TECHNICAL INFORMATION

POLIPLEX® PE100

HYDRAULIC DESIGN

PRESSURE PIPELINE DESIGN FOR WATER AND SEWERAGE

FITTINGS

Permanent POLIplex® pressure pipeline systems will usually incorporate bends, tees, tapers, tappings and flange connectors. When welded to pipes or used with compression joints, these fittings do not require the thrust blocks necessary for rubber ring jointed systems.

AIR VALVES AND ANTI-VACUUM VALVES

Air must be expelled from a pressure pipeline during the filling operation and also allowed to enter the pipeline if it is being emptied for any reason.

Water can carry substantial quantities of dissolved gases in solution. As water moves through a pipeline the hydraulic gradient may lead to a reduction of the internal pressure. The dissolved air will then be partially liberated, collecting at the high points of the system. Air accumulations have the effect of lessening the effective pipe diameter leading to reduced discharge or increased friction head. In extreme situations the flow may actually cease (see Fig. 1.1). Pressure surges of high magnitude may also result from the unstable flow conditions created by 'slugs' of air moving along the pipeline.

An automatic air valve is comprised of a ball float confined in a chamber with an orifice to atmosphere at the top and connection to the pipeline at the bottom. When the chamber is full of water the ball floats into and seals the orifice, but when air from the line enters the chamber or the pressure drops below atmospheric, the ball drops opening the pipeline to the atmosphere. It remains open until water refills the chamber after air is bled from the line.

Where the hydraulic grade is close to the high point of a pipeline, a simple vent tube extending above the grade line may be used as an air valve.

Manual air valves or ordinary stop cocks may suffice on short pressure mains or for a trial period to determine whether the expense of an automatic valve is warranted. On reticulation mains with numerous services and fire hydrants, there is usually no need for air valves as air is bled from the main during normal draw off from hydrants and services.

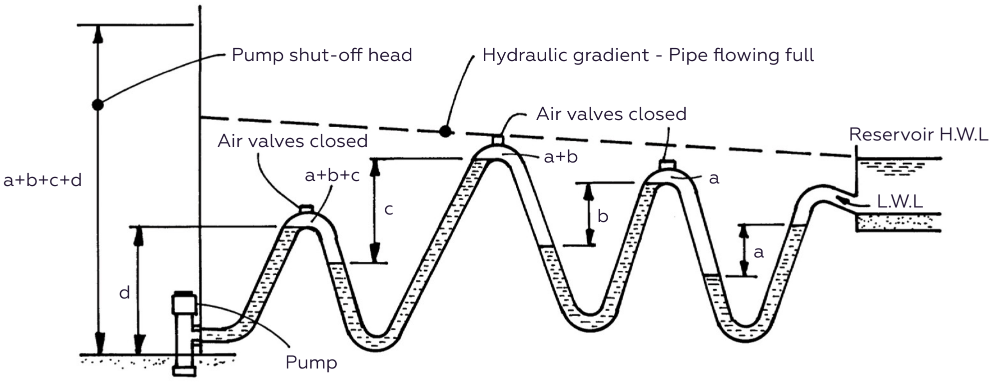

Fig 1.1 Complete flow stoppage due to air pockets

HYDRAULIC DESIGN

LOCATION OF AIR VALVES

The air (and other gases) periodically released from solution by temperature or pressure changes will accumulate at many of the ‘peaks’ in a pipeline. For this reason, sudden unplanned changes in elevation in a pressure pipeline during construction should be avoided. Pipes should be laid evenly to grade between peaks to ensure that all possible locations of potential air pockets can be established and vented. Potential troublesome ‘peaks’ are sometimes best identified by reference to the hydraulic gradient rather than to a horizontal datum.

Generally the large orifice diameter should be at least 0.1 of the pipe diameter. The volume rate of flow air through an orifice is roughly 40 times that of water under the same pressure differential.

The following is a list of typical conditions where air valves may be found necessary.

1. Where a section of pipeline
   (a) runs parallel to the hydraulic gradient.
   (b) or has a long horizontal run, double air valves are required at the end of the run, and single air valves at every 500-1000 metres of run.

2. Where a pipeline peaks above the operating hydraulic gradient but below the higher (source) level, air can be expelled at this point by installing a manually operated gate valve (not an air valve) which is opened when the lower (outlet) level valve is closed. This operation should be carried out at regular intervals. Should a pipeline peak above the higher (source) level, syphoning will be needed for flow to continue and special provision may have to be made to remove air, such as a vacuum pump. It is recommended that peaks above the hydraulic gradient, or the source level, be avoided if possible.

3. Where abrupt changes of grade occur on both upward and downward slopes, a small orifice air valve should be sufficient.

4. During long ascents, large orifice air valves are required at 500-1000 metre intervals.

5. During long descents, double air valves are required at 500-1000 metre intervals.

6. A large orifice valve is required on the downstream side of section valves in trunk mains, or if the flow is in both directions, on both sides.

HYDRAULIC DESIGN

In large diameter pipelines (e.g.DN 630 or greater), consideration should be given to the hydraulic conditions at flow capacities significantly below the maximum design figures, i.e. where the pipeline flows partially full or as 'open channel' flow. Hydraulic jumps will occur in some sections of the pipeline and where the downstream portion of a jump completely fills the pipe, air may accumulate further downstream. This should be removed from the pipeline by suitably placed vents. A series of interconnected tappings which permit air to return to the air space upstream of the jump may be appropriate (see Fig. 1.2).

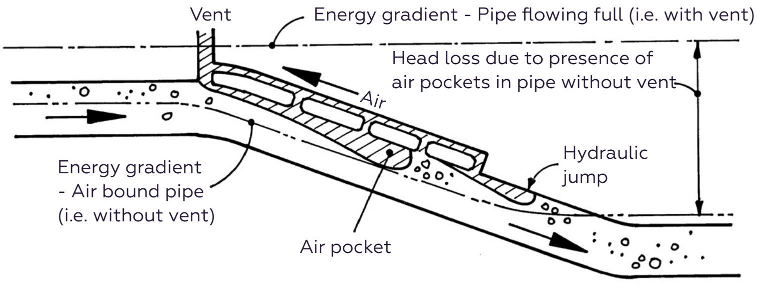

Fig 1.2 - Hydraulic jumps require additional vents

AIR VALVE INSTALLATION

Small air valves are usually installed on a short length of threaded metal pipe which in tum is mounted on a flexible tapping band or elongated mechanical joint. The larger double air valves are bolted to flanged branch tees.

Where air valves are required on mains of major importance, it is good practice to install an isolating valve to permit servicing of the air valve without closing down the main. Air valve assemblies often incorporate these valves. Under operating conditions, care should be taken to ensure that this valve is always left in the open position.

TYPES OF AUTOMATIC AIR VALVES

SINGLE AIR VALVES

The Single Air Valve, with a small orifice (Fig. 1.3), is used to release small quantities of air which may accumulate in a charged water main. Although designated by the size of the inlet connection, typically 25mm, this does not directly relate to the orifice size which may be of the order of only 3mm.

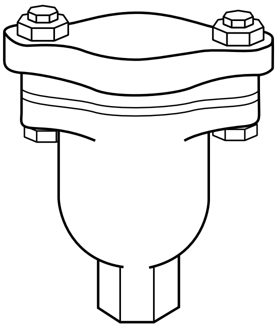

Fig 1.3 - Single Air Valve

HYDRAULIC DESIGN

DOUBLE AIR VALVES

The Double Air Valve, with small and large orifices in separate chambers (Fig. 1.4), performs the dual function of releasing small quantities of air as it collects (similar to the Single Air Valve), and admitting or releasing large volumes of air when a pipeline is emptied or filled. They are designated by their inlet connection although the large orifice diameter is usually slightly smaller. Sizes range from 50mm to 100mm.

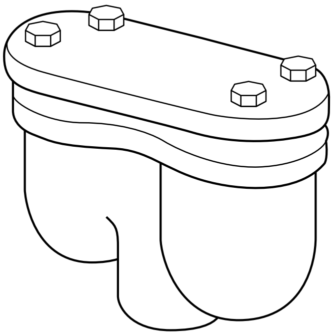

Fig 1.4 - Double Air Valve

KINETIC TYPE AIR VALVES

A difficulty sometimes experienced with large orifice air valves is that the ball tends to blow shut when a water main is being filled quickly. Under these conditions a pressure differential of 100 kPa can lead to air velocities approaching 300m/sec, i.e. the speed of sound. The Kinetic Air Valve has a float chamber constructed in such a way that air expelled from a rapidly filling main cannot blow the valve shut, however high the emergent air velocity.

ANTI-VACUUM VALVES

Anti-vacuum valves have the primary function of preventing the formation of a vacuum in large diameter water mains e.g. hydro-electric penstocks. They are much larger in size than conventional air valves owing to the low pressure differential with orifice sizes ranging from DN200 to DN500. The corresponding air flows at 50% vacuum will range from 5m^3 per second to 50m^3 per second respectively.

SCOUR VALVES

Scouring points located in depressions along a pressure main are essential so that the line can be drained for maintenance purposes and possibly sediment removal. Flanged branch scour tees with branches set at or below invert level are necessary for best results.

HYDRAULIC DESIGN

TABLE 1.1 TYPICAL SCOUR SIZES

DN	SCOUR DIAMETER
200-280	80
315-400	100
450-560	150
630-800	200

The discharge from a scouring point is usually piped to a nearby stormwater drain unless the effluent will cause pollution. In such cases a detention tank should be provided so that foul water can be removed by tanker.

SURGE & WATER HAMMER EFFECTS

Water hammer or pressure surging will occur in all gravity or pumped pipelines as a result of flow variations. The basic classical equations are given in this section using the following symbols:

a = celerity of pressure wave (mis)
d = internal pipe dia. (mm)
E = modulus of elasticity of the pipe material (Pa)
g = acceleration due to gravity (m/sec^2)
ΔH = change in pressure head (m)
H_0 = initial head (m)
K = liquid bulk modulus (Pa)

L = length of pipeline (m)
t = pipe wall thickness (mm)
T = total time
ΔV = change in liquid velocity (m/sec)
V_0= initial velocity (mis)
ρ = liquid density kg/m^3
μ = return period of pressure wave (sec)

Transient pressure surges due to gradual changes in flow are of limited magnitude. They can be estimated using 'rigid column' theory which ignores the elasticity of the pipes and the liquid, and is based on inertial effects only using Newton's second law. The equation for this theory is:

$$\frac{-\,LdV}{gdt} = \Delta H \qquad \textit{Eqn. 1.1}$$

For a linear effective rate of valve closure (a uniform negative rate of velocity change), in a pipeline of constant diameter, at the moment of closure the increase in head is:

$$\Delta H = \frac{LV_0}{gT} \qquad \textit{Eqn. 1.2}$$

HYDRAULIC DESIGN

Sudden changes in flow velocity can cause shock waves or water hammer within the pipeline of sufficient magnitude to cause damage. In such cases calculations must be made using 'elastic column' theory. The usual causes of water hammer are the opening and closing of valves, or the starting and stopping of pumps, especially where this is the result of power failure.

This phenomenon and its control are described in a text called 'Water Hammer' prepared by T.Webb and B.W.Gould for James Hardie & Company Pty Limited and published by the University of N.S.W. Press. For the purpose of this manual, however, some simple background theory is given here.

An approximate relationship for the pressure variation at a given point in a straight pipeline with negligible friction loss resulting from a change in fluid velocity can be calculated from Joukousky's formula:

$$\Delta H = \frac{a \, \Delta V}{g} \qquad \textit{Eqn. 1.3}$$

Joukousky's law applies when the change of velocity takes place within a critical time of:

$$\mu = \frac{2L}{a} \qquad \textit{Eqn. 1.4}$$

The surge celerity in a pipeline filled with liquid can be determined for homogeneous materials by:

$$a = \sqrt{\frac{1}{\rho\left[\frac{1}{K} + \frac{d}{Et}\right]}} \qquad \textit{Eqn. 1.5}$$

A graph showing the celerity to SDR relationship for various commonly used pipeline materials carrying water is shown in Fig. 1.1. The values for the short term elastic moduli for the thermoplastics materials shown are:

Polyethylene = 1000MPa
PVC = 3000MPa
and bulk modulus of water = 2031 MPa

It should be noted that polyethylene celerities lie in the range 150 to 300m/s which is 12 to 24% of iron pipe values. The correspondingly low water hammer pressures are the reason for PE being used in plumbing installations where water hammer effects are likely to be a nuisance.

HYDRAULIC DESIGN

TYPICAL CAUSES OF WATER HAMMER

Operational conditions which sometimes lead to water hammer problems are illustrated in Fig 1.6. This shows a pipeline with both hydraulic gradients (due to steady state flow) and water hammer pressure envelopes sketched to demonstrate their relative significance in some circumstances. The pipeline is comprised of two sections AB and BC, being gravity flow and pumped flow respectively. The surge characteristics of pipeline AB are similar, irrespective of whether a valve or pump at B changes the flow rate. The changes in operation to be considered are:

Event 1 - Valve Closure or Pump Stop (At B in line AB)

Water hammer in pressurised systems often results from the sudden operation of a valve. A "sudden closure" in this context means the closing of a valve in a time equal or less than m of Eqn 1.2. To mitigate these effects the Manual of British Water Engineering Practice recommends that the time to close the last tenth of travel of a shutting valve should occupy at least 10 μ, i.e. 10 x wave return period. For POLIplex® this corresponds to approximately 100 seconds for each kilometre of pipe length.

Event 2 - Valve Opening or Pump Start (At B in line AB)

A sudden opening of a valve will also generate a surge initially of negative pressure. This may result in water column separation and the subsequent rejoining impact can damage pipes and equipment.

Event 3 - Pump Start-up (At B in line BC)

The pressure rise associated with the starting of a pump in a fully charged pipeline is a function of the rate of acceleration of the pumping unit and the characteristics of the pump. The surge pressure will not exceed the pressure of the head/flow characteristic curve of the pumps and is generally not a problem. Where the pipeline is empty prior to start-up the flow should be restricted by a control valve at the pump. A safe rate of filling would be the equivalent of a velocity of 0.05m/sec.

Event 4 - Pump Shut-down (At B in line BC)

A sudden pump shut-down such as may be caused by a power failure is a frequent cause of water hammer problems. The negative surge pressures may result in sub-atmospheric pressures in the pipeline, separation of the water column and subsequent rejoining with high positive surge pressures sufficient to damage pipes and equipment.

WATER HAMMER CONTROLS

These may take the form of motorised valve operation, surge control valves, surge towers, one-way surge tanks, air chambers, pump flywheels and staged start-up and shut-down of pumps. The judicious use of these devices to reduce surge magnitudes can permit substantial reductions in pipeline costs through the use of lower classes of pipes. Professional advice is essential to obtain the optimum solution in any particular case as every pipeline is different. Modem computer software can give accurate predictions of transient flow behaviour.

In the case of the example (in Events 2 and 4) in Fig 1.6, the negative surges at X and Y could be prevented by the use of controls such as one-way surge tanks. These can eliminate separation of the water column and the accompanying, possibly complex/severe secondary surges.

HYDRAULIC DESIGN

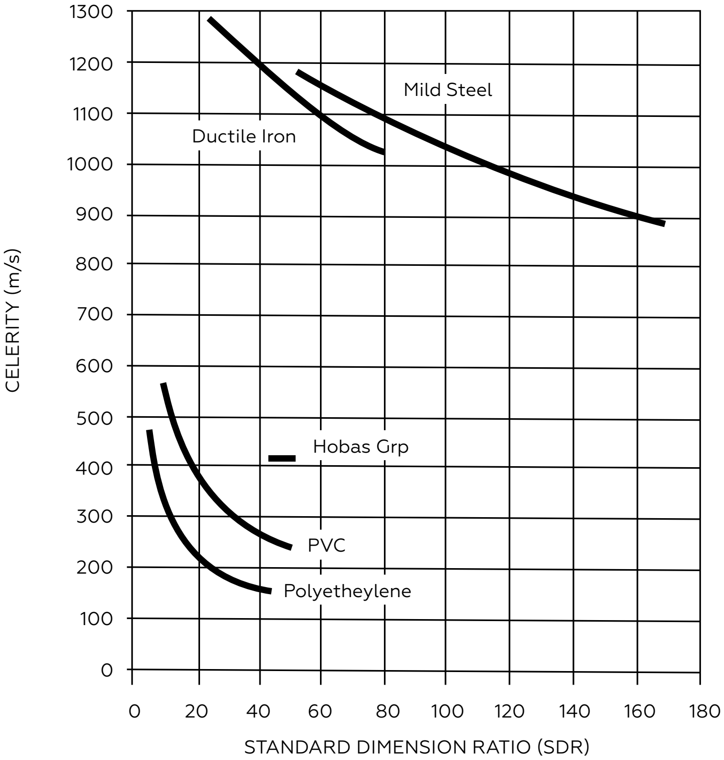

Figure 1.5 Water hammer surge celerity for various SDR values and materials

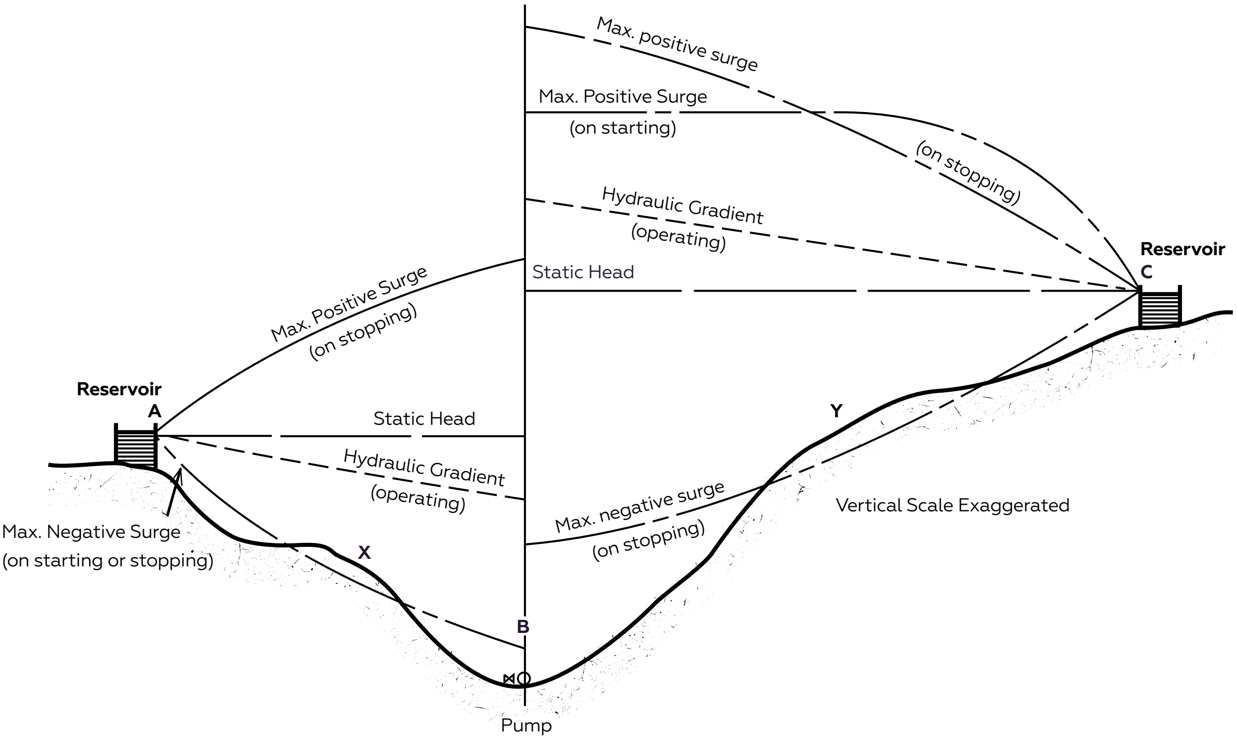

Figure 1.6 Surges in a typical pumped pipeline

HYDRAULIC DESIGN

SURGE AND FATIGUE LIMITS

There have been no reported failures of PE pipes which can be attributed to surge or fatigue effects. However due to problems in the UK in the 1970s with PVC, now attributed to poor quality material especially in respect of its toughness, surge effects were examined by J.J.Stapel (see Pipes and Pipelines International Feb '77 and April '77 issues) and others. It was found that water supply reticulations are often subjected to cyclical pressure changes of significant amplitude and frequency. Laboratory research at the time appeared to show a reduction in strength where PVC was subjected to rapid repetitive stressing although it is now suggested that heat generated during the accelerated testing contributed to this.

The British Code of Practice CP312: Part 2: 1973 (AMD 2337 Sept '77) 'Unplasticised PVC pipework for the conveyance of liquids under pressure' therefore took a conservative approach and recommended a limit of total surge pressure variation from minimum to maximum of 50 percent of the maximum allowable pressure of the pipe class.
For example, this maximum allowable variation in the case of a PN 10 pipe could range between 0.5 MPa and 1.0 MPa. or between 0.25 MPa and 0.75 MPa. Negative pressures as low as minus 0.05 MPa could derate a PN 10 pipe to 0.45 MPa maximum. As there had been minimal research on 2nd and 3rd generation polyethylenes the Water Research Centre of the UK adopted the same recommendation for these materials pending further investigation.

Now, according to the latest Draft (version 2.2) Information and Guidance Note of the UK Water Industry and Engineering and Operations Committee on 'Design against Surge Conditions for Plastic Pipes' more recent research on the behaviour of modern high toughness PVC and PE pressure pipes has shown that, in the opinion of the committee, this conservative position is not in the best interests of the water industry.

It is important to differentiate between surge which is defined as a very short term overload combined with a rapid loading rate, and fatigue which is associated with cyclical loading where the stress oscillates rapidly about a mean level. That is surge and fatigue should be treated as separate phenomena.

Plastics such as polyethylene subjected to rapid loading rates are stronger and stiffer than they are at lower loading rates. Figure 1.7 shows this effect on MDPE under both biaxial and uniaxial stress. The converse is also true as has been explained in Section 3.8 which deals with the subject of longer stress-time regression testing. The UK Guidance Note concludes that PE can withstand very short term overpressures of 2.9 times the static pressure rating.

Beech et al* have determined that surge rates in PE will not exceed 800 kPa per second. They also confirm that modern polyethylene materials have a higher resistance to fatigue than other polymers. It is their recommendation that transient pressures of up to 1.25 x class rating will not reduce the service life of PE 80 or PE 100 for at least 2 x 106 cycles.

** Reference: Beech, Headford, Hunt & Sandilands, "The resistance of polyethylene water systems to surge pressure" Plastic Pipes IX, Edinburgh Sept 1995.*

HYDRAULIC DESIGN

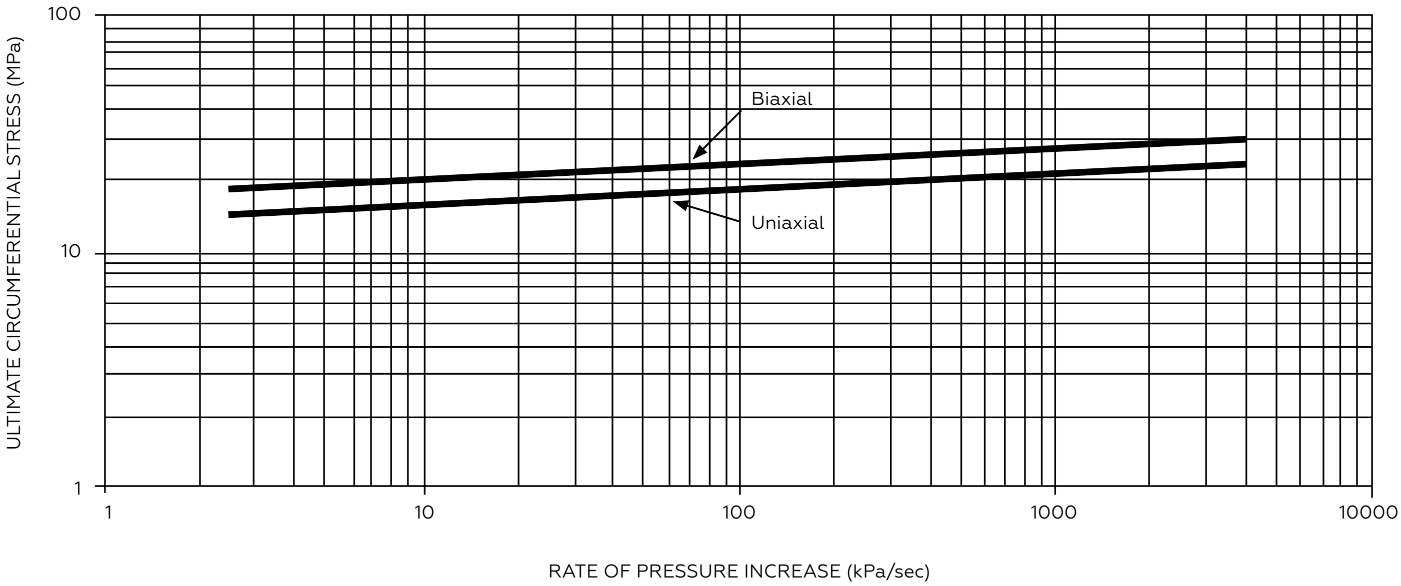

Figure 1.7 Pipe strength variation with rate of pressure increase (after Beech et al)*