

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

respect of each alternative involving a specific pipeline size and the corresponding pumpsets. A comparison of the total investment so required in respect of the several alternatives examined would indicate the most economical pipeline size to be adopted for any particular project.

- (v) In all the above computations, the rate of interest plays an important role and for proper comparison, it may be taken as the rate demanded for the loan repayment.

6.14.3 SCOPE OF SINKING FUND

In the methods of comparison outlined above, any provision for a sinking fund to replace the pipeline or the pumpsets at the end of the design or loan repayment period where needed has been advisedly not included. It would tantamount to the present generation paying in advance for the amenities for the next generation, in addition to paying for its own amenities through the design period of 30 years. Such a procedure is neither equitable nor expedient, particularly when local finances are unable to shoulder the financial commitments even against the initial installations of such projects.

6.14.4 PIPELINE COST UNDER DIFFERENT ALTERNATIVES

There are three independent factors bearing on the problem viz., the design period usually limited to a maximum of 30 years, the loan repayment period of 30 - 40 years and the life of the pipeline which may be anything from 50 to 100 years. There is one particular pipe size for which cost should be minimum, considering its capital and maintenance charge, for the loan repayment period. The size of the pipe will be larger if the period considered is the life of the pipeline and this larger size would appear to be less economical if the period is restricted to the loan repayment period.

The issue, therefore, hinges on which size to choose out of the two in a particular project. Whichever size is adopted, the loan therefore has to be repaid, within the specified period, long before the pipeline ceases to be of use. For the investor, the pipe size which will cost him the minimum is the criterion, pipe costs and maintenance being considered over the loan repayment period. The other size based on the life of the pipe material would cost him additional financial burden although it may be the cheapest when considered over the life period of the pipeline.

The sale price for the water will have to be based on the financial obligations on the repayment of the loan and the maintenance costs. The period of repayment of the loan thus enters into the question and the consumer will have to pay a higher price if the comparison is based on the life time of the pipe and not on the loan repayment period or the design period, as the case may be.

The life period of the pipeline as also other components would become a more rational factor when the project is financed entirely from perpetual public debts to be incurred by the promoters and the community pays back in perpetuity against loans raised from time to time

for additions, alternations and expansions needed.

Whether the pipe size is based on the loan repayment period or the lifetime of the pipe, its utility to the community will be there even after repayments of the loan. Since the incidence of the financial burden on the consumer will be less in the former case, the method is to be preferred.

6.14.5 RECURRING CHARGES-DESIGN PERIOD VS. PERPETUITY

Annual recurring charges on energy and operation and maintenance are perpetuity, irrespective of the design period or the life of the pipeline. Their capitalized value is restricted to the design period or the loan repayment period whichever is greater, as reflecting the commitment involved relevant to such period for a proper comparison between alternatives. Otherwise a possible method may be to consider an initial investment which would yield an interest to meet such recurring charges in perpetuity. It is, however, more rational to consider capitalization of the recurring charges over the design or loan repayment period.

6.14.6 CAPITALISATION V/S ANNUITY METHODS

In 6.14.2(v), the comparison suggested was on the basis of present capitalized value. In the alternative, the capital installation cost of the pipeline could be converted into an annuity for the design period, or loan repayment period whichever is greater, in the same way as a loan discharged through annuities and such annuity added on to the other annual recurring charges for a total comparison between the alternatives.

6.14.7 SELECTION

The method suggested in 6.14.2 would give a comparative idea of the total capital investment involved whereas the method suggested in 6.14.6 would indicate the annuities involved as between the alternatives. A better concept is perhaps afforded by the former method.

The most economical size of a main can be arrived by evaluating the capital and maintenance cost (capitalized value) for different diameters. Mathematical solution is also possible. The objective (cost) function is formulated to ensure desired system performance. Several optimization techniques are available for minimizing the objective function. One of the simpler methods is one in which its (objective function) first partial derivatives with respect to the several decision variables are set equal to zero. The resulting system of equations is solved exactly or approximately and the principal minors of the determinant of second partial derivatives are investigated to ascertain whether a maximum or minimum is involved (see Appendix 6.5).

While determining the type of the pipe material to be used, alternative alignments, cost of cross drainage works, cost of valves, specials and other appurtenances, should all be

considered to determine the most economical size for the conveying main.

6.15 CORROSION

Causes of corrosion and the protective and preventive measures have been discussed in 9.8.

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.

The valve usually takes the form of a rigid buoyant vulcanite or rubber-covered ball seated on a rubber or metal ring. The sealing element i.e., the ball is slated against an opening at the top of the valve when the pipe is full and seals the opening. When the pressure inside the pipe falls below external pressure, the ball drops thereby permitting air to be drawn into the pipe. The valves are mainly available in two forms, either single-ball or double ball. The single ball type can have either a large orifice or a small orifice, the former being only suitable for emptying and filling of pipelines and latter for discharging small quantities of entrained air. Double air valves are available which can be classified as dual purpose with a large orifice and small orifice in one unit, with a common connection to the main. For large aqueduct pipelines, a triple orifice air valve is available with two large orifices and one small. For high pressures, stainless steel floats are used instead of the vulcanite-covered balls.

Special designs of air valves are also available which operate satisfactorily with high-velocity air discharges. If normal air valves are used under these conditions, there is a danger that the ball might be carried on to its seat by the air stream before the accumulated air has been fully released.

Air valves can be provided with an integral stop valve or alternatively and preferably, a standard sluice valve can be bolted to the inlet flange, which must be of adequate size for its duty. Regular maintenance checks on atleast an annual basis should be carried out to ensure that the balls are free to move and that the seats do not leak. If an air valve is isolated for any reason in very cold weather, the body should be drained to prevent frost damage; a plug cock can be fitted at the base of the body for this purpose. Trapped chamber drainage is essential to prevent any possibility of stagnant or polluted water or air entering the pipeline.

Automatic air valves in urban streets present a serious contamination risk, since they must have air vents that could, in some circumstances, admit polluted surface water. Constructing an air valve chamber as water tight as possible and fitting a ball valve interceptor as an outlet to a storm water sewer is a practice to obviate this possibility. Using manually operated air

valves in the streets, it being the routine duty of a turncock in the area to air the main, to minimize the risk of serious contamination, is yet another practice.

The following ratios of air valves to conduit diameter provide common but rough estimates of needed sizes:

For release of air only 1:12

For admission as well as release of air 1:8

An analysis of air-inlet valves for steel pipelines, Parmakian takes the compressibility of air into account and combines equations for safe differential pressures of cylindrical steel pipe, pipeflow, and air flow, in the following approximate relationships:

$$d_a/d = 1.99 \times 10^{-2} \sqrt{\Delta V/C} \left[1 - \frac{P_2}{P_1} \times 0.288 \right] - 0.25 \quad (6.15)$$

for $P_2 > 0.53 P_1$ and as

$$d_a/d = 3.91 \times 10^{-2} \sqrt{\Delta V/C} \left(\frac{P_2}{P_1} \right)^{0.356} \quad (6.16)$$

for $P_2 \leq 0.53 P_1$, because air flow cannot increase beyond a critical differential of 0.488 Kg/cm².

In these equations, d_a and d are respectively the diameter of the air orifice and pipe, ΔV is the difference in the velocities of flow on each side of the inlet valve, C is the coefficient of discharge of the valve, and P_2 and P_1 , are the pressures inside and outside the pipe respectively, with $P_1 - P_2$ not exceeding one half the collapsing pressure as a matter of safety.

The equations apply strictly only to elevations of 304.8m above mean sea level at 40 degrees latitude ($g = 9.81$ mps) temperatures of 25.32°C, 20% humidity, an adiabatic expansion for which $pv^n = pv^{1.40}$, the air occupying a volume of 0.87 cum/Kg.

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 vacuum 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 (vacuum 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 vacuum. 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 value 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

bypass valve alongside the main valve and provision of automatic control arrangements for the main valve to close first at a fairly rapid rate, followed by the smaller bypass valve at a much lower speed.

6.16.13 VENTURIMETERS

These are used to measure the flow in line and are discussed in 4.3.1.1.

6.16.14 SPACING OF VALVES AND INTERCONNECTIONS

The pipeline should be divided into sections by valves to avoid the necessity of emptying the whole pipeline in case of repair, each section being provided with an air valve and scouring facilities. The need for scour should be particularly borne in mind when layout of the pipeline and siting of the valves is finalized, as they cannot always be arranged in the best position due to likely difficulty in disposing of the discharge. They are necessary for scouring the mains and hence should be in proportion to the size of the main.

It is desirable to have valves close together in more densely built up areas. Ease of access to the valves is also important as the time taken in shutting of a valve in an emergency may be mostly spent in reaching it. In gravity mains, automatic valves, self-closing if pipe bursts, may also be provided for protection to property as well as to prevent excessive wastage of water.

Where there is more than one pipeline, they should be interconnected at each site of main valves, so that only shortest possible length of one pipeline need be put out of commission at a time. The interconnection will entail only negligible loss of head if its area is not less than two-thirds that of the largest main.

Also, when two or more mains are connected in parallel, the scours may be interconnected so that either main can be refilled from the other while the master valve is shut. Charging through a scour can be done speedily with less risk than charging over a summit, the danger of surging from trapped air being much reduced.

Bypasses around the main valves are convenient for regulating the flow during the charging or emptying of a pipeline and may be a part of the main valve itself, or arranged as a connecting between tees on each side of the valve. Bypasses may also be essential in order to balance up pressures on each side of the main valve before attempting to open it up.

6.16.15 MANHOLES

Access manholes are spaced 300 to 600m apart on large conduits. They are helpful during construction and serve later on for inspection and repairs. Their most useful positions are at summits, discharges and downstream of main valves. They are less common on cast iron and asbestos cement lines than on steel and concrete lines.

6.16.16 INSULATION JOINTS

They are used to introduce resistance to the flow of stray electric currents along metallic pipelines and may help in the control of electrolysis. Modern insulation joints make use of

rubber gaskets or rings and of rubber covered sections of pipe if they are sufficiently long to introduce appreciable resistance.

6.16.17 EXPANSION JOINTS

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

6.16.18 ANCHORAGES

Anchorage 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 (shearing) 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. The unbalanced static pressure at ends computed by the expression $1/2 \pi d^2 p \sin \alpha/2$ with the two component pressures in the direction of each pipe leg being $1/4 \pi d^2 \alpha p$ (where d = dia of pipe, α = degree of bend and p the water pressure in the pipeline) is compared with the magnitude of the resistance of the pipe joint (which is 14.06 Kg/cm² for lead joint) and anchorages are designed to resist the balance force. Horizontal thrust F at Bend = $2 A \beta \sin \alpha/2$, where β = internal pressure in Kg/cm², A area of pipe in sq cms, and α is angle of deviation of pipe in degrees.

Anchorage take many forms. For bends, both horizontal and vertical they may be designed as concrete buttresses or 'Kick blocks' that resist the unbalanced pressure by their weight, in much the same manner as a gravity dam resists the pressure of the water that it impounds. The resistance offered by the pipe joints themselves, by the friction of the pipe exterior and by the bearing value of the soil in which the block is buried may be taken into consideration if the cost of the block is to be a minimum. Steel straps attached to heavy boulders or to bedrock are used in place of buttresses where it is possible and convenient to do so.

The unbalanced thrust may be counteracted by longitudinal tension in an all-welded pipeline, or by a concrete thrust block bearing against the foundation material. In the case of a jointed pipeline the size of the block may be calculated using soil mechanics theory. In addition to frictional resistance on the bottom of the thrust block and the circumference of the pipeline, there is a lateral resistance against the outer face of the pipe and block. The maximum resisting pressure a soil mass will offer is termed the passive resistance and is given by

$$fp = \gamma_s \cdot h \left[\frac{1 + \sin \theta}{1 - \sin \theta} \right] + 2C \sqrt{\frac{1 + \sin \theta}{1 - \sin \theta}} \quad (6.17)$$

The lateral resistance of soil against the thrust block

$$F_p = \gamma_s \frac{H^2}{2} L \left[\frac{1 + \sin \theta}{1 - \sin \theta} \right] + 2CHL \sqrt{\frac{1 + \sin \theta}{1 - \sin \theta}} \quad (6.18)$$

This maximum possible resistance will only be developed if the thrust block is able to move into the soil mass slightly. The corresponding maximum soil pressure is termed the passive pressure. The minimum pressure which may occur on the thrust block is the active pressure, which may develop if the thrust block were free to yield away from the soil mass.

$$f_a = \gamma_s h \left[\frac{1 - \sin \theta}{1 + \sin \theta} \right] - 2C \sqrt{\frac{1 - \sin \theta}{1 + \sin \theta}} \quad (6.19)$$

F_p, f_p = Lateral resistance of soil against the thrust block in tons,

f_a = Lateral resistance of soil against the projection of pipe in tons/m²,

γ_s = soil density in T/m³,

h = depth in m,

θ = angle of friction in degrees,

C = cohesion of soil in N/m²,

($C = 0$ for gravel and sand, 0.007 for silt, 0.035 for dense clay, and 0.15 for soft saturated clay),

H = height of thrust block in m,

L = the length of thrust block in m,

The active pressure is considerably less than the passive pressure and will only be developed if the force on which it is acting is free to move away from the soil exerting the pressure.

A thrust block should be designed so that the line of action of the resultant of the resisting forces coincides with the line of thrust of the pipe. This will prevent overturning or unbalanced stresses. This may best be done graphically or by taking moments about the centre of the pipe. Anchor blocks for expansion joints can also be designed on the basis of I.S.5330-1984.

Thrust blocks are needed not only at changes in vertical or horizontal alignment of the pipeline, but also, at fittings that may not be able to transmit longitudinal forces such as flexible couplings.

When laying a pipe parallel to an existing pipe, the trench excavation for a bend would deprive the existing pipe of the needed support. The simplest solution is to stop the flow in the original pipe while the work is carried out and a new thrust block is constructed, but

where this is not possible, one alternative is to anchor the thrust block of the original pipe to an anchor block of concrete by means of steel bars. Another method is to provide additional support by piling on the outside of the bend before excavation commences. It is advisable to avoid sharp bends above 45° and in soft ground it is better not to put two bends together but to separate them by at least a length of straight pipe. Cast iron pipes and fittings can be cast with lugs through which tie rods are passed when it is desired to prevent movement of the pipe. Where steel pipes with welded joints are used, full anchorage is not generally necessary, since the longitudinal continuity of the pipe is capable of distributing the forces into the ground. If the pressures are high enough to merit it and sleeve joints are being used, the joints on the bends and on two pipes either side of them should be fully welded inside and outside and the trench refilled with concrete to 150mm above these pipes and bends. About half the thrust will be taken by the weight of the concrete and the remainder by the longitudinal stress in the pipes. In order to restrain the motion of steel pipes or force it to take place at expansion joints that have been inserted for that purpose, the pipe may be anchored in much the same way as described for bends. Due attention must be paid to the bounding of the pipe to the anchors. Pipes laid on steep inclines should be anchored by transversed blocks or other precautions taken to prevent slippage and measures to overcome unbalanced pressures provided.

In the absence of expansion joints, steel pipes must be anchored at each side of gates and meters in order to prevent their destruction. Where gate chambers are used, they may be so designed, of steel and concrete, that they hold the two ends of the steel line rigidly in place. In the absence of anchors, flanged gates are sometimes bolted on one side and the other side to a cast iron nipple that is connected to the pipe by means of a sleeve or expansion joint. See Figure 6.1 for typical Thrust Block and Appendix 6.6 for a worked out example.

6.17 WATER HAMMER

6.17.1 OCCURENCE

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 rise or water hammer is manifest 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 place 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 reverses and surges back and forth through the pipe, getting weaker on each successive reversal. The velocity of the wave is that of ^{sound} 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 mentioned above.

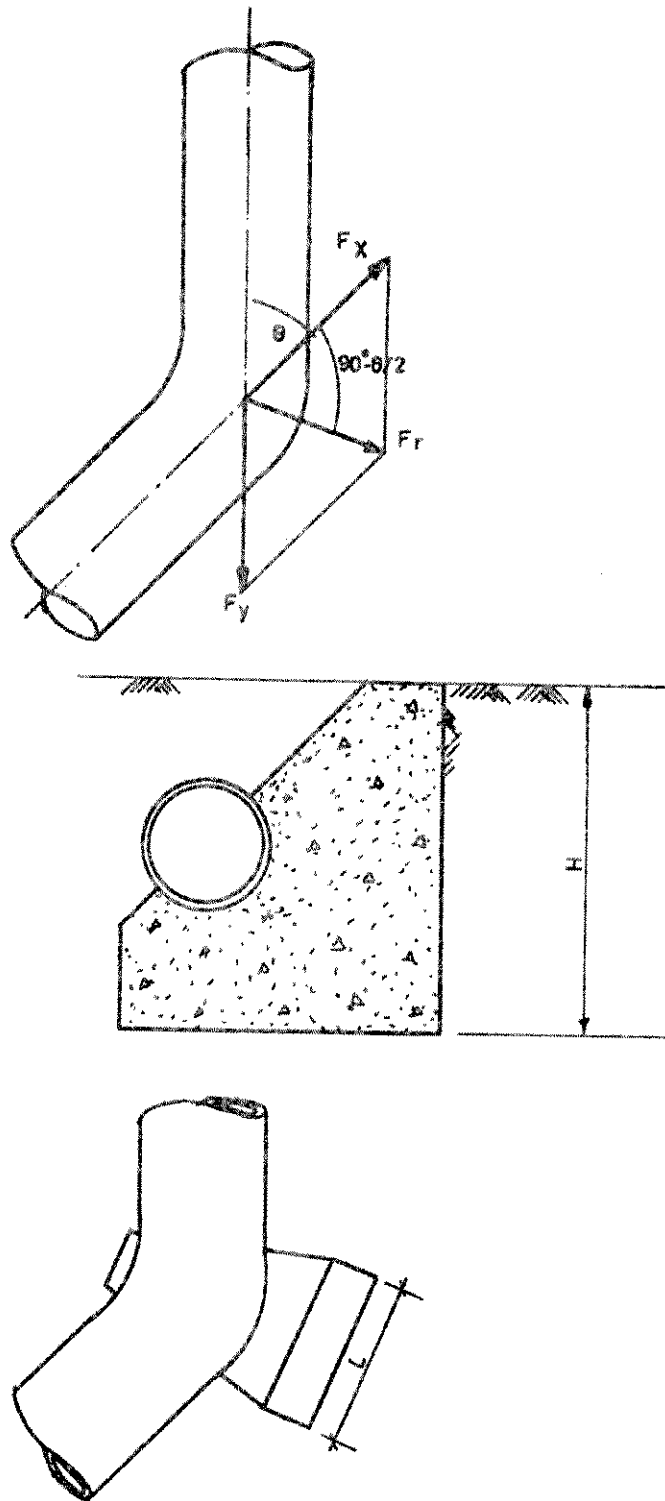


FIGURE 6.1 : THRUST AT A BEND & THRUST BLOCK

6.17.2 COMPUTATIONS

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

$$H_{\max} = \frac{C \cdot V_0}{g} \quad (6.20)$$

Where,

H_{\max} = maximum pressure rise in the closed conduit above the normal pressure in m |

C = velocity of pressure wave travel in m/s,

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

V_0 = normal velocity in the pipeline, before sudden closure in m/s

$$C = \frac{1425}{\sqrt{1 + \frac{kd}{EC_t}}} \quad (6.21)$$

Where,

k = bulk modulus of water ($2.07 \times 10^8 \text{ kg/m}^2$)

d = diameter of pipe in m,

C_t = wall thickness of pipe in m and

E = modulus of elasticity of pipe material in kg/m^2

Table 6.7 gives values of E that may be adopted for different materials:

TABLE 6.7 : VALUES OF E FOR DIFFERENT MATERIALS

Material	E (Kg/m^2)
Polyethylene – soft	1.2×10^7
Polyethylene – hard	9×10^7
P V C	3×10^8
Concrete	2.8×10^9
Asbestos Cement	3×10^9
Reinforced Cement Concrete	3.1×10^9
Prestressed Concrete	3.5×10^9
Cast Iron	7.5×10^9
Ductile Iron	1.7×10^{10}
Wrought Iron	1.8×10^{10}
Steel	2.1×10^{10}

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.

In some cases a surge relief is called for, at or near the outlet end of the line. Depending on the size of the line and the pressures involved, this may be an air chamber, a relief valve, or an open overflow which lets the oncoming water spill out of the pipeline above some pre-determined elevation. Although provision for surge at the outlet end of the line will not necessarily prevent all reversal of flow, it does tend to cushion shock there and at the same time decreases the magnitude of the reversal that is thrown back toward the pump.

Two devices can be provided for cushioning shock in the discharge line at a pump. The first concerns the check or other form of non-return valve at the pump. The ordinary swing-check valve tends to slam shut on reversal of flow, thus causing unnecessarily severe shock pressure. This trouble can be reduced by using a non-slam filling-disc check-valve, or some form of power operated valve which is controlled by a relay actuated from the power circuit or discharge pressure at the pump. Immediately on power interruption, the relay acts to start closing the valve whose operating mechanism can be timed to complete closure before reversal of flow can take place. In some cases a spring closing device can be used successfully on a swing-check valve to ensure having the tap close before back surge can start.

Although the aforesaid devices obviate the slamming to be expected with an ordinary swing check, they cannot prevent a considerable rise in pressure when reversal of flow is stopped at the closed valve. Hence, a sound device in the nature of a supplement is required which may take the form of an air chamber or a relief valve of ample size. Air chambers sometimes perform more effectively when damped with orifices or check-valves in the connecting pipe.

The necessity of replenishing the air in air chambers should be recognized in considering their use as water hammer suppressors. In some cases, restricting the passages between the pipeline and the air chambers increases the effectiveness of a given size of air chamber. Suppressors as a general rule, do not eliminate shock entirely but will reduce it by 10% to 40%, which often is sufficient to remove the clanking sound.

A pressure vessel with air cushion can serve as an automatic water accumulator. The effective volume that can be taken from the vessel depends on the switching on and switching-off pressures. Owing to the fact that water absorbs some of the compressed air that forms the air cushion, fresh air has to be introduced into the vessel from time to time. This can be done by means of a small compressor or, in the case of small units, a self-priming pump which is capable of dealing with water and air, the latter entering through a small adjustable intake in the pump suction branch.

The effective capacity of a pressure reservoir necessary for an automatic pumping plant is governed by the permissible switching frequency of the electric equipment and by the pump capacity. As a rule, the pump capacity must be such as to cover, by itself, the highest consumption expected.

✓ Pumps with steep head/flow characteristic often induce high starting pressures when the power is switched on. This is because the flow is small (or zero) when the pump is switched on, so a wave with a head equal to the closed valve head is generated.

By partly closing the pump delivery valves during starting, the starting pressures can be