TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE

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ABOVE-GROUND HIGH DENSITY POLYETHYLENE (HDPE) PIPE

BACKGROUND

Occasionally, we work on projects that require pipe to be laid 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 the economic considerations of a temporary piping system, the presence of rock and the cost for blasting a trench, land rights, cultural resources, or an easement that prevents burial of the pipe.

Polyethylene (PE) pipe provides good 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 above-ground installation of polyethylene (PE) pipe. This technical note will discuss the effects of temperature extremes, chemical exposure, ultraviolet radiation and potential mechanical impact or loading. Engineering design considerations for both on grade and suspended, or cradled, polyethylene pipe installations are also discussed.

DESIGN CRITERIA

An Excel spreadsheet has been developed to assist with the commutations and analysis. The spreadsheet is located on the WA state engineering webpage.

The design criteria that can influence the behavior of PE pipe installed above ground include:

- Temperature
- Chemical resistance
- Ultraviolet exposure
- Potential mechanical impact or loading
- Fire damage

Temperature

Above ground pipe installations are exposed to wide fluctuations in temperature. By contrast a buried installation has temperatures that are usually relatively stable. There are three main types of temperature changes that affect any piping material installed above the ground. These changes are: irradiation by the sunlight, seasonal temperature extremes, and day to night temperature changes. As a rule, polyethylene pipe can be used safely at temperatures as low as -70 ^{o}F and as high as 150 ^{o}F. However, temperature does affect the engineering properties of polyethylene pipe.

Pressure capability of polyethylene pipe is predicated on the long-term hydrostatic strength (LTHS) of the polymer used in its manufacture. The LTHS decreases as much as 50% as the temperature to which the PE pipe is exposed increases. Correspondingly, the pressure rating of a specific pipe is increased as much as 150% as the service temperature decreases.

Information regarding the temperature responsive nature of a specific PE pipe is available from the respective pipe manufacturer.

Chemical Resistance

Polyethylene pipe will not rust, rot, pit or corrode because of chemical, electronic 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 PE pipe. The continued exposure of polyethylene to strong oxidizing agents may lead to crack formations or a crazing of the pipe surface. Usually, occasional or intermittent exposure to these agents will not significantly affect the long-term performance of a PE pipe.

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 pipe unless the material is sufficiently protected. Polyethylene pipe produced with a minimum of 2% concentration of finely divided and evenly dispersed carbon black is protected from the harmful effects of UV radiation.

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, the pipe requires extra protection. The PE pipe 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 PE system must pass under a roadway or other access and/or where an underground installation of a portion of the system is necessary.

In general, in an 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. When the PE pipe has been excessively or repeatedly deflected or flattened, it may exhibit stress-whitening, crazing or cracking, or other visible damage. Any such regions should be removed and replaced with new pipe material.

Fire Damage

A major consideration for the use of above ground PE pipe is the potential damage from fire. PE materials will sag, deform, and/or burn when subjected to high 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 established fire breaks.

DESIGN METHOD: 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 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 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 PE pipe based upon the expected maximum service temperature.

Example 1

What is the pressure capability for a SDR 11 series of PE 3408 pipe designed to operation at 100 °F?

From the manufacturer's data, the pressure capability rating for SDR 11, PE 3408 pipe with water at 74.3 °F is 160 psi.

Table 1 – Pressure Capability Design Factors, PE 3408 Pipe

Service Temperature °F (°C)	Apparent Modulus of Elasticity (E_S) psi	Apparent Long-Term Modulus of Elasticity (E_L) psi	Pressure Design Factor (F_T)
140 (60)	50,000	12,000	0.50
130 (55)	57,000	13,000	0.60
120 (49)	65,000	15,000	0.63
110 (44)	80,000	18,000	0.75
100 (38)	100,000	23,000	0.78
90 (32)	103,000	24,000	0.90
80 (27)	108,000	25,000	1.00
73 (23)	130,000	30,000	1.00
60 (16)	150,000	35,000	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

From **Table 1**, the 100 °F (38 °C) pressure design factor is 0.78, therefore the design pressure capacity, P (100 °F) would be the allowable design pressure multiplied by the design pressure factor:

$$160 \text{ psi. } (0.78) = 125 \text{ psi.}$$

DESIGN METHOD: EXPANSION AND CONTRACTION

The expansion and contraction for an unrestrained PE pipe can be calculated by the following equation:

Change in Length = $\triangle L = \alpha\,(T_2 - T_1)\,L$ **Equation 1**

Where:

$\triangle L$ = theoretical length change, inches
  Where: positive values = expansion,
  negative values = contraction

α = coefficient of linear expansion
  $\alpha = 1.0$ to 1.1×10^{-4} in/in/°F for PE 3408 materials
  $\alpha = 1.0 \times 10^{-4}$ in/in/°F for PE 2406 materials

T_1 = initial temperature °F

T_2 = final temperature °F

L = length of pipe, inches (at temperature T_1)

Example 2

A 1000 ft section of 2” SDR 11 material (PE 3408) is left unrestrained overnight. If the initial temperature is 70 °F, determine the change in length of the pipe section after a night time temperature of 30 °F.

$$\triangle L = \alpha\ (T_2 - T_1)\ L$$

$$\triangle L = 1.0 \times 10^{-4} \text{ in/in/°F } (30\text{°F} - 70\text{°F})\ (1000 \text{ ft} \times 12 \text{ in/ft})$$

$$\triangle L = -48.0 \text{ inches}$$

As shown in **Example 2** the change in pipe length for PE pipe 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 of polyethylene pipe has shown that the actual contractions or expansions that occur 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 PE pipe is exposed to temperature changes and restrained from moving, the specific anchor(s) must resist the stresses developed in the pipe wall. Typical devices include: tie down straps, concrete anchors, thrust blocks, etc.

DESIGN METHOD: LONGITUDINAL STRESS VS. TEMPERATURE CHANGE

Longitudinal Stress = $\sigma_T = \alpha (T_2 - T_1) E_S$ **Equation 2**

And

Longitudinal Force = $F_T = (\sigma_T) A$ **Equation 3**

Where:

σ_T = Theoretical longitudinal stress, psi
Where: positive values = expansion
negative values = contraction

α = coefficient of expansion or contraction (as in Equation 1)
$\alpha = 1.0$ to 1.1×10^{-4} in/in/°F for PE 3408 materials
$\alpha = 1.0 \times 10^{-4}$ in/in/°F for PE 2406 materials

T_1 = initial temperature ^oF

T_2 = final temperature ^oF

E_S = apparent short term modulus of elasticity, psi
(see Table 1) at lowest temperature

F_T = Theoretical longitudinal force, lbs

A = pipe wall cross sectional area, in^2

Example 3

Asuming the same conditions as Example 2, what would the maximum theoretical force developed on the unrestrained end of a PE pipe if the other end is restrained? The cross sectional area of the pipe wall is approximately 1.5 in^2, the temperature change is instantaneous, and the frictional resistance against the soil is zero.

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

$\sigma_T = 1.0 \times 10^{-4}$ in/in/°F (30 ^oF -70 ^oF) (200,000 psi)

$\sigma_T = -800$ psi

$F_T = (\sigma_T)\ A$

$F_T = (-800\ \text{psi})\ 1.5\ \text{in}^2$

$F_T = -1200$ lbs

For the conditions where the temperature change is gradual the actual stress level is approximately half that of the theoretical value. This would result in an actual force of about -600 lbs or 50% of the theoretical force (F_T) of 1200 lbs.

INSTALLATION CONSIDERATIONS

There are two basic types of above ground installations. One type is on grade or 'stringing out' over the naturally occurring grade or terrain. The other type is 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 the variations. The designer has two options available to counteract this phenomenon. The pipe may be installed in an unrestrained manner, allowing the pipe to move freely in response to temperature change. The other option is to use a restrained system where the pipe may be anchored by some means that will control any change of the pipe's physical dimensions.

Unrestrained (Free) Movement of Pipe

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 PE pipe along the right of way.

An otherwise free moving PE pipe must eventually terminate at or connect to a rigid structure (i.e. inlet structure, trough, pump, etc). Transitions from free moving PE 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 concentrating stress 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 since 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 ft, have adequately served this purpose. A closer spacing is generally needed for bends.

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

$$\textbf{Length between anchors} = L = \frac{(T_S)\,(OD)^2\,((1/DR)-(1/DR)^2)}{(0.7)\,(W)\,(1+\sin b)} \qquad \textbf{Equation 4}$$

Where:

L = Maximum length between anchors, ft.

T_S = Allowable tensile strength for pipe, psi (for desired max operating pressure)

OD = Outside diameter of pipe, inches

DR = Dimension ratio of pipe

W = Total weight of pipe + water, lbs/ft

b = Uphill or downhill slope, degrees (1% slope is 0.573 degrees)

Example 4

HDPE, PE 3408 pipe operating at 100^{o}F, T_S is 2800 psi, 1 ½” diameter, DR 9, OD is 1.461 inches, wall thickness is 0.211 inches, weight of pipe is 0.48 lbs/ft, weight of water is 0.367 lbs/ft, ground slope is 5%.

$$L = \frac{(2800\text{ psi})\,(1.461\text{ in})^2\ \ ((1/9)-(1/9)^2)}{(0.7)\,(0.48\text{ lb/ft} + 0.367\text{ lb/ft})\,(1 + \sin 2.87^{o})}$$

$$L = 948.2\text{ ft}$$

Restrained Movement of Pipe

Designs for a restrained above ground installation must consider the means by which the movement will be controlled, the anchoring or restraining force needed to control the anticipated expansion, and contraction stresses. Common restraint methods include earthen berms, pylons, augered anchors, 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 soil 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 feet. Other means of intermittent stabilization listed above 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:

Restrained Pipe Lateral Deflection = $\triangle y = L\,(0.5\,\alpha\,\triangle T)^{1/2}$ **Equation 5**

Where:

$\triangle y$ = lateral deflection, inches

L = Distance between anchor points, inches

α = Coefficient of expansion/contraction, in/in/°F

$\alpha = 1.0 \times 10^{-4}$ in/in/°F for PE materials

$\triangle T$ = Temperature change (T_2-T_1) in ^{o}F

Bending Strain Development = $\varepsilon = \dfrac{OD\,(96\,\alpha\,\triangle T)^{1/2}}{L}$ **Equation 6**

Where:

ε = Strain in pipe wall, percent (%)

OD = Outside diameter of pipe, inches

α = Coefficient of expansion/contraction

$\alpha = 1.0 \times 10^{-4}$ in/in/°F for PE materials

$\triangle T$ = (T_2-T_1) in ^{o}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 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 as determined by Equation 6.

Equations 5 and 6 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, the flow stream and that most temperature variations are not normally instantaneous.

Example 5

Assume that a 10” OD, SDR 11, PE pipe is strung out to grade and anchored at 100 ft intervals. What is the maximum theoretical lateral deflection possible, given a 50 ^{o}F temperature increase? What strain is developed in the pipe wall by this temperature change?

Lateral Deflection

$$\triangle y = L\,(0.5\ \alpha\ \triangle T)^{1/2}$$

$$\triangle y = 100\text{ ft }(12\text{in/ft})\,((0.5)\,(0.0001\text{ in/in/°F})\,(50\,^{o}\text{F}))^{1/2}$$

$$\triangle y = 60\text{ inches}$$

Bending Strain

$$\varepsilon = \frac{OD\,(96\ \alpha\ \triangle T)^{1/2}}{L}$$

$$\varepsilon = \frac{10\text{ in }((96)\,(0.0001\text{ in/in/°F})\,(50\,^{o}\text{F}))^{1/2}}{100\text{ ft }(12\text{in/ft})}$$

$$\varepsilon = 0.58\%$$

From the calculations in Example 5, it is apparent that lateral deflections that appear significant may account for relatively small strains in the actual 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 PE pipe 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: 1) beam deflection and 2) support or anchor configuration. Since this type of installation is not often used on NRCS projects with PE pipe, information on these procedures are shown in the reference sited at the conclusion of this note.

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 stress 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. Anywhere unusual loadings or excessive temperatures are 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 or one third of the pipe perimeter. 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 minimum distance of one full pipe diameter on both sides of the PE pipe. 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

PE pipe has been used 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 technical note is intended to serve a guide by which the designer and/or installer may take advantage of the unique properties of PE pipe for these types of applications. Using careful design and installation allows excellent service even under the damaging conditions found with above ground installations.

REFERENCES, LITERATURE

THE PLASTIC PIPE INSTITUTE, HANDBOOK OF POLYETHYLENE PIPE; First Edition, 2006; Washington DC; Chapter 8, pages 305-327

USDA NRCS – Idaho Web Site (www.id.nrcs.usda.gov) Technical Note 17 - ABOVE-GROUND APPLICATIONS FOR POLYETHYLENE PIPE; written by G. Arthur Shoemaker, retired

Attached - High Density Polyethylene (HDPE) Pipe, by Joseph Lange, NRCS, WA

High Density Polyethylene (HDPE) Pipe

ASTM D-3550 designates a classification system for HDPE pipe and shall be used to determine NRCS acceptance for HDPE pipe material. In accordance to ASTM D-3550 the classification system consists of six digits and one letter. Each digit and letter represents a property or characteristic of polyethylene. The following may be used for material classification:

1) For the material to be classified as HD (high density) polyethylene the first number in the classification must be a 3, 4, or 5. If the first number is a 1 then the material is low density. If the first number is a 2 then the material is medium density.

2) For the material to be pressure rated the sixth number in the classification must be a 1 through 4. If the sixth number is a zero then the material is not pressure rated and therefore cannot be used for pipelines. This is typically the case for conduit.

3) For the material to be UV protected the letter must be "C", “D”, or “E”. If the letter is "A" or "B", then the material is not UV protected and cannot be used for above ground installations. Letter “C” is black with 2% minimum carbon black with UV stabilizer, letter "D" is natural with UV stabilizer, and letter "E" is colored with UV stabilizer.

Example #1: The classification system for a polyethylene pipe material is "345464C". A material with this designation would be applicable for above ground pipelines. The pressure rating for this material depends on the standard dimension ratio (SDR) of the pipe. If the pipe were to have a SDR=11, then the pressure rating of this material would be 160 psi.

Example #2: The classification system for a polyethylene conduit material is "345460E". A material with this designation would not be applicable for any pipelines because it is not pressure rated (sixth number is zero).

According to several manufacturers, most fiber-optic conduit is composed of high density polyethylene (HDPE). HDPE material may be used for above ground pipeline installations if it is protected from UV (ultraviolet) and if it meets the hydrostatic pressure requirements of the design. Unfortunately most fiber-optic conduit is not pressure rated. If this is the case then the conduit cannot be used for a pipeline.

In summary, the applicability of HDPE pipe material for NRCS use shall be determined by the classification system as designated in ASTM D-3550. If a Cooperator wants to use a HDPE material for a pipeline, then they should submit the material classification in accordance to ASTM D-3550 to NRCS for review and approval.