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## ABOVE-GROUND APPLICATIONS FOR POLYETHYLENE PIPE

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# ABOVE-GROUND APPLICATIONS FOR POLYETHYLENE PIPE

## Introduction

Some projects require that a pipe be laid out, or “strung out”, across the prevailing terrain. The pipe may simply be placed on the ground surface, or it may be suspended or “cradled” in support structures. Above-ground installations may be desired due to (1) the economic considerations of a temporary piping system, (2) presence of rock and the cost for blasting a trench or (3) landrights or easements prevent burial of the pipe.

Polyethylene pipe provides joint integrity, toughness, flexibility, and low weight to make its use practical for many “above-ground” applications. This Technical Note presents design criteria and prevailing engineering methods that are recommended by the Plastic Pipe Institute for the above-ground installation of polyethylene pipe. The effects of temperature changes/extremes, chemical exposure, ultraviolet radiation and potential mechanical impact or loading are discussed. Engineering design considerations for both “on-grade” and suspended or cradled polyethylene pipe installations are discussed.

## Design Considerations

### Temperature

Above-ground pipe installations are exposed to wide fluctuations in temperature as contrasted to a buried installation where temperatures are usually relatively stable. Irradiation by sunlight, seasonal temperature extremes and day-to-night temperature changes effect any piping material installed above the ground. As a rule, polyethylene pipe can be used safely at temperatures as low as -75°F (-60°C) and as high as 150°F (65°C). However, temperature does affect the engineering properties of polyethylene pipe.

The pressure capability of a polyethylene pipe is predicated on the long-term hydrostatic strength (LTHS) of the polymer used in its manufacture. As the temperature to which the polyethylene pipe is exposed increases, the LTHS decreases. Correspondingly, the pressure rating of a specific pipe is reduced as the service temperature increases. On the other hand, if the service temperature is lowered, the LTHS and pressure rating increase.

The temperature effects on elasticity and pressure ratings for polyethylene PE3408 pipe are illustrated in Table 1. This table lists pressure design factors that are applied to the standard pressure ratings at 73.4°F (23°C) to derive an estimation of the true long-term pressure capability of a polyethylene pipe at a specific service temperature. The use of these factors is illustrated in Example 1. Information regarding the temperature-responsive nature of a specific polyethylene pipe is available from the respective pipe manufacturer.

**Table 1 - Pressure Capability Design Factors**

Service Temperature OF (OC)	Apparent Modulus of Elasticity (E ) psi	Apparent Long-Term Modulus of Elasticity (E ) psi	Pressure Design Factor
140 (60)	50,000	12,000	0.50
130 (55)	57,000	13,000	0.50
120 (49)	65,000	15,000	0.70
110 (44)	80,000	18,000	0.75
100 (38)	100,000	23,000	0.80
90 (32)	103,000	24,000	0.90
80 (27)	108,000	25,000	0.95
73.4 (23)	130,000	30,000	1.00
60 (16)	130,000	30,000	1.15
50 (10)	165,000	38,000	1.30
40 (4)	170,000	39,000	1.40
30 (-1)	200,000	46,000	1.60

Generally, the limitation of extremely low environmental temperature is embrittlement of the material. The actual low temperature embrittlement of most polyethylene pipe is below -180°F (-118°C). The effect of low temperature on the modulus of elasticity for polyethylene pipe (as shown in Table 1) increases as temperatures are lowered. In effect, the pipe becomes stiffer but retains its ductile qualities. In actual practice, polyethylene pipe has been used in temperatures as low as -75°F (-60°C). Obviously, service conditions at these extremes may warrant insulation to prevent heat loss and freezing of the material being conveyed.

The coefficient of linear expansion for unrestrained polyethylene pipe is approximately ten times that of metal or concrete. The result is that large changes in the length of unrestrained polyethylene piping may occur due to temperature fluctuations.

### **Chemical Resistance**

Polyethylene pipe will not rust, rot, pit or corrode because of chemical, electrolytic or galvanic action. The only chemical environments that pose potentially serious problems for polyethylene pipe are strong oxidizing agents and certain hydrocarbons. Concentrated sulphuric and nitric acids are strong oxidizers while diesel and fuel oils typify the hydrocarbons.

Environments that contain oxidizing agents may affect the performance characteristics of polyethylene pipe. The continued exposure of polyethylene to strong oxidizing agents may lead to crack formation or crazing of the pipe surface. However, occasional or intermittent exposure to these agents will not significantly affect the long-term performance of a polyethylene pipe.

Hydrocarbon exposures normally cause only temporary effects on polyethylene. The result of the exposure is, for the most part, evident only as long as the exposure is maintained. Exposure to certain hydrocarbons tends to reduce the pressure capability of the polyethylene. It is also evidenced by a reduction in tensile strength and an increase in physical dimensions (swelling) due to adsorption of the hydrocarbon by the polyethylene structure. Continued exposure can lead to permeation of the polyethylene pipe wall and eventual leaching of the material being conveyed. The degree of permeation is a function of pressure, temperature, the nature of the hydrocarbons and the polymer structure of the piping material.

### **Ultraviolet Exposure**

Polyethylene pipe utilized outdoors in above-ground applications is subjected to extended periods of direct sunlight. The ultraviolet component in sunlight can produce a deleterious effect on the polyethylene unless the material is sufficiently protected. Polyethylene pipe produced with a minimum 2% concentration of finely divided and evenly dispersed carbon black is protected from the harmful effects of UV radiation. Black pipe (containing 2% minimum carbon black) is normally recommended for above-ground use. Consult the manufacturer's recommendations for any non-black pipe that is used.

### **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. Design criteria for the installation of buried flexible thermoplastic pipe should be used for those areas where the above-ground polyethylene system must pass under a roadway or other access, and where an underground installation of a portion of the system is necessary.

In general, in an installation in which any section of polyethylene pipe has been gouged in excess of 10% of the minimum wall thickness, the gouged portion should be removed. When the polyethylene 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.



## Fire

A major consideration for the use of above-ground polyethylene pipe is the potential damage from fire. Polyethylene materials will sag, deform and /or burn when subjected to temperatures associated with fire. The potential for wildfire along the path of any above-ground pipe installation needs to be addressed in the Operation and Maintenance Plan. Items may include the use of fire retardant vegetation along the pipeline route and establishing fire breaks.

## DESIGN METHODOLOGY

### Allowable Design Pressure

The exposure of above-ground pipe to sunlight can result in extremely high outside surface temperatures. In the majority of cases, the water flowing in the pipe is substantially cooler than the exterior of the exposed above-ground pipe and the water flowing through the pipe tends to moderate the surface temperature of the exposed pipe. This can result in a pipe wall temperature that is only slightly above that of the temperature of the water flowing through the pipe. However, in pipeline systems with occasional flow, the temperature increase can be much higher. The site specific design needs to determine the allowable pressure rating of the specific polyethylene pipe based upon the expected maximum service temperature.

#### Example 1

What is the pressure capability for a SDR 11 series of PE 3408 polyethylene pipe designed to operate at 100°F (38°C)?

From the Manufacturer's data, the pressure capability rating for PE 3408 pipe for water at 73.4°F (23°C) is 160 psi.

From Table 1, the 100°F (38°C) pressure design factor is 0.80.

Therefore:  $P(100^{\circ}\text{F}) = 160 \text{ psi} \times 0.80 = 128 \text{ psi}$

### Expansion and Contraction

The expansion or contraction for an unrestrained polyethylene pipe can be calculated by the following equation.

$$\Delta L = (T_1 - T_2) (a) (L) \quad \text{EQ 1}$$

Where:  $\Delta L$  = Theoretical length change (inches)

$\Delta L > 0$  is expansion :  $\Delta L < 0$  is contraction

$a$  = Coefficient of linear expansion

$a = 1.0 \text{ to } 1.1 \times 10^{-4} \text{ in/in/}^{\circ}\text{F}$  for PE3408 materials

$a = 1.0 \times 10^{-4} \text{ in/in/}^{\circ}\text{F}$  for PE2406 materials

$T_1$  = Initial temperature ( $^{\circ}\text{F}$ )

$T_2$  = Final temperature ( $^{\circ}\text{F}$ )

$L$  = Length of pipe (inches) at temperature  $T_1$

#### Example 2

A 1000 foot section of 2-inch (2.375-inch OD) SDR 11 (PE3408) material is left unrestrained overnight. If the initial temperature is 70°F (21°C), determine the length of the pipe section at dawn the next morning if the pipe stabilizes at a night time temperature of 30°F (-1°C).

$$\Delta L = (T_1 - T_2) (a) (L) \quad \text{EQ 1}$$

$$\Delta L = (30^{\circ} - 70^{\circ}) (1.1 \times 10^{-4}) (1000 \text{ ft})(12 \text{ in/ft})$$

$$= -52.8 \text{ Inches}$$

The negative sign indicates a contraction, therefore the final length is 995 feet, 7.2 inches.

As shown in Example 2, the contraction or expansion due to temperature change can be 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 the ground on which the pipe is resting creates a retarding effect on the theoretical movement due to friction. Practical field experience for polyethylene pipe has shown that the actual contraction or expansion that occurs because of



temperature change is approximately one-half 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 is given to the effects of temperature variation when the flow stream is static or even when the pipe is empty.

When polyethylene pipe exposed to temperature changes is restrained from moving, the specific anchor(s) must resist the stresses developed in the pipe wall.

Longitudinal Stress vs. Temperature Change

$$s_T = a(T_2 - T_1)E \quad \text{EQ 2}$$

and

$$F_T = (s_T) A \quad \text{EQ 3}$$

where:  $s_T$  = Theoretical longitudinal stress (psi)  
 (Negative for contraction; positive for expansion)  
 $a$  = Coefficient of expansion or contraction (see EQ 2)  
 $T_1$  = Initial temperature (°F)  
 $T_2$  = Final temperature (°F)  
 $E$  = Apparent short-term modulus of elasticity (see Table 1) at lowest temperature  $T_M$   
 where  $T = (T_1 + T_2)/2$   
 $F_T$  = Theoretical longitudinal force (lbs)  
 $A$  = Pipe wall cross-sectional area (in<sup>2</sup>)

**Example 3**

Assuming the same conditions as Example 2, what would be the maximum theoretical force developed on a pipe section with a 120°F temperature change. The cross-sectional area of the pipe wall is approximately 1.5 in<sup>2</sup>, the temperature change is instantaneous, and the frictional resistance against the soil is zero.

$$s_T = a(T_2 - T_1)E \quad \text{EQ 2}$$

$$= (1.1 \times 10^{-4})(30^\circ - 70^\circ) (200,000)$$

$$= - 880 \text{ psi}$$

$$F_T = (s_T)(A) \quad \text{EQ 3}$$

$$= - 880 \text{ psi} \times 1.5 \text{ in}^2$$

$$= - 1,320 \text{ lbs}$$

For the 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 of about -660 lbs.

These design considerations provide a general introduction of temperature effects on polyethylene 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 Considerations**

There are two basic types of above-ground installations: (1) “stringing-out” or laying the pipe over the naturally-occurring grade or terrain, and (2) suspending/supporting the pipe from various saddles and/or support structures. Each of these installations involves different design methodologies.

**On-Grade Installations**

As discussed 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. The pipe may be installed in an unrestrained manner, thus allowing the pipe to move freely in response to temperature change. Alternatively, the pipe may be anchored by some means that will control any change of the pipe’s physical dimensions.

### Unrestrained (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 as expansion/contraction occurs without potential for damage from abrasion or point loadings. This installation method usually entails "snaking" the polyethylene pipe along the right-of-way.

An otherwise free-moving polyethylene pipe must eventually terminate at or connect to a rigid structure (i.e. inlet structure, trough, pump, etc.). Transitions from free-moving polyethylene pipe to a rigid pipe appurtenance must be stabilized to prevent stress concentration within the transition connection. Some common methods used to restrain the pipe adjacent to a rigid termination/connection are:

- An earth covered section of pipe
- A reinforced concrete thrust block
- Mechanical pipe anchor

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. Equations 2 and 3 can be used to determine expected pipe expansion/contraction and the design stress on anchors.

In many instances, it is desirable to control the zone of pipe movement on an unrestrained reach of pipe. This is especially important on sloping land as unrestrained pipe will move down slope as expansion-contraction occurs. In addition, this technique can be used to limit the zone of horizontal movement where the ground surface must be modified to create a suitable surface on which to lay the pipe. This can be accomplished by placing posts along a desired pipe route and allowing the pipe to move freely within the designated zone. Posts, at a spacing of approximately 300 feet, have adequately served this purpose. A smaller spacing is generally needed for bends. (The smaller the radius, the closer the required post spacing).

On sloping land, sufficient restraints need to be placed along the pipeline to ensure that the stress created in the pipe wall, from the long-term downhill movement of the pipe during expansion and the need for the pipe to pull itself uphill during contraction, does not exceed the allowable stress limits for the pipe material. When pipe goes straight upslope or down slope, the maximum distance between anchors (restraints) for straight reaches of pipe will be determined as follows:

$$L = \frac{(TS) (OD)^2 [(1/DR) - (1/DR)^2]}{(0.7) (W) (1 + \sin b)} \quad \text{EQ 4}$$

where: L = Maximum length between anchors  
TS = Allowable tensile strength for pipe (psi for desired maximum operating pressure)  
OD = Outside diameter of pipe (inches)  
DR = Dimension Ratio of pipe  
W = Weight of pipe + water  
b = Uphill or downhill slope (degree)

Example 4 : PE 3408 pipe operating at 100°F, TS is 2800 psi (Manufacturer's data)  
1-1/2 Diameter, DR 9 HDPE pipe, OD is 1.461 inches, wall thickness is 0.211 inches,  
weight of pipe 0.48 lbs/ft, weight of water 0.367 lbs/ft, ground slope 5% (b = 2.87°)

$$L = \frac{(2800)(1.461)^2 [(1/9) - (1/9)^2]}{(0.7)(0.48 + 0.367)(1 + \sin 2.87^\circ)}$$

L = 947 feet

### Restrained Pipelines

The design for a restrained above-ground installation must consider the means by which the movement will be controlled and the anchoring or restraining force needed to 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. 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 five to ten (5-10) feet. Other means of intermittent stabilization such as pylons, augered anchors or concrete cradles provide equally effective restraint of the pipeline.

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.)

$$D_y = L [(0.5 a) (D_T)]^{1/2} \quad \text{EQ 5}$$

where:  $D_y$  = Lateral deflection (inches)  
 $L$  = Distance between anchor points (inches)  
 $a$  = Coefficient of expansion/contraction (0.0001 in/in/°F)  
 $D_T$  = Temperature change ( $T_2 - T_1$ ) in °F

Bending Strain Development

$$e = \frac{D [(96 a) (D_T)]^{1/2}}{L} \quad \text{EQ 6}$$

where:  $e$  = Strain In pipe wall (%)  
 $D$  = Outside diameter of pipe (inches)  
 $a$  = Coefficient of expansion/contraction = 0.0001 in/in/°F  
 $D_T$  = ( $T_2 - T_1$ ) in °F  
 $L$  = Length between anchor points (inches)

As a 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 polyethylene 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, as determined by Equation 4.

Equations 4 and 5 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.

#### Example 5

Assume that a 10-inch (OD) SDR 11 polyethylene 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?

$$D_y = L [(0.5 a) (D_T)]^{1/2} \quad \text{EQ 5}$$

$$= 100 \times 12 [0.5(0.0001)(50)]^{1/2}$$

$$= 60 \text{ inches lateral displacement}$$

$$e = \frac{D [(96 a) (D_T)]^{1/2}}{L} \quad \text{EQ 6}$$

$$\begin{aligned}
 & L \\
 & = \frac{10 [(96) (0.0001)(50)]^{1/2}}{100(12)} \\
 & = 0.58\% \text{ strain}
 \end{aligned}$$

From the calculations in Example 5, it is apparent that lateral deflections that 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 for the restraints.

### Supported or Suspended Pipelines

When polyethylene 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 spacing for polyethylene pipe is determined much the same as for other types of suspended pipelines. The design methodology involves simple-beam or continuous-beam analysis of the proposed installation and is based on limiting bending stress.

#### Support Spacing Requirements

$$L = \frac{(3) (OD^4 - ID^4) (s_m) (p)}{(8)(q)(OD)} \quad \text{EQ 7}$$

where: L = Center-to-center span (inches)  
 OD = Outside diameter (inches)  
 ID = Inside diameter (inches)  
 $s_m$  = Maximum bending stress (psi)  
       = 100 psi for pressurized pipelines  
       = 400 psi for non-pressurized pipelines  
 q = Load per unit length (lb/in.)

$$\text{Where } q = \frac{W}{12} + \frac{[(p) (s) (ID)^2]}{6912} \quad \text{EQ 8}$$

q = Load per unit length (lb/in)  
 W = Weight of pipe (lbs/ft)  
 s = Density of Internal fluid (lb/ft<sup>3</sup>)  
 p = 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 at a given temperature that occurs between spans may be determined based on this type of analysis as shown in Equation 8. The accumulative effects of uniform loading plus thermal expansion deflection are reflected in Equation 9.

#### Simple Beam Deflection Analysis; Based on Limiting Deflection

$$D = (5qL^4)/(384E_L I) \quad \text{EQ 9}$$

where d = Deflection or sag (inches)  
 L = Span length (inches)  
 q = Load per unit length (lb/in)  
 $E_L$  = Apparent long-term modulus of elasticity at average long-term temperature (Table 1)  
 I = Moment of inertia (In<sup>4</sup>) =  $(p/64)(OD^4 - ID^4)$



- 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.

### **Summary**

Polyethylene pipe has been used to advantage for many years in above-ground applications. The unique light-weight, joint integrity, and overall toughness of polyethylene has resulted in the above-ground installation of polyethylene 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 polyethylene 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 polyethylene 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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