23

Pressure Conduits

23.1. Definition, Etc.

A pressure conduit (such as a penstock) is a pipe which runs under pressure and, therefore, runs full. This type of conduits prove economical than canals or flumes, because they can generally follow shorter routes. Moreover, their biggest advantage is: that the water or any other fluid flowing through them is not exposed anywhere and hence, there are no chances or very less chances of its getting polluted. Hence, these pressure conduits are preferably used for city water supplies. Since the water wasted in percolation, evaporation, etc. is also saved, when water is carried through these conduits, they are preferably used when water is scarce. The flow of water through conduit pipes is generally turbulent, and hence, it will be considered so, while dealing with the hydraulics of flow through such pipes.

23.2. Hydraulics of Flow and Discharging Capacities of Pressure Conduits

The pressure conduits are designed in such a way that the available pressure head is just lost in overcoming the frictional resistance offered to the flow of water by the pipe. The velocities generated in these pipes should neither be too small to require a large size diameter pipe, nor should be so large as to cause excessive loss of pressure head.

The head loss by pipe friction may be found by using either of the following formulas :

(*i*) **Darcy-Weisbach Equation.** It states that

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

where H_L = Head loss in metres.

L = Length of the pipe in metres.

d = Diameter of the pipe in metres.

V = Velocity of flow through the pipe in m/sec.

f' = The friction factor, which depends upon Reynold number $\left(i.e.\ R_e = \frac{Vd}{\nu}\right)$ and relative roughness of the pipe.

The relative roughness $\left(\delta = \frac{2e}{d}\right)$ of a pipe depends on the absolute roughness (e) of the inside surface and the diameter of the pipe d. The approximate values of f' are given by the following empirical relations :

$$f' = 0.04\left[1 + \frac{1}{35\,d}\right] \text{ for old pipes} \qquad ...(23.2)$$

and $$f' = 0.02\left[1 + \frac{1}{35\,d}\right] \text{ for new pipes} \quad ...(23.3)$$

The accurate value of f' depends on R_e and δ, and may be given by formula, such as

$$f' = a + \frac{b}{R_e^m} \quad ...(23.4)$$

where a, b and m are constants depending upon δ.

For R_e varying between 20,000 to 20,00,000, Schiller has given

$$f' = 0.005 + \frac{0.396}{R_e^{0.3}} \quad ...(23.5)$$

and Nikuradse has given for values of R_e varying between 20,000 to 32,40,000 as

$$f' = 0.0032 + \frac{0.221}{R_e^{0.237}} \quad ...(23.6)$$

(*ii*) **Manning's formula.** Manning's formula is also applicable to turbulent flow in pressure conduits and yields good results, provided the roughness coefficient n is accurately estimated. Head loss according to Manning's equation is given as :

$$H_L = \frac{n^2 \cdot V^2 \cdot L}{R^{4/3}} \quad ...(23.7)$$

where n = Manning's rugosity coefficient.
L = Length of pipe in metres.
V = Flow velocity through pipe in m/sec.
R = Hydraulic mean depth of pipe

$$\left[i.e.,\ R = \frac{A}{P} = \frac{\frac{\pi d^2}{4}}{\pi d} = \frac{d}{4}\right] \text{ in metres}$$

(*iii*) **Hazen-William's formula.** This formula is widely used for pipe flows and states

$$V = 0.85\, C_H \cdot R^{0.63}\, S^{0.54} \quad ...(23.8)$$

where C_H = Coefficient given by Table 23.1.
R = Hydraulic mean depth of pipe, $= (d/4)$ in metres.
S = Slope of the energy line.
V = Flow velocity through the pipe in m/sec.

Table 23.1. Values of C_H for Hazen William's Formula

Pipe material	*Value of C_H*
Concrete (regardless of age)	130
Cast Iron	
New	130
5 years old	120
20 years old	100
Welded steel (New)	120
Riveted steel (New)	110
Vitrified clay	110
Brick Sewers	100
Asbestos-cement	140

The carrying capacities of pipes decrease with time, because with the passage of time, their interior surfaces go on becoming more and more rough. Hence, it is customary to select higher values of e and n and lower values of C_H for old pipes than are generally taken for new pipes.

23.3. Forces Acting on Pressure Conduits

Pressure pipes must be designed to withstand the following forces :

(1) *Internal pressure of water*

(2) *Water hammer pressures.*

(3) *Pressure due to external loads* (when buried under the ground).

(4) *Temperatures stresses* (when laid above the ground).

(5) *Longitudinal stresses* due to flow around bends or change in cross-section.

(6) *Flexural stresses* (when laid over supports at intervals or on bridges).

These forces are discussed below :

(1) **Internal Pressure of Water.** The pressure exerted on the walls of the pipe by the flowing water, in the form of Hoope's tension, is the internal pressure. The circumferential tensile stress produced is given as :

$$\sigma_1 = \frac{p_1 d}{2t} \text{ in kN/m}^2 \quad \text{...(23.9)}$$

where p_1 = Internal static pressure in kN/m^2.

d = Diameter of the pipe in metres.

t = Thickness of the pipe shell in metres.

σ_1 = Circumferential tensile stress to be counteracted by providing Hoope's reinforcement.

(2) **Water Hammer Pressure.** When a liquid flowing in a pipe line is abruptly stopped by the closing of a valve, the velocity of the water column behind, is retarded, and its momentum is destroyed. This exerts a thrust on the valve and additional pressure on the pipe shell behind. The more rapid the closure of the valve, the more rapid is the change in momentum, and hence, greater is the additional pressure developed. The pressures so developed are known as *water-hammer pressures* and may be so high as to cause bursting of the pipe shell (due to increased circumferential tension) if not accounted for in the designs.

The maximum pressure developed in pipe lines due to water hammer is given by the formula

$$p_2 = \frac{14.762 \cdot V}{\sqrt{1 + \frac{K \cdot d}{t}}} \quad \text{...(23.10)}$$

where V = Velocity of water just before the closing of the valve in m/sec.

d = Diameter of pipe in metres.

t = Thickness of pipe shell in metres.

K = Constant

$$= \frac{\text{Modulus of elasticity of pipe material}}{\text{Bulk modulus of elasticity of water}}$$

The value of K for steel comes out to be 0.01, for cast iron = 0.02, and for cement concrete = 0.1.

The water hammer pressure can be calculated by using the above equation. But for design purposes, its value is generally taken as 840 kN/m^2 for small size pipes of 7.5 to 25 cm diameter, and is gradually reduced to 490 kN/m^2 for pipes above 1.2 m diameter, as given in Table 23.2.

Table 23.2. Water Hammer Pressures

Pipe diameter in cm	*Water hammer Pressure in kN/m^2*
7.5 to 25	840
30 to 40	770
50	630
60	600
75	560
90	490
105 to 135	490

The circumferential tensile stress caused by water hammer pressure may then be calculated easily by using

$$\sigma_2 = \frac{p_2 \cdot d}{2t}$$

(3) **Stress due to External Loads.** When large pipes are buried deep under the ground, the weight of the earth-fill may produce large stresses in the pipe material. The stress due to the external earth fill load is given by

$$f = 22.7 \frac{h \cdot d^2}{t} \qquad \text{...(23.11)}$$

where h = depth of the earth-fill above the crown in metres.

d = diameter of pipe in metres.

f = stress produced in kN/m^2.

Note. In the above formula, it is assumed that the earth to the sides does not give any lateral support and weighs about 18.4 kN/m^3.

(4) **Temperatures Stresses.** When pipes are laid above the ground, they are exposed to the atmosphere and are, therefore, subjected to temperature changes. They expand during day time and contract at night. If this expansion or contraction is prevented due to fixation or friction over the supports, longitudinal stresses are produced in the pipe material. The amount of these stresses may be calculated by the formula :

$$f = E \cdot \alpha \cdot T \qquad \text{...(23.12)}$$

where E = Modulus of elasticity of the pipe material.

α = Co-efficient of expansion of the pipe material.

T = Change in temperature in °C.

Expansion joints at suitable intervals (say 20 m to 30 m or so) must be provided to counteract these stresses.

(5) **Stresses due to Flow Around Bends and Change in Cross-Section.** Whenever the velocity of a flow (either magnitude or direction) changes, there is a change in the momentum, and therefore, by Newton's Second Law, a force is exerted, which is proportional to the rate of change of momentum. The force required to bring this change in momentum comes from the pressure variation within the fluid and from forces transmitted to the fluid from the pipe walls.

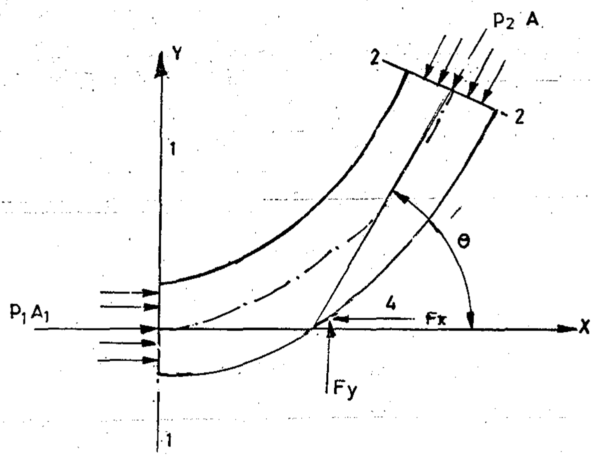

Fig. 23.1. Forces at a pipe bend.

The free-body diagram of various forces acting on the water contained in a horizontal pipe bend is shown in Fig. 23.1. Applying momentum equation, and resolving the forces in x and y direction, we get

$$p_1A_1 - F_x - p_2A_2 \cos\theta = \frac{\gamma_w Q}{g}\left[V_2 \cos\theta - V_1\right] \quad ...(23.13)$$

and
$$F_y - p_2A_2 \sin\theta = \frac{\gamma_w Q}{g}\left[V_2 \sin\theta\right] \quad ...(23.14)$$

where p_1 and p_2 are the pressures, V_1 and V_2 are the velocities at sections 1-1 and 2-2 respectively. The forces F_x and F_y are the forces which are transmitted from the pipe to the water. An equal and opposite force must, therefore, be developed in the form of stresses in the pipe wall. Similar forces will be developed when the cross-sectional area of the pipe is suddenly changed, as shown in Fig. 23.2.

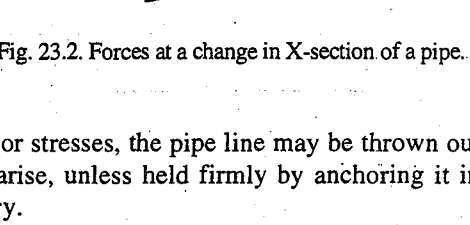

Fig. 23.2. Forces at a change in X-section of a pipe.

Due to these impressed external forces or stresses, the pipe line may be thrown out of alignment as and when such situations arise, unless held firmly by anchoring it in massive blocks of concrete or stone masonry.

(6) **Flexural Stresses.** Many a times, steel pipes are laid over concrete supports, built above the ground ; and sometimes the rain water, etc. may wash off the ground from below the pipes at intervals. Under all such circumstances, bending stresses get produced in the pipe, since the pipe then acts like a beam with loads resulting from the weight of the pipe, weight of water in the pipe and any other superimposed loads. The stresses caused by this beam action may be determined by usual methods of analysis applied to the beams. However, these stresses are generally negligible except for long spans or where there are huge superimposed loads.

23.4. Various Types of Pressure Conduits

Depending upon the construction material, the various types of pressure conduits are :

(1) Cast iron conduits.

(2) Steel conduits.

(3) Reinforced cement concrete conduits.

(4) Hume steel conduits.

(5) Vitrified clay conduits.

(6) Asbestos cement conduits.

(7) Miscellaneous types of conduits.

The selection of a particular type of material for the conduit depends mainly upon their relative economy and also upon the availability of material, labour, etc. for construction in the vicinity of site.

(1) **Cast Iron Conduits.** Cast iron pipes are widely used for city water supplies. They are sufficiently resistant to corrosion and may last as long as 100/years or so. They are generally manufactured in lengths of about 3.6 metres but may be manufactured in lengths up to 6 m or so on special orders. Cast iron pipes in different thicknesses, are generally available for withstanding different pressures upto a maximum of 2400 kN/m^2 (24.5 kg/cm^2).

In order to protect the pipes from corrosion, almost all the metal pipes are given some kind of protective coatings. Larger pipes are generally protected by bituminous linings or by cement mortar (1 : 2) linings. Smaller size pipes, such as those required for small service lanes in a water supply distribution system, are generally coated with zinc, and are known as galvanised iron pipes.

Bell and spigot joint (Fig. 23.3) is often used for connecting cast iron pipes.

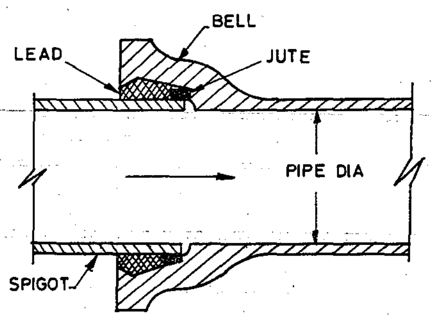

Fig. 23.3. Bell and spigot joint for cast iron pipes.

A few strands of jute are wrapped around the spigot before inserting it into the bell, and then, more jute is packed into the joint. The remaining space between the bell and the spigot is finally filled with molten lead, which gets solidified and tightly chalked into the joint after cooling, and thus making a water-tight joint. The quantity of lead required varies from 3.5 to 4 kg for 15 cm dia pipe to about 45 to 50 kg for 1.2 metres dia pipe.

(2) **Steel conduits.** Steel pipes can be used for large diameters, say upto or above 6 metres or so. Steel plates of varying thicknesses for withstanding different pressures, are generally bent and welded or sometimes riveted. Welded pipes are smoother and stronger than riveted pipes, and are, therefore, generally used these days. Since steel is strong in tension, even large size diameter pipes can be made of thin shells. They are, therefore, lighter than cast iron pipes.

Galvanised steel pipes with circumferential corrugations are much more stronger than ordinary steel pipes. They are, therefore, used where large dia pipes of smaller wall thicknesses are required. Such pipes are usually manufactured in various sizes varying from 20 cm to 2 metres in diameter, and are lighter and can be more easily transported at distances.

Expansion joints are generally not required in steel pipes which are buried under the ground, because they are not subjected to large temperature changes. However, pipes which are exposed to the atmosphere may require expansion joints so as to minimise temperature changes.

Steel pipes get rusted quickly, which, reduces their life as well as carrying capacities. They are, therefore, protected on the inside as well as outside by protective coatings. Under ordinary conditions, steel pipes may last as long as 40 years or so. The various pipe lengths in case of steel pipes are connected by welded or riveted joints.

(3) **Reinforced Cement Concrete Conduits.** Ordinary cement concrete pipes are manufactured in small sizes (*i.e.* up to say 0.6 m diameter) ; while they are reinforced with steel for large dia pipes. They are easily available in sizes up to diameters say about 1.8 metres and may be got manufactured for larger diameters say up to about 4.5 metres, on special orders. These pipes may either be prepared at site by transporting various ingradients (*i.e.* cement, steel aggregates, water, etc.) or can be manufactured in factories and then transported to site. They are known as '*cast in situ*' pipes in the former case, and '*precast pipes*' in the latter case. Cast in situ pipes are useful when the site conditions are difficult, and where it may be difficult to carry the pipes. But since such pipes are cast at site, lesser supervision and check is possible, as compared to the case of precast pipes which are cast in the factories, and thus subjected to greater quality control and supervision.

R.C.C. pipes can be manufactured in three different ways, *viz.*

(*a*) pipes having bar and mesh reinforcement, and concrete poured by usual ordinary methods of concrete pouring, and tamped ;

(*b*) pipes made by rotating the mould or the form rapidly about the pipe axis. The mould contains concrete and fabricated reinforcement. The centrifugal force throws off the concrete which then spreads in a uniform layer over the internal surface of the mould and embed the reinforcement ; thus providing a high density watertight concrete surface. This type is known as *centrifugal type* ;

(*c*) the third type of pipes are made by lining thin cylindrical steel shells both internally and externally with rich cement concrete. These are stronger and more watertight than the first two. They are known as *cylinder type.*

R.C.C. pipes are generally made from 1 : 2 : 4 cement concrete with maximum size of aggregates as 6 mm. They are provided with circumferential reinforcement to carry hoop tension and a nominal longitudinal reinforncement equal to 0.25% of cross-sectional area of concrete. The thickness of R.C.C. pipes generally varies from 7.5 cm to 0.6 m for pipes of diameters* varying from 0.2 m to 2.75 m.

(4) **Hume Steel Conduits.** Hume steel pipes are R.C.C. pipes patented under this name. They consist of thin steel shells coated from inside with cement mortar by centrifugal process. The thickness of the inside coating varies from 1.2 cm to 3 cm depending upon the size of the pipe. They are also coated from outside so as to protect the steel shell from external weather or soil action. The thickness of external coating is 2.5 cm for pipes upto 1 metre in diameter and is 3.75 cm for pipes of larger diameters.

* The standard mentioned diameter of pipes is always the internal diameter.

The thickness of steel shell depends upon the size of the pipe and also upon the pressure to be borne by the pipe. Like all R.C.C. pipes, they are heavy and difficult to handle.

(5) **Vitrified Clay Conduits.** They are generally not used as pressure conduits, but are extensively used for carrying sewage and drainage at partial depths. These pipes are free from corrosion and provide a smooth hydraulically efficient surface. They are not used as pressure pipes, because clay is weak in tension, and formation of water-tight joints becomes difficult in them. Clay pipes are commonly made in lengths of about 0.6 m to 1.2 m or so.

(6) **Asbestos Conduits.** Asbestos, silica and cement are converted under pressure to a dense, homogeneous material possessing high strength, called *asbestos cement.* This material is used for casting these pipes. The asbestos fibre which is thoroughly mixed with cement serves as reinforcement. These pipes are generally available in different sizes, say from 10 cm to 90 cm in diameters and in about 4 metres lengths. These pipes are generally made in 4 different grades to withstand pressures of 350 kN/m^2 to 140 kN/m^2. These pipes are joined by means of special type of flexible joint called '*simplex joint*'. The assembly consists of a pipe sleeve and two rubber rings which are compressed between the pipe and the interior of the sleeve.

Advantages. The advantages of asbestos cement pipes are :

(*i*) They are light and hence easy to transport.

(*ii*) They can be easily assembled without skilled labour.

(*iii*) They are highly resistant to corrosion.

(*iv*) They are highly flexible and may permit as much as 12° deflection in laying them around curves.

(*v*) Expansion joints are not required as the coefficient of expansion is low and the joints are also flexible.

(*vi*) They are very smooth and thus provide a hydraulically efficient pipe. Their carrying capacities do not reduce with time.

(*vii*) They are very suitable to be used as small size distribution pipes.

Disadvantages and limitations. Their disadvantages are :

(*i*) They are costly.

(*ii*) These pipes do not have much strength and are brittle and soft. They are liable to get damaged by excavating tools or during transportation transits.

(*iii*) The rubber joint seals may deteriorate if exposed to gasoline or other petroleum products, and hence cannot be used for transporting petroleum products.

(7) **Miscellaneous Types of Conduits.** Various other materials which may be used for manufacturing pipe conduits are : copper, wrought iron, plastics, etc. *Copper pipes* are very costly although they are highly resistant to acidic as well as alkaline waters, they can be bent easily and do not sag due to heat. They are, therefore, very useful for carrying hot water in the interior of the buildings. Wrought iron pipes are lighter than cast iron pipes and can be more easily cut, threaded and worked. They are more costly but neat in appearance. They are generally manufactured in small sizes and are very useful for indoor works. However, they corrode quickly and are less durable. they are,

therefore, generally protected by galvanising them with zinc coatings and they are then known as galvanised iron pipes.

Plastic pipes are lighter and free from corrosion. But they are of low strengths and less durable. Moreover, they can not withstand high temperatures exceeding 60°C or so. They may, however, be used for very minor works in house connections, etc. HDPE pipes are however, being increasingly used these days for various uses, such as in tubewell boarings, sewage mains, etc. etc. They are however, still not being made in large sizes suitable as penstock pipes.

PROBLEMS

1. (*a*) What is meant by a pressure conduit ? Discuss briefly the forces acting on a pressure conduit.

(*b*) Write a brief note on the design capacities of pressure pipes.

2. What are the different construction materials which are used for manufacturing pressure pipes ? Discuss their comparative merits and demerits.

3. Write a note on Pressure conduits'.