Dealing with longitudinal forces in a polyethylene pipeline under pressure

When a pipeline is pressurised, the pipe wall is put under stress and depending on the pipe material and how the pipeline is restrained can have the effect of pulling the pipe out of a joint or fitting. To prevent the pipe and joint from separating and creating a leak path, either the joint needs to be able to resist longitudinal forces or anchoring needs to be used to minimise movement of the pipe in the joint.

Background

When a polyethylene pipeline is pressurised, the pipe wall is put under a triaxial state of stress, these stress components being axial (longitudinal), circumferential (hoop) and radial. In general, this triaxial state of stress has the effect of causing the pipe, when it is free to move longitudinally, to increase in diameter and reduce in length when pressurised. However, where the pipes ends are restrained, then the pipe will be placed in a state of axial tensile stress which in turn will apply a tensile force to the joints. This has the effect of pulling the pipe away from any joint.

The Water Industry's Information and Guidance Note IGN 4-01-02: Issue 3: December 2017[1] illustrates simply how these forces act on a joint. In addition, when a new pipe is installed and filled with water, there is likely to be a difference in the ambient temperature of the pipe wall (which has been above ground or in an open trench) and the temperature of the water. Where the temperature of the water introduced into the pipeline is lower than the temperature of the pipe material, this would lead to the following effects:

- Where the pipe is free to move longitudinally (such as two lengths of pipe joined centrally by a fitting and capped at each end by blanking plates in a trench with no backfill), the stress would be accommodated by contraction of the pipe length.
- Where the pipe is not free to move longitudinally (such as two lengths of pipe joined centrally by a fitting and capped at each end by blanking plates which are anchored), the pipe will be placed in a state of axial tensile stress which in turn will apply a tensile force to the anchored blanking plates or joint.

The IGN was developed in response to pipeline failures from pull-out where it was not recognised that forces arise from both thermal changes and internal pressure.

[1] IGN 4-01-02 https://www.water.org.uk/wp-content/uploads/2018/11/IGN-4-01-02v3-Dec-2017-.pdf

Full end load resistance

Polyethylene piping systems with correctly made butt fusion welds are naturally fully end-load bearing. This means that the joint can withstand a longitudinal tensile force equivalent to that required to cause yield of the pipe. Most electrofusion joints are also fully end-load bearing but for large diameters, the pipeline designer should seek information from the manufacturer. **Where full end-load resistance is required, BPF Pipes Group members recommend the use of fusion joints.**

Mechanical fittings can be designed to be fully end-load resistant (known as Type 1)[2]. To identify the test forces which need to be applied to a fitting to demonstrate this, IGN 4-01-02 shows the equation used to calculate longitudinal force from pipe yield stress and pipe wall cross-sectional area. It is not necessary for the pipeline engineer to calculate this as the work is already done in Appendix A and B of the IGN.

Additional anchoring is not required for a fully end-load resistant joint to resist the longitudinal force arising from thermal contraction and pressurisation of pipelines. However, where there is a transition to a component or a system which is not able to resist these forces (for example when connecting to iron or PVC mains), suitable measures need to be taken to protect the joint to avoid pull-out.

End load resistance

a) UK practice

At the high forces associated with full end load resistance especially in large diameters, the design of fittings and availability of test facilities might limit the choice of products available to the market. In reality, pipelines are not operated at the limit of pipe material performance therefore the pipeline designers may choose not to use a fully end load resistant solution.

In water industry applications, the test pressures used to assess the integrity of the pipeline are high and it is recommended for safety that all anchoring and backfilling of trenches are completed prior to testing (see IGN 4-01-03: Issue 2: 2015[3] which provides guidance on pressure testing of pipes and fittings). It is likely that longitudinal forces due to both thermal contraction and hydrostatic pressures will be acting on the fitting as the pipeline is filled with cold water and subsequently pressure tested. (These are likely to be higher than forces due to temperature changes and pressure during service).

These forces can be calculated from basic principles and are illustrated in IGN 4-01-02. It determines the capability of a fitting in typical pipeline operating conditions (known as Type 2) considering forces due to both change of temperature and hydrostatic pressure. The test forces against which Type 2 fittings can be evaluated are given in the IGN for connecting to PE80 pipes in diameters from 63mm – 180mm and to PE100 pipes in diameters from 63mm – 1200mm. Again, it is not necessary for the pipeline engineer to calculate these forces as the work is already done in the IGN.

[2] Note: Fittings up to 63mm are required to be fully end load resistant.

[3] IGN 4-01-03 https://www.water.org.uk/wp-content/uploads/2018/11/IGN-4-01-03-31-Nov-2015.pdf

For most water industry applications, fittings tested to the Type 2 end loads in the IGN are recommended. **When specifying mechanical fittings, manufacturers should be asked to demonstrate the capability of products against the values in IGN 4-01-02: Issue 3: 2017.**

Where the fittings or jointing system can achieve Type 2 performance then additional anchoring is not normally required for the system to resist the applied forces arising from pressurisation and thermal contraction. The pipeline designer should check that the assumptions made in IGN 4-01-02 with respect to working pressure, test pressure and maximum temperature variation hold true for the specific project and where necessary add anchor points/ thrust blocks or change to a fully end load resistant system.

b) European Standards

European and International Standards for mechanical fittings[4] do not include a specific test for end-load resistance. The pressure testing of fitting / pipe assemblies adequately addresses the longitudinal forces due to hydrostatic pressures acting on the fitting, but it does not address the forces due to thermal contraction.

When specifying and / or purchasing fittings (including polyethylene flanges) to these standards, it should not be presumed that they offer end-load resistance. The pipeline designer should seek information from the manufacturer on the capability of products against the values in IGN 4-01-02: Issue 3: 2017. The designer may need to consider how the installation procedure needs to be adapted to allow contraction of pipe due to any temperature changes to take place before movement of the pipeline is restricted by, for example, tying in the ends of a new pipeline to an existing network.

No end load resistance

A simple socket and spigot joint includes a sealing element which forms a frictionless seal on the external surface of the pipe. This type of joint provides no real resistance to end load forces and local anchor blocks would always need to be provided. This is also true of any mechanical fittings which cannot be demonstrated to meet the minimum requirements for an end load resistant (Type 2) fitting. When designing anchorage, the pipeline engineer should consider all aspects of the system, including the unbalanced forces loads imposed by testing procedures, unusual configurations, large temperature variations, etc. and where excessive load on the pipe system is envisaged, additional anchorage might need to be provided.

Guidance on the design of anchor points and thrust blocks can be found in CIRIA Report 128 ‘Guide to the design of thrust blocks for buried pressure pipelines’ Thorley A.R.D and Atkinson J.H, published by Thomas Telford 1994.

[4] BS EN 12201, BS EN 12842, BS EN 14525