Asset lifecycle – Guidance Note

Anchoring of pipelines

DRINKING WATER SUPPLY

Purpose

The purpose of this Guidance Note is to clarify the application and location of pipeline anchoring requirements for pressurised pipelines.

Overview

Pressure pipelines have potential to move when pressurised and require anchoring to prevent dislodgment at unrestrained joints (e.g. spigot and socket); and to reduce forces on certain restraint joint types. Generally, the backfill material above a straight length of pipe provides adequate vertical loading for minor variations in alignment, however the forces generated at changes in direction (generally horizontal) or reductions in diameter need to be balanced with thrust / anchor blocks. These anchors ensure that forces created by pressure through bends, reducers and tees are transferred to the undisturbed soil (bearing surface) or counteracted by a vertical anchor to prevent joint dislodgement.

In addition, pipe materials with elastic properties such as polyethylene (PE) are characteristically susceptible to the "Poisson effect", where circumferential expansion creates longitudinal forces, and requires anchoring where these pipes transition to unrestrained joint types. Thus, the necessary design diligence should be taken when designing polyethylene pipes, especially in brownfields sites where the new pipe may invariably link up with an unrestrained pipe material such as PVC-U, Ductile Iron (DI), or Asbestos Cement (AC).

Calculating thrust for unrestrained joints

The size of the thrust or anchor block can only be determined once the **strength of the supporting ground** is known. Generally, a "safe" bearing capacity for pipes at a depth of 800mm below the ground can be assumed to be $75kN/m^2$ as a minimum - equivalent to soft clay.

Thus, thrust blocks in rock or harder material will therefore be smaller in size due to the inherent strength of the in-situ material. A safety factor 1.25 – 1.5 should be applied to account for variations in the presumptive soil values, construction, and temperature forces. The outward horizontal force generated at bends (requiring restraint) from the change in direction of the pipeline is calculated with the formula:

$$F_R = P \times A \times 2\sin(\theta/2) \qquad \text{(Formula 1)}$$

Where:

F_R = Resultant force generated at bends in N

P = maximum (gauge) pressure that could occur in pipe (working or test pressure or surge) in MPa (N/mm^2)

θ = angle of bend / change in pipeline direction

A = cross-sectional internal area of pipe (mm^2)

References

Watercare

- Code of Practice for Land Development and Subdivision – Chapter 6: Water
- DW02: Code of Practice for Land Development – Water drawing set
- Code of Practice for Land Development and Subdivision – Chapter 5: Wastewater
- DP-07: Design Principles for transmission water and wastewater pipelines

Other

- **AWWA M55:** PE Pipe – Design and Installation
- **UK Water Industry –** The determination of end-loads for the performance testing of fittings for polyethylene pipe (IGN 4-01-02)
- **Performance pipe** – Technical Note 813-TN
- **AS/NZS 4130**: Polyethylene pipes (PE) for pressure applications

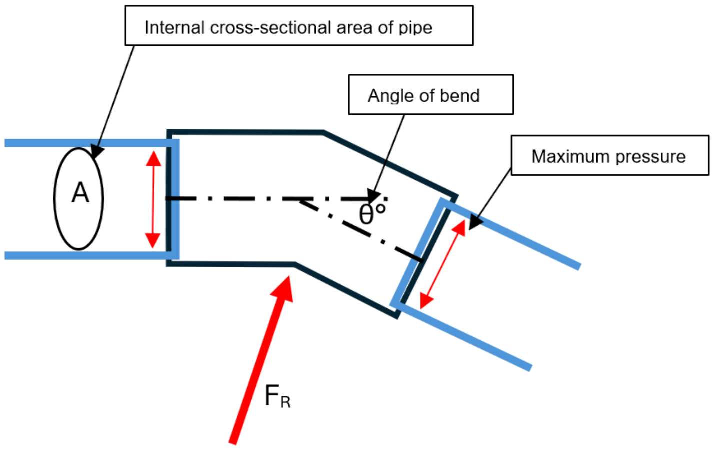

***Figure 1**: Resultant force and applicable parameters used to derive it.*

Similarly, the force at blank ends, tees, valve closures and reducers can be calculated using the formulas below:

Resultant force at **blank ends, tees, and valve closure**: $F_R = P \times A$ (Formula 2)

Resultant force at **reducers**: $F_R = P (A_1 – A_2)$ (Formula 3)

Where:

A_1 = Larger internal cross-sectional area of pipe in mm^2

A_2 = Smaller internal cross-sectional area of pipe in mm^2

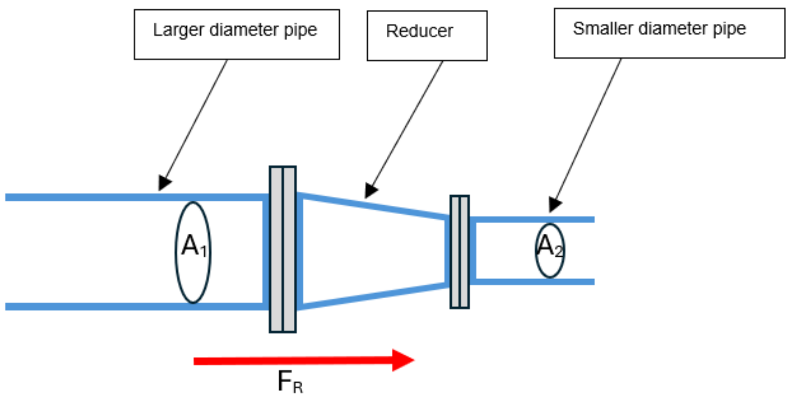

***Figure 2**: Resultant force and applicable areas where reducers are installed.*

Vertical thrust

Where a vertical bend is installed, the restraining force can be calculated in the same way as for horizontal forces in Figure 1. If the upward force is greater than the weight of the backfill material, an anchor block must be included in the design. In practice, it may be necessary to excavate and expose the pipe while pressurised in future so backfill weight becomes irrelevant. The anchor block can be placed above the bend, but the preference is for the pipe to be strapped to an anchor block below the pipe as this assists with future maintenance access.

Polyethylene pipes and thrust blocks

Polyethylene (PE) pipe joints are considered fully restrained, if welded correctly or acceptable mechanical fittings are installed properly. Butt / fusion welding forms a fully ductile bond between pipe and fitting effectively fusing the materials into a continuous length of pipe.

Generally, thrust blocks are not required for PE installations, however the design needs to consider end forces and the "Poisson effect" which can result in pull-out where PE joins to other pipe materials. The correct joint type, fitting or thrust restraint should be installed to prevent pull-out and account for internal pressure (F_L), the longitudinal force resulting from the Poisson effect (F_R), and forces induced due to temperature variations (F_T).

Internal pressure force (F_L)

This is the force looking to pull apart a fitting or joint as a result of the internal operating pressure.

$$F_L = \frac{P \times \pi \times D^2}{4}$$ (Formula 4) (Reference UK Water Industry: IGN 4-01-02)

Where:

F_L = Longitudinal force (N)

P = maximum internal pressure (MPa)

D = outside diameter of pipe (mm)

Longitudinal force resulting from Poisson effect (F_R)

By definition the "Poisson effect" implies that when ductile materials such as PE are pressurised, the diameter expands circumferentially, while the length decreases based on the unique Poisson ratio of the material.

Where PE pipes are installed and connected to non-PE pipe which includes un-restrained joints such as PVC-U, Ductile Iron (DI), or Asbestos Cement (AC) spigot and socket joints, the transition area should be protected against the pull-out force generated by the Poisson effect.

This can be provided by installing:

- External joint restraints at unrestrained joints;
- An in-line concrete wall anchor to prevent longitudinal movement; or
- A combination of both techniques.

Conventional anchoring at directional fittings (bends, tees etc.) is not effective against Poisson effect pull-out because conventional thrust blocks are connected to the joint fittings and are intended to resist pressure and fluid flow thrust forces that would push the fitting off the end of the pipe. These thrust blocks don't counteract forces that would pull the pipe end out of the joint itself, as the pipe effectively shortens in length.

Note: Where PE pipes pass through walls or chambers, an appropriate flex restraint fitting may be used to limit movement. This is generally applicable to pipe sizes larger than 160mm OD.

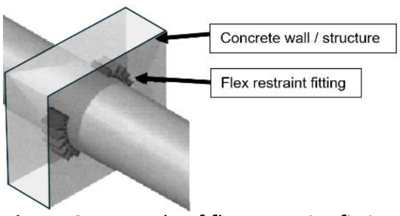

***Figure 3**: Example of flex restraint fitting where PE pipe passes through a wall or chamber*

***Figure 4**: PE pipe not properly restrained against the Poisson effect and pulls out from a non-PE pipe.*

The resultant longitudinal force can be calculated using the formula below.

$$F_R = \mu \times \sigma_H \times A = \frac{\mu \times P \times (D-t) \times A}{2t}$$ (Formula 5) (Reference UK Water Industry: IGN 4-01-02)

Where:

μ = Poisson's ratio (0.4 for PE 100 pipe)

P = maximum internal pressure (MPa)

D = pipe outside diameter (mm)

d = pipe internal diameter (mm)

t = pipe wall thickness (mm)

A = pipe wall cross-sectional area = $\frac{\pi \times (D^2 - d^2)}{4}$

The formula below from *AWWA M55* can also be used to derive the value of F_R.

$$F_R = S \times \mu \times \pi \times D^2 \left(\frac{1}{SDR} - \frac{1}{SDR^2}\right)$$ (Formula 6) (Reference: AWWA M55)

Where:

S = internal hoop stress pressure = $\frac{P \times (SDR-1)}{2}$

SDR = standard dimensional ratio ($\frac{D}{t}$)

Longitudinal force resulting from temperature effects (F_T)

The ambient temperature around a pipe along with its ability to expand and contract can also result in an induced force between and pipe and fitting.

The resultant longitudinal force can be calculated using the formula below.

$$F_T = \Delta T \times K \times E \times A$$ (Formula 7) (Reference UK Water Industry: IGN 4-01-02)

Where:

ΔT = Change in temperature (°C)

K = Coefficient of expansion (°C^{-1})

E = Young's modulus (MPa)

A = pipe wall cross-sectional area = $\frac{\pi \times (D^2 - d^2)}{4}$

***Table 1**: Coefficients of expansion for pipe materials*

Material	K (°C^{-1})
Polyethylene (PE 100)	1.3×10^{-4}
Polyethylene (PE 80)	1.45×10^{-4}
Mild steel (CLS)	0.12×10^{-4}
Stainless Steel	0.17×10^{-4}
PVC-U	0.52×10^{-4}
Ductile Iron	0.11×10^{-4}
Concrete	0.12×10^{-4}

The maximum longitudinal force on a restrained fitting would be the sum of longitudinal forces resulting from the Poisson effect and temperature effects ($F_R + F_T$).

A restrained fitting or in-line anchor (or combination) should be able to withstand the sum of F_R and F_T. The design must be compatible with materials on either side and be verified by the manufacturer and anchorage calculations.

When using fittings between pipe segments, multiple restraints may be required on unrestrained joints along a straight length of pipe to restrain the forces, considering loading of the backfill material and soil bearing capacity.

Anchoring design

In-line anchor blocks are generally cast concrete structures, where excavation beyond the trench width is carried out to create the "undisturbed" bearing surface. It is important mechanical assemblies are tightened and anchor structures completed (including curing time for concrete) before any pressure or leak-testing takes place.

In some instances, it may be possible to physically restrain joints adjacent to existing structures which don't require in-situ concrete. In all situations, fixtures (bolts etc) on all fittings and joints should be accessible for future maintenance.

Examples

Example 1: Horizontal unrestrained joint bend

Question:

Calculate the size of an anchor block to be placed behind a 45° bend for a DN 200mm diameter pipeline, where the working pressure is 0.8MPa (~80m). Assume a safe ground bearing capacity of 75kN/m^2

Answer:

The hydraulic test pressure will be 1.5 times working pressure i.e. 1.2MPa for a PN12.5 (1.25MPa) pipe or up to 1.25 times the rated pressure of the pipe i.e. 1.56MPa.

Test pressure will therefore 1.2MPa, as the maximum design pressure is 0.8MPa (water network).

Pipe area A = 31,416mm^2

Using the formula **F = P x A x 2sin (θ/2)** (Formula 1)

Force = 1.2MPa x 31,416mm^2 x 0.765

= 28,8854N = 28.8kN

Applying a FoS of 1.25 = 28.8kN x 1.25 = 36kN

Thus, area of the thrust block will be 36kN / 75kN/m^2 = 0.48m^2

Note: Ideal thrust block height should be at least 1.5 times the pipe diameter to ensure it is sufficiently robust i.e. 0.3m high for a 200mm pipe. We will assume a height of 0.6m, therefore the length required is 0.8m (Total area: 0.48m^2)

Example 2: Vertical unrestrained joint anchor

Question:

Calculate the mass of a vertical anchor block to secure a DN 500mm diameter 15° bend in a transmission water main with a surge pressure of 1.8MPa. In this instance we will ignore the mass of backfill material.

Answer:

Assume the surge pressure being 1.8MPa

Pipe area A = 196,350mm^2

Using the formula **F = P x A x 2sin (θ/2)** (Formula 1)

Force = 1.8MPa x 196,350mm^2 x 0.261

= 92,264N = 92.3kN

Applying a FoS of 1.25 = 92.3kN x 1.25 = 115.1kN

Mass of concrete is 24kN/m^3

Thus, will require 115.1kN / 24kN/m^3 = 4.8m^3 of concrete is require (example dimension 1.7m high x 1.7m wide x 1.7m long – 4.9m^3)

Note: Where CLS pipe is used for transmission pipelines in practice, joint welds create fully restrained mechanical joints and anchor blocks will not be required.

Where it is not possible to have an anchor block (e.g. pipe bridge) concrete supports are provided, and the pipe is secured with holding down bolts and corrosion-protected hoop strapping.

***Figure 5**: Example of hoop strapping installed on pipe bridge*

Example 3: Pull-out for protection for ductile materials (Poisson effect)

Question:

A 250mm (OD) PE 100 pipe SDR 13.6 is installed on a brownfield watermain which connects to an PVC-U pipe with unrestrained joints. Calculate the maximum longitudinal force experienced by the connection between PE and PVC and appropriately size the anchoring required to stop the movement and prevent pull-out of the joint. Assume a maximum working pressure of 800 kPa, and site test pressure of 1.5 times the maximum work pressure. Ground tests has shown the in-situ ground to have a bearing capacity of 100 kPa.

Answer:

***Table 2**: Summary of all properties and conditions of the installation*

Parameter	Symbol	Value	Unit
Maximum working pressure	Pw	0.8	MPa
Maximum site test pressure	Ps	1.2	MPa
Maximum temperature of pipe wall	T_{max}	20	°C
Water temperature	T_w	10	°C
Maximum temperature variation	ΔT	10	°C
Poisson's ratio	μ	0.4	(PE 100)
Young's modulus (at 20°C)	E	712	MPa
Coefficient of expansion	K	1.3×10^{-4}	°C-1
External wall diameter	D	250.0	mm
Internal wall diameter	d	210.4	mm
Wall thickness	t	19.8	mm

1) Calculate force resulting from the Poisson effect using Formula 5 (or 6):

$$F_R = \frac{\mu \times p \times (D-t) \times A}{2t} = \left(\frac{0.4 \times 1.2MPa \times (250mm - 19.8mm) \times [\frac{\pi(250mm^2 - 210.4mm^2)}{4}]}{2 \times 19.8mm} \right) / 1000 = 40.0kN$$

2) Calculate the force resulting from temperature variations using Formula 7:

$F_T = \Delta T \times K \times E \times A$ = (10°C x 1.3x10^{-4} x 712MPa x $\frac{\pi(250mm^2 - 210.4mm^2)}{4}$) / 1000 = 13.3kN

Thus, the total force on the connection is $F_R + F_T$ = 40kN + 13.3kN = 53.3kN

The size of an anchor block required to resist longitudinal pull-out force may be determined by dividing the calculated total longitudinal force by the soil bearing strength and applying an adequate safety factor.

For anchoring a PE to PVC-U connection, a thrust block size can be calculated as shown below and installed on a puddle flange which prevents the connection from pulling out.

The bearing area against undisturbed soil should therefore be 53.3kN / 100kPa (kN/m^2) = 0.53m^2.

Applying a factor of safety of 1.25, the required bearing area becomes 0.67 m^2. This should be the minimum bearing area outside of the pipe trench, where the in-line anchor block should be cast against undisturbed ground.

Figure 6 below shows the bearing areas required to compensate for the longitudinal thrust calculated, where A_1 (0.16m^2) + A_2 (0.16m^2) + A_3 (0.42m^2) = 0.74m^2 (Final FoS = 0.74m^2 / 0.53m^2 = 1.4)

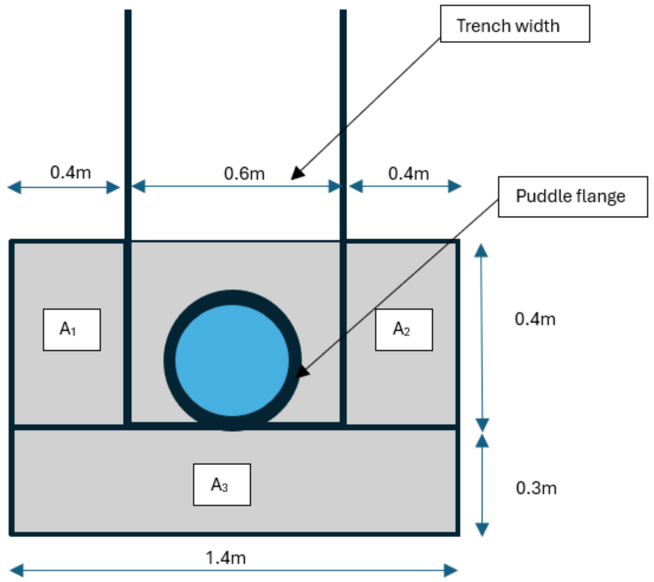

***Figure 6**: Example dimension for the calculated bearing area required (Not to scale)*

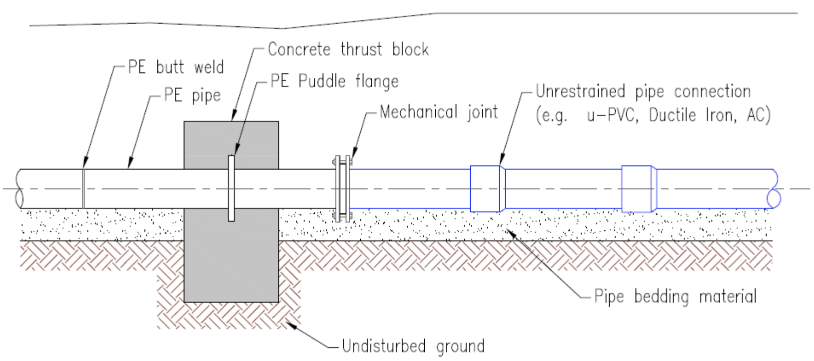

***Figure 7**: Example sketch of thrust restraint where PE pipe transitions to unrestrained pipe. Note thrust block cast away from dismantlable mechanical joint*

Note: Appropriate reinforcement (and the required cover to ensure reinforcement doesn't corrode) should be included for the design around the puddle flange and to ensure that the thrust protection acts as a monolithic structure. This also requires that the concrete be cast in a continuous poor.