_e . The value of C_e is around 0.6. To arrive at the correct value of C_e refer to IS: 9108-1979, section 9.6.

$$\therefore Q = \frac{2}{3} (2g)^{1/2} C_e b \, h^{3/2}$$

$$\text{or } Q = 2.95 C_e b \, h^{3/2} \text{ m}^3 / \text{second} \quad \text{where } b \text{ \& } h \text{ are in m}$$

3 Standard suppressed rectangular weir

A standard suppressed rectangular weir, also known as a full width weir, is illustrated in figure 3. The crest consisting of a thin plate is far above the bottom of the channel such that full crest contraction is developed. Special care must be taken with a suppressed weir to secure proper aeration beneath the nappe at the crest. This is accomplished by providing proper vent holes under the nappe, from both sides of the channel.

There is no lateral contraction in a standard suppressed rectangular weir because the sides of the weir coincide with the sides of the approach channel. The width of the approach channel should also extend downstream beyond the crest to prevent lateral expansion of the nappe. The **conditions** of accurate flow measurement, as listed in section 2.1, excepting those related to side contraction, also apply to a suppressed weir.

The formula for determining the flow rate is the same as derived in section 2.2 excepting that the value of the discharge coefficient C_e is different. This value is approximately 0.6. However, for a more accurate value of the discharge coefficient, refer to IS:9108-1979 section 9.7.

4 Triangular notch thin plate weir

The triangular notch weir consists of a vertical V-shaped notch fabricated in a thin stainless steel plate. A diagrammatic illustration of triangular notch weir is shown in figure 5. The weir is plane and rigid and is perpendicular to the walls and floor of the channel. The upstream face of the plate is smooth.

The weir operates in a manner similar to a contracted weir and all conditions of accuracy as stated for the standard contracted weir apply in this case also (see section 2.1). However, the distance from the sides of the weir measured from the point of maximum water level, to the sides of the channel should be atleast twice the head on the weir. Moreover, the minimum distance from the crest to the bottom pool should be measured from the vertex of the notch to the channel floor.

A V-notch is used where a small flow rate has to be measured. As the V-shaped notch weir has a pointed bottom, the head generated for even a small flow is greater than that in a rectangular weir. In case of a small discharge, this is an advantage,

because the nappe springs free of the crest; whereas in other kinds of weir, it clings to the crest and makes the measurement worthless.

A weir with a 90° V-notch is suitable for measurement of flow rates of 0.03-0.3 m³/second or 30-300 litre/ second. For a flow rate of less than 30 litre/second, a 45° or a 22.5° V-notch is preferable. As a general rule, the head in the case of a V-notch weir should not be less than 6 cm to prevent the nappe from clinging to the crest.

4.1 Flow measurement formula

Flow through any infinitesimal section of a V-notch weir with an angle of α at the vertex and width dy is:

$$\begin{aligned}
 dQ &= \text{area} \times \text{velocity} \\
 &= 2x \, dy \, [2g(h-y)]^{1/2} \\
 \text{or } Q &= \int_0^h 2x \, [2g(h-y)]^{1/2} \, dy \\
 &= \int_0^h 2y \tan \frac{\alpha}{2} \, [2g(h-y)]^{1/2} \, dy \\
 \text{Let } z &= h-y \\
 \text{or } dz &= -dy \\
 \text{or } Q &= - \int_0^h 2(h-z) \tan \frac{\alpha}{2} \, [2g(z)]^{1/2} \, dz \\
 &= - \int_0^h 2(2g)^{1/2} \tan \frac{\alpha}{2} (h-z) (z)^{1/2} \, dz \\
 &= 2(2g)^{1/2} \tan \frac{\alpha}{2} \left[\frac{2}{3} h z^{3/2} - \frac{2}{5} z^{5/2} \right]_0^h
 \end{aligned}$$

or $Q = \frac{8}{15} (2g)^{1/2} \tan \frac{\alpha}{2} h^{5/2}$

In actual practice, to determine the correct flow rate, the term on the right hand side has to be multiplied by a coefficient of discharge C_e. The value of C_e is around 0.6. To arrive at the correct value of C_e, refer to IS: 9108-1979, section 10.5.

$$\begin{aligned}
 Q &= \frac{8}{15} (2g)^{1/2} C_e \tan \frac{\alpha}{2} h^{5/2} \\
 \text{or } Q &= 2.36 \tan \frac{\alpha}{2} C_e h^{5/2} \text{ m}^3/\text{second} \quad \text{where } h \text{ is in m}
 \end{aligned}$$

For a 90° V-notch

$$\begin{aligned}
 Q_{90} &= 2.36 C_e h^{5/2} \text{ m}^3/\text{second} \quad \text{where } h \text{ is in m} \\
 \text{or } Q_{90} &= 0.024 C_e h^{5/2} \text{ litre/second} \quad \text{where } h \text{ is in cm} \quad \text{Equation 4.1}
 \end{aligned}$$

5 Water head measurement systems

In order to measure the discharge over the weir accurately, the head over the weir should be correctly measured. Generally, to avoid water-level variations caused by waves, turbulence or vibration, the head-water level should be measured in a stilling well. The stilling well to be built near the approach channel should be connected to the upstream water flow by means of a suitable conduit, equipped if necessary, with a throttle valve to dampen the oscillations. Alternatively, a gage well may be built upstream of the weir in the approach channel itself.

The head measurement section should be located at a sufficient distance upstream from the weir because the flow at the brink of the weir is sloping down and curvilinear in nature. The depth at the drop is therefore not equal to the critical depth as computed by the principle based on parallel flow. The location of the head measurement section will be satisfactory if it is located at a distance of 4-5 times the maximum head upstream over the weir at any time.

The accuracy of the head measurement is critically dependent upon the determination of the level of the weir crest (rectangular weir) or the level of the vertex of the notch (triangular notch weir). This level is to be taken as the zero value for any head

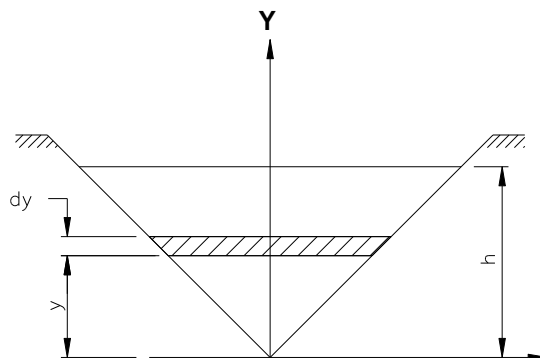


Figure 5

measurement in a stilling well or gage well. The method of determining the gage zero is described in section 9.4 of IS:9108. The procedure essentially consists of drawing still water in the approach channel to a level below the weir crest or the vertex. The depth of the weir crest or the vertex from the top of the weir is then measured with a precise vernier height gage. The depth of the still water is also measured with the same vernier height gage. This difference in the two depths is then added to the level of water, as measured at the same time in the stilling well or the gage well.

Encardio-rite offers the following three methods for measurement of the head produced in the approach channel of the weir:

5.1 Mechanical measurement

On the downstream face of the weir, along one side of the V-notch or the rectangular weir, is etched a scale with a least count of 0.5 cm. The zero of this scale coincides with the vertex of the V-notch or the crest of the rectangular weir. As stated earlier, this direct reading of the head on the weir is somewhat lower than the actual head based on parallel flow. Necessary correction should be made in computing the flow rate.

If requested, Encardio-rite also provides a **staff gage** on which a scale is etched with a least count of 1 cm. The staff gage can be used for measuring the water level in the stilling well or the gage well.

5.2 Level transmitter with indicator

The Encardio-rite model ELT-20T/S immersion type level transmitter can be installed in the gage well or the stilling well. The cable is routed to the observation room, where the Encardio-rite model EDI-50 digital indicator gives a direct reading of the head in mm or cm, depending upon the head.

Alternatively, if a tapping is available from near the bottom of the stilling well or the side of the approach channel, the Encardio-rite model EDPT-12 transmitter can be used to give a 4-20 mA signal proportional to the water level. As in the case of the model ELT-20T/S, the 4-20 mA signal is fed into a model EDI-50 digital indicator located in the observation room to give the reading of the water head in mm or cm, as required.

5.3 Vibrating wire system with submersible cylinder

The Encardio-rite model ESM-10V vibrating wire sensor with submersible cylinder, along with Encardio-rite portable strain indicator model EDI-51V or Encardio-rite data acquisition system model CR10X can be used for monitoring the water head developed over a weir.

The vibrating wire sensor is essentially an electron beam welded hermetically sealed load cell. Electron beam welding of the sensor ensures that there will be a vacuum of 10^{-3} Torr (1/760,000 atmosphere) inside the sensor body. This feature makes the sensor suitable for any location where there is a lot of water all the time and the humidity level is high. The load cell is fixed on a base plate which is grouted on top of the stilling well or the gage well. A submersible cylinder is gently suspended from the load cell. The cable from the load cell is properly laid and routed to the observation room.

The sensor works on the Archimedes principle which states:

When a body is fully or partially immersed in a fluid, there is an apparent loss in its weight and this loss in weight is equal to the weight of the fluid displaced by the body.

The measurement of water head by this principle is best illustrated by a practical example in which the flow rate is 30 litre/second over a 90° V-notch.

Example:

For a flow rate of 30 litre/second over a 90° V-notch, the head generated will be 21.26 cm over the gage zero, in case the coefficient of discharge is 0.6 (calculate on basis of equation 4.1). For this kind of head generation, Encardio-rite supplies a submersible cylinder with a diameter of 12.5 cm and a length of 35 cm. The weight of the submersible cylinder is adjusted to a value of 5 kg. The reason for this would soon become clear. The submersible cylinder should be installed on the load cell such that its bottom is around 5 cm below the vertex of the 90° V-notch.

Assuming density of water to be 1 gm/cm^3 the loss in weight W_L of the cylinder due to the water level increasing by 21.26 cm will be as follows:

$$W_L = \frac{\pi}{4} \times 12.5^2 \times 21.26 / 1000 \text{ kg} = 2.61 \text{ kg}$$

For the submersible cylinder set at 5 cm below the vertex, the weight on the load cell will vary between 4.4 kg to 1.8 kg for a variation of water head over the vertex of 0 - 21.26 cm. Taking safety into consideration and providing sufficient overload protection, the load cell to be supplied should be of 10 kg capacity.

It will be clear from this example that the size of the submersible cylinder and the load cell capacity may vary from application to application.

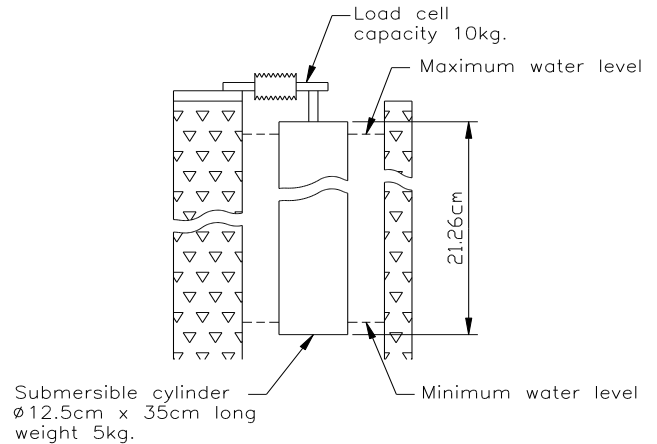


Figure 6

6 References

- 6.1 Seepage Measurement Devices, Chapter 3, pages, 71-99, Volume - 5, Proceedings of Workshop on Instrumentation and Dam Safety, 1989, Ministry of Water Resources, CWC, Dam Safety Service Organisation.
- 6.2 IS: 9108-1979: Liquid flow measurement in open channels using thin plate weirs.
- 6.3 IS: 9117-1979: Recommendation for liquid flow measurement in open channels by weirs and flumes - end depth method for estimation of flow in non-rectangular channels with a free over fall (approximate method).
- 6.4 IS: 9922-1981: Guide for selection of method of measuring flow in open channels.
- 6.5 Encardio-rite application note AN-9602, Earth and rockfill dams.