# 5. DESIGN

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# PIPE SELECTION

## Static Stresses

- The ratio between the diameter and the wall thickness.
- The hydrostatic design stress (Sigma value) varies for the particular pipe material used.
- The duration of applied pressure over the pipeline lifetime.
- The pipe material service temperature.

The above must all be factored when designing for hydrostatic pressure conditions using the Barlow formula as follows:

$$T = \frac{PD}{2S + P}$$

Where
T = minimum wall thickness (mm)
P = working pressure (MPa)
D = maximum mean OD (mm)
S = design hoop stress (MPa)

The Dynamic loads normally considered during operation are:

- internal cyclic loading e.g. surge associated with pumping regimes or the rapid closure of valves; the amplitude (or range of surge pressure) should be limited to one half of the maximum allowable working pressure of the pipe.
- external cyclic loadings due to traffic conditions; the total pressure should not in any case exceed this rated pressure of the pipe.

# Hydrostatic Design Stress and Minimum Required Strength Values

## - for MDPE

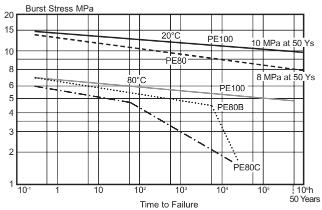
| Material Designation | Minimum Required Strength (MRS)MPa | Hydrostatic DesignStress (S) MPa |
|---|---|---|
| PE63 | 5.0 | 6.3 |
| PE80 | 6.3 | 8.0 |
| PE100 | 8.0 | 10.0 |

## - for PVC

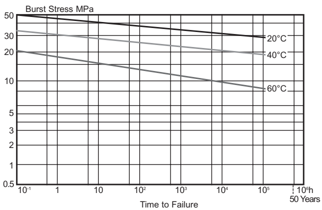
| Material Designation | Minimum Required Strength (MRS)MPa |
|---|---|
| up to 20mm nominal size - | 9.8 MPa |
| 25 to 150 nominal size - | 11.0 MPa |
| 175 nominal size and larger - | 12.3 MPa |

## Dynamic Stresses

Nominal working pressures assigned to the various classes of pressure pipes are based on the stress regression line principle for pipes subjected to constant internal pressure. It is well known that a form of failure due to material fatigue can arise if stress fluctuations of sufficient magnitude and frequency occur in any material.
Pressure pipes are capable of handling accidental events, such as pressure fluctuations due to a power cut. however, if repetitive surges are likely to exceed about 100,000 occurrences, which is equivalent to an average of one surge wave every four hours for the total life of the pipe, then fatigue is a possibility and a fatigue design should be considered. In most water supply lines this frequency of surges should never occur.
If stress peaks in excess of the design stresses are present, fatigue proceeds more rapidly and failure can occur earlier. For this reason peak pressures should not be allowed to exceed maximum recommended working pressures, including water hammer.




Principal stress/time curves for PE80 and PE100 pipes at 20°C and 80°C. The standard curve for HDPE Type 2 at 80°C (acc. to DIN 8075) is shown for comparison. The minimum required strength (MRS) at 20°C and 50 years is 10 MPa for PE100 and 8 MPa for PE80 giving the design stress 8 MPa and 6.3 MPa, respectively.




Stress/time curves for PVC at 20°C, 40°C and 60°C.

## FATIGUE RESPONSE

Studies of fatigue response have shown that a fatigue crack initiates from some dislocation in the material matrix, usually towards the inside surface of the pipe where stress levels are highest, and propagates or grows with each stress cycle at a rate dependent on the magnitude of the stress. Ultimately the crack will penetrate the pipe wall, extending from a few millimetres to a few centimetres long in the axial direction and will produce a leak. On occasion, particularly with larger pipes containing air entrained in the line, a large surge may cause unstable crack propagation and the pipe will burst.

It is important to appreciate that the growth of a fatigue crack is primarily dependent on the stress cycle amplitude, i.e. the maximum pressure minus the minimum pressure. Therefore a pipe subjected to a pressure cycle of zero to half working pressure is as much in danger of fatigue as one subjected to a pressure cycle of half to full working pressure. Thus pipe fatigue failures occur just as frequently at high points in the system as at low points where the total pressure is greater.

### Design Criteria for Fatigue

A design for fatigue must involve:

1. An estimate of the magnitude of pressure fluctuations likely to occur in the pipeline, i.e. the difference between maximum and minimum pressures.
2. An estimate of the frequency, usually expressed as cycles per day, at which fluctuations will occur.
3. A statement of the required service life needed from the pipe.

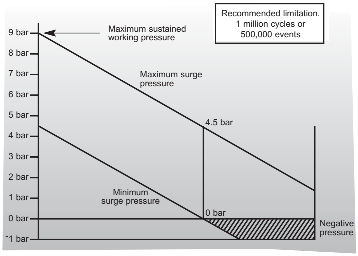
The DYNAMIC loads normaly considered during operation are:

- internal cyclic loading e.g. surge associated with pumping regimes or the rapid closure of valves;
- external cyclic loadings due to traffic conditions.

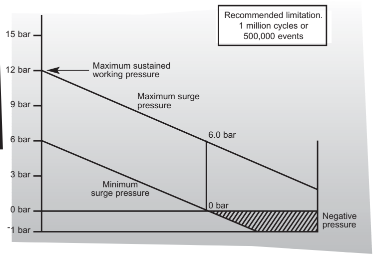
In general terms and for normal use, polymer pipelines which are correctly laid, bedded and supported are capable of withstanding such imposed loadings, within these recommendations.

## SURGE PRESSURE ENVELOPES - PVC

### 9 Bar PVC-U pipe

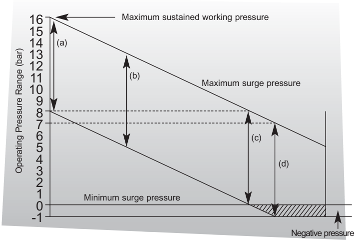



### 12 Bar PVC-U pipe



## SURGE PRESSURE ENVELOPES - PE

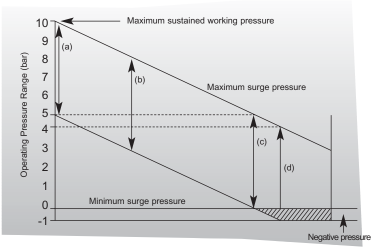
### PE100, SDR 11




In fluctuating pressure conditions, the pipe should operate within the pressure envelope. The vertical lines a, b, c & d illustrate that the permissible range of pressure fluctuation due to surge should not exceed 8 bar and may be, for example,between the following limits:

a) from 8 bar to 16 bar
b) from 5 bar to 13 bar
c) from 0 bar to 8 bar
d) from –1 bar to 7 bar (possible vacuum conditions which means the system can be operated at 8 bar pressure and can still work within the pressure envelope)

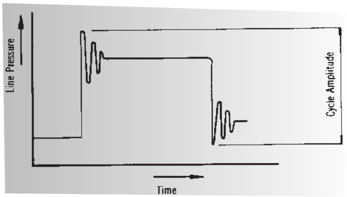
### PE100 (SDR 17.6) and PE80 (SDR 11)




The vertical lines a, b, c, d illustrate that the permissable range of fluctuation in pressure should not exceed 5 bar and may be, for example, between the following limits;
(a) from 5-10 bar,
(b) from 3-8 bar,
(c) from 0-5 bar,
(d) from 1-4 bar (possible vacuum conditions).
This applies to 10 bar PE pipe, eg. PE100 pipes at SDR 17.6 and PE80 pipes at SDR 11.

## DEFINITION OF CYCLE AMPLITUDE

In the simplest terms the pressure cycle amplitude is defined as the maximum pressure, minus the minimum pressure experienced by the system, including all transients, both positive and negative. For purposes of fatigue design, transient pressures due to accidental events such as power failure may be ignored, since they are not repetitive. Only primary repetitive operational events need be considered.




## EFFECT OF SURGES

Pumping systems are frequently subject to surging due to the effects of switching. The resultant pressure wave will decay exponentially and the system will then experience a number of minor pressure cycles of diminishing magnitude. In order to take this into account, the effect of each minor cycle is related to the primary cycle in terms of the number of such cycles which would produce the same crack growth as one primary cycle.
According to this technique, a typical exponentially decaying surge regime is equivalent to two primary cycles. Thus for design purposes, the primary cycle amplitude only is considered, with the frequency doubled.

## WATER HAMMER

Water hammer is a temporary change in pressure in a pipeline due to a change in the velocity of flow in a pipe with respect to time, e.g. a valve opens or closes or a pump starts or stops. Accidental events such as a pipe blockage can also be a cause. The effects are exacerbated by:

- Fast closing/stopping valves/pumps
- High water velocities
- Air in the line
- Poor layout of the pipe network, positioning of pumps
- Pump start method

Note that water hammer pressure may be positive or negative. Both can be detrimental to pipe systems; not only pipes, but pumps, valves and thrust supports can be damaged. Negative pressures can cause “separation” (vacuum formation), with very high positive pressures on “rejoinder” (collapse of the vacuum). For these reasons, water hammer should be eliminated as far as possible.

Water hammer pressures can be reduced by:
- Controlling and slowing valve and pump operations
- Reducing velocities by using larger diameter pipes
- Using pipe material with lower elastic modulus
- Astute layout of network, valves, pumps and air valves
- Fast-acting pressure relief valves.

It is beyond the scope of this manual to give a complete description of water hammer analysis and mitigation.

## DESIGN HINTS

To reduce the effect of dynamic fatigue in an installation, the designer can:

1. Limit the number of cycles by:
   (a) Increasing well capacity for a pumping station.
   (b) Matching pump performance to tank size eliminate short demand cycles for an automatic pressure unit.
   (c) Using double-acting float valves or limiting starts on the pump by the use of a time clock when filling a reservoir.
2. Reduce the dynamic range by:
   (a) Eliminating excessive water hammer.
   (b) Using a larger bore pipe to reduce friction loss.

## EFFECT OF TEMPERATURE

Research to date (ref.[2]) suggests that crack growth rates in uPVC is not greatly affected by temperature change.

Therefore while temperature rating principles must be applied in pressure rating selection for static pressures, (ductile burst), no adjustment need be applied for dynamic design. Select the highest according to:

(a) static design including temperature derating
or
(b) dynamic design as discussed in this section.

## SAFETY FACTORS

The analysis and design method adopted by Joseph can be considered conservative. Given reasonable confidence in prediction of pressure cycle amplitude, no additional factor of safety need be applied for selection of pipe class.

The more likely area of deficiency is in the frequency of number of cycles. Lack of confidence in this parameter may warrant application of an appropriate factor of safety. This judgement is in the hands of the designer. It is recommended that systems that are of concern to the designer should be monitored on commissioning to ensure that operation is in accordance with design criteria. Pressure cycling outside acceptable limits can be mitigated by a number of techniques, as outlined above.

## FITTINGS

Complex stress patterns in fittings can “amplify” the stress cycling in the fitting. This factor is particularly prevalent in branch fittings such as tees, where amplification factors of up to four times have been observed. The condition can be aggravated by the existence of stress cycling from other sources. For example, bending stresses induced by flexing under hydraulic thrust when improperly supported, or vibration induced fatigue caused by direct connection of pipe work to pumps, e.g. flanged connections. Isolation from vibration should always be provided in the design. Injection moulded fittings up to and including 50 mm diam. should be rated PN15. Larger sizes are rated PN12. In large pipe installations, where high pressures are expected, cast iron fittings are preferred. With PVC full faced flanges should be fitted with backing rings behind both bolt head and nut when used at pressures above 240kPa. Stub flanges are recommended.

## WAVE SPEED TRANSMISSION

In applications where surgepressures may occur, the relatively low shock wave transmission speed in polymer pipes (compared with that of a pipe of a more rigid material), can be particularly beneficial.

The range of wave transmissions speeds in water for various pipematerials and wall thicknesses. Wave speed is approximately related to pressure change by the Joukowski formula:

$$\Delta p = p.a.\ \Delta V$$

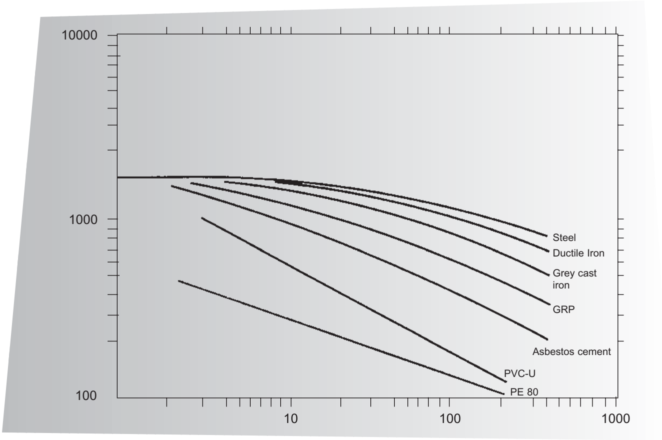
where

$\Delta p$ = pressure change (N/m$^2$)
p = fluid density (kg/m$^3$)
a = wave speed (m/s)
$\Delta C$ = velocity change (m/s)

Therefore for a given density and change in velocity, the surge pressure is approximately proportional to wave speed. This illustrates how, for a given surge ‘event’, the surge pressures generated in Marley Pressure pipes will be considerably less than the magnitude of surge developed in other pipe materials.

For external dynamic loading conditions the use of PE pressure mains under major carriageways is dependent on the type of trench bedding conditions used.

PE 80 and PE 100 pressure mains should be laid under major roads with the correct installation techniques.




**Wave speeds for water in various pipes of diameter (D) and wall thickness (e)**

## CELERITY

The velocity of the pressure wave, referred to as celerity (C), depends on the pipe material, pipe dimensions and the liquid properties in accordance with the following relationship

$$C = \left[ W \left( \frac{1}{K} + \frac{SDR}{E} \right) \right]^{-0.5} \times 10^3 \text{ m/sec}$$

where
W = liquid density (1000 kg/m$^3$ for water)
SDR = Standard Dimension Ratio of the pipe
K = liquid bulk modulus (2150 MPa)
E = pipe material short term modulus (MPa)

The time taken for the pressure wave to travel the length of the pipeline and return is

$$t = \frac{2L}{C}$$

where
t = time in seconds
L = length of pipeline

If the valve closure time $t_c$ is less than t, the pressure rise due to the valve closure is given by:

$$P_1 = C.V$$

where
P1 = pressure rise in kPa
v = liquid velocity in m/sec

If the valve closure time $t_c$ is greater than t, then the pressure rise is approximated by:

$$P_2 = \left[ \frac{t}{t_c} \right] P_1$$

## SURGE CELERITY

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

$$C = \left[ W \left( \frac{1}{K} + \frac{SDR}{E} \right) \right]^{-0.5} \times 10^3 \text{ m/sec}$$

where
W = liquid density (1000 kg/m$^3$ for water)
SDR = Standard Dimension Ratio of the pipe
K = liquid bulk modulus (2150 MPa)
E = pipe material 'instantaneous' modulus (taken as 1000 MPa for PE80B, 1200MPa for PE80C, 1500 MPa for PE100)

### MDPE Surge Celerity

| SDR | Celerity m/s MDPE (PE 80B) | HDPE (PE 100) |
|---|---|---|
| 41 | 160 | 190 |
| 33 | 170 | 210 |
| 26 | 190 | 240 |
| 21 | 220 | 260 |
| 17 | 240 | 290 |
| 13.6 | 270 | 320 |
| 11 | 300 | 360 |
| 9 | 330 | 390 |
| 7.4 | 360 | 430 |

### PVC Surge Celerity

| PN | SIZE UP TO AND INCL. DN 150 | | SIZES DN 175 AND LARGER | |
|---|---|---|---|---|
| Class | SDR | a(m/s) | SDR | a(m/s) |
| 6 | 36.7 | 281 | 39.3 | 272 |
| 9 | 24.4 | 341 | 26.2 | 330 |
| 12 | 18.3 | 390 | 19.7 | 377 |
| 15 | 14.7 | 432 | 15.7 | 419 |
| 18 | 13.8 | 444 | 14.8 | 430 |

Dimension Ratio (SDR) and Celerity (a)

For buried pipes increase the wave celerity (a) by 7%.

### Complex Cycle Patterns

In general, a similar technique may be applied to any situation where smaller cycles exist in addition to the primary cycle. Empirically, crack growth is related to stress cycle amplitude according to ( $\Delta S)^{3.2}$. Thus n secondary cycles of magnitude $\Delta P_1$, may be deemed equivalent in effect to one primary cycle, $\Delta P_0$.

$$\text{where } n = \left(\frac{\Delta P_1}{\Delta P_0}\right)^{3.2}$$

For example a secondary cycle of half the magnitude of the primary cycle is expressed as:

$$n = \left(\frac{2}{1}\right)^{3.2} = 9.2$$

so it would require nine secondary cycles to produce the same effect as one primary cycle. If these are occurring at the same frequency, the effective frequency of primary cycling is increased by 1.1 for the purpose of design.

## HYDRAULIC FLOW

The velocity of flow in Marley pipes should not normally exceed 1-2 metres per second in distribution mains. Where higher velocities are expected, consideration should be given to the effects of surge.

The hydraulically smooth bore of a Marley pipe gives excellent flow characteristics which are usually retained through its operational life. The hydraulic frictional coefficients normally used in the design of continuous straight PE pipes working under pressure are:

- Colebrook-White Ks = 0.003mm
- Hazen Williams C = 144

The metric Colebrook- White formula for the velocity of water in a smooth bore pipe under laminar conditions takes the form:

$$V = -2\sqrt{2gDi.} \cdot \log.\left[\frac{Ks}{3.7D} + \frac{2.51v}{D\sqrt{2gDi}}\right]$$

Depending on the nature of the surface of a pipe and the velocity of fluid that it is carrying, the flow in a pipe will either be rough turbulent, smooth turbulent or most probably somewhere in between.

The Colebrook-White transition equation incorporates the smooth turbulent and rough turbulent conditions. For smooth pipe the first term in the brackets tends to zero and the second term predominates. For a rough pipe the first term in the brackets predominates, particularly at flows with a high Reynolds Number. This equation is therefore an almost universal application to virtually any surface roughness, pipe size, fluid or velocity of flow in the turbulent range.

Substituting for f in the Darcy equation note that:

$Q$ = flow velocity x pipe internal area.
Where $Q$ = discharge ($m^3/s$)

This leads to the following expression upon which the flow charts are based

$$Q = \frac{\pi D^2}{4} \bullet \sqrt{2gD\frac{H}{L}} \bullet \log_{10}\left[\frac{D}{\frac{k}{3.7} + \frac{2.51v}{\sqrt{2gD\frac{H}{L}}}}\right]^2$$

Where
- V = velocity in metres per second
- g = gravitational acceleration (a valve of 9.807 ms-2 maybe assumed)
- i = hydraulic gradient
- v = kinetic viscosity (a value of 1.141 x 10-6 may be assumed).
- Ks = linear measure of roughness in mm = 0.003
- D = mean internal diameter of pipe in metres
- Q = discharge (litres/second)
- H = head of loss (meters/100 metres of pipe)

Flowcharts for pipe systems using this formula have been in operation in New Zealand for over 20 years for transmission of water and have been proven in practical installations.

## Other Pipe Flow Formulas

a) The Manning formula

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

b) The Hazen-Williams formula

$$V = 0.849\ C\ R^{0.63} \left(\frac{H}{L}\right)^{0.54}$$

Where: n = Manning roughness coefficient
C = Hazen-Williams roughness coeffiecient
R = hydraulic radius (m)
(R = D/4 for a pipe flowing full)

$\frac{H}{L}$ = hydraulic gradient (m/m)

Though both formulas do not give the same accuracy as the Colebrook-White equation over a wide range of flows they are often used in hydraulics because of the comparative simplicity.

## Water Temperature

The viscosity of water decreases with increasing temperature. As the temperature increases the friction head will decrease.

An approximate allowance for the effect of the variation in water temperature is as follows:

1. **Pipe diameter < 150mm**
   Increase the chart value of the hydraulic gradient by 1% for each 2°C below 20°C.
   Decrease the chart value of the hydraulic gradient by 1% for each 2°C above 20°C.
2. **Pipe diameter> 150mm**
   Increase the chart value of the hydraulic gradient by1% for each 3°C below 20°C.
   Decrease the chart value of the hydraulic gradient by1% for each 3°C above 20°C.

## Manufacturing Diameter Tolerance

Marley pressure pipe is manufactured in accordance with AS/NZS 1477 and NZ/4130 which permits specific manufacturing tolerance on both its mean outside diameter and wall thickness. Hence the mean bore of a pipe is given by:

Mean bore = De - 2 • te
mean OD mean wall thickness

The “Nominal Size” lines on the flow chart correspond to the mean bore of that size and class of pipe.

However, it is conceivable that a pipe could be manufactured with a maximum OD and a minimum wall thickness within approved tolerances. In this case the discharge will be more than that indicated by the charts. Similarly a pipe with a minimum OD and a maximum wall thickness will have a lower discharge than indicated.
For a given discharge the variation in friction head loss or hydraulic gradient due to this effect can be of the order of 2% to 10% depending on the pipe size and class. For pipe sizes greater than 100mm, this variation is usually limited to 6% for a PN18 pipe.

## Roughness Considerations

The value of k, the roughness coefficient, has been chosen as 0.003mm for new, clean, concentrically jointed Marley pressure pipe. This figure for k agrees with recommended values given in Australian Standard 2200 (Design Charts for Water Supply and Sewage). It also is in line with work by Housen at the University of Texas which confirms that results for Marley pipe compare favourably with accepted values for smooth pipes for flows with Reynolds’ Number exceeding $10^4$.
Roughness may vary within a pipeline for a variety of reasons. However, in water supply pipelines using clean Marley pressure pipe these effects are minimised if not eliminated and k can be reliably taken as being equal to 0.003 mm.

Factors which may result in a higher k value include:

- Wear or roughness due to conveyed solids
- Growth of slime or other incrustations on the inside
- Joint irregularities and deflections in line and grade

**Note:** Significant additional losses can be caused by design or operational faults such as air entrapment, sedimentation, partly closed valves or other artificial restrictions. Every effort should be made to eliminate such problems. It is not recommended that k values be adjusted to compensate, since this may lead to errors of judgement concerning the true hydraulic gradient.

Engineers who wish to adopt higher values of k should take into account some of the above effects in relation to their particular circumstances. The maximum suggested value is 0.015 mm. Table 6 lists the percentage increase in the hydraulic gradient for typical k values above 0.003 mm for various flow velocities.

(1) HOUSEN, “Tests find friction factors in uPVC pipe”. Oil and Gas Journal Vol. 75, 1977.

### Percentage increase in Hydraulic Gradient for Values of k Higher than 0.003 mm.

| SIZE | FLOW VELOCITY (m/s) | k = 0.006 (mm) | k = 0.015 (mm) |
|---|---|---|---|
| 50 | 0.5 | 0.6% | 2.3% |
| | 1.0 | 1.0% | 3.8% |
| | 2.0 | 1.6% | 6.2% |
| | 4.0 | 2.7% | 9.8% |
| 100 | 0.5 | 0.5% | 2.0% |
| | 1.0 | 0.9% | 3.3% |
| | 2.0 | 1.5% | 5.5% |
| | 4.0 | 2.4% | 8.8% |
| 200 | 0.5 | 0.4% | 1.8% |
| | 1.0 | 0.8% | 2.9% |
| | 2.0 | 1.3% | 4.9% |
| | 4.0 | 2.2% | 7.9% |
| 300 | 0.5 | 0.4% | 1.6% |
| | 1.0 | 0.7% | 2.8% |
| | 2.0 | 1.2% | 4.6% |
| | 4.0 | 2.0% | 7.4% |
| 450 | 0.5 | 0.4% | 1.5% |
| | 1.0 | 0.6% | 2.5% |
| | 2.0 | 1.1% | 4.3% |
| | 4.0 | 1.9% | 6.9% |

### Relating Roughness Coefficients

Knowing **k** the equivalent roughness coefficients n and C for the other two formulas can be compared as follows:

$$\frac{1}{n} = 5.04\, D^{-1/6} \sqrt{2g}\, \log_{10} \left[ \frac{D}{\dfrac{k}{3.7} + \dfrac{2.51\nu}{\sqrt{2gD \dfrac{H}{L}}}} \right]$$

$$C = 5.64\, D^{0.13} \left(\frac{H}{L}\right)^{-0.04} \sqrt{2g}\, \log_{10} \left[ \frac{D}{\dfrac{k}{3.7} + \dfrac{2.51\nu}{\sqrt{2gD \dfrac{H}{L}}}} \right]$$

### EQUIVALENT ROUGHNESS COEFFICIENTS

| ID (m) | k (m) | v (m²/s) | H/L (mm) | n | C |
|---|---|---|---|---|---|
| 0.20 | $0.003 \times 10^{-3}$ | $1 \times 10^{-6}$ | 0.01 | 0.0082 | 154 |
| | $0.015 \times 10^{-3}$ | $1 \times 10^{-6}$ | 0.01 | 0.0084 | 154 |
| 0.45 | $0.003 \times 10^{-3}$ | $1 \times 10^{-6}$ | 0.01 | 0.0084 | 156 |
| | $0.015 \times 10^{-3}$ | $1 \times 10^{-6}$ | 0.01 | 0.0086 | 152 |

## AIR VALVES

All water contains dissolved air. Normally this would be about 2% but it can vary largely depending on temperature and pressure. Air trapped in the line in pockets is continually moving in and out of solution.

Air in the line not only reduces the flow by causing a restriction but amplifies the effects of pressure surges. Air valves should be placed in the line at sufficient intervals so that air can be evacuated, or, if the line is drained, air can enter the line.

Air valves should be placed along the pipe line at all high points or significant changes in grade. On long rising grades or flat runs where there are no significant high points or grade changes, air valves should be placed at least every 500-1,000 metres at the engineer's discretion.

### Recommended Air Valve Size

| Size | Air Valve Size |
|---|---|
| Up to 100 | 25 single |
| 100-200 | 50 double |
| 200-450 | 80 double |

## HEAD LOSS DUE TO FRICTION IN PIPE

$$H = f \frac{Lv^2}{D2g}$$

Where

- $f$ = Darcy friction factor
- $H$ = head loss due to friction (m)
- $D$ = pipe internal diameter (m)
- $L$ = pipe length (metres)
- $v$ = flow velocity (m/s)
- $g$ = gravitational acceleration (9.8 m/s²)
- $R$ = Reynolds Number

This is valid for the laminar flow region. However, as most pipes are likely to operate in the transition zone between smooth and full turbulence, the transition function developed by Colebrook-White is necessary to establish the relationship between f and R.

$$\frac{1}{\sqrt{f}} = -2 \,\mathrm{Log}_{10} \left[ \frac{K}{3.7D} + \frac{2.51}{R\sqrt{f}} \right]$$

Where

- $K$ = Colebrook-White roughness coefficient (m)

For ease of reference, typical design flow charts in this manual based upon k = 0.003mm are reproduced.

## Head Loss Through Fittings

The frictional losses occasioned by flow through valves and fittings are approximately proportional to the square of the liquid velocity,

$$H = \frac{Kv^2}{2g}$$

where

H = loss of head
v = liquid velocity
g = acceleration due to gravity
K = coefficient dependent on type of fitting

Perhaps a more convenient way of allowing for the frictional resistance of valves, fittings, obstruction, etc is to consider an equivalent straight length of pipe which would create the same frictional resistance.

Actual headloss characteristics for a range of service pipe sizes and appropriate fittings to determine overall headloss for PE 80 pipes service installations.

The effect of the frictional resistance created by the internal beads in butt welded joints is hardly significant in normal distribution installations in smaller diameters or where the joints are frequent (e.g. for a joint once every 2 metres, an increase in the frictional resistance of about 2% should be allowed).

For practical purposes, designers of water mains for normal housing layouts may consider alternative methods to take account of all secondary and minor losses for small and medium sized developments.

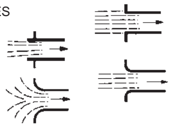
## Average Headloss in Fittings and Components

| Table | Fitting/Component | Size mm/" | Headloss (m) at flow rates of: | | | | |
|---|---|---|---|---|---|---|---|
| | | | L/m 10 | 25 | 35 | 100 | 160 |
| | | | L/s 0.16 | 0.42 | 0.58 | 1.66 | 2.66 |
| 1 | Ferrule connection | 20 | 0.1 | 0.9 | 2.0 | | |
| | | 25 | 0.1 | 0.7 | 1.5 | | |
| | | 32 | | 0.2 | 0.4 | | |
| | | 63 | | | | 0.5 | 1.5 |
| 2 | Stop valves | _ | 0.6 | 3.7 | 9.5 | | |
| | | _ | 0.2 | 1.2 | 1.9 | | |
| | | 1 | | 0.4 | 0.7 | | |
| | | 1 _ | | 0.1 | 0.2 | 0.9 | 2.2 |
| | | 2 | | | 0.1 | 0.4 | 0.8 |
| 3 | Boundary boxes | 20 | 0.8 | 4.5 | 10.0 | | |
| | (with meter) | 25 | 0.7 | 3.2 | 6.1 | | |
| | Boundary boxes | 25 | 0.5 | 1.9 | 3.4 | | |
| | (without meter) | | | | | | |
| 4 | Double check valves | 20 | 1.8 | 4.0 | 6.0 | | |
| | | 25 | 1.2 | 2.0 | 2.7 | | |
| | | 32 | | 1.3 | 1.8 | | |
| | | 50 | | | | 2.5 | |
| | | 63 | | | | 0.4 | 0.9 |
| 5 | Adaptors | 20 | 0.4 | 0.5 | | | |
| | | 25 | | 0.1 | 0.1 | | |
| | | 32 | | | 0.1 | | |
| 6 | Elbows | 20 | 0.3 | 1.3 | 2.4 | | |
| | | 25 | 0.1 | 0.2 | 0.4 | | |
| | | 32 | | 0.1 | 0.2 | | |
| | | 50 | | | | 0.2 | |
| | | 63 | | | | | 0.1 |
| 7 | Tees (on branch) | 20 | 0.2 | 1.0 | | | |
| | | 25 | | 0.3 | 0.6 | | |
| | | 32 | | 0.1 | 0.2 | | |
| | | 50 | | | | 0.3 | |
| | | 63 | | | | | 0.2 |

# Design

## RESISTANCE COEFFICIENTS FOR VALVES, FITTINGS AND CHANGES IN PIPE CROSS-SECTION.

### PIPE ENTRY LOSSES



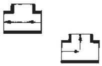
| TYPE OF FITTING | K |
|---|---|
| Square Inlet | 0.50 |
| Re-entrant Inlet | 0.80 |
| Slightly rounded Inlet | 0.25 |
| Bellmouth Inlet | 0.05 |

### PIPE INTERMEDIATE LOSSES

| TYPE OF FITTING | | K |
|---|---|---|
| Elbows: R/D < 0.6 e.g. uPVC | 45° | 0.35 |
| | 90° | 1.10 |

| TYPE OF FITTING | | K |
|---|---|---|
| Long Radius Bends (R/D>2) | $11\frac{1}{4}$° | 0.05 |
| | $22\frac{1}{2}$° | 0.10 |
| | 45° | 0.20 |
| | 90° | 0.50 |

### TEES

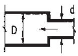


| TYPE OF FITTING | K |
|---|---|
| (a) Flow in line | 0.35 |
| (b) Line to branch flow | 1.00 |

### SUDDEN ENLARGEMENTS

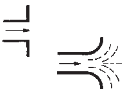

| Ratio d/D | K |
|---|---|
| 0.9 | 0.04 |
| 0.8 | 0.13 |
| 0.7 | 0.26 |
| 0.6 | 0.41 |
| 0.5 | 0.56 |
| 0.4 | 0.71 |
| 0.3 | 0.83 |
| 0.2 | 0.92 |
| <0.2 | 1.00 |

### SUDDEN CONTRACTIONS



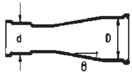

| Ratio d/D | K |
|---|---|
| 0.9 | 0.10 |
| 0.8 | 0.18 |
| 0.7 | 0.26 |
| 0.6 | 0.32 |
| 0.5 | 0.38 |
| 0.4 | 0.42 |
| 0.3 | 0.46 |
| 0.2 | 0.48 |
| <0.2 | 0.50 |

### PIPE EXIT LOSSES



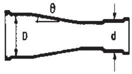
| TYPE OF FITTING | K |
|---|---|
| Square Outlet | 1.00 |
| Rounded Outlet | 1.00 |

### GRADUAL ENLARGEMENTS



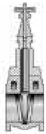

| Ratio d/D q = 10° typical | K |
|---|---|
| 0.9 | 0.02 |
| 0.7 | 0.13 |
| 0.5 | 0.29 |
| 0.3 | 0.42 |

### GRADUAL CONTRACTIONS

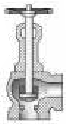


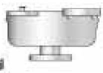
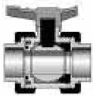

| Ratio d/D q = 10° typical | K |
|---|---|
| 0.9 | 0.03 |
| 0.7 | 0.08 |
| 0.5 | 0.12 |
| 0.3 | 0.14 |

### VALVES







| TYPE OF FITTING | K |
|---|---|
| Gate Valve (fully open) | 0.20 |
| Reflux Valve | 2.50 |
| Globe Valve | [illegible].00 |
| Butterfly Valve (fully open) | 0.20 |
| Angle Valve | 5.00 |
| Foot Valve with strainer hinged disc valve | 15.00 |
| unhinged (poppet) disc valve | 10.00 |
| Air Valves | zero |
| Ball Valve | 0.10 |

## NEGATIVE PRESSURE EFFECTS

The buckling performance limit may govern the design of a flexible pipe under conditions of internal vacuum or underwater installations.
Reduced pressures can be generated in pumped mains due to sudden change in system operation. In some instances these transients can generate sub-atmospheric pressures in the pipeline. The magnitude of negative pressure conditions is limited by the vapour pressure of the fluid conveyed. For water at 20°C the vapour pressure is 2.34 kPa. As atmospheric pressure is nominally 101.3 kPa, full negative head can not exceed 99 kPa or 10 metres head. In practise, negative head is only a transient phenomenon and is also mitigated by leakage past valves and control devices.
PVC rubber ring jointed pressure pipes are capable of performing under the most severe conditions of negative pressure. Both AS1477 and AS2977 specify that joints must withstand a minimum vacuum of 90 kPa for 2 hours without leakage.
For a circular ring subjected to a uniform external pressure (or internal vacuum) the critical buckling pressure $P_{CR}$ is defined by Timoshenko as:

$$P_{CR} = \frac{2.E}{\left(\frac{D - t}{t}\right)^3}$$

where
E = Young's Modulus (MPa)
D = outside diameter (mm)
t = wall thickness (mm)

For long tubes such as pipelines under combined stress, Poissons effect must be taken into account, and the equation becomes:

$$P_{CR} = \frac{2.E}{1 - \upsilon^2} \times \left(\frac{t}{D - t}\right)^3$$

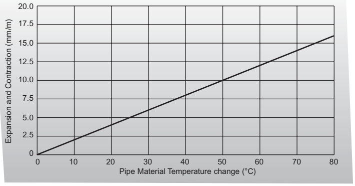
Young's Modulus (E) for short term loading i.e. where the negative pressure is only present for a short duration, such as column separation under severe water hammer conditions, = 2750 MPa.
Young's Modulus (E) for long term loading, such as for pipe installed underwater is recommended as = 1370 MPa.
Poisson's Ratio
$\upsilon$ = 0.38

## EXPANSION AND CONTRACTION

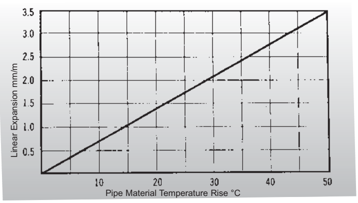
Expansion and contraction of Marley pipes occurs with changes in the pipe material service temperature.
This is in common with all pipe material and in order to determine the actual amount of expansion or contraction, the actual temperature change, and the degree of restraint of the installed pipeline need to be known.
For design purposes, an average value of
$2.0 \times 10^{-4}$/°C for Marley PE pipes
$8.0 \times 10^{-5}$/°C for Marley PVC pipes
may be used.
The relationship between temperature change and length change for different materials.
Where pipes are buried, the changes in temperature are small and slow acting, and the amount of expansion/contraction of the pipe is relatively small. In addition, the frictional support of the backfill against the outside of the pipe restrains the movement and any thermal effects are translated into stress in the wall of the pipe.
Accordingly, in buried pipelines the main consideration of thermal movement is during installation in high ambient temperatures.
Above ground PE pipes require no expansion/contraction considerations for free ended pipe or where lateral movement is of no concern on site. Alternatively, pipes may be anchored at intervals to allow lateral movement to be spread evenly along the length of the pipeline. But with PVC pipes allowance must be made for expansion and contraction.

## Thermal Expansion and Contraction

### - for MDPE



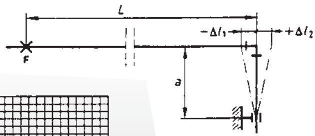

### - for PVC



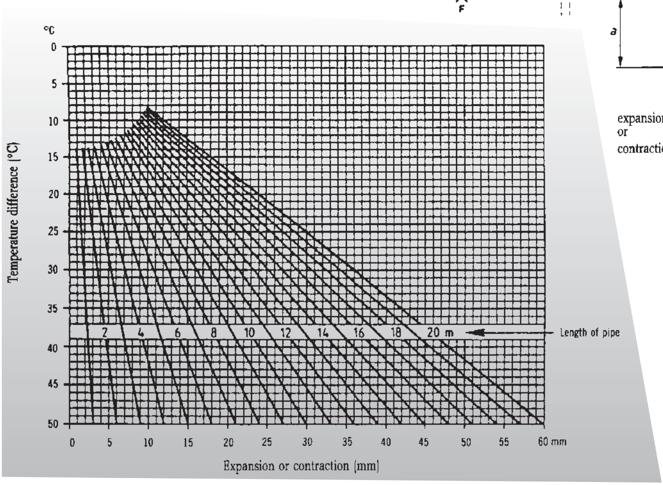
# Design

## THERMAL EXPANSION OR CONTRACTION

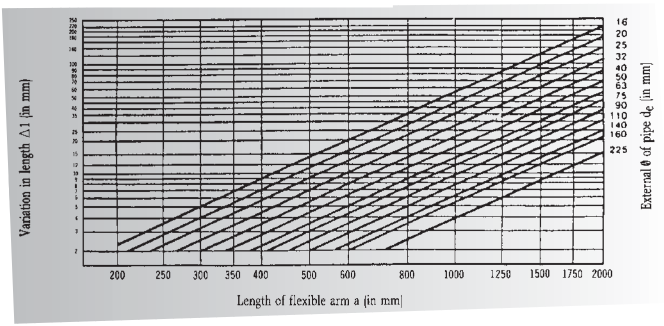
**Maximum Expansion or Contraction of Unplasticised uPVC Pipe**

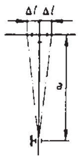



expansion $\Delta l_2$
or
contraction $\Delta l_1$




**Determination of the Length of the Flexible Arm**




Example: For a pipe with expansion of 10mm and an external diameter ($d_e$) of 50mm, the length of the arm (a) shall be at least 750mm.

# 6. INSTALLATION

RETURN TO CONTENTS

- **Design Consideration**
- **Loads on Pipes**
- **External Pressure**
- **Deflection**
- **Below Ground Installation**
- **Thrust Support**
- **Pipelines on Steep Slopes**
- **Pipeline Buoyancy**
- **Expansion Joints**
- **Pipeline Detection**
- **Bends & Bending**
- **Concrete Encasement**
- **Above Ground Installation**
- **Pneumatic Design**
- **Trenchless Installation**

## 6.1 DESIGN CONSIDERATION

1. Where Marley Pressure Pipes are selected the designer must consider:
   - the use of straight or coiled pipes
   - the jointing method
   - the trench width (standard or narrow)
   - directional drilling – no trench installation

2. Marley Pressure pipes are available either in coils or straight lengths depending upon pipe size and material selected.

   Straight pipes are usually produced in 6m or 12m lengths and MDPE coils are currently available in sizes up to 125mm.
3. Open trench pipeline must allow for the jointing, cooling and snaking of the pipe. When using 'normal' trench widths, this can mean greater inconvenience to traffic but allows flexibility to overcome unforeseen obstructions and also ensures the ability to bed and surround the pipe properly. Narrow trenching with PE has the considerable advantages of reduced reinstatement costs and less spoil to handle but not all subsoils are conducive to such a technique and proper laying, bedding and compaction is not always possible at the required depths of cover. Trenchless techniques such as directional drilling and impact moling can be used particularly well with PE systems.

4. The flexibility of PE allows the accurate alignment of the pipeline to awkwardly contoured kerb races on housing sites. The reinstatement or replacement of pipes in established areas will minimise disruption for major cost advantages.

## 6.2 LOADS ON PIPES

### 6.2.1 Soil and Traffic Loads

Loads are exerted on buried pipe due to:
- Soil pressures
- Superimposed loads
- Traffic loads

For normal water supply systems, the minimum depths of burial (cover) stipulated in AS/NZ 2053 should be observed. Under these conditions and up to a maximum of 3 metres cover, soil and traffic loadings are of little significance and design calculations are not warranted. This applies to all classes of pipe.

For depth shallower than those recommended, traffic loading may be of significance.

At greater depths, soil loadings may control selection of pipe class. In these instances, lighter pipe classes may not be suitable and specific design calculations and/or special construction techniques may be required. Wet trench conditions may also require further investigation.

For design purposes, AS 2566 (Australian Standards 2566 plastics pipelaying design) sets out procedures to be adopted.

Special construction techniques can involve backfill stabilisation, load bearing overlay or slab protection.

It should be noted that cover of less than 1.5 diameters may result in flotation of empty pipes under wet conditions. Low covers may also result in pipe "jacking" (lifting at vertically deflected joints) when pressurised.

### 6.2.2 Bending Loads

Under bending stress Marley Pressure pipes will bend rather than break. However, the following precautions are very important.

1. In below ground installations, the pipes must have uniform, stable support.

2. In above ground installations, proper, correctly spaced supports must be provided.

3. In above ground installations, pumps, valves and other heavy appendages must be supported independantly.

## 6.3 EXTERNAL PRESSURE

All flexible pipe materials can be subject to buckling due to external pressure and PE pipes behave in a similar fashion to PVC and steel pipes.

For a uniform section pipe the critical buckling pressure Pc can be calculated as follows:

$$P_c = \frac{2380\ E}{(SDR - 1)^3}$$

Where

| | | |
|---|---|---|
| E | = | modulus of elasticity (Gpa) |
| U | = | Poissons Ratio (0.4) |
| t | = | wall thickness (mm) |
| $D_m$ | = | mean pipe diameter (mm) |

Where pipes are buried and supported by backfill soil the additional support may be calculated from:

$$P_b = 1.15(P_c E`)^{0.5}$$

Where

E` = soil modulus from AS2566-Plastic Pipelaying Design.

See table Section

Tabulations of the value of E` for various combinations of soil types and compactions are contained in AS2566.

The development of any restraint from the surrounding soil is governed by the depth of installation and for installations less than 3 pipe diameters deep, the effect should be disregarded.

The value of Pc calculated requires a factor of safety to be applied and a factor of 1.5 may be applied for those conditions where the negative pressure conditions can be accurately assessed.
Where soil support is taken into account then a factor of 3 is more appropriate.
In general terms a Class 9 pipe should be used as a minimum for pump suction lines or when negative pressure will be generated due to gradient the pipe is laid.
Where the individual installation conditions result in negative pressure conditions that are not present in operation, then regard must be paid to construction techniques. For example pipes may need to be filled with water during concrete encasement when being used as vertical or horizontal ducting.
In operation, fluid may be removed from the pipeline faster than it is supplied from the source. This can arise from valve operation, draining of the line or rupture of the line in service. Air valves must be provided at high points in the line and downstream from control valves to allow the entry of air into the line and prevent the creation of vacuum conditions. Generally, in long pipelines air valves should be provided each 250 metres along the line.

## 6.4 EXTERNAL LOADING

Underground pipes behave as structural elements and as such are required to withstand external loads from various sources.
The actual loading on the pipe may be caused by one of more of the following:

1) Earth loads in either trench or embankment installations.
2) Imposed loading either concentrated point loading or uniformly distributed loading such as in footings or foundations.
3) Traffic loads from aircraft, railway and motor vehicles.

AS/NZS2555 – Plastics Pipelaying Design provides a methodology of calculating these loads operating on buried pipes under various installation conditions.
The basis of the AS/NZ2566.1 and 2566.2 is that developed by Marston in the USA and for each of the load sources listed in 1,2 and 3 is as follows:

4) Earth Loads

Trench

a) Embankment
b) $W = C_e w D^2$

1) Imposed Loads

Uniformly distributed load

2) Trench
$W = C_u B U$
3) Embankment

The load U is expressed as an equivalent height of fill and added to the embankment height.

$$h = \frac{U}{w}$$

4) Traffic Loads

$$W = Cp\,\frac{M\alpha}{l}$$

The symbols expressed in these formulate for evaluating the loads acting on the pipes are contained in AS/NZ2566 and are as follows:

| | | |
|---|---|---|
| W | = | load on pipe (kN/m) |
| C | = | load coefficient |
| | = | impact factor |
| l | = | length of pipe over which concentrated load acts (m) |
| M | = | concentrated load (kN) |
| D | = | mean pipe outside diameter (m) |
| B | = | trench width (m) |
| U | = | uniformity distributed load (kPa) |
| w | = | density of fill ($t/m^3$) |

## 6.5 DEFLECTION

Flexible pipes resist external loading by a combination of ring stiffness of the pipe and the soil support developed as a result of deflection of the pipe under loading.
This deflection invokes passive support and provides the major portion of the total installed pipe strength.
The amount of passive support is determined by the type of soil and the amount of compaction in the soil at the side of the pipe.
The determination of this support is contained in the various sections of AS2566 and is specific to each installation.
For flexible pipes the maximum load bearing capacity is determined by the deflection of the pipe from the original diameter.
Traditionally, in New Zealand the maximum allowable deflection has been 5% of the pipe outside the diameter and this value has been adopted in AS1477 & AS/NZS4130. This value originally related to the limit applied to cement lined steel pipe as being the limit before the lining cracked under loading.
In the case of homogeneous flexible pipes this limit has not engineering basis and may be exceeded without structural damage. For such pipes deflection of 20% O.D may be tolerated without structural distress.
In several overseas countries deflection values of 7 and 12.5% O.D. are used for design purposes.
The actual maximum design value adopted may be selected by the designer taking into account the particular requirements of the installation, such as the need to pass mechanical cleaning equipment down the bore of the pipe.
For the pipe deflected at 5% O.D. the hydraulic capacity of the pipe is 99.9% of the capacity of the same pipe as a perfect circle.
The calculation of the deflection of the pipe caused by the external loading is performed in AS2566 using the approach developed by Spangler in the USA at Iowa State College.

In this case the deflection is calculated as follows:

$$\Delta x = \frac{1.5 \times 10^{6} L_D R (D/T)^{3} W}{E_c + 0.0915 E` (D/T)^{3}}$$

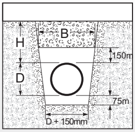
Where

| | | |
|---|---|---|
| Δ | = | diametrical deflection (m) |
| D | = | mean pipe diameter (m) |
| T | = | pipe wall thickness (m) |
| Ec | = | elastic modulus of pipe material (MPa) |
| E` | = | modulus of soil reaction (MPa) |
| W | = | load acting on pipe (N/m) |

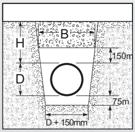
Marley design engineers can supply a computer program for design in accordance with AS/NZS2566.

As indicated previously, the major support in the installed pipeline is derived from the supporting soil and the attention of the designer is drawn to modifying the Type of standard compaction as the preferred method of increasing the load resistance of the pipeline.
The standard levels of compaction contained in AS/NZS2566 and the intended usage areas as follows:

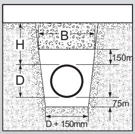
a) Type 1
The highest level of compaction as used in the highway and road pavements and requires mechanical compaction techniques.

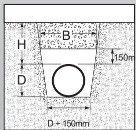



b) Type 2
The level of compaction attained by thorough hand tamping methods normally used in trench and embankment conditions for sewer and drain applications.




c) Type 3
The level of compaction attained where the sidefill is not compacted and side support arises from natural soil consolidation. Normally used in stormwater and pressure pipe applications where no additional external loads are encountered.




## 6.6 BELOW GROUND INSTALLATION

### 6.6.1 Preparing the Pipes

Before installation, each pipe and fitting should be inspected to see that its bore is free from foreign matter and that its outside surface has no large scores or any other damage. Pipe ends should be checked to ensure that the spigots and sockets are free from damage.
Pipes of the required diameter and pressure rating should be identified and matched with their respective fittings and placed ready for installation.

### 6.6.2 Preparing the Trench

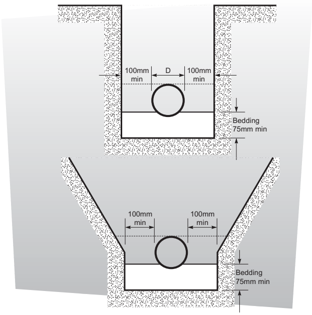
Marley pipe can be damaged or deformed if its support by the ground on which it is laid is not made as uniform as possible. The trench bottom should be examined for irregularities and any hard projections removed.
The minimum trench width should allow for adequate tamping of side support material and should be not less than 200mm greater than the diameter of the pipe. In very small diameter pipes this may be reduced to a trench width of twice the pipe diameter.
The maximum trench width should be as restricted as possible depending on the soil conditions. This is necessary for both economics and to develop side support.
Where wide trenches or embankments are encountered then the pipe should be installed on a 75mm layer of tamped or compacted bedding material as shown on the cross section diagrams. Where possible a sub trench should be constructed at the base of the main trench to reduce the soil loads developed.
AS/NZS2566 provides full details for evaluating the loads developed under wide trench conditions.

### Recommended Trench Widths

| SIZE DN | MINIMUM (mm) | MAXIMUM (mm) |
|---|---|---|
| 100 | 320 | 800 |
| 125 | 340 | 825 |
| 150 | 360 | 825 |
| 175 | 400 | 875 |
| 200 | 425 | 900 |
| 225 | 450 | 925 |
| 300 | 515 | 1000 |
| 375 | 600 | 1200 |

## Trench Widths

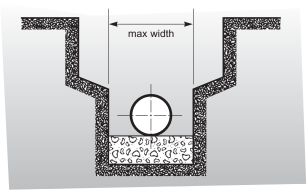
In general, the width of trenches should be kept to the minimum that enable construction to readily proceed.




The width of trenches used with PE pipe may be reduced from those used with PVC by jointing above ground in the case of butt or electrofusion welding and then feeding the jointed pipe into the trench.Similarly, small diameter pipe in coil form can be welded or mechanically jointed above ground and then fed into the trench.

## 6.6.3 Wide Trenches

For deep trenches where significant soil loading may occur, the trench should not exceed the widths given in 6.6.2 without further investigation.
Alternatively the trench should be widened until stability is reached. At this point, a smaller trench may then be excavated in the bottom on the trench to accept the pipe. In either case do not exceed the maximum trench width at the top of the pipe unless allowance has been made for the increased load.




## 6.6.4 Trench Depths

The recommended minimum trench depth is determined by the loads imposed on the pipe such as the mass of backfill material, the anticipated traffic loads and any other superimposed loads. The depth of the trench should be sufficient to prevent damage to the pipe when the anticipated loads are imposed upon it.

## 6.6.5 Minimum Cover

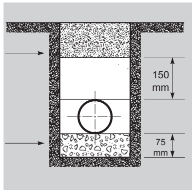
Trenches should be excavated to allow for the specified depth of bedding, the pipe diameter and the minimum recommend cover, overlay plus backfill, above the pipes. Table below provides recommendations for minimum cover to pipe crown.

## Minimum Cover

| Loading | Cover (mm) |
|---|---|
| Roads and streets | 750 |
| Driveways and similar areas subject to traffic | 600 |
| Footpaths, gardens | 500 |
| Construction traffic | 750 |

The above cover requirements will provide adequate protection for all pressure ratings of pipe. Where it is necessary to use lower covers, several options are available.

- Provide additional structural load bearing bridging over the trench. Temporary steel plates may be used in the case of construction loads.
- Use a high quality granular backfill e.g. crushed gravel or road base.
- Use a higher class of pipe than required for normal pressure or other considerations.




## 6.6.6 Bedding Material

Preferred bedding materials are listed in AS/NZ2655.1 and are as follows:

a) Suitable sand, free from rock or other hard or sharp objects that would be retained on a 13.2 mm sieve.

b) Crushed rock or gravel evenly graded up to a maximum size of 20 mm.

c) The excavated material may provide a suitable pipe underlay if it is free from rock or hard matter and broken up so that it contains no soil lumps having any dimension greater than 40 mm which would prevent adequate compaction of the bedding.

The suitability of a material depends on its compactability. Granular materials (gravel or sand) containing little or no fines, or specification graded materials, requiring little or no compaction, are preferred.
Sands containing fines, and clays, are difficult to compact and should only be used where it can be demonstrated that appropriate compaction can be achieved.

Variations in the hard bed should never exceed 20% of the bedding depth. Absolute minimum underlay should be 50 mm.

### 6.6.7 Pipe Side Support

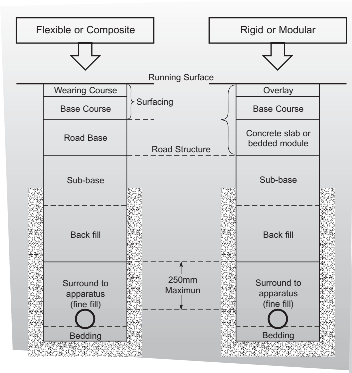
Material selected for pipe side support should be adequately tamped in layers of not more than 75mm for pipes up to 250mm diameter and 150mm for pipes of diameters 300mm and above. Care should be taken not to damage the exposed pipe and to tamp evenly on either side of the pipe to prevent pipe distortion. Care should be taken not to disturb the line or grade of the pipeline, where this is critical, by excessive tamping.

Unless otherwise specified, the pipe side support and pipe overlay material used should be identical with the pipe bedding material.

Compaction should be brought evenly to the design value required by AS/NZS2566 for the specification installation.

### 6.6.8 Backfill

Unless otherwise specified, excavated material from the site should constitute the back fill.
Gravel and sand can be compacted by vibratory methods and clays by tamping. This is best achieved when the soils are wet. If water flooding is used and extra soil has to be added to the original backfill, this should be done only when the flooded backfill is firm enough to walk on.
When flooding the trench, care should be taken not to float the pipe, or wash fines into rear joints.
All ground should be compacted back to 91-




**Trench Reinstatement Zone Terminology**

95%.The loads arise from two sources; the static or pressure force and the kinetic or velocity force.

## 6.7 THRUST SUPPORT

An imbalanced thrust is developed by a pipeline at:
- Direction changes (>10°), e.g. tees and bends.
- Changes in pipeline size at reducers.
- Pipeline terminations, e.g. at blank ends and valves.

The support system or soil must be capable of sustaining such thrusts.
Pressure thrust results from internal pressure in the line acting on fittings. Velocity thrust results from inertial forces developed by a change in direction or flow. The latter is usually insignificant compared to the former.

### 6.7.1 Anchorage and Thrust Blocks MDPE

1. One of the fundamental features of fully integrated Butt welded PE pipe systems is that they are end-load resistant and anchorage is not normally required at junctions or bends.

2. However, for push-fit systems or where individual non end-load resistant fittings are used, anchor blocks to withstand the resultant thrusts must be provided in the traditional manner. For pipes greater than 63mm, the use of concrete anchor blocks should be specified.

### 6.7.2 Anchorage and Thrust Blocks PVC

Underground PVC pipelines jointed with rubber ring joints require concrete thrust blocks to prevent movement of the pipeline when a pressure load is applied. In some circumstances, thrust support may also be advisable in solvent cement jointed systems. Uneven thrust will be present at most fittings. The thrust block transfers the load from the fitting, around which it is placed, to the larger bearing surface of the solid trench wall.

### 6.7.3 Anchorage at Fittings

It is advisable to rigidly clamp at valves and other fittings located at or near sharp directional changes, particularly when the line is subjected to wide temperature variations.
Ffittings should be supported individually and valves should be braced against operating torque.

### Pressure Thrust

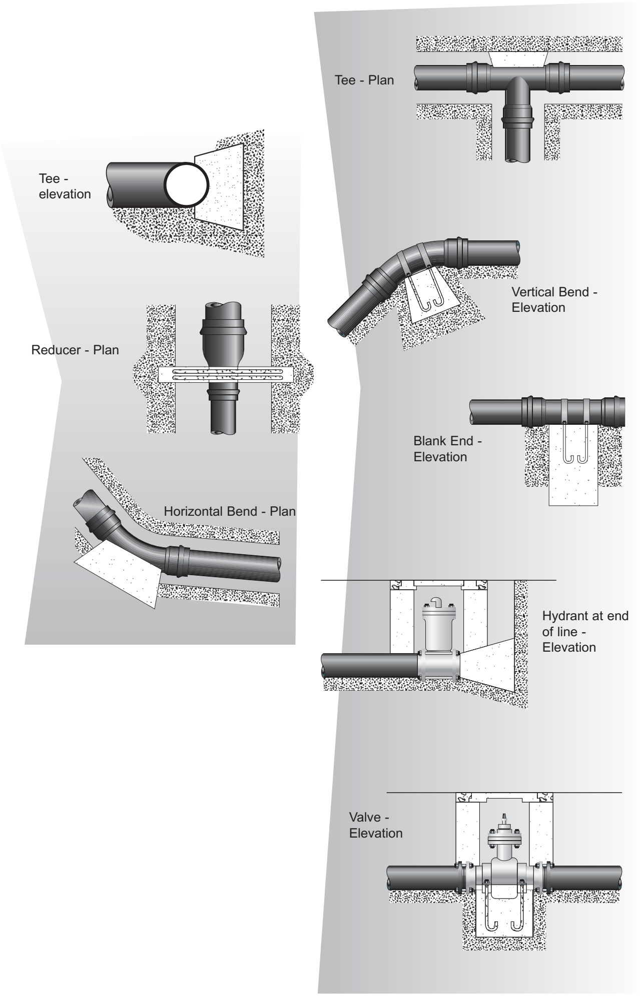
The pressure thrust developed for various types of fittings can be calculated as follows:

Blank ends, tees, valves $F = A\ P\ 10^{-3}$
Reducers and tapers $F = (A_1 - A_2)\ P\ 10^{-3}$
Bends $F = 2\ A\ P \sin(O/2)\ 10^{-3}$

Where:
F = resultant thrust force (kN)
A = area of pipe taken at the OD ($mm^2$)
P = design internal pressure (MPa)
O = included angle of bend (degrees)

The design pressure used should be the maximum pressure, including water hammer, to be applied to the line. This will usually be the field test pressure.

## THRUST SUPPORT DETAIL



### Pressure Thrust at Fittings in kN for Each 10 Metres Head of Water

| SIZE DN | AREA (mm2) | BENDS 11 Qr ° | 22 Qw ° | 45° | 90° | TEES ENDS |
|---|---|---|---|---|---|---|
| 15 | 363 | .01 | .01 | .03 | .05 | .04 |
| 20 | 568 | .01 | .02 | .04 | .08 | .06 |
| 25 | 892 | .02 | .03 | .07 | .12 | .09 |
| 32 | 1410 | .03 | .05 | .11 | .20 | .14 |
| 40 | 1840 | .04 | .07 | .14 | .26 | .18 |
| 50 | 2870 | .06 | .11 | .22 | .40 | .28 |
| 65 | 4480 | .09 | .17 | .34 | .62 | .44 |
| 80 | 6240 | .12 | .24 | .47 | .87 | .61 |
| 100 | 6240 | .20 | .39 | .77 | 1.43 | 1.01 |
| 125 | 10300 | .30 | .59 | 1.16 | 2.15 | 1.52 |
| 150 | 20200 | .39 | .77 | 1.52 | 2.80 | 1.98 |
| 200 | 40000 | .77 | 1.53 | 3.00 | 5.55 | 3.92 |
| 225 | 49400 | .95 | 1.89 | 3.71 | 6.85 | 4.84 |
| 250 | 61900 | 1.19 | 2.37 | 4.65 | 8.58 | 6.07 |
| 300 | 78400 | 1.51 | 3.00 | 5.88 | 10.87 | 7.69 |
| 375 | 126000 | 2.42 | 4.82 | 9.46 | 17.47 | 12.36 |

### 6.7.4 Construction of Thrust Blocks

Concrete should be placed around the fitting in a wedge shape with its widest part against the solid trench wall. Some forming may be necessary to achieve an adequate bearing area with a minimum of concrete. The concrete mix should be allowed to cure for seven days before pressurisation.

A thrust block should bear firmly against the side of the trench and to achieve this, it may be necessary to hand trim the trench side or hand excavate the trench wall to form a recess. The thrust acts through the centre line of the fitting and the thrust block should be constructed symmetrically about this centre line.

Pipes and fittings should be covered with a protective membrane of PVC, polyethylene or felt when adjacent to concrete so that they can move without being damaged.

The designer should consider all aspects of the system, including the unbalanced loads imposed by testing procedures, unusual configurations, large temperature variations, etc and where excessive load on the pipe system is envisaged, additional anchorage should be considered. To establish thrust block size establish the pressure to be applied to the line, calculate thrust developed consider the safe bearing capacity of the soil type using one 3 x safety factor.

In shallow (<600mm) cover, installations or in unstable conditions of fill, the soil support may be considerably reduced and a complete soil analysis may be needed.

The velocity thrust is generally small in comparison to the pressure thrust.

The pressure used in the calculations should be the maximum working or test pressure applied to the line.

Where pipes are installed on steep slopes (greater than 1:5) then bulkheads may need to be placed along the pipeline to prevent movement of the pipes, these can be placed at such support points as flange locations. Additional supports, such as sand bags, may be required to prevent scouring of bedding and backfill materials down the trench floor.

### Calculating Thrust Block Size.

**1) Establish the maximum working or test pressure to be applied to the line.**
**2) Calculate the thrust developed at the fitting being considered.**
**3) Divide 2) above by the safe bearing capacity per square metre for the soil type against which the thrust block must bear.**

Example

What bearing area of thrust block is required for a 150mm Class 12 90º. Bend in hard dry clay.

i) Maximum working pressure of Class 12 pipe is 1.2 MPa. Test pressure is 1.5 times working pressure = 1.0 MPa.

ii) A 150mm x 90º bend develops a thrust of $24.9 \times 10^{-3}$ newtons for each pascal of pressure applied.
Therefore thrust =
$(24.9 \times 10^{-3}) \times (1.8 \times 10^{6}) = 4.4 \times 10^{4}$ newtons.

iii) Bearing capacity of hard dry clay is $15 \times 10^{4}$ newtons per square metre. Therefore bearing area of thrust block =

### Velocity Thrust

Applies only at changes in direction of flow:

$$F = W\,a\,V^2 \cdot 2\sin(0/2) \cdot 10^{-9} \quad \text{(kN)}$$

Where:

a = cross sectional area of pipe take at the inside diameter (mm²)
W = density of fluid (water = 1,000) (kg/m³)
V = velocity of flow (m/s)

### 6.7.5 Bearing Loads of Soils

The indicative capacities of various soil types are tabulated below:

| Soil Type | Safe Bearing Capacity (newtons per square metre) |
|---|---|
| Rock and sandstone (hard thick layers) | $100 \times 10^5$ |
| Rock – solid shale and hard medium layers | $90 \times 10^4$ |
| Rock – poor shale, poor limestone, etc | $24 \times 10^4$ |
| Gravel and coarse sand (mixed) | $20 \times 10^4$ |
| Sand – compacted, firm, dry | $15 \times 10^4$ |
| Clay – hard, dry | $15 \times 10^4$ |
| Clay – readily indented by thumb but penetrated with difficulty | $12 \times 10^4$ |
| Clay – easily penetrated several inches by thumb, sand loam | $9 \times 10^4$ |
| Peat, wet alluvial soils, silt, etc | nil |

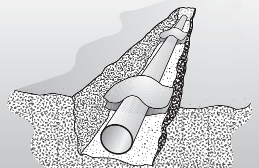
## 6.8 PIPELINES ON STEEP SLOPES

Two problems can occur when pipes are installed on steep slopes, i.e. slopes steeper than 20% (1:5).

1. The pipes may slide downhill so that the witness mark positioning is lost. It may be necessary to support each pipe with some cover during construction to prevent the pipe sliding.

2. The generally coarse backfill around the pipe may be scoured out by water movement in the backfill. Clay stops or sandbags should be placed in appropriate intervals above and below the pipe to stop erosion of the backfill.

Pipelines on steep slopes



## 6.9 PIPELINE BUOYANCY

Pipe under wet conditions can become buoyant in the trench. Marley pipes, being lighter than most pipe materials should be covered with sufficient overlay and backfill material to prevent inadvertent flotation and movement. A depth of cover over the pipe of 1.5 times the diameter is usually adequate.

## 6.10 EXPANSION JOINTS

For above ground installations with solvent cement joints provision should be made in the pipeline for expansion and contraction. If the ends are constrained and there is likely to be significant thermal variation, then a rubber ring joint should be installed at least every 12m to allow for movement within the pipeline, or such spacing as determined by calculation.

## 6.11 PIPELINE DETECTION

Marley pipes are electrically non-conductive and cannot be detected by metallic detection devices in underground installations.
Several techniques are available to detect buried pipelines.

### 6.11.1 Metal Detector Tapes

Foil based tapes may be located in the trench on top of the pipe overlay material (150-300mm above the pipe crown), these tapes can be detected at depths up to 600mm by metal detection equipment operating in the 4-20$MH_Z$ frequency range.
The tape backs may also be colour coded and printed in order to provide early warning of the presence of the pipeline during later excavation.

### 6.11.2 Tracer Wires

Pipes installed deeper than 600mm may be detected by the use of tracer wires placed on, or taped to,the top of the pipes.
Application of a suppressed current allows the detection of pipes up to a depth of three metres. However, both ends of the tracer wire must be accessible, and a complete electrical circuit present over the entire length of the pipeline.

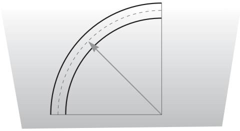
### 6.11.3 Audio Detection

Acoustic, or ultrasonic, noise detection devices are available which use either the noise from water flowing in the pipes, or an introduced noise signal, to detect the presence of buried pipelines.

## 6.12 BENDS AND BENDING

### 6.12.1 Bending MDPE Pipes

1. The bending of PE pipe is permissible and the properties of fusion jointed systems enable changes of direction without recourse to the provision of special bends or anchor blocks. However, for PE materials the pipe should not normally be cold bent to a radius less than 20 times the outside diameter of the pipe. No joints or tappings should occur on the bend.



2. A full range of standard preformed bends are available and are preferable for the larger sizes. Special configurations are similarly available upon request.

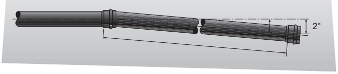
### 6.12.1 Bending PVC Pipes

When installing PVC pipes on a curve, the pipe should be jointed straight and then laid to the curve.
Significant bending moments should not be exerted on the joints, since this introduces undesirable stresses in the spigot and socket that may be detrimental to long term performance. To avoid this, the joints in curved lines must be thoroughly supported by compacted soil, with the bending occurring primarily at the centre of each pipe.
Some changes in the alignment of the pipe may be achieved without the use of direction-change fittings such as elbows and sweeps. PVC pipe is capable of controlled longitudinal bending within acceptable limits. A combination of axial flexure and joint deflection can achieve further longitudinal deviation of the pipeline. As a guide, PVC pipe can be bent to a radius equal to 130 times the diameter. However, Marley recommends that pipe under pressure should be bent to a radius not less than 300 times the diameter, e.g. a 100 mm pipe should have a minimum radius of curvature of 30 metres.

### 6.12.3 Joint Deflection

PVC Solvent cement joints have no flexibility but rubber ring joints can provide some joint deflection. The allowable deflection at the pipe Z socket should not be greater than a deflection of 2°.

**Angular deflection of a single pipe joint (shown exaggerated for clarity).**




### Flexural Stress

One critical limit to the bending of PVC pipe is long term flexural stress. Axial bending causes only a small amount of ovalisation or diametric deflection of the pipe, which indicates some change in circumferential stress. PVC pipe has short term strengths of 48 - 55 MPa in tension and 75 - 100 MPa in flexure. The long term strength of PVC pipe in tension, compression or flexure can conservatively be assumed to equal the ultimate hydrostatic design stress of 23.6 MPa. The recommended design stress of 11.0 MPa for PVC pipe at 20°C be used for the allowable long term flexural stress in rubber ring pipe that is free of longitudinal stress from longitudinal pressure thrust. However, when the joints are restrained as they are when solvent cemented, and the pipe is not snaked in the trench, then the end thrust from internal pressure imposes a longitudinal tensile stress equal to one half of the hoop stress.

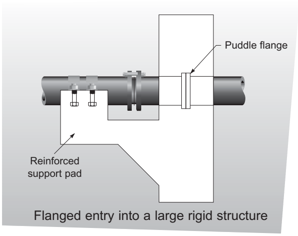
# 6.13 CONCRETE ENCASEMENT

## 6.13.1 Pipe Entry Into Structures

1. Wherever pipework meets or passes through rigid structures, careful consideration should be given to:

- the need to effect a watertight seal at the pipe/structure interface;
- the extent to which the structure itself is required to withstand forces transmitted from the pipe;
- where there is rigid connection between pipe and structure, whether the adaptation of standard fittings influence the degree to which compressive, tensile, bending and shear forces are generated;
- where differential settlement may occur, the extent to which the pipe and fittings flexibility can normally be relied upon to withstand the bending and shear stresses set up.
- an annular space of not less than 6mm should be left around the pipe or fitting. This clearance should be maintained and sealed with a flexible sealant such as loosely packed felt, a rubber convolute sleeve or other suitable flexible sealing material.
- if the pipeline has to pass through a fire rated wall, advice on suitable fire stop methods is available from our product manager.

2. Where pipe is to be connected by a flange to a large rigid structure, localised movement and bending at the flange can be prevented by a reinforced support pad as shown below. This pad should extend one pipe diameter or a minimum of 300mm from the flanged joint. The strapping should be provided with a compressible protection to the pipe.




Flanged entry into a large rigid structure

3. Although the flexibility and toughness of PE is advantageous in these situations it is recommended that before filling;

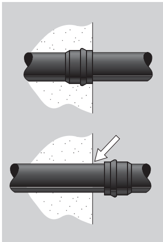
- all bolts should have a check retightening before final backfill;
- particular attention is paid to the compaction around and several diameters beyond, all fittings associated with the connection. Compaction to 90%. Proctor density or greater in these areas should be ensured.

4. These points of detail are important since these connections are often deep and sometimes associated with underdrainage, (e.g.outlets to reservoirs). This usually means any subsequent defect is difficult to identify, expensive to locate and very costly to remedy.

## 6.13.2 Setting of Pipes in Concrete

When PVC pipes are encased in concrete, certain precautions should be taken:

1. Pipes should be fully wrapped with a compressible material such as felt or poly film.
2. Alternatively, flexible (rubber ring) joints should be provided at entry to and exit from the concrete as shown. This procedure also allows for possible differential movement between the pipeline and concrete structure. It must be borne in mind, however, that without a compressible membrane, stress transfer to the concrete will occur and may damage the concrete section.



3. Expansion joints coinciding with concrete expansion joints should be provided to accommodate movement due to thermal expansion or contraction in the concrete.

PE pipes behave as flexible structures when externally loaded, and care needs to be exercised by the designer when using concrete encasement so that the effective strength of the pipeline is not reduced.

# 6.14 ABOVE GROUND INSTALLATION

Pipes may be stored above ground for pressure and non pressure applications in both direct exposure and protected conditions.

Black PE pipes made to AS/NZS 4130 requirements may be used in direct sunlight exposure conditions without any additional protection. Where MDPE pipes of colours other than black are used in exposed conditions, then the pipes may need to be protected from sunlight. PVC pipes all have 1.5PHR of Titanium Dioxide to act as a UV absorber. Localised temperature build up conditions such as proximity to steam lines, radiators or exhaust stacks must be avoided unless the pipes are suitably protected. Where lagging materials are used, these must be suitable for external exposure applications.

### 6.14.1 Support Spacing

The spacing of supports for a uPVC pipeline depends on factors such as the diameter of the pipe, the density of the fluid being conveyed and the maximum temperature likely to be reached by the pipe material.
Table 8 below, shows the support spacing in metres for uPVC pipe carrying water at 20°C. These spacings do not allow for additional extraneous loading.

## Recommended Support Spacing

### - for PVC pipes

| SIZE | MAXIMUM SUPPORT SPACING | |
|---|---|---|
| | HORIZONTAL (m) | VERTICAL (m) |
| 15 | 0.60 | 1.20 |
| 20 | 0.70 | 1.40 |
| 25 | 0.75 | 1.50 |
| 32 | 0.85 | 1.70 |
| 40 | 0.90 | 1.80 |
| 50 | 1.05 | 2.10 |
| 65 | 1.20 | 2.40 |
| 80 | 1.35 | 2.70 |
| 100 | 1.50 | 3.00 |
| 125 | 1.70 | 3.40 |
| 150 | 2.00 | 4.00 |
| 175 | 2.20 | 4.40 |
| 200 | 2.30 | 4.60 |
| 225 | 2.50 | 5.00 |
| 300 | 3.00 | 6.00 |

### - for MDPE pipes

| Nominal Pipe OD (mm) | Maximum Recommended Spacing (m) |
|---|---|
| 16 | 0.25 |
| 20 | 0.30 |
| 25 | 0.35 |
| 32 | 0.38 |
| 40 | 0.43 |
| 50 | 0.45 |
| 63 | 0.50 |
| 75 | 0.60 |
| 90 | 0.67 |
| 125 | 0.75 |
| 140 | 0.85 |
| 160 | 1.00 |
| 200 | 1.10 |
| 225 | 1.15 |
| 250 | 1.25 |
| 280 | 1.30 |
| 355 | 1.50 |

If temperatures are in excess of 20°C the horizontal spacing should be reduced by 25% for every 10°C. At 60°C , continuous horizontal support is required.

### 6.14.2 Vertical Installation

Generally, vertical runs are supported by spring hangers and guided with rings or long U-bolts which restrict movement of the rise to one plane. It is sometimes helpful to support a long riser with a saddle at the bottom.

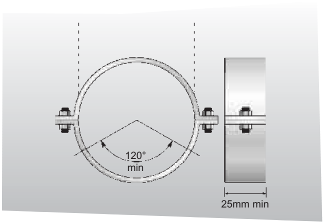
### 6.14.3 Brackets and Clips

For either free or fixed pipelines supports using brackets or clips, the bearing surface should provide continuous support for at least 120° of the circumference.

### Straps

Metal straps used as supports should be at least 25mm wide, either plastic coated or wrapped in a protective material such as nylon, PE, PVC or rubber sheet. If a strap is fastened around a pipe, it should not distort the pipe in any way.

**Location and type of support must take into account provision for thermal movement, if required. If the supports are to resist thermal movement, an assessment of the stress induced in pipes, fittings and supports may need to be made.**




### Free Support

A fee support allows the pipe to move without restraint along its axis while still being supported. To prevent the support from scuffing or damaging the pipe as it expands and contracts, a 6mm thick layer of felt or lagging material is wrapped around the support. Alternatively, a swinging type of support can be used and the support strap, protected with felt or lagging, must be securely fixed to the pipe.

### Fixed Supports

A fixed support rigidly connects the pipeline to a structure totally restricting movement in a least two planes of direction. Such a support can be used to absorb moments and thrusts.

### Placement of Support

Careful consideration should be given to the layout of piping and its support system. Even for non pressure lines the effects of thermal expansion and contraction have to be taken into account. In particular, the layout should ensure that thermal and other movements do not induce significant bending moments at rigid connections to fixed equipment or at bends or tees.
For solvent cement jointed pipe any expansion coupling must be securely clamped with a fixed support. Other pipe clamps should allow for movement due to expansion and contraction. Rubber ring jointed pipe should have fixed supports behind each pipe socket.

## 6.15 INSTALLATION CONSIDERATIONS

### 6.15.1 Expansion and Contraction

Pipe will expand or contract if it is installed during very hot or very cold weather, so it is recommended that the final pipe connections be made when the temperature of the pipe is stabilized at a temperature close to that of the backfilled trench.
Will MDPE lines laid directly on the natural surface by snaking the pipe during installation and allowing the pipe to move freely in service. Where the final joint connections are made in high ambient temperature, sufficient pipe length must be allowed to permit the pipe to cool, and hence contract, without pulling out of non end load bearing joints.
For solvent cemented systems, the lines should be free to move until a strong bond has been developed (see solvent cement jointing procedures) and installation procedure should ensure that contraction does not impose strain on newly made joints.
For rubber ring jointed pipes, if contraction accumulates over several lengths, pull out of a joint can occur. To avoid this possibility the preferred technique is to back fill each length, at least partially, as laying proceeds. (It may be required to leave joints exposed for test and inspection.)
It should be noted that rubber ring joint design allows for contraction to occur. Provided joints are made to the witness mark in the first instance, and contraction is taken up approx. evenly at each joint, there is no danger of loss of seal. A gap between witness mark and socket of up to 10 mm after contraction is quite acceptable.
Further contraction may be observed on pressurisation of the line (so-called Poisson contraction due to circumferential strain). Again this is anticipated in joint design and quite in order.

### 6.15.2 Heat sources

Pipes and fittings should be protected from external heat sources which would bring the continuous pipe material service temperature above 60°C.
Where the pipes are installed above ground, the protection system used must be resistant to ultra violet radiation and the effects of weathering, pipes running across roofing should be supported above the roof sheeting in order to prevent temperature build up.

### 6.15.3 Vibration

Direct connection to sources of high frequency such as pump outlet falnges should be avoided. Allfabricated fittings manufactured by cutting and welding techniques must be isolated from vibration. Where high frequency vibration sources exist in the pipeline, the sections should be connected using a flexible joint such as a repair coupling, expansion joint, or wire reinforced rubber bellows joint. When used above ground such joints may need to be restrained to prevent pipe end pullout.

### 6.15.4 Conductivity

Marley pipes are non-conductive and cannot be used for electrical earthing purposes or dissipating static electricity charges.
When pipes are used to replace existing metal water pipes, the designer must consider any existing systems used for earthing. In these cases the appropriate electrician must be consulted to determine the requirements.

### 6.15.5 Fire Rating

Marley MDPE pipe systems will support combustion and as such are not suitable for use in fire rated zones in buildings without suitable protection.

### 6.15.6 Ploughing In

MDPE pipe may be ploughed directly into the ground.
The pipe must be stationary in relation to the surrounding soil and care must be taken to ensure that the pipe is not excessively tensioned during the ploughing activities.
Ploughing should not be attempted where the soil contains rock or sharp stones or shale outcrops.

## 6.16 PNEUMATIC DESIGN

### 6.16.1 Pneumatic Flow

Marley MDPE pipe systems are ideal for the transmission of gases both in the high and low pressure range.
The use of compressible fluids in PE pipes requires a number of specific design considerations as distinct from the techniques adopted for fluids such as water.
In particular:
Safety factor for different gases should be considered in any design.
Natural gas 2.0
Compressed air 2.0.

I. Compressed air may be at a higher temperature than the ambient air and PE pipes require temperature re-rating accordingly.
For air cooled compressors the air temperature averages 15ºC above the surrounding air temperature.
For water cooled compressors the air temperature averages 10ºC above the cooling water temperature.

II. For underground applications the surrounding temperature may reach 30ºC and the pipe properties require adjustment accordingly.

III. High pressure lines must be protected from damage, especially in exposed installations.

IV. Valve closing sped must be reduced to prevent a build up of pressure waves in the compressible gas flow.

V. Where gaseous fuels such as propane, natural gas or mixtures are carried the gas must be dry and free from liquid contamination which may cause stress cracking in the PE pipe walls.

VI. MDPE pipes should not be connected directly to compressor outlets or air receivers. A 20 metre length of metal pipe should be inserted between the air receiver and the start of the PE pipe to allow for cooling of the compressed air.

VII. Dry gases and gas/solids mixtures may generate static electrical charges and these must be dissipated to prevent the possibility of explosion.

VIII. Compressed air must be dry and filters installed in the line to prevent stress cracking in the PE pipe.

IX. The fitting systems used must be pressure compatible with the pipe and pressure compatible with the pipe and where meta; couplings and shouldered ends are used, the maximum pressure is limited to 0.6MPa.

Several empirical flow formulae are in widespread use and any of these e.g. Weymouth, Spitzglass or Harris, may be used to calculate the flow of gas through PE pipes.

### 6.16.2 Compressed Air Formula

It is customary to find the inside Diameter of the pipe by using formulas such as those shown below. The formulas used are generally for approximation purposes only, surmising that the temperature of the compressed air corresponds roughly to the induction temperature. You will obtain an acceptable appriximation through the following equation.

$$di = \sqrt[5]{\frac{450.l.\frac{dV^{1.85}}{dt}}{\Delta p.p}}$$

Where

| | | |
|---|---|---|
| $\Delta p$ | = | pressure decrease (bar) |
| p | = | working pressure (bar) |
| V | = | volumetric flowrate (l/s) |
| dV/dt | = | atmosphere (l/s) |
| l | = | pipe length (m) |
| od | = | outside diameter (mm) |

The values are specific to each fluid type and the properties should be available from testing.
It is not permitted under the New Zealand Health and Safety Act to use PVC for compressed air lines.

## 6.17 TRENCHLESS INSTALLATION

Marley's plastic pipes are a versatile material and particularly through their toughness and flexibility, they are able to be used with a range of cost effective "no dig" methods for the pressure pipelines installation.

In particular:

- Guided drilling - directional drilling
- Pipe cracking
- Close-fit lining - Slip lining