CHAPTER 02

Sources of Water and its Conveyance

INTRODUCTION

In this chapter, we will focus on the proper assessment of surface water and ground water resources. After estimating the total water requirement for the proposed water supply scheme, the designer of the scheme must go in search of nearby water sources, which may be able to supply the required amount of water. We will also discuss a proper distribution system for a particular city or town to fulfil the all water requirement with minimum leakage loss and operation cost.

2.1 Sources of Water

Water is the most essential natural resource for life next to air and is likely to become a critical scarce resource in many regions of the world. The various sources of water available on the earth can be divided into the following two categories.

A. Surface Sources: For example

(i) Pond and lakes
(ii) Streams and rivers
(iii) Storage reservoirs and
(iv) Oceans, generally not used for water supplies at present.

B. Sub-Surface Sources or Underground Sources: For example

(i) Springs
(ii) Infiltration galleries
(iii) Infiltration wells
(iv) Wells and tube-walls

A Surface Sources

- Surface sources are such sources of water in which the water flows over the surface of earth and is thus directly available for water supplies like natural pond, lakes, rivers and streams.
- Most of the earth's water sources get their water supplies from precipitation, which may fall in various forms such as rains, snow, hail, dew etc.
- Rains, no doubt, form the principle and the major part of the resultant supplies but sometimes, the underground water through some spring, also enters natural depressions and get collected there, forming ponds and lakes.

NOTE

1. The quality of water in a lake is generally good and does not need much purification.
2. Larger and older lakes, however, provide comparatively pure water than smaller and newer lakes.
3. Rivers are most important sources of water for public water supply schemes because.
   (a) The quality of river water is generally good due to self purification and does not need much purification.
   (b) Most of cities are settled near the rivers where water is easily available for water supplies.

B. Sub Surface Sources or Underground Water Sources

The underground water is generally available in the following forms:

1. Infiltration galleries
2. Infiltration wells
3. Springs
4. Well, including tubewells

1. Infiltration Galleries

Infiltration galleries are sometimes called horizontal wells because they are the horizontal tunnel constructed at shallow depths (3 to 5 metres) along the banks of rivers through the water strata as shown in figure:

- The galleries are generally constructed of masonry walls with roof slabs, and extract water from the aquifer by various porous lateral drain pipes located at suitable interval in the gallery.

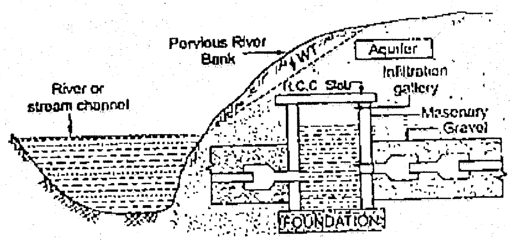


Fig. 2.1 Section of an Infiltration gallery

- These tunnels or galleries are generally laid at a slope, and the water collected in them is taken to a sump well, from where it is pumped, treated and distributed to the consumers.
- These infiltration galleries are quite useful when water is available in sufficient quantity just below the ground level.

Discharge from Infiltration galleries can be computed using Darcy's law as

$$Q = kL\cdot\left(\frac{H^2-h^2}{2R}\right)$$

Where,
Q = Total discharge from infiltration galleries
K = Permeability coefficient of the aquifer
L = Length of gallery ($\perp$ to paper)
H = Static water level above bottom of gallery
R = Radius of influence
h = depth of water in gallery on pumping equilibrium

Example 2.1 600 m³/day of water is to be obtained from a proposed Infiltration gallery, which is placed at 6 m depth from sub-surface water table. The coefficient of permeability of the soil aquifer is 100 m/day. Find the length of gallery if the drawdown in the gallery on pumping is not exceed 4 m. The radius of influence may be assumed to be 100 m.

Solution: Data Given, Q = 600 m³/day; H = 6 m; h = 6 – 4 = 2 m; R = 100 m; k = 100 m/day

The equation of discharge from infiltration gallery

$$Q = k \cdot L \cdot \left(\frac{H^2 - h^2}{2R}\right)$$

Substituting the value, we get

$$600\ m^3/day = 100\ m/day \times L \times \left(\frac{6^2 - 2^2}{2 \times 100}\right)$$

$$600 = \left(100 \times L \times \frac{32}{200}\right) m$$

$$L = \frac{600 \times 200}{100 \times 32} = 37.5\ m$$

2. Infiltration Wells

Infiltration wells are the shallow wells constructed in series along the banks of a river in order to collect the river water seeping through their bottom as shown in figure 2.2.

- These wells are generally constructed of brick masonry with open joints and they are generally covered at the top and kept open at the bottom.
- The various infiltration wells are connected by porous pipes to a sump well, called as jack well, as shown in figure 2.3.
- These wells are very useful for drawing water from polluted stream and very common in France.

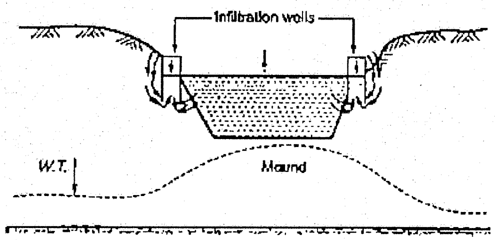


Fig. 2.2 Locations of infiltration wells

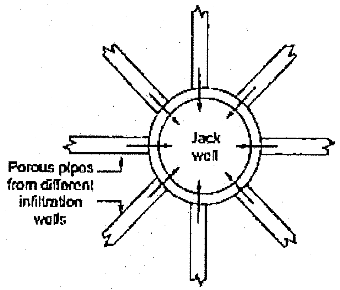


Fig. 2.3 Plan of a Jack well receiving water from a number of infiltration wells

NOTE: A very new technique 'Ranney Well' that has recently started is to construct a vertical well 3 to 6 m in diameter with horizontal radial collector, and is known as radial well.

3. Springs

The natural outflow of ground water at earth's surface is said to form a spring:

- A pervious layer sandwiched between two impervious layers, give rise to a natural spring.
- A spring indicates the outcropping of the watertable.
- The springs are generally capable of supplying very small amounts of waters, and are, therefore, generally not regarded as sources of water supplies.
- However, good developed springs may sometimes be used as water supply source for small town especially in hilly areas.

NOTE

Certain springs, sometimes discharge hot water due to the presence of sulphur in them. These hot springs usually emit sulphur mixed water (warm to boiling), and hence cannot be used for water supplies. Such type of hot springs in India is are in Sohana in haryana and one in Tattapani near Simla at the bank of Sutluj river.

Formation and Types of Springs

Springs are usually formed under three general conditions of geological formation, as explained below:

(a) Gravity Springs

- When the ground water table rises high and water overflow through the sides of a natural valley or a depression, the spring formed is known as gravity spring (Fig.2.4).
- The flow from such a spring varies with the rise or fall of the watertable.

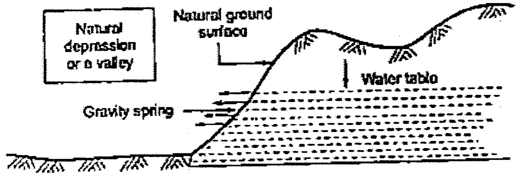


Fig. 2.4 Gravity spring

(b) Surface springs

Sometimes, an impervious obstruction or stratum supporting the underground storage becomes inclined (as shown in figure 2.5), causing the watertable to go up and get exposed to the ground surface. This type of spring is known as surface spring

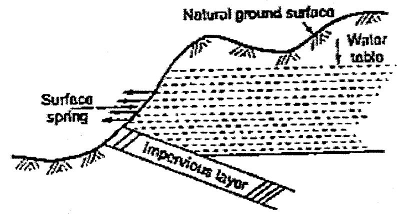


Fig. 2.5 Surface spring

(c) Artesian Springs

When the surface springs storage is under pressure i.e. under some confined aquifer, the spring formed is known as artesian spring. This type of spring are capable to provide almost uniform quantity of water. Since the water oozes out under pressure, they are able to provide higher yields and may be thought of as the possible sources of water supply.

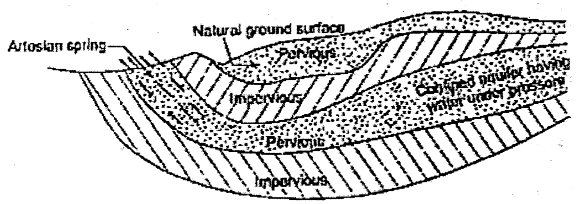


Fig. 2.6 Artesian spring

4. Wells

A hole usually vertical, excavated in the earth for bringing ground water to the surface is called water well.

Open Wells or Dug Wells

Smaller amount of ground water has been utilised from ancient times by open wells. They are generally open masonry wells having comparatively bigger diameters and are suitable for low discharges.

- The yield of an open well is limited because such wells can be excavated only to a limited depth, where the ground water storage is also limited.

- One of the recent methods used to improve the yield of an open well is to put in a 8 to 10 cm diameter bore hole in the centre of the well, so as the tap the additional water from an aquifer, or from fissures in the rock.
- Open wells may be classified into the following two types.
  (a) Shallow wells (b) Deep wells
- A shallow well is the one which rests in a pervious strata and draws its supplies from the surrounding material.
- On the other hand, a deep well is the one which rests on an impervious 'mota' or "magasan" layer and draws its supply from the pervious formation lying below the mota layer, through a bore hole made into the mota layer.

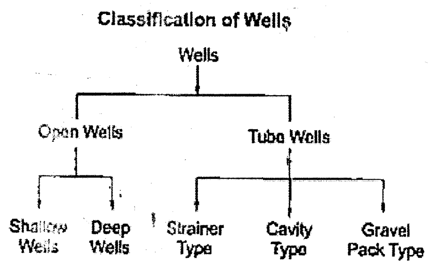


Fig. 2.7 Artesian spring

Do you know? The nomenclature of the shallow and deep wells is purely technical, and has nothing to do with actual depth of the well. A "shallow well" might be having more depth than a "deep well".

Remember: A hand pump generally used in many part of India, uses a reciprocating type of a pumping arrangement to lift the water.

2.2 Yield of an Open Well

The yield of an open well can be calculated by

(a) Theoretical method

(b) Practical method
  1. Pumping test
  2. Recuperating test

(c) By carrying out practical tests and calculating it from the observations.

(a) Theoretical method

If a well is penetrated through an aquifer water will rush into it with a velocity V. If A_s is the surface area of the aquifer opening into the well, then

$$Q = V \cdot A_s \qquad \boxed{Q = n \cdot V_a \cdot A_s}$$

where, $V = n \cdot V_a$

where, V_a = actual flow velocity, n = porosity

(b) Practical method

1. Pumping Test

A pump is, first of all, installed so as to draw sufficient supplies of water from the open well, and to cause heavy drawdown in its water level. The rate of pumping is then changed and so adjusted that the water level in the well becomes constant.

- In this condition of equilibrium, the rate of pumping will be equal to the rate of yield, and hence rate of pumping will directly give us the yield of the well at a particular drawdown.
  Knowing this yield say Q_1 at a certain known drawdown say s_1, the yield (Q) at any other drawdown (s) can be evaluated as follows.

By Darcy's law

$$Q = K \cdot i \cdot A = K\left(\frac{s}{L}\right) \cdot A = \frac{K}{L} \cdot A \cdot s$$

or $$\boxed{Q = c \cdot A \cdot s} \qquad \text{...(i)}$$

where s is the depression head or drawdown in the well

If Q_1 is the known discharge at a certain known drawdown s_1, we have

$$\boxed{Q_1 = c \cdot A \cdot s_1} \qquad \text{...(ii)}$$

Knowing Q_1, A and s_1 above, the value of C can be calculated. Hence discharge Q at any other value of depression head (s) can be easily worked out.

(b) Recuperating Test

Although the pumping test gives accurate value of safe yield, it is sometimes very difficult to adjust the rate of pumping, so as to keep the well water level constant. In such circumstances, recuperating test is adopted.

$$Q = \left(\frac{C}{A}\right) \cdot A \cdot S$$

where, $$\frac{C}{A} = \frac{2.3}{T} \log_{10} \frac{S_1}{S_2}$$ where, s_1, s_2 = depression head at time t_1 and t_2

So, $$\boxed{Q = \left(\frac{2.3}{T} \log_{10} \frac{S_1}{S_2}\right) \cdot A \cdot S}$$ $\frac{C}{A}$ = Specific yield or specific capacity

(c) Third Method

This method is useful for determining the yield of open wells (i.e. for unconfined aquifer) as well as those of tube well (i.e. for confined aquifer) is based on Dupuit's and Theim's formula.

Example 2.2 Match List-I (Tests) with List-II (Features) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Pumping test	1. The gradual rise of water level in well is observed as time progresses
B. Recuperation Test	2. Rate of pumping is adjusted to constant level of water in well
C. Pressure Test	3. Vigorous mixing of the chemical followed by slow mixing
D. Jar Test	4. Pipeline is filled up with water, allowed to stand for sometime and then at least double the maximum pressure is applied

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	4	3
(c)	1	2	4	3
(d)	2	1	3	4

Ans. (b)

Example 2.3 Design an open well in coarse sand for a yield of 0.004 cumecs when operated under a depression head of 3 metres.

Solution: The discharge required from the well = 0.004 cumecs

= 0.004 cubic metre per second

= 0.004 x 60 x 60 x cubic metres per hour = 14.4 m^3/hr

We know that, $$Q = \left(\frac{C'}{A}\right)\cdot A\cdot s$$

where, $$\frac{C'}{A} = 1\ m^3/hr/m \text{ for coarse sand}$$

so, $$14.4 = \left(\frac{C'}{A}\right)\times A\cdot s$$

$$14.4 = 1.00\times A\times 3$$

if d_w is the diameter of the well, then

$$\frac{\pi d_w^2}{4} = 4.8 \quad \text{or,} \quad d_w = \sqrt{\frac{4.8\times 4}{\pi}} = 2.48\ m \simeq 2.5\ m \text{ Say } 2.5\ m$$

Example 2.4 During a recuperation test, the water level in an open well was depressed by pumping by 2.5 metres and is recuperated by an amount of 1.8 metres in 70 minutes.

(a) Determine the yield from a well of 3 m diameter under a depression head of 3.5 metres.

(b) Also determine the diameter of the well to yield 10 litres/second under a depression head of 2.5 metres.

Solution: We know that, $$\frac{C'}{A} = \frac{2.3}{T}\log_{10}\frac{s_1}{s_2}$$

where, s_1 = initial drawdown = 2.5 m; s_2 = final drawdown = 2.5 − 1.6 = 0.9 m

$$T = \text{Time} = 70 \text{ minutes} = \frac{70}{60}\text{hr} = 1.167\ hr$$

$$\therefore \quad \frac{C'}{A} = \frac{2.3}{1.167}\log_{10}\frac{2.5}{0.9} = 0.875\ m^3/hr/m \text{ of depression head}$$

(a) Yield from a well of 3 m diameter, under a depression head of 3.5 m is given as

$$Q = \left(\frac{C'}{A}\right)\cdot A\cdot s$$

$$\therefore \quad = 0.875\times\left(\frac{\pi}{4}\times 3^2\right)\times 3.5 = 21.65\ m^3/hr = 6.02 \text{ litres/sec}$$

(b) If $$Q = 10 \text{ litre/sec} = \frac{10\times 60\times 60}{1000}\ m^3/hr = 36\ m^3/hr$$

$$Q = \left(\frac{C'}{A}\right)\cdot A\cdot s$$

$$36 = (0.875)\times A\times 2.5$$

$$A = \frac{36}{0.875\times 2.5} = 16.46\ m^2$$

or $$\frac{\pi}{4}d^2 = 16.46$$

or $$d = 4.58\ m; \text{ say } 4.6\ m$$

Hence, the diameter of the required well = 4.6 m

2.3 Yield of Wells

There are several methods for estimation of yield of ground water but the best method is by means of actual pumping tests carried on for a sufficient length of time so that state of equilibrium is achieved.

Types of Aquifers: Aquifers are mainly of two types.

(a) Unconfined aquifer (b) Confined aquifer

Unconfined aquifer or water table aquifer is the one in which water table is the upper surface of the zone of saturation. It is also known as the free, phreatic or non-artesian aquifer. Rise and fall in the water table correspond to changes in the volume of water in storage within the unconfined aquifer.

Confined aquifer or artesian aquifer is the one in which ground water is confined under pressure greater than atmospheric by overlying relatively impermeable strata

(a) Unconfined Aquifer

$$Q = \frac{\pi K\left(h_2^2 - h_1^2\right)}{2.3\log_{10}(r_2/r_1)}$$

Let, r_w = radius of well

H = thickness of the aquifer, measured above the impermeable layer to the initial level water table

d_w = drawn down of the well

h_w = depth of water in the well measured above the impermeable layer

$= (H - d_w)$

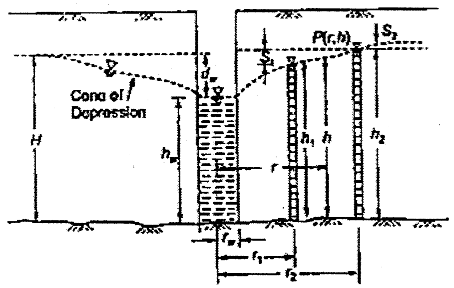


Fig. 2.8 Unconfined Aquifer

Here, $T = kH$ is known as coefficient of transmissibility. h_1 and h_2 are the values of depth of water at r_1 and r_2 respectively. If k is expressed in cubic meter per day per square meter of the area of sub-soil, then the discharge will be in cubic metre per day (Figure 2.8).

(b) Confined Aquifer

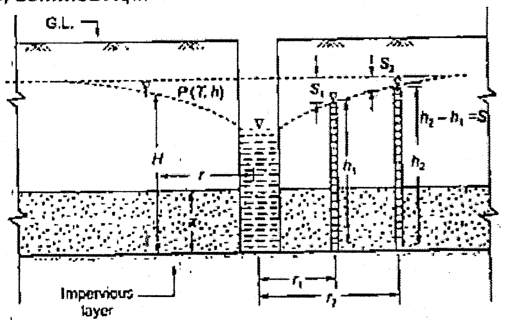


Fig. 2.9 Confined Aquifer

$$Q = \frac{2\pi T(s_1 - s_2)}{2.3\log_{10}\frac{r_2}{r_1}}$$

Here, $T = kz$

or $$Q = \frac{2\pi kz(S_1 - S_2)}{2.3\log_{10}(r_2/r_1)}$$

Example 2.5 A well having a diameter of 15 cm has been drilled in a confined aquifer having a thickness of 12 meter. Radius of influence is 350 m from the centre of the well. If coefficient of permeability of soil is 15 m/day, find the discharge in the well for a draw down of 2 m.

Solution:

$$Q = \frac{2\pi kD(H-h)}{2.3\log_{10}(R/r)} = \frac{2\pi\times15\times12\times2}{2.3\log_{10}(350/0.075)} = \frac{\pi\times30\times24}{2.3\log_{10}(4666.7)} = 268.15\ \text{m}^3/\text{day}$$

Example 2.6 **To determine the specific yield of a well of 0.5 m dia recuperation test was done when the normal water level was found to be 7 m below ground level. Pumping decreased water level to 12 m below the ground level. The water rose to 10 m below ground level after 4 hours of stopping the pumping calculate (a) specify yield of the well and (b) yield under a draw down of 3.0 m.**

Solution:

(a) Using the formula, $K = 2.303\frac{A}{T}\log_{10}\frac{h_2}{h_1}$

Here, $A = \frac{\pi\times0.5^2}{4} = 0.1965\ \text{m}^2$

$T = 4$ hours; $h_1 = 12 - 7 = 5$ m; $h_2 = 10 - 7 = 3$ m

$\therefore$ $K = 2.303\times\frac{0.1965}{4}\log_{10}\frac{5}{3} = 2.303\times0.0491\times0.222 = 0.0251\ \text{m}^2/\text{hr}$

(b) $Q = Kh = 0.0251\times3 = 7.53\ \text{m}^3/\text{hr}$

Example 2.7 **A 20 cm diameter well was drilled 20 meter below the static water table. In two observation, wells at a distance of 80 m and 35 m from the centre of well, the water level was found to be lowered by 50 cm and 110 cm respectively at a discharge of 6000 litres/min in 24 hours. Calculate the transmissibility of aquifer.**

Solution: For discharge, we have the equation

$$Q = \frac{\pi k(h_2^2 - h_1^2)}{2.3\log_{10}(r_2/r_1)} \qquad h_2 = 20 - 0.5 = 19.5\ \text{m},\quad h_1 = 20 - 1.1 = 18.9\ \text{m}$$

$$\frac{6000}{1000} = \frac{\pi\times k\times(19.5^2 - 18.9^2)}{2.3\log_{10}\left(\frac{80}{35}\right)}$$

$\therefore$ $k = 0.0684$ m/min

Now, $T = kH = 0.0684\times20 = 1.368\ \text{m}^2/\text{min}$

Example 2.8 **In order to determine the average permeability of a bed, sandy soil 14 metres thick overlying on an impermeable stratum, a well was sunk and pumping test was carried out. After an interval of time, the discharge was 12.4 litres per second and draw down in the observation wells at 16 m and 33 m from the pumping well were found to be 1.787 m and 1.495 m respectively. If original ground water table was found to be 2.14 m below ground level, find out the coefficient of permeability of the soil.**

Solution: Equation for coefficient of permeability

$$K = \frac{2.3\,Q\log_{10} r_2/r_1}{\pi(h_2^2 - h_1^2)}$$

$r_1 = 16$ m; $r_2 = 33$ m

$h_1 = 14 - (2.14 + 1.787) = 10.073$ m

$h_2 = 14 - (2.14 + 1.495) = 10.365$ m

$Q = 12.4$ litre/sec $= \frac{12.4}{1000}\times60\times60\times24 = 1071.36\ \text{m}^3/\text{day}$

$\therefore$ $$K = \frac{2.3\times1071.36}{\pi\left[(10.365)^2 - (10.073)^2\right]}\log_{10}\frac{33}{16} = 41.32\ \text{m/day}$$

$$= \frac{41.32\times100}{24\times60\times60} = 0.0478\ \text{cm/s}$$

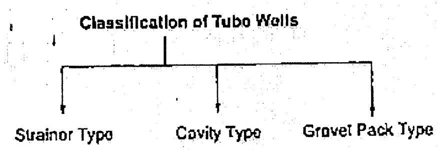
2.4 Tube Wells

To obtain large discharge, mechanical tubewell which is a long pipe or a tube, is bored or drilled deep into the ground, intercepting one or more water bearing strata.

2.4.1 Strainer Type

A strainer tube well uses assembled strainer lengths over perforated pipe which are lowered into the bore hole located opposite to the water bearing formation whereas plain pipe length are located opposite to the non water bearing strata.

- Water enters into the well through these strainers and perforations in pipe from the sides and the flow in the well is thus radial.
- A strainer consists of a perforated pipe with a fine wire mesh wrapped round the pipe which prevents sand particles of size larger than mesh entering into the well.



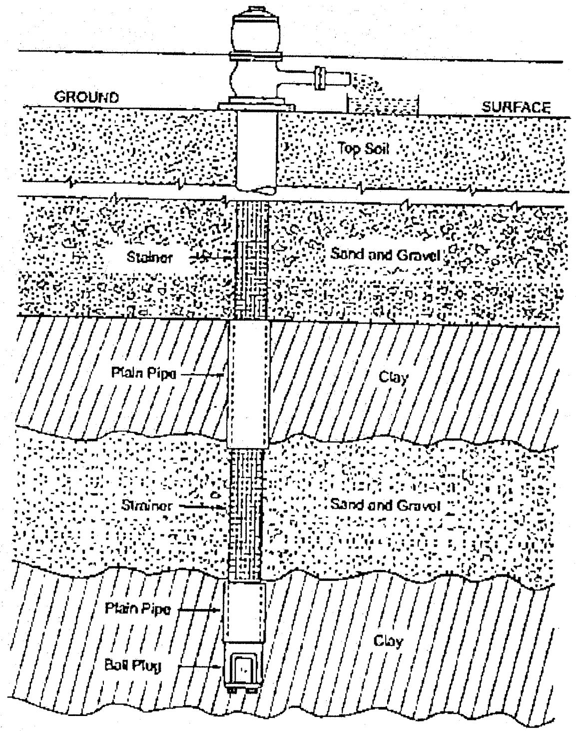


Fig. 2.10 A strainer tubewell

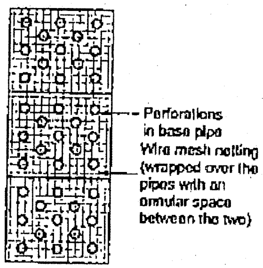


Fig. 2.11 A typical strainer

Remember: A strainer type tubewell is generally unsuitable for fine sandy strata due to choking problem of strainer.

2.4.2 Gravel Pack Tubewell

A gravel pack slotted pipe tubewell uses a slotted pipe without being covered by any wire mesh.

- A slotted pipe is lowered into the bore hole and the external gap between the bore hole and slotted pipe is filled up with graded gravel.

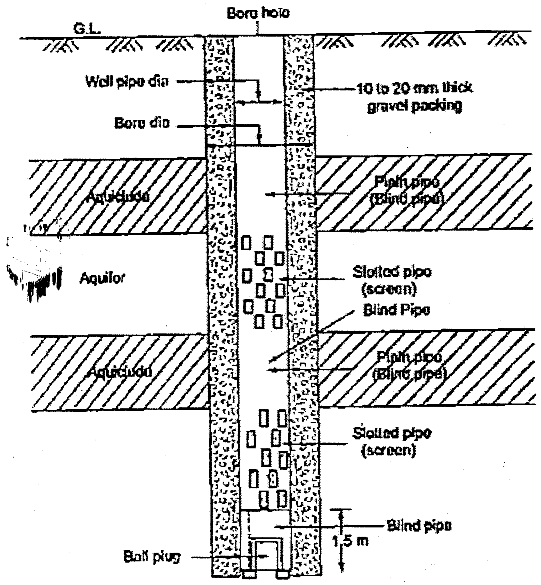


Fig. 2.12 Slotted pipe gravel tubewell

Do you know? In most of the states in our country, deep tubewell has been constructed in fine alluvial soil, by providing cast in situ gravel packs around the slotted mild steel pipes.

2.4.3 Cavity Type Tubewell

A cavity type tubewell draws water from the bottom of the well, and not from the sides as is done by a screen well. The flow in a cavity well, therefore, is essentially spherical, and not radial like that of a screen well.

Such a tubewell, however, is very economical, as it requires only plain well pipe which is lowered into the bore, made through the ground strata upto the required depths, so as to tap the requisite aquifer

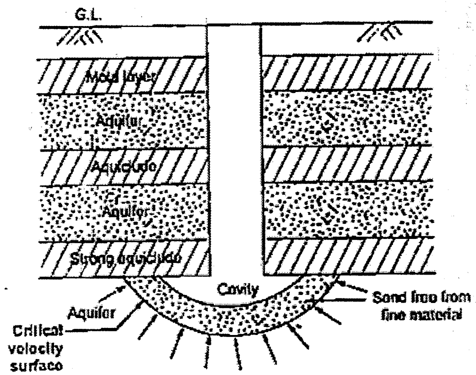


Fig. 2.13 Cavity type tubewell

Remember: Cavity type tubewell can be used only for small supplies, particularly for domestic supply.

2.5 Collection of Surface Water

Whenever water is withdrawn from a surface source such as lakes, rivers or reservoirs, and entrance of the withdrawal conduit is not an integral part of a dam and other water retaining structure, then an intake structure is constructed at the entrance of the conduit. Hence, it can be defined that an intake is a structure constructed at the surface water source to facilitate the conveying of water to the treatment plant either by gravity or into a sump when pumping is required.

2.5.1 Factors Governing the Location of an Intake

1. The intake is to be located as near as possible to the treatment plant so that the cost of conveying water to the treatment plant is minimised. It should be located around a relatively clearer zone of the source so that load on the treatment plant is minimized.
2. Arrangement of intakes should be provided such that elimination of silt and floating matter is possible to a great extent so that they may be prevented from entering the conduit.
3. The intake site is to be free from sources of contamination.
4. Location should be such that it can draw water from the source in all seasons. The site should be free from currents and should be founded on stable ground.
5. It should be located in the straight portion of the source and erosion of banks should be minimum. The intake should be located such that its lowest silt level can be kept below the low water level of the source.
6. In case of a river with fluctuating flow, the approach channel from the centre of the source to the intake should be capable of being dredged to clear of silt deposition.
7. The location should be such that water may be drawn to the treatment plant by gravity.

2.5.2 Components of Intake

A water intake consists of the following component:

1. Intake structure
2. A conduit with protection work
3. Inlets
4. Screens or gratings
5. Gates and valves to regulate flow

2.6 Conduits for Water Supply

Depending upon the conditions and characteristics of flow, the conduits may be divided into

1. Gravity Conduits
2. Pressure Conduits

These are described below:

1. **Gravity Conduits:** Gravity conduits are those in which the water flows under the more action of gravity.

   In such a conduit, the hydraulic gradient line will coincide with the water surface and will be parallel to the bed of the conduit. This is so because in such a flow, the water is all along at atmospheric pressure and thus there is no pressure term in Bernoulli's equation.

   Gravity conduit can be in the form of following:

   (a) Canal: Canal are the open channels which are constructed by cutting high grounds and constructing banks on low ground.

   - They are generally constructed in balanced cut and fill, and are cheap to build in suitable soils.
   - They may be either lined or unlined depending upon the nature of the ground, available slopes, design, velocity, quality of water required, losses of water etc.

   (b) Flumes: Open channel supported above the ground over trestles, etc. are called flumes.

   - They are used to convey water across valleys and minor depression or over drains and other obstruction in their path.
   - They may be made of masonry, R.C.C, metal or wood and are usually circular or rectangular in cross-section

   (c) Aqueducts: Aqueducts or strictly speaking grade aqueducts are closed, rectangular or circular or horse shoe sections, built of masonry or R.C.C..

2. **Pressure Conduits:** In pressure conduits, which are closed conduits and as such no air can enter into them, the water flows under pressure above the atmospheric pressure.
   - The hydraulic gradient line for such a conduit can be obtained by joining the water surface elevations in the piezometers installed in the conduit at various places.
   - The pressure pipes can, therefore, follow the natural available ground surface and can freely go up and down hills or deep beneath valleys or mountains.
   - Sometimes even rising (ensure negative pressure) above the hydraulic gradient lines and thus requiring lesser length of conduits.

2.7 Calculation of Head loss caused by Pipe Friction

It can be found by using either of the formula

1. Darcy Weisbach formula
2. Manning's formula
3. Hazen-William's formula
4. Modified Hazen-William's formula

Out of the above formula's, Hazen-William's formula is most widely used.

1. **Darcy Weisbach formula**

   It is more than 100 year old formula, and states that

   $$H_L = \frac{f'L}{d}\cdot\frac{V^2}{2g}$$

   where, H_L = Head loss in meter
   L = length of pipes in meters
   d = diameter of pipe in meters
   V = mean velocity of flow through pipe in m/sec
   g = acceleration due to gravity
   f' = Dimensionless friction factor, generally varying between 0.02 (for new smooth pipe) to 0.075 (for old pipes)

Do You Know?

Friction factor f' (dimensionless) depends upon Reynold's number $\left(i.e.\ R_n = \frac{\rho V d}{\nu}\right)$ and relative roughness $\left(i.e.\ \delta = \frac{2e}{d}\right)$.

- Relative roughness depends upon absolute roughness (e) of the inside surface and diameter of the pipe 'd'

2. **Manning's Formula:** Generally used for gravity conduits,

   $$V = \frac{1}{n}R^{2/3}\,S^{1/2}$$

   where n = Manning's rugosity coefficient;

$$V = \frac{1}{n} R^{2/3} \left(\frac{h_f}{L}\right)^{1/2}$$

L = Length of pipes in meters;

V = Flow of velocity (m/sec);

R = Hydraulic mean depth of pipe

$$= \left[\frac{A}{P} = \frac{\frac{\pi d^2}{4}}{\pi d} = \frac{d}{4}\right] \text{in meters}$$

3. **Hazen-William's Formula:** This formula widely used to pipe flows and states that

$$\boxed{V = 0.85 C_H \cdot L^{0.63} \cdot S^{0.54}}$$

where, C_H = Roughness coefficient

R = Hydraulic mean depth (m)

S = Slope of energy line = $\frac{H_L}{L}$

V = Flow of velocity (m/sec)

Remember: 1. The smoother the pipe, the greater is the value of C_H.

2. The C_H has dimension of $L^{0.37}\,T^{-1}$.

4. **Modified Hazen-William's Formula:** It states that

$$\boxed{V = 143.534\, C_R \cdot R^{0.6575} \cdot S^{0.5525}}$$

where, R = Hydraulic mean depth (m)

S = Friction slope = $\frac{H_L}{L}$

and friction head loss for circular conduit

$$H_L = \text{friction head loss} = \frac{L \cdot \left(\frac{Q}{C_R}\right)^{1.81}}{99.462 \times d^{1.81}}$$

where, d = Internal dia of pipe (m)

Q = flow in pipe

Example 2.9 In a water supply scheme to be designed for serving a population of 4 lakhs, the storage reservoir is situated at 8 km away from the city and the loss of head from source to city is 16 metres. Calculate the size of the supply main by using Weisbach formula as well as by using Hazen's formula assuming a maximum daily demand of 200 litres per day per person and half of the daily supply to be pumped in 8 hours. Assume coefficient of friction for the pipe material as 0.012 in Weisbach formula, and C_H = 130 in Hazen's formula.

Solution:

Maximum per capita demand = 200 litres/person/day

Population = 4,00,000

Maximum water demand per day

= 4,00,000 × 200 litres/day = 80 million litres/day = 80 MLD.

Maximum water demand for which the supply main is to be designed

$$= \frac{12}{8} \times 40 \text{ MLD} \quad (\because \text{half the daily supply is to be pumped in 8 hours})$$

$$= 60 \text{ MLD}$$

$$= \frac{60 \times 10^6}{10^3} \text{ cubic meters/day}$$

$$= \frac{60 \times 10^3}{24 \times 60 \times 60} \text{ cumecs}$$

$$= 0.695 \text{ cumecs}$$

Now, Q = 0.695 cumecs

L = 8 km = 8000 metres

H_L = 16 metres

d = ?

(a) Using Darcy-Weisbach formula

$$H_L = \frac{f' \cdot L}{d} \cdot \frac{V^2}{2g}$$

But
$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4} d^2}$$

$$\therefore \quad H_L = \frac{f' \cdot L}{d} \cdot \frac{\left[\frac{Q}{\frac{\pi}{4} d^2}\right]^2}{2g} = \frac{f' \cdot LQ^2}{12.1 d^5}$$

Using f' = 0.012 (given), we get

$$16 = \frac{(0.012)(8000)(00.695)^2}{12.1 \times d^5}$$

Solving, we get, $d^5 = 0.2395$

or $d = (0.2395)^{\frac{1}{5}} = 0.7514$ m

So, use the nearest standard available dia pipe (say 1 m)

(b) Using Hazen-William's formula

$$V = 0.85\, C_H \times R^{0.63} \times S^{0.54}$$

where C_H = 130 (given)

$R = \frac{d}{4}$ for circular pipe running full

$$V = \frac{Q}{A} = \frac{0.695}{\frac{\pi}{4} d^2}$$

$$\therefore \quad \frac{0.695}{\frac{\pi}{4} d^2} = 0.85 \times 130 \left(\frac{d}{4}\right)^{0.63} \cdot \left(\frac{H_L}{L}\right)^{0.54}$$

$$= 0.85 \times 130 \frac{(d)^{0.63}}{2.4} \cdot \left(\frac{16}{8000}\right)^{0.54}$$

or $\frac{0.885}{d^2} = 46\, d^{0.63} \frac{1}{28.7}$

or $\frac{0.885 \times 28.7}{46} = d^{2.63}$

or $d^{2.63} = 0.5521$

or $d = (.5521)^{\frac{1}{2.63}} = 0.7978\text{ m}$

So, use the nearest standard available dia pipe (say 1) m dia.

2.8 Forces Acting on Pressure Conduits

The structural design of the pressure pipe should be carried out, so as to enable them to withstand the various forces likely to come on them.

The following forces generally come into play in the pressure pipes.

1. **Internal pressure of water including water hammer pressure**
   To be resisted by using materials strong in a tension.
2. **Pressure due to external loads**
   These are in the form of backfill, traffic loads etc. – to be resisted by using material strong in compression
3. **Longitudinal temperature stress**
   Created when pipes are laid above the ground – to be resisted by providing expansion joints.
4. **Longitudinal stress**
   Due to unbalanced pressure at bends, or at points of change of cross-section – to be resisted by holding the pipe firmly by anchoring it in massive blocks of concrete or stone masonry
5. **Flexural Stress**
   Produced when pipes are supported over trestles etc.

Water Hammer Pressure

When a liquid flowing in a pipe is abruptly stopped by closing of a valve, etc, the velocity of the water column behind is retarded, and its momentum gets dissipated due to conversion of kinetic energy into elastic energy. A series of positive and negative pressure waves are produced, which travel back and forth in the pipe, till they are damped by friction. This phenomenon is known as water hammer.

- This pressure rise or water hammer is manifested as a series of shocks, sounding like hammer blows, which may have sufficient magnitude to rupture the pipe or damage the connected equipment.
- It may be caused by the nearly instantaneous or rapid closing of a valve.
- The excess pressure due to water hammer is additive to the normal hydrostatic pressure in the pipe and depends on the elastic properties of the liquid and pipe and on the magnitude and rigidity of change in velocity.

Computations of Water Hammer Pressure

Maximum water hammer pressure (which occur at critical time of closure T_c or any time less than T_c) is given by

$$H_{max} = \frac{CV_0}{g}$$

where, H_{max} = Maximum pressure rise in the closed conduit above the normal pressure (in m)
C = Velocity of pressure wave travel (in m/sec)
V_0 = Normal velocity in the pipeline, before sudden closure (in m/sec)
g = Acceleration due to gravity (in m/sec²)

If the actual time of closure T is greater than the T_c, the actual water hammer is reduced approximately in proportion to $\left(\frac{T_c}{T}\right)$.

i.e. $$H'_{max} = H_{max} \times \frac{T_c}{T}$$

- If L is the distance of the valve from the reservoir, than the time taken by the wave in going to the reservoir and coming back to the valve, called critical time is given by $T_c = \frac{2L}{C}$.
- The velocity of pressure waves generated is given by the equation

$$C = \sqrt{\frac{E_w}{\rho_w}} \times \frac{1}{\sqrt{1 + \frac{E_w \cdot d}{E_p t}}}$$

E_w = Bulk modulus of water (2.07×10^8 kg/m²)
E_p = Modulus of elasticity of pipe material (in kg/m²)
ρ_w = Density of water
d = Diameter of pipe (in m)
t = Wall thickness of pipe (in m)

- According to GOI manual, $C = \frac{1425}{\sqrt{1 + \frac{E_w \cdot d}{E_p t}}}$
- The term $\sqrt{E_w / \rho_w}$ represents the velocity of pressure wave in water when we do not consider the elasticity of pipe.
- The velocity of pressure wave created by water hammer is however, reduced and is less than $\sqrt{E_w / \rho_w}$ because of the elasticity of the pipe wall.

Remember: Generally $\sqrt{E_w/\rho_w}$ (i.e. velocity of sound in water) is taken as ≃ 1433 m/sec

Do you know? To safeguard against water hammer pressure, a surge tank is provided in the water pipe line.

Example 2.10 The velocity of water flowing from a reservoir into a 1 meter dia steel pipe is 2 m/sec. If a valve is situated in the pipe line at a point 2 km from the reservoir, evaluate the water hammer pressure developed by the closure of this valve, if

(a) the closure time is 2 sec, (b) the closure time is 6 sec.

The thickness of the pipe-shell may be taken to be 2.5 cm

Solution:

we have

$$C = \sqrt{\frac{E_w}{\rho_w}} \frac{1}{\sqrt{1 + \frac{E_w}{E_p} \cdot \frac{d}{t}}}$$

But from equation, $\sqrt{\frac{E_w}{\rho_w}} = 1433 \text{ m/sec}$

Also, $\frac{E_w}{E_p} = \frac{\text{Modulus of elasticity of water}}{\text{Modulus of elasticity of steel pipe}} = \frac{21\times10^5 \text{kN/m}^2}{21\times10^7 \text{kN/m}^2} = 0.01$

d = 1 metre (given)

t = 2.5 cm = 0.025 m (given)

$$\therefore \quad C = 1433\frac{1}{\sqrt{1+\frac{0.01\times1}{0.025}}} \text{m/s} = 1433\cdot\frac{1}{\sqrt{1+0.4}}\text{m/s} = 1433\cdot\frac{1}{\sqrt{1.4}} = 1210 \text{ m/sec}$$

$$\text{Critical time } T_c = \frac{2\cdot S}{C} = \frac{2\times(2\text{ km})}{1210(\text{m/sec})} = \frac{2\times2000}{1210}\text{sec} = 3.3 \text{ sec}$$

Now. $P_{h(max)}$ = Maximum water hammer pressure = $\rho_w \times C \times V$

$$= \left(\frac{1000}{1000}\right)\times1210\times2 \text{ kN/m}^2 = 2420 \text{ kN/m}^2$$

Case (a) When the time of closure

$T = 2$ sec

and since critical time, $T = 3.3$ sec (calculated above)

we have $T < T_c$

Therefore, full water hammer pressure = 2420 kN/m² will be developed

Case (b) When $T = 6$ sec, $T_c = 3.3$ sec, the water hammer pressure developed is given by equation as

$$= \left(\frac{T_c}{T}\right)P_{h(max)} = \frac{3.3}{6}\times2420 \text{ kN/m}^2 = 1325.5 \text{ kN/m}^2$$

Example 2.11 A steel penstock 60 cm in diameter has a shell thickness of 1.2 cm. The modulus of elasticity of the pipe shell material is 2.1 × 10⁶ kgf/cm² (2.1 × 10⁵ N/mm²) with Poisson's ratio of 1/4, and the volume modulus of elasticity of water is 2.1 × 10⁴ kgf/cm² (2.1 × 10³ N/mm²). The pipe is designed to discharge water at mean velocity of 2.1 m/sec. Determine the water hammer pressure rise caused by sudden closure of the valve at the downstream end; (1) neglecting the elasticity of the pipe material; and (2) considering also the elasticity of the pipe material.

Solution: Case (1) When elasticity of pipe is ignored, then

$$C = \sqrt{\frac{E_w}{\rho_w}} = \sqrt{\frac{2.1\times10^9}{10^3}} = 1449.14$$

$$P_{h(max)} = 1449.14\cdot\rho_w\cdot V = 1449.14\times1000\times\frac{2.1 \text{ N/m}^2}{1000}$$

$$\because \quad P_{h(max)} = 3043.2 \text{ kN/m}^2$$

Case (2) When elasticity of pipe shell is considered

$$P_{h(max)} = C\cdot\rho_w\cdot V\left[\frac{1}{\sqrt{1+\frac{E_w}{E_p}\cdot\frac{d}{t}}}\right] = 3043.2\left[\frac{1}{\sqrt{1+\frac{2.1\times10^4}{2.1\times10^6}\times\frac{60}{1.2}}}\right]$$

$\because \quad E_w = 2.1\times10^4$ kgf/cm²; $E_p = 2.1\times10^6$ kgf/cm² ; $d = 60$ cm; $t = 1.2$ cm

$$\therefore \quad P_{h(max)} = 3043.2\left[\frac{1}{\sqrt{1+0.5}}\right] = 2484.75 \text{ kN/cm}^2$$

Example 2.12 **A 0.5 m diameter and 100 m long pipeline carrying 0.5 m³/sec discharge is fitted with a valve at downstream end. Calculate the rise of pressure caused within the pipe due to the valve closure in (i) 1 second, (ii) instantaneously. Take the Sonic velocity as 1430 m/s.**

Solution: The velocity of pressure wave generated by water hammer is given by equation as

$$C = \sqrt{\frac{E_w}{\rho}}\frac{1}{\sqrt{1+\frac{E_w}{\rho_p}\cdot\frac{d}{t}}}$$

Where the term $\frac{1}{\sqrt{1+\frac{E_w}{\rho_p}\cdot\frac{d}{t}}}$ represents the reduction caused in the velocity of the pressure wave by the elasticity of the pipe material. This term can be ignored, since the results will be on conservative side, and because the thickness of the pipe (t) and the material of pipe to reflect its E_p are not given.

Hence, $C = \sqrt{\frac{E_w}{\rho_w}}$ = Sonic velocity = 1430 m/s

Now, Maximum water hammer pressure $P_{h(max)}$

$= \rho_w\cdot C\cdot V$

where $V = \frac{Q}{A} = \frac{0.5}{\frac{\pi}{4}\times(0.5)^2} = 2.548 \text{ m/s}$

$$\therefore \quad P_{h(max)} = \frac{1000}{1000}\times1430\times2.548 \text{ kN/m}^2 = 3643.64 \text{ kN/m}^2$$

This maximum water hammer pressure will be caused when the valve is closed instantaneously. However, when the valve is closed in $T = 1$ sec, the pressure is given by equation, as

$$P_h = \left(\frac{T_c}{T}\right)P_{h(max)}$$

$$\therefore \quad T_c = \frac{2\times100}{1430}\text{s} = 0.14 \text{ s}$$

$$\therefore \quad P_h = \left(\frac{0.14}{1}\right)\times3643.64 \text{ kN/m}^2 = 510.1 \text{ kN/m}^2$$

Hence (i) Pressure developed by the closure of the valve in 1 sec = **510.1 kN/m²**

(ii) Pressure developed by the closure of the valve instantaneously = **3643.64 kN/m²**

2.9 Types of Pipes

Depending on construction materials following three types of pipes are available for various use in the water supply system.

1. Metal Pipes 2. Cement Concrete Pipes 3. Plastic Pipes

1. **Metal Pipes:** Following type of metal pipe are used

(i) Cast-iron pipes (ii) Steel pipes
(iii) Wrought iron pipes (iv) Copper, lead and brass pipes

(i) **Cast Iron Pipes:** Cast iron pipes are most widely used in water supply for trunk as well as distributary mains due to there durability, strength, resistance to corrosion, ease in laying and simplicity in repairs and maintenance. There are two general processes for manufacture of cast iron water pipes: (a) Foundry method, (b) The centrifugal process

(a) **Foundry Method:** Foundry method of casting in fire sand moulds of more popularly brown pit-cast pipe. Pipes are cast in vertical moulds with hub end down for pipes greater than 45 cm diameter and horizontally casted pipes are called Mc. Wane Pipes.

(b) **The Centrifugal Process:** In this process, the core is omitted and the mould placed horizontally is rotated while the iron is pored so that by centrifugal force the molten iron is evenly distributed around the mould.

- Pipes made by centrifugal process is having less variation in thickness, stronger and more uniform as well as lighter.
- They are popularly known as spuniron.

Disadvantages of cast iron pipes are:

- Water carrying capacity decrease with the time, as the valve friction factor increases due to tuberculation in certain waters
- They cannot be used for high pressure. Generally not used for pressure above 700 kN/m^2
- When large, they are very heavy and uneconomical
- They are likely to break during transportation or while making connection.

(ii) **Steel Pipes:** Steel pipes of larger sizes made from steel plate made to circular form

- Used as water mains passing over bridges and culverts of longer span.
- Steep pipes are frequently used for raw water trunk mains, inverted syphons, or pumping mains, where pressure is high and sizes are larger.
- Life is generally taken around 40 years under ordinary conditions.
- Steel pipes are not adopted to withstand external loads of backfill, traffic etc. while a partial vacuum caused by emptying of the pipe may cause collapse or distortions, if not designed properly.

NOTE: To protect from higher negative pressure, pipes are coated from inside as well as outside with 1 : 2 cement mortar.

(iii) **Wrought Iron Pipes:** Wrought iron pipes are lighter than cast iron pipes and are easily threaded and worked.

- For protection against corrosion, they are galvanised with zinc coating and are known as "Galvanised Iron Pipes".
- Due to easy workability, they are used for water distribution lines inside buildings.

Remember: G.I Pipes are liable to be affected by acidic and alkaline water.

(iv) **Copper, Lead and Brass Pipes:** Pipes of small diameter known as conduits are manufactured with copper, lead and brass for specific uses.

- They are mostly used as a part of the plumbing work of buildings such as gooseneck, hot water piping, chlorination and alum during piping of water supply system.
- Copper pipes are although costly, they are used in acidic and alkaline environments as they are highly resistant to acids and alkaline
- They can be used for carrying hot water inside building and factories because they can be bent easily and do not sag due to heat.
- Brass pipes are harder than copper pipes and are used for decorative plumbing.
- Lead pipes are more common in sanitary plumbing.

NOTE: Lead pipes are not used to convey domestic water supply because it may cause lead poisoning.

2. **Cement Concrete Pipes:** They are of following types:

(i) Prestressed concrete pipes (ii) Reinforced cement concrete pipes
(iii) Plain cement concrete pipes (iv) Glass fibre reinforced concrete pipes
(v) Vitrified clay pipes (vi) Asbestos pipes

(i) **Prestressed concrete pipes**

- Made by tensioning high tensile wire wound spirally around cylindrical core.
- Core consist of either concrete or of a thin steel cylinder.
- Advantage of pre-stressed concrete pipes is that they are found to be cheaper than other pipes above 300 mm diameter at higher pressure.
- They are corrosion resistant.
- Disadvantage is that they have got very limited flexibility.

(ii) **Reinforced cement concrete pipes**

- RCC are similar to pre-stressed concrete pipes except that in place of high tensile steel wires mild steel rods are used.
- They are available in diameter from 200 mm to 1800 mm.
- They are mostly used as water mains.

Advantage:

- They can resist external compressive loads and do not collapse under nominal vacuums and traffic loads.
- They are not corroded from inside by normal potable water and from outside by ordinary soils.
- They are quite strong and have life of 75 years or so.
- They are easy to construct at sites or at factory.
- If laid under water, the empty pipes do not float because of heavy weight.

Disadvantage:

- They are likely to get corroded by ground water due to presence of acids, alkalis or sulphur compounds.
- They are difficult to repair.
- They cannot withstand very high pressure.

- They are heavy and bulky, hence difficult to transport.
- They tend to leak due to shrinkage cracks and porosity.

Table: 2.1 Ordinary RCC pipes as per IS 458: 1988

Category	Dia available	Test pressure in kN/m²	Places where used
Class P_1	80 - 1200 mm	200	Used on gravity mains, design pressure not exceeding 2/3 of test pressure
Class P_2	80 - 600 mm	400	Used on pumping mains, the design pressure not exceeding 1/2 of the test pressure.
Class P_3	80 - 400 mm	600	do

(iii) Plain cement concrete pipes
- They are manufactured in small sizes (i.e. upto a maximum of about 0.6 m diameter)
- They are reinforced with steel for large diameter pipes.

(iv) Glass fibre reinforced concrete pipes
- Alkali resistant glass fibre are used.
- The reinforcement is stronger than ordinary steel and are more resistant to the normal corrosion agencies, hence, lesser pipe thickness is required.

(v) Vitrified clay pipes
- They are generally not used as pressure pipes for carrying waters but are extensively used for carrying sewage and drainage at partial depths.
- These pipes are free from corrosion
- They are not used as pressure pipes because clay is very weak in tension.

(vi) Asbestos pipes: Asbestos, silica and cement are converted under pressure to a dense homo generous material possessing high strength called asbestos cement

Advantages
- They are light and hence easy to transport
- They can be easily assembled without skilled labour.
- They are highly resistant to corrosion
- Expansion joints are not required as the coefficient of expansion is low and the joints are also flexible.
- They are very suitable to be used as small size distribution system.

Disadvantages
- They are costly
- These pipes do not have much strength and are brittle and soft.
- The rubber joint seals may deteriorate if exposed to gasoline or other petroleum products, hence cannot be used for transporting petroleum products.

3. Plastic Pipes: Following types of plastic pipes are used in water works for water supplies
(i) Unplasticised poly vinyl chloride (UPVC) pipes (ii) Polyethylene pipes
(iii) Glass reinforced plastic (GRP) pipes

(I) Unplasticised poly vinyl chloride (UPVC) pipes
- These pipes are used for water distribution system in size ranging from 15 to 150 mm in diameter
- The main advantage of UPVC pipes is its resistance to corrosion
- These pipes are composed of poly vinyl chloride plus necessary additive for getting surface and finish and mechanical strength.
- Lightness and resistant to wide range of chemicals, fungi, bacterias, corrosive agents are its main advantage.
- Due to their elastic property, they can withstand deformation resulting from earth shock movement.
- They are not suitable for hot water supply

(II) Polyethylene pipes
- Polyethylene is a thermoplastic material, which softens with heat. In its natural state, it is translucent but when used for pipes a black or blue pigment is added to reduce the degrading effect of ultraviolet light.
- They are light in weight and flexible, resistant to abrasion and corrosion and have better impact resistance at low temperature than UPVC pipes.
- Two types of these pipes are available for water supply purpose.

(a) Low density polyethylene (LDPE) pipes, (b) High density polyethylene (HDPE) pipes

(III) Glass Reinforced Plastic (GRP) pipes: They are manufactured of isophtalic and bisphenol polyester or emoxy resins reinforced with glass fibre.

Advantage of Plastic Pipes:
- Resistance to corrosion
- Light weight
- Toughness
- Rigidity
- Plastic pipes do not become pitted or tuberculated
- Low thermal conductivity ensure water transported at a more uniform temperature

Example 2.13 Consider the following statements:
The basic difference between water pipes and sewer pipes is
1. In the material used for the pipes
2. In the pressure of the liquid flow
3. In the suspended solids they carry

Which of these statements is/are correct?
(a) 1 and 3 (b) 1 only (c) 2 and 3 (d) 1, 2 and 3

Ans. (c)

Cast iron pipes can be used for both water pipes and sewer pipes. However, the basic difference is pressure flow in water pipe and suspended solids carried in sewage.

Example 2.14 Match List-I (Type of Pipe) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Steel pipe	1. House plumbing
B. Cast iron pipe	2. Hot water carrying
C. GI Pipe	3. Distribution main
D. PVC pipe	4. Pumping main

Codes:

	A	B	C	D		A	B	C	D
(a)	4	1	2	3	(b)	4	3	2	1
(c)	2	1	4	3	(d)	2	3	4	1

Ans. (b)

Example 2.15 : Match List-I with List-II and select the correct answer using the code given below the lists:

List-I	List-II
A. Steel pipe	1. Highly resistant to corrosion but can break easily
B. Concrete pipe	2. Virtually corrosion resistant
C. AC pipe	3. Sulphide corrosion
D. Vitrified clay	4. Electrolyte corrosion

Codes:

	A	B	C	D		A	B	C	D
(a)	2	3	1	4	(b)	4	3	1	2
(c)	2	1	3	4	(d)	4	1	3	2

Ans. (b)

The biggest drawback of the concrete sewers is the fact that they easily get corroded and pitted by the action of sulphuric acid produced from hydrogen sulphide gas (evolved from the stale sewage) or from such other chemicals present in sewage.

The sulphide corrosion cement concrete pipes is a big problem in areas where the sewage is strong, stale and very warm because under such conditions the bacterial activity responsible for producting hydrogen sulphide gas gets accelerated. Hence, in all such cases, vitrified clay (popularly called stone ware) pipes should be used for sewers as it is highly resistant to corrosion.

2.10 Joints in Water Supply Piping

Water supply pipes whether main or sub-mains are available in small lengths. Hence, joints have got an important part to play in piping system.

Following are the important types of joints in water mains:

(i) Spigot and socket joint (ii) Flanged joint
(iii) Expansion joint (iv) Collared joint
(v) Flexible joint (vi) Threaded joint
(vii) Simplex joint

(I) Spigot and Socket Joint

- The joint is also called bell and spigot joint.
- The enlarged end is called 'socket' or 'bell' whereas the normal end is called spigot.
- The normal end is fitted into the socket and proper alignment is done.
- The yarn of jute is wounded round the spigot end and a rubber gasket is placed tightly.

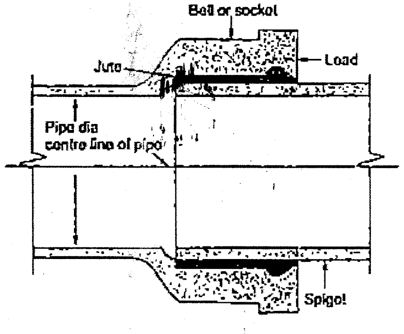


Fig. 2.14 A socket and spigot joint

- The remaining space between the socket and the spigot is finally filled with molten lead. The molten lead solidifies quickly and makes the joints water tight.
- The joint is some what flexible and allows the pipe to be laid on flat curves without the use of special mounting.
- Mostly mains and submains of cast iron, spun iron or steel are joined with this type of joint.

(II) Flanged Joint

- This joints are used for pumping stations, filter plants and at other locations where the pipe line may be shifted.
- These joint are used in steel pipes and cast iron pipes.
- Two flanges are brought together, keeping a rubber washer (called gasket) in between them. They are then fixed by means of nuts and bolts.
- These joints are strong but rigid and hence cannot be used where deflections or vibration are expected.
- They are expensive and mostly used for indoor works.

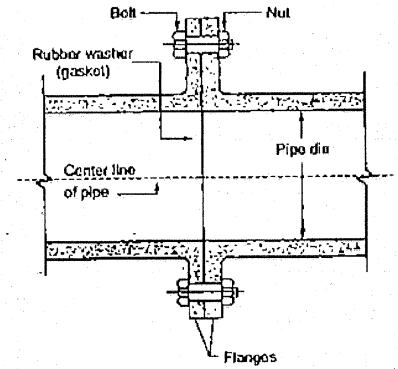


Fig. 2.15 A Flanged joint

(III) Expansion Joint

- These joints are provided at suitable intervals in the pipe lines, so as to counteract the thermal stresses produced due to temperature variations.
- For providing expansion joints in cast iron pipes, the socket end is cast flanged and the spigot end in plain.

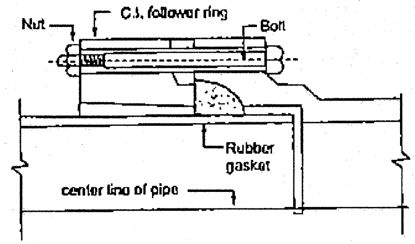


Fig. 2.16 An expansion joint

(iv) Collared Joint

- Concrete pipes are mostly joined by collared joints.
- Pipes are having spigot at one end and socket at the other and joined by a gasket and clean cement.

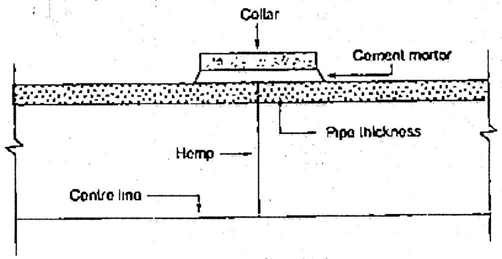


Fig. 2.17 Collared Joint

(v) Flexible Joint

- These are used where large seals, flexibilities are required.
- The pipes to be provided with such a joint are cast with special types of ends. The socket is spherical and the spigot having a bead at the end.

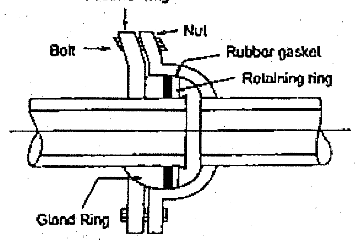


Fig. 2.18 Flexible joint

(vi) Threaded Joint

Threaded joint are used for connecting G.I. pipes.

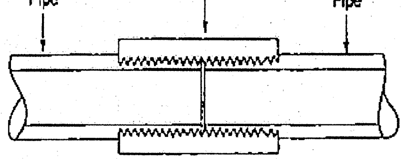


Fig. 2.19 Threaded joint

(vii) Simplex Joint

- These joint consists of a pipe sleeve and two rubber gasket
- These joints are used in asbestos cement pipes

2.11 Corrosion in Pipes (Metals)

- When water flows through a metal pipe (such as a cast iron or a steel pipe), It attacks and disintegrates the surface of the pipe. The material of the pipe thus gets dissolved and rusted. thereby reducing the life and carrying capacity of the pipe. This phenomenon which leads to the disintegrating of the pipe is known as corrosion. The corrosion of pipes reduces their life and carrying capacities, and may also impart colour and odour to the flowing water.
- There are many reasons of corrosion, but corrosion of metal pipes may often occur due to electrolysis. Stray (D.C) electric currents from any grounded device may enter the pipe, and flow through it to some point of departure. Also when two dissimilar metals are immersed in an electrolyte such as water, an electric potential is developed and an electric current starts flowing between the metals. The metal which lies high in the "electrochemical series" will get dissolved and deposition will start, on the metal which lies low in the "electrochemical series". Thus the metal which is high in the series becomes the anode, and the metal which is lower in the series becomes the cathode. This type of potential may develop between the pipe metal and the pipe fittings (of different metal); and also between the pipe metal and other metals present as impurities in the pipe metal.
- Thus, if the material of the pipe fittings are such as to fall in the electrochemical series at a place lower than that of the pipe metal itself naturally electrolyis will set up and the pipe metal will go on dissolving. The dissolved metal being washed down by the flowing water, and thus making it impure. The corrosion continues indefinitely, if not checked, thus leading to the complete destruction of the pipe.

Factors Responsible for Corrosion

→ Oxygen content of the water
→ Temperature and Soil bacteria
→ Composition of pipe material
→ pH valve
→ Moisture content

- In general, the corrosion of metal pipes may occur if iron enter solutions as positive ions (i.e Fe^{++} ions) and combines with the negative ions of water (i.e. OH^- ions), thus forming ferrous hydroxide $[Fe(OH)_2]$

$$Fe^{++} + 2OH^- \rightarrow Fe(OH)_2$$

- When water is alkaline and free from corbon dioxide

$$2Fe(OH)_2 + \frac{1}{2}O_2 + H2O \rightarrow 2Fe(OH)_3$$ (Ferric hydroxide sticks to anode i.e. pipe surface)

- When water is acidic and contains free CO_2

$$Fe(OH)_2 + 2CO_2 \rightarrow Fe(HCO_3)_2$$ Ferrous bicarbonate

$$2Fe(HCO_3)_2 + O_2 + H_2 \rightarrow 2Fe(OH)_3 + 4CO_2\uparrow$$ (Ferrous hydroxide slicks to anode)

- This ferric hydroxide $[Fe(OH)_3]$ is in the form of insoluble red precipitate and gets deposited on the pipe surface.
- This leads to the formation of tubercules of ferriec hydroxide on the inside surface of the pipe, this process is known as "tuberculation". Tuberculation leads to increase in pipe roughness and hence reduce the carrying capacity.

Corrosion Control

Corrosion of metal pipes may be reduced in various ways as described below:

(i) **Protective Coating**

- Pipe surfaces are coated with coatings of paint, galvanizing bituminous compounds, cement lining, etc.
- Red lead paint and zinc pigment are used for painting the exteriors of the pipes.

(ii) **Selecting proper pipe material**

- The pipe metal may be chosen to be more resistant to corrosion
- Certain alloys of iron or steel with chromium, copper or nickel found to be better than the pure iron and steel.
- If steel or iron are to be used then they should be as pure as possible.

(iii) **Quality of water**

- The water passing through the pipe should be made as less corrosive as possible.
- This can be accomplished by raising the pH of water by adding alkalinity in the form of lime or powdered chalk.
- By reducing the dissolved O_2 and CO_2.
- By adding chemical compound which reduces tuberculation such as sodium hexa-metaphosphate.

(iv) **Cathodic protection**

- Electrolytic corrosion can be prevented by connecting the pipe with negative terminal of a D.C. generator and positive terminal with blocks of zinc or magnesium buried in the ground near the pipe.

Example 2.16 Which of the following are the advantages of cast-iron pipe for its use in water supply?

1. Resistant to corrosion to a reasonable extent
2. Very easy to join the pipes
3. Easy to transport
4. Longer life

Select the correct answer using the codes given below:

(a) 1, 3 and 4 (b) 1, 2 and 3 (c) 1 and 4 only (d) 2, 3 and 4

Ans. (c)

The advantages of cast iron pipes are:

(i) Moderate in cost
(ii) Easy to join
(iii) Strong and durable
(iv) Corrosion resistant
(v) Long life
(vi) Service connections can be easily made

But if their size becomes large, then they are very heavy and uneconomical. Also they are likely to break during transportation or while making connections.

2.12 Pipe Appurtenances

When pumps lift water and water is delivered through large diameter pipes to treatment plants and distribution points, for safety and proper functioning of the supply and to isolate and drain the pipe line, the pipe line is divided in several section, for test, inspection, cleaning and repair. A number of appurtenances provided such as gates, valves, manholes, insulation joints, expansion joints, anchorages etc. are at several suitable places along the pipe line as described below.

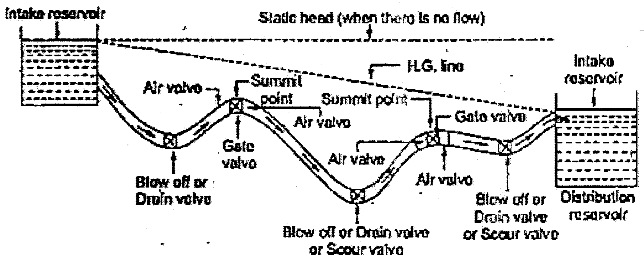


Fig. 2.20 Profile of the pressure pipe showing the locations of gates and valves

(i) Gate Valves or Sluice Valves

- These valves are used to regulate the flow of water through the pipes.
- They are generally located along the large pipe line at intervals of about 3 to 5 km to divide the pipe into different sections.
- These valves are placed at the summits of the pressure conduits.
  'Summits' represent the point of low pressure.
- The valve is made up of cast iron with brass, bronze or stainless steel mounting.
- They are either solid wedge type or double disk type.

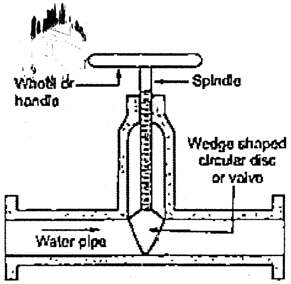


Fig. 2.21
Vertical section of a typical sluice valve

(ii) Air Valves

- These valves are placed along the pipe at "summits" on both sides of the sluice valves and also on the downstream side of all other sluice valves.
- These valves are also known as air inlet valves because water flowing through the pipe line always carries some air with it.
- This air tends to accumulate at the summit of pipe line. The accumulated air obstruct the free flow of water and the pipe may get air locked.
- Air relief valve are, therefore required to be provided at all summit to remove the accumulated air.

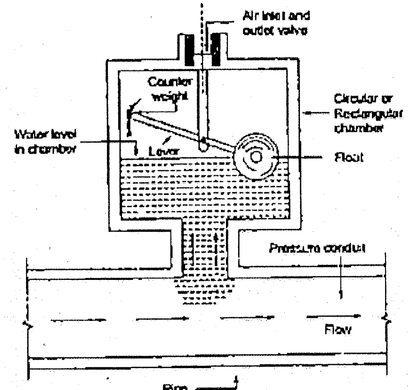


Fig. 2.22 Vertical section of a poppet type air-valve

(iii) Check Valves

- These valves are also known as non-return valves or reflux valves.
- They allow the water to flow in one direction only.
- They may be installed on the delivery side of the pumping set so as to prevent the back flow of stored or pumped water, when the pump is stopped (Figure 2.23).
- When the pump is operated, the valve is opened, but when the pump is suddenly stopped the valve is automatically closed. This prevent backward flow of water to the pump (Figure 2.23).

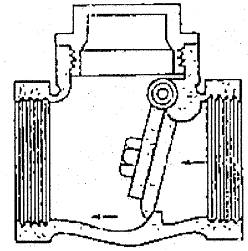


Fig. 2.23 Swing Type of Check Valve (Flap Type)

(iv) Relief Valve or Safety Valve

- These valves are also called pressure relief valves or safety valve or cut-off valves (Figure 2.29).
- These valves adjusted to open out automatically as soon as the pressure in pipe exceeds a certain fixed predetermined value and the excess pressure is released instantaneously. Thus, the pipe line is protected form bursting.
- As soon as the water hammer pressure reduces, and the pressure in pipe falls, the valve will close automatically.
- Water hammer pressure in pressure pipe can be reduced by using these valves.
- Such types of value are useful for small pipelines.

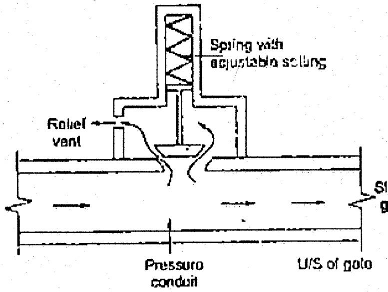


Fig. 2.24 Vertical section of a pressure relief valve in open position

(v) Scour Valve or Blow Off Valve or Drain Valve

- These valves are also known as washout valves.
- To remove the entire water from pipe after closing the supply, small gate valves are provided at low print.
- These valves, are necessary at low level points for completely emptying the pipe for inspection, repairs etc.
- To avoid the possibility of pollution travelling into the water pipe, there should be no direct connection between the valve and the sewer or drain.

(vi) Foot Valve

- These Valve is used at the end of pump suction pipe. Fig. 2.25
- They prevent entry of debris into the pumping system and back flow.

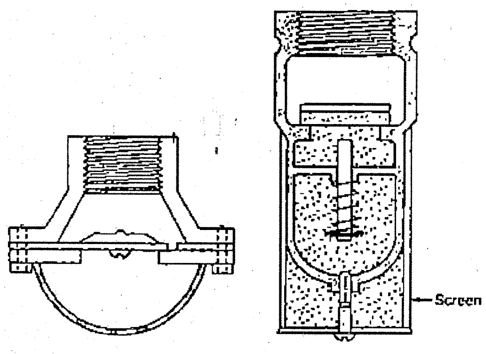


Fig. 2.25 Two types of Foot Valves

(vii) Butterfly Valve

- They are used to regulate and stop the flow especially in large size conduits.
- They are cheaper than sluice valve for larger sizes and occupy less space.
- They involve slightly higher head loss than sluice valves and also are not suitable for continues throttling.

(viii) Globe Valve

- The flow changes its direction 90° twice a time, which causes high head loss.
- These valves are used in tap or small bore pipe work, although a variation is used as a control valve.

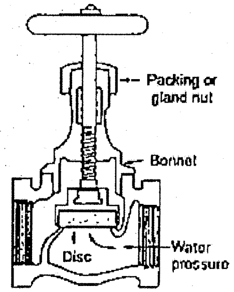


Fig. 2.26 Globe valve

(ix) Needle and Cone Valve

- Similar to sluice valve but are more expensive than sluice and butterfly valves.
- It is suitable for throttling flow.
- These valves are not commonly used in water supply but are occasionally used as water hammer release valves.

(x) Ball Valves or Ball Float Valve

- These valve are used to maintain a constant level in a service reservoir or elevated tank.
- In both cases, the float follows the water level in the reservoir and permit the valve to admit additional water on a falling level and less water on a rising level and to close entirely when the overflow level is reached.

(xi) Pilot Valve

- It is a small valve that controls a limited-flow control feed to separate piloted valve. Typically, this controls a high pressure or high flow feed.
- These valves are often used in critical applications (*i.e.* emergency and safety controls) and are human operated.

(xii) Stop Cocks

- They are practically sluice valve of small sizes (Fig. 2.27).
- They are provided on the pipe line leading to wash basin, water tank etc to stop or open the flow of water when necessary.
- They are made of gun metal or bass.

(xiii) Bib Cocks

- These are small size water taps which are fixed on the pipe line in wash basins, bathrooms, kitchens etc from where the consumers obtain water. (Fig. 2.28)
- Generally made of brass or gun metal or plastic

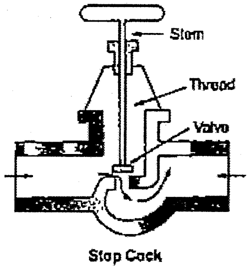


Fig. 2.27 Stop Cocks

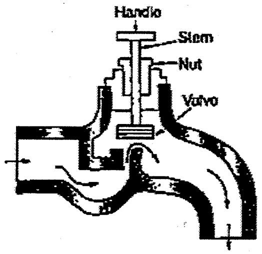


Fig. 2.28 Bib Cocks

(xiv) Fire Hydrants

- These are used in an outlet provided in a water distribution main for tapping water in case of fire outbreaks.
- During a fire breakout, the nearest hydrant is connected to the fire hose, which takes water to the fire engine to boost the pressure to at least 32 m of water head so that water can reach multi-storeyed building (Figure 2.29).
- They are of two types :
  (a) Flush fire hydrant : They are provided below road level.
  (b) Post fire hydrant : They are provided above road level.

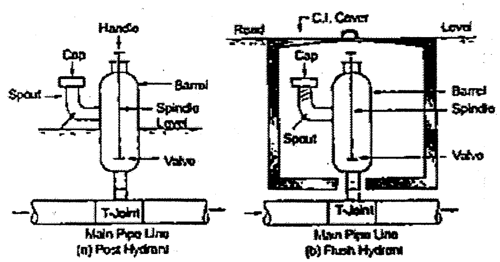


Fig. 2.29 Fire Hydrant

(xv) Water Meter

- Water meter measures and records the quantity of water flowing through a particular point.
- It helps directly to compute the volume of water used.

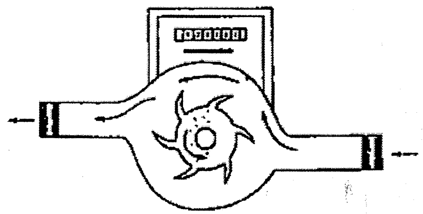


Fig. 2.30 Water Meter

- The domestic type water meter are employed for house fitted into the service pipe with unions, which enables the meter to be changed where necessary.

The Meters may be of following types

(a) Displacement type or positive displacement meter

- It records the number of times container of known volume is filled up and emptied by the flowing water.
- The volume of water can be calculated from the reading.
- Used in residential houses for measuring small flows.

(b) Velocity type or inferential meter

- It gives a reading according to the velocity of flow of water.
- The volume can be calculated from the manufacture's table according to the meter reading.
- They are used for measuring high flows.
- They are generally not used for small domestic supplies.
- They are used for measuring supplies of industries and trade.

Example 2.17 Match List-I (Valves) with List-II (Uses) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Sluice valve	1. Used where gravity flow is required through pipe line
B. Check valve	2. Used to maintain constant level of water
C. Air inlet valve	3. Used for reversal of flow
D. Ball valve	4. Used for Isolating

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	4	2	1	3
(c)	1	2	4	3
(d)	4	3	1	2

Ans. (d)

Sluice valve can be used to isolate any part of distribution system during repairs. Air inlet valves release high pressure and admit air during vacuum. Thus they ensure gravity flow under atmospheric pressure.

Ball valve are provided in the cistern to maintain constant level of water. They are also provided with overflow pipe to drain out excess incoming water.

Example 2.18 Match List-I (Fixture) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Surge arrester	1. Prevention of reversal of flow in a pipeline
B. Butterfly valve	2. Regulating or stopping the flow especially in large size conduits
C. Scour valve	3. Control of water hammer
D. Check valve	4. Draining or emptying the pipeline section

Codes:

	A	B	C	D
(a)	1	2	4	3
(b)	3	2	4	1
(c)	1	4	2	3
(d)	3	4	2	1

Ans. (b)

2.13 Testing of the Pipe Lines

After the pipe lines has been laid, fitted with all appurtenances and accessories, painted both from inside as well as outside by means or protective paints etc, the pipe line will be tested for the soundness in its construction.

Steps and Procedure:

(i) The pipe line is tested section by section. Thus at a time only one particular section lying between two sluice valves is taken up for testing.

(ii) The downstream sluice valve is closed and water is admitted into the pipe through the upstream sluice valve, the air valve will be properly operated during filling up of the pipe.

(iii) The upstream valve, through which water was admitted is closed, so as to completely isolate the pipe section from the rest of the pipe.

(iv) Pressure gauges are then fitted along the length of the pipe section at suitable intervals on the crown

(v) The pipe section is then connected to the delivery side of a pump through a small by-pass valve and the pump is started, so as to develop pressure in the pipe.

(vi) The by-pass valve is then closed and the pumping is disconnected.

(vii) The pipe is thus kept under pressure for 24 hours and inspected for possible defects, leakage at the joints. This completes the test.

(viii) The pipe is emptied and the observed defects are rectified. So as to make the line fit for use.

Example 2.19 For water supply of a town, water is pumped from a river 3 km away into a reservoir is 20 m. The population of the town is 50000 and per capita water demand is 120 liter/day. If the pumps are to operate for a total of 8 hours and the efficiency of pumps is 80%, determine the horse power of the pumps. Assume friction factor as 0.03, the velocity of flow as 2 m/s, and maximum daily demand as 1.5 times the average daily demand.

Solution:

Average water required = Population × per capita demand

$$= \frac{50000 \times 120}{1000} m^3/day = 6000\ m^3/d$$

Maximum daily water required = $1.5 \times 6000\ m^3/d = 9000\ m^3/d$

This quantity has to be pumped from the river in 8 hours to the reservoir

$\therefore$ Water lifted per second = $\dfrac{9000}{8 \times 3600} m^3/sec = 0.3125\ m^3/s$

Velocity through the pipe lifting the discharge ($0.3125\ m^3/s$) is 2 m/s (given)

$\therefore$ Dia of pipe (d) is obtained as

$$2 \times \left(\frac{\pi}{4} d^2\right) = 0.3125$$

$$d = \sqrt{\frac{0.3125 \times 4}{2\pi}} = 0.446\ m \simeq 0.45\ m$$

H_L = Head loss through the pipe of 3000 m long and diameter 0.45 m

$$= \frac{fLV^2}{2gd} = \frac{0.03 \times 3000 \times 2^2}{2 \times 9.81 \times 0.45} = 40.77\ m$$

Total lift H = Actual difference of WL in reservoir and river + H_L

$= 20 + 40.77\ m = 60.77\ m$

$$H.P \text{ of pump} = \frac{\gamma_w QH}{0.735\,\eta} = \frac{9.81 \times 0.3125 \times 60.77}{0.735 \times 0.8} = \text{mHP}$$

2.14 Economical Diameter of the Pumping Mains

- The diameter of a pipe can be reduced (for passing a certain fixed discharge) by increasing the flow velocity through the pipe.
- But, the increased velocity will lead to higher frictional head loss, and thus increased cost of pumping.
- Hence, although the dia and the cost of pipe can be reduced by choosing a higher flow velocity, the horse power of the pump required will increase, thus increasing the cost of pumping.
- For optimum condition, we must choose such a diameter which together with the pumping cost will make the total annual expenses, the minimum. The diameter which provides such optimum conditions is known as the Economical Diameter of the pipe.
- An empirical formula given by Lea, connecting the dia and the discharge is

$$\boxed{D = 0.97 \text{ to } 1.22\sqrt{Q}}$$

where,

D = Economical dia (in meter)

Q = Discharge to be pumped in (m^3/sec)

- This relationship gives optimum flow velocity varying between 0.8 to 1.35 m/sec.

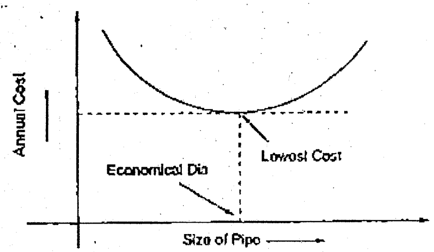


Fig. 2.31 Size of Pipe with Annual Cost

Example 2.20 From a clear water reservoir 3 m deep and maximum water level at 30. Water is to be pumped to an elevated reservoir at 75 at the constant rate of 9,00,000 litres per hour. The distance is 1500 m. Give the economical diameter of the rising main and the water horse power of the pump. Neglect minor losses and take $f = 0.01$ (Darcy's friction coefficient)

Solution:

Discharge, $Q = 9 \times 10^5\ l/h = \dfrac{9 \times 10^5}{1000 \times 3600}\ m^3/sec = 0.25\ m^3/sec$

For economical diameter of the rising main, by using LEA'S FORMULA, then we have,

$D = 1.22\sqrt{Q} = 1.22\sqrt{0.25}$

$D = 0.61\ m$

The head loss in pipe $H_f = \dfrac{f L v^2}{2gd}$

where, $f = 4f' = 4 \times 0.01 = 0.04$

v = velocity of flow $= \dfrac{Q}{A} = \dfrac{0.25}{\frac{\pi}{4}(0.61)^2} = 0.855$ m/sec

Substituting the value we get, $H_f = \dfrac{0.04 \times 1500 \times 0.855^2}{2 \times 9.81 \times 0.61} = 3.66\ m$

Neglecting entrance and exist losses as well as the losses in bend then we have,

Total losses $= H_L = H_f = 3.66\ m$

Head including maximum suction and delivery head, against which the pump has to work

$= 45 + 3 = 48$

Total head, $H = 3.66 + 48\ m = 51.66\ m$

$\therefore$ Water horse power of pump $= \dfrac{\gamma_w QH}{0.735} = \dfrac{9.81 \times 0.25 \times 51.66}{0.735} = 172.4$ mHP

Illustrative Examples

Example 2.21 A town of 200,000 population is to be supplied water from a source 2500 m away. The lowest water level in the sources is 15 m below the water works of the town. The demand of water is estimated as 150 l/capita/day. A pump of 300 HP is operated for 15 hours. If the maximum demand is 1.5 times the average demand, the velocity of flow through the rising main is 1.3 m/s and the pump efficiency is 70% determine.

(i) Hydraulic gradient (ii) Friction factor for the pipe

Solution:

Maximum Demand = Population × 1.5 × average demand

$= 2 \times 10^5 \times 1.5 \times 150 = 45$ MLD

The pumping is done for 15 hours a day, so maximum discharge required for pumping

$$Q = \frac{45 \times 10^6}{10^3 \times 15 \times 3600} = 0.8333\ m^3/sec$$

now, $HP = \dfrac{\gamma_w QH}{0.735 \times \eta}$

$300 = \dfrac{9.81 \times 0.8333 \times H}{0.735 \times 0.7}$

$\Rightarrow$ $H = 18.88\ m$

But total head (H) = head difference between source and water works + head loss due to friction in rising main.

$\Rightarrow$ $18.88 = 15 + h_f$

$\Rightarrow$ $h_f = 3.88\ m$

(i) Hydraulic gradient $= \dfrac{h_f}{L} = \dfrac{3.88}{2500} = \dfrac{1}{644}$

(ii) and, $h_f = \dfrac{fLv^2}{2gd}$

Now, $\dfrac{\pi d^2}{4} = \dfrac{Q}{v} = \dfrac{0.8333}{1.3}$

$$\therefore \quad d = \sqrt{\frac{0.8333}{1.3} \times \frac{4}{\pi}} \quad \Rightarrow \quad d = 0.9 \text{ m}$$

$$\because \quad h_f = \frac{fLv^2}{2gd}$$

$$\Rightarrow \quad f = \frac{3.88 \times 2 \times 9.81 \times 0.9}{2500 \times (1.3)^2} = 0.0162$$

Example 2.22 In a pumping station 18000 m³ water is to be raised per day from an intake well to a sedimentation tank under the static head of 21 m. Length of suction pipes and rising main are 40 m and 150 m respectively. Diameter of pipes is 50 cm. There are two shifts of working of pumps each of 8 hours. Take coefficient of friction as 0.01 and combined efficiency of motor and pump as 80%. Recommend the number of units of pump each having BHP of 30.

Solution:

Total Volume of water to be raised per day in two shifts of 8 hours each = 18000 m³.

$\therefore$ Volume of water to be raised in each shift = $\frac{18000}{2} = 9000 \text{ m}^3$

Discharge of water per shift of 8 hours, $Q = \frac{9000}{8 \times 3600} = 0.3125 \text{ m}^3/\text{s}$

The head loss due to friction may be given by Darcy-weisbach equation as below

$$h_f = \frac{fLv^2}{2gd}$$

$$v = \frac{Q}{A} = \frac{4Q}{\pi d^2}$$

$$h_f = \frac{fL}{2gd} \times \left(\frac{4Q}{\pi d^2}\right)^2 = \frac{fLQ^2}{12.1d^5} = \frac{4f'LQ^2}{12.1d^5} \qquad [\because f = 4f']$$

$$h_f = \frac{4 \times 0.01 \times 190 \times (0.3125)^2}{12.1 \times (0.5)^5} \qquad [\text{here given } f = 0.01 \text{ and } d = 0.5 \text{ m}]$$

$$\Rightarrow \quad h_f = 1.96 \text{ m}$$

Total head against which pumping is done = static head + head loss due to friction

= 21 + 1.96 = 22.96 m

So, if η is the efficiency of the pump set, then brake horse power (BHP) of the pump is given by

$$\text{BHP} = \frac{\gamma_w QH}{\eta \times 0.735}$$

$$\Rightarrow \quad \text{BHP} = \frac{9.81 \times 0.3125 \times 22.96}{0.8 \times 0.735} = 119.7 \text{ mHP}$$

Total number of units of pump of 30 BHP each = $\frac{119.7}{30} = 4$ thus, 4 units of pumps each having a BHP of 30 can be used.

Example 2.23 A 30 cm diameter well penetrates 25 m below the static watertable. After 24 hours of pumping @ 5400 litres/minute, the water level in a test well at 90 m is lowered by 0.53 m, and in a well 30 m away the drawdown is 1.11 m. (a) What is the transmissibility of the aquifer? (b) Also determine the drawdown in the main well.

Solution:

Since the well penetrates 25 m below the static water table, it evidently is the case of unconfined aquifer. The Thiem's discharge equation for such a well is given by equation as

$$Q = \frac{\pi K.(h_2^2 - h_1^2)}{2.3 \log_{10} \frac{r_2}{r_1}}$$

where,

$h_2 = d - s_2 = 25 - 0.53 = 24.47$ m

$h_1 = d - s_1 = 25 - 1.11 = 23.89$ m

$r_2 = 90$ m

$r_1 = 30$ m

$Q = 5400$ l/min = 5.4 m³/min = 0.09 m³/s

Substituting the given values in the above equation, we have

$$0.09 = \frac{3.14 \times K.\left[(24.47)^2 - (23.89)^2\right]}{2.3 \log_{10} \frac{90}{30}}$$

or

$$K = \frac{0.09 \times 2.3 \times \log_{10} 3}{3.14\left[(24.47)^2 - (23.89)^2\right]} = 1.121 \times 10^{-3} \text{ m/s}$$

Now $\quad T = Kd = 1.121 \times 10^{-3} \times 25 \text{ m}^2/\text{s} = 0.028 \text{ m}^2/\text{s} = 1.68 \text{ m}^2/\text{min}$

(b) To determine the drawdown in the main well, use the above equation as

$$Q = \frac{\pi K(h_1^2 - h_w^2)}{2.3 \log_{10} \frac{r_1}{r_w}}$$

or

$$0.09 = \frac{1.121 \times 10^{-3}\left[(23.89)^2 - h_w^2\right]}{2.3 \log_{10} \frac{30}{0.15}}$$

or $\quad h_w = 12.08$ m

$\therefore \quad s_w = d - h_w = 25 - 12.08 = 12.92$ m

Hence, the drawdown in the main well = 12.92 m

Example 2.24 Water is to be supplied to a town with one lakh population at the rate of 150 litres per capita per day from a river 1.8 km away. The difference in elevation between the lowest water level in the sump and service reservoir is 36 meters. Determine the size of the main and the horse power of the pump required. Assume suitable data where necessary.

Solution:

Per capita demand = 150 litres per day

Population = 1 lakh

Average quantity of water required

= 150 × 1,00,000 litres per day

= 15 million litres per day = 15 MLD

Assuming the maximum demand to be 1.8 times the average annual demand, we have

$$\text{Maximum demand} = 15 \times 1.8 \text{ MLD} = 27 \text{ MLD}$$

$$= \frac{27 \times 10^6}{10^3} \text{ cubic metres per day}$$

$$= \frac{27 \times 10^3}{24 \times 60 \times 60} \text{ cubic metres per sec} = 0.312 \text{ cumec}$$

Further, assuming that the pumps are working for 12 hours a day to supply full days demand, we have

$$\text{Maximum draft required} = 0.312 \times \frac{24}{12} = 0.624 \text{ cumecs}$$

Now, assuming the flow velocity through the pressure pipe to be 1.5 m/sec, we have

$$\text{Area of the pipe required} = A = \frac{Q}{V} = \frac{0.624}{1.5} \text{ m}^2$$

$\therefore$ Dia of the pipe required = 0.728 m

So use 0.75 m dia pipe

$$\therefore \quad \text{Actual area provided} = \frac{\pi}{4} \times (0.75)^2 = 0.441 \text{ m}^2$$

$$\text{The actual velocity} \quad V = \frac{Q}{A} = \frac{0.624}{0.441} = 1.42 \text{ m/sec}$$

Head loss can now be calculated by using

$$V = 0.85\, C_H R^{0.63} S^{0.54}$$

Assuming $C_H = 120$

$R = \frac{d}{4}$, we have

$$1.42 = 0.85 \times 120 \times \left(\frac{0.75}{4}\right)^{0.63} S^{0.54}$$

or $1.42 = 35.5\, S^{0.54}$

or $S^{0.54} = \frac{1.42}{35.5} = 0.04$

or $S = (0.04)^{\frac{1}{0.54} = 1.85} = 0.0026$

or $\frac{H_L}{L} = 0.0026$ or $H_L = 0.0026 \times 1800 = 4.68$ m

The head difference between the elevation of sump well and service reservoir = 36 m (given)

The head loss in supply main = 4.68 m (calculated above)

Total head lift required = 36 + 4.68 = 40.68 m

$$\text{The power of the motor required} = \frac{\gamma_w Q H}{\eta} \text{kW}$$

where

γ_w = unit weight of water in kN/m³ = 9.81 kN/m³

Q = discharge in m³/s

H = Total head lift required in m

η = Efficiency of pump set

Brake horse power of pumps required (metric) is, hence, given as

$$\boxed{BHP = \frac{\gamma_w \cdot Q \cdot H}{0.735\, \eta}}$$

$\because$ 1 Metric H.P. = 0.735 kW

$$\therefore \quad H.P. = \frac{9.81 \times 0.624 \times 40.68}{0.735 \times 0.65} \text{ (assuming } \eta = 0.65) = 522 \text{ mHP}$$

NOTE: The horse power of the pumps can be reduced by reducing the head loss (at present 4.68 m) in conveyance by choosing smaller velocity and, thus bigger sized pipe. But in that case, the cost of pipe shall go up. That is why an optimum velocity of about 1.2 to 2.6 m/sec is generally adopted. In fact, it is a question of economics and the economy can be worked out by designing pipes at various velocities and the cheapest velocity chosen, keeping in consideration its non-silting and non-scouring value.

Important Expressions

1. Discharge from Infiltration Galleries

$$\boxed{Q = k \cdot L \cdot \left(\frac{H^2 - h^2}{2R}\right)}$$

Where, Q = Total Discharge, k = permeability,
L = Length of gallery, H = Static water level,
h = depth of water on pumping equilibrium
R = Radius of influence

2. Discharge from Pumping Test

$$Q = k \cdot i \cdot A = k \cdot \left(\frac{S}{L}\right) \cdot A = \frac{k}{L} \cdot A \cdot S = C \cdot A \cdot S$$

$\therefore \boxed{Q = C \cdot A \cdot S}$ where, Q = yield of well
S = depression head
A = Area

3. Discharge (Yield) from Recuperating Test, $Q = \left(\frac{2.3}{T} \log_{10} \frac{S_1}{S_2}\right) A \cdot S$

4. Yield of Unconfined Aquifer, $Q = \frac{\pi k (h_2^2 - h_1^2)}{2.303 \log_{10}(r_2 / r_1)}$

where, $T = kH$ = coefficient of Transmissibility, S_1, S_2 = value of drawdown

5. Yield of Confined Aquifer, $Q = \frac{2\pi k z (h_2 - h_1)}{2.303 \log_{10}\left(\frac{r_2}{r_1}\right)}$

6. Darcy-Weisbach formula

Head loss, $H_L = \frac{f \cdot L \cdot V^2}{2g \cdot d}$ here f = friction factor = 4 f

7. **Manning's Formula**

Head loss, $h_L = \frac{n^2V^2L}{R^{4/3}}$ Where, n = Manning rugosity coefficient, L = Length of pipe
V = Velocity (m/sec), R = Hydraulic mean depth

8. **Hazen-William Formula**, $V = 0.85\, C_H \cdot R^{0.63} \cdot S^{0.54}$
Where, C_H = Coefficient of Hydraulic capacity, R = Hydraulic radius (m)
S = Slope of energy line, V = Velocity of flow

9. **Water Hammer Pressure**

$H_{max} = \frac{CV_0}{g}$ where, C = Velocity of pressure wave travel (in m/sec)
V_0 = Normal velocity, g = acceleration due to gravity

10. **BHP (Brake Horse Power)**, $BHP = \frac{WHP}{\eta} = \frac{\rho QgH}{735 \times \eta}$

11. **Water Horse Power (WHP)**, $WHP = \frac{\rho QgH}{735}$

Summary

1. Larger and older lakes, however provide comparatively pure water than smaller and newer lakes due to self purification.
2. "Ranney Well" is a modern technique to construct vertical well.
3. Certain spring, sometimes, discharge hot water due to the presence of sulphur in them.
4. To resist the water hammer pressure, we use piping material which is strong in tension.
   - Velocity of sound in water is taken as 1433 m/sec
   - The biggest disadvantages of cast-iron pipe is tuberculation of pipe in certain water.
   - To safeguard against higher negative pressure, the pipes are coated from inside as well as outside with 1 : 2 cement mortar.
   - For protection against corrosion, the wrought iron pipes are galvanised with zinc coating and are called "Galvanised" Iron pipes or G.I. Pipes.
   - The corrosion of metal pipes can be controlled by increasing pH, reducing CO_2 and Zn coating.

Objective Brain Teasers

Q.1 Two reservoirs at different levels are connected by two parallel pipes of diameter '2d' and 'd'. The ratio of the flows in the two pipes (larger: smaller) is

(a) $\sqrt{2}:1$ (b) $2:1$
(c) $4:1$ (d) $4\sqrt{2}:1$

Q.2 Which one of the following pairs is not correctly matched?

(a) Check valve : To check water flow in all directions
(b) Sluice valve : To control flow of water through pipelines
(c) Air valve : To release the accumulated air
(d) Scour valve : To remove silt in a pipeline

Q.3 The following steps are involved in making a spigot and socket joint of cast iron pipes used in water supply systems:

1. Tarred gasket or hemp yarn is wrapped around the spigot.
2. The spigot end is centered into the socket end of the preceding pipe.
3. A jointing ring is placed around the barrel and against the face of the socket.
4. The gasket or hemp yarn is caulked slightly.
5. Molten pig lead is poured and then caulked.

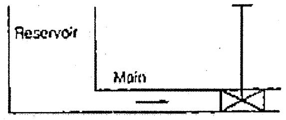
The correct sequence of these steps is

(a) 2, 1, 4, 3, 5 (b) 2, 1, 3, 4, 5
(c) 1, 2, 4, 5, 3 (d) 1, 2, 3, 5, 4

Q.4 Service connection consists of

(a) ferrule, stopcock and gooseneck
(b) ferrule, check valve and gooseneck
(c) stopcock, meter and sluice valve
(d) sluice valve, check valve and meter

Q.5 The following sketch shows a water supply main from a storage reservoir provided with a sluice valve:



The type of valve most suitable for this pipeline is

(a) air valve
(b) scour valve
(c) pressure relief valve
(d) None of the above

Q.6 In sanitary plumbing of buildings, a two pipe system signifies

(a) separate soil pipes and waste pipe without vent pipes
(b) a soil-cum-waste pipe and a ventilating pipe
(c) separate soil and waste pipe and a common ventilating pipe
(d) separate soil pipe and waste pipe, each with its own vent pipe

Q.7 Consider the following statements:
While deciding to locate an intake structure for a city situated on a river bank, intake for water supply should be located

1. in deep waters
2. sufficiently away from shore lines
3. upstream of the populated city
4. near navigational channel

Which of these statements are correct?

(a) 1, 2 and 4 (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 1, 3 and 4

Q.8 Consider the following valves in a water distribution system:

1. Check valve
2. Pressure-reducing valve
3. Air relief valve
4. Scour valve
5. Sluice valve

Which of these work automatically?

(a) 1, 3 and 4 (b) 2, 4 and 5
(c) 3, 4 and 5 (d) 1, 2 and 3

Q.9 Match List-I (Equation/Method) with List-II (Application) and select the correct answer using the codes given below the lists:

List-I
A. Manning's Equation
B. Darcy-Weisbach
C. Hardy Cross Method
D. Rational Method

List-II
1. Frictional head loss estimation in pipe flow
2. Sanitary sewer design
3. Storm sewer design
4. Water distribution system design

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	1	4	3	2
(c)	2	1	3	4
(d)	1	4	2	3

Q.10 Which one of the following valves is seldom used in water distribution systems because of high head loss characteristics?

(a) Butterfly (b) Globe
(c) Plug (d) Sluice

Q.11 Sonoscope is used for which one of the following?

(a) Checking the accuracy of water meters
(b) Regulating the fire hydrants
(c) As a replacement of venturimeter for discharge measurement
(d) Detection of leakage in underground water mains

Q.12 What is the depth of water seal in the traps?
(a) < 2.5 cm (b) 2.5 – 7.5 cm
(c) 7.5 – 12.5 cm (d) Not less than 15 cm

Q.13 Consider the following statements:
In a water supply system,
1. drain valves are provided at elevated or higher, points to remove accumulated air.
2. reflux valve allows flow in one direction only.
3. drain valves are provided at low points to remove silt and other deposits.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 2 only
(c) 2 and 3 only (d) 3 only

Q.14 Consider the following statements:
The disadvantages of employing steel pipes in conveyance and distribution of water are, they
1. cannot withstand high negative pressures or vacuums that may be created in them, especially the combined effects of vacuum and external loads of backfill and traffic.
2. are easily affected by acidic or alkaline waters and even atmospheric agencies may produce adverse effects on them.
3. cannot be used for high pressures. (Generally not used for pressures above 7 kg/cm^2)

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 only

Q.15 Match List-I (Soil classification of an aquifer) with List-II (Values of the range of hydraulic conductivities in metre per day) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Fine gravel	1. 1 to 10
B. Very fine sand	2. 0.1 to 0.01
C. Silt	3. 100 to 1000
D. Pure clay	4. 10^{-5} to 10^{-6}

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	1	3	2	4
(c)	3	1	4	2
(d)	3	1	2	4

Q.16 A commonly used handpump is the
(a) centrifugal pump
(b) reciprocating pump
(c) rotary pump
(d) axial flow pump

Q.17 Consider the following statements:
1. Infiltration galleries are placed along the river beds at a depth 4 to 6 m.
2. The draw-down for the infiltration galleries is more than that for radial wells.
3. Clogging of pipe pores in infiltration galleries is less than that for radial wells.
4. The cost of extracting unit volume of water is more in case of infiltration galleries as compared to radial wells.

Which of these statements is/are correct?
(a) 1 and 2 (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 4 only

Q.18 As recommended by Sichardt, the radius of influence is
(a) Inversely proportional to draw-down
(b) Linearly proportional to draw-down
(c) Independent of draw-down
(d) Proportional to square root of draw-down

Q.19 The usual size of residential ferrule bore varies from
(a) 1 mm to 5 mm
(b) 10 mm to 50 mm
(c) 100 mm to 500 mm
(d) 1000 mm to 5000 mm

Direction: Each of the next consists of two statements, one labelled as the 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.20 Assertion (A): In a strainer type tube well, strainer pipes are surrounded by wire mesh.
Reason (R): This prevents the fine particles from entering the well pipe.

Q.21 Assertion (A) : Rainwater is collected and harvested using storage structures like underground tanks for future use and also for recharging the aquifer.
Reason (R): Rainwater harvesting pits allow the rainwater to percolate and recharge the aquifer.

Q.22 Assertion (A): The leakage losses are less when the water supply is intermittent.
Reason (R): Pressure is less in intermittent water supply.

Answers

1. (d)	2. (a)	3. (c)	4. (a)	5. (c)
6. (d)	7. (b)	8. (d)	9. (a)	10. (c)
11. (d)	12. (b)	13. (c)	14. (b)	15. (d)
16. (b)	17. (b)	18. (b)	19. (b)	20. (a)
21. (a)	22. (c)			

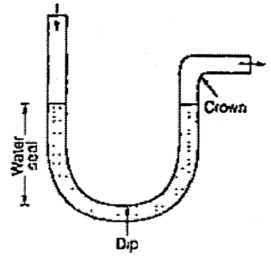
Hints and Explanations:

Ans.3 (c)
The enlarged end of pipe is called 'socket' or 'bell' and normal end is called 'spigot'. Such questions are based on common sense and not information.
If suppose we choose 2 first, then it is impossible to wrap tarred gasket or hemp yarn in the pipe thereafter.
So 1 should precede 2. Caulking means filling the space. Now gasket or hemp yarn cannot be caulked after a jointing ring is placed around the barrel and against the face of the socket. So caulking of hemp yarn and pouring of molten pig lead is to be completed before placing jointing ring.

Ans.4 (a)
Service pipe and water meter are other service connections.

Ans.5 (c)
Water hammer phenomena will cause considerable damage to pipe when sluice valve is suddenly opened. Water hammer pressure can be reduced by providing pressure relief valve upstream of sluice valve.

Ans.11 (b)
Traps are the fittings placed at the ends of the soil pipes or the sullage pipes to prevent the passage of foul gases from the pipes to the outside. This is possible because traps do enclose or maintain water seal between the pipe and outside. This water depth does not allow gases to escape to the outside of pipe. The efficiency and effectiveness of a trap will depend upon the depth of water seal.
Greater is this depth more effective the trap will be. This water seal generally varies from 25 mm to 75 mm; 50 mm being quite common in most of the traps.



Ans.16 (b)
In the case of radial wells, pumping of water from substratum increases the cost.

Ans.17 (b)
The usual size of residential ferrule varies from 10 mm to 50 mm. For connections of more than 50 mm diameter, a tee branch connection is used.

■■■■