Environmental Engineering- I (BCE-26) Online Lecture

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Topic- Transmission of Water

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INTRODUCTION

- Water supply system broadly involves transmission of water from the sources to the area of consumption through free flow channels or conduits or pressure mains. Depending on topography and local conditions, conveyance may be in free flow and/or pressure conduits.
- Transmission of water accounts for an appreciable part of the capital outlay and hence careful consideration of the economics is called for, before deciding on the best mode of conveyance. While water is being conveyed, it's necessary to ensure that there is no possibility of pollution from surrounding areas.

FREE FLOW AND PRESSURE CONDUITS

OPEN CHANNELS

- Economical sections for open channels are generally trapezoidal while rectangular sections prove economical when rock cutting is involved.
- Uniform flow occurs where the dimensions of the cross-section, the slope and the nature of the surface are the same throughout the length of the channel and when the slope is just equal to that required to overcome the friction and other losses at the velocity at which the water is flowing.

- Open channels have restricted use in water works practice in view of the losses due to percolation and evaporation as also the possibility of pollution and misuse of water. Also, they need to be taken along the gradient and therefore the initial cost and maintain may be high.
- While open channels and canals are not recommended to be a conveyance of treated water, they may be adopted for conveying raw water.
- Sometimes diversion channels meant for carrying floodwaters from other catchments are also used to augment the yield from the reservoirs.

GRAVITY AQUEDUCTS AND TUNNELS

- Aqueducts and tunnels are designed such that they flow three quarter full at required capacity of supply in most circumstances. For structural and non-hydraulic reasons, gravity tunnels are generally horseshoe shaped.
- Gravity flow tunnels are built to shorten the route, conserve the head and to reduce the cost of aqueducts, traversing uneven terrain. They are usually lined to conserve head and reduce seepage but they may be left unlined when they are constructed by blasting stable rock
- Mean velocities, which will not erode channels after ageing, range from 0.30 to .60 mps for unlined canals and to 2 metres per second for lined canals .

PRESSURE AQUEDUCTS AND TUNNELS

- They are ordinarily circular in section. In the case of pressure tunnels, the weight overburden is relied upon to resist internal pressure.
- When there is not enough counter- balance to the internal pressure, steel cylinders or other reinforcing structure, for example, provide necessary tightness and strength

PIPELINES

- Pipelines normally follow the profile of the ground surface quite closely. Gravity pipeline have to be laid below the hydraulic gradient.
- Pipes are of cast iron, ductile iron, mild steel, prestressed concrete, reinforced cement concrete, GRP. asbestos cement, plastic etc.

HYDRAULICS OF CONDUITS

- The design of supply conduits in dependent on resistance to flow, available pressure or head, allowable velocities of flow, scour, sediment transport, quality of water and relative cost.

cost.

6.2.1 FORMULAE

There are a number of formulae available for use in calculating the velocity of flow ... However, Hazen-Williams formula for pressure conduits and Manning's formula for free flow conduits have been popularly used.

(a) Hazen-Williams Formula

The Hazen-Williams formula is expressed as:

$$V = 0.849\ C\ r^{0.63} S^{0.54} \qquad (6.1)$$

For circular conduits, the expression becomes

$$V = 4.567 \times 10^{-3}\ C\ d^{0.63}\ S^{0.54} \qquad (6.2)$$

and

$$Q = 1.292 \times 10^{-5}\ C\ d^{2.63} S^{0.54} \qquad (6.3)$$

Where,

Q = discharge in cubic metre per hour

d = diameter of pipe in mm

V = velocity in mps

r = hydraulic radius in m

S = slope of hydraulic gradeline and

C = Hazen-Williams coefficient.

A chart for the Hazen-Williams formula is given in Appendix 6.1

(b) Manning's Formula

The Manning's formula is:

$$V = \frac{1}{n} r^{2/3} S^{1/2} \qquad (6.4)$$

For circular conduits:

$$V = \frac{3.968 \times 10^{-3} \times d^{2/3} \times S^{1/2}}{n} \quad \text{and} \qquad (6.5)$$

$$Q = 8.661 \times 10^{-7} \times \frac{1}{n} d^{8/3} \times S^{1/2} \qquad (6.6)$$

Where,

Q = discharge in cubic metre per hour

S = slope of hydraulic gradient

d = diameter of pipe in mm,

r = hydraulic radius in metres,

V = velocity in mps, and

n = Manning's coefficient of roughness

A chart for Manning's formula is given in Appendix 6.2.

(c) Darcy-Weisbach's Formula

Darcy and Weisbach suggested the first dimensionless equation for pipe flow problems as,

$$S = \frac{H}{L} = \frac{f V^2}{2 g D} \qquad (6.7)$$

Where,

H = head loss due to friction over length L in metres

f = dimensionless friction factor, and

g = acceleration due to gravity in m/s^2

V = velocity in mps

L = length in metres

D = dia in metres

(d) Colebrook-White formula

The Colebrook - White formula for calculation of frictional coefficient is

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\left(\frac{k}{3.7d}\right) + \frac{2.51}{R_e\sqrt{f}}\right]$$

Where

f = Darcy's Friction Coefficient

R_e = Reynold's Number = Velocity x Diameter/Viscosity

d = Diameter of pipe ; k = Roughness projection

For more details of the Colebrook-White formula, reference may be made to any standard reference book on Fluid Mechanics. Recommended Design Values of roughness (k) for pipe materials are shown below.

S.No.	Pipe Material	Value of 'k' mm	
		New	Design
1.	Metallic Pipes - Cast iron and Ductile Iron	0.15	*
2.	Metallic Pipes - Mild Steel	0.06	*
3.	Asbestos Cement, Cement Concrete, Cement Mortar or epoxy lined Steel, C I and D I pipes	0.035	0.035
4.	PVC,GRP and other plastic Pipes	0.003	0.003

* *Reference may be made to IS : 2951 for roughness values of aged metallic pipes.*

COEFFICIENT OF ROUGHNESS

- In today's economy climate, it is essential that all water utilities ensure that their resources are invested judiciously and hence is an urgent need to avoid over designing of the pipelines.
- Despite technological advancements, improved methods of manufacturing of all types of pipes and advent of new pipes material, the current practice of adopting conservative Coefficient of Roughness Value(C values) is resulting in under utilization of the pipe material
- The coefficient of roughness depends on Reynolds number (hence on velocity and diameter) and relative roughness (d/k). For Reynolds number greater than 10^7 the friction factor ‘f’ (and hence the C value) is relatively independent of diameter and velocity.
- However, for normal ranges of Reynolds number of 4000 to 10^6 the friction factor ‘f’ (hence the C value) do depend on Diameter, Velocity and relative roughness
- PVC Glass Reinforced Plastic (GRP) and other plastic pipes are inherently smooth as compared to Asbestos Cement (ACC). Concrete and cement mortar/epoxylined metallic pipes.
- Depending on quality of workmanship during manufactured and the manufacturing process, the ACC, Concrete and cement mortar/eporylined metallic pipes tend to be as smooth as PVC, GRP and other plastic pipes.

- The metallic pipes lined with cement mortar or epoxy and Concrete pipes behave as smooth pipes and have shown C values ranging from 140 to 145 depending on diameter a velocity. Reference may be made to " Manual of Water Supply Practices", AWWA/M9 published by American Water Works Association (AWWA), second edition 1995.
- With a view to reduce corrosion, increase smoothness, and prolong the life of pipe materials, the metallic pipes are being provided with durable smooth internal linings AC Concrete and cement mortar/epoxylined metallic pipe, PVC, GRP and other plastic pipe may not show any significant reduction in their carrying capacity with age and therefore the design roughness coefficient values (C values) should not be substantially different from hose adopted for new pipes.
- However, pipes carrying raw water are susceptible to deposition of silt and development organic growth resulting in reduction of carrying capacity of such pipes.
- In case of buildup substantial growth/ buildup of deposits in such pipes, they can be removed by scraping and pigging the pipelines.
- Unlined metallic pipes under several field conditions such a carrying water having tendency for incrustation and corrosion, low flow velocity and stagnant water and alternate wet and dry conditions (resulting from intermittent operations), undergo substantial reduction their carrying capacity with age.
- Therefore, lower “C” values have been recommended for design of unlined metallic pipes. As such, use of unlined metallic pipe should be discouraged.

Table 6.1: HAZEN - WILLIAMS COEFFICIENTS

Pipe Material	Recommended C Values	
	New Pipes@	Design Purpose
Unlined Metallic Pipes		
Cast Iron, Ductile Iron	130	100
Mild Steel	140	100
Galvanized Iron above 50 mm dia. #	120	100
Galvanized Iron 50 mm dia and below used for house service connections. #	120	55
Centrifugally Lined Metallic Pipes		
Cast Iron, Ductile Iron and Mild Steel Pipes lined with cement mortar or Epoxy		
Up to 1200 mm dia	140	140
Above 1200 mm dia	145	145
Projection Method Cement Mortar Lined Metallic Pipes		
Cast Iron, Ductile Iron and Mild Steel Pipes	130*	110**
Non Metallic Pipes		
RCC Spun Concrete,		
Prestressed Concrete		
Up to 1200 mm dia	140	140
Above 1200 mm dia	145	145
Asbestos Cement	150	140
PVC, GRP and other Plastic pipes.	150	145

@ *The C values for new pipes included in the Table 6.1 are for determining the acceptability of surface finish of new pipelines. The user agency may specify that flow test may be conducted for determining the C values of laid pipelines.*

\# *The quality of galvanizing should be in accordance with the relevant standards to ensure resistance to corrosion through out its design life.*

* *For pipes of diameter 500 mm and above; the range of C values may be from 90 to 125 for pipes less than 500mm..*

** *In the absence of specific data, this value is recommended. However, in case authentic field data is available, higher values upto 130 may be adopted.*

The coefficient of roughness for use in Manning's formula for different materials as presented in Table 6.2 may be adopted generally for design purposes unless local experimental results or other considerations warrant the adoption of any other lower value for the coefficient. For general design purposes, however, the value for all sizes may be taken as 0.013 for plastic pipes and 0.015 for other pipes.

Table 6.2 : MANNING'S COEFFICIENT OF ROUGHNESS

Type of lining	Condition	n
Glazed coating of enamel Timber	In perfect order	0.010
	(a) Plane boards carefully laid	0.014
	(b) Plane Boards inferior workmanship or aged,	0.016
	(c) Non-plane boards carefully laid	0.016
	(d) Non-plane boards inferior workmanship or aged	0.018
Masonry	(a) Neat cement plaster	0.013
	(b) Sand and cement plaster	0.015
	(c) Concrete, Steel troweled	0.014
	(d) Concrete, wood troweled	0.015
	(e) Brick in good condition	0.015
	(f) Brick in rough condition	0.017
	(g) Masonry in bad condition	0.020
Stone work	(a) Smooth, dressed ashlar	0.015
	(b) Rubble set in cement	0.017
	(c) Fine, well packed gravel	0.020
Earth	(a) Regular surface in good condition	0.020
	(b) In ordinary condition	0.025
	(c) With stones and weeds	0.030

Type of lining	Condition	n
	(d) In poor condition	0.035
	(e) Partially obstructed with debris or weeds	0.050
Steel	(a) Welded	0.013
	(b) Riveted	0.017
	(c) Slightly tuberculated	0.020
	(d) Cement Mortar lined	0.011
Cast Iron & Ductile Iron	(a) Unlined	0.013
	(b) Cement mortar lined	0.011
Asbestos Cement		0.012
Plastic (smooth)		0.011

Note : *Values of n may be taken as 0.015 for unlined metallic pipes and 0.011 for plastic and other smooth pipes.*

The friction factor values in practice for commonly used pipe materials are given in Table 6.3.

TABLE6.3: RECOMMENDED FRICTION FACTORS IN DARCY-WEISBACH FORMULA

Sl. No	Pipe Material	Diameter(mm)		Friction Factor	
		From	To	New	For Design Period of 30 Years
1.	R.C.C.	100	2000	0.01 to 0.02	0.01 to 0.02
2.	A.C	100	600	0.01 to 0.02	0.01 to 0.02
3.	HDPE/PVC	20	100	0.01 to 0.02	0.01 to 0.02
4.	SGSW	100	600	0.01 to 0.02	0.01 to 0.02
5.	C.I. (for corrosive waters)	100	1000	0.01 to 0.02	0.053 to 0.03
6.	C.I (for non-corrosive waters)	100	1000	0.01 to 0.02	0.034 to 0.07
7.	Cement Mortar or Epoxy Lined metallic pipes (Cast Iron, Ductile Iron, Steel)	100	2000	0.01 to 0.02	0.01 to 0.02
8.	G.I.	15	100	0. 014 to 0.03	0.0315 to 0.06

(Reference may be made to I.S. 2951 for calculation of Head Loss due to friction according to Darcy-Weisbach formula).

6.2.3 HAZEN-WILLIAMS FORMULA

The commonly used Hazen-Williams formula has following inherent limitations:

(i) The numerical constant of Hazen-Williams formula (1.318 in FPS units or 0.85 in MKS units) has been calculated for an assumed hydraulic radius of 1 foot and friction slope of 1/1000. However, the formula is used for all ranges of diameter and friction slopes. This practice may result in an error of upto ± 30% in the evaluation of velocity and ± 55% in estimation of frictional resistance head loss.

(ii) The Darcy-Weisbach formula is dimensionally consistent. The Hazen-Williams coefficient C is usually considered independent of pipe diameter, velocity of flow and viscosity. However to be dimensionally consistent and to be representative of friction conditions, it must depend on relative roughness of pipe and Reynold's number. A comparison between estimates of Darcy-Weisbach friction factor f, and its equivalent value computed from Hazen-Williams C for different pipe materials brings out the error in estimation of 'f' upto ±45% in using Hazen Williams formula. It has been observed that for higher 'C' values (new and smooth pipes) and larger diameters, the error is less, whereas it is appreciable for lower 'C' values (old and rough pipes) and lower diameters at higher velocities.

(iii) The Hazen-Williams formula is dimensionally inconsistent, since the Hazen-Williams C has the dimension of $L^{0.37}\ T^{-1}$ and therefore is dependent on units employed.

6.2.3.1 Discussion On Various Formulae For Estimation Of Frictional Resistance

(i) With a view to avoid the limitations of the Hazen Williams formula, the present trend is to use the Colebrook-White equation for estimation of friction factors and then use the Darcy-Weisbach formula for estimation of head-loss due to friction in the pipelines. This practice will yield correct results compared to the Hazen Williams formula.

The estimation of Darcy's 'f' for variations in velocity and diameter involves repetitive and tedious calculations. Further, there is a need for assuming a correct k value in the Colebrook-White equation for calculation of friction coefficient 'f' in the Darcy-Weisbach formula. Conservative assumption of 'k' values will also result in under-utilization of carrying capacity of the pipes. However it is recommended that frictional losses should be estimated with Darcy-Weisbach formula by changing 'f' values for varying velocity and diameter combinations and assuming a correct k value in the Colebrook-White equation.

Recommended 'k' values for use in Colebrook-White formula are shown in 6.2.1 (d)

(ii) If there is a choice for use of pipe friction formulae, Darcy-Wiesbach yields accurate results but involves extra computational effort and therefore Hazen Williams (HW) formula is commonly used. The Modified Hazen Williams (MHW) formula being an improvement was suggested for use in lieu of HW formula. The MHW formula shown in Para 6.2.4 is derived from Darcy Weisbach (DW) and Colebrook- White equations. Since the friction coefficient depends on relative roughness of pipe and Reynolds number; C_R values also have to be varied for various diameter and velocity combinations to give correct estimation of the frictional resistance which also results in extra computational efforts. Average C_R values are given in Table 6.4 for use in the Modified Hazen Williams formula which will estimate frictional resistance within ±5% accuracy as per Table 6.4. Darcy-Weisbach formula coupled with Colebrook-White equation gives most accurate results followed by modified Hazen-Williams formula and Hazen-Williams formula.

(iii) It is significant to note that irrespective of the formula used for estimation of frictional resistance, it is necessary to adopt different roughness coefficient values for the various velocity-diameter combinations if the frictional resistance is to be accurately estimated involving changing the C values, k or 'f' or C_R values for the same pipe material. In design, various velocity-diameter combinations are required.

6.2.4 MODIFIED HAZEN-WILLIAMS FORMULA

The Modified Hazen Williams formula has been derived from Darcy-Weisbach and Colebrook-White equations and obviates the limitations of Hazen-Williams formula.

$$V = 3.83\ C_R d^{0.6575}\ (gs)^{0.5525} / \nu^{0.105} \quad (6.8)$$

Where,

C_R = coefficient of roughness

d = pipe diameter

g = acceleration due to gravity

s = friction slope

ν = viscosity of liquid

For circular conduits, $\nu_{20^\circ C}$ for water = 10^{-6} m^2/s and g = 9.81 m/s^2

The Modified Hazen Williams formula derived as

$$V = 143.534\ C_R\ r^{0.6575}\ S^{0.5525} \quad (6.9)$$

$$h = [L(Q/C_R)^{1.81}]/994.62 D^{4.81} \quad (6.10)$$

in which,

V = velocity of flow in m/s;

C_R = pipe roughness coefficient; (1 for smooth pipes; <1 for rough pipes);

r = hydraulic radius in m;

s = friction slope;

D = internal diameter of pipe in m;

h = friction head loss in m;

L = length of pipe in m; and

Q = flow in pipe in m^3/s.

A nomograph for estimation of head loss by Modified Hazen-Williams formula is presented in the Appendix. 6.3.

6.2.5 EFFECT OF TEMPERATURE ON COEFFICIENT OF ROUGHNESS

Analysis carried out to evaluate effect of temperature (viscosity) on value of C_R reveals that the maximum variation of C_R for a temperature range of 10°C to 30°C is 4.5% for a diameter of 2000 mm at a velocity of 3.0 m/s. In the light of this revelation, C_R values are presented for average temperature of 20°C.

REDUCTION IN CARRYING CAPACITY OF PIPES WITH AGE

- The values of Hazen Williams ‘C’ are at present arbitrarily reduced by about 20 to 30 percent in carrying capacity of pipe with age. Studies have revealed that chemical bacteriological quality of water and velocity of flow affect the carrying capacity with age.
- The data on existing systems in some cities have been analyzed along with the experimental information gathered during the study to bring out a rational approach to the reduction in capacity of pipes with age.
- The C_R values obtained in such studies have shown that, except in the case of CI and steel pipes while carrying corrosive water, the current practice of arbitrary reduction in 'C' values as per section 6.2.2 results in under utilization of pipe material to the extent of 38 to 71 percent for CI pipes for non-corrosive water,46 to 93 percent for RCC pipes and 25 to 64 percent for AC and HDPE pipes.

DESIGN RECOMMENDATIONS FOR USE OF MODIFIED HAZEN-WILLIAMS FORMULA

i. New CI, DI, Steel, RCC, AC and HDPE pipes behaves as hydraulically smooth and hence CR of 1 is recommended.

ii. For design period of 30 years, no redaction in CR needs to be effected for RCC, AC PVC and HDPE pipes irrespective of the quality of water. However, care must be taken to ensure self-cleansing velocity to prevent formation of slimes and consequent reduction in carrying capacity of these pipes with age.

iii. For design period of 30 years, 15 percent reduction is required for unlined CI and DI pipes of non corrosive water is to be transported. The design must also ensure self cleansing velocity.

iv. While carrying corrosive water, unlined CI, DI, and steel pipes will loose 47 and 27 percent of the capacity respectively over a design period of 30 years. Hence, a cost trade-off analysis must be carried out between chemical and bio-chemical correction of water quality, provision of a protective lining to the pipe interiors and design at reduced CR value for ascertaining the utility of CI,DI and steel pipe material in the transmission of corrosive waters.

TABLE 6.4

RECOMMENDED C_R VALUES IN MODIFIED HAZEN-WILLIAMS FORMULA (AT 20°C)

Sl. No.	Pipe Material	Diameter(mm) From	Diameter(mm) To	Velocity(m/s) From	Velocity(m/s) To	C_R Value When New	C_R Value For Design Period of 30 Years
1.	RCC	100	2000	0.3	1.8	1.00	1.00
2.	AC	100	600	0.3	2.0	1.00	1.00
3.	HDPE and PVC	20	100	0.3	1.8	1.00	1.00
4.	CI/DI (for water with positive Langelier's index)	100	1000	0.3	1.8	1.00	0.85*
5.	CI/DI (For waters with negative Langelier's index)	100	1000	0.3	1.8	1.00	0.53*
6.	Metallic pipes lined with cement mortar or epoxy (for water with negative Langelier's index)	100	2000	0.3	2.1	1.00	1.00
7.	SGSW	100	600	0.3	2.1	1.00	1.00
8.	GI (for waters with positive Langeliers Index)	15	100	0.3	1.5	0.87*	0.74

**These are average C_R values which result in a maximum error of ± 5% in estimation of surface resistance.*

6.2.10 GUIDELINES FOR COST EFFECTIVE DESIGN OF PIPELINES

The cost of transmission and distribution system constitutes a major portion of the project cost. It is desirable to adopt the following guidelines:

(i) The design velocity should not be less than 0.6 m/s in order to avoid depositions and consequent loss of carrying capacity.

(ii) In design of distribution systems, the design velocity should not be less than 0.6 m/s to avoid low velocity conditions which may encourage deposition and/or corrosion resulting in deterioration in quality. However, where inevitable due to minimum pipe diameter criteria or other hydraulic constraints, lower velocities may be adopted with adequate provision for scouring.

(iii) In all hydraulic calculations, the actual internal diameter of the pipe shall be adopted after accounting for the thickness of lining, if any, instead of the nominal diameter or outside diameters (OD)

(iv) In providing for head loss due to fittings, specials and other appurtenances, actual head loss calculations based on consideration included in subsection 6.2.9 should be done instead of making an arbitrary provision

6.3 PIPE MATERIALS

Pipelines are major investments in water supply projects and as such constitute a major part of the assets of water authorities. Pipes represent a large proportion of the capital invested in water supply undertakings and therefore are of particular importance. Therefore pipe materials shall have to be judiciously selected not only from the point of view of durability, life and over all cost which includes, besides the pipe cost, the installation and maintenance costs necessary to ensure the required function and performance of the pipeline throughout its designed life time.

6.3.1 CHOICE OF PIPE MATERIALS

The various types of pipes used are:

I. Metallic pipes : C.I., D.I., M.S., G.I.
   - (i) Unlined Metallic pipes
   - (ii) Metallic pipes lined with cement mortar or epoxy lining;

II. Non Metallic pipes
   - (i) Reinforced Concrete, Prestressed Concrete, Bar Wrapped Steel Cylinder Concrete, Asbestos Cement
   - (ii) Plastic Pipes : PVC, Polyethylence, Glass Reinforced Plastic, etc.

The determination of the suitability in all respects of the pipes and specials, for any work is a matter of decision by the Engineer concerned on the basis of requirements for the scheme.

Several technical factors affect the final choice of pipe material such as internal pressures, coefficient of roughness, hydraulic and operating conditions, maximum permissible diameter, internal and external corrosion problems, laying and jointing, type of soil, special conditions, etc.

Selection of pipe materials must be based on the following considerations:

(a) The initial carrying capacity of the pipe and its reduction with use, defined, for example, by the Hazen-Williams coefficient C.

Values of C vary for different conduit materials and their relative deterioration in service. They vary with size and shape to some extent.

(b) The strength of the pipe as measured by its ability to resist internal pressures and external loads.

(c) The life and durability of pipe as determined by the resistance of cast iron and steel pipe to corrosion; of concrete and A.C. pipe to erosion and disintegration and plastic pipe to cracking and disintegration.

(d) The ease or difficulty of transportation, handling and laying and jointing under different conditions of topography, geology and other prevailing local conditions.

(e) The safety, economy and availability of manufactured sizes of pipes and specials.

(f) The availability of skilled personnel in construction and commissioning of pipelines.

(g) The ease or difficulty of operations and maintenance.

The life and durability of the pipe depends on several factors including inherent strength of the pipe material, the manufacturing process along with quality control, handling, transportation, laying and jointing of the pipeline, surrounding soil conditions and quality of water. Normally, the design period of pipelines is considered as 30 years. Where the pipelines have been manufactured properly as per specifications, designed and installed with adequate quality control and strict supervision, some of them have lasted more than the designed life provided the quality of water is non-corrosive. However, pipeline failures for various pipe materials even before the expiry of the designed life have been reported probably due to lack of rigid quality control during manufacture and installation, improper design, presence of corrosive waters, corrosive soil environment, improper bedding and other relevant factors.

Lined metallic pipelines are expected to last beyond the normal design life of 30 years. However, the relative age of such pipes depends on the thickness and quality of lining available for corrosion. The cost of the pipe material and its durability or design life are the two major governing factors in the selection of the pipe material. The pipeline may have very long life but may also be relatively expensive in terms of capital and recurring costs and, therefore, it is very necessary to carryout a detailed economic analysis before selecting a pipe material.

The metallic pipes are being provided with internal lining either with cement mortar or epoxy so as to reduce corrosion, increase smoothness and prolong the life.

Underground metallic pipelines may require protection against external corrosion depending on the soil environment and corrosive ground water. Protection against external corrosion is provided with cement mortar guniting or hot applied coal-tar asphaltic enamel reinforced with fibreglass fabric yarn.

The determination of the suitability in all respects of the pipeline for any work is a matter of decision by the engineer concerned on the basis of the requirements for the scheme. A checklist in Table 6.7 for selection of pipe material has been provided to facilitate the decision makers in selecting the economical and reliable pipe material for the given conditions.

6.4 CAST IRON PIPES

6.4.1 GENERAL

Most of the old Cast Iron pipes were cast vertically but this type has been largely superceded by centrifugally spun cast iron type manufactured upto a diameter of 1050 mm(IS- 1536-1989). Though the vertically cast iron pipe is heavy in weight, low in tensile strength, and liable to defects of inner surface, it is widely used because of its good lasting qualities. There are many examples of cast iron mains in this country which continue to give satisfactory service even after a century of use.

Cast Iron pipes and fittings are being manufactured in this country for several years. Due to its strength and corrosion resistance, C.I. pipes can be used in corrosive soils and for waters of slightly aggressive character. They are well suited for pressure mains and laterals where tapings are made for house connections. It is preferable to have coating inside and outside of the pipe.

Vertically cast iron pipes shall conform to I.S. 1537-1976. The pipes are manufactured by vertical casting in sand moulds. The metal used for the manufacture of this pipe is not less than grade 15. The pipes shall be stripped with all precautions necessary to avoid wrapping or shrinking defects. The pipes shall be such that they could be cut, drilled or machined.

Cast Iron flanged pipes and fittings are usually cast in the larger diameters. Smaller sizes have loose flanges screwed on the ends of double spigot-spun pipe.

The method of Cast Iron pipe production used universally today is to form pipes by spinning or centrifugal action. Compared with vertical casting in sand moulds, the spun process results in faster production, longer pipes with vastly improved metal qualities, smoother inner surface and reduced thickness and consequent lightweight(IS. 1536 –1989).

Centrifugally cast iron pipes are available in diameters from 80mm to 1050mm and are covered with protective coatings. Pipes are supplied in 3.66m and 5.5m lengths and a variety of joints are available including socket and spigot and flanged joints.

The pipes have been classified as LA, A and B according to their thicknesses. Class LA pipes have been taken as the basis for evolving the series of pipes. Class A allows a 10% increase in thickness over class LA. Class B allows a 20% increase in thickness over class LA.

The pipes are spigot and socket type. When the pipes are to be used for conveying potable water, the inside coating shall not contain any constituent soluble in water or any ingredient which could impart any taste or odour whatsoever to the potable water, after sterilization and suitable washing of the main.

Experiments in centrifugal casting of iron pipes were started in 1914 by a French Engineer which ultimately resulted in commercial production of spun pipes. Spun pipes are about 3/4 of the weight of vertically cast pipes of the same class. The greater tensile strength of the spun iron is due to close grain allowing use of thinner wall than for that of a vertically Cast Iron pipe of equal length. It is possible by this process to increase the length of the pipe whilst a further advantage lies in the smoothness of the inner surface.

6.4.2 LAYING AND JOINTING

Before laying the pipes, the detailed map of the area showing the alignment, sluice valves, scour valves, air valves and fire hydrants along with the existing intercepting sewers, telephone and electric cables and gas pipes will have to be studied. Care should be taken to avoid damage to the existing sewer, telephone and electric cables and gas pipes. The pipeline may be laid on the side of the street where the population is dense. Pipes are laid underground with a minimum cover of 1 metre on the top of the pipe.

Laying of cast iron pipes for water supply purposes has been generally governed by the regulations laid down by the various municipalities and corporations. These regulations are intended to ensure proper laying of pipes giving due consideration to economy and safety of workers engaged in laying.

6.4.2.1 Excavation And Preparation Of Trench

Excavation may be done by hand or by machine. The trench shall be so dug that the pipe may be laid to the required gradient and at the required depth. When the pipeline is under a roadway a minimum cover of 1.0 m is recommended. The width of the trench at bottom shall provide not less than 200mm clearance on both sides of the pipe. Additional width shall be provided at positions of sockets and flanges for jointing. Depths of pits at such places shall also be sufficient to permit finishing of joints.

6.4.2.2 Handling Of Pipes

While unloading, pipes shall not be thrown down but may be carefully unloaded on inclined timber skids. Pipes shall not be dragged over other pipes and along concrete and similar pavements to avoid damage to pipes.

6.4.2.3 Detection Of Cracks In Pipes

The pipes and fittings shall be inspected for defects and be rung with a light hammer, preferably while suspended, to detect cracks. Smearing the outside with chalk dust helps in the location of cracks. If doubt persists further confirmation may be obtained by pouring a little kerosene on the inside of the pipe at the suspected spot. If a crack is present the kerosene seeps through and shows on the outer surface. Any pipe found unsuitable after inspection before laying shall be rejected.

6.4.2.4 Lowering Of Pipes And Fittings

All pipes, fittings, valves and hydrants shall be carefully lowered into the trench by means of derrick, ropes or other suitable tools and equipment to prevent damage to pipe materials and protective coatings and linings. Pipes over 300mm dia shall be handled and lowered into trenches with the help of chain pulley blocks.

6.4.2.5 Cleaning Of Pipes And Fittings

All lumps, blisters and excess coating material shall be removed from socket and spigot end of each pipe and outside of the spigot and inside of the socket shall be wire-brushed and wiped clean and dry and free from oil and grease before the pipe is laid.

After placing a length of pipe in the trench, the spigot end shall be centered in the socket and the pipe forced home and aligned to gradient. The pipe shall be secured in place with approved back fill material packed on both sides except at socket.

The socket end should face the upstream while laying the pipeline on level ground; when the pipeline runs uphill, the socket ends should face the up gradient. When the pipes run beneath the heavy loads, suitable size of casing pipes or culverts may be provided to protect the casing of pipe. High pressure mains need anchorage at dead ends and bends as appreciable thrust occurs which tend to cause draw and even "blow out" joints. Where thrust is appreciable concrete blocks should be installed at all points where movement may occur. Anchorages are necessary to resist the tendency of the pipes to pull apart at bends or other points of unbalanced pressure, or when they are laid on steep gradients and the resistance of their joints to longitudinal or shear stresses is either exceeded or inadequate. They are also used to restrain or direct the expansion and contraction of rigidly joined pipes under the influence of temperature changes. Anchor or thrust blocks shall be designed in accordance with I.S. 5330-1984.

6.4.3 JOINTS

Several types of joints such as rubber gasket joint known as Tyton joint, mechanical joint known as Screw Gland joint, and conventional joint known as Lead joint are used.

6.4.3.1 Categories Of Joints

Joints are classified into the following three categories depending upon their capacity for movement.

a) Rigid joints

Rigid joints are those which admit no movement at all and comprise of flanged, welded and turned and bored joints. Flanged joints require perfect alignment and close fittings are frequently used where a longitudinal thrust must be taken such as at the valves and meters. The gaskets used between flanges of pipes shall be of compressed fibre board or natural or synthetic rubber. Welded joints produce a continuous line of pipes with the advantage that interior and exterior coatings can be made properly and are not subsequently disrupted by the movement of joints.

(b) Semi Rigid joints

Semi rigid joint is represented by the spigot and socket with caulked lead joint. A semi rigid joint allows partial movement due to vibration etc. The socketed end of the pipe should be kept against the flow of water and the spigot end of the other pipe is inserted into the socket. A twisted spun yarn is filled into this gap and it is adjusted by the yarning tool and is then caulked well. A rope is then placed at the outer end of the socket and is made tight by applying wet clay, leaving two holes for the escape of the entrapped air inside. The rope is taken out and molten lead is poured into the annular space by means of a funnel. The clay is then removed and the lead is caulked with a caulking tool. Lead wool may be used in wet conditions. Lead covered yarn is of great use in repair work, since the leaded yarn caulked into place will keep back water under very low pressure while the joint is being made.

(c) Flexible joints

Flexible joints are used where rigidity is undesirable such as with filling of granular medium and when two sections cannot be welded. They comprise mainly mechanical and rubber ring joints or tyton joints which permit some degree of deflection at each joint and are therefore able to stand vibration and movement. In rubber jointing special type of rubber gaskets are used to connect cast iron pipe which are cast with a special type of spigot and socket in the groove, the spigot end being lubricated with grease and slipped into the socket by means of a jack used on the other end. The working conditions of absence of light, presence of water and relatively cool uniform temperature are all conducive to the preservation of rubber and consequently this type of joint is expected to last as long as the pipes. Hence, rubber jointing is to be preferred to lead jointing.

6.4.4 TESTING OF THE PIPELINE

6.4.4.1 General

After laying and jointing, the pipeline must be pressure tested to ensure that pipes and joints are sound enough to withstand the maximum pressure likely to be developed under working conditions.

6.4.4.2 Testing Of Pressure Pipes

The field test pressure to be imposed should be not less than the maximum of the following:

(a) 1 1/2 times the maximum sustained operating pressure.

(b) 1 1/2 times the maximum pipeline static pressure.

(c) Sum of the maximum sustained operating pressure and the maximum surge pressure.

(d) Sum of the maximum pipeline static pressure and the maximum surge pressure, subject to a maximum equal to the work test pressure for any pipe fittings incorporated.

The field test pressure should wherever possible be not less than 2/3 work test pressure appropriate to the class of pipe except in the case of spun iron pipes and should be applied and maintained for atleast four hours. If the visual inspection satisfies that there is no leakage, the test can be passed.

Where the field test pressure is less than 2/3 the work test pressure, the period of test should be increased to atleast 24 hours. The test pressure shall be gradually raised at the rate of 1 kg/cm²/min. If the pressure measurements are not made at the lowest point of the section, an allowance should be made for the difference in static head between the lowest point and the point of measurement to ensure that the maximum pressure is not exceeded at the lowest point. If a drop in pressure occurs, the quantity of water added in order to re-establish the test pressure should be carefully measured. This should not exceed 0.1 litre per mm of pipe diameter per KM of pipeline per day for each 30 metre head of pressure applied.

In case of gravity pipes, maximum working pressure shall be 2/3 work test pressure

The hydrostatic test pressure at works and at field after installation and the working pressure for different classes of pipes are given in Appendix. 6.4.

The allowable leakage during the maintenance stage of pipes carefully laid and well tested during construction, however should not exceed;

$$qL = \frac{ND\sqrt{P}}{115} \qquad (6.11)$$

Where,

qL = Allowable leakage in cm³/hour

N = No of joints in the length of pipe line

D = Diameter in mm

P = The average test pressure during the leakage test in kg/cm²

where any test of pipe laid indicates leakage greater than that specified as per the above formula, the defective pipe(s) or joint(s) shall be repaired/replaced until the leakage is within the specified allowance.

The above is applicable to spigot and socket Cast Iron pipes and A.C. pressure pipes, whereas, twice this figure may be taken for steel and prestressed concrete pipes

6.4.4.3 Testing Of Non-Pressure Conduits

In case of testing of non-pressure conduits, the pipeline shall be subject to a test for of 2.5 meters head of water at the highest point of the section under test for 10 minutes. The leakage or quantity of water to be supplied to maintain the test pressure during the period of 10 minutes shall not exceed 0.2 litres/mm dia of pipes per kilometer length per day.

6.5 STEEL PIPES

6.5.1 GENERAL

Steel pipes of smaller diameter can be made from solid bar sections by hot or col drawing processes and these tubes are referred to as seamless. But the larger sizes are made by welding together the edges of suitably curved plates, the sockets being formed later in a press(IS:3589). The thickness of steel used is often controlled by the need to make the pip stiff enough to keep its circular shape during storage, transportation and laying as also to prevent excessive deflection under the load of trench back filling. The thickness of a steel pipe is however always considerably less than the thickness of the corresponding vertica cast or spun iron pipe. Owing to the higher tensile strength of the steel, it is possible to mak steel pipe of lower wall thickness and lower weight. Specials of all kinds can be fabricat without difficulty to suit the different site conditions. Due to their elasticity, steel pipes ado themselves to changes in relative ground level without failure and hence are very suitable for laying in ground liable to subsidence. If the pipes are joined by a form of flexible joint, i provides an additional safeguard against failure. Steel pipes being flexible are best suited f high dynamic loading.

6.5.2 PROTECTION AGAINST CORROSION

It must be borne in mind, however, that steel mains need protection from corrosi internally and externally. Against internal corrosion, steel pipes are given epoxy lining or h applied coal tar/asphalt lining or rich cement mortar lining at works or in the field by centrifugal process. The outer coating for under ground pipeline may be in cement-s guniting or hot applied coal-tar asphaltic enamel reinforced with fibreglass fabric yarn.

6.5.3 LAYING AND JOINTING

Small size mild steel pipes have got threaded ends with one socket. They are lowe down in the trenches and laid to alignment and gradient. The jointing materials for this ty of pipes are white lead and spun yarn. The white lead is applied on the threaded end w spun yarn and inserted into socket of another pipe. The pipe is then turned to tighten When these pipes are used in the construction of tube wells, the socketed ends af positioning without any jointing material are welded and lowered down. Lining and ou coating is done by different methods to protect steel pipes. While laying, the pipes alrea stocked along the trenches are lowered down into the trenches with the help of chain pull block. The formation of bed should be uniform. The pipes are laid true to the alignment a gradient before jointing. The ends of these pipes are butted against each other, welded and

coat of rich cement mortar is applied after welding. Steel pipes may be joined with flexible joints or by welding but lead or other filler joints, hot or cold, are not recommended. The welded joint is to be preferred. In areas prone to subsidence this joint is satisfactory but flexible joints must be provided to isolate valves and branches.

When welding is adopted, plain-ended pipes may be jointed by butt welds or sleeved pipes by means of fillet welds. For laying long straight lengths of pipelines, butt joint technique may be employed. The steel pipes used for water supply include hydraulic lap welded, electric fusion welded, submerged arc welded and spiral welded pipes. The latter are being made from steel strip. For laying of welded steel pipe I.S. 5822-1986 may be referred to.

For more details on different types of steel pipes used, reference may be made to the ISI codes indicated in Appendix 'C'.

For hydraulic testing of steel pipelines, the procedure described for cast iron spun pipes and ductile iron pipes may be followed.

6.6 DUCTILE IRON PIPES

6.6.1 GENERAL

Ductile Iron is made by a metallurgical process which involves the addition of magnesium into molten iron of low sulfur content. The magnesium causes the graphite in the iron to precipitate in the form of microscopic (6.25 micron) spheres rather than the flakes found in ordinary cast iron. The spheroidal graphite in iron improves the properties of ductile iron. It possesses properties of high mechanical strength, excellent impact resistance and good casting qualities of grey cast iron. Ductile iron pipes are normally prepared using the centrifugal cast process. The ductile iron pipes are usually provided with cement mortar lining at the factory by centrifugal process to ensure a uniform thickness through out its length. Cement mortar lining is superior to bituminous lining as the former provides a smooth surface and prevents tuberculation by creating a high pH at the pipe wall and ultimately by providing a physical and chemical barrier to the water.

The Indian standard IS 8329-1994 provides specifications for the centrifugally cast ductile iron pipes(Similar to ISO:2531-1998 and EN:545-1994). These pipes are available in the range of 80 mm to 1000 mm diameter; in lengths of 5.5 to 6 m. These pipes are being manufactured in the country with ISO 9002 accreditation.

Ductile iron pipes have excellent properties of machinability, impact resistance, high wear and tear resistance, high tensile strength, ductility and corrosion resistance. DI pipes having same composition of CI pipe, it will have same expected life as that of CI pipes. The ductile iron pipes are strong, both inner and outer surfaces are smooth, free from lumps, cracks blisters and scars. Ductile Iron pipes stand up to hydraulic pressure tests as required by service regulations. These pipes are approximately 30% lighter than conventional cast iron pipes.

Ductile iron pipes are lined with cement mortar in the factory by centrifugal process and unlined ductile iron pipes are also available. For more details reference may be made to IS 8329 - 1994 for Ductile Iron Pipes.

6.6.2 Ductile Iron Fittings

The ductile iron fittings are manufactured conforming to IS 9523-1980 for Ductile Iron fittings.

6.6.3 Joints

The joints for ductile iron pipes are suitable for use of rubber gaskets conforming to IS 5383.

6.6.4 Laying And Jointing

Reference may be made to para 6.4.2 (laying and jointing of cast iron pipes).

6.6.5 Testing Of Ductile Iron Pipelines

The Ductile Iron pipelines are tested as per para 6.4.4 (testing of the pipeline) The test pressures shall be as per IS 8329 - 1994.

6.7 ASBESTOS CEMENT PIPES

6.7.1 General

Asbestos cement pipes are made of a mixture of asbestos paste and cement compressed by steel rollers to form a laminated material of great strength and density. Its carrying capacity remains substantially constant as when first laid, irrespective of the quality of water. It can be drilled and tapped for connecting but does not have the same strength or suitability for threading as iron and any leakage at the thread will become worse as time passes. However, this difficulty can be over come by screwing the ferrules through malleable iron saddles fixed at the point of service connections as is the general practice. These pipes are not suitable for use in sulphate soils. Due to expansion and contraction of black cotton soil, usage of these pipes may be avoided as far as possible in Black Cotton soils, except where the depth of B.C. soil is clearly less than 0.9 metre below ground level.

The available safety against bursting under pressure and against failure in longitudinal bending, though less than that for spun iron pipes, is nevertheless adequate and increases as the pipe ages. In most cases, good bedding of the pipes and the use of flexible joints are of greater importance in preventing failure by bending, than the strength of pipe itself. Flexible joints are used at regular intervals to provide for repairing of pipes, if necessary.

AC pipes are manufactured from classes 5 to 25 and nominal diameters of 80mm to 600mm with the test pressure of 5 to 25 Kg/cm^2.

AC pipe can meet the general requirements of water supply undertakings for rising main as well as distribution main. It is classified as class 5, 10, 15, 20 and 25, which have test pressures 5, 10, 15, 20 and 25 Kg/cm^2 respectively. Working pressures shall not be greater

than 50% of test pressure for pumping mains and 67% for gravity mains.

For further details, refer to IS 1592-1989.

6.7.2 Handling

Utmost care must be taken while loading, transportation, unloading, stacking and retransporting to the site to avoid damage to the pipes.

6.7.2.1 Laying And Jointing

The width of the trench should be uniform throughout the length and greater than the outside diameter of the pipe by 300mm on either side of the pipe. The depth of the trench is usually kept 1 meter above the top of the pipe. For heavy traffic, a cover of atleast 1.25 meter is provided on the top of the pipe.

The AC pipes to be laid are stacked along the trenches on the side or opposite to the spoils. Each pipe should be examined for any defects such as cracks, chipped ends, crusting of the sides etc. The defective pipes should be removed forthwith from the site as otherwise they are likely to be mixed up with the good pipes. Before use the inside of the pipes will have to be cleaned. The lighter pipes weighing less than 80Kg can be lowered in the trench by hand. If the sides of the trench slope too much, ropes must be used. The pipes of medium weight upto 200Kg are lowered by means of ropes looped around both the ends. One end of the rope is fastened to a wooden or steel stack driven into the ground and the other end of the rope is held by men and is slowly released to lower the pipe into the trench. After their being lowered into the trench they are aligned for jointing. The bed of the trench should be uniform.

6.7.3 Pipe Joints

There are two types of joints for AC pipes.

- Cast iron detachable joint, (CID)and
- AC coupling joint.

(a) Cast Iron Detachable Joints

This consists of two cast iron flanges, a cast iron central collar and two rubber rings along with a set of nuts and bolts for the particular joint. For this joint, the AC pipes should have flush ends. For jointing a flange, a rubber ring and a collar are slipped to the first pipe in that order; a flange and a rubber ring being introduced from the jointing of the next pipe. Both the pipes are now aligned and the collar centralized and the joints of the flanges tightened with nuts and bolts.

(b) A.C. Coupling Joint

This consists of an A.C. Coupling and three special rubber rings. The pipes for these joints have chamfered ends. These rubber rings are positioned in the grooves inside the coupling, then grease is applied on the chamfered end and the pipe and coupling is pushed the coupling end and then pushed so as to bring the two chamfered ends close to each other. Wherever necessary, change over from cast iron pipe to AC pipes or vice-versa should be done with the help of suitable adapters. I.S. 6530 - 1972 may be followed for laying A.C. pipes.

with the help of a jack against the pipe. The mouth of the pipe is then placed in the mouth of

6.7.4 Pressure Testing

The procedure for the test as adopted is as follows:

(a) At a time one section of the pipeline between two sluice valves is taken up for testing. The section usually taken is about 500 meters long.

(b) One of the valves is closed and the water is admitted into the pipe through the other, manipulating air valves suitably.

(If there are no sluice valves in between the section, the end of the section can be sealed temporarily with an end cap having an outlet which can serve as an air relief vent or for filling the fine as may be required. The pipeline after it is filled, should be allowed to stand for 24 hours before pressure testing).

(c) After filling, the sluice valve is closed and the pipe section is isolated.

(d) Pressure gauges are fitted at suitable intervals on the crown into the holes meant for the purpose.

(e) The pipe section is then connected to the delivery side of a pump through a small valve.

(f) The pump is then operated till the pressure inside reaches the designed value which can be read from the pressure gauges fixed.

(g) After the required pressure has been attained, the valve is closed and the pump disconnected.

(h) The pipe is then kept under the desired pressure during inspection for any defect, i.e. leakages at the joints etc. The test pressures will be generally as specified in 6.7.1 and Appendix 6.4. The water will then be emptied through scour valves and defects observed in the test will be rectified.

6.8 CONCRETE PIPES

6.8.1 General

Reinforced concrete pipes used in water supplies are classified as P1, P2 and P3 with test pressures of 2.0, 4.0, and 6.0 Kg/cm^2 respectively. For use as gravity mains, the working pressure should not exceed 2/3 of the test pressure. For use as pumping mains, the working pressure should not exceed half of the test pressure.

Generally concrete pipes have corrosion resistant properties similar to those of prestressed concrete pipes although they have their own features which significantly affect corrosion performance. Concrete pipes are made by centrifugal spinning of vibratory process. Centrifugally spun pipes are subjected to high rotational forces during manufacture with improved corrosion resistance properties. The line of development most likely to bring concrete pressure pipes into more general acceptance is the use of P.S.C. pipes which are widely used to replace reinforced concrete pipes.

6.8.2 Laying and Jointing

The concrete pipes should be carefully loaded, transported and unloaded avoiding impact. The use of inclined planes or chain pulley block is recommended. Free working space on either side of the pipe shall be provided in the trench which shall not be greater than 1/3 the dia of the pipe but not less than 15 cm on either side.

Laying of pipes shall proceed upgrade of a slope. If the pipes have spigot and socket joints the socket ends shall face upstream, The pipes shall be joined in such a way to provide as little unevenness as possible along the inside of the pipe. Where the natural foundation is inadequate, the pipes shall be laid in a concrete cradle supported on proper foundation or any other suitably designed structure. If a concrete cradle is used, the depth of concrete below the bottom of the pipes shall be at least 1/4 the internal diameter of pipe with the range of 10-30cm. It shall extend upto the sides of the pipe atleast to a distance of 1/4 the dia for larger than 300mm.

The pipe shall be laid in the concrete bedding before the concrete has set.

Trenches shall be back filled immediately after the pipe has been laid to a depth of 300mm above the pipe subject to the condition that the jointing material has hardened (say 12 hours at the most). The backfill material shall be free from boulders, roots of trees etc. The tamping shall be by hand or by other hand operated mechanical means. The water content of the soil shall be as near the optimum moisture content as possible. Filling of trench shall be carried on simultaneously on both sides of the pipe to avoid development of unequal pressures. The back fill shall be rammed in 150mm layers upto 900mm above the top of the pipe.

Joints may be of any of the following types

(i) Bandage joint

(ii) Spigot and socket joint (rigid and semi-flexible)

(iii) Collar joint (rigid and semi-flexible)

(iv) Flush joint. (internal and external)

For more details of jointing procedure, reference may be made to I.S. 783-1985.

In all pressure pipelines, the recesses at the ends of the pipe shall be filled with jute braiding dipped in hot bitumen. The quantity of jute and bitumen in the ring shall be just sufficient to fill the recess in the pipe when pressed hard by jacking or any other suitable method.

The number of pipes that shall be jacked together at a time depends upon the dia of the pipe and the bearing capacity of soil. For small pipe upto 250mm dia, six pipes can be jacked together at a time. Before and during jacking, care should be taken to see that there is no offset at the joint. Loose collar shall be set up over the joint so as to have an even caulking space all round and into this caulking space shall be rammed a 1 : 1.5 mixture of cement and sand just sufficiently moistened to hold together in the form of a clod when compressed in the hand. The caulking shall be so firm that it shall be difficult to drive the point of a penknife into it. The caulking shall be employed at both the ends in a slope of 1:1. In the case of non-pressure pipes the recess at the end of the pipes shall be filled with cement mortar 1: 2 instead of jute braiding soaked in bitumen. It shall be kept wet for 10 days for maturing.

6.8.3 Pressure Test

When testing the pipeline hydraulically, the line shall be kept filled completely with water for a week. The pressure shall then be increased gradually to full test pressure as indicated in 6.4.4.2. and maintained at this pressure during the period of test with the permissible allowance indicated therein. For further details, reference may be made to I.S. 458-1971.

6.9 PRESTRESSED CONCRETE PIPES

6.9.1 General

While RCC pipes can cater to the needs where pressures are upto 6.0 kg/cm^2 and CI and steel pipes cater to the needs of higher pressures around 24 kg/cm^2, the Prestressed Concrete (PSC) pipes cater to intermediate pressure range, while RCC pipes would not be suitable.

The strength of a PSC pipe is achieved by helically binding high tensile steel wire under tension around a concrete core thereby putting the core into compression. When the pipe is pressurized the stresses induced relieve the compressive stress but they are not sufficient to subject the core to tensile stresses. The prestressing wire is protected against corrosion by a surround of cementatious cover coat giving atleast 25mm thick cover.

The PSC pipes are suited for water supply mains where pressures in the range of 6 kg/cm^2 to 20 kg/cm^2 are encountered.

Two types of P.S.C. pipes are in use today:

(i) Cylinder type: Consists of a concrete lined steel cylinder with steel joint rings welded to its ends wrapped with a helix of highly stressed wire and coated with dense cement mortar or concrete.

Recommended specifications for above pipe are covered by Indian and foreign codes IS: 784- 1978 AWWA C-301 EN-639 and EN-642.

(a) Steel Cylinder Prestressed Concrete Pipes are used in America and Europe Confirming to AWWA C-301 and in Europe EN - 642.

Prestressed Concrete Cylinder pipe has the following two general types of construction : (1) a steel cylinder lined with a concrete core or (2) a steel cylinder embedded in a concrete core. In either type of construction, manufacturing begins with a full length welded steel cylinder. Joint rings are attached to each end and the pipe is hydrostatically tested to ensure water-tightness. A concrete core with a minimum thickness of one-sixteenth times the pipe diameter is placed either by the centrifugal process, radial compaction, or by vertical casting. After the core is cured, the pipe is helically wrapped with high strength, hard drawn wire using a stress of 75 percent of the minimum specified tensile strength. The wrapping stress ranges between 150,000 and 189,000 psi (1034 and 1303 Mpa)depending on the wire size and class. The wire spacing is accurately controlled to produce a predetermined residual compression in the concrete core. The wire is embedded in a thick cement slurry and coated with a dense mortar that is rich in cement content.

Size Range : AWWA C-301 covers prestressed concrete cylinder pipe 16 in. (410 mm) in inside diameter and larger. Lined cylinder pipe is commonly available in inside diameters ranging from 16 to 48 in. (410 to 1,220 mm). Sizes upto 60 in. are available from some manufacturers. Embedded cylinder pipe has been manufactured larger than 250 in. (6,350 mm) in diameter and is commonly available in inside diameters of 48 in. (1,220 mm) and larger. Lengths are generally 16 - 24 ft (4.9-7.3 m), although longer units can be furnished.

The technology for manufacture of these pipes is now available with some of the Indian manufacturers.

(ii) **Non cylinder type** : Consists of a concrete core which is pre-compressed both in longitudinal and circumferential directions by a highly stressed wire. The wire wrapping is protected by a coat of cement mortar or concrete.

Physical behaviour of PSC pipes under internal and external load is superior to RCC pipes. The PSC pipe wall is always in a state of compression which is the most favourable factor for impermeability. These pipes can resist high external loads. The protective cover of cement and mortar which covers the tensioned wire wrapping by its ability to create and maintain alkaline environment around the steel inhibits corrosion. PSC pipes are jointed with flexible rubber rings.

The deflection possible during laying of main is relatively small and the pipes cannot be cut to size to close gaps in the pipeline. Special closure units (consisting of a short double spigot piece and a plain ended concrete lined steel tube with a follower-ring assembled at each end) are manufactured for this purpose. The closure unit (minimum length 1.27m) must be ordered specially to the exact length.

Specials such as bends, bevel pipes, flanged tees, tapers and adapters to flange the couplings are generally fabricated as mild steel fittings lined and coated with concrete.

It is worth while when designing the pipeline to make provision for as many branches as are likely to be required in the future and then to install sluice valves or blank flanges on these branches. It is possible to make connections to the installed pipeline by emptying, breaking out and using a special closure unit but this is a costly item.

6.9.2 Laying And Jointing

PSC pressure pipes are provided with flexible joints, the joints being made by the use of rubber gasket. They have socket spigot ends to suit the rubber ring joint. The rubber gasket is intended to keep the joint water tight under all normal conditions of service including expansion, contraction and normal earth settlement. The quality of rubber used for the gasket should be waterproof, flexible and should have a low permanent set. Refer to IS 784 -1978, for laying of PSC pipes.

6.9.3 Pressure Testing

Testing of PSC pipe is the same as given in the para 6.4.4.2.

However the quantity of water added in order to re-establish the test pressure should not exceed 3 litres (instead of 0.1 litres) per mm dia, per km per 24 hours per 30m head for non-absorbent pipes as per the IS 783 (para 15.5.3 pages 28 & 29).

6.9.4 Bar Wrapped Steel Cylinder Concrete Pressure Pipes

6.9.4.1 General

Bar Wrapped Steel Cylinder Concrete Pressure Pipes (confirming to AWWA C 303 and EN639 & EN 641) are reported to be manufactured in India. No Indian Standard is presently available for these pipes. Bar Wrapped Steel Cylinder Concrete Pressure Pipes are available in diameters of 250 mm to 1500 mm and higher diameter pipes can be designed for working pressures upto 25 kgs per sq. cm.. Standard lengths are generally 5 to 6m. Longer length pipes can also be custom made.

6.9.4.2 Manufacture

Manufacture of Bar Wrapped Steel Cylinder Concrete Pressure Pipes begins with fabrication of a thin steel pipe cylinder. Thicker steel joint rings are welded at both ends. Each pipe is hydrostatically tested. A cement mortar lining is placed by centrifugal process inside the cylinder. The lining varies from 12mm to 25 mm. After the lining is cured by steam or water, mild steel rod is wrapped on the cylinder using moderate tension in the bar. The wrapping is to be done under controlled tension ensuring intimate contact with the cylinder. The cylinder and bar wrapping are covered with a cement slurry and a dense mortar coating that is rich in cement. The coating is cured by steam or water.

6.9.4.3 Joints

The standard joint consists of steel joint rings and a continuous solid rubber ring gasket. The field joint can be over lapping/sliding, butt welded or with confined rubber ring as per the clients requirement. In the case of welded & rubber joints, the exterior joint recess is

normally grouted and the internal joint space may or may not be pointed with mortar. The AWWA C-303 provides for use of elastomeric sealing ring (rubber joint), and EN 641 provides both elastomeric sealing ring and steel end rings welded together on site. At present the pipes available in India use steel end rings welded at site.

6.10 PLASTIC PIPES

6.10.1 General

Plastic pipes are produced by extrusion process followed by calibration to ensure maintenance of accurate internal diameter with smooth internal bores. These pipes generally come in lengths of 6 meters. A wide range of injection moulded fittings, including tees, elbows, reducers, caps, pipe saddles, inserts and threaded adapters for pipe sizes upto 200mm are available.

6.10.2 PVC Pipes

The chief advantages of PVC pipes are

- Resistance to corrosion
- Light weight
- Toughness
- Rigidity
- Economical in laying, jointing and maintenance
- Ease of fabrication

The PVC pipes are much lighter than conventional pipe materials. Because of their lightweight, PVC pipes are easy to handle, transport, and install. Solvent cementing technique for jointing PVC pipe lengths is cheaper, more efficient and far simpler. PVC pipes do not become pitted or tuberculated and are unaffected by fungi and bacteria and are resistant to a wide range of chemicals. They are immune to galvanic and electrolytic attack, a problem frequently encountered in metal pipes, especially when burried in corrosive soils or near brackish waters. PVC pipes have elastic properties and their resistance to deformation resulting from earth movements is superior compared to conventional pipe materials specially AC. Thermal conductivity of PVC is very low compared to metals. Consequently water transported in these pipes remain at a more uniform temperature.

Rigid PVC pipes weigh only $1/5^{th}$ of conventional steel pipes of comparable sizes. PVC pipes are available in sizes of outer dia, 20, 25, 32, 50, 63, 75, 90, 110, 140, 160, 250, 290, and 315mm at working pressures of 2,5,4,6, 10 Kg/cm^2 as per IS 4985 - 1988.

Since deterioration and decomposition of plastics are accelerated by ultraviolet light and frequent changes in temperature which are particularly severe in India, it is not advisable to use PVC pipes above ground. The deterioration starts with discolouration, surface cracking and ultimately ends with brittleness, and the life of the pipe may be reduced to 15-20 years.

6.10.3 PRECAUTIONS IN HANDLING AND STORAGE

Because of their lightweight, there may be a tendency for the PVC pipes to be thrown much more than their metal counterparts. This should be discouraged and reasonable care should be taken in handling and storage to prevent damage to the pipes. On no account should pipes be dragged along the ground. Pipes should be given adequate support at all times. These pipes should not be stacked in large piles, specially under warm temperature conditions, as the bottom pipes may be distorted thus giving rise to difficulty in pipe alignment and jointing. For temporary storage in the field, where racks are not provided, care should be taken that the ground is level, and free from loose stones. Pipes stored thus should not exceed three layers and should be so stacked as to prevent movement. It is also recommended not to store one pipe inside another. It is advisable to follow the practices mentioned as per IS 7634 – Part I.

6.10.4 LAYING AND JOINTING PROCEDURE

6.10.4.1 Trench Preparation

The trench bed must be free from any rock projections. The trench bottom where it is rocky and uneven a layer of sand or alluvial earth equal to 1/3 dia of pipe or 100mm whichever is less should be provided under the pipes.

The trench bottom should be carefully examined for the presence of hard objects such as flints, rock, projections or tree roots. In uniform, relatively soft fine grained soils found to be free of such objects and where the trench bottom can readily be brought to an even finish providing a uniform support for the pipes over their lengths, the pipes may normally be laid directly on the trench bottom. In other cases, the trench should be cut correspondingly deeper and the pipes laid on a prepared under-bedding, which may be drawn from the excavated material if suitable.

6.10.4.2 Laying And Jointing

As a rule, trenching should not be carried out too far ahead of pipe laying. The trench should be as narrow as practicable. This may be kept from 0.30m over the outside diameter of pipe and depth may be kept at 0.60 -1.0m depending upon traffic conditions. Pipe lengths are placed end to end along the trench. The glued spigot and socket jointing technique as mentioned later is adopted. The jointed lengths are then lowered in the trench and when sufficient length has been laid, the trench is filled.

If trucks, lorries, or other heavy traffic will pass across the pipeline, concrete tiles 600 x 600mm of suitable thickness and reinforcement should be laid about 2m above the pipe to distribute the load. If the pipeline crosses a river, the pipe should be buried at least 2m below bed level to protect the pipe.

For bending, the cleaned pipe is filled with sand and compacted by tapping with wooden stick and pipe ends plugged. The pipe section is heated with flame and the portion bent as required. The bend is then cooled with water, the plug removed, the sand poured out and the pipe (bend) cooled again. Heating in hot air over hot oil bath, hot gas or other heating devices are also practiced. Joints may be heat welded, or flamed or with rubber gaskets or made with solvent cement. Threaded joints are also feasible but are not recommended. Jointing of PVC pipes can be made in following ways:

i) Solvent cement

ii) Rubber ring joint

iii) Flanged joint

iv) Threaded joint

For further details on laying & jointing of PVC pipes, reference can be made to IS 4985 – 1988, IS 7634 – Part 1-3.

Socket and spigot joint is usually preferred for all PVC pipes upto 150mm in dia. The socket length should at least be one and half times the outer dia for sizes upto 100mm dia and equal to the outer dia for larger sizes.

For pipe installation, solvent gluing is preferable to welding. The glued spigot socket connection has greater strength than can ever be achieved by welding. The surfaces to be glued are thoroughly scoured with dry cloth and preferably chamfered to 30^0. If the pipes have become heavily contaminated by grease or oil, methylene cement is applied with a brush evenly to the outside surface of the spigot on one pipe and to the inside of the socket on the other. The spigot is then inserted immediately in the socket upto the shoulder and thereafter a quarter (90^0) turn is given to evenly distribute the cement over the treated surface. The excess cement which is pushed out of the socket must be removed at once with a clean cloth. Jointing must be carried out in minimum possible time, time of making complete joint not being more than one minute. Joints should not be disturbed for at least 5 minutes. Half strength is attained in 30 minutes and full in 24 hours. Gluing should be avoided in rainy or foggy weather, as the colour of glue will turn cloudy and milky as a result of water contamination.

6.10.4.3 Pre-Fabricated Connections

In laying, long lengths of pipe, prefabricated double socketed connections are frequently used to join successive pipe lengths of either the same or one size different. The socket in this case must be formed over a steel mandrel. A short length of pipe is flared at both ends and used as the socket connection. The mandrel used is sized such that the internal dia of the flared socket matches the outer dia of the spigot to be connected. By proper sizing of the two ends of a connector, it is possible to achieve reduction (or expansion) of pipe size across the connector.

6.10.4.4 Standard Threaded Connections

Normally PVC pipes should not be threaded. For the connections of PVC pipes to metal pipes, a piece of a special thick wall PVC connecting tube threaded at one end is used. The other end is connected to the normal PVC pipe by means of a glued spigot and socket joint. Before installation, the condition of the threads should be carefully examined for cracks and impurities.

Glue can be used for making joints leak proof. Yarn and other materials generally used with metal pipe and fittings should not be used. Generally, it is advisable to use PVC as the spigot portion of the joint.

6.10.5 Pressure Testing

The method which is commonly in use is filling the pipe with water, taking care to evacuate any entrapped air and slowly raising the system to appropriate test pressure. The pressure testing may be followed as in 6.4.4.2.

After the specified test time has elapsed, usually one hour, a measured quantity of water is pumped into the line to bring it to the original test pressure, if there has been loss of pressure during the test. The pipe shall be judged to have passed the test satisfactorily if the quantity of water required to restore the test pressure of 30m for 24 hours does not exceed 1.5 litres per 10 mm of nominal bore for a length of 1 Km.

6.11 POLYETHYLENE PIPES

Rigid PVC and high-density polyethylene pipes have been used for water distribution systems mostly ranging from 15 -150mm dia and occasionally upto 350mm.

Among the recent developments is the use of High-Density Polyethylene pipes. These pipes are not brittle and as such a hard fall at the time of loading and unloading etc. may not do any harm to it. HDPE pipes as per IS 4984 - 1987 can be joined with detachable joints and can be detached at the time of shifting the pipeline from one place to another. Though for all practical purposes HDPE pipes are rigid and tough, at the same time they are resilient and conform to the topography of land when laid over ground or in trenches. They are coilable, easily be bent in installation, eliminating the use of specials like bends, elbows etc., there by reducing fitting and installation costs. HDPE pipes are easy to carry and install. They are lighter in weight and can be carried to heights as on hills. They can withstand movement of heavy traffic. This would not cause damage to the pipes because of their flexural strength. HDPE has excellent free flowing properties. They have non-adherent surface which reject (not attract) any foreign materials which would impede the flow. HDPE pipes are anti-corrosive, have smooth inner surface so that there is less friction and pressure loss is comparatively less.

HDPE pipes can be jointed by welding.

For further details of PVC and HDPE pipes refer to:

IS 7834 - 1975 Parts1-8

IS 8008 - 1976 Parts1-7

IS 7634 - 1975 Parts1-3

IS 3076 - 1985

IS 4984 - 1987

6.11.1 Medium Density Polyethylene (MDPE) Pipes

The medium density Polyethylene Pipes (MDPE) are now being manufactured in India conforming to ISO specifications (ISO 4427 and BS 6730 - 1986) for carrying potable water. However no BIS is available for these pipes. The MDPE pipes are being used for consumer connection pipes as an alternative to GI pipes. The Polyethylene material used for making the MDPE pipes conforms to PE 80 grade and the MDPE pipes when used for conveying potable water does not constitute toxic hazard and does not support any microbial growth. Further, it does not impart any taste, odour or colour to the water.

The Polyethylene material conforms to PE 80 grade. The MDPE pipes are colour coded black with blue strips in sizes ranging from 20 mm to 110 mm dia for pressure class of PN3.2, PN4, PN6, PN10 and PN16. The maximum admissible working pressures are worked out for temperature of 20 degrees centigrade as per ISO 4427. The pipes are supplied in coils and minimum coil diameter is about 18 times diameter of the pipe.

MDPE compression fittings made of PP, AABS, UPVC are also available in India for use with MDPE pipes. The materials used for the fittings are also suitable for conveying potable water like MDPE pipes. The jointing materials of fittings consists of thermoplastic resins of Polyethylene type, NBR 'O' ring of Nitrile and clamp of Polypropylene, copolymer body, Zinc plated steel reinforcing ring, nuts and balls of special NBR gasket.

The MDPE pipes are lightweight, robust and non-corrodible and hence can be used as alternative material for consumer connections. Since the pipes are supplied in coils, there will be no joints under the roads and bends are avoided resulting in fast, simple and efficient jointing.

6.12 GLASS FIBRE REINFORCED PLASTIC PIPES (G.R.P. PIPES)

Glass fibre Reinforced Plastic (GRP) pipes are now being manufactured in India conforming to IS 12709. The diameter range is from 350 mm to 2400 mm. The pressure class is 3,6,9,12 & 15 kgs/sq. cm. The field test pressures are 4.5,9,13.5,18,22.5 kgs/sq cm. The factory test pressures are 6,12,18,24& 30 kgs/sq cm. Depending on the type of installation, overburden above the crown of the pipe and the soil conditions, four types of stiffness class pipes are available. Standard lengths are 6 & 12 metres, however custom made lengths can also be made. The specials are made out of the same pipe material i.e. Glass fibre Reinforced Plastic (GRP).

The pipes are jointed as per the techniques; Double bell coupling (GRP) for GRP to GRP; Flange Joint (GRP) for GRP to valves, CI pipes or flanged pipes.

Mechanical Coupling (Steel) for GRP to GRP / steel pipe and Butt - strap joint (GRP) for GRP to GRP.

GRP pipes are corrosion resistant, have smooth surface and high strength to weight ratio. It is lighter in weight compared to metallic and concrete pipes. Longer lengths and hence minimum joints enable faster installation.

G.R.P. pipes are widely used in other countries where corrosion resistant pipes are required at reasonable costs. GRP can be used as a lining material for conventional pipes, which are subject to corrosion. These pipes can resist external and internal corrosion whether the corrosion mechanism is galvanic or chemical in nature.

6.13 STRENGTH OF PIPES

The stresses in a pipe are normally induced by internal pressure, external loading, surge forces and change of temperature, although torsional stresses can also arise. Internal pressure induces circumferential and longitudinal stresses, the latter developing where the line changes in size or direction, or has a closed end. A pipe is usually chosen so as to carry the circumferential stress without extra strengthening or support but if the joints cannot safely transmit the longitudinal stress, anchorages or some other means of taking the load must be provided. Longitudinal stress is absorbed by friction between the outside surface of the pipe and the material in which the line is buried.

A pipe must withstand the highest internal pressure it is likely to be subjected, the general provisions for which have been discussed in section 6.4.4, while surging or water hammer is discussed in 6.17.

External loads generally arise from the weight of the pipe and its contents and that of the trench filling from superimposed loads, including impact from traffic, from subsidence and from wind loads in the case of pipes laid above ground. If a pipe is laid on good and uniform continuous bed and the cover does not greatly exceed the normal, no special strengthening to resist external loading is generally necessary. Loading likely to arise from subsidence is best dealt with by the use of flexible joints and steel pipes. External loading becomes important usually when a line is laid on a foundation providing uneven support (e.g. across a sewer, trench or in rock under deep cover) or is subjected to heavy superimposed surface loads at less than normal cover. The necessity of stronger pipes can often be avoided by careful bedding and trench filling to give additional support. The importance of good bedding under and around the pipe upto at least the horizontal diameter cannot be overemphasized and in some cases concreting may be required.

Excessive distortion of a steel pipe may cause failure of its protective coating but can be limited by the use of strengthening rings. This problem is only likely to arise in very large mains. Distortions at flexible joints can cause leakage.

When a pipeline has to be laid above ground over some obstruction, such as waterway or railway, it may either be carried on a pipe-bridge or be supported on pillars. In the latter case, the pipe ends must be properly designed to resist shear, if the full strength of the pipe as a beam is to be realized. A small diameter pipe is usually thick enough to span short lengths with its ends simply supported, but as diameter and lengths of span increase, the problem becomes more complex and the ends must be supported in saddles or restrained by ring girders. For pipes of more than 900mm in dia the ring girder method will probably provide the most economical design. Structural design of buried pipes is discussed in detail in the companion volume "Manual on Sewerage and Sewage Treatment".

The temperature of the water in a transmission main varies during the year. If the water is derived from underground sources the variation is relatively small, but if it is obtained from surface sources and is filtered through slow sand filters, the variation may be as much as 20°C during the year. Furthermore, the temperature changes may take place fairly quickly and for these and other reasons, long lengths of rigid mains are to be avoided. Provision of expansion joints to take care of these stresses is necessary. Thrust and anchor blocks are provided to keep the pipe curve in position. In small mains, i.e. the mains with spigot and socket lead joints, the joints themselves allow sufficient movement, although some recaulking may be occasionally necessary. On large steel pipelines with welded joints expansion can be allowed to give a longitudinal stress in the pipes, when first laid. In about four years or so, the ground normally consolidates sufficiently around the pipe so that the stress is transferred to the ground. Valves require to be bridged by steel or reinforced concrete blocks so that the valve bodies are not stressed, as this could affect their water tightness.

In case of PVC pipelines, it should be noted that the coefficient of expansion of PVC is eight times greater than steel and considerable movement can take place in long lengths of rigidly jointed pipelines.

6.13.1 STRUCTURAL REQUIREMENTS

Structurally, closed conduits must resist a number of different forces singly or in combination.

(a) Internal pressure equal to the full head of water to which the conduit can be subjected (see Appendix 6.4).

(b) Unbalanced pressures at bends, contractions, and closures which have been discussed in 6.16. 18.

(c) Water hammer or increased internal pressure caused by sudden reduction in the velocity of the water; by the rapid closing of a gate or shut down of a pump, for example, which has been discussed in 6.17.

(d) External loads in the from of backfill, traffic, and their own weight between external supports (piers or hangers). A reference may be made to the Manual on Sewerage and Sewage Treatment.

(e) Temperature induced expansion and contraction, which is discussed in 6.13.2.

Internal pressure, including water hammer, creates transverse stress or hoop tension. Bends and closures at dead ends or gates produce unbalanced pressures and longitudinal stress. When conduits are not permitted to change length, variations in temperature likewise create longitudinal stress. External loads and foundation reactions (manner of support), including the weight of the full conduit, and atmospheric pressure (when the conduit is under vacuum) produce flexural stress.

6.13.2 TEMPERATURE INDUCED EXPANSION AND CONTRACTION

When the conduits are not permitted to change length due to variations in temperature, longitudinal stresses are created in the conduits, which is calculated as shown below:

(i) Change in pipe length with temperature

$$\Delta = C\,\theta\,L \qquad (6.12)$$

Where θ = change in temperature and C = coefficient of expansion of conduit per Degree Centigrade and is equal to 11.9×10^{-6} for steel, 8.5×10^{-6} for Cast Iron, and 10×10^{-6} for concrete, L = length of pipe.

(ii) Resulting longitudinal stress, $S = C\,\theta\,E$ (6.13)

for pipeline with fixed ends, and E = Young's Modulus of Elasticity, 2,10,000 N/m² for steel, 1,00,000 N/m² for cast iron, and 1400 - 40,000 N/m² for concrete.

(iii) Resulting longitudinal force $P = \pi\,(d+t)\,t\,s$ (6.14)

6.13.4 DEPTH OF COVER

One metre cover on pipeline is normal and generally sufficient to protect the lines from external damage. When heavy traffic is anticipated, depth of cover has to be arrived at taking into consideration the structural and other aspects as detailed in 6.13.2. When freezing is anticipated, 1. 5m cover is recommended as discussed in 10.12.

6.14 ECONOMICAL SIZE OF CONVEYING MAIN

6.14.1 GENERAL CONSIDERATIONS

When the source is separated by a long distance from the area of consumption, the conveyance of the water over the distance involves the provision of a pressure pipeline or a free flow conduit entailing an appreciable capital outlay. The most economical arrangement for the conveyance is therefore of importance.

The available fall from the source to the town and the ground profile in between should generally help to decide if a free flow conduit is feasible. Once this is decided, the material of the conduit is to be selected keeping in view the local costs and the nature of the terrain to be traversed. Even when a fall is available, a pumping or force main independently or in combination with gravity main could also be considered. Optimization techniques need to be adopted to help decisions. The most economical size for the conveyance main will be based on a proper analysis of the following factors:

(a) The period of design considered or the period of loan repayment if it is greater than the design period for the project and the quantities to be conveyed during different phases of such period.

(b) The different pipe sizes against different hydraulic slopes which can be considered for the quantity to be conveyed.

(c) The different pipe materials which can be used for the purpose and their relative costs as laid in position.

(d) The duty, capacity and installed cost of the pump sets required against the corresponding sizes of the pipelines under consideration.

(e) The recurring costs on

(i) Energy charges for running the pump sets,

(ii) Staff for operation of the pump sets,

(iii) Cost of repairs and renewals of the pump sets,

(iv) Cost of miscellaneous consumable stores, and

(v) Cost of replacement of the pumpsets installed to meet the immediate requirements, by new sets at an intermediate stage of design period. The full design period or the repayment period may be 30 years or more while the

pumpsets are designed to serve a period of 15 years.

6.14.2 EVALUATION OF COMPARABLE FACTORS

Every alternative, when analyzed on the above lines, could be evaluated in terms of cost figures on a common comparable basis by:

(i) Capital cost of the most suitable pipe material as laid and jointed and ready for service, including cost of valves and fittings and all ancillaries to the pipeline.

(ii) (a) Capital cost, as installed, of the necessary pump sets corresponding to the pipeline size in (i) above.

(b) The amount which should be invested at present such as would yield with compound interest, the amount necessary to replace the pumpsets in (ii) (a) at the end of their useful life with bigger pumpsets for once or often to cater to the requirements during the design period or the loan repayment period.

(iii) Energy charges; if the pumpsets in (ii) (a) are designed to serve for, say 15 years, the daily pumpage will vary from the initial requirements to the intermediate demand after 15 years. The energy charges will be based on the average of these two daily pumpages, leading to an average annual expenditure on energy charges on such basis.

The replacing of pumps under (ii) (b) will, likewise, involve annual recurring energy charges for the average of the demands during the subsequent 15 years period for the project design or the loan repayment period whichever is greater.

The two annual recurring costs should be capitalized for inclusion as a part of the present investment. For this purpose it is necessary to derive:

(a) The amount of the present investment which would yield an annuity for 15 years equal to the annual energy charges on the initial pump sets, and

(b) The amount of present investment which would commence to yield, over the subsequent 15 years period, the annual energy charges for the replaced pumpsets in (ii) (b),

(c) Apart from the energy charges, the other recurring annual charges comprising the cost of operation and maintenance staff, ordinary repairs and miscellaneous consumable stores.

The present investment which would yield an annuity equal to such annual recurring charges throughout the design period, or loan repayment period (if it exceeds the former), would represent the capitalized cost, for inclusion as part of the total investment now required.

(iv) The addition of the present investment figures as worked out under (i), (ii), (a), (ii) (b), (iii) and (iv) would represent the total capital investment called for in

6.16 APPURTENANCES

To isolate and drain pipe sections for test, installation, cleaning and repairs, a number of appurtenances or auxiliaries are generally installed in the line.

6.16.1 LINE VALVES

Main line valves are provided to stop and regulate the flow of water in the course of ordinary operations and in an emergency. There are many types of valves for use in pipeline the choice of which depends on the duty. The spacing varies principally with the terrain traversed by the line. In urban areas with connections in the distribution system, main aim is to sectionalise the line in order to maintain reasonable service. In larger lines isolating valves are frequently installed at intervals of 1 to 5 Km. The principle considerations in location of the valves are accessibility and proximity to special points such as branches, stream crossings etc. The spacing of valves is a function of economics and operating problems. Sections of the pipeline may have to be isolated to repair leaks. The volume of water which would have to be drained to waste would be a function of spacing of isolating valves.

These valves are usually placed at major summits of pressure conduits. Summits identify the sections of the line that can be drained by gravity, and pressures are least at these points permitting cheaper valves and easier operation. Gravity conduits are provided with valves at points strategic for the operation of supply points, at the two ends of sag pipes and wherever it is convenient to drain the given section.

Normally valves are sized slightly smaller than the pipe diameter and installed with a reducer on either side. In choosing the size; the cost of the valve should be weighed against the cost of head loss through it, although in certain circumstances it may be desirable to maintain the full pipe bore (to prevent erosion or blockage).

It is sometimes advisable to install small diameter bypass valves around large diameter inline valves to equalize pressures across the gate and thus facilitate opening.

6.16.1.1 Sluice Valves

Sluice valves or gate valves are the normal type of valves used for isolating or scouring. They seal well under high pressures and when fully open, offer little resistance to fluid flow. There are two types of spindles for raising the gate; a rising spindle which is attached to the gate and does not rotate with the hand wheel, and a non rising spindle which is rotated in a screwed attachment in the gate. The rising spindle is easy to lubricate.

The gate may be parallel sided or wedge shaped. The wedge gate seals best, but may be damaged by grit. For low pressure, resilient or gunmetal scaling faces may be used. For high pressure, stainless steel seals are preferred.

Sluice valves are not intended to be used for continuous throttling, as erosion of the seats and body cavitation may occur. If small flows are required the bypass, valve is more suitable for this duty.

Despite sluice valve's simplicity and positive action, they are sometimes troublesome to operate. They need a big force to unseat them against high unbalanced pressure and large valves take many minutes to turn open or closed, for which power operated or manual operated actuators are also used. Some of these problems can be over come by installing a valve with a smaller bore than the pipeline diameter.

In special situations variations of sluice valves suited to the needs are used; needle valves are preferred for fine control of flow, butterfly valves for ease of operation and cone valves for regulating the time of closure and controlling water hammer.

6.16.1.2 Butterfly Valves

Butterfly valves are used to regulate and stop the flow especially in large size conduits. They are sometimes cheaper than sluice valves for larger sizes and occupy less space. Butterfly valves with no sliding parts have the advantages of ease of operation, compact size, reduced chamber or valve house and improved closing and retarding characteristics.

These would involve slightly higher head loss than sluice valves and also are not suitable for continuous throttling. The sealing is sometimes not as effective as for sluice valves especially at high pressures. They also offer a fairly high resistance to flow even in fully open state, because the thickness of the disc obstructs the flow even when it is rotated to fully open position. Butterfly valves as well as sluice valves are not suited for operation in partly open positions as the gates and seatings would erode rapidly. Both types require high torques to open them against high pressure, they often have geared hand wheels or power driven actuators.

Butterfly Valves with loose sealing ring are sometimes not effective, especially at higher pressures. Butterfly valves with fixed liner can overcome this shortcoming, further the butterfly valves with fixed liner needs no frequent maintenance for replacement of sealing ring as in the case of butterfly valves with loose sealing ring. The fixed liner design butterfly valves are now available in India suitable for working pressures up to 16 kgs/sq cm. Presently there is no IS for the fixed liner Butterfly valves.

6.16.1.3 Globe Valves

Globe valves have a circular seal connected axially to a vertical spindle and hand wheel. The seating is a ring perpendicular to the pipe axis. The flow changes direction through 90° twice thus resulting in high head losses. These valves are normally used in small bore pipe work and as taps, although a variation is used as a control valve.

6.16.1.4 Needle And Cone Valves

Needle valves are more expensive than sluice and butterfly valves but are well suited for throttling flow. They have a gradual throttling action as they close, whereas sluice valves and butterfly valves offer little flow resistance until practically shut and may suffer cavitation damage. Needle valves may be used with counter balance weights, springs, or actuators to maintain constant pressure conditions either upstream or downstream of the valve or to maintain a constant flow. They are resistant to wear even at high flow velocities. The method of sealing is to push an axial needle or spear shaped cone into a seat. There is often a pilot needle which operates first to balance the heads before opening. The cone valve is a variation of the needle valve but the sealing cone rotates away from the pipe axis instead of being withdrawn axially.

The needle and cone valves are not commonly used in water supply but are occasionally used as water hammer release valves when coupled to an electric or hydraulic actuator.

6.16.2 Scour Valves

In pressure conduits, small gate off-take known as blow-off or scour valves are provided at low points above line valves situated in the line on a slope such that each section of the line between valves can be emptied and drained completely. They discharge into natural drainage channel or empty into a sump from which water can be pumped to waste.

The exact location of scour valves is frequently influenced by opportunities to dispose off the water. Where a main crosses a stream or drainage structure, there will usually be a low point in the line, but if the main goes under the stream or drain, it cannot be completely drained into the channel. In such a situation it is better to locate a scour connection at the lowest point that will drain by gravity and provide for pumping out the part below the drain pipeline.

There should be no direct connection to sewers or polluted watercourses except through a specially designed trap chamber or pit. For safety, two blow off valves are placed in series. The outlet into the channel should be above the high water line. If the outlet must be below high water, a check valve must be placed to prevent back flow.

The size depends on local circumstances especially upon the time in which a given section of line is designed to be emptied and upon the resulting velocity of flow. Calculations are based upon orifice discharge under a falling head, equal to the difference in elevation of the water surface in the conduit and the blow off less the friction head. Frequency of operation depends upon the quality of the water carried, especially on silt loads.

6.16.3 Air Valves

When a pipeline is filled, air could be trapped at peaks along the profile thereby increasing head losses and reducing the capacity of the pipeline. It is also undesirable to have air pockets in the pipe as they may cause water hammer pressure fluctuations during operation of the pipeline. Other problems due to air include corrosion, reduced pump efficiency, malfunctioning of valves or vibrations. Air valves are fitted to release the air automatically when a pipeline is being filled and also to permit air to enter the pipeline when it is being emptied. Additionally air valves have also to release any entrained air, which might be accumulated at high points in the pipeline during normal operations.

Without air valves, vacuum may occur at peaks and the pipe could collapse or it may not be possible to drain the pipeline completely.

Air valves require care in selection and even more care in siting and it is good practice to plan the pipeline alignment to avoid air troubles altogether. A special study of the possible air problems is necessary at the design stage itself and provision should be made for suitable corrective measures rather than positioning arbitrary air valves at pipeline peaks.

Locations of air valves can be at both sides of gates at summits, the downstream side of other gates and changes in grade to steeper slopes in sections of line not otherwise protected by air valves.

6.16.3.1 Air Release Valves

Air Release valves are designed specifically to vent, automatically and when necessary, air accumulations from lines in which water is flowing. Such accumulations of air tend to collect at high points in the pipeline. Air which accumulates at such peaks, reduces the useful cross sectional area of the pipe, and therefore induces a friction head factor that lowers the pumping capacity of the entire line. The use of air release valves eliminates the possibility of this air binding and permits the flow of water without damage to pipeline.

Small orifice air valves are designated by their inlet connection size, usually 12 to 50 mm diameter. This has nothing to do with the air release orifice size which may be from 1 to 10 mm diameter. The larger the pressure in the pipeline, the smaller need be the orifice size. The volume of air to be released will be a function of the air entrained which is on the

average 2% of the volume of water (at atmospheric pressure).

The small orifice release valves are sealed by a floating ball, or needle which is attached to a float. When a certain amount of air has accumulated in the connection on top of the pipe, the ball will drop or the needle valve will open and release the air. Small orifice release valves are often combined with large orifice air vent valves on a common connection on top of the pipe. The arrangement is called a double air valve. An isolating sluice valve is normally fitted between the pipe and the air valves.

Double air valves should be installed at peaks in the pipeline, both with respect to the horizontal and the maximum hydraulic gradient. They should also be installed at the ends and intermediate points along a length of pipeline which is parallel to the hydraulic grade line. It should be borne in mind that air may be dragged along in the direction of flow in the pipeline and may even accumulate in sections falling slowly in relation to the hydraulic gradient. Double air valves should be fitted every 1/2 to 1 KM along descending sections, especially at points where the pipe dips steeply.

Air release valves should also be installed all along ascending lengths of pipeline where air is likely to be released from solution due to the lowering of the pressure, again especially at points of decrease in gradient. Other places where air valves are required are on the discharge side of pumps and at high points on large mains and upstream of orifice plates and reducing tapers.

Air-Relief towers are provided at the first summit of the line to remove air that is mechanically entrained as water is drawn into the entrance of the pipeline.

6.16.3.2 Air Inlet Valves

In the design and operation of large steel pipelines, where gravity flow occurs, considerations must be given to the possibility of collapse in case the internal pressure is reduced below that of atmosphere. Should a break occur in the line at the lower end of a slope, a vaccum will in all probability be formed at some point upstream from the break due to the sudden rush of water from the line. To prevent the pipe from collapsing, air inlet (vaccum breaking) valves are used at critical points.

These valves, normally held shut by water pressure, automatically open when this pressure is reduced to slightly below atmosphere, permitting large quantities of air to enter the pipe, thus effectively preventing the formation of any vaccum. In addition to offering positive protection against extensive damage to large pipelines, by prevention of vacuum, they also facilitate the initial filling of the line by the expulsion of air wherever the valves are installed.

Air inlet valves should be installed at peaks in the pipeline, both relative to the horizontal and relative to the hydraulic gradient. Various possible hydraulic gradients, including reverse gradients during scouring, should be considered. They are normally fitted in combination with an air release valve.

Often air release valves are used in conjunction with them, the purpose of these being to vent air accumulations that may occur at the peaks after the line has been put into operation. Please refer to 6.17.3 also for more information.

6.16.4 KINETIC AIR VALVES

In case of ordinary air valve, single orifice (small or large) type, the air or water from the rising main is admitted in the ball chamber of the air valve from one side of the ball. The disadvantages with this type of valve are that (a) once the ball goes up, it does not come down even when air accumulates in the ball chamber and (b) due to air rushing in, it stirs the ball making it stick to the upper opening which does not fall down unless the pressure in the main drops. The Kinetic air valve, overcomes these deficiencies since the air or water enters from the bottom side of the ball and the air rushing around ball exerts the pressure and loosens the contact with the top opening and allows the ball to drop down.

6.16.5 PRESSURE RELIEF VALVES

These, also called as over-flow towers, are provided in one or more summits of the conveyance main to keep the pressure in the line below given value by causing water to flow to waste when the pressure builds up beyond the design value. Usually they are spring or weight loaded and are not sufficiently responsive to rapid fluctuations of pressure to be used as surge protection devices. The latter are dealt in 6.17.4.

6.16.6 CHECK VALVES

Check valves, also called non-return valves or reflux valves, automatically prevent reversal of flow in a pipeline. They are particularly useful in pumping mains when positioned near pumping stations to prevent backflow, when pumps shut down. The closure of the valve should be such that it will not set up excessive shock conditions within the system. The remedial measures are discussed in 6.17.4. For more details of swing check reflux valves, reference may be made to IS 5312 - Pt I-1984 & Pt II-1986.

6.16.6.1 Dual Plate Check Valves

Dual plate check valves employ two spring loaded plates hinged on a central hinge pin. When the flow decreases, the plates close by torsion spring action without requiring reverse flow. As compared to conventional swing check valve which operates on mass movement, the Dual plate check valve are provided with accurately designed and tested torsion springs to suit the varying flow conditions. The Dual plate check valves are of non-slamming type and arrest the tendency of reversal of flow. Presently there is no IS for the Dual Plate Check Valves.

6.16.7 SURGE TANKS

These are provided at the end of the line where water hammer is created by rapid closing of a valve and are discussed in detail in 6.17.

6.16.8 PRESSURE-REDUCING VALVES

These are used to automatically maintain a reduced pressure within reasonable limits in the downstream side of the pipeline. This type of valve is always in movement and requires scheduled maintenance on a regular basis. This work is facilitated if the valve is fitted on a bypass with isolating valves to permit work to proceed without taking the main out of service. If the pressure reducing valve is fitted on the main pipeline, a bypass can be provided for emergency use. Needle type valves which can be hydraulically controlled or motor operated with a pressure regulator are used for large aqueduct mains.

6.16.9 PRESSURE SUSTAINING VALVES

Pressure sustaining valves are similar in design and construction to pressure reducing valves and are used to maintain automatically the pressure on the upstream side of the pipeline.

6.16.10 BALL VALVES OR BALL FLOAT VALVES

Ball valves or ball float valves are used to maintain a constant level in a service reservoir or elevated tank or standpipe. The equilibrium type of valve is the most effective and it is designed to ensure that the forces on each side of the piston are nearly balanced. For severe operating conditions, a more expensive needle type of valve will give better service.

In both cases the float follows the water level in the reservoir and permits 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. The disadvantage of this system is that the valve may operate for long periods in a throttled condition, but this can be avoided by arranging for the float to function in a small auxiliary cylinder or a tank. When the water reaches the top of the auxiliary tank, the ball will rise fairly quickly from the fully open position to the closed position without shock. The valve will not open again until the water level in the reservoir reaches the base of the auxiliary tank, at which point the water will drain away and the ball valve will move to the fully open position. With this method the valve is not in a state of almost continuous movement and throttling and erosion of the seats are avoided.

6.16.11 AUTOMATIC SHUT-OFF VALVES

These are used on the mains to close automatically when the velocity in the mains exceeds a predetermined valve in case of accident to the line.

6.16.12 AUTOMATIC BURST CONTROL

With large steel mains suitably protected against corrosion and laid properly, particularly at change of direction and the ground is not liable to subsidence, the possibility of a major burst is ruled out.

The simplest arrangement as explained in 6.16.14 is to insert an interrupter timer in the motor circuit so arranged that the final quarter travel of a sluice valve occurs in slow steps to the point of closure. The costlier arrangement will be insertion of a smaller power operated

EXPANSION JOINTS

- Expansion are not needed if the pipe joints themselves take care of the pipe movements induced du to temperature changes, which is mostly the case for long buried pipe without any bend or dip.
- Steel pipes laid with rigid transverse joints particularly in the open must either be allowed to expand at definite point or its motion be rigidly restrained by anchoring the line.

WATER HAMMER

OCCURRENCE

- If the velocity of water flowing in a pipe is suddenly diminished, the energy given up by the water will be divided between compressing the water itself, stretching the pipe walls and frictional resistance to wave propagation. This pressure rises or water hammer is manifests as a series of shocks, sounding like hammer blows, which may have sufficient magnitude to rupture the pipe or damage connected equipment.
- It may be caused by the nearly instantaneous or too rapid closing of a valve in the line, or by an equivalent stoppage of flow such as would take lace with the sudden failure of electricity supply to a motor driven pump. The shock pressure is not concentrated to the valve and if rupture occurs, it may take place near the valve simply because it acts there first. The pressure wave due to water hammer travels back upstream to the inlet end of the pipe, where it reserves and surges back and forth through the pipe, getting weaker on each successive reversal.
- The velocity of the wave is that of acoustic wave in an elastic medium, the elasticity of the medium in this case being a compromise between that of the liquid and the pipe. 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 rapidity of change in velocity. Complete stoppage of flow is not necessary to produce water hammer, as any sudden changes in velocity will create it to a greater or lesser degree depending on the conditions ted, mentioned above.

If the actual time of closure T is greater than the critical time T_c, the actual water hammer is reduced approximately in proportion to T_c/T.

Water hammer wave velocity may be as high as 1370 m/s for a rigid pipe or as low as 850 m/s for a steel pipe and for plastic pipes may be as low as 200 m/s.

6.17.3 CONTROL MEASURES

The internal design pressure for any section of a pipeline should not be less than the maximum operating pressure or the pipeline static pressure obtaining at the lowest portion of the pipeline considered including any allowance required for surge pressure. The maximum surge pressure should be calculated and the following allowances made.

(a) If the sum of the maximum operating pressure or the maximum pipeline static pressure whichever is higher and the calculated surge pressure does not exceed 1.1 times the internal design pressure, no allowance for surge pressure is required,

(b) If the sum exceeds 1.1 times the internal design pressure, then protective devices should be installed and

(c) In no case the sum of the maximum operating pressure and the calculated surge pressure should exceed the field hydrostatic test pressure.

Depending upon the layout of the plant, the profile and the length of the pipeline, surging in pipelines can be counteracted in two fundamentally different ways (1) by checking the formation of the initial reduced pressure wave itself by means of flywheels (which lengthen the slowing down time of the pump) and air vessels (which continues to feed water into the pipeline until the reflected pressure wave again reaches the pump) and (2) by neutralizing the reflected wave from the reservoir by installing special devices in the pipelines, some of which are automatically controlled quick closing valves, automatically controlled bypasses and pressure relief valves. To obtain greatest effectiveness, the relief valve or other form of suppressor should be located as close as possible to the source of disturbance.

Since the maximum water hammer pressure in metres is about 125 times the velocity of flow in mps and the time of closure of gate valves varies inversely with the size of the main, water hammer is held within bounds in small pipelines by operating them at moderate velocities of 1 to 2 mps. In larger mains, the pressure is held down by changing velocities at sufficiently slow rate so that the relief valve returns to position of control before excessive pressures are reached. If this is not practicable, pressure relief or surge valves are used. For mains larger than 1.75m, which operate economically at relatively high velocities of 2 to 3 mps and cannot be designed to withstand water hammer without prohibitive cost, the energy is dissipated slowly by employing surge tanks. In its simplest form, a surge tank is a standpipe placed at the end of the line next to the point of velocity control. If this control is a gate, the surge tank accepts water and builds up backpressure when velocities are regulated downward. When the demand on the line increases, the surge tank affords an immediate supply of water and, in so doing, generates the excess hydraulic gradient needed to accelerate the flow through the conduit following a change in the discharge rate. The water level in a surge tank oscillates slowly till the excess energy is dissipated by hydraulic friction through the system.

6.17.3.1 Causes Of Water Hammer And Remedial Measures

The three common causes of water hammer encountered in water supply systems are: (1) rapid closure of valves (2) sudden shut off or unexpected failure of power supply to centrifugal pumps and (3) pulsation problems due to hydraulic rams and reciprocating pumps.

6.17.3.2 Rapid Closure Of Valves

Gate valves are to be preferred to stop valves. The valve closure period should be slowed down to take longer than the critical time of closure. The first 80% of valve travel can be executed as quickly as convenient, but the last 20% (which is effective in shutting off approximately 80% of the flow) should be done as deliberately as possible. This not only tends to minimize water hammer but is expedient owing to the greater resistance to closure offered as shut-off is approached. Where power driven operating devices are used, similar precautions should be taken. For geared gate valves, closure may have to be considerably slower in the initial period than in the case of valves without gears; the mechanical advantage available is of great assistance in effecting the last 20% of closure, particularly with large gate valves at high rates of flow. Similar measures have to be adopted for prevention of rapid opening of valves. By passes are help in closing or opening of large valves and should be closed last. Care should also be taken to avoid setting up excessive water hammer through too rapid operation of fire hydrants.

6.17.3.3 Remedial Measures For Sudden Shut Off Of Pumps

When the power supply to centrifugal pump is suddenly shut off for some reason or fails unexpectedly, severe water hammer may be set up in either the pump discharge or suction piping or both, depending upon the layout due to the momentum of the column of water flowing through the pipe which tries to continue towards its destination even after the power interruption.

(a) Shut- off Effects on Discharge Line

Immediately after interruption, the impeller slows down and the column of water coasts along the discharge pipe away from the pump with an ensuing drop in pressure at the pump. The column then slows down and reverses its direction of flow so as to come back towards the point of low pressure at the pump. If there is a check valve at the pump, on continued reversal of flow is possible and a back pressure builds up against the check valve which, in general, will be about equal to the preceding drop below normal. The shock pressure may reach twice the normal head if there has been no breaking of the water column or, if the column has broken, the pressure may rise to a much higher value than twice the normal head. Increased flywheel capacity of a pump will, in cases of power failure, maintain pumping action to an extent sufficient to prevent excessive fall of pressure.

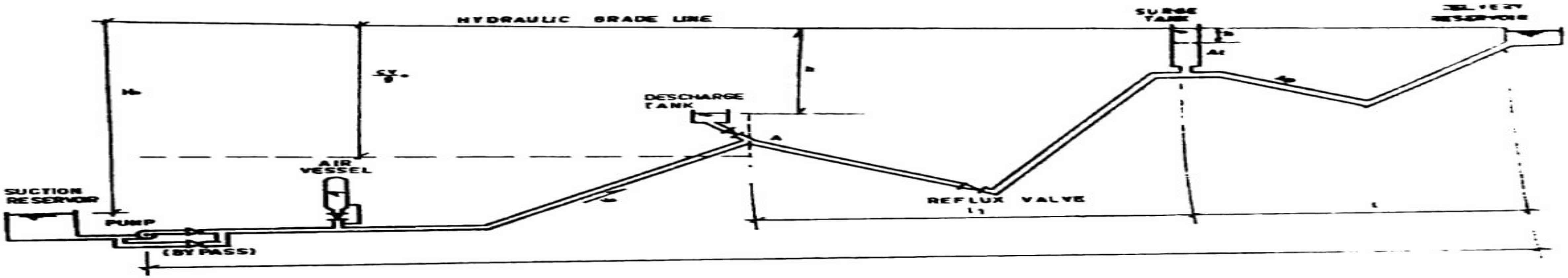

FIG.6.2 : PIPELINE PROFILE ILLUSTRATTING SUITABLE LOCATION FOR VARIOUS DEVICES FOR WATE HAMMER PROTECTION

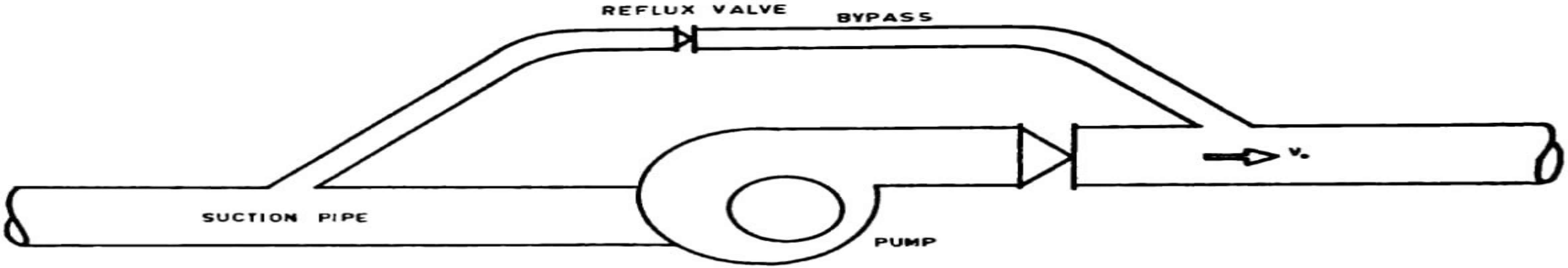

FIG.6.3: PUMP WITH BYPASS REFLUX VALUE

Pump Bypass Reflux Valve

- One of the simplest arrangements for protecting pumping main against water hammer is a reflux valve installed in parallel with the pump (Fig (63).
- The reflux or non-return would discharge only in the same direction as the pumps. Under normal pumping condition the pumping head would be higher than the suction head and the pressure difference would maintain the reflux valve in a closed position.
- On stopping the pumps, the head in the delivery pipe would tend to drop below the suction head, in which case water would drawn through the bypass valve.
- The pressure would therefore only drop to the suction pressure less any friction loss in the bypass. The return wave over pressure would be reduced correspondingly. Fig. 6.4. gives the maximum and minimum head at pump after power failure.

Discharge Tanks

- In situations where the pipeline profile is considerably lower than the hydraulic grade line it may still be possible to use a tank, but one which under normal operating conditions is isolated from the pipeline. The tank water surface would be subjected to atmospheric pressure but would be below the hydraulic grade line, as opposed to that of a surge tank.
- A discharge tank would normally be situated on the first rise along the pipeline and possibly on subsequent and successively higher rises.

- The tank will be more efficient in reducing pressure variations, the nearer the level in the tank is to the hydraulic grade line. It should be connected to the pipeline via a reflux valve installed to discharge from the tank into the pipeline if the pipeline head drops below the water surface elevation in the tank.
- Normally the reflux valve would be held shut by the pressure in the pumping line. A small-bore bypass to the reflux valve, connected to a float valve in the tank, should be installed to fill the tank slowly after it has discharged. Fig. depicts a typical discharge tank arrangement.
- The function of a discharge tank is to fill any low-pressure zone caused by pump stoppage, thus preventing water column separation. The water column between the tank and the discharge end of the pipeline (or a subsequent tank) will gradually decelerate under the action of the head differences between the two ends.

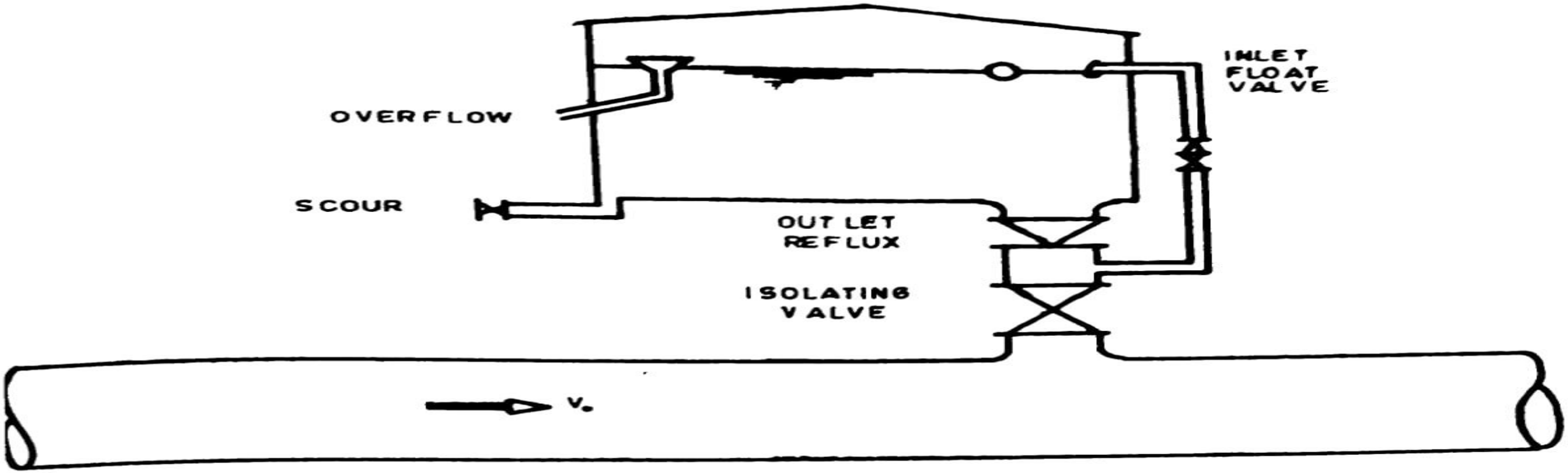

FIG. 6.5 : DISCHARGE TANK

AIR VESSELS

- If the profile of a pipeline is not high enough to use a surge tank or discharge tank to protect the line, it may be possible to force water into the pipe behind the low-pressure wave by means of compressed air in a vessel.
- The pressure in the vessel will gradually decrease as water is released until the pressure in the vessel equals that in the adjacent line. At this stage the decelerating water column will tend to reverse. However, whereas the outlet of the air vessel should be unrestricted, the inlet should be throttled.
- A suitable arrangement is to have the water discharge out through a reflux valve that shuts when the water column reverses. A small orifice open bypass would allow the vessel to refill slowly. (Fig)
- A rational design of air vessel involves calculation of the dimensionless parameters, as follows:

Pipeline parameter = $\rho = CV_o / 2gH_0$

Air vessel parameter= $\rho \frac{2C_0 C}{Q_0 L}$

Kc = Coefficient of Head Loss such that $K_c H_0$ is the total head loss for a flow of Q_o into air vessel C is water hammer wave velocity, V_o is initial velocity and H_o is absolute head (including atmospheric head), Co is the volume of Air, L is the length of pipeline.

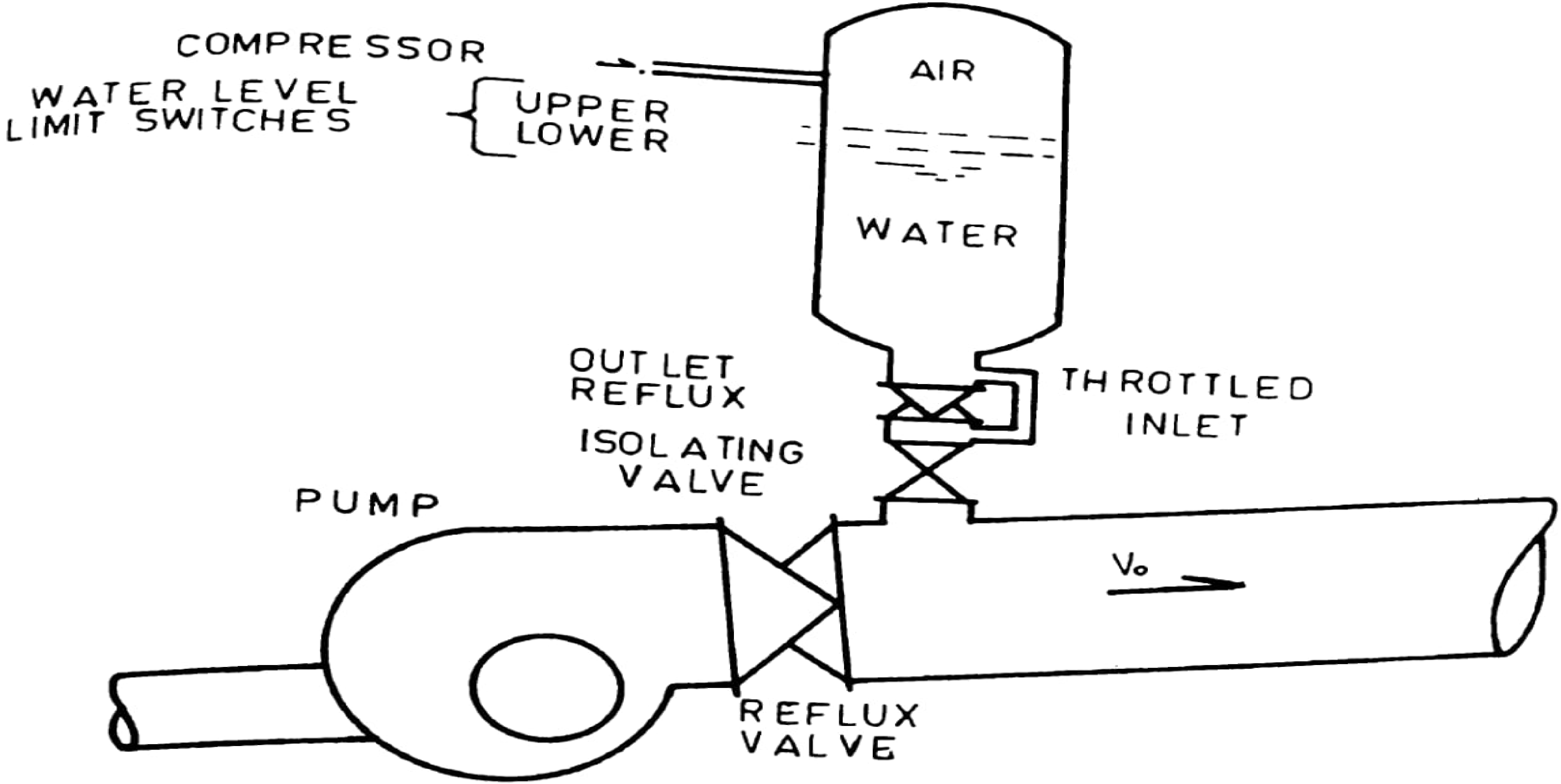

FIGURE 6.6 : AIR VESSEL

In-Line Reflux Valves

- Inline reflux valves would normally be used in conjunction with surge tanks, discharge tanks or Air vessel. Following pumps shutdown, the tank or vessel would discharge war into the pipe either side of the reflux valve.
- This would alleviate the violent pressure drop and convert the phenomenon into a slow motion effect .The reflux valve would then rate the water column at the time of reversal, which coincides with the point of minimum kinetic energy and maximum potential energy of the water column.
- There would therefore be little momentum change in the water column when the reflux valve is shut and consequent negligible water hammer pressure rise.

Release Valves

- There are a number of sophisticated water hammer release valves (often referred to as surge relief valve or surge suppression) available commercially.
- These valves have hydraulic actuators which automatically open, then gradually close after pumps tripping The valves are normally the needle type, which discharge into a pipe leading to the suction reservoir, or else sleeve valves, mounted in the suction reservoir.
- The valves must have a gradual throttling effect over the complete range of closure. Needle and sleeve valves are suitably designed to minimize cavitation and corrosion associated with the high discharge velocities which occur during the throttling process.
- The valves are usually installed on the delivery side of the pump reflux valves and discharge directly to the suction reservoir. They should not discharge into the suction pipe as they invariably draw air through the throat, and this could reach the pumps

SPECIAL DEVICES FOR CONTROL OF WATER HAMMER

The philosophy is

i. to minimize the length of the returning water column causing water hammer

ii. to dissipate energy of the water column length by air cushion valve and

iii. to provide a quick opening pressure relief valve to relieve any rise in pressure in critical zone.

These objectives are achieved by the following three valves.

ZERO VELOCITY VALVE

- The principle behind the design of this valve is to arrest the forward moving water column at zero momentum i.e. when its velocity is zero and before any return velocity is established.
- The valve fitted in the pipeline consists of an outer shell and an inner fixed dome leaving a streamlined annular passage for water. A closing disc is mounted on central and peripheral guide rods and is held in the closed position by one or more springs when there is no flow of water.
- A bypass connects the upstream and downstream sides of the disc. The springs are so designed that the disc remains in fully open position for velocity of water equal to 25% of the designed maximum velocity in the pipeline.

AIR CUSHION VALVE

- The principle of this valve s to allow large quantities of air in the pumping main during separation, entrap the sir, compress with the returning ait column and expel the air under controlled pressure so as to dissipate the energy of the returning water column. An effective air cushion is thus provided.

- The valve n mounted on TEE-join on the ring main at locations where water column separation is likely. The valve has a spring loaded armet part, an outlet normally closed by a float, a spring loaded outlet poppet valve and an adjustable needle valve control orifice.
- When there in sudden stoppage of pump due to power failure, partial vacuum is created in the main. With differential pressure, the spring-loaded port opens and admits outside air into the main. When the pressure in the main becomes near atmosphere, the inlet valve closes under spring pressure.
- The entrapped air is than compressed by the returning water column till the poppet valve opens. With float in dropped position, the air is expelled through poppet valve and controlled orifice under predetermined pressure thus dissipating the energy of the returning water column.

OPPOSED POPPET VALVE

- As the name implies, the valve has two poppets of lightly different areas mounted on the same stem. The actual load on the stem is thus the difference in load on the two poppet and in thus light. A weak spring in therefore, able to keep the valve closed under normal working pressure.

- If pressure in the water main increases beyond a certain limit, the increase in differential pressure overcomes the holding pressure of the spring, opens the valve and allows water to discharge through both the poppet

- On account of the light spring the valve is able to open quickly and thus reduce the peak surge pressure to the desired limit.

cost of the pipe itself will be reduced.

Example 6.2. *Estimate the hydraulic gradient in a 2 m diameter smooth concrete pipe carrying a discharge of 3 cumecs at 10°C temperature by using (a) Darcy-Weisbach formula ; (b) by Manning's formula, (c) by Hazen-William's formula ; (d) by Modified Hazen-William's formula. Assume suitable data not given.*

Solution. Q = 3 cumecs.

Dia of pipe = 2 m

Area of pipe $= A = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times 4 = 3.14 \text{ m}^2$

$\therefore$ Velocity of flow $= V = \frac{Q}{A} = \frac{3}{3.14} = 0.955$ m/sec.

(*a*) *Darcy-Weisbach formula* (Eq. 6.1) states that

$$H_L = \frac{f' L}{d} \cdot \frac{V^2}{2g} \quad \text{...(i.e. Eq. 6.1)}$$

Let us evaluate f', first

Now, R_e = Reynold number $= \frac{Vd}{\nu}$

where ν = kinematic viscosity of water at 10°C from table 9.1

$= 1.31 \times 10^{-6}$ m²/sec

$$\therefore \quad R_e = \frac{0.955 \times 2}{1.31 \times 10^{-6}} = 1.46 \times 10^6 = 14{,}60{,}000$$

Using Eq. (6.8), we have

$$f' = 0.005 + \frac{0.396}{R_e^{0.3}}$$

$$\therefore \quad f' = 0.005 + \frac{0.396}{(14{,}60{,}000)^{0.3}} = 0.005 + \frac{0.396}{69.5}$$

$= 0.005 + 0.0057 = 0.0107$; say 0.011.

When the value of f' is obtained by Eq. (6.6), we get

$$\left[\frac{1}{\sqrt{f'}} = 2 \log_{10} R_e \sqrt{f'} - 0.8\right] \quad \text{...(i.e. Eq. 6.6)}$$

$$\frac{1}{\sqrt{f'}} = 2 \log_{10} (1.46 \times 10^6) \sqrt{f'} - 0.8$$

or $$\frac{1}{\sqrt{f'}} = 2 \times 6.14 \sqrt{f'} - 0.8$$

or $$1 = 12.28 f' - 0.8 \sqrt{f'}$$

or $$f' - 0.0652 \sqrt{f'} - 0.0815 = 0$$

or $$\sqrt{f'} = \frac{0.0652 \pm \sqrt{0.00425 + 0.326}}{2} = \frac{0.0652 \pm \sqrt{0.3302}}{2}$$

or $$= \frac{0.0652 \pm 0.514}{2} \quad \text{(Ignoring unfeasible negative sign)}$$

$$= \frac{0.639}{2} = 0.32$$

$\therefore$ $f' = 0.01 \approx 0.011$, as given by equation 6.8

Hence use $f' = 0.011$.

Now using **Eq. (6.1)**, we have

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

or $$H_L = \frac{0.011 \times L}{2} \frac{(0.955)^2}{2 \times 9.81}$$

or $$\frac{H_L}{L} = \frac{0.011}{2} \times \frac{0.911}{19.62} = \frac{0.011 \times 0.911}{39.24} = \frac{1}{3920}$$

Thus, the hydraulic gradient is $\frac{1}{3920}$, *i.e.*, 1 m fall in 3920 m length. **Ans.**

(*b*) *Using Manning's formula i.e.* Eq. (6.11)

we have $$H_L = \frac{n^2 V^2}{R^{4/3}} \cdot L$$

Using $n = 0.013$, $R = \frac{d}{4} = 2/4 = 0.5$ m, we get

$$\frac{H_L}{L} = \frac{(0.013)^2 \times (0.955)^2}{(0.5)^{1.33}}$$

$$= \frac{0.000169 \times 0.911}{0.397} = \frac{1}{2480}$$

Thus, the hydraulic gradient is $\frac{1}{2480}$, *i.e.* 1 m fall in 2480 m length. **Ans.**

(*c*) *Using Hazen-William's formula i.e.* Eq. (6.12)

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

Using $C_H = 130$ (from Table 6.2)

we have $0.955 = 0.85 \times 130 \times \left(\frac{2}{4}\right)^{0.63} . S^{0.54}$

or $0.955 = 0.85 \times 130(0.5)^{0.63} . S^{0.54}$

$= 0.85 \times 130 \times 0.646 . S^{0.54}$

or $S^{0.54} = \frac{0.955}{0.85 \times 130 \times 0.646} = \frac{1}{74.8}$

or $S = \frac{1}{(74.8)^{\frac{1}{0.54}}} = \frac{1}{(74.8)^{1.852}} = \frac{1}{2950}$

Thus, the hydraulic gradient is $\frac{1}{2950}$, *i.e.* 1 m fall in 2950 m length. **Ans.**

(*d*) *Using Modified Hazen-William's formula* ; *i.e.* Eq. (6.14),

we have $V = 143.534\, C_R . R^{0.6575} . S^{0.5525}$

where $V = 0.955$ m/s (computed earlier)

$C_R = 1.0$ (from Table 6.3 for concrete pipe)

$R = \frac{d}{4} = \frac{2\text{m}}{4} = 0.5$

$S = ?$

Putting the values, we get

$0.955 = 143.534 \times 1 \times (0.5)^{0.6575} . (S)^{0.5525}$

or $0.955 = 143.534 \times 0.634\, S^{0.5525}$

or $S^{0.5525} = \frac{0.955}{143.534 \times 0.634} = 0.01049$

or $S = (0.01049)^{\frac{1}{0.5525}} = 2.6185 \times 10^{-4} \simeq \frac{1}{3819}$

Thus, the hydraulic gradient by Modified Hazen-William's formula will be $\frac{1}{3819}$ *i.e.* 1 m fall in 3819 m length ; which value will be close to the value obtained from Darcy-Weisbach formula. **Ans.**

Certain Important Definitions

Here we shall define certain important terms which are frequently used in India for defining various pressures in pressure pipes by the manufacturers of these pipes.

Working Pressure.

Working pressure may be defined as the actual maximum pressure (including abnormal conditions such as water hammer) to which the pipe will be subjected during its operation.

Design Pressure.

Design pressure may be defined as the maximum pressure for which the pipe has been designed. This is equal to the product of the working pressure and suitable factor of safety to cover abnormal increase in pressure due to unforeseen circumstances.

Test Pressure.

Test pressure may be defined as the maximum pressure which the pipe can withstand without any leakage when tested for hydrostatic pressure in accordance with the standard methods of testing

Testing of the Pipe Lines

After a pipe line has been laid, fitted with all appurtenances and accessories, painted both from inside as well as outside by means of protective paints, etc., the pipe line will be tested for the soundness in its construction. The sounds of the construction is examined by performing the pressure test on the pipe line. The step by step procedure adopted for performing this test described below:

I. The pipe line is tested from section to section. Thus, at time, only a particular section lying between two sluice valves in taken up 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 in late the pipe section from the rest of the pipe.

IV. Pressure gauges are then fitted along the length of the pipe section at suitable interval (say 1 km or so) on the crown, through holes left for the purpose.

V. The pressure in the pipe line is now raised by means of a small hand force pump or a hydraulic pressure pump, till the test pressure (to be measured in the pressure gauge fitted on the pipe) is nearly 25-50% above highest working pressure.

VI. The pipe and the joints are then visualised for water tightness. The applied test pressure should also maintain itself without any appreciable loss during the observation period, which may be at least 4 hours. When the field test procedure in less than two-third the works test pressure, then the observation period should be increased to at least 24 hours.

- The pipe is finally emptied through drain valve, and the observed defects (in the test) are rectified, so as to make the line fit for use. The pipe is again tested by repeating the test, so as to ensure proper rectification of defect already done.

- After the satisfactory completion of the pressure test, a leakage test at pressure to be specified by the authority for a duration of 2 hours may also be performed. Leakage in defined as the quantity of water that is required to be supplied for maintaining the specified leakage test pressure after the pipe has been filled with water and the air is expelled.

- In a newly laid pipe line, there should generally be no leakage. Moreover, the allowable leakage during the maintenance stage of pipes carefully laid and well tested during construction should also not exceed the value given by Eq below

$$q_L = \frac{N.D\sqrt{P}}{115}$$

Where

q_L = Allowable leakage in em³/hr

N= No, of joints in the length of the pipe line

D = Diameter of pipe in mm

P= The average test pressure during the leakage test in kg/cm^2 (i.e. 10 m of water head)

Disinfection of Pipe Lines before Use.

- After the pipeline has been toasted and corrected for defects, it is ready for transporting untreated water to the city from the source. However, when the pipe lines are carrying treated water, they must be disinfected before use.

- The pipes are disinfected by keeping them full with water and adding chlorine in amounts, as to maintain a residue of 50 mg/l (i.e. 50 ppm). This residue is maintained for 12 hours and the pipe is emptied and flushed with fresh treated water, thus making the pipe ready for carrying potable water to the consumers or to the storage tanks.