## Chapter 8

# Above-Ground Applications for PE Pipe

### Introduction

In above ground applications PE piping may be suspended or cradled in support structures or, it may simply be placed directly on the ground surface. These types of installations may be warranted by any one of several factors. One is the economic considerations of a temporary piping system. Another is the ease of inspection and maintenance. Still another is simply that prevailing local conditions and even the nature of the application itself may require that the pipe be installed above ground.

PE pipe provides unique joint integrity, toughness, flexibility, and low weight. These factors combine to make its use practical for many "above-ground" applications. This resilient material has been used for temporary water lines, various types of bypass lines, dredge lines, mine tailings, and fines-disposal piping. PE pipe is used for slurry transport in many industries such as those that work with kaolins and phosphates. The ease of installation and exceptional toughness of PE pipe often make it practical for oil and gas collection. The economics and continued successful performance of this unique piping material is evident despite the extreme climatic conditions that may sometimes exist in some of these diverse applications.

This chapter presents design criteria and prevailing engineering methods that are used for above-ground installation of PE pipe. The effects of temperature extremes, chemical exposure, ultraviolet radiation, and mechanical impact are discussed in detail. Engineering design methodology for both "on-grade" and suspended or cradled PE pipe installations are presented and illustrated with typical sample calculations. All equations in the design methodology were obtained from published design references. These references are listed so the designer can verify the applicability of the methodology to his particular project. Additional installation considerations are also discussed.

## Design Criteria

Conditions and effects which can influence the behavior and thus, the design of above ground PE piping systems include:

· Temperature

· Chemical exposure

· Ultraviolet radiation

· Potential mechanical impact or loading

- Internal Pressure

**Figure 1** Above-Ground Installation of PE Pipe in a Wyoming Mining Operation

### Temperature

The diversity of applications for which PE pipes are used in above-ground applications reflects the usable temperature range for this material. Above-grade installations are usually exposed to demanding fluctuations in temperature extremes as contrasted to a buried installation where system temperatures can be relatively stable. Irradiation by sunlight, seasonal changes, and day-to-night transitions can impose a significant effect on any piping material installed above the ground.

As a general rule, PE pipe for pressure applications can be safely used at temperatures as low as -40°F (-40°C) and as high as 140°F (60°C). For non-pressure service, the allowable temperature range widens up to 180°F (82°C). There are a few PE piping materials that have qualified for a pressure rating at 180°F. The interested reader is advised to consult with the PPI for more information on these materials. However, PE is a thermoplastic material and, as such, these extremes impact the engineering properties of the piping. Additional information in this regard is available within the engineering properties chapter of this handbook.

### Pressure Capability

Because above ground installations of PE piping can be subject to exposures to wider temperature and pressure fluctuations and, sometimes also to effects of different environments, careful attention should be paid in the selection of PE piping which has an appropriate pressure rating for the anticipated temperature and environmental exposure. A detailed discussion of these issues is included in Chapters 6.

## Low Temperature Extremes

Generally speaking, the limitation for extremely low environmental service temperature is the potential for embrittlement of the material. Note, however, that most PE piping materials tested at extremely low temperatures have shown no indication of embrittlement.

The effect of low temperature on PE pipe is unique. As discussed in Chapter 3 and as shown in tables in the Appendix of Chapter 3, the apparent modulus of elasticity increases as temperatures are lowered. In effect, the pipe becomes stiffer but retains its ductile qualities. The actual low temperature embrittlement of most PE is below -180°F (-118°C). In actual practice, PE pipe has been used in temperatures as low as -75°F (-60° C).[4,5] Obviously, service conditions at these extremes may warrant insulation to prevent heat loss and freezing of the material being conveyed.

It should be noted that in extreme service applications operating at high pressure and increasingly lower temperature that the ability of some PE piping materials to absorb and dissipate energy such as that associated with sudden impact may be compromised. In these situations, it is possible that, with the addition of a sustaining or driving force, a through-wall crack can form which is capable of traveling for significant distances along the longitudinal axis of the pipe. This phenomenon is generally referred to as rapid crack propagation or RCP, and can occur in any pressure piping or pressure vessel design regardless of the material of manufacture.

This type of phenomenon is generally not experienced in PE in liquid transport applications as the energy dissipation associated with the sudden release of fluid from the pipe mediates the driving force required to sustain the crack. Gas or compressed air handling applications do not provide for the dissipation of energy and, as such, a driving or sustaining force is a potential possibility. For these reasons, the operation of PE pipe above ground in extremely cold environments (<32°F) should be carefully researched in light of the potential application and prevailing service conditions. The reader is referred to the pipe manufacturer for additional information regarding RCP and specific design measurers for above ground, cold weather installations.

## Expansion and Contraction

The coefficient of linear expansion for unrestrained PE pipe is approximately ten times that of metal or concrete. The end result is that large changes in the length of unrestrained PE piping may occur due to temperature fluctuations. While the potential for expansion (or contraction) is large when compared with that of metal, concrete, or vitrified clay pipe, note that the apparent modulus of elasticity for PE is substantially lower than that of these alternative piping materials. This implies that the degree of potential movement associated with a specific temperature change may be higher for the PE, but the stress associated with restraint of this movement is significantly less. The end result is that the means of restraint required to control this movement potential is often less elaborate or expensive. The stresses imposed by contraction or expansion of a PE piping system are usually on an order of 5% to 10% of those encountered with rigid piping materials.

## Chemical Exposure

Standard pressure ratings for PE pipe are for water at 73°F (23°C). Also, as is well established, in common installations either below or above ground, PE pipe will not rust, rot, corrode or be subject to galvanic corrosion. However, if the pipe is intended for the conveyance of a fluid other than water or, if it is intended to be installed in a chemically aggressive environment, consideration should be given to the appropriateness of the assigned standard pressure rating. Continuous exposure to certain substances can result in a reduction in the long-term strength of the PE material due to chemical attack or adsorption.

In some cases, such as with strong oxidizing or other agents that chemically attack PE, a gradual and irreversible reduction in strength may seriously compromise performance properties. In these cases the useful service life depends on the chemical aggressiveness of the agent, its concentration, total time of exposure and temperature. There are many cases where even though there is gradual chemical attack, PE pipe still offers sufficiently long life and is the most economical alternative.

In cases where PE piping is exposed to liquid hydrocarbons, a small adsorption of these materials into the pipe wall can occur which may result in a decrease in long-term strength. The effect is limited by the maximum amount of hydrocarbon that can be adsorbed which depends on the nature of the hydrocarbon and the temperature of the service. This effect on long-term strength is generally limited because hydrocarbon adsorption does not attack PE's chemical structure. Further, it should be noted that adsorption may slowly reverse when exposure to the hydrocarbon is decreased or removed. For lighter weight hydrocarbons such as condensates of gaseous hydrocarbons, adsorption reversal may occur within weeks or months after removal from exposure. However, the reverse adsorption of heavier liquid hydrocarbons may be so slow that the effect may be considered permanent. Exposure to most gaseous hydrocarbons is not known to reduce the long term strength of PE.

Finally, heat fusion joining between pipes after adsorption of liquid hydrocarbons can be affected. The presence of adsorbed liquid hydrocarbons in the pipe wall can result in low-strength heat fusion joining because the adsorbed hydrocarbons will liquefy and then vaporize when heated and reduce or prevent melt fusion. Hydrocarbon contamination is usually identified by a bubbly or pockmarked melt appearance upon heater plate removal. Because the strength and reliability of hydrocarbon contaminated joints is suspect, mechanical joining methods are used in these situations. The strength and reliability of heat fusion joints made before hydrocarbon adsorption is not affected

### Ultraviolet Exposure

When PE pipe is utilized outdoors in above-ground applications, it will be subjected to extended periods of direct sunlight. The ultraviolet component in sunlight can produce a deleterious effect on the PE unless the material is sufficiently protected. Weathering studies have shown that pipe produced with a minimum 2.0% concentration of finely divided and evenly dispersed carbon black is protected from the harmful effects of UV radiation for indefinite periods of time.[18] PE pipe that is protected in this manner is the principal material selected for above-ground installations. Black pipe (containing 2.0% minimum carbon black) is normally recommended for above-ground use. Consult the manufacturer's recommendations for any non-black pipe that is either used or stored above ground.

## Mechanical Impact or Loading

Any piping material that is installed in an exposed location is subject to the rigors of the surrounding environment. It can be damaged by the movement of vehicles or other equipment, and such damage generally results in gouging, deflecting or flattening of the pipe surfaces. If an above-ground installation must be located in a region of high traffic or excessive mechanical abuse (along a roadway, etc.), the pipe requires extra protection. It may be protected by building a berm or by encasing the pipe where damage is most likely. Other devices may be used, as appropriate to the situation. Design criteria for the installation of buried flexible thermoplastic pipe should be used for those areas where the above-ground PE system must pass under a roadway or other access, and where an underground installation of a portion of the system is necessary.[7,8] In general, in a pressurized installation in which any section of PE pipe has been gouged in excess of 10% of the minimum wall thickness, the gouged portion should be removed and replaced. This has long been an established procedure in the use of smaller diameter (up to 16-inch) PE pipe in natural gas applications. However, it is noted that this rule only applies to smaller size pipe.

Therefore, for any gouges or damage to larger pipe sizes with thicker walls, the user is advised to consult the manufacturer for assistance. When the PE pipe has been excessively or repeatedly deflected or flattened, it may exhibit stress-whitening, crazing, cracking, or other visible damage, and any such regions should be removed and replaced with new pipe material.

## Design Methodology

As previously discussed, above-ground piping systems can be subjected to variations in temperature. These temperature fluctuations can impact the pressure capability of the exposed piping to some degree. The possible effects resulting from expansion and contraction characteristics of PE pipe must also be addressed in light of the anticipated variations in temperature. Further, the installation characteristics of the proposed above-ground system must be analyzed in some detail. Each of these concerns will be briefly discussed in the sections which follow. This discussion will be supplemented and facilitated with a few example calculations.

## Pressure Capability

As mentioned earlier, the design of PE piping for internal pressure service is covered in significant detail in Chapter 6 of this Handbook. In addition, the Appendix to Chapter 3 contains a table of re-rating factors that can be applied to arrive at the appropriate pressure rating for the application under consideration.

Likewise, where the apparent modulus of elasticity of the pipe material is a consideration, the reader is referred to the modulus tables and associated temperature re-rating factors also found in Appendix, Chapter 3.

The following four example calculations are being presented to illustrate the effect of temperature on various design considerations for hypothetical above- ground PE pipe installations.

### EXAMPLE 1

What is the pressure capability of an SDR 11 series of PE 4710 PE pipe used to transport water at 73°F (23°C)?
From Chapter 5,

$$P = 2\,(HDS)(F_T) / (SDR - 1)$$

**WHERE**

HDS = **Hydrostatic Design Stress for PE Material at 73ºF (23ºC). For PE4710 = 1000 psig**

$F_T$ = **Temperature Re-rating Design Factor; at 73ºF, $F_T$ = 1.0 per Appendix, Chapter 3.**

P = **2(1000)(1.0) / (11-1) = 200psig at 73ºF**

What is this pipe's pressure capability at 100°F (38°C)?
From Appendix, Chapter 3, $F_T$ at 100°F = 0.78

$$P = 2(1000)\,(0.78)/(11\text{ -}1) = 156 \text{ psig at } 100°F$$

Example 1 assumes that exposure of the pipe to sunlight, combined with the thermal properties of the material flowing within the pipe, has resulted in a normal average operating temperature for the system at 100°F (38°C). Exposure of the pipe to direct sunlight can result in high, up to about 150°F outside surface temperatures, particularly if the pipe is black.(9) In the majority of cases, the material flowing within the pipe is substantially cooler than the exterior of the exposed above-ground pipe. The cooler nature of the material flowing through the pipe tends to moderate the outside surface temperature of the exposed pipe. This results in a pipe wall temperature that is intermediate between that of the outside surface of the pipe and that of the flow stream. Obviously, the longer the period of irradiation of the pipe by sunlight, the greater the potential will be to raise the temperature of the flow stream.

Several texts related to temperature design criteria and flow are included in the literature references of this chapter.(10,11)

In addition, the reader is referred to Chapters 3 and 6 for more detailed information on the topic of the pressure ratings of the different PE materials designation codes and applicable temperature re-rating factors.

## Expansion and Contraction

As noted in the Design Criteria section of this chapter, temperature changes can produce a substantial change in the physical dimensions of PE pipe. This is evidenced by a coefficient of expansion or contraction that is notably higher than that of many other piping materials. The design methodology for above-ground installation must take this potential for expansion or contraction into consideration.

The expansion or contraction for an unrestrained PE pipe can be calculated by using the following Equation.

**Pipe Length vs. Temperature Change**

**(3)** $$\Delta L = \alpha\,(T_2 - T_1)\,L$$

**WHERE**

$\Delta L$ **= Theoretical length change (in.)**

$\Delta L$**>0 is expansion**

$\Delta L$**<0 is contraction**

$\alpha$ **= Coefficient of linear expansion, see Appendix, Chapter 3**

$T_1$ **= Initial temperature (°F)**

$T_2$ **= Final temperature (°F)**

L **= Length of pipe (in.) at initial temperature,** $T_1$

## EXAMPLE 2

A 100 foot section of 10-inch (10.75-inch OD) SDR 11 (PE 4710 pipe) is left unrestrained overnight. If the initial temperature is 70°F (21°C), determine the change in length of the pipe section at dawn the next morning if the pipe stabilizes at a nighttime temperature of 30°F (-1°C).

**Using Equation 3,**

$$\Delta L = (8.0 \times 10^{-5})(30° - 70°)(100 \text{ ft})(12 \text{ in/ft}) = -3.84 \text{ Inches}$$

The negative sign indicates a contraction, so the final length is 99 ft., 8.16 in.

As shown in Example 2, the contraction or expansion due to temperature change can be quite significant. However, this calculated change in length assumes both an unrestrained movement of the pipe and an instantaneous drop in temperature. Actually, no temperature drop is instantaneous, and obviously, the ground on which the pipe is resting creates a retarding effect on the theoretical movement due to friction. Practical field experience for PE pipe has shown that the actual contraction or expansion that occurs as a result of temperature change is approximately one-half that of the theoretical amount.

Field experience has also shown that changes in physical length are often further mitigated by the thermal properties or heat-sink nature of the flow stream within the pipe. However, conservative engineering design warrants that consideration be given to the effects of temperature variation when the flow stream is static or even when there is no flow stream.

In cases where PE pipe will be exposed to temperature changes, it is common practice to control the pipe movement by judiciously placing restraining devices. Typical devices include tie-down straps, concrete anchors, thrust blocks, etc. The anchor selection must consider the stresses developed in the pipe wall and the resultant loads that are generated as a result of the anticipated temperature changes. While Equations 4 and 5 provide examples of how to calculate generated loads and stress, the Equations are not all inclusive.

**(4) Longitudinal Stress vs. Temperature Change**

$$\sigma_T = \alpha (T_2 - T_1) E$$

**WHERE**

$\sigma_T$ **= Theoretical longitudinal stress (psi)(Negative for contraction; positive for expansion)**

$\alpha$ **= Coefficient of expansion or contraction (see Eq. 3)**

$T_1$ **= Initial temperature (°F)**

$T_2$ **= Final temperature (°F)**

$E$ **= Apparent short-term modulus of elasticity (see Appendix, Chapter 3) at average temperature ($T_m$)**

$T_m$ **= ($T_2$ + $T_1$ )/2**

**(5) Longitudinal Force vs. Temperature Change**

$$F_T = \sigma_T (A)$$

**WHERE**

$F_T$ **= Theoretical longitudinal force (lbs)**

$\sigma_T$ **= Theoretical longitudinal stress (psi) from Eq. 4**

$A$ **= Pipe wall cross-sectional area (in$^2$)**

**EXAMPLE 3**

Assuming the same conditions as Example 2, what would be the potential maximum theoretical force developed on the unrestrained end of the 100 foot section if the other end is restrained effectively? Assume that the cross-sectional area of the pipe wall is approximately 30 in$^2$, the temperature change is instantaneous, and the frictional resistance against the soil is zero.

$$\sigma_T = \alpha (T_2 - T_1) E$$

**Note:** This E (apparent modulus) value is the average of the materials value at each of the two temperatures used in this example calculation.

**= (8.0 x 10$^{-5}$)(30°-70°) (130,000 x [1.65 + 1.00] /2)**

**= -551 psi**

$$F_T = (\sigma_T)(A)$$

**= - 551 psi x 30 in$^2$**

**=-16,530 lbs**

As previously mentioned, for these conditions where the temperature change is gradual, the actual stress level is approximately half that of the theoretical value. This would account for an actual force at the free end of about -8,265 Ibs. To illustrate the differences between the expansion and contraction characteristics of PE pipe versus those of steel, consider the following example:

**EXAMPLE 4**

Assume the same conditions as Example 2 for 10-inch Schedule 40 steel pipe. The pipe wall has a cross-sectional area of 11.90 $in^2$, the value of $\alpha$ for steel is 6.5 x $10^{-6}$ in/in/°F, and the value of E for this material is 30,000,000. [14]

$$\sigma_T = \alpha_{steel} (T_2 - T_1) E$$

$= (6.5 \times 10^{-6}) (30° - 70°) (3 \times 10^7)$

$= -7,800$ psi

$$F_T = (\sigma_T)(A)$$

$= -7,800 \text{ psi} \times 11.90 \text{ in}^2$

$= -92,820$ lbs

Thus, as shown by Examples 3 and 4, even though the coefficient of thermal expansion is high in comparison to other materials, the comparatively low modulus of elasticity results in correspondingly reduced thermal stresses and generated loads.

These design considerations provide a general introduction to the understanding of temperature effects on PE pipe in above-ground applications. They do not include other factors such as the weight of the installed pipe, frictional resistance of pipe lying on-grade, or grade irregularities. All of these factors affect the overall expansion or contraction characteristics, and individual pipe manufacturers should be consulted for further detail.

## Installation Characteristics

There are two basic types of above-ground installations. One of these involves "stringing-out" the pipe over the naturally-occurring grade or terrain. The second involves suspending the pipe from various support structures available along the pipeline right-of-way. Figure 2 illustrates some typical installations for both types. Each type of installation involves different design methodologies, so the installation types are discussed separately.

## On-Grade Installations

As indicated previously, pipe subjected to temperature variation will expand and contract in response to temperature variations. The designer has two options available to counteract this phenomenon. Basically the pipe may be installed in an unrestrained manner, thus allowing the pipe to move freely in response to temperature change. Or the pipe may be anchored by some means that will control any change of physical dimensions; anchoring can take advantage of PE's unique stress relaxation properties to control movement and deflection mechanically.(12)

## Free Movement

An unrestrained pipe installation requires that the pipe be placed on a bed or right-of-way that is free of material that may abrade or otherwise damage the exterior pipe surface. The object is to let the pipe "wander" freely without restriction or potential for point damage. This installation method usually entails "snaking" the PE pipe along the right-of-way. The excess pipe then allows some slack that will be taken up when the temperature drops and the pipe contracts.

**Figure 2** Typical Above-Ground Installations with PE Pipe

**Figure 2a** On-grade Installation of PE Pipe in an Industrial Application. Note "snaking" along right of way.

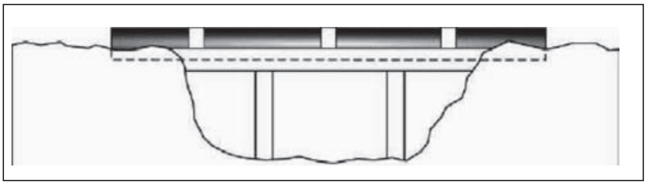

**Figure 2b** Continuous Support of PE Pipe at Ravine Crossing

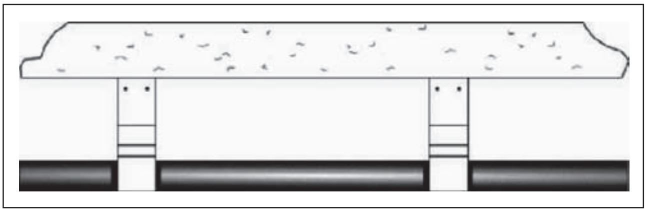

**Figure 2c** Intermittent Support of PE Pipe Suspended from Rigid Structure

In all likelihood, a free-moving PE pipe must eventually terminate at or connect to a rigid structure of some sort. It is highly recommended that transitions from free-moving PE pipe to a rigid pipe appurtenance be fully stabilized so as to prevent stress concentration within the transition connection.

Figure 3 illustrates some common methods used to restrain the pipe at a distance of one to three pipe diameters away from the rigid termination. This circumvents the stress-concentrating effect of lateral pipe movement at termination points by relieving the stresses associated with thermal expansion or contraction within the pipe wall itself.

**Figure 3** Typical Anchoring Methods at Rigid Terminations of Free-Moving PE Pipe Sections

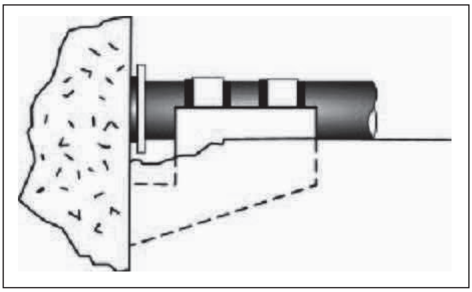

**Figure 3a** Connection to Concrete Vault Using Grade Beam

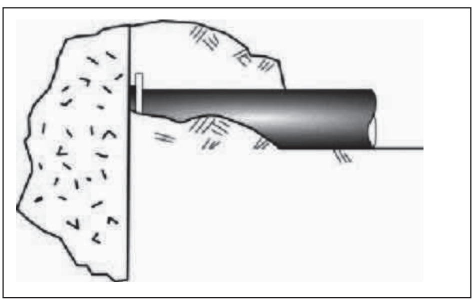

**Figure 3b** Connection to Rigid Structure Using Consolidated Earthen Berm

## Restrained Pipelines

The design for an above-ground installation that includes restraint must consider the means by which the movement will be controlled and the anchoring or restraining force needed to compensate for, or control, the anticipated expansion and contraction stresses. Common restraint methods include earthen berms, pylons, augered anchors, and concrete cradles or thrust blocks.

The earthen berm technique may be either continuous or intermittent. The pipeline may be completely covered with a shallow layer of native earth over its entire length, or it may be stabilized at specific intervals with the earthen berms between the anchor locations. Typical earthen berm configurations are presented in Figure 4.

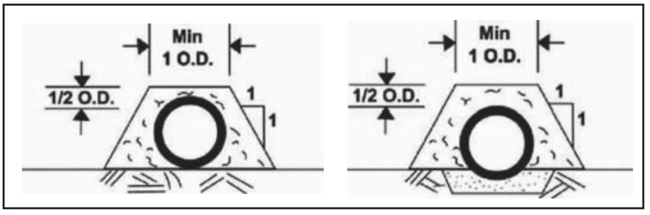


**Figure 4** Earthern Berm Configurations

The continuous earthen berm serves not only to stabilize the pipe and restrain its movement but also to moderate temperature fluctuations. With less temperature fluctuation the tendency for pipe movement is reduced.

An intermittent earthen berm installation entails stabilization of the pipe at fixed intervals along the length of the pipeline. At each point of stabilization the above-ground pipe is encased with earthen fill for a distance of one to three pipe diameters. The economy of this method of pipeline restraint is fairly obvious.

Other means of intermittent stabilization are available which provide equally effective restraint of the pipeline with a greater degree of ease of operation and maintenance. These methods include pylons, augered anchors [13], or concrete cradles. These restraint techniques are depicted schematically in Figures 5 through 7.

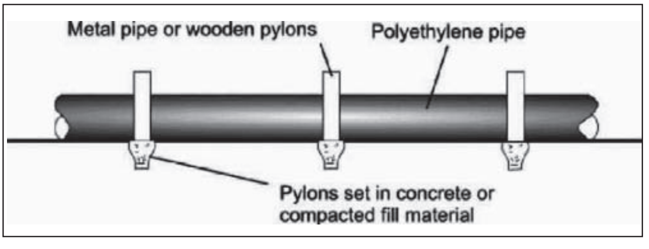


**Figure 5** Pylon Type Stabilization

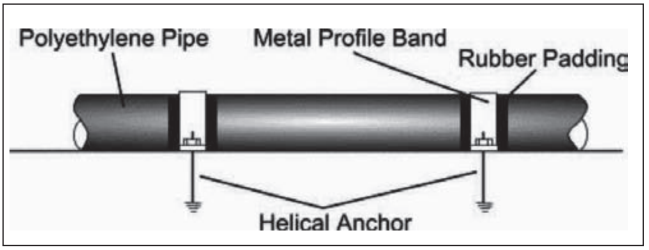


**Figure 6** Augered Anchor Stabilization

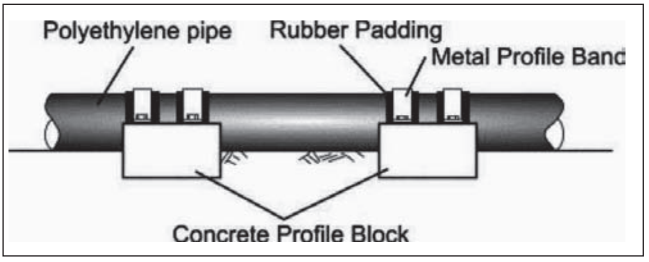


**Figure 7** Concrete Cradle or Thrust Block Stabilization

A pipeline that is anchored intermittently will deflect laterally in response to temperature variations, and this lateral displacement creates stress within the pipe wall. The relationships between these variables are determined as follows:

**Lateral Deflection (Approximate from Catenary Eq.)**

**(6)** $\Delta y = L \sqrt{0.5\, \alpha\, (\Delta T)}$

**WHERE**

$\Delta_y$ = **Lateral deflection (in.)**

$L$ = **Distance between anchor points (in.)**

$\alpha$= **Coefficient of expansion/contraction; see Appendix, Chapter 3**

$\Delta T$ = **Temperature change ($T_2$ - $T_1$ ) in °F**

**(7) Bending Strain Development**

$$\varepsilon = \frac{D \sqrt{96\, \alpha\, (\Delta T)}}{L}$$

**WHERE**

$\varepsilon$ = **Strain in pipe wall (%)**

$D$ = **Outside diameter of pipe (in)**

$\alpha$= **Coefficient of expansion/contraction; see Appendix, Chapter 3**

$\Delta T$ = **($T_2$ - $T_1$) in °F**

$L$ = **Length between anchor points (in)**

As a general rule, the frequency of stabilization points is an economic decision. For example, if lateral deflection must be severely limited, the frequency of stabilization points increases significantly. On the other hand, if substantial lateral deflection is permissible, fewer anchor points will be required, and the associated costs are decreased.

Allowable lateral deflection of PE is not without a limit. The upper limit is determined by the maximum permissible strain in the pipe wall itself. This limit is a conservative 5% for the majority of above-ground applications. It is determined by use of Equation 7 based on the assumption that the pipe is anchored between two posts at a distance L from each other. Equations 6 and 7 are used to determine the theoretical lateral deflection or strain in overland pipelines. Actual deflections and strain characteristics may be significantly less due to the friction imposed by the prevailing terrain, the weight of the pipe and flow stream, and given that most temperature variations are not normally instantaneous. These factors allow for stress relaxation during the process of temperature fluctuation.

**EXAMPLE 5**

Assume that a 10-inch (OD = 10.75) SDR 11 (PE 4710) pipe is strung out to grade and anchored at 100-foot intervals. What is the maximum theoretical lateral deflection possible, given a 50°F (27.8°C) temperature increase? What strain is developed in the pipe wall by this temperature change? What if the pipe is anchored at 50-foot intervals?

**Calculations for 100-foot intervals:**

$$\Delta y = L\sqrt{0.5\alpha\,(\Delta T)}$$

$$= 100 \times 12\,[0.5\,(8 \times 10^{-5})\,(50)]^{1/2}$$

**= 53.7 inches lateral displacement**

$$\varepsilon = \frac{D\sqrt{96\alpha(\Delta T)}}{L}$$

$$= \frac{10.75\sqrt{(96)\,(8 \times 10^{-5})(50)}}{100(12)}$$

**= 0.56% strain**

**Calculations for 50-foot intervals:**

$$\Delta y = L\sqrt{0.5\alpha(\Delta T)}$$

**= 50 x 12 [0.5(8 x 10$^{-5}$)(50)]$^{1/2}$**

**= 26.8 inches lateral displacement**

$$\varepsilon = D\sqrt{\frac{96\alpha(\Delta T)}{L}}$$

$$= 10.75\sqrt{\frac{96\,(0.0001\,)\,(50)}{50\,(\,12\,)}}$$

**= 1.11% strain**

From the calculations in Example 5, it is apparent that lateral deflections which appear significant may account for relatively small strains in the pipe wall. The relationship between lateral deflection and strain rate is highly dependent on the selected spacing interval.

## Supported or Suspended Pipelines

When PE pipeline installations are supported or suspended, the temperature and corresponding deflection characteristics are similar to those discussed above for unsupported pipelines with intermittent anchors. There are two additional parameters to be considered as well: beam deflection and support or anchor configuration.

### Support or Suspension Spacing

Allowable spans for horizontal lines are principally influenced by the need to comply with these objectives:

- Keep the pipe bending stresses within suitable limits
- Limit deflections (sagging), if necessary for
  - Appearance
  - Avoiding pockets (to allow complete drainage)
  - Avoid interferences with other pipes or, items

In most cases, the limiting pipe spans which allow the above objectives to be met can readily be obtained from the equations which are presented below. These equations are based on the simple beam relationship.

**(8) Support Spacing Requirements**

$$L = \left(\frac{3\,(OD^4 - ID^4)\,\sigma_m\pi}{8qOD}\right)^{1/2}$$

**WHERE**

$L$ **= Center-to-center span (in)**

$OD$ **= Outside diameter (in)**

$ID$ **= Inside diameter (in)**

$\sigma_m$ **= Maximum allowable bending stress (psi); see Note below**

**= 100 psi for pressurized pipelines**

**= 400 psi for non-pressurized pipelines**

$q$ **= Load per unit length (lb/in.)**

**Note:** A common and conservative design objective (in the case on non-pressure pipelines) is to limit the bending stress to one half of the PE pipe material's HDS for the maximum anticipated operating temperature. For pressure pipelines, the objective is to limit the bending stress to 1/8th of the HDS. For example, for a PE4710 material – one having an HDS of 1000psi for water for 73°F – the corresponding bending limits for 73°F would be 500 (for non-pressure) and 125psi (for pressure). And, for a different maximum operating temperature these limits would be modified in accordance with the temperature adjustment factors given in the Appendix to Chapter 3. Also, if environment is a factor this should also be recognized.

**(9) Load per Unit Length**

$$q = \frac{W}{12} + \frac{\pi\sigma(ID)^2}{6912}$$

**WHERE**

$q$ **= Load per unit length (lb/in)**

$W$ **= Weight of pipe (lbs/ft)**

$\sigma$ **= Density of Internal fluid (lb/ft$^3$)**

$\pi$ **= 3.1416**

This calculation gives a conservative estimate of the support span in cases where the pipe is not completely restrained by the supports. (The pipe is free to move within the supports.) A more complex analysis of the bending stresses in the pipe may be performed by treating the pipe as a uniformly loaded beam with fixed ends. The actual deflection that occurs between spans may be determined on the basis of this type of analysis, as shown in Equation 10.

**(10) Simple Beam Deflection Analysis[14,15] Based on Limiting Deflection**

$$d = \frac{fqL^4}{E_L I}$$

**WHERE**

$d$ **= Deflection or sag (in)**

$f$ **= Deflection Coefficient, (Refer to Table 2)**

$L$ **= Span length (in)**

$q$ **= Load per unit length (lb/in)**

$E_L$ **= Apparent long-term modulus of elasticity at average long-term temperature from Appendix, Chapter 3**
$I$ **= Moment of inertia ($in^4$)**
**= $(\pi/64)(OD^4 - ID^4)$**

Simple beam analysis reflects the deflection associated with the proposed support spacing configuration and the apparent modulus of elasticity at a given service temperature. It does not take into consideration the increased or decreased deflection that may be attributed to expansion or contraction due to thermal variations. These phenomena are additive - Equation 11 illustrates the cumulative effect.

**(11) Cumulative Deflection Effects**

**Total deflection = beam deflection + thermal expansion deflection**

$$= d + \Delta y$$

$$d = \frac{fqL^4}{E_L I} + L\sqrt{0.5\alpha(\Delta T)}$$

Simple beam analysis assumes one support point at each end of a single span. Most supported pipelines include more than one single span. Normally, they consist of a series of uniformly spaced spans with relatively equal lengths. The designer may analyze each individual segment of a multiple-span suspended pipeline on the basis of simple beam analysis. However, this approach may prove overly conservative in the majority of multiple-span supported pipelines. Equation 12 presents a more realistic approach to deflection determination on the basis of continuous beam analysis.

**(12) Continuous Beam Analysis**

$$d = \frac{fqL^4}{E_L I}$$

**WHERE**

$d$ **= Deflection or sag (in)**
$f$ **= Deflection coefficient (Refer to Table 2)**
$q$ **= Load per unit length (lbs/in)**
$L$ **= Span length (in)**
$E_L$ **= Apparent long-term modulus of elasticity at average long-term temperature from Appendix, Chapter 3**
$I$ **= Moment of inertia ($in^4$)**
**= $(\pi/64)(OD^4 - ID^4)$**

The deflection coefficient, f, is a function of the number of spans included and whether the pipe is clamped securely, fixed, or simply guided (not fixed) within the supports. Practical values for the deflection coefficient, f, are provided in Table 2.

**TABLE 2**
**Deflection Coefficients, f, for Various span Configurations [17]**

| 1 Span | 2 Spans | 3 Spans | 4 Spans |
|---|---|---|---|
| N-N | N-N-N | N-N-N-N | N-N-N-N-N |
| | | 1 2 1 | 1 2 2 1 |
| f=0.013 | f=0.0069 | f1=0.0069 | f1=0.0065 |
| | | f2=0.0026 | f2=0.0031 |
| F–N | F-N-N | F-N-N–N | F-N-N-N-N |
| | 1 2 | 1 2 2 | 1 2 2 2 |
| f=0.0054 | f=0.0026 | f1=0.0026 | f1=0.0026 |
| | f2=0.0054 | f2=0.0054 | f2=0.0054 |
| F-F | F-N-F | F-N-N-F | F-N-N-N-F |
| | | 1 2 1 | 1 2 2 1 |
| f=0.0026 | f=0.0026 | f1=0.0026 | f1=0.0026 |
| | | f2=0.0031 | f2=0.0031 |
| | F-F-F | F-F-F-F | F-F-F-F-F |
| | f=0.0026 | f=0.0026 | f=0.0026 |
| F = Fixed Securely N = Not Fixed | | | |

As was the case for simple beam analysis, continuous beam analysis addresses the deflection resulting from a given span geometry at a specified service temperature. The equation does not take into consideration the additional deflection associated with expansion or contraction due to temperature variations. Equation 13 combines the effect of deflection due to span geometry (using continuous beam analysis) with deflection resulting from expansion due to a temperature increase. A total span deflection of ½ to 1 inch is generally considered as a maximum.

**(13) Total Span Deflection Based on Continous Beam Analysis and Thermal Response**

$$\text{Total Deflection (in)} = \frac{fqL^4}{E_L I} + L\sqrt{0.5\alpha(\Delta T)}$$

**WHERE**

f = **Deflection Coefficient (Refer to Table 2)**

q = **Load per unit length from Eq. 9 (lbs/in)**

L = **Span length from Eq. 8 (in)**

$E_L$ = **Apparent long-term modulus of elasticity at average long-term temperature from Appendix, Chapter 3**

I = **Moment of inertia (in.$^4$)**

= **$(\pi/64)(OD^4 - ID^4)$**

## Anchor and Support Design

Proper design of anchors and supports is as important with PE piping as it is with other piping materials. A variety of factors must be considered.

Some installations of PE pipe have the pipe lying directly on the earth's surface. In this type of installation, the surface under the pipe must be free from boulders, crevices, or other irregularities that could create a point-loading situation on the pipe.

On-grade placement over bed rock or "hard pan" should be avoided unless a uniform bed of material is prepared that will cushion the pipe. If the PE pipe rests directly on a hard surface, this creates a point loading situation and can increase abrasion of the outer pipe surface as it "wanders" in response to temperature variations.

Intermittent pipe supports should be spaced properly, using the design parameters discussed in the preceding pages. Where excessive temperatures or unusual loading is encountered, continuous support should be considered.

Supports that simply cradle the pipe, rather than grip or clamp the pipe, should be from one-half to one-pipe diameter in length and should support at least 120 degrees of the pipe diameter. All supports should be free from sharp edges.

The supports should have adequate strength to restrain the pipe from lateral or longitudinal deflection, given the anticipated service conditions. If the design allows free movement during expansion, the sliding supports should provide a guide without restraint in the direction of movement. If on the other hand, the support is designed to grip the pipe firmly, the support must either be mounted flexibly or have adequate strength to withstand the anticipated stresses.

Heavy fittings or flanges should be fully supported and restrained for a distance of one full pipe diameter, minimum, on both sides. This supported fitting represents a rigid structure within the flexible pipe system and should be fully isolated from bending stresses associated with beam sag or thermal deflection.

Figure 8 includes some typical pipe hanger and support arrangements that are appropriate for use with PE pipe, and Figure 9 shows some anchoring details and cradle arrangements.

## Pressure-Testing

It is common practice to pressure-test a pipe system prior to placing it in service. For the above-ground systems described in this chapter, this test should be conducted hydrostatically. Hydrostatic testing procedures are described in a number of publications, including PPI Technical Report 31.[8] The Plastics Pipe Institute does not recommend pneumatic pressure testing of an above-ground installation.[16] An ASTM test method for leakage testing of PE pipe installations is under development and may be applicable. The reader is also advised to refer to Chapter 2 of this Handbook where the subject of pressure testing of installed PE pipe systems is covered in greater detail.

**Figure 8** Typical Pipe Hangers and Supports

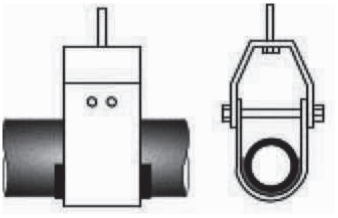

**Figure 8.1** Pipe Stirrup Support

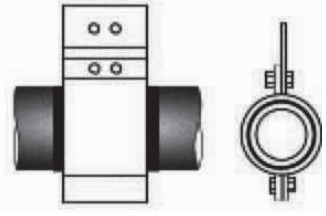

**Figure 8.2** Clam Shell Support

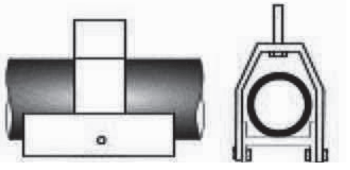

**Figure 8.3** Suspended I-Beam or Channel-Continuous Support

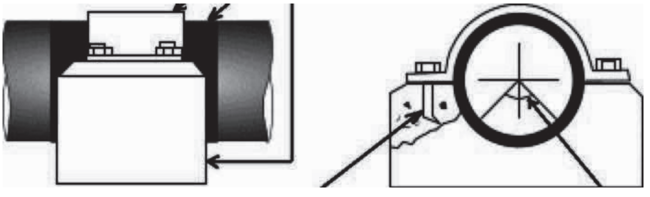

**Figure 9** Typical Anchoring and Cradling Details

## Conclusion

PE pipe has been used to advantage for many years in above-ground applications. The unique light weight, joint integrity, and overall toughness of PE has resulted in the above-ground installation of PE pipe in various mining, oil, gas production and municipal distribution applications. Many of these systems have provided years of cost-effective service without showing any signs of deterioration.

The key to obtaining a quality above-ground PE piping system lies in careful design and installation. This chapter is intended to serve as a guide by which the designer and/or installer may take advantage of the unique properties of PE pipe for these types of applications. In this way, excellent service is assured, even under the demanding conditions found with above-ground installations.

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Eq 11. Ibid.
Eq 12. Ibid.